2021 Materials Science & Engineering Fellowship Help Packet
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NSF Graduate Research Fellowship (NSF GRF)

Purpose of NSF GRFP: The Graduate Research Fellowship Program (GRFP) is a National Science Foundation-wide program that provides Fellowships to individuals selected early in their graduate careers based on their demonstrated potential for significant research achievements in science, technology, engineering or mathematics (STEM) or in STEM education. The program goals are: 1) to select, recognize, and financially support, early in their careers, individuals with the demonstrated potential to be high achieving scientists and engineers, and 2) to broaden participation in science and engineering of underrepresented groups, including women, minorities, persons with disabilities, and veterans. NSF especially encourages women, members of underrepresented minority groups, persons with disabilities, veterans, and undergraduate seniors to apply. GRFP is a critical program in NSF’s overall strategy to develop the globally engaged workforce necessary to ensure the Nation’s leadership in advancing science and engineering research and innovation.

Format: The maximum length of the Personal, Relevant Background and Future Goals Statement is three pages. The maximum length of the Graduate Research Plan Statement is two pages. These page limits include all references, citations, charts, figures, images, and lists of publications and presentations.

standard 8.5” x 11” page size
Times New Roman font for all text, Cambria Math font for equations, Symbol font for non-alphabetic characters (it is recommended that equations and symbols be inserted as an image), no smaller than 11-point, except text that is part of an image
1” margins on all sides, no text inside 1” margins (no header, footer, name, or page number)
No less than single-spacing (approximately 6 lines per inch). Do not use line spacing options such as "exactly 11 point," that are less than single spaced.

Criteria: Both statements must address NSF’s review criteria of Intellectual Merit and Broader Impacts (described in detail in Section VI). In each statement, applicants should address Intellectual Merit and Broader Impacts under separate headings, to provide reviewers with the information necessary to evaluate the application with respect to both Criteria.

*Intellectual Merit: The Intellectual Merit criterion encompasses the potential to advance knowledge.*

Intellectual Merit is based on a holistic analysis of the complete application, including the Personal, Relevant Background, and Future Goals Statement, Graduate Research Plan Statement, strength of the academic record, description of previous research experience or publication/presentations, and references. Reviewers are asked to assess applications using a holistic, comprehensive approach, giving balanced consideration to all components of the application, including educational and research record, leadership, outreach, service activities, and future plans as well as individual competencies, experiences, and other attributes.

*Broader Impacts: The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.* Broader impacts is based on a holistic analysis of the complete application, including by personal experiences, professional experiences, educational experiences and future plans. Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of
societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the US; and enhanced infrastructure for research and education.

The following elements should be considered in the review for both criteria:
What is the potential for the proposed activity to:
Advance knowledge and understanding within its own field or across different fields (Intellectual Merit);
Benefit society or advance desired societal outcomes (Broader Impacts)?
To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
How well qualified is the individual, team, or organization to conduct the proposed activities?
Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Tips: Be concise and format your statements effectively. Remember that reviewers will have limited time to read your application. Clearly labeling different sections and addressing explicitly each requirement will make the statement more effective and clearer for reviewers.

*Keep in mind that NSF does not just seek to fund scientists and engineers; NSF seeks to fund future STEM leaders.* Use the statements to show leadership potential, self-starter capabilities, and the ability to work well with others (scientists, students, people in the community, etc.). Show passion, motivation for a STEM career, and initiative in your past research and other experiences.

*Be yourself.* An application that conveys a clear sense of who you are as a person, with a narrative that has energy and flow, will generally be better received than an application that is impersonal and flat. Remember that the GRFP recognizes individuals based on their demonstrated potential for significant achievements in science and engineering. That is, the potential of individuals is evaluated, not just the proposed research.

*Use appropriate scientific form* (hypothesis, figures, references) in the Graduate Research Statement.

*Don’t get bogged down in the specifics, or be overly technical.* Instead of elaborate details on theory, focus on the rationale for your studies and the existing literature as it supports your proposed work. While reviewers will generally be knowledge experts in your general field, they probably will not be experts in your specific proposed research topic.

*Develop a consistent theme in both of the statements,* weaving together your personal story with your academic and career plans and past experiences to make a compelling case why NSF should award you the fellowship. The decision will be based on your demonstrated potential for significant achievements in science and engineering. Keep in mind that reviewers will read your complete application package.
Suggested Anatomy of an NSF GRF Research Statement

**Overview:** the research proposal directly and succinctly relates the academic research you plan to perform using fellowship funds. NSF does not expect a highly detailed account of experimental protocols for this GRF research proposal. Rather, it is desired that you convey a comprehensive picture of the motivations and methods of your proposed research. The general content of an NSF GRF research proposal is given below in their recommended order. **In each statement, applicants should address Intellectual Merit and Broader Impacts under separate headings to provide reviewers with the information necessary to evaluate the application with respect to both Criteria.**

**Motivation** (~2 paragraphs) Establish the motivation for the proposed research, and the justification for funding your proposed research. Do not be afraid to use relevant facts and statistics to make your point. However, do not overwhelm the reader with excessive and pointless numbers.

Some questions to address include:
- What problem does the proposed research address and why is it worth caring about?
- How will this research impact lives and whose lives will it impact?
- What are possible financial impacts of the proposed research?
- What aspect is lacking in the status quo and is addressed by your proposed research?
- What about your proposed research is unique and needed in this particular field?

**Background and Previous Research** (1-2 paragraphs) Present the scientific knowledge required to understand the hypothesis/goal and plan proposed. You can generally assume that the reader has a scientific background; however, do not assume that he or she is familiar with your field. Acronyms should be defined. When in doubt, more explanation is better than none. Relevant images may be used if they are necessary for the clear explanation of concepts.

**Hypothesis/Goal** (1 paragraph) Concisely address the hypotheses and goals of your proposed research. Other relevant questions to be addressed may include:
- How will your proposed goals and hypotheses contribute to the significance and impacts stated above? What is unique and novel about these hypotheses and goals?

**Plan** (1-2 paragraphs) Explain the methods by which you will prove your hypothesis and/or achieve your proposed goals. It is important to demonstrate your scientific expertise in the proposed field while maintaining the readability at a level that can be understood by scientists not in your field. Again, images may be used for clarity if absolutely necessary. Some relevant questions to be addressed include:
- What experiments will you perform and what data will you gather? What controls will you use?
- What are your anticipated results? What are potential problems and alternative approaches that you may use?

**Intellectual Merit** (1 paragraph)

**Broader Impacts** (1 paragraph)

**Summary** (1 short paragraph) and References
Summarize the main points you have made in this research proposal. It is important to end with a concise but powerful take-away message. References (typically no more than 4-5) should be included at the end of the document.
Writing an Effective NSF GRFP Personal Statement

Overview: of the two required essays, the personal statement typically allows the most freedom in content and structure. It is an opportunity for you to explain yourself as a scientist and as a person. The NSF is interested in funding people whom they feel will be devoted to excellence and will contribute to science and society for life. Personal statements may be structured and written in any number of ways. Give specific examples instead of spouting abstractions. Do not be afraid to open up and get personal. Below is one effective layout for addressing the kind of questions that may need answered. In each statement, applicants should address Intellectual Merit and Broader Impacts under separate headings, to provide reviewers with the information necessary to evaluate the application with respect to both Criteria.

Scientific Interest
Where does your interest in science and scientific research come from?
What motivates your continued studies in a scientific field?
What motivates you to work in the field/on the topic described in your research proposal?
What lead you to pursue a graduate degree?
Why are you fascinated by your research area?

Leadership Potential
What experiences have made you confident in your abilities to be a leader (in your field, in the lab, in the school, etc)?
What examples of leadership skills and unique characteristics do you bring to your chosen field?
What personal and individual strength do you have that make you a qualified applicant, and where do they come from?

Broad Impacts on Society
What are some activities you have participated in that demonstrate your commitment to improving society?
What outreach programs (scientific or otherwise) have you participated in for the benefit of demographics in need (e.g. minorities, women, etc)?
How does your previous research and proposed research benefit demographics in need?

Future Plans
What are your career goals?
What do you hope to gain by obtaining a graduate degree and how do you plan on using that degree?
What are your ultimate goals as a scientist? An effective Future Plans section ties into and demonstrates plans for further action on the broad impacts, leadership potential, and scientific interest sections described above.
Previous research aspect of the personal statement:

**Overview:** This is an opportunity to highlight your experience and expertise. Research experiences that have significantly impacted your growth as a scientist and research experiences that relate to the proposed research should be emphasized. For each research experience described, the following questions should typically be addressed:

What research did you do and where did you do it?
What was your motivation for doing this research?
What results did you obtain?
What goals did you accomplish?
Where there any tangibles resulting from the research (e.g. publications, presentations, reports)?
How did this research contribute to your growth as a scientist (skills learned and experience gained)?

**Weaving together these experiences:**

Weave your leadership, community service, academic, and research experiences together. You want to show how your past experiences have prepared you to be the best possible graduate student. For example:

Show how your leadership experiences motivated you to seek a student research position.
Show how leading an organization gave you the skills to lead your senior design team.
Show how by working with an after school program gave you great time management skills that helped you run successful experiments.
Show how your research in graduate school and your outreach activities have BOTH inspired you to be a professor.
Example NSF GRFP Award-Winning Applications (2018-2021)

Example 1 NSF (Award Winner 2021)

[Example 1]: Personal Statement

**Introduction:** One of the best decisions of my life was to not apply to graduate school. By senior year, while I had enjoyed classes and my research opportunities, I realized that I did not have any data about what life was like outside of being a student. On top of that, I had met my fair share of disillusioned graduate students, and my course-heavy academic program had left me feeling nearly burned out. Instead, I decided to test the waters of industry, and became a research engineer at W. L. Gore and Associates, where I tackled various problems with hydrogen fuel cell and flow-battery membranes.

While my two years at Gore taught me a lot about research, communication, and mentorship, several things left me wanting more. Even though we relied heavily on the scientific literature, we were reluctant to contribute to it. Instead, we prioritized our competitive advantage over publishing our findings. Over the summers, I had the pleasure of mentoring several interns through research projects, but there were fewer teaching and mentoring opportunities for me outside of that. Finally, I realized I needed deeper training and mentorship in computer modeling and programming, which would have allowed me to answer many questions about membrane properties, performance, and failure mechanisms. Conversations with my PhD coworkers and my undergraduate advisors made it clear: the place to study foundational theories, teach and mentor students, and freely share research results was graduate school.

This renewed outlook led me to pursue a PhD in Materials Science and Engineering at Northwestern University. Here, I am applying computational materials science to the development of models that can help us understand systems that are difficult to study experimentally. In particular, I am studying the properties of biomineralized tissues, which form and degrade in nanoscale, *in vivo* systems. Through this project, I hope to bring new perspectives and approaches to the biomineralization research community, as well as to serve as a mentor for undergraduates in the class and in the lab.

**Intellectual merit:** As an undergraduate at the University of Pennsylvania, I was part of a small, competitive program called the Vagelos Integrated Program in Energy Research (VIPER). Through VIPER, I was required to complete one degree in engineering, one in the sciences, as well as conduct research over the summers.

For my first summer of VIPER-sponsored research, I chose to work with Professor Robert Carpick, whose group studies friction (tribology) at the nanoscale. Our overarching research goal was to use insights about the anti-wear properties of the engine-oil additive ZDDP to inform the design of better additives. In order to study the formation of a protective film of ZDDP between sliding interfaces, we developed a novel AFM technique. Using a micron-sized colloidal particle of steel attached to the AFM tip, we could simultaneously form and image the film, which we described in a publication to introduce the technique to the tribology community. Carefully polishing steel substrates by hand and staring at MATLAB codes for data processing felt totally worth it to be able to walk into the campus’s shiny new laboratory as a facility user. I was able to continue my work with the Carpick group into the semester and the following summer. In a second publication, we demonstrated ZDDP film formation in a system free of iron by using an alumina colloidal tip and a high purity aluminum substrate, which weakens a particular hypothesis about the chemistry of film formation. Beyond the lab work, group meetings with the Carpick group were deeply engaging, from watching students prep for their qualifying exams to presenting my own results with figures and data I had collected.

After working with Professor Carpick, I realized I wanted some research experience in my second major,
which was Environmental Science. Professor Jane Dmochowski had been my original academic advisor, and I was delighted to be able to work for her for my last summer of research. Our work focused on the ecology of the Santa Monica Mountains. Using time-series satellite data from the Landsat program, we tracked seasonal changes in vegetation over three decades, which we could correlate to various environmental and human factors. Because this project was still in its early stages, Professor Dmochowski encouraged me to attend the American Geophysicist Union fall conference to solicit feedback from other scientists for ideas. By successfully applying for a travel grant, I was able to attend and present my poster at my first conference external to the university. This massive event drew in 24,000 participants, and walking through the exhibition floor and attending talks opened my eyes to the scope of the scientific community and the opportunities for interdisciplinary research.

At Gore, I worked with a team of scientists and technicians to push the boundaries of performance for polymer-based proton exchange membranes. These membranes play a key role in the function of hydrogen fuel cells and vanadium redox flow batteries. We worked to develop membranes that were lower resistance, more mechanically and chemically durable, with materials and processes that reduced cost to compete with conventional technologies. In order to prove these properties to our customers, I also worked extensively on test method development and validation. While I ultimately decided to leave Gore for graduate school, the lessons I learned about project management, working across teams, and communicating my results continue to benefit me.

Now, at Northwestern, I am working with Professor Derk Joester and Professor Peter Voorhees. Our project uses computational materials science methods, like atomistic simulations and phase-field models, to study the biomineral hydroxylapatite. I was attracted to Northwestern’s materials program because the professors here, experts in their own individual fields, are also very interested in collaboration. Professor Joester’s expertise in biomineral characterization leverages the atom probe tomography facilities on campus, as well as the Advanced Photon Source at Argonne National Labs, to resolve compositional and structural nuances at the nanoscale. Professor Voorhees is an expert in developing phase-field models of microstructural dynamics, and Northwestern’s computing cluster Quest is a vital tool in his group’s computations. With these resources, I am uniquely positioned to apply computational tools to biominerals, an approach that has thus far been underutilized.

**Teaching and mentoring experiences:** One of the most fulfilling parts of my time at Gore was in mentoring several interns and co-op students. I played a large role in teaching them how to use our lab facilities to answer research questions of interest to the team. It was exciting to watch how research helped them grow, honing both their scientific understanding and communication skills over a few short months. Pretty soon, I began structuring my work so that there was room for intern projects, as well as developing “on-boarding” materials to quickly integrate new team members.

These mentoring opportunities at Gore also reminded me of how much I enjoyed teaching as an undergrad. As a TA in our materials science lab course, I took initiative to implement course improvements based on student feedback. This included writing new pre-class assignments that were integrated with the course’s lab reports and emphasized analyzing data from the lab experiments. During the summers, I was involved with the Penn Summer Science Initiative, a free, month-long exposure to materials science for local high school students. Beyond leading them through lab experiments, I also developed a new lecture series with interactive demos.

I knew that graduate school would bring me more opportunities to improve as a mentor, and I was particularly attracted to Northwestern’s Searle Center for Advanced Learning and Teaching. Through this program, I have been able to participate in discussions and workshops about teaching with students and professors across STEM, and I plan on continuing my involvement through their Teaching Certificate Program. I’ve already begun TAing, and my conversations with my advisor regularly include discussions
about how to adapt portions of my codes to create teaching modules, as well as research directions that would be appropriate for an REU student.

**Broader impacts:** During my undergraduate research experiences, I took for granted how welcome and comfortable I felt with my advisors and lab groups. As an Asian man, I am rarely challenged on whether I belong in STEM. When I started working at Gore, though, I became much more cautious about how I carried myself. In any given meeting, I was often the only non-white person, and I was almost definitely the only LGBT person in the room. This led me to second-guess how much of my personal life I should talk about, and it made it harder to feel like I was full member of the team. My undergraduate advisors had been fantastic role-models for how to create an inclusive culture, and now I saw how much impact I could have as a leader in STEM to do the same.

At Northwestern, I’ve started this work by taking on a leadership role in our Materials Science Alliance for an Inclusive Community (MatSAIC). Our goal in MatSAIC is for all students to feel included, and for their contributions to be valued. We organize a peer mentorship program for new graduate students to reduce attrition and increase student success. This year, I organized more structured introduction and follow-up events for mentor-mentee pairs. We also host seminars with visiting STEM professors to share their outreach and diversity efforts at their home institutions. In the summer during the COVID lockdowns, I facilitated a web Q&A with Professor Hironao Okahana of Georgetown University, who studies diversity in STEM programs. This event brought in students and faculty from several different departments for a conversation about how to address unequal outcomes within our departments.

My involvement with MatSAIC also highlighted for me how much work needs to be done farther up the STEM pipeline in order to make STEM careers more accessible. Through the Coding Club with the Chicago Boys and Girls Club, I am paired each week with high school students in the Chicago area and work with them on Python coding projects. Drawing on my experiences with the Penn Summer Science Initiative, I constantly try to give my students personalized attention with instruction that starts with what they know. By getting involved early on in my PhD, I have time to grow into leadership positions here to continuously update the curriculum and coordinate with our external partners. Data visualization is one of the ways to make coding a more visual, artistic activity, and my experiences working with creating figures of 2D and 3D microstructural dynamics will complement my ability to teach this to students. As at Gore, I am constantly trying to take a step back and parse out which aspects of my research can be most readily shared with other people.

**Future goals:** My TA and mentoring experiences have profoundly affected my career goals. As a professor at a liberal-arts college, I can continue teaching while using interdisciplinary basic research to expand access to science. This environment prioritizes pedagogy and the foundations of scientific theories. My research area then applies these theories to biominerals, lying at an exciting intersection of materials science and biology. Further, while smaller colleges have limited access to lab and research facilities, computational research is already moving towards distributed, remote resources. As such, my work could leverage NSF and DOE resources like XSEDE and Aurora to bring research experiences to undergrads for whom cutting-edge research may feel out of reach. When considering the future of STEM, people often emphasize the need for interdisciplinary approaches and expanded use of computational skills. I believe that my experiences, both in and out of the lab, will help me lead the next generation of students towards that future.
Research plan: Multi-scale computational modeling of biogenic apatite demineralization

Motivation: Although the biomineralization community has made great advances in characterizing the nanoscale structure and composition of mineralized tissues; how they are remodeled, resorbed, or degraded is much less understood. From an engineering perspective, this knowledge is necessary to design biomaterials such as bioglasses. Further, biominal dissolution is fundamental to many life processes, from osteoporosis in humans to the resorption and molting of crustacean carapaces. Deeper understanding requires a quantitative model of dissolution in a multi-phase material that couples elastic, surface, and bulk energies to dynamic transport and aqueous equilibria. Enamel is a biominal that is important to human health, and controlled dissolution experiments can be used to benchmark a newly developed model. Therefore, I propose to use \textit{ab initio} density functional theory (DFT) to predict the bulk thermodynamics of enamel, and to use phase field modeling (PFM) to simulate its dissolution.

Background: Tooth enamel is composed of elongated nanocrystallites of biogenic apatite (B-Ap) cemented together by a thin film of amorphous calcium phosphate (ACP). B-Ap is crystalline hydroxylapatite (formula $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$), while ACP is amorphous and contains a small amount of water and organic molecules. Both phases host impurity ions that affect solubility. For example, work from the Joester group shows that a higher concentration of Mg$^{2+}$ in ACP leads to preferential dissolution, while enrichment in Fe$^{3+}$ (as occurs in beavers and some rats) leads to stabilization of ACP relative to B-Ap$^1$. Quantifying the effect of impurity ions on the thermodynamic stability of ACP in lab is challenging because bulk ACP is unstable. A recent study has further demonstrated that B-Ap in human enamel has a core-shell distribution in the concentration of these ions$^2$. These concentration gradients are expected to give rise to residual stresses that affect dissolution morphology. Indeed, careful etching experiments on human enamel show preferential hollowing out of the enamel crystallites (fig 1a). The relative contributions of the chemical and elastic (stress) effects to these observations are unknown.

Research Plan: Despite the ubiquity of B-Ap and ACP in teeth and bones, a systematic study of how the ions mentioned above affect their structural and thermodynamic properties has not been conducted. As a result, there are no quantitative models of the formation of these structures. My proposed work strives to address these two gaps.
in enamel research, by 1) calculating relevant structural and thermodynamic data from \textit{ab initio} DFT, and 2) developing a coarse-grained, phase-field model of enamel dissolution using the parameters from part 1.

\textbf{1a) DFT calculation of structural properties of B-Ap.} I will determine the effect of ionic impurities on the lattice parameters and elastic properties of B-Ap with DFT. \textit{Hypothesis:} these calculations will reveal whether different ions have additive or cancelling effects on the stress state in apatite. My preliminary results, based on DFT parameters recommended in the literature, reproduce the structure and stiffness of pure B-Ap. Mg impurities are shown to cause an anisotropic contraction, in agreement with the literature, and further predict a reduction in stiffness. Future work will require similar calculations for relevant impurities (Mg, CO$_3$) as well as impurities occurring in pairs, at a range of concentrations.

\textbf{1b) DFT calculation of thermodynamic properties of B-Ap and ACP.} By comparing the DFT energies of B-Ap and ACP to those on structures with tabulated thermochemical data, I will calculate the formation energy of both phases as a function of impurity concentration. \textit{Hypothesis:} DFT calculations will show that Fe$^{3+}$ stabilizes the ACP, while Mg$^{2+}$ and water further destabilize it. To generate the ACP structures, I will use \textit{ab initio} molecular dynamics (MD) at unphysically high temperatures to amorphize initially crystalline calcium phosphate structures of the desired composition. Comparison of bond lengths, angles, and charge density distributions between structures will reveal mechanisms of stabilization and destabilization. These results can also set a range for the value of the B-Ap/ACP interfacial energy. A potential pitfall of both 1a and 1b is that calculations of dilute impurities require large unit cells and may be too computationally expensive to be feasible. A combination of virtual-crystal approximation (VCA) and supplementing with MD simulations with empirical force fields will be used to reduce the computational cost. In both cases, benchmarking against \textit{ab initio} DFT on subsets of the planned calculations would increase confidence in the results.

\textbf{2) Phase-field modeling (PFM) of mineralization.} In parallel with the thermodynamic calculations in part 1, I am developing a PFM that captures the dynamics of enamel dissolution. \textit{Hypothesis:} by validating the PFM against etching experiments, we will find that the elastic stresses and dynamics of transport have a non-negligible effect on dissolution. My preliminary work includes a B-Ap phase dissolving into a fluid phase (fig. 1b) with an arbitrary chemical driving force, concentration profile, and kinetic anisotropy. Results from this model indicate that an equilibrium dissolution profile develops, and its depth depends on the solubility of the crystal core. Further, if a low mobility surface orientation aligns with the dissolution direction, the profile is blunted, as shown in fig. 1c. This agrees with an AFM study on apatite etch-pits and points to the value of additional experiments characterizing etching profiles. Our future work with this model will involve adding explicit consideration of the ACP phase, elastic stresses, and transport and aqueous speciation of ions in the fluid. As a coarse-grained method, a PFM will not allow us to directly study atomistic behavior at the interfaces, like surface ion-exchange or chemical reactions. Even so, a model that includes the known, bulk energetic effects is a vital first-step to any more complete model of dissolution. The PFM as described will also enable the prediction of the overall effect of those processes on kinetic parameters. \textbf{Resources:} Verification of the equations used in the PFM is ongoing under the guidance of Professor Voorhees, who has extensive experience in the field, and is conducted in parallel with the work of part 1. Within the Joester group, nano-characterization methods like atom probe tomography, TEM, and focused ion beam will continue to provide benchmarks for model validation. Computational resources for this project include a new workstation in the Joester group, Northwestern’s cluster Quest, as well as resource allocation requests I have made through the NSF’s Extreme Science and Engineering Discovery Environment (XSEDE).

\textbf{Intellectual Merit:} By considering the effects of impurities and chemical transport, this project will output the most comprehensive model of biomineralization to date. It will reveal the relative contribution of chemical, elastic, and dynamic effects to enamel dissolution. By capturing this physics, the model will also form the basis for any model of biomineral formation. Systems such as bone or biogenic calcite can be similarly modeled with the published codes, allowing researchers to make predictions for processes like bone remodeling and resorption, or structure formation in organisms like sea urchins. Making my final codes freely available ensures the reproducibility and transferability of the results.
Broader Impact: More broadly, since the PFM equations are chemically agnostic, it would also be applicable to dissolution and stress evaluation in any multicomponent ceramic. Our DFT calculations will supplement the existing thermodynamic data on inorganic phosphates. These results would directly benefit researchers in fields as diverse as bone remodeling and geology. This project also complements my goals to advance science education. For example, I will adapt portions of the PFM code to create models used in the lab portion of the class I am TAing with Professor Joester, which is the capstone thermodynamics course for MSE majors. We are also working to involve an REU student whom I will mentor in the DFT components, which creates a socially-distanced summer research opportunity. Finally, the data visualization skills I am practicing will be included in my mentorship of Coding Club students, highlighting the way that coding and artistic design intersect. Overall, this allows me to translate both technical results and general skills across the STEM pipeline.


Example 1: Rating Sheet

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit: Excellent

Explanation to Applicant

The applicant has several awards in the materials science. Before applying to grad school, he spent two years working as an engineer on problems with hydrogen fuel cell and flow-battery membranes. The applicant has strong research background from his undergraduate studies and summer research, including several publications; outstanding letters of support. His grades are very good. The project aims to use initio density functional theory (DFT) to predict the bulk thermodynamics of tooth enamel, and to use phase field modeling (PFM) to simulate its dissolution. The intellectual merit is that this project will produce the most comprehensive model of biomineralization to date and the relative contribution of chemical, elastic, and dynamic effects to enamel dissolution. The proposal is well written, with clearly stated objectives, hypotheses, milestones, analyses of potential pitfalls and solid methodology.

Broader Impacts Criterion

Overall Assessment of Broader Impacts: Excellent

Explanation to Applicant

In addition to its immediate scientific impact, this work will also form the basis for any general model of biomineral formation, including processes like bone remodeling and resorption, or structure formation in organisms like sea urchins. The applicant has demonstrated outstanding service to the community, such as his involvement in Materials Science Alliance for an Inclusive Community, mentoring and teaching experiences. He intends to use his research results to continue these efforts, with a well-developed plan outlined.

Summary Comments: This is an excellent application from an outstanding candidate. The area of research is significant; intellectual merit and broader impact are well outlined. The application has a potential for a significant impact.
Broader Impacts Criterion

Overall Assessment of Broader Impacts: Excellent

Explanation to Applicant

The models generated by the applicant can be useful for other fields for development of biological enamel structures. The project will also add to existing information on inorganic phosphates. Applicant discusses a plan to work with REU students and also utilize TA opportunities. Weakness: Applicant may consider including some interaction or demo opportunities with school kids.

Summary Comments: Applicant proposes to use DFT and phase field modeling to predict bulk thermodynamics of enamel. Applicant has co-authored 2 high impact journal papers. Recommendation letters are excellent.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit: Excellent

Explanation to Applicant

The applicant has completed one degree in Engineering and one degree in Sciences. The applicant has also actively participated in summer research and published two papers as co-author. It is impressive that the applicant has maintained a stella GPA. Through summer research, the applicant has developed experimental skills. The applicant has also presented a poster on an environmental science project in a national conference. Before attending graduate program, the applicant has worked in a company for two years, when the applicant learned project management, working in a team, and communicate the work with laypersons. Taken together, the applicant has demonstrated excellent intellectual merits. The applicant has great resources (computational resource, experimental validation, etc.) to carry out the proposed research, which is to develop multiscale computational models that capture biogenic apatite demineralization. The project has merits towards human health and biomedical applications.

Example 2 NSF (Award Winner 2021)

Introduction and Influences: My journey to reach graduate school was a non-traditional one. Most students do not choose to pursue a PhD after 5 years of experience in industrial research. However, in 2017, I had an experience that lit a fire under my passions for combatting climate change and undertaking fundamental research. While living in Houston during my time with Dow Chemical, I saw firsthand the destruction caused by Hurricane Harvey. I witnessed communities, including my friends and colleagues, repair their homes after being inundated by floodwaters. It was after helping to remove water-damaged drywall from a home, that I viscerally understood the personal impact a changing climate can have. From that time forward, I decided to take an active role in solving today’s climate crisis. I resolved to take my passion for research and pursue a PhD in the area of battery science for the purpose of advancing renewable energy production and use. Although it was a difficult decision to leave my career at Dow, I felt it was necessary to chase this opportunity to conduct in-depth research and fulfil my role in solving the greatest challenge of our time. With my background in chemical engineering and chemistry, I saw a PhD in material
science and engineering as a chance to both expand my acumen and pivot towards fundamental materials research where I could have the most impact in advancing energy storage. I am thankful to now be pursing research in the Hersam Lab at Northwestern University in the area of solid-state electrolytes for improved safety and energy density in energy storage devices. This process has already expanded my knowledge base and provided me a basis by which I can launch my career. Thus far I have coauthored two journal articles, one published and one in submission and I hope to continue in this line of research.\textsuperscript{1,2}

**Intellectual Merit - Academic Research Experiences:** Among the many positive experiences I had at the University of Minnesota (UMN), performing undergraduate research was the most transformative. I began my work in Professor Hillmyer’s lab on a project related to bio-based and renewable polymers. As he was the director of the NSF Center for Sustainable Polymers at UMN, I sought out Professor Hillmyer’s research as an opportunity to develop competitive biodegradable polymers. My first semester in the Hillmyer lab was dedicated to assisting a doctoral student, Louis, in characterizing nanoporous polyethylene for use as a battery separator. The nanoporous polyethylene structure was made possible by chemically etching the polylactide from a polylactide-polyethylene block copolymer. My efforts focused on confirming the completed etching through Fourier transform infrared analysis (FTIR) and scanning electron microscopy (SEM). I presented my work on the polymer characterization via a poster session at the Undergraduate Research Opportunity Program (UROP) annual symposium. After the completion of this project, I began independent work where I synthesized block copolymer structures to improve the mechanical properties of biodegradable polymers. I was able to synthesize a multiblock copolymer with rubber-based and biodegradable blocks generating a degradable product with improved toughness compared to the traditional polylactide. I characterized the resulting polymer by FTIR, size exclusion chromatography (SEC), nuclear magnetic resonance (NMR), and mechanical tensile testing. The results of this work were compiled into a final report and the data was later used as the basis for other published work. Throughout my time in the Hillmyer lab, Louis provided guidance for my efforts and gave me the independence to chart the course for my own projects. He helped me to hone my critical thinking skills, maximize my experimental results, develop my lab techniques, and prepare me for graduate level research.\textsuperscript{3}

After returning from an R&D internship at Ecolab Inc. during the summer of my sophomore year, I wanted to diversify my research experiences into engineering-related projects. I sought out work in the Tsapatsis group within the chemical engineering department at UMN. Under the supervision of another doctoral student, Kumar, I worked independently to develop a zeolite-based membrane for the energy efficient separation of CO\textsubscript{2} from flue-gas. As part of this project, I formulated an antifoam and surfactant stabilized zeolite suspension such that the zeolite nanosheets were evenly deposited on an alumina substrate by vacuum filtration. By careful selection of the antifoam and surfactant, I was able to optimize the zeta potential of the suspension until adequate dispersion was achieved. After the deposition was completed, I characterized the resulting film by SEM to ascertain the thickness and quality before gas separation trials. Throughout this process, Kumar taught me to have perseverance in the face of research challenges and to continue my tenacity, a skill that served me well in my professional career and now in my doctoral research. My time performing this research also taught me to have excellent time management skills as I juggled core classes in addition to leadership in student groups. Lastly, Kumar also showed me that it was possible to be a successful graduate student after working several years in industry as he had done before starting his PhD at UMN. He was certainly a model for me later in life as he challenged the typical path to a PhD.\textsuperscript{3,4}

**Intellectual Merit - Professional Research Experiences:** I was fortunate during my undergraduate career to gain industrial research experience. In addition to academic research, I wanted to entertain industrial research as a potential career avenue where I could make a large impact. I applied for an extended internship with Dow Chemical and was selected as one of two to enter the program among fifty applicants. My internship projects varied from improving production plant simulations to enhancing the efficiency of a polyethylene pilot plant. As a result of the simulation work I performed, I was given the Dow Diamond Award, which is the highest recognition award available to a Dow Employee. Due to my positive internship
experience, I made the difficult choice to forego graduate research as I had the opportunity to pursue research at the same pilot plant where I had been an intern. In my role as a full-time pilot plant engineer, I helped to develop improved polymers for automobile weight reduction and to make process improvements for production-level energy efficiency.

Starting my full-time career at Dow in a research environment was rewarding as it allowed me to use the toolkit I had developed in my undergraduate research. For instance, I executed a multi-year project to pilot a high efficiency polymerization catalyst enabling lower-emission production of synthetic rubber. It required many months and several dozen experiments to understand the intricacies of how to reliably operate with this new catalyst and reproduce existing commercial products. In fact, it required the installation of a vacuum extruder, a specialized polymer processing unit, which I became the subject matter expert in operating. After many iterations of polymer characterization, troubleshooting, and adjustments, we achieved successful pilot production. Today this catalyst has been implemented at the production scale resulting in a 10% reduction in CO2 emissions per ton of synthetic rubber product produced. This new catalyst technology enabled research into a new differentiated class of products that was later patented with myself as a co-inventor. Subsequently, another study with these various catalysts resulted in a coauthored external publication. Although this project was ultimately successful, it required careful attention to detail, strategic and inventive thinking, and countless late nights to accomplish the end goal. Through this effort I learned to rapidly break a problem down to its fundamental components and begin approaching it in a systematic manner. For my efforts with this new catalyst and the vacuum extruder, I was honored with another Dow Diamond Award.

After several years working in the pilot plant setting, I moved to a role as an implementation engineer where my job was to take technologies developed at the pilot scale and implement them at production facilities. In this role, I appreciated the teamwork required across multiple disciplines, geographies, and often languages. No longer was I the expert on a particular plant, but I relied on plant engineers in Louisiana, Argentina, and Spain to help me with instituting production efficiency improvements. One of the most exciting projects was the implementation of a new spray coating system to prevent aggregation of polymer pellets inside processing equipment. This project involved many months of planning, several trial executions at production scale, and troubleshooting on-the-fly to resolve issues. The spray coating system I helped to design is now in use and has helped to increase that plant’s reliability by >30%. This coating project was an exciting part of my role, however, the most rewarding experience I had was training new engineers. Much like Louis and Kumar guided me as I learned, I introduced others to the technology of polyethylene production. I helped to advise and train three interns as well as two full-time engineers and enjoyed the opportunity to share my knowledge and help them develop their skills.

**Broader Impacts:** My time at UMN provided me many opportunities to pursue independent research. However, my passion to have a positive impact on the world drove me to volunteer my time and talents where I could. Throughout my freshman and sophomore years, I would commute weekly to an underserved high school in Minneapolis and tutor students in math. It brought me great joy to see how the students internalized material they once saw as intractable. I also worked during that time with Engineers Without Borders, where an interdisciplinary group of engineering students designed a water distribution system for installation in a remote town in Sudan. As part of my role, I helped to design the piping and water storage vessel that was installed several years later. Later in my undergraduate career, I became involved in the local chapter of the American Institute of Chemical Engineers (AIChE) where I was elected as the Car Team leader and later the president of the club. As Car Team leader, I orchestrated a group of students in designing UMN’s first fuel cell powered design for the regional AIChE car competition. As president, I submitted and won several grants to continue funding the UMN AIChE Car Team as well as plant tours and events that introduced chemical engineering students to various industrial careers.

Even after earning my undergraduate degree, I continued to find opportunities to volunteer. I was so
moved by the destruction wrought by Hurricane Harvey in Houston that I felt I had to help where I could. I volunteered to help families remove water damaged portions of their home, mitigate mold growth and start the rebuilding process. These experiences revealed to me that climate change will disproportionately affect those that can least afford it. In turn, this process was a big driver for me to be more ambitious in my goals to affect climate change and eventually to pursue graduate research. Once at Northwestern, I chose to become involved in Junior Science Club (JSC) where graduate students facilitate safe and educational activities for elementary age students at the Pederson-McCormick Boys and Girls Club of Chicago. My favorite memory at JSC is of an activity that involved building a tower out of graham crackers and frosting. Much of the tower supplies were eaten in the process, however, seeing the determination of the students as we coached them to build higher towers was extremely rewarding. Following the outbreak of COVID-19, I redirected my efforts by working with the Rogers Park Community Response Team (RPCRT), which was created to meet the needs of my Chicago neighborhood in the fallout from the pandemic. I started by delivering donated items such as medication, diapers, and food and eventually began packing grocery boxes for individuals at a local food pantry. As activities with RPCRT begin to wind down with public funding nearing its end, I am now starting to mentor local students as part of Northwestern’s Mentorship Opportunities for Research Engagement (MORE) program. I will provide virtual mentoring for high school students interested in a STEM career as they go through the college application process and decide on a specific field. I’m looking forward to helping underrepresented students achieve their goals in STEM.

**Future Goals:** As a result of the revelations I had following Hurricane Harvey, I now aim to turn my advanced degree in material science into a career in the advancement of battery science. Advances in energy storage are one of the keys to expanding the production of renewable energy and stemming the tide of climate change. Having performed both industrial and academic research, I believe I would find the most fulfillment as a researcher in a national lab such as part of the Joint Center for Energy Storage Research (JCESR) at Argonne National Lab. After completing my PhD, my goal is to earn a post-doctoral position at a national lab and convert this into a full-time position focused on materials research in the field of battery science. As I progress through my career, I plan to continue to volunteer and mentor others. With my unique perspective, I can provide help to those seeking a career in STEM and remind them that there is not a predefined path they must follow. Support from the NSF Graduate Research Fellowship Program would allow me the freedom to continue my current line of energy research and provide a platform for me to achieve my goals. I thank you for your time and appreciate your careful consideration.


**Example 2:** Research Proposal

**Hexagonal Boron Nitride Ionogel Electrolytes for Flexible Solid-State Lithium Metal Batteries:**

**Motivation and Background:** The lithium ion battery (LIB) is the prevailing portable energy storage technology for modern powered devices. With the advent of advanced computing, artificial intelligence, and the Internet of Things (IoT), the need for safe mobile power sources is expected to increase, especially in environments where conventional LIBs are unstable such as wireless sensors near high temperature (>60 °C) equipment or powered medical devices that require thermal sterilization (130 °C). Conventional liquid electrolytes for LIBs are limited in their application at high temperatures as the constituent volatile solvents used will vaporize leading to catastrophic failure. In addition, current casings that contain the liquid electrolytes are not amenable to mechanically flexible applications or non-planar form factors. Flexible solid-state electrolytes (SSE) have the potential to resolve these issues by concurrently functioning as a thermally stable electrolyte and separator without rigid casing requirements. However, current flexible SSEs (e.g., solid polymer electrolytes) suffer from poor ionic conductivity at room temperature, limited mechanical stability.
at high temperatures, and electrochemical instability at high voltages.\textsuperscript{1, 2} In contrast, this proposal focuses on nanocomposite ionogel electrolytes, which is an emerging class of SSEs that is uniquely positioned to overcome the aforementioned shortcomings for use in energy storage devices. Nanocomposite ion gel or ionogel electrolytes (NIE) consist of an ionic liquid (IL) with dissolved lithium salt and a nanostructured matrix to provide mechanical stabilization. In comparison to traditional oxide or sulfide based SSEs, NIEs are mechanically flexible, robust, and possess high thermal stability up to \( \sim 300^\circ C \).\textsuperscript{3} Furthermore, the high surface area of the nanostructured matrix enables high mechanical moduli (>1 MPa) without sacrificing high ionic conductivity (>1 mS/cm).\textsuperscript{3} These attributes suppress lithium dendrite growth and thus prevent the electrical short circuits that lead to thermal runaway in conventional LIBs.\textsuperscript{3, 5} Hexagonal boron nitride (hBN) nanoplatelets are particularly attractive as an NIE matrix material due to their desirable inherent properties such as chemical inertness, thermal stability, and mechanical strength.\textsuperscript{6} As a result of these attributes, prior work from the Hersam Group has demonstrated that exfoliated hBN based NIEs are capable of rechargeable battery operation up to \( 175 \, ^\circ C \).\textsuperscript{7}

In addition to mechanical flexibility and thermal stability, high energy density is also required in modern rechargeable batteries. A lithium metal battery (LMB) consisting of a lithium metal anode and a high voltage cathode (5 V vs. Li/Li\textsuperscript{+}) presents an unprecedented opportunity for improving cell-level energy density.\textsuperscript{2} Conventional liquid LIB electrolytes are incompatible in a LMB configuration as they are unstable over wide voltage ranges due to deleterious \textit{in-operando} side reactions that compromise cycle life.\textsuperscript{4} Although ILs provide a comparatively wider electrochemical window, no known IL possesses a sufficiently wide electrochemical stability window for operation in a LMB with a high voltage cathode. For example, while the ILs 1-ethyl-3-methylimidazolium tetrafluoroborate (EMIM-BF\textsubscript{4}) and 1-ethyl-3-methylimidazolium bis(fluorosulfonyl)imide (EMIM-FSI) each have high ionic conductivities, their electrochemical stability windows are limited to high voltages (1.1 – 5.2 V vs. Li/Li\textsuperscript{+}) or low voltages (< 0 – 3.8 V vs. Li/Li\textsuperscript{+}), respectively.\textsuperscript{8} Herein, this proposal details the use of a novel bilayer NIE structure to circumvent this limitation. Taking advantage of the strong interactions between ILs and the NIE matrix that suppress intermixing, bilayer NIEs allow for the separation of ILs contacting each electrode.

\textbf{Objective:} To realize a flexible, high temperature LMB, this proposal aims to use hBN based NIEs in a bilayer structure (Figure 1) to extend the electrochemical stability of processable and thermally stable NIEs. Based on the individual IL electrochemical stability windows, a layer of EMIM-FSI and EMIM-BF\textsubscript{4} based NIE will be used for the anode and cathode side respectively. Using this electrolyte structure, this project aims to (1) develop a novel multilayer ionogel electrolyte for stable use with a high voltage cathode (5 V vs. Li/Li\textsuperscript{+}) and lithium metal anode, (2) Demonstrate a flexible LMB capable of safely operating at 60 °C (>99.9 \% coulombic efficiency) and withstanding thermal sterilization (130 °C) without cell failure.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Schematic cutaway of the proposed flexible LMB with a bilayer of hBN ionogel electrolyte.}
\end{figure}
Preliminary Results: Initial testing of an EMIM-BF$_4$ based ionogel with 50 wt% exfoliated hBN has revealed superlative mechanical strength (~10 MPa storage modulus) with high ionic conductivity (>3 mS/cm). Additionally, thermogravimetric analysis (TGA) and linear sweep voltammetry (LSV) show that the NIE is thermally stable up to 300 °C and 5.2 V vs. Li/Li$^+$, respectively. Furthermore, literature examples of liquid electrolytes with high salt concentration show denser lithium plating and a more stable lithium|electrolyte interface. Early investigations of a concentrated lithium salt (3 M LiFSI in EMIM-FSI)NIE have demonstrated improved stability in plating/stripping of lithium compared to lower concentrations.

Research Plan: (1) Electrolyte Development and Validation – The low-voltage and high-voltage NIEs must first be formulated and validated to ensure desirable attributes by adjusting the concentration of exfoliated hBN matrix and lithium salt. The NIEs will be characterized via dynamic mechanical analysis, electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV), and TGA to determine the mechanical moduli, ionic conductivities, and electrochemical and thermal stabilities, respectively. Targets for each NIE include >1 mS/cm ionic conductivity at 20 °C and a storage modulus of 1-10 MPa for fast lithium transport and inhibition of lithium dendrite growth. Most importantly, the electrochemical windows should be sufficiently wide so that the anode (EMIM-FSI based) and cathode (EMIM-BF$_4$ based) NIEare stable against a lithium metal anode and high voltage cathode (e.g., LiNi$_{0.5}$Mn$_{1.5}$O$_4$ (LNMO), 4.7 V vs. Li/Li$^+$), respectively. Although the aforementioned ILs are expected to be stable in this range, additional ILs will also be evaluated to further improve electrochemical stability as needed. Lastly, the anode NIE will be tested for lithium plating and stripping efficiency by galvanostatic cycling of the NIE between a lithium metal anode and copper counter electrode. To be suitable for LMBs, a coulombic efficiency of >99.9% will be necessary. A study of the lithium|electrolyte surface morphology and composition via scanning electronmicroscopy (SEM) and X-ray photoelectron spectroscopy (XPS), respectively, will be used to understand and develop mitigation strategies for any deleterious reactions.

(2) Construction and Testing of Flexible LMBs – Once the individual anode and cathode NIEs have been optimized and validated, their integration into a bilayer electrolyte for LMBs will be tested. Towards this end, a method for consistently depositing a thin (~15 µm) layer of each ionogel onto the anode or cathode will be developed (e.g., manual deposition, extrusion, or blade coating). Next, a flexible LMB cell will be constructed using the structure displayed in Figure 1. The lithium anode and LNMO cathode will be placed on copper and aluminum current collectors, respectively, separated by the bilayer NIE, and encapsulated by a thermally stable polymer substrate (e.g., polyimide). This flexible cell will be charged and discharged galvanostatically at 60 °C with and without bending. Lastly, the ability of the cell to undergo thermal sterilization at 130 °C without failure will be tested. Further investigation via EIS, SEM, and XPS will ascertain and mitigate the source of any observed capacity fading.

Resources: Existing equipment is available within the Hersam Laboratory for hBN exfoliation, NIE and electrode production, and coin cell construction. SEM and other characterization capabilities are available within the Northwestern University Atomic and Nanoscale Characterization Center (NUANCE). Intellectual Merit: The development of a high temperature flexible energy storage device based on a novel bilayer NIE will have broad implications in sectors ranging from portable IoT sensors to powered medical devices. If successful, this proposal will advance energy storage technology in energy density, operational conditions, and safety, which are critical metrics for powered portable devices and sensors.

Broader Impacts: Due to the ubiquity of powered devices and wide interest in batteries, research in this proposal can be used in highly accessible outreach events. For instance, the proposed LMB cells can be used in demos with transparent encapsulation to enable education on its various components. Additionally, the improved safety can be demonstrated via a puncture test and subsequently compared to videos of more flammable LIBs. These demonstrations could be used in conjunction with my ongoing work with high school students through Northwestern’s Mentorship Opportunities for Research Engagement program.

[Example 2]: Rating Sheet

**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

**Explanation to Applicant:**
Applicant has presentation and publication experience. Applicant has industry experience (5 years). Applicant has a well thought out and explained research proposal with very clear metrics/goals.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Excellent

**Explanation to Applicant:**
Applicant has personal motivation for proposed research in renewable energy to combat climate change, a timely and relevant project. Applicant has continued volunteering experience with mentoring students/interns/employees/high school students and sharing their knowledge and STEM ideas with others.

**Summary Comments:** Applicant's proposed research is well-developed. Applicant has clear plans for conducting this research and sharing this research with others, including youths to interest them in STEM.

**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Very Good

**Explanation to Applicant:**
The academic standing of the applicant is excellent along with research skills. The applicant co-authored journal publications. The research plan has scientific merit and consists of preliminary data. However, post-test structural and microstructural analysis of the cells would provide insight regarding degradation mechanisms due to the new electrolyte and electrode interactions. Is the thermal, mechanical, and chemical properties of hBN the only reason for selection as nanoparticles in the composite? If so, there are many materials fulfilling these requirements. What is the uniqueness of hBN?

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Very Good

**Explanation to Applicant:**
The applicant demonstrated outreach activities not only related to STEM education but also for volunteering for other humanitarian services to the community.

**Summary Comments:** The applicant has excellent academic standing and research experience as well as working experience in the industry. The research problem is well defined but lacks to justify the uniqueness for selecting hBN. The applicant has clear career goal along with serving the society beyond research/education related activities.

**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

**Explanation to Applicant:**
One first author paper thus far in graduate school, great for a second-year student. Very interesting background in corporate R&D environment, which is not usually found in a PhD student. This will bring a new perspective on how feasible it is to take research from the bench to full production. Excellent research plan and thoughtful developmental processes. Strong academic record in both undergrad and graduate course.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Very Good

**Explanation to Applicant:**
Very strong history of volunteer work during undergraduate and graduate school. Some volunteering while working for industry by helping with storm clean-up from Harvey. I really appreciate that the volunteer work is both technical and non-technical in nature, and would like to see more STEM outreach in the future. Strong future goals section on working for a national laboratory, which could turn into a strong career in government scientific service.

**Summary Comments:** Overall, a good application and strong student with a background in commercial R&D, which will bring a good perspective on transitioning research from the lab to industry. The student has received awards from their time as a research engineer that demonstrates strong intellectual merit (nearly 1 award per year at the company). The student also has strong outreach and volunteer experiences and could continue to expand upon the STEM outreach into their graduate work.
[Example 3]: Personal Statement

Four months after I started working in a research lab, I began to consider graduate school. It suddenly occurred to me to ask one of the graduate students in my lab how she could afford five more years of tuition. She chuckled, smiling as she let me in on what seemed like a big secret at the time: she was paid to be a graduate student. With the realization that tuition might not be a barrier to a PhD, a flame of possibility flickered to life in my mind. Having this barrier lifted was exciting—I genuinely enjoy research. My inherent curiosity and diligence have allowed me to thrive in the lab. I’ve always felt it was my duty to help others and knowing that cost was no longer a barrier to graduate education was the missing puzzle piece that helped me realize I could turn this passion into a career. Graduate school will allow me to become an expert in materials science, so that I can become a PI and continue contributing to cutting edge research. Having the flexibility to choose what I want to study and how to do so is important; planning and carrying out my own experiments is gratifying and applying my knowledge to real world problems with far-reaching applications is exhilarating. My goal as a PI is not only to advance knowledge in the field, but to inspire younger women to do the same.

The graduate student I asked about tuition was Lily Hale, a female PhD student in my first lab, the Szymczak group. I learned about being a woman in science from Lily; for the first year of my work with Dr. Szymczak she and I were the only women in his lab out of 11 students. She was not my research mentor, but she seemed to know everything. She was approachable, willing to help, and she always reminded me to “start with the fundamentals” when I was struggling. As I look back on my time in Prof. Szymczak’s lab, I realize that without her female representation, I may not have stuck with research. As a PI in industry or academia, I will have the opportunity to influence the lives of other women the way that Lily influenced mine. I want to teach my students not to be discouraged when they look around and don’t see anyone like them, because they bring unique perspectives that will drive the research our society needs. As Lily and other female role models showed me, women belong in science and now it’s my turn to pass this sentiment on to the next generation of budding scientists.

Research Experiences: My first research experience was working for Professor Nathaniel Szymczak in the University of Michigan (U-M) chemistry department beginning in the spring of my freshman year. In the 2+ years that I spent working there, I changed immensely as a person and researcher. My first project in this lab was investigating a ruthenium catalyst for reversible CO2 hydrogenation. I applied for, and won, a 2015 U-M Energy Institute Summer Fellowship to work on this project, because the work that I was proposing could allow CO2 to be used as a hydrogen carrier and renewable fuel. I worked on this project for a year and a half and became experienced with using a large glovebox, ordering chemicals and supplies, multi-step catalyst synthesis, and 1H nuclear magnetic resonance (NMR) spectroscopy. I used gaseous CO2 and H2 at pressures up to 70 bar and became intimately familiar with the safety guidelines associated with using gases, vacuum pumps, dangerous chemicals, and liquid nitrogen in the lab. By the end of my CO2 project, I had discovered that differences in the secondary coordination spheres of Ru catalysts with the same ligand backbone led to pronounced differences in catalytic activity for both hydrogenation and dehydrogenation. I presented these findings during my junior year at the 253rd national meeting of the American Chemical Society (ACS) in April 2017, in addition to the poster I presented at the U-M Energy Institute symposium. In July 2018, this work was published in Chemical Communications (DOI: 10.1039/C8CC04370A). My success in the Szymczak lab led to my receipt of the chemistry department’s ACS Inorganic Chemistry award as a junior.

Motivated to gain research experience outside of U-M, I applied to the NSF REU program at the Colorado Center for Biorefining and Bioproducts (C2B2). I was fortunate enough to be accepted and spent the summer following my sophomore year working for Professor J. Will Medlin at the University of Colorado – Boulder. My project in his lab was to investigate the relationship between structure and thermal stability of heterogeneous...
catalysts functionalized with thiolate self-assembled monolayers (SAMs). Most of the Medlin lab students used these catalysts for transformations converting biomass to useful chemicals, so the model for stability that I was creating was especially impactful for the lab. I synthesized 36 different catalysts and characterized them with IR spectroscopy and temperature programmed desorption. Having experience with IR spectroscopy is important for my proposed research, as I will be studying drug molecules which typically have spectroscopic signatures in the IR. I discovered that the alcohol functional group was detrimental for thermal stability, metal-oxide support made no difference for stability, but catalytic metal affected removal of the head group and tracked well with sulfur affinity of each metal. I presented my findings at the C2B2 Symposium and authored a report for the REU directors. When my fellowship ended, I headed back to U-M with a deeper interest in research and a wider understanding of my own capabilities.

Back in the Szymczak lab for my junior year, I investigated a new project recycling CHF2CF3 refrigerant (R-125) as a chemical feedstock. I proposed this project to the U-M Energy Institute in spring 2017, won another fellowship, and eagerly began work. At this point, I functioned largely independently of my mentor and the graduate students often remarked that I was basically one of them (a graduate student). At first, I quickly denied this because I didn’t feel confidently independent, but as the summer progressed, I found myself asking fewer questions of Lily and my mentor and instead finding answers in the literature. I drew on previous experience with gases and air-sensitive chemicals for this project and characterized my reactions using more complicated 19F, 11B, and 13C NMR. I successfully synthesized a pentafluoroethylating reagent from R-125 with a half-life 50 times longer than the original hit. The independence I exhibited while working on this project made me a more confident researcher and taught me how to research efficiently, an important skill for graduate school. As I thought more about this prospect, I realized that I loved the lab I was working in, but not the field of chemistry. I was instead captivated by its applications and wanted experience with them.

I joined Professor Max Shtein’s materials science lab at the beginning of my senior year and haven’t looked back. The research that our group does has potential to impact the lives of so many, and for me, this is the best part of applications-based research. In this lab I’ve learned many more analytical techniques, but more importantly I’ve learned how to identify gaps in the literature and narrow my focus into high-impact research. I currently work independently on three distinct projects. They are mainly fundamental studies which will inform the design and invention of new technology. I’ve learned scanning electron microscopy (SEM), ellipsometry, vacuum thermal evaporation (VTE), organic vapor jet printing (OVJP), UV-Visible spectroscopy (UV-Vis), thermogravimetric analysis (TGA), atomic force microscopy (AFM), and silicon wafer cleaning and handling techniques. Most, if not all, of these characterization techniques will be necessary for the success of my proposed research project, especially OVJP, SEM, and UV-Vis. I’ve also refined my visual communications skills and become part of an NSF Engineering Research Consortium (CELL-MET). My work in Dr. Shtein’s lab demonstrates that I am ready to be a graduate student and I am committed to research as a career. I graduated in April 2018 with a bachelor’s in chemical engineering and minors in both chemistry and environmental engineering. I am currently taking a gap year before graduate school to continue working on the exciting research in the Shtein lab and complete the projects I began before my graduation.

Personal/Professional Experiences: Research is only one aspect of my life. Outside of the lab, I’m involved on campus with multiple student groups. My largest commitment is Tau Beta Pi (TBP), the national engineering academic honor society. When I joined TBP as a sophomore, I committed myself to community outreach, achieving at least 34 hours of service each of the five semesters since. I became involved in TBP leadership as a chairperson, moved on to be Secretary – an executive board position which I held junior year, before becoming President my senior year. Leading the team of 18 officers, six advisors, and 19 chairs taught me how to manage others, communicate effectively, and run efficient meetings. Planning and running chapter meetings for 100+ TBP
members taught me about how to graciously receive and learn from criticism, as well as how to motivate others to fulfill their officer duties and be engaged. I used what I knew from being swim captain in high school and on Residential Advising staff to support the officers and took on extra responsibilities when necessary. The most important skill that I developed in my leadership positions around the College of Engineering (CoE) is initiative. Initiative is critically important in a researcher, but arguably more so in a leader, especially the leader of a field. Initiative is what propels the leader or researcher to try new things, to test the boundaries of what is known, and to put the impetus on themselves and their team to make things happen. As President of TBP, the initiative I had been building manifest itself in the initiation of 70 new members, a chapter record.

As president, I recognized a need for stricter budgeting habits and worked with two others to create financial policies to guide future budgeting processes and institute controls on chapter and officer spending. I came into office and found that the chapter had five $500 awards to give away which had sat in an account with TBP nationals for over five years. I created and distributed a scholarship application to the college, selected award recipients with chapter advisors, and worked with CoE administration to ensure awardees were recognized at the annual Awards Luncheon. Finally, I saw that the chapter lacked links between new and existing members, resulting in low active retention post-initiation. To combat this, I created and piloted a Chapter Mentorship program in March 2018. I now serve as a chapter advisor, and I’ve continued to work on the Mentorship Program. Working with a chairperson this term, we’ve rolled out the program in earnest, assigning mentors to the 97 joining members.

**Broader Impacts and Intellectual Merit:** Without the representation Lily provided for me, I don’t know if I would have considered a career in research as a possibility. I hope to not only fill this role for other young women, but to create a space where other minorities feel comfortable, as well. As a graduate student, I plan to mentor and support as many undergraduates as possible, utilizing my mentoring experience as a Peer Advisor for the Engineering Honors Program and the management skills I learned as TBP President. Looking beyond graduate school, as the PI of a laboratory in industry or academia, I will actively seek out diverse candidates when hiring, and draw again on my leadership and mentoring experiences to nurture these young scientists. I strongly believe that international and cross-disciplinary collaborations are key for future innovation and I intend to create an environment in my lab that makes this possible. My past experiences and future plans make me uniquely qualified to contribute significantly to research, education, and future engineering innovation.
Summary: My proposed device is an improvement on epinephrine autoinjectors that combines microfluidics and organic vapor jet printing (OVJP) to provide rapid drug delivery, and yet increase shelf life and ease of administration. This proposal is aimed at a healthcare application; however, it focuses on the specific scientific and technological challenges to be addressed to enable a breakthrough and generalizable solution.

Background and Current Technology Limitations: In a medical emergency, every second counts. Heart attack, angina, stroke, and epilepsy are treated with fast-acting drugs followed by care at a hospital. Quick release pills (e.g. orally administered, fast-dissolving nitroglycerin) exist for these conditions, but not for the life-threatening emergency of anaphylactic shock, requiring epinephrine delivered via an autoinjector. In the event of anaphylaxis, time between symptom onset and fatal cardiac arrest is 5-35 minutes, thus it is critical that medication be administered expeditiously. Epinephrine as packaged in an autoinjector, however, has a limited shelf-life (<18 months due to photodegradation/oxidation in the aqueous solution) and requires user training to administer. Solid-form storage of active pharmaceutical ingredients (APIs) tends to extend shelf-life, but many solid-form APIs dissolve very slowly. Consequently, for many APIs, including epinephrine, a quick-release pill, sublingual or buccal patch formulation does not exist.

Proposed Solution: My approach couples well-established microfluidic technology with a novel means of generating complex API morphology to achieve quick dissolution and enhance stability in storage. Microfluidic devices generally use micropumps, magnetic actuation, chemical degradation, diffusion, or localized heating to release drug. However, none use thin films as the drug source or deliver epinephrine. In my device, epinephrine will be stored as a thin film and sealed into microfluidic drug-release channels, enabling stable, long-term storage. Rapid dissolution is enabled by the fact that API films printed via OVJP possess a nanoparticle morphology with extremely high surface area. Furthermore, the ability to selectively pattern such films allows for collective storage of multiple doses on one microchip, so a single implant could be used for many years. An implantable epinephrine microchip is extremely beneficial for children, as it eliminates the fear of being caught without this life-saving medication or improper injection in case of emergency. In one implementation, the microchip could be integrated with a biosensor to automatically dose a child undergoing anaphylactic shock.

Methods: Figure 1(a) illustrates the approach, which enables feedback control for dosage: a passive sensor monitors biological compound(s) relevant to treatment, if there is a change in the person’s system, the sensor activates the pump and device, and drug is delivered. Figure 1(b) shows examples of microfluidic architectures embodying this concept; their design will be explored further to comply with dosage constraints (rate, concentration, etc.). Prototypes will be fabricated with glass as a substrate for printing and polydimethylsiloxane (PDMS) as the microfluidic channel architecture overlaid onto the glass, shown in Fig. 1(c). Other biocompatible materials will be explored in later versions of the device to achieve maximum implantability.

![Figure 1. Proposed device schematic. (a) Basic feedback control scheme for proposed epinephrine dosage device. (b) Sample microfluidic device architecture with parallel or series drug reservoirs for different applications. (c) Cross-sectional view.](image-url)
To achieve consistent dosing, dissolution from the thin films must be reproducible, thus film processing conditions, microfluidic architecture, and pumping mechanism will be thoroughly explored for a number of formulations besides epinephrine. This device also can serve as a platform for detailed investigations of the fundamentals of dissolution processes, central to pharmacology, ecology, corrosion, and other fields.

**Intellectual Merit:** The integration of OVJP with established microfluidic platforms allows for controlled drug release easily applicable to many other illnesses, especially rapid-response or complex therapies, and has the potential to revolutionize the field of controlled drug delivery. This hybrid technology is new, and the dissolution kinetics of these API films are not well-understood. Additionally, while dosage and sensing devices have been independently fabricated, there are very few examples of a combination sensor and dosage device, as described here. Achieving effective drug delivery from my device means that the shelf-life and stability of other therapies delivered in this fashion benefit, with increased initial rates of release over conventional solid-state counterparts, while the number of doses per chip is expanded. Outside of epinephrine specifically, the knowledge gained from this use case is readily applicable to other APIs with the same device platform. As someone who has experience with OVJP and studying dissolution kinetics from my work in the Shtein lab, as well as a chemical engineering background in fluid dynamics, mass transport, and controls, I am uniquely qualified to pursue this device.

**Broader Impacts:** The approach described above opens the path to creating a multi-dose implantable epinephrine microchip that can save the lives of children with anaphylactic allergies. The multi-dose nature of the chip could combat the issue of steep refill costs, which is prohibitive for low-income families. Expanding to other quick-release systems, this device can be adapted to deliver relevant API(s) in the event of heart attack, seizure, angina, or other emergency. Beyond emergency medication delivery, I will explore other release profiles, such as pulsed and slow release, with the goal of culminating in highly-controlled multicomponent delivery (e.g. combination therapy for AIDS). Microfluidic devices are easily amenable to use in STEM outreach, so as an experienced leader with years of outreach and organizing experience, I can bring fluid dynamics concepts to children in an engaging manner via my microfluidic research.

**References:**

[Example 3]: Rating Sheet

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The applicant has excellent academic record, including a number of scholarships, internships, fellowships, presentations, and other honors. As an undergraduate, she has been actively involved in research and had several poster presentations along with a publication in a scientific journal (Chem. Commun.), which is indicative of the applicant's research potential. Overall, the application was written by a highly motivated, curious, and passionate individual, who has already accumulated a unique set of experience and skills to work on the proposed project. The letters of reference support this observation and intellectual merit of the applicant. The proposed work seeks to combine microfluidics with organic vapor jet printing to quickly deliver and dissolve drugs. The applicant clearly outlines the current limitations in active pharmaceutical ingredients and proposes a solution. While it is not clear if the applicant came up with research proposal on her own or with significant help from her advisor at UM, the plan to study both fundamentals of drug dissolution kinetics and practical applications of the technique has high merit.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: The applicant has an outstanding outreach record and embodies the future of scientific leadership. As an undergraduate, she has been heavily involved with engineering honor society TBP, eventually becoming its president. The applicant initiated mentorship program for incoming members of the TBP society and activities dedicated to diversity-equity inclusion, and has clearly demonstrated her commitment to diversity. It should be noted that all letters of reference mention both intellectual merit and broader impacts of applicants' work, and it is clear that the applicant has a bright and successful future ahead of her.

**Summary Comments:** This is an excellent proposal that addresses a significant problem that can benefit many areas of science, and at the same time Applicant wants to have an impact on helping people learn more and be more involved with science.

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: excellent GPA, research experiences, awarded by UMch/scholarships, 2nd author paper, could provide explanation of current research and transition to MSE given Chemistry/ChemE background. Proposed research interesting (seems like a better fit for biomedical engineering) and is described at very high level - more detail-specific lines of investigation would show command of the field

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: involved on campus (residential staff, peer advisor, TBP), interested in developing women in science

**Summary Comments:** Candidate has demonstrated excellent academic performance and has been awarded widely at her university. She is demonstrably involved with several organizations that aim to promote STEM and her goal of promoting women in STEM is a noble one. The proposed research is fairly broad and could improve with more specific aims and detailed lines of research. The work also seems to be a better fit for biomedical engineering rather than MSE.
**Example 4 NSF (Award Winner 2020)**

**[Example 4]: Personal Statement**

**Introduction:** Before ever stepping foot in an academic research lab, I worked as an archivist in the University of California, Los Angeles (UCLA) Library. Within the Special Collections Department, I documented the personal papers of influential inventors, scientists, artists, and activists. My job was to preserve the university’s collections of primary documents for generations of researchers to come. Working in Special Collections for three years as a student has provided me with a valuable perspective: a behind-the-scenes look at the evolution of innovations made by influential figures. While viewing their handwritten notes, their personal photos, and their letters, I found myself becoming intimately close to the people who have changed the world. I also curated unique items from these collections and created public presentations that told a more personal narrative about these figures. As much as I cherished preserving and sharing about the papers of influential people, working as an archivist has energized me to be among that class of discoverers. Today, I am still inspired by the innovators whose things I would rummage through; I dream of contributing to that body of knowledge that I was once a steward of. Despite my valuable experience at Special Collections and being offered a full-time position after graduating, I chose to pursue scientific research endeavors in the hopes of becoming one of these innovators I so admired as an archivist.

While I was incubating a fondness for historical preservation while working in UCLA Special Collections, I also dove into undergraduate research on energy storage devices. Because of how vital energy storage is to our modern electronics, I became intrigued by how this science developed in a lab could be scaled-up to enable technologies that improve the quality of everyday life. This desire was further shaped by my tenure at a small UCLA spin-off company, where I worked on commercializing academic research on superhard metal composites for two years before leaving for graduate school at Northwestern University. My time there solidified my resolve to continue working on bringing promising technologies from the lab to a wider audience.

These research opportunities and professional engagements have nurtured and sharpened the raw inventive spirit that I have possessed from a young age. My fantasy of building self-tying shoes in elementary school has since evolved into a vision of designing novel printable batteries at Northwestern University as I discuss in my Graduate Research Plan. And while the self-tying shoes idea did not come to fruition, my multifaceted academic journey has instead led me down a path of advancing knowledge in energy storage research so that I can realize my vision. Furthermore, my direct familiarity with the challenges of commercialization beyond lab-scale research empower me to engage with industrial and marketing groups to use my research to broadly impact society.

**Intellectual Merit:** While an undergraduate at UCLA, I worked in Dr. Richard Kaner’s lab with my post-doctorate mentor on designing and constructing hybrid supercapacitors. Because a supercapacitor stores energy via the physical separation of charge across the electrode-electrolyte interface, it does not rely on the kinetics of ion diffusion like the chemical energy storage of batteries. This endows supercapacitors with superior discharge rates and power density. While these merits are widely recognized, supercapacitors have not reached widespread commercial success due to their relatively low energy density compared to batteries. Our strategy to improve this key metric entailed constructing hybrid supercapacitors by combining high surface area reduced graphene oxide (rGO) electrodes with pseudocapacitive metal oxides. I solution-processed and drop casted the precursor materials onto flexible plastic substrates and reduced to rGO using a low-power laser. The resulting electrodes were constructed into devices, which I evaluated using electrochemical tests like cyclic voltammetry. From these performance tests, I determined values for capacitance, energy density, and power density. My specific contributions to the project were in the preparation of the rGO/metal oxide hybrid electrodes and the execution and subsequent analysis of the electrochemical tests. My efforts led us to the conclusion that our devices made from an rGO/MnO2 hybrid system could hold as much energy per volume as a lead acid battery. In 2015, we published our results in the Proceedings of the National Academy of Sciences. I communicated our findings through a number
of poster presentations, including at the ACS Southern California Undergraduate Research Conference in Chemistry, the UCLA Women in Physical Sciences Poster Session, and the UCLA Research Poster Day where I won the Dean’s Prize. I also gave an interview in the university newspaper, The Daily Bruin, about the emergence of supercapacitors as a viable commercial energy storage technology. This undergraduate research experience taught me valuable skills in electrochemistry and challenged me to effectively communicate results to a wide audience. It also exposed me to the world of energy storage research, which set me on the road towards my PhD work.

After graduating from UCLA with an interdepartmental degree in Chemistry and Materials Science, I joined the budding UCLA spin-off company SuperMetalix as a full-time researcher. Our goal was to commercialize academic research on superhard metals for drill bits and abrasives. I worked directly with the Chief Science Officer to produce a high-quality, non-porous composite that retained the integrity of the hard material while increasing toughness through the addition of a metal binder. This opportunity expanded my portfolio of lab skills well beyond my previous experiences. I optimized processing conditions for particle size reduction, classification, and sintering of metal powders, executed wear resistance tests according to industry standards, and performed extensive characterization to determine the hardness, oxidation resistance, and microstructural features of the sintered composites. Being part of a young startup, I pursued leadership opportunities in other area of the company beyond the walls of the lab. In addition to research and development, I was active in building contacts with industry partners; I established and maintained a relationship with a partner company to have our abrasive powders integrated with their production scheme. I also produced figures for and helped design marketing brochures for distribution to customers and participated in quarterly investor meetings where I was notably the only woman in the room. Finally, I represented our technology at the 2018 Gordon Research Conference in Solid State Chemistry. Before leaving for graduate school, I designed the training procedure and mentored my successor on the job that I had defined over my two-year tenure.

Last year, I joined the Hersam Lab at Northwestern University where my work focuses on developing a library of functional inks to print the conducting, semiconducting, and insulating components of electrical devices. In particular, I was drawn to the Hersam Lab’s NSF-funded initiative for the scalable manufacturing of graphene-based water sensors. These sensors can rapidly detect unsafe levels of lead in tap water, and I am intrigued that the particular focus of this project is to increase access to a technology that can improve public health through efficient scale-up. Our goal is to demonstrate that these sensors can be produced for only a few cents per device, making their widespread distribution viable. As part of this initiative, I have been implementing innovative techniques for the large-scale exfoliation and purification of graphene, which I use to make printing inks for the conductive components of our devices. I have utilized the skills I developed in industry to establish a relationship with an external company to test a novel method of graphene synthesis. In a separate project, I am exploring how additive manufacturing techniques like aerosol jet printing can be used to fully print the individual components of lithium ion batteries, including a novel ionogel electrolyte. Overall, my work in the Hersam Lab has challenged me to creatively solve problems associated with converting lab-scale technologies into those that can be mass-produced.

**Broader Impacts:** During my time at SuperMetalix, I tackled the unique challenges of translating lab results into a commercial product. For example, scaling up our synthesis method from individual gram-scale reactions to kilogram-scale high-temperature furnace runs required immense ingenuity and persistence. This has taught me that it is not trivial to bridge the gap between often superficial claims of potential research applications and the actual implementation of such claims. However, working in this fast-paced and demanding environment also allowed me to understand and appreciate what it takes to commercialize academic research. I have also been fortunate in my life to have role models that have nurtured my curiosity and shaped my aspirations. Whether they were the educators that directly mentored me or the figures I got to know through their preserved
belongings in Special Collections, these relationships have been foundational for me. Because of my belief in the importance of visible role models to foster developing scientists, I have always been passionate about STEM outreach. As an undergraduate, I was an intern in the UCLA California Teach program whose mission is to expose undergraduates to STEM K-12 teaching. Through this program, I interned in a third-grade science class, taught and received feedback on my own science lesson, and learned classroom management strategies and education theory. I also shared my experiences weekly with my internship cohort, whose support helped me solve the challenges I faced during the process.

I have continued this commitment to outreach in graduate school by joining initiatives aimed at making science more accessible to kids. For example, through the student-run Northwestern program Splash!, I designed a liquid nitrogen demonstration for a room of local high school students. I also mentor a fifth grader through the Letters to a Pre-Scientist program, where I have recently used the topic of cell phone explosions as a hook to engage his interest in my research on lithium ion batteries. Finally, I am one of the founding members of an initiative to implement a teen coding program run by graduate student mentors at the Pendersen-McCormick Boys and Girls Club in Chicago. In its inaugural year, the program has attracted 20 high school students weekly to learn Python. Because it is a completely new initiative, I helped define the very structure of the club meetings and created and taught the first lesson of the year. Seeing this initiative grow from scratch, I have become very invested in its success and solving its unique challenges. Instead of designing attention-grabbing demonstrations, I must focus on teaching extended and clear lessons that encourage students with varying amounts of coding experience to come back each week. My ability to measure my students’ engagement and tailor my content accordingly is universal to effective communication. Whether to ignite interest in STEM topics or to convey innovative results from the lab, I consistently practice scientific communication skills. This, along with my experience in industry, poise me to engage effectively with investors and collaborators to help translate my academic research to meaningful applications.

Conclusions and Future Goals: I am extremely passionate about seeing my ideas converted to real-world technologies, and my projects have consistently involved solutions to pertinent societal challenges. I have both performed undergraduate research on graphene-based energy storage and worked in a startup aimed at scaling up and commercializing a novel hard composite. My exposure to both academia and industry has allowed me to form a unique perspective that incorporates both domains of research and continually feeds my determination to work on translational technologies like sensors and batteries. My long-term professional goal is to lead a research team in bringing innovative energy storage research from the laboratory to market. The NSF Graduate Research Fellowship would support me as I build the skills to be an innovator and a leader, while bringing up younger students who share my aspirations to make a positive impact on society.

References:
Hexagonal Boron Nitride Ionogel Electrolytes for Printable and Flexible Energy Storage

Introduction: The lithium-ion battery (LIB), notably winning the 2019 Nobel Prize in Chemistry, is the premier energy storage technology in modern portable electronics. While widely implemented, LIBs have garnered severe safety concerns due to the conventional, highly flammable liquid electrolytes that shuttle lithium ions between LIB electrodes. Meanwhile, solid electrolytes are emerging as a safer alternative while simultaneously presenting fresh design challenges, including high interfacial resistance and low ionic conductivity. My proposal focuses on emerging solid/liquid hybrid electrolytes, which have the potential to address the limitations in both systems. These ‘ionogel’ electrolytes are composite materials comprised of an ionic liquid and a solid confining matrix. Contrary to incumbent liquid electrolytes, ionogels can be formulated into inks, enabling deposition on flexible substrates by additive manufacturing methods like aerosol jet printing (AJP).

Objectives: I propose to (1) improve the safety of traditional LIBs by replacing the conventional liquid electrolyte and polymer separator with a hexagonal boron nitride (hBN) ionogel electrolyte, and (2) achieve scalable deposition of these ionogel electrolytes via additive manufacturing.

Background: The volatile and highly flammable liquid electrolyte currently used in LIBs presents clear hazards. Puncturing the separator can short the electrodes, generating high temperatures that induce electrolyte ignition. Furthermore, high operating temperatures (above 60°C) will cause the polymer separator to degrade and the organic electrolyte to volatilize due to its high vapor pressure. Finally, the propensity for dendrite growth from lithium anodes through liquid electrolytes provides another pathway to shorting the battery. Ionogel electrolytes are an attractive alternative because they contain nonflammable ionic liquids and possess higher thermal stability. Note that ionogel electrolytes replace both the liquid electrolyte and the separator in a single component, which simplifies manufacturing and eliminates the risk of electrolyte leakage. Furthermore, the high mechanical modulus imparted by the solid matrix has been shown to effectively suppress lithium dendrite growth in addition to providing overall mechanical integrity to the cell.

The high chemical and thermal stability and mechanical robustness of hBN render it a promising candidate for a solid matrix in ionogel electrolytes. When hBN, a 2D electrically insulating isomorph to graphene, is mixed with an ionic liquid, gelation occurs via the formation of a network of agglomerated hBN. Recent work has incorporated bulk hBN in electrolytes, resulting in enhanced LIB operating temperatures up to 150°C. However, the relatively large hBN particles of this work weaken gelation and hinder ionic conduction. The Hersam Lab has demonstrated that hBN is compatible with liquid-phase exfoliation from the bulk phase, enabling the synthesis of 2D nanoflakes. Moreover, imparting solution processability to ionogel electrolytes is desirable for large-scale implementation. Previous work on ionogel electrolytes has relied on manual deposition, which results in poor control of the electrolyte footprint and thickness. In contrast, I propose to develop ionogel electrolytes that are deposited with AJP, an emerging printing method where materials suspended in a liquid ink are aerosolized and delivered to a substrate by a carrier gas (Figure 1). AJP permits unprecedented digital control over print geometry and allows compatibility with diverse ink viscosities and substrate materials compared to alternative printing methods. Hypothesis: Exfoliated hBN will improve the ion movement in the gel electrolyte because of its nanoscale matrix size. It will also strengthen gelation due to the enlarged surface area available for inter-particle interactions. Furthermore, it is
postulated that the adsorption of ionic liquid on the large surface area of exfoliated hBN stabilizes the ionic liquid in the gel electrolyte at high voltages, leading to improved electrochemical stability for high energy density.

**Preliminary Results:** Preliminary tests of our ionogel electrolytes based on liquid-phase exfoliated hBN have confirmed the significant enhancement of both the mechanical strength (storage modulus: > 1 MPa) and ionic conductivity (> 1 mS cm⁻¹ at room temperature) compared to bulk hBN gels. Thermogravimetric analysis shows that the gel composite is stable up to 300°C, enabling high operating temperatures. Finally, linear sweep voltammetry confirms high electrochemical stability up to 5.2 V (vs Li/Li⁺), ensuring compatibility with high-voltage cathodes.⁸

**Research Plan:**

**Phase 1: Ink formulation for aerosol jet printing.** Formulating the gel into a functional ink will enable the deposition of a high-quality film on a target electrode by AJP. There are two major ink formulation parameters to consider: solvent type and solids loading. The boiling point of the solvent will affect aerosolization and subsequent film morphology, while solids loading will affect the uniformity of the deposition. Optimization will require a thorough study of compatible co-solvent systems that can disperse the gel. Once basic deposition is achieved, printing parameters will then be optimized, including atomization frequency, gas flow rates, and print speed.

**Phase 2: Performance assessment of printed electrolytes.** Following successful ink formulation, the mechanical modulus and ionic conductivity will be evaluated to ensure that processing the ionogel for AJP compatibility does not negatively modify its properties. Next, the electrochemical performance of the printed ionogel electrolytes will be assessed by determining capacity, Coulombic efficiency, full operating temperature range, and effectiveness in suppressing lithium dendrite formation with lithium anodes. Impedance spectroscopy, potentiostat measurements at elevated temperatures, and charge/discharge measurements will be employed for half-cell and full-cell structures. These tests will also identify the optimal printing thickness (from nanometers to tens of microns), balancing the tradeoff between impeding ionic conduction in thick films and compromising mechanical robustness and lithium dendrite suppression in thin films.

**Resources and Potential Alternatives:** To accomplish these goals, I will leverage the vast expertise of the Hersam Lab. We have the skills and equipment to execute each aspect of this proposal including solution processing of 2D materials, printing with functional inks, and constructing and testing LIBs. Furthermore, if I am unable to deposit the electrolyte via the proposed methodology of AJP, there are alternative, more established thin-film deposition techniques to explore including inkjet printing or blade coating. Finally, even with modifications, a comprehensive study of hBN ionogel inks will contribute to the growing body of knowledge surrounding ionogel electrolytes.

**Broader Impacts:** LIBs are the culprit in recent spontaneous cell phone explosions that have many questioning their safety. Using the nonflammable and printable ionogels I have proposed eliminates this public safety concern and guarantees their continued implementation in innovative applications. However, I can also use this recent media spotlight on the infamous flammability of LIBs as a teaching opportunity to inspire curiosity in a battery’s inner workings. By developing engaging but safe demonstrations, I can show how much heat a short circuit generates and how explosive lithium is when added to water. By using the Northwestern outreach initiatives I am involved in as my platform, I will spread awareness about LIB technology to future scientists across Chicago.

**References:**

[Example 4]: Rating Sheet

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Very Good
Explanation to Applicant: Interesting research topic with great potential benefits. Articulating how this would translate (quantified metrics) into performance would give the research higher visibility.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Very Good
Explanation to Applicant: Applicant already has teaching experience with a broad audience and uses research to interest potential scientists in a way that is meaningful.

**Summary Comments:** Applicant is poised to become a good researcher and educator.

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Very Good
Explanation to Applicant: The applicant proposed to improve the performance of the traditional lithium-ion battery using hybrid ion gel electrolyte and use additive manufacturing technique to fabricate/deposit them with controlled microstructure. The applicant has relevant research experiences in electrochemistry, energy storage and composites, during her undergraduate studies, to achieve the above-mentioned objectives. The applicant won some awards and scholarships and has both academic and industrial experience. Her past academic research contributions were resulted in journal articles and presentation at symposiums and conferences. Her industry work experience was also resulted in training procedure for design marketing broacher that aims to commercialize the research idea and help to bring the lab-based research in real world applications.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Very Good
Explanation to Applicant: The applicant was involved in some outreach activities that exposes undergraduates to STEM K-12 teaching. In this effort, she taught in a third-grade science class. She also showed these commitment in graduate school as well. For instance, she joined student-run program at Northwestern University and designed some demonstration for high-school students to create interest in STEM field. She has some experience with commercialization and how to build industry-academia relationship through her industrial work experience. The outcome of her research will have an impact on energy storage field, in particular batteries.

**Summary Comments:** The applicant is a strong candidate. There is a clear explanation for the intellectual merit of the past and future research.

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The proposed study on emerging solid/liquid hybrid electrolytes, have the potential to address the current limitations.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Very Good
Explanation to Applicant: Using the nonflammable and printable ionogels can eliminate the public safety concern and guarantees their continued implementation in innovative applications.

**Summary Comments:** The proposed work is very well addressed. The work plan is clear. The applicant is well qualified.
Example 5 NSF (Award Winner 2020)

**[Example 5]: Personal Statement**

**Personal Background and Summary of Goals** - My parents grew up in a culture that believed hard sciences were suitable for sons, not daughters. As a young girl, I was never encouraged to expand upon my interest in STEM, which manifested in playing with laboratory-grade flasks as toys or “synthesizing” hair-dyes for my Barbie dolls. Additionally, none of my female relatives had STEM careers; I had no role models to look up to. Finally, I struggled with math in elementary and middle school, enough that I could not visualize my own success in a science or engineering-oriented career. I truly believed that I was confined to a stereotypically feminine field, such as fashion design, until I was fifteen.

I did not discover my own love for science until I failed my first chemistry test in high school. This initial failure led me to take additional time studying the subject and pay close attention in class. Though I found reading the textbook on my own to be interesting, it was the life and passion my chemistry teacher exuded in each lesson that unraveled my own innate love for the atomic scale. Since then, I have sought a career allowing me to combine my passion for science with my desire to nurture future generations of students. My undergraduate experiences in materials science research, teaching, mentorship, and education outreach cemented my desire to make an impact in the classroom as a career.

Thus, I am currently pursuing a PhD in Materials Science and Engineering at Northwestern University to become a professor in the field. In pursuing an academic career, my objectives are to 1) investigate scalable nanomaterial processing methods in relationship to sustainability, expanding upon my past and current research, 2) teach undergraduate and graduate courses effectively, and 3) actively organize and engage in educational/STEM outreach opportunities for underrepresented student groups.

**Research Interests and Experiences** - As a rising sophomore at Rice University, I was serendipitously assigned to the projects in Dr. Jun Lou’s lab that has since shaped my overarching research interest—the intersectionality of nanomaterials and sustainability. To me, sustainability is synonymous with influencing the quality of life for future generations within the earth’s resources.

In Jun Lou’s lab, I worked on two projects throughout my sophomore year: 1) self-adaptive composite materials for oil spill clean-ups and 2) carbon nanotube (CNT) films for water desalination. In my first project, I fabricated self-healing materials, composites of polymer blends, and optimized for absorption properties for various types of oils and fuels. In my second project, I used chemical vapor deposition (CVD) to synthesize films of CNTs, characterizing physical adsorption properties as a mechanism for desalination. I presented my findings from the second project at the annual Rice Undergraduate Research Symposium (RURS) in spring 2016.

The following summer, I travelled to Shandong University in Jinan, Shandong, China to research with Dr. Lijie Ci under the Joint Center for Carbon Nanomaterials, a collaboration between Rice and Shandong University. There, I used the experiences from my two projects on oil removal and CVD-growth of CNTs to design an independent project. At Shandong, I synthesized a hydrothermally reduced graphene aerogel and grew CNTs via CVD on the aerogel to enhance oil absorption properties. Returning from China, I presented my summer work at Materials Science & Technology (MS&T) 2016.

As I returned to Rice for my junior year, I built upon my work at Shandong and expanded on my earlier project on water treatment with CNTs, synthesizing composite films of graphene aerogels and CNTs as electrodes in capacitive deionization (CDI), an emerging water desalination technology. In this project, I investigated how film processing...
and morphology influences electrical conductivity and surface area, two key metrics for CDI electrodes. I reported my results for this novel water desalination method at RURS Spring 2017. At the end of my junior year, I was awarded “Undergraduate Research Excellence,” which is allotted to one student in the Materials Science department annually.

Switching gears from water sustainability-specific applications of carbon nanomaterials, I was challenged to conduct foundational work on aerosol jet-printing liquid-exfoliated 2D nanomaterials such as MoS2 at Northwestern University’s Materials Science and Engineering Center (MRSEC) REU program Summer 2017 under Dr. Mark Hersam. Because fabricating 2D devices by aerosol jet-printing liquid-exfoliated nanomaterials had not been attempted in previous literature, I had the opportunity to work closely with a graduate student in developing creative approaches. My project was summarized as a presentation in the final symposium at the REU program. By the end of the project, I contributed useful insight on a novel, scalable fabrication method that potentially can be used in photovoltaics and energy-efficient devices, work that the Hersam group intends to build upon in the near and far future.

Though my REU was far different from my past experiences, I applied my gained technical skills specifically as a unique approach in my project when I returned to the Lou group. In my senior year, I conducted an independent project in which I fabricated and tuned the morphology of CDI electrodes for selective removal of heavy ion contaminants via liquid exfoliation of carbon nanomaterials. I additionally had the opportunity to mentor a freshman undergraduate on this project. In Spring 2018, I summarized findings of my project in my Rice Undergraduate Scholars Program seminar course. For my continuous efforts on carbon nanomaterials in water treatment, spanning from sophomore to senior year, I earned the honor of “Distinction in Research and Creative Works” on my diploma as I graduated from Rice.

For graduate school, I returned to the Hersam Laboratory at Northwestern University in Fall 2018. In my current research project, I am expanding on my previous REU experiences to formulate and characterize inks of semiconducting liquid-exfoliated 2D nanomaterials for scalable, large-area, printable electronics. I am focusing on the interfaces between liquid-exfoliated nanosheets to engineer such inks, using precursors and additives as a novel approach to improve charge transport across nanosheet interfaces. As fabricating electronic devices with liquid-exfoliated materials remains a challenge, my project has potential to make significant advances in the solution-processing. My research can further serve as a stepping-stone towards the growing demand for artificial intelligence and advanced computing at reduced energy input, relating back to the theme of sustainability. I plan on using the specific skillset gained during my PhD to further study scalable processing methods of low-dimensional materials for sustainable applications in my professional research career. Furthermore, I will mentor undergraduates and visiting REU students on my project, just as I was mentored during my REU in the Hersam group, in turn training a new generation of scientists.

**Teaching and Educational Outreach Experiences** - Beyond the lab, my undergraduate experiences with teaching and education inequality have bolstered my goal of influencing students as an educator. As a freshman, I volunteered as a STEM-mentor to underserved students at a local high school known as a “drop-out factory.” However, the program felt too surface level, as mentors would only meet for an hour with the students every other week. To dive deeper into the problem of education inequality, I explored local and state-level educational policy issues as a week-long service trip in Houston my sophomore year. I subsequently became involved in Splash, an educational outreach program with chapters at various universities, in which college students teach their own self-designed courses to middle or high school students. Rice Splash is a free day-long program where hundreds of underserved, local
Houston middle schoolers take such classes at Rice campus. For Rice Splash’s program in April 2016, I developed and taught three sections of a class introducing the students to the discipline of materials science and its relevance. This experience was significant, as it was the first time for the students to be at a college campus and consider what a career in STEM might look like.

As a junior, I became further involved with Splash. During Fall 2017, I travelled to MIT’s Splash chapter to teach a self-designed class on the wider applications of nanotechnology to nearly two-hundred high-school students. More significantly, I became external vice president of Rice Splash. I oversaw logistical coordination with the local schools in bringing five hundred students to Rice Splash 2017, where over ninety-five percent of the students served came from minority backgrounds. I continued to serve as external vice president my senior year, further establishing Rice’s Splash chapter and expanding the program’s range of target reach.

Simultaneously, I served as a teaching assistant for the introductory undergraduate materials science course my junior and senior years. As a teaching assistant, I not only assessed students through graded assignments, but also prepared four exam recitation sessions for eighty students, through which I had the opportunity to teach. As a special topics lecture, I additionally presented my research on carbon nanomaterials as CDI electrodes in this course and related class concepts to broader applications outside the classroom.

My involvement with teaching and educational outreach has not stopped with my undergraduate years. Since Fall 2018, I have served as the student recruitment director of Northwestern Splash. Drawing on my previous experience in Rice Splash, I communicate with local schools and organizations with an aim to increase participation of students from low-income backgrounds. For Northwestern Splash 2019, my efforts manifested as a 46% increase in attendance from the previous year, and my goal is to continue along this trajectory. Finally, I plan on serving as a teaching assistant in my third and fourth years and enrolling in the Teaching Certificate Program (TCP) at Northwestern’s Searle Center for Advancing Learning and Teaching. With TCP, I will formulate a teaching statement, develop my own course, and receive structured teaching feedback.

**Broader Impact** - Having seen the tangible impact of education in my own life, in my professional career, I am motivated to inspire students as an effective educator as well as engage in STEM outreach for women and minorities. As a professor, I hope to organize outreach events, inviting traditionally underrepresented groups in STEM for lab tours and science demonstrations, and serve as a faculty sponsor for existing educational outreach organizations. My objective is to enable underserved students to visualize themselves in STEM and/or higher education, as I did when inspired by a teacher’s passion. To continually develop myself professionally, I plan to revisit my teaching philosophy every few years and attend workshops for enhancing my teaching practice. Furthermore, as a woman of color, I plan on being a vocal advocate for diversity at the department and university level, for both students and new faculty hires alike.

In parallel, I hope my current and future research in scalable nanomaterial processing approaches will not only impact my field of study, but also further advance ways to address broad issues in sustainability, such as energy, water, and environment. As these challenges are increasingly relevant, my work in the intersectionality of nanomaterials and sustainability is likely to have significant societal implications. Ultimately, in pursuing my PhD and a career in academia, I aim to influence current and future generations through advances in sustainability as well as mentorship, teaching, and outreach. Becoming an NSF Graduate Research Fellow would enable me to initiate efforts that spark my passions, sustainable nanomaterials and education.
Tuning Interfaces of Liquid-Phase Exfoliated MoS$_2$ for Printable Neuromorphic Computing

Motivation – Neuromorphic computing architectures mimic biological systems by simultaneously processing and storing information, enabling high-performance computing with substantially reduced power input. These energy-efficient architectures can potentially meet the growing demand for artificial intelligence and machine learning. An emerging device known as a memristor can further advance neuromorphic architectures due its ultralow energy consumption and smaller footprint. Memristors are non-volatile switches, retaining memory without power, with tunable resistance and several intermediate resistive states. By realizing multi-state information storage in a single device, memristors can compute analogously to biological neural systems. However, further study into scalable processing of memristive materials is required to enable high endurance, cost-effective neuromorphic architectures. To address this deficit, I propose using liquid-phase exfoliated (LPE) two-dimensional (2D) molybdenum disulfide (MoS$_2$) with tailored interfaces as a printable electronic material for artificial synapses and neurons.

Background – 2D semiconductors, such as MoS$_2$, are atomically-thin, having unique electrical properties not exhibited in its bulk form. Furthermore, 2D memristors enable scaled-down devices and tunability of the set voltage, providing advantages over their 3D counterparts. Recently, 2D MoS$_2$ has been demonstrated in memristive systems. Sulfur vacancy motion mediated by grain boundaries in polycrystalline, chemical vapor deposition (CVD) MoS$_2$ is responsible for observed memristive behavior. The resistance across a grain boundary, facilitating the field-driven motion of sulfur vacancies, can be tuned by electrodes in contact with the grain. However, CVD MoS$_2$ memristors require precise control over grain size and extensive optimization of growth parameters. Alternatively, atomically-thin MoS$_2$ has already been achieved through liquid-phase exfoliation (LPE), which is a more scalable approach than CVD.

LPE is an economical method of obtaining nanosheets of 2D materials. A bulk crystalline layered material, held together by weak van der Waals forces, is ultrasonically exfoliated in a solvent with a matched surface energy. LPE results in inks containing solvent-stabilized, exfoliated flakes which enable printable and large-area electronics, a key advantage over CVD. Although LPE is often assumed to produce flakes with compromised electronic properties, my preliminary work with MoS$_2$ exfoliated in 2-butanone solvent has demonstrated that a high-yield of electronic-grade material can be achieved (up to 10 mg/mL). Despite the advantages of LPE, producing high conductivity films remains a challenge due to poor contact between the nanosheets when inks are deposited. Therefore, my efforts will focus on flake interfaces in thin films. From my preliminary work, solution-processable precursors to MoS$_2$, such as ammonium tetrathiomolybdate (ATTM), show promise in bridging LPE MoS$_2$ nanosheets. ATTM is a single-source precursor containing molybdenum and sulfur, decomposing to form crystalline MoS$_2$ between 300°C and 800°C.

Proposed Research Plan – Previous studies on CVD MoS$_2$ point to the importance of interfaces in memristive behavior. Thus, I plan to: 1) tune the interfaces between LPE nanosheets using the ATTM precursor, 2) construct a memristor using the engineered film, and 3) characterize the device to understand mechanisms of memristive behavior from solution-processed nanosheets. The overarching goal of the proposed work is to tune 2D LPE nanosheet interfaces to enable high-performance, printable neuromorphic computing applications.

1) Expanding on my past work, I plan to exfoliate bulk MoS$_2$ powder in 2-butanone by bath sonication and subsequent centrifugation. ATTM will be added at various concentrations to the LPE MoS$_2$ to formulate inks. The MoS$_2$/ATTM ink will be deposited onto a SiO$_2$ substrate by aerosol jet printing, followed by an annealing step. Hypothesis: The decomposed ATTM will crystallize at the interfaces between the LPE MoS$_2$ nanosheets when annealed, thereby bridging the sheets and facilitating charge transport to enable memristive behavior. Films will be optimized by exfoliation, precursor, printing, and annealing parameters. Scanning electron microscopy and atomic
force microscopy will provide insight on film morphology. Raman spectroscopy will give chemical information and indicate degree of crystallinity.

2) A memristor with vertical geometry will be constructed by depositing gold electrodes via thermal evaporation below and on top of the printed MoS$_2$ film (Fig. 1). The resulting device will be characterized by measuring current-voltage curves. A hysteresis loop at positive and negative voltages, representing switching of resistance states, will indicate memristive behavior. Previously reported CVD MoS$_2$ memristors will be used as a benchmark ($>$10$^6$ on/off ratio, $>$10$^3$ switching ratio, $<$80 V operating voltage, $>$ 475 cycle stability).$^{4,6}$

3) Memristive mechanism will be studied using electrostatic force microscopy, probing changes in electrostatic potential across MoS$_2$ nanosheet interfaces. Reduced potential drops across flake interfaces at the decomposed ATTM bridges will confirm improved charge transport. Photoluminescence and Raman spectroscopy will map the spatial variation of defects in the films during in-situ device operation.

The largest anticipated obstacle is the control of MoS$_2$ nanosheet interfaces to a point enabling high electrical conductivity. This challenge will be addressed by first optimizing ATTM content, which has the greatest influence on film morphology. Another likely challenge is fabricating a successful memristive device, which will be addressed by making electrical measurements on the vertical memristors before tuning device geometry to optimize performance. The Hersam Laboratory has extensive experience with device fabrication and testing to efficiently resolve device issues.

**Intellectual Merit** – Fabricating LPE MoS$_2$ memristors would be the first demonstration of a printable memristor, a significant leap towards large-scale implementation of high-performing neuromorphic architectures. Additionally, using precursors to improve charge transport is a unique and previously undemonstrated approach. This work will further provide insight on how to optimize LPE MoS$_2$ memristors in a manner that can be extended to other 2D materials. As the need for advanced computing and large-scale data processing continues to grow, constructing neuromorphic architectures using LPE, a much more scalable approach than CVD, is likely to have broad implications on energy efficient, next-generation computing technologies.

**Broader Impact** – Beyond the lab, I plan to integrate my latest research into courses that I previously designed for middle and high school students at Rice and MIT Splash. I will teach this revamped class for underserved high schoolers at Northwestern Splash and introduce students to the relationship between materials properties, processing, and real-world applications, using the example of my research. Ultimately, this course will inspire students by showing how emerging science can relate to daily life and encourage the pursuit of STEM and higher education.

**References**
[Example 5]: Rating Sheet

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The applicant has an outstanding academic record as an undergraduate and graduate student including earning awards for research as an undergraduate. The applicant has had multiple research experiences resulting in several publications and presentations. The proposal contains a well-developed research plan. The proposed research could lead to advances in the deployment of high performing neuromorphic architectures. If successful, this would be the first demonstration of a printable memristor. This work could have significant impact on next generation computing technologies. The applicant's reference letters show strong endorsement and support.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: As an undergraduate and graduate student, the applicant mentored and taught in the Splash educational outreach program at multiple institutions as well as several other tutoring and STEM mentoring activities. The applicant intends to pursue an academic career to teach courses in Materials Science and also engage in STEM outreach activities for underrepresented groups. The applicant has also expressed an interest in exploring the intersection of nanomaterials and sustainability which could have impact on the broader community.

Summary Comments: The applicant has an outstanding academic background and multiple research experiences which have contributed to current success. The applicant has an outstanding record in STEM educational outreach as an undergraduate and graduate student, and has plans to continue similar mentoring and advocacy activities for underrepresented groups as a professor. The proposed research would aid in large scale implementation of neuromorphic architectures which may impact several other areas such as high performance computing.

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: Sizeable number of poster presentations and co-authorship on an accepted paper as well as submitted manuscripts show very good level of academic performance. Clear description of research plan that is well-reasoned, balanced, is original and bears the potential of high impact results

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: Clear professional career goal. Many collaborations formed that are active. Impressive involvement in educational outreach efforts.

Summary Comments: Excellent overall proposal.

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Very Good
Explanation to Applicant: The applicant has proposed a well thought out research plan and has weaved her experiences, relevant to her proposed work, seamlessly. The applicant brings excellent motivation, leadership, and academic preparation to support her research. The applicant has demonstrated her ability to pursue independent research and has methodically built her capability as a researcher. The applicant is pursuing an advanced degree and has demonstrated through her myriad of experiences the qualities to become a successful teacher-scholar. Her work experiences, publications, and awards during her undergraduate years is commendable.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Very Good
Explanation to Applicant: The applicant has articulated the broader impact of her research and her outreach activities well. Her continued participation in SPLASH and leadership within the organization is commendable. This program has enabled her to influence and mentor many STEM aspirants from within the under served population. She plans to continue this activity during her graduate education as well as a teacher-scholar. This is bound to be very impactful.

Summary Comments: Overall a well written proposal highlighting the intellectual merit and broader impact of the applicants contributions.
Example 6 NSF (Award Winner 2019)

[Example 6]: Personal Statement

Recently I became an uncle. One of my favorite things to do with my new nephew is play peek-a-boo; his face lights with an infectious joy that makes any rough day better. It is this feeling of jubilation that I find myself with periodically, and it is a reminder of why I am pursuing a PhD. Such childlike revelations can start with a passing comment by a professor in lecture and continue into a conversation with classmates afterwards or when I check the results of an experiment and everything ran smoothly. Studying physics as an undergraduate at the Massachusetts Institute of Technology (MIT), my statistical mechanics classes often brought this sense of wonder. Thermodynamics being phenomenologically driven, there was an explanation and intuition for each term, whereas the potentials used in quantum mechanics seemed arbitrary at times. What impressed me most, for example, was the multitude of ways to derive the ideal gas law. In my first class, we spent half a lecture deriving the ideal gas law from quantum particles in a 3D box; my next class spent three days working through kinetic theory equations to derive the hydrodynamic equations, which at zeroth order is the ideal gas law.

My passion for thermodynamics does not stem from classwork, but from research. I spent a year working on a project to rank-order steady-state biological systems out of equilibrium based on their energy dissipation rates. In my quest to understand my project at a fundamental level and learn how to realize my objectives, I read a lot of literature on nonequilibrium thermodynamics -- specifically stochastic statistical mechanics. The difficulty of the project and profound results captivated me in a way that other areas of physics could not. I aspire to expand our ability to understand and describe dynamic phenomena through thermodynamic and statistical concepts. This led me to Northwestern University’s Materials Science and Engineering program, where I hope to investigate these concepts through computational methods.

**Professional Development:** As a freshman at MIT, I became fascinated with material properties. Talking with a member of the marine robotics team, I learned about a project they were working on involving nitinol – a material that expanded at low temperatures. They were testing it for use within an undersea glider to replace a battery-powered water pump. The idea and benefits of swapping out an electrical pump with a material amazed me; the main power draw could be removed, allowing for a smaller battery or more sensors and there wasn’t concern about losing the glider due to pump failure (as the nitinol would further expand as the glider dove deeper, ejecting more water). This made me think about how understanding material properties impact society.

Eager to study peculiar material properties, I joined a research group under Professor Mildred Dresselhaus characterizing the optical properties of 2D materials. I was given the opportunity to select an understudied material to probe its properties with Raman spectroscopy, whereupon I chose gallium telluride for its strong photovoltaic response. Over the course of two years, I studied its optical anisotropy using polarized Raman spectroscopy to measure phonon mode response dependence on incident light polarization. I became involved with all experimental aspects of the work, including sample preparation, data acquisition and analysis, which culminated in a coauthored paper published in ACS Nano [1]. Following that work, I stayed with the group to study the light-induced degradation of gallium telluride before deciding to explore other areas of material physics.

With an initial grasp of research responsibilities, I joined Professor Nikta Fakhri’s lab that focus’ on how energy is used in the cell and connecting that with pattern formation of the cell actomyosin cortex. I first recognized my interests in biophysics while taking an ecology class my junior year that studied population dynamics, where microbial dynamics and competition models caught my attention as powerful phenomenological equations. My specific project was to develop a methodological framework for extracting information about the entropy production of a physical mechanism from the time-reversal asymmetry of particle trajectories driven by the process. Although different from why I initially was interested in biophysics, this project was the first time I
encountered thermodynamic concepts in a research setting and is largely the reason I aspire to develop nonequilibrium thermodynamic concepts. I read extensively about fluctuation theorems and stochastic thermodynamics in addition to mathematical estimators for entropy and time series analysis. My objective was to apply a known theorem on experimental data, an assignment which exercised my creativity and galvanized my interest in pursuing a PhD. I spent a little over a year on this project, which became my undergraduate thesis work. I am grateful for the many opportunities I had in the group to learn the process of communicating ideas to the broader academic community, starting with a poster at the end of my first summer, a presentation at the APS March conference and I am excited to be first author on a paper currently in preparation for submission.

In my project with Dresselhaus, I gained an understanding of the diligence involved in experimental work and data collection. In my project with Fakhri, I learned an appreciation for analyzing results and being able to communicate them. While formative, my success in these groups depended on skills I developed through my coursework. My proudest accomplishment while at MIT (outside of research) is a paper I wrote for my 3rd course in quantum mechanics. The paper was meant to imitate the style of Physical Review Letters and be written at the level of the class. At the time I was still working with Millie Dresselhaus so I chose to write on density functional theory as I had come across the phrase in papers. I decided to take the opportunity to learn more about what I came across in the literature that was not directly related to my research project. The subject was much more ambitious than I had expected; I had to revise my scope and work through notation inconsistent across reviews. The endeavor was rewarding and I gained experience in distilling information and technical writing. In addition, I took two lab classes that required writing numerous papers, giving several fifteen-minute talks and one poster presentation between them. While giving me a lot of exposure to a variety of experimental systems, the talks were pivotal in being an experience I could draw on for my APS talk a year later. Through my lab class I also gained experience in designing an experiment. For the final project in my second lab class, my partner and I planned our own experiment to measure perovskite degradation using X-ray diffraction. The initial suggestion by our professor was to look at phase transformations of barium titanate, but my partner and I decided to go beyond the suggestion and we ordered materials and synthesized lead and bromide perovskites, as they are of interest for solar cell applications, but are limited by instability in ambient conditions. We then kept them in humidity controlled chambers to compare degradation rates across time and humidity levels by looking at their diffraction patterns for how much of the sample had reverted into their precursors.

I chose to go to Northwestern because I know I have a lot left to learn. Important to me in choosing an advisor, was that I could get instruction to develop my ability to write and give presentations and otherwise communicate my ideas, both big and small, to my colleagues. In my physics undergraduate education I developed an intuition for fundamental properties of materials that I now want to apply to realistic material systems. Northwestern is strong in computational methods, which I want to master for its potential to recreate experiments that allow an understanding of dynamic processes otherwise invisible experimentally. There are ample resources and a strong collaborative environment that I can learn from. I am confident that I may express my academic creativity and that it will mature under this department.

**Broader Impacts and Legacy:** I want to use the skills I have developed to improve public education and lower barriers to higher education. I went to school in areas with a large migrant population and their options after graduating high school are often limited and familial obligations prevent them from prioritizing education. Due to this interest and my close work with her, Prof. Millie Dresselhaus became one of my role models. She greatly improved the climate for female researchers and served the country as a director for the Department of Energy. I would consider myself successful if I could continue her legacy of making the academic community more inclusive of all races and genders. I hope that as I succeed in life, I am able to use my influence to advocate or and increase accessibility for women and underrepresented minorities to higher education.
In the spirit of helping aspiring academics achieve their goals, I searched for roles that allowed me to use the knowledge I had gained to aid students who were either struggling or wanting to gain more from their coursework. As a teaching assistant for the Office of Minority Education at MIT, I reviewed concepts learned in lecture and designed practice problems for students who wanted more instruction in their introductory physics and math courses. My role was to provide a new perspective and examples of using concepts in class, developing worksheets, to reinforce the concepts for my students. In addition to lecture-based teaching, I became also a lab assistant for the physics lab class, helping students to understand troubleshoot their experiments. This was exciting for me, as these experiments probed fundamental physics topics that I would engage the students with on the understanding, and was also a way for me to learn communication strategies for experimental techniques. To apply my skillset towards engaging high school students in physics, I spent a semester with Janet Conrad working on a desktop muon counter. The project was to create an experiment for high schoolers to expose them to particle physics at a younger age. Through this assignment I helped a couple of high school students to build their own muon counter for the science fair at their respective schools.

My advisor, Erik Luijten, has attended workshops overseas, such as Ethiopia and Cuba, to instruct other researchers in computational methods. I share his enthusiasm for these events and he has been encouraging in terms of organizing workshops and developing practice problems for them. We have discussed organizing similar workshops in the future. I have experience running workshops from my undergraduate education. My first week at MIT, I took part in a week long student-led program for incoming freshmen to learn about ocean engineering. I became heavily involved in all aspects of this program throughout my time at MIT.

I want my legacy to be as much about helping others to reach their academic potential as it is about my research. I plan to utilize any opportunity to give my colleagues and those aspiring to academia the tools they need to achieve success.

References:
Research Proposal

Exploring the foundations of nonequilibrium statistical mechanics

Overview: Thermodynamics and statistical mechanics provide a universal framework used across many disciplines. Starting from very few assumptions, this framework enables us to understand the tendencies and characteristics of materials from molecular interactions. Such insight has enabled chemists, material scientists and physicists to design experiments that predict and explain numerous aspects of the physical world. Interesting results come from looking at thermodynamic potentials or free energy diagrams. The framework is, unfortunately, only valid for systems in equilibrium. This is frustratingly restrictive, as the vast majority of everyday systems and environments exist far from equilibrium, driven by potential differences and external energy input.

My goal is to create a framework that extend these powerful methods to nonequilibrium systems, either by creating a mapping from certain classes of nonequilibrium systems to equilibrium systems or by creating effective definitions for state functions and formulating generalized principles outside of equilibrium (examples include an effective temperature or stochastic thermodynamic entropy and work). Discovery of a nonequilibrium framework for thermodynamics would be conceptually profound, as thermodynamics is inherently phenomenological and would bring novel perspectives to enhance our understanding of the world we live in. It is also practical: researchers will be able to design experiments and control systems that are dynamical in nature.

To gain an understanding of nonequilibrium thermodynamics and make progress towards this goal, I plan on simulating a series of increasingly complex active matter systems. These simulations will be coordinated with experimentalists at the Center for Bio-inspired Energy Sciences (CBES) and the Northwestern Materials Research Science and Engineering Center (NU-MRSEC) which will allow me to interpret and extend their experiments in ways otherwise inaccessible. By developing new computational methods, I will enable access to quantities currently impractical to calculate, from which we can establish the existence (or lack thereof) of nonequilibrium phase diagrams.

Background: Our conceptual understanding of nonequilibrium thermodynamics has seen remarkable growth in recent years with the development of generalized fluctuation theorems and stochastic thermodynamics. These theorems are currently being tested experimentally and computationally, but interpretations of these approaches are still unrefined. My undergraduate research experience involved applying stochastic thermodynamic theorems to a biologically active system as a way of obtaining energy dissipation information non-invasively, and it allowed me to familiarize myself with the contemporary stochastic thermodynamic literature. This approach applies when considering a system on the mesoscale, where contributions from fluctuations are non-negligible. It is most well-developed for systems in a nonequilibrium steady state; although, there are many nonequilibrium processes that do not fall into this category, and also, the efficacy of these theories beyond the mesoscopic realm is questionable.

In a parallel development, attempts are underway to search for nonequilibrium critical phenomena. One of the most promising findings published thus far is the notion of an effective temperature, which has been shown to describe nonequilibrium phenomena in a manner comparable to thermal behavior behaves in conventional equilibrium systems. The discovery of such a description, which suggests a universality among nonequilibrium processes that could prove groundbreaking in terms of our understanding of the natural world. Since this approach makes strong claims, their veracity should be determined through exhaustive experimental testing or counter-examples.

Objectives: My advisor at Northwestern, Erik Luijten, has previously collaborated with Steve Granick (Center for Soft and Living Matter, Korea) and discovered critical behavior in terms of an effective temperature in a 2D system of Janus particles [1]. It is unclear if this result is an artifact or coincidence,
and it is merely preliminary. My first steps will be an extension of this project. There are three ways in which I can modify the system to support the notion of universal nonequilibrium criticality: extend the system to 3D, incorporate long-range interactions and look for phase transitions in systems with a vector order parameter. Identifying and understanding such systems are foundational to elucidating the relationships between equilibrium and nonequilibrium thermodynamics. Furthermore, the development of computational techniques for nonequilibrium systems will by itself be of use to the larger academic community and the primary challenge in realizing this step.

The next step in the process is a conceptual question. Is this model system related to an equilibrium system? It is possible that a simplified Janus particle system could be mapped to an equilibrium problem. If this is the case, it suggests that certain classes of nonequilibrium processes can be thought of as effectively equilibrium processes when described in terms of the appropriate observables, enormously simplifying the analysis of those systems. It also poses the question whether there are other types of nonequilibrium systems that can be represented by an equilibrium model. Assuming positive results in the first steps, I aim to create a phase diagram for Janus particles that could be used as a classification for other systems. In the negative case, such a notion would need to be reworked to create the effective equivalent of a free-energy in nonequilibrium systems. It is at this point where I plan to check our model of criticality with the developments of stochastic thermodynamics. It is important for the two approaches to nonequilibrium thermodynamics to be consistent, where a proven consistency will reinforce their validity and extend their range of applicability.

The third step is to apply the above analysis to categorically distinct systems and biologically active matter. Is criticality still observed and do the previously found critical parameters serve the same role? Can these systems be divided into classes or subclasses in terms of their thermodynamic properties? Having refined the methods of simulating and analyzing complex systems, I will be able to determine the existence of a nonequilibrium thermodynamic framework by applying the methods to pertinent experimental systems. Ideally, I will establish the foundations of critical phenomena in nonequilibrium systems, while in the negative case I will have discovered deficiencies in existing theoretical approaches to nonequilibrium phenomena.

**Impact:** The computational developments necessary for this daunting task will naturally have an impact across disciplines, with new algorithms and techniques that can be repurposed in different contexts and provide complimentary information to existing methods of data analysis. For example, improved algorithms may facilitate materials discovery. Most importantly, improved conceptual understanding of nonequilibrium systems has the potential to deeply affect our insight into vast classes of biological and synthetic materials.

**References:**
**[Example 6]: Rating Sheet**

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: Applicant proposes to enhance the understanding of non-equilibrium statistical mechanics. While this is an extremely complex and big problem, he has provided ideas on how to improve our understanding. Strengths: + He has a very strong background, both experimental and theoretical, which should allow him to make significant advances in the field + He wants to study systems where there are available experimental data that can be used to validate the new theorems + He has broken the problem into 3 distinct steps, where progress in any of the three areas will be a significant achievement. Weaknesses: - Because the problem is so complex and so big, it will be difficult to quantify the impact of the work, at least in the near term. It will be useful to set a few quantifiable milestones to measure progress against.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: Improving the understanding and applicability of non-equilibrium thermodynamics would impact many areas of science. Initially the impact will likely be on model systems, but eventually it could be applied to real world problems. Strengths: + Outstanding letters of recommendation. + Active in making science available to underrepresented groups through many activities + Very active in research while an undergraduate

**Summary Comments**: This is an excellent proposal that addresses a significant problem that can benefit many areas of science, and at the same time Applicant wants to have an impact on helping people learn more and be more involved with science.

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The applicant’s academic accomplishment is exceptional and his dedication to and enthusiasm in research clear. The proposed research sounds exciting with quite interesting components but misses clear executive plans and key measures.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Good
Explanation to Applicant: The success and impact of the proposed research is not fully warranted based on what is presented as it is. The applicant’s effort and demonstration in teaching, leadership, international engagement, and outreach are modest in the same applicant pool.

**Summary Comments**: This is exceptionally strong application in intellectual merit but its broader impact is not very strong.

**Intellectual Merit Criterion**
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The student has a very strong undergraduate education in physics and has had very good professors who have trained him to be a good materials scientist. To his credit, he has broadened himself by studying biology, biophysics and related disciplines. The student has demonstrated his ability to reach technical goals while keeping the bigger picture in view. His proposal to create a phase diagram for Janus particles that could be used as a classification for other systems is interesting. The end goal of applying these ideas to understand the thermodynamics of biological systems is quite challenging. Both are worth pursuing since at the very least the insights and the computational tools that will be developed in the process are broadly applicable to other areas of materials science.

**Broader Impacts Criterion**
Overall Assessment of Broader Impacts: Very Good
Explanation to Applicant: The student was actively involved in teaching, for instance as a teaching assistant in the office of minority education, and as a lab assistant. He has also worked with high school student and recognizes the the importance of communication skills while working with different age groups. These soft skills as well as a strong background in physics will serve him well in his goal that his legacy has to as much about helping others to reach their academic potential as it is advancing his own research.

**Summary Comments**: The student has a very strong academic background as demonstrate by the difficult course work and GPA of 4.8 (out of 5). He has trained with excellent professors. He comes with uniformly strong recommendations. His proposal is difficult but is carefully thought out. His statement of broader impact is in line with his interests and what he is able to deliver.
Early Influences: From an early age, my life has been irrevocably shaped by educators. My parents, engineers in their own fields, were my first teachers. They showed me how to see science in all aspects of my world, from pointing out Benard cells while cooking breakfast to explaining how watering our tomato plants helped them grow, and encouraged a healthy curiosity by answering my endless questions. Upon starting school, I was fortunate to have teachers who continued to foster my education and nurture my inquisitive behavior—I still remember my seventh grade science teacher telling me that he knew he’d be calling me ‘Dr. Vratsanos’ before too long. By the time I entered high school, I had developed an insatiable passion for science, born out of a desire to understand how the world worked. In particular, I had a love for chemistry – I was fascinated by the idea of a set of atoms that served as building blocks for the world around me, much like the Legos I adored playing with as a child. However, by this time, I had also become an educator in my own right to my older brother. After watching him struggle with my parents’ lessons because of his autism, I realized that his brain did not quite work the same way as mine. Thus, I started trying to translate what I grasped easily from my parents into a concept that would make sense to Alex, which fostered my ability to think objectively, communicate effectively, and push the boundaries of my own understanding.

Upon starting college, I realized that I was uncommonly privileged in having so many wonderful educators in my life. My parents were always on the sideline, providing seasoned advice and cheering me on at every science fair; my teachers would answer my incessant questions that inevitably went beyond the scope of the course; and once I began doing research, my colleagues invariably took the time to teach me new skills, listen to my thoughts and ideas, and guide me on how best to proceed with my projects. This constant encouragement gave me immense confidence in my abilities, which was a welcome change from many of the doubts and insecurities I had experienced during my younger years. From this, I realized that I had a love for educating – I wanted to be able to pass that gift of encouragement and support onto others so that they could discover their passions. Just as people had kindled and nurtured the spark that I had for chemistry, I wanted to foster that for another’s calling. As a result, I began to seek out teaching positions. Starting small in high school, I took on tutoring responsibilities in a number of subjects, including French, science, and math. Math was my favorite to teach – I enjoyed translating a concept from how the teacher presented it to a way the student would understand and seeing their eyes light up when something clicked. During this time, a local chemical company awarded me a scholarship for students pursuing chemistry-related fields.

When I got to Case Western Reserve University, my first class was Chemistry of Materials, which I found fascinating. The professor happened to be the head of the macromolecular science and engineering department, and he eloquently described how atomic characteristics translated to bulk scale material properties, and how intrinsic materials are to the everyday lives of so many people. Understanding how something as simple as the geometry of a unit cell can translate to an entirely different material was eye opening, and I realized that I wanted to use nature’s building blocks to create new materials that could be used for novel applications. As a result, I decided to TA for the class in the hopes that I would be able to make that connection for a future student.
One of my proudest moments remains hearing the news that Samuel Kaplan, one of my students, had switched into the macro department – it felt like I was building a legacy.

**Undergraduate Research:** The summer after high school, I was a summer intern with Intertek’s analytical services branch. This was the first time I was able to see how lab practices related to sand benefitted society as a whole. Though my involvement was limited to sample preparation and characterization, this internship allowed me to see how much thought and engineering is involved in seemingly basic products – we worked on systems as simple as polystyrene cups to ensure that the material delivered optimal performance for all aspects of a user experience.

After the aforementioned chemistry of materials class and the internship, I was inspired to explore research for myself. I joined Dr. Gary Wnek’s lab for Biomimicking Macromolecular Systems, where I worked for over four years, even staying after graduation to tie up some loose ends. I was involved with developing a highly salted poly(acrylic acid) hydrogel. Early on, I noted that gels made with high concentrations (~2M) of certain ionic salts exhibited novel elastomeric properties. I performed extensive physical characterizations of our materials to ascertain the relationship between synthesis, structure, and properties. The data I gathered concluded that our system was a novel class of soft materials, which we patented for their useful properties.1 Further, I was able to help characterize these materials at the Advanced Photon Source at Argonne National Lab, where we performed x-ray absorption fine structure analysis to investigate the arrangement of metal salts in our hydrogel system. I presented several posters on this work over the course of my time in the group at both internal and external symposia.

Following my first year at CWRU, I participated in an NSF Research Experience for Undergraduates (REU) at Worcester Polytechnic Institute with Dr. George Pins, whose work focuses on myocardial regeneration via cell-seeded scaffolds. I was tasked with redesigning the scaffold fabrication protocol such that the constructs were conducive to mechanical characterization, namely, measurement of modulus. This entailed synthesizing fibrin microthreads, optically evaluating the diameter of the threads, and performing uniaxial tensile testing on the threads in both their dried form and hydrated state within the composite scaffold. I presented the data I acquired at the Biomedical Engineering Society’s annual meeting, and it appeared in the group’s publication on scaffolds for myocardial tissue regeneration.2

The summer of 2016, I took part in a polymer focused REU at Virginia Tech, where I worked with Dr. Christopher Williams on the stereolithography of new photocurable molecules. The project was centered on developing two materials: an ionic liquid-containing acrylate and a biodegradable polyester. For the former, I explored the relationship between resin formulation and printing resolution. I also evaluated the strength of the printed part, as it was hypothesized that the electrostatic interactions of the ionic liquid would improve interlayer adhesion. Over the course of these projects, I performed biodegradation studies, analyzed printed parts via SEM, and performed thermomechanical analysis to evaluate the quality of finished parts. My graduate mentor presented this research on my behalf at the symposium for Solid Free Form Fabrication.3

Hoping to increase the breadth of my knowledge and experience, I spent the following summer working for Battelle Memorial Institute, a non-profit research company, to get perspective on how engineering research exists outside of an academic setting. My projects with Battelle included performing a
comprehensive assessment and comparison of a subset of the medical device market and optimizing materials and design of a reverse engineered device.

Throughout all of these research experiences, I discovered a passion for translational research. I relished gathering a fundamental understanding of how a system worked, and then being able to use that fundamental knowledge to use that system for real world applications. In particular, I liked working on systems of materials that could be used in the medical field for therapeutic purposes. As such, after accepting Northwestern’s offer of admission, I decided to work with Professor Nathan Gianneschi, as his group had the perfect combination of research focuses on basic material science, and using the materials they build to create novel therapies. I had the opportunity to work with Professor Gianneschi prior to starting in the graduate program. This was a wonderful experience, as it allowed me to get hands on experience and training from more experienced graduate students, as well as granting me the chance to sample all of the lab’s projects before committing to Professor Gianneschi as an advisor. During those two months, I shadowed senior graduate students and learned a variety of biochemical and microscopy techniques, including peptide synthesis and functionalization, elemental characterization, and liquid cell transmission electron microscopy. *This invaluable experience gave me the perspective on the group’s research to envision future directions that my own research could take, as well as the skills I needed for a strong start with these projects.*

**Broader Impacts and Intellectual Merit:** I never considered being an educator until I found myself thrust into that position. As a TA, I got to teach my favorite topics to eager young engineers, but often felt ineffective—these students were already STEM oriented and enrolled at a prestigious university. However, I was asked to become the Education Director for my sorority, which meant that I was in charge of promoting scholarship and academic engagement to a group of nearly one hundred women; this prompted me to drastically reevaluate what it means to be an educator. In my capacity as Education Director, I realized the importance of broadening education—so often, it is easy to acquire tunnel vision and become entrenched in one’s own field and neglect the greater academic community. As such, I emphasized to my students and sisters that scholarship is so much more than what happens in the classroom—there is so much more to learn than what is required for your major, and things that can only be learned by doing. My work in this area earned me recognition on both a campus and national level through various awards and scholarships. Isolation within a given discipline inherently leads to disconnect. **My goal is to become an educator and work to reduce the perceived separation between scientific and nonscientific communities.** STEM often seems very alienated in the media and reduced to a generic niche, when the reality is that it is incredibly multidisciplinary—chemists work on art conservation so pieces will be around for the study of future generations, material science has shaped the rise and fall of civilizations, the interplay goes on and on. Yet so much of the public sees science as inaccessible. To alleviate this, I am going to create programming for youth that integrates STEM concepts with general curricula to help bridge the gap between science and society, and show kids how science relates to everyday life.

**Example 7: Research Proposal**

**Liquid-Phase Electron Microscopy to Observe Folding of Single-Chain Nanoparticles**

**Goal:** Polymers that fold on themselves to form single-chain nanoparticles can act as synthetic analogues of proteins. The folding process can be initiated using externally applied stimuli, including temperature and light. The objective of this proposal is to image the folding process of single-chain polymers into nanoparticles. We propose a proof-of-concept demonstration, examining this process in the liquid phase at high spatial and temporal resolution by liquid cell transmission electron microscopy (LCTEM). The approach is to (i): prepare UV-responsive single polymer chain nanoparticles, (ii): confirm structure and response to UV light via cryoTEM and light scattering (iii): initiate folding using UV light or the electron beam in situ, in a solution TEM cell by liquid cell TEM (LCTEM).

**Introduction:** Single chain nanoparticles (SCNPs) are an emerging class of materials that are exciting due to their potential to imitate the behavior of biological molecules. SCNPs are single polymer molecules that are prompted to fold by intramolecular interactions between functional groups along the polymer backbone. The chemical nature, spacing, and quantity of these coupled functional groups have the ability to determine the precise folding of the nanoparticle, much as the amino acids in a peptide chain dictate the higher order structure that the protein adopts. SCNPs have therapeutic potential in their ability to organize binding moieties and functional groups in defined 3-D space. SCNPs could, if properly controlled, replace complex, higher dispersity, multicomponent multichain nanoparticles in medical applications.

The major obstacle to advancing SCNPs is their characterization during and after the folding process. The only chemical change exhibited upon collapse is within the reactive linker moieties. Therefore, NMR provides chemical information with light scattering useful in observing changes in the hydrodynamic radius of the SCNP. Mass spectrometry is also a powerful tool to investigate the mechanism by which the chain collapse occurs. Surprisingly, SCNPs have only been imaged via SEM and dry state TEM, neither of which give accurate, or high enough resolution images of SCNPs in their solvated state. Therefore, NMR provides chemical information with light scattering useful in observing changes in the hydrodynamic radius of the SCNP. Mass spectrometry is also a powerful tool to investigate the mechanism by which the chain collapse occurs.

In this work, we will deploy high resolution cryoTEM, utilizing direct electron detectors on state-of-the-art instruments at Northwestern University. In addition, the Gianneschi group are pioneers in the use of LCTEM for the visualization of materials in a solvated state, unlike traditional dry-state TEM, by examining small volumes (<nL) of liquid between two silicon nitride (SiN₃) chips to withstand the vacuum of the TEM. LCTEM has been successfully implemented to observe nanoscale processes in solution at high spatial and temporal resolution, but has largely been utilized for inorganic, hard materials because of their high contrast. However, methods have been developed which allow imaging of soft (low-Z) materials, which are challenging because of their inherent low contrast. Work has included observations of the self-assembly of discrete micellar nanoparticles and the degradation of individual chains. These results provide evidence that a SCNP system can be designed with labile crosslinking functionalization triggered by application of the electron beam for real time observation of the transition from a dilute solution of polymer chains to discrete, well-defined nanoparticles.

**Proposed Research: Synthesis and initial observation:** A candidate system for this approach is the styrene-chloromethylstyrene copolymer with 4-hydroxy-2,5-dimethylbenzophenone functionality. This material is simply synthesized and undergoes Diels-Alder ligation after mild UV irradiation, suggesting that it will be compatible with the electron beam. Our group has used the beam effect to mimic UV to see polymerization in situ. The system will be synthesized and irradiated, after which cryo-TEM will be used to confirm synthesis. Observation in the hydrated state: SCNP precursors will be deposited into a liquid...
cell, loaded into the TEM, and imaged at low beam intensity, methodically imaging the entire region of observation to ensure a comprehensive view. Our recent acquisition of a direct electron detector is critical to this, as it permits high resolution at the length scale of interest (<50nm). If the above system is not conducive to imaging, an alternate strategy would be to take a non-UV responsive system and add a photolabile protecting group to the folding moieties.

**Confirmation of formation:** Ongoing work in the Gianneschi group shows that matrix-assisted laser desorption ionization imaging mass spectroscopy (MALDI-IMS) can be effectively used to analyze the chemistry of materials on the windows of SiNₓ chips after an in situ experiment. This technique rasters a laser over the windows to spatially map the surface by MALDI such that it is possible to identify where various chemical species of interest are located. This technique has been instrumental in characterizing the products formed in situ, serving as post-mortem analysis to confirm that the observed phenomena are consistent with the hypothesized behavior. This is a key aspect of the proposed research, as many groups using LCTEM have not developed viable methods of corroborating the results observed where beam damage can perturb the system. The picoliter quantities of reactants included in the liquid cell are not conducive to many analytical techniques, making it difficult to analyze what occurred. MALDI-IMS will be able to tell that the photolabile linkers have undergone the necessary chemical change to cause chain collapse, corroborating that any physical transformations seen during microscopy are self-assembly.

**Broader Impacts:** Visualization of SCNP folding would be the first evidence that in situ observation is possible. This would give important mechanistic details, sequence-structure relationships, leading to more informed polymer design. These systems have great potential in in silico modeling, which will be used to predict the self-assembly process. A partnership with Juan DePablo’s group will be used to facilitate the computational modeling. This technique can then be extended to more complex molecules. The Gianneschi group has been investigating proteinlike polymers (PLPs), which are synthetic macromolecules with peptide side chains forming a brush polymer. The protein-like nature results from the addition of peptide side chains, which induces a transition to a globular state. By developing the above technique for linear polymers, we are working towards the imaging of these PLPs, which are unprecedented synthetic biopolymers. Nascent collaborations focused on hyperbranched polymers (Haifeng Gao, Notre Dame) and assembly of DNA strands (Chengde Mao, Purdue) are promising areas for future applications.

The proposed imaging program will make the research more accessible to the public, as it allows depiction of a complex molecular process. Videos of a synthetic material folding like a protein would be a powerful way to demonstrate the utility and applications of polymer research. I will also present my research at conferences and collaborate with scientists in various fields.

[Example 7]: Rating Sheet

**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

Explanation to Applicant: The application of APPLICANT is of superior intellectual merit both in terms of the merit of the applicant as well as innovativeness of the proposed PhD project. Strength: She already has several diverse research experience including few REU projects and industrial internship, indicating her preparedness for a graduate career. The reference letters are extremely enthusiastic and detailed. She seemed to have already co-authored publications and has been listed as co-inventor in patents. The proposed research project involving in situ microscopy to observed folding of polymer chains is quite innovative and worthy of a PhD project which can be also be very transformative based on the large amount if mechanistic knowledge it can potentially generate. Weakness: The performance in chemistry courses is the best and some of them are below average.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Excellent

Explanation to Applicant: Has some limited broader impact related experience through GTA responsibilities. May need to widen the broader impact activities more to impact communities in a practical scale.

**Summary Comments:** The application is fairly strong owing to the merit and academic readiness of the applicant as well as high quality of the proposed PhD research project.

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**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

Explanation to Applicant: Applicant has extensive industrial and academic research experience in polymers and materials characterization, from structural characterization to tissue engineering and medical device design to resins for stereolithography. She proposes to study the folding of single polymer chains into nanoparticles using liquid-state transmission electron microscopy in concert with mass spectrometry. The need for the work and the goals are very clearly defined, but the proposal contains some undefined terms (e.g., the electron beam effect) and lacks detail about the polymer synthesis.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Excellent

Explanation to Applicant: The application conveys her clear passion for teaching, starting from a young age and continuing to tutoring and then serving as an undergraduate TA for Chemistry of Materials. Currently serving as Education Director for her sorority, she's realized the importance of bridging the communication gap between the scientific and non-scientific communities and wishes to work toward this goal throughout her career. Additionally, she proposes excellent potential collaborations with computational groups and other synthetic groups to broaden the scope of her research. The results from this work, particularly in the form of videos, have the potential to be highly educational.

**Summary Comments:** She is an outstanding student (GPA 3.7) with an exceptional research record and commitment to education and outreach. She submitted a very innovative proposal with high potential to advance fundamental understanding of polymers and prepare well-defined nanoparticles for medicine and beyond. All of her letters were incredibly strong, attesting to her tremendous potential, excellence in lab and in classes, and strong interest in the impact of her work.

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**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

Explanation to Applicant: The application of liquid cell transmission electron microscopy to study chain folding into single chain nanoparticles is intriguing. How the observations will improve polymer design could be clarified.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Excellent

Explanation to Applicant: Videos of synthetic materials folding like proteins should generate interest. Broader impacts could be expanded to include educational opportunities for the public.

**Summary Comments:** I am excited in the use of TEM to detect motion of polymer chains in a liquid cell.
In my early teen years, I found myself passionately engaged in two seemingly incongruous activities: research and breakdancing. Rather than conflict, however, these activities have symbiotically evolved to represent larger purposes that define my life.

I grew up in the suburbs of St. Louis. My childhood was one of cul-de-sac’s, backyard football, and summer camps. It was a comfortable upbringing, but one without much racial or socioeconomic diversity. In middle school, a few of my friends started breakdancing, and dragged by social inertia, I followed. Within months, I was hooked. Over the years, my practices moved from my basement to local sessions, where amidst flurries of limbs I found brotherhood with dancers who were predominantly African American and from low income backgrounds. As we grew closer, I learned the extent of disparity in our experiences and the profound importance of breakdancing in their lives. Dance was more than hobby; it was confidence, self-reliance, and passion – vital traits in an environment where the vices of poverty are too often crippling. I have since worked to instill these traits in low income youth, through dance as well as other methods. Around the time I entered the dance community, my parents were pressuring me to apply for a high school research program through Washington University in St. Louis. I was always highly curious about science – the phrase “that question is beyond the scope of this class” was all too familiar – but I remained skeptical of science’s practical applications. However, after enrolling in the program, I was quickly astounded by how wrong I had been. I was amazed at the revolutionary ideas being developed and the impact of science in advancing technology. My project focused on developing syntheses for the mineral products of carbon sequestration, and I was enthralled that my work, published in *Environmental Science & Technology*, could help understand a process aimed at reducing carbon pollution. Even in high school, I considered climate change the most pressing issue facing mankind, and in science, I found a home where my once irksome questions were not only valued, but could even help reduce greenhouse gas emissions. Through breakdancing, I was exposed to the unique challenges facing low income youth, inspiring persistent action to improve these circumstances; through research, I found purpose in applying curious, analytical thinking to develop clean energy technology. These parallel currents have run throughout my life, and I am continuously finding new approaches to pursue them both.

**Research Experiences - Intellectual Merit**

Inspired by my high school research, I enrolled in the chemical engineering department at Washington University and began searching for renewable energy research. After learning that the intermittency of many renewable sources limited their usage, I became fascinated with grid-scale batteries as proposed solutions to this issue. Thus, the summer after freshman year, I worked on a new initiative in Professor Richard Axelbaum’s lab to synthesize sodium ion battery cathodes using a spray-pyrolysis reactor. As one of the first in the group to pursue sodium ion batteries, I selected a cathode material and conducted the entire synthesis, characterization, and testing process. Through iterative trials we achieved 95% theoretical reversible capacity and demonstrated spray-pyrolysis as a method for scalable cathode synthesis. These results were published in *MRS Communications*. This first foray into battery research impressed upon me the potential for energy conversion and storage technologies to promote renewable energy as well as the immense amount of progress still required before these technologies could be commercialized.

The following summer, I was curious of the extent to which energy storage could enhance renewable energy integration. In pursuit of this interest, I participated in the Undergraduate Research Opportunities Program (UROP), where I worked at RWTH Aachen University in Germany. At RWTH, I used the General Algebraic Modeling System to create an optimization simulation which output the economically optimal number of solar panels and wind turbines for a given location. In a case study of RWTH, my model illustrated that without energy storage alternative energy technologies were limited to supply less
than 30% of the energy demand. I was selected to share my results as a speaker at the UROP symposium, where the audience was composed of students from universities across the US and Canada in fields as diverse as biology to urban planning. Preparing for this presentation taught me techniques to communicate my methods and results in ways that were easily digestible yet maintained the nuances of my work. Convinced of the importance of energy storage, I returned to battery research in my junior year at Washington University in Professor Pratim Biswas’ lab. In this project, I synthesized layered columnar SnO2/TiO2 nanocomposite anodes using aerosol chemical vapor deposition (ACVD). The aim of this project was to encase nanocolumns of SnO2 in a nanolayer of TiO2 to mitigate the pulverization caused by SnO2 expansion during charging. By understanding the theory behind aerosol deposition, we were able to methodically alter the synthesis parameters to achieve the desired morphology. Our SnO2/TiO2 composite structure displayed a reversible capacity over 200 cycles that was 1.4 times that of commercial graphite anodes, a result published in Energy Technology. In addition to reinforcing my familiarity with lab procedures and techniques, my work in Professor Biswas’ lab demonstrated how a fundamental understanding of theory can successfully guide experimental design.

By the end of my junior year, I had read literature describing several battery systems outside the conventional scope of lithium ion batteries. Curious of the advantages these systems could confer, I ventured into the nascent field of lithium-sulfur batteries during an REU program at the University of Pittsburgh. I was fascinated with sulfur cathodes which feature incredibly high lithium capacity but suffer from capacity fading due to sulfur dissolution. My project aimed to trap sulfur inside the micropores of two metal organic frameworks (MOFs) that had not been synthesized in the group. I was challenged to start from MOF synthesis and achieve stable full cells in just 10 weeks. Forfeiting nights and weekends, I dedicated myself to iteratively synthesizing cathode materials, performing X-ray diffraction and Fourier-transform infrared spectroscopy, cycle-testing cells, analyzing flaws, and readjusting syntheses. By the end of the summer, my cathodes reversibly achieved two-thirds of sulfur’s theoretical capacity. My work in Pittsburgh and in Professor Biswas’ lab not only taught me the skills and ingenuity necessary to synthesize and characterize complex microstructures, but also rooted an appreciation for the significant improvements in performance possible through innovative microstructural design.

A year ago, I joined Professor Sossina Haile’s group at Northwestern University as a graduate student in materials science and engineering. Transitioning from chemical engineering to materials science has been a transformative revelation of the fundamental principles which govern material properties. My research in the past year has been defined by creatively utilizing these principles to augment material performance. For example, my first project studied the influence of co-dopants on the stability range of the proton-conductive cubic phase of CsH2PO4 (CDP), a fuel cell electrolyte. However, after analyzing the thermodynamics of phase transformations, I realized that the cubic phase might be achieved at significantly lower temperatures by heavily co-doping CDP to induce a high entropy eutectoid transition. This realization prompted a major shift in my research, opening exciting possibilities from what was an introductory project. Moving forward, I hope to combine my growing understanding of fundamental principles with my background in microstructural design to create fuel cells with significantly enhanced performance.

**Leadership and Outreach – Broader Impacts**

Although Washington University afforded me an excellent education and research experiences, it is also one of the most insular universities in the country. Boasting the wealthiest undergraduate student body, Washington University is notoriously disconnected with the surrounding low-income areas. As an undergraduate, I was president of the breakdancing club for 2 years where I worked to mend this divide. In addition to hosting regular practices where locals and students organically exchanged ideas and banter, I organized multiple breakdancing competitions on campus – the largest of which was funded for $10,000
and drew 120 competitors from across the country as well as over 500 spectators. These events were an opportunity for the student body to appreciate the astounding physical mastery and vibrant culture developed by a community that is seldom represented in higher education.

As powerful as dance can be, I recognized that combating socioeconomic inequality would require action on many more fronts. Thus, I also served as outreach chair for Engage 360, a club which engages various student groups to volunteer in the development of at-risk youth living in impoverished communities. As outreach chair, I coordinated with shelters and temporary homes, to set up monthly volunteer times and activities. Through collaboration with these organizations, our club renovated living spaces for at-risk youth and worked directly with children to foster key character traits such as self-worth, teamwork, and communication.

Starting at Northwestern, I joined Junior Science Club (JSC), an organization which leads bi-weekly science demonstrations at a Boys & Girls Club in Chicago. Although enamored by JSC’s mission, I found that accomplishing real positive change was immensely challenging. The demonstrations were chaotic, with some children intent upon derailing the lesson, and others giving up after an initial unsuccessful effort. After my first year, JSC’s future was uncertain with only two other students even considering retaining the club. Emphasizing JSC’s potential to make a profound impact, I managed to convince the other students that the issues of the previous year could be resolved with more deliberate organization and adjusted lesson plans. This year, after implementing new teaching strategies and recruiting more volunteers, JSC is off to a fantastic start. The opportunity to encourage children to work past hurdles which were previously overwhelming is immensely rewarding. I will continue to be a leader at JSC throughout my graduate career, where I aim not only to inspire a fascination in science but also to instill self-belief and confidence.

In addition to working with youth, I am also the vice-president of Materials Science Umbrella Society (MSUS), which organizes events for professional development and career advancement for Northwestern’s materials science department. In my past year as vice-president, I have organized panels for those seeking industry jobs and postdoc positions as well as a MATLAB workshop to help ease the graduate school transition for 1st year students. Outside of MSUS, I recently organized an event communicating the state of energy to a broad audience of Northwestern students, in hopes of inspiring increased political will to combat climate change.

Future Goals

The seemingly incongruous passions I uncovered as a teen have taken numerous forms throughout my life, but the principle motivations persist and will continue to drive my work in the future. Perhaps surprisingly, I am still an active breakdancer, and my experiences as a dancer will always compel me to provide education and guidance to those less fortunate. Concurrently, I aspire to develop and commercialize technologies that reduce greenhouse gas emissions. I am currently taking an engineering entrepreneurship course, and I plan to continue taking advantage of collaborations between Northwestern’s schools of engineering and management such as NUvention Energy, a program which aims to bring to market novel energy technology. Following graduate school, I hope to either found or join a startup working on clean energy conversion systems. My extensive research experience with charge transfer systems coupled with my leadership in various organizations establish a solid foundation for continued growth.
Achieving High Power-Density in Intermediate Temperature Fuel Cells

Background: Global efforts to reduce carbon emissions motivate the development of fuel cells as energy-dense methods for clean, efficient conversion of stored chemical energy to electrical energy. Unfortunately, the commercialization of several prominent fuel cell systems has been obstructed in part by challenges inherent to cell operation below 100 °C, such as polymer electrolyte membrane fuel cells (PEMFCs), are susceptible to catalyst poisoning from trace amounts of impurities; whereas fuel cells which operate above 800 °C, such as solid oxide fuel cells (SOFCs), incur high production costs in processing materials which can withstand such high temperatures. However, intermediate temperature (200-500 °C) fuel cells, operating between these two extremes, benefit from both impurity tolerance and ease of processing. Thus far, intermediate temperature fuel cells have not achieved power densities comparable to those of PEM or SOFCs, but a promising contender is the solid acid fuel cell (SAFC). State-of-the-art SAFCs employ a CsH2PO4 (CDP) electrolyte and operate between 230-300 °C. Within this temperature range and with sufficient humidification, CDP exists as a cubic phase with proton conductivity on the order of 10^{-2} S cm^{-1}, which is on par with those of PEMFC and SOFCs. However, SAFCs thus far have produced lower power densities than these competitors due to a highly resistive cathodic oxygen reduction reaction (ORR). Specifically, the ORR resistance in SAFCs is an order of magnitude greater than the anodic hydrogen oxidation resistance. This suggests that substantial improvements in power could be realized by reducing the ORR resistance with higher activity catalysts. Notably, Pd:Pt alloys demonstrate impressive activity; the most active alloy composition produces a current density more than twice that of Pt at a realistic operating voltage (0.6 V). Unfortunately, Pd alloys deleteriously react with CDP, degrading cell performance within hours of operation. Passivation of this reaction would stabilize the initial high-performance of Pd:Pt catalysts, achieving roughly double the power output of Pt-based SAFCs and significantly advancing SAFCs toward commercial deployment.

Prior work: Previous studies in the Haile group evaluated oxide layers as proton-conductive barriers between reactive electrolyte materials. Electrochemical impedance spectroscopy (EIS) measurements demonstrated that thin film oxides (30 nm TiO₂, 5 nm Ta₂O₅) deposited between layers of CDP do not produce observable increases in ohmic resistance compared to bulk CDP. Therefore, I hypothesize that thin film oxides physically separating CDP and Pd:Pt catalysts would permit efficient proton transport while preventing deleterious reaction.

Objectives: This proposal aims to create stable Pd:Pt-based cathodes with enhanced ORR activity by separating Pd:Pt catalysts from CDP using a proton-transparent thin film oxide. The proposed cathode architecture features CDP particles first encapsulated by an oxide film deposited by atomic layer deposition (ALD) and then coated with Pd:Pt nanoparticles via metal-organic chemical vapor deposition (MOCVD) (Fig. 1). This project first aims to (1) determine the minimum film thickness needed for each oxide (TiO₂, Ta₂O₅) to prevent reaction between Pd and CDP. The introduction of an oxide coating and the resultant oxide-catalyst interface may alter the activity of Pd:Pt catalysts by inducing a new rate determining step. Thus, one cannot assume that the performance observed in studies of the catalyst deposited on CDP will be identical to that observed with this new architecture. Therefore, the second objective aims to (2) identify the combination of oxide and Pd:Pt catalyst composition that maximizes ORR activity.


The third objective will utilize the best oxide/catalyst combination and (3) optimize catalyst particle size and loading for performance and cost. Previous studies have demonstrated that activity plateaus with excessive loading. Thus, optimized loading will maximize performance at minimal cost. Investigating the effect of particle size will additionally reveal whether the ORR occurs at a triple/double phase boundary, potentially informing further improvements in cathode architecture. Finally, a fuel cell will be constructed optimizing stability, performance, and cost.

**Research Plan:** (1) **Film thickness** - CDP particles in a rotating ALD chamber will be uniformly coated by TiO$_2$ or Ta$_2$O$_5$ films of varying thickness. Next, Pd nanoparticles will be deposited by MOCVD onto the oxide-coated CDP. The microstructure of the cathode particles will be examined after each step using scanning electron microscopy (SEM). The powders will then be annealed at 250 °C for several days, and degradation will be assessed by comparing pre- and postanneal X-ray diffraction patterns. From these studies, the minimum thickness required for stability will be determined for each oxide.

(2) **Oxide/catalyst pairing** - Anode supported half cells will be constructed via previously established procedures (Fig. 1). On the exposed electrolyte face, a thin oxide film will be deposited by ALD to ensure stability between the cathode and electrolyte. Various cathodes will be synthesized by depositing a range of Pd:Pt compositions onto CDP particles coated with either the minimum thickness of TiO$_2$ or Ta$_2$O$_5$, creating a library of oxide/catalyst combinations. The activity of these cathodes will be determined from joint polarization and EIS measurements. The highest performance combination will be identified for further optimization. Should TiO$_2$ and Ta$_2$O$_5$ significantly inhibit the ORR, additional oxides such as CeO$_2$ and Al$_2$O$_3$ will be considered.

(3) **Catalyst particle size and loading** - Catalyst loading will be controlled through the MOCVD precursor composition. Catalyst particle size will be increased by annealing and then measured by SEM to estimate triple/double phase boundary areas. The influence of these parameters on ORR activity will then be measured. Finally, the cathode architecture will be optimized using these insights to achieve stable, high power output.

**Intellectual Merit:** Executing this research plan will combine my extensive experience in microstructural design and the skills in electrochemical characterization that I have gained in the Haile group. By stabilizing high activity Pd:Pt catalysts with CDP, this work will achieve high power, intermediate temperature fuel cells, constituting a major step toward the realization of fuel cells as competitive devices for clean energy conversion. This work will also inspire further SAFC research such as exploration of low cost non-noble metal catalysts which are otherwise unstable with CDP. Additionally, developing an understanding of oxide barriers in electrode composites will allow stabilization of reactive components in other protonic fuel cell systems.

**Broader Impacts:** The Haile group routinely hosts students from Research Experiences for Undergraduates (REU) and Teachers (RET) programs, and throughout this project I plan to mentor multiple undergraduate and high school students. As a mentor, I will not only relay fundamental techniques in materials synthesis and characterization, but also impart an appreciation for science’s role in developing next-generation technology. Furthermore, I will participate in the Joint Undertaking for an African Materials Institute, an initiative founded by Professor Haile to promote collaborative materials research with scientists in African nations through a series of workshops and lectures. In addition to guiding electrochemistry exercises, I will share my work and explore collaborative opportunities that help shape the future of energy technology in Africa.

**References:**

[Example 8]: Rating Sheet

**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

Explanation to Applicant: An excellent record of undergraduate research with several publications and presentations especially in battery technologies. This has served well to develop the research proposal on fuel cells. The research plan is detailed and based on available knowledge with a good chance of success.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Excellent

Explanation to Applicant: Development of fuel cells with an aim to reduce carbon emission is a worthy goal and the proposed methodology is innovative. Through extracurricular pursuits, is keenly aware of the socioeconomic situation around him and has shown interest in helping at-risk youth. Teaching undergraduate students in REU and TET programs during the fellowship is very encouraging.

**Summary Comments:** A combination of excellent academic record and relevant research experience will serve well to achieve the goals of the proposed research program. A healthy interest in broadening science outreach is commendable.

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**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

Explanation to Applicant: Excellent academic performance and contributions to publications.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Very Good

Explanation to Applicant: Applicant's passion for breakdancing is unique way to connect with different socioeconomic groups. He has joined other outreach clubs since starting graduate school. Interested in commercialization of technology.

**Summary Comments:** Candidate has performed admirably both in the classroom and in prior research experiences. He is interested in commercializing technology and is at a good program to get training to do so. Research proposal is a little high level and could be improved with stronger hypotheses.

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**Intellectual Merit Criterion**

**Overall Assessment of Intellectual Merit:** Excellent

Explanation to Applicant: Clearly articulates the potential innovation and impact of the proposed research. A clear hypothesis is presented, with planning for how each element will be tested.

**Broader Impacts Criterion**

**Overall Assessment of Broader Impacts:** Excellent

Explanation to Applicant: Uses non-traditional methods of engaging under-represented communities, and involved in organization of outreach

**Summary Comments:** A strong academic record is supported by a well articulated research idea, and involvement with a broad range of outreach activities.
Example 9 NSF (Award Winner 2019)

[Example 9]: Personal Statement

**Background and Motivation:** I can trace the roots of my foray into science and engineering to the portrait of Richard Feynman hanging in my dad’s office, a physicist we have both long admired. I was raised with a healthy enthusiasm for the imaginative adventures of science fiction; I frequently fell asleep to Star Trek humming on the TV and curiously skimmed my parents’ volumes by Ray Bradbury and Isaac Asimov on the shelves. Just down the street from our house was the NASA Goddard Space Flight Center, where we celebrated my 4th birthday party. Sci-Fi showed me our world’s limitless potential; growing up, I dreamed about not only building the futuristic devices I saw and read about, but also exciting the public with my scientific discoveries like Prof. Feynman.

In high school, I participated in a program called Project Lead the Way geared towards introducing students to engineering, which showed me that engineering could be my career. Being Latino in a homogeneous suburban town, I already felt out of place and was further dismayed to find that I was among very few girls in the classroom. Because of this, I sought out strong role models who shaped my growth as an aspiring engineer. A pioneering family friend, Prof. Anne Spence, was the first woman to earn a PhD in engineering at my eventual alma mater; she invited me to her lab, introduced me to her students and answered my questions about her experiences in a male-dominated field. After meeting with her multiple times, the elation I felt about creating the inventions I had once imagined overshadowed any uncertainty about being in the minority. In her lab, I set my sights on an engineering degree and haven’t looked back since.

**Intellectual Merit - Research Experience:** After enrolling at the University of Maryland with a full academic scholarship, I met Prof. Bing Hu when he gave a presentation to my honors cohort about nanotechnology research. I was captivated by these tiny systems, so I approached him to learn more. I went on and co-authored a proposal for the honors program with Prof. Hu focused on improving the functional properties of cellulose nanopaper (CNP) to mitigate the environmental impact of plastic substrates used in roll-to-roll printing of flexible electronics. After it was accepted, we recruited a team of 13 driven undergraduates to join the four-year project. I assumed a leading role while performing experiments in parallel, applying my minor studies in project management to keep our goals on track. My sub-team formulated conductive carbon nanotube coatings on CNP to observe suitably low sheet resistance measurements for electronic applications. Our findings were featured at the 2017 Materials Research Society Spring Meeting in Phoenix and the TAPPI International Conference on Nanotechnology in Grenoble. I also presented for our team at the Honors College Symposium, where we won Best Thesis Defense. This endeavor gave me enormous fulfillment, an ardent love for teamwork, and a thirst to continue researching.

After my sophomore year, I was determined to explore nanotechnology further on an international research team. Out of 200 applicants, I was selected as one of 14 NSF Fellows for the NanoJapan International Research Experience for Undergraduates, a three-month immersive cultural and research program in Kyoto, Japan. I was co-mentored by Prof. Junichiro Kono (Rice U.), Profs. Koichiro Tanaka and Takashi Arikawa (Kyoto U.). As a visitor in the Solid-State Spectroscopy Group, I was responsible for probing low-energy nonlinear carrier dynamics of aligned single-wall carbon nanotube films in the terahertz (THz) region. Through a series of spectroscopy experiments, I discovered that induced transparency became dominant in the spectra under high-intensity fields, a relevant insight for future THz modulation device design. During the externship, I presented my findings at two conferences: the MTSA/TeraNano 6 International Conference in Okinawa, Japan and the Smalley-Curl Institute Summer Research Colloquium at Rice University. This unique, challenging and vibrant adventure pushed me...
beyond my preconceived limits; I had to produce high-quality work while living alone for the first time in a city where I knew no other native English speakers at just 19 years old. Nevertheless, I left Japan with self-confidence and a desire to pursue more international collaborations.

I returned to the University of Maryland encouraged by my success in Japan and wanting to gain insight into other fields. I met with Prof. Alison Flatau after hearing about her solicitation for a materials student to assist her group in the aerospace engineering department. Prof. Flatau quickly became a powerful role model for me due to her approachability, enthusiasm, strong leadership and incredible knowledge – traits that I continuously try to emulate in my research and mentorship since working with her. In her group, I studied the effect of compressive pre-stress on the magnetostrictive behaviors of Galfenol (Fe$_{81}$Ga$_{19}$) and Alfenol (Fe$_{80}$Al$_{20}$) for improved flow sensor and energy harvester performance. During my projects I designed a compact stress fixture to compress my samples, studied magnetization trends using vibrating sample magnetometry, and observed considerable improvement in the performance of our sensor materials through extensive strain measurements. I presented my work at both a junior conference and the 61st Magnetism and Magnetic Materials Conference in New Orleans. Through this work, I also published a 1st author paper and contributed my expertise to two other co-authored publications in Dr. Flatau’s group.$^{2,3}$

This experience was pivotal in fortifying my maturity as a researcher, and after many talks with Prof. Flatau, I was motivated to pursue a PhD.

Having taken advantage of the opportunities to pursue research in different areas, I honed in on nanomaterials as my thesis topic for graduate school. As a PhD student in Materials Science and Engineering PhD student at Northwestern, I joined the research group of Prof. Mark Hersam (Materials Science Dept.) which specializes in the study and development of nanoscale materials for alternative energy and device applications. In my first year of doctoral research, I focused on industrial-scale, top-down exfoliation of two-dimensional (2D) materials such as graphene and boron nitride. I used these materials to formulate inks for applications ranging from screen to inkjet printing, and fabricated devices out of them for collaborators at the University of Wisconsin on an NSF project. Additionally, I began investigating a novel strategy for sorting 2D materials in collaboration with the General Electric Company. I optimized a cross-flow filtration scheme typically used in biological applications for 2D nanomaterials, and I am currently preparing to publish these findings as I continue to work in the Hersam group.

**Broader Impacts – Representation, Mentorship and Future Plans:** As an ethnically mixed, Hispanic woman in STEM, I felt intimidated throughout my academic career when I did not see many engineers who looked like me in the classroom. Empowered by these experiences, I am committed to engaging the next generation of researchers – particularly, young women and other underrepresented groups. I am grateful for the role models I had along the way who supported and believed in me early on, like Prof. Spence and my parents. Since visual representation is extremely important to encourage diversity in the field, I am determined to continue bestowing the support and encouragement I received from my mentors to young students throughout my career.

Mentoring younger students directly as an undergraduate at the University of Maryland was a conduit for this goal. During my freshman year, I enjoyed working on my first proposal so much that I felt compelled to help future young students navigate research for the first time. To this end, I served as a teaching assistant for two classes – “Freshman Honors Colloquium” and “Science, Technology and Society” - within my academic honors program over a three-year period. I volunteered time outside of the classroom to sit down with my students one-on-one, review their work and help them interpret literature in their respective fields. I also worked with the instructor directly to re-design the course curriculum and train other teaching assistants. In parallel, I trained a junior undergraduate student in the Flatau lab in a research internship which led to her first publication with me as a co-author.$^2$ Mentoring another young female
researcher while working in the lab of an eminent female professor was extremely meaningful after my own high school experiences. This summer, I again advised a student as part of the Materials Research Center REU Program in the Hersam lab. In this role, I used what I had learned to support the keen intellect and creativity I observed in my mentee. This student quickly excelled as an experimentalist, gave two strong presentations and is now applying for graduate school.

Beyond mentoring undergraduate students, I also participated in the Letters to a PreScientist (LPS) program during my first year at Northwestern. LPS is a mentorship program that pairs career scientists with K-12 students in disadvantaged areas who are interested in becoming scientists themselves. Over the course of the year, my pen pal Isaac and I exchanged letters about the science behind LEGOS, such as polymer extrusion methods and injection molding. I wanted to inspire Isaac’s enthusiasm for science through everyday objects to make science directly accessible to him. Similarly, I wanted to get involved in science outreach locally; I volunteer biweekly for the Junior Science Club (JSC) at Pedersen-McCormick Boys and Girls Club in Chicago with elementary school students. In my favorite moment at JSC, one student built a tower out of paper that was sturdy enough to support a dictionary; she was so thrilled that she ran around the room to show her peers. I also planned and taught a course for Splash, a weekend-long symposium for local high schoolers, focused on a manned mission to Mars – a topic reminiscent of my childhood near NASA. My students, many of whom were considering studying engineering in college, came up with intricate designs to power a manned vessel based on the energy technologies we discussed in the class. The wonder, energy and ingenuity I’ve seen in the eyes of these students across all of my outreach activities energizes me whenever I work with them. Finally, I took a leading role in a student organization when I joined the board of the newlyassembled Graduate Society of Women Engineers at Northwestern. As treasurer, I have planned campus-wide events with 100+ attendees, interacting with our undergraduate SWE chapter and coordinating professional development opportunities. Working directly with other female engineers to grow our community is very empowering; I am cultivating the visible support network for young girls that Prof. Spence and I wished for years ago.

Next year, I plan to expand the organization’s initiatives as Vice President to include activities with local K-12 students, site visits to Argonne National Laboratory and nearby industry partners, and a series of entrepreneurial seminars for members in collaboration with the business school at Northwestern.

“There’s plenty of room at the bottom” Feynman quipped in 1959, later inspiring a generation of scientists to explore impossibly small structures that Bradbury and Asimov could have only dreamed of. A decade of engineering classes, proposals, teaching experience, mentorship, and research - both at home and abroad - have helped me develop the skills to join those in pursuit of Feynman’s quest. To this end, I am pursuing a PhD in materials science and engineering with a focus on scalable manufacturing of electronic nanomaterials. Being honored as an NSF GRFP Fellow will bring me closer to my goal of leading a team in nanotechnology research and development at a multinational company or at my own startup. I plan to establish new mentorship and outreach programs that connect with the next generation of underrepresented young scientists and engineers who are ready to turn science fiction into reality, as I once was.

Scalable Nanomanufacturing and Size Selection of 2D Materials for Functional Inks

Motivation: The growing field of two-dimensional (2D) nanomaterials has led to increasing demand for the production and integration of graphene, molybdenum disulfide (MoS₂), and hexagonal boron nitride (h-BN) into electronic and optical devices.¹ The Hersam Laboratory previously demonstrated gram-scale production of the aforementioned 2D nanomaterials via liquid phase exfoliation (Fig. 1a) utilizing the stabilizing polymer ethyl cellulose (EC).² However, a grand challenge in the field of nanotechnology involves transitioning from lab-scale production to industrial-scale production of 2D materials. Due to size-dependent properties at the nanoscale, this high-volume production must be achieved in a manner that results in monodisperse flake size that is preserved throughout downstream additive manufacturing processes (e.g., screen printing², gravure printing³ and blade coating⁴).

Background: While particle sorting is achieved through density gradient ultracentrifugation⁵ and liquid cascade centrifugation⁶, these techniques are time-consuming and not scalable. Cross-flow filtration (CFF) is an approach that is employed in the biologics industry to rapidly sort particles and proteins of various sizes at the nanoscale. Utilizing a flow-based process (Fig. 1b), a feed flow of particles in a solvent is fed tangentially through the filter column with a peristaltic pump. A secondary pump pulls permeate material of the target size through the filter membrane to be collected externally. Unsorted material (the retentate) is recycled through the filtration pathway. In contrast to vacuum filtration, the advantage of recycling is desirable for nanotechnology applications; this is not possible in vacuum filtration because the feed flow material impinges perpendicular the membrane and does not recirculate. CFF has been used to remove nanoparticle contaminants (the permeate) from 1D nanowires (the retentate).⁷ On the other hand, I propose an alternative sorting scheme using permeated ultrathin 2D material flakes as the product.

Objective: To fully realize scalable production of graphene/EC powder, I propose CFF as an effective, innovative method for 2D material sorting that bypasses the limitations of centrifugation. By sequentially decreasing the filter pore size and recycling material, graphene/EC dispersions can be serially filtered to decrease the polydispersity of graphene flakes in solution. CFF as integrated with pilot plant-scale shear mixing in the Hersam Laboratory will lead to a fully continuous, scalable and liquid-based scheme for producing and sorting 2D nanomaterials with clear scalability advantages compared to incumbent approaches.

Preliminary Work: Using a range of pore sizes, I successfully sorted shear-mixed graphene flakes via cross-flow filtration as shown in Fig. 1c. In this setup, I calibrated a series of peristaltic pumps to feed dispersions of graphene/EC through hollow fiber microfiltration cartridges of varying pore size. I used atomic force microscopy (AFM) to show that permeate containing sorted graphene has

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Figure 1. Preliminary size selection of graphene flakes via cross-flow filtration. (a) Graphene continuous flow shear mixer assembled in the Hersam Laboratory. (b) Schematic of the cross-flow filtration (CFF) process as used by Pradel et al. to purify 1D nanomaterials. (c) Size distribution of exfoliated graphene flakes sorted with CFF using a 200 nm pore filter.
a flake size distribution that matches the pore size of each filter. However, challenges included processing
time for large volumes of dispersion and filter fouling. 2D material flakes conformally seal the membrane
pores over time, halting the process temporarily for filter cleaning.

Research Plan: 
(1): Sequential sorting of Gr/EC dispersions. I plan to utilize an external peristaltic pump
to further increase the speed of the CFF process, thus reducing process time and mitigating fouling. Filter
lifetime studies at higher recirculation rates will reveal strategies for reuse, facilitating the continuous
sorting paradigm and enhancing throughput. Using exfoliated graphene/EC powders sorted with a
centrifuge as my control sample, I will then characterize CFFsorted graphene/EC powders using Raman
spectroscopy to investigate the defect behavior and Xray photoelectron spectroscopy to probe C1s binding
energy peak intensities.

(2): Ink formulation for device fabrication. Next, I will formulate spin-coatable conductive
graphene inks with CFF-sorted Gr/EC powders and use four-point probe measurements to gauge
conductivity of these films. I will then fabricate conductive electrodes using inkjet and aerosol jet printing.
These simple, all-printed devices will be functionalized for water sensing applications by collaborators at
the University of Wisconsin. I will first probe the electrical performance of these devices to demonstrate
the viability of CFF-sorted graphene and then evaluate the material in other applications such as battery
electrodes and electrochemical sensors.

(3): Integration of CFF with continuous-flow shear mixing. After establishing the effectiveness of
CFF, it will be integrated with the automated, continuous-flow shear mixing process in the Hersam
Laboratory, creating a closed system for graphene and related 2D material size selection. A scaled-up
version of the preliminary CFF system will be directly connected to the exfoliation tank with conductive
tubing and customized for high solids loading. This work will then be generalized beyond graphene to
related 2D materials (h-BN and MoS2).

Resources: Existing instrumentation in the Hersam lab, including a pilot plant-scale shear mixing
system and a CFF instrument acquired from General Electric Co., enables the experiments proposed in the
research plan. Characterization will be performed within the Northwestern University Atomic and
Nanoscale Characterization Experimental Center (NUANCE) in addition to collaborating groups at
General Electric and the University of Wisconsin.

Intellectual Merit: This research adapts methods common to biological engineering to create a new
paradigm of 2D materials processing. Cross flow filtration addresses the challenge of polydispersity in
dispersions of liquid phase exfoliated 2D materials in a scalable and more easily reproducible manner.
This augments further study of fundamental behaviors, such as quantum effects related to lateral size.6
CFF is compatible with any 2D material powder - even one produced by non-solution-based methods such
as arc discharge - dispersed in solvents compatible with the membranes, enabling a processing universality
similar to centrifugation. Thus, CFF possesses the potential to become a staple processing tool for 2D
material researchers and manufacturers alike.

Broader Impacts: This project seeks to promote an unprecedented shift from batch processing to
continuous production of 2D nanomaterials, a highly impactful contribution to the field of
nanotechnology. If these scalable manufacturing methods are adopted by major chemical companies, the
production of tons/yr of conductive graphene inks will enable novel technologies such as electrodes for
lithium ion batteries, photodetectors, and energy storage devices at low cost. There is also significant
commercial interest in the success of the proposed work; once completed, the proposed system and
associated findings will be patented and may contribute to a start-up.

[Example 9]: Rating Sheet

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Good
Explanation to Applicant: Strengths: The student provides strong preliminary results of the proposed research. There is a good level of detail provided in the research statement. Weaknesses: The research statement could be strengthened with a clearly articulated quantifiable/testable hypothesis (i.e., the goal of ’scalable production’ is not testable).

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Good
Explanation to Applicant: Strengths: The student touches on the broader impacts of the research to society. The student shows a prior record of outreach activity. Weaknesses: The broader impacts statements are a bit vague/general. Although not required by NSF, given trends in applications, it would be helpful if the student articulated plans for outreach to broaden the impact of the research.
Summary Comments: The student provided strong preliminary research results for the proposed research, with a decent level of detail, but the hypothesis provided should be strengthened to ensure that it is provable/testable.

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Excellent
Strengths include a strong research background with different topics and good preliminary results.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: Strengths include good connection of research to societal impact and STEM outreach in many organizations and activities.
Summary Comments: The PI exhibits a strong academic background with good knowledge of the research field and a well written proposal. Broader impacts include good STEM outreach and connection to research.

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The candidate shows a strong pattern of identifying and pursuing opportunities to expand their knowledge, including pursuing research internationally.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: Strong outreach within and beyond an academic environment, clearly understands the importance of her involvement as a role model to fellow students from underrepresented groups.
Summary Comments: The candidate has effectively balanced being an enthusiastic and independent research with involvement in outreach activities.
As a first-generation immigrant, being born in the U.S. was my first best step towards a new future. With it, my mother handed me the keys to a new life out of the shadow of the Somali civil war. My parents (my mother’s family in particular) sought political asylum in the U.S. from the Somali government, and the tribulations of tribalism. Upon becoming naturalized citizens, we moved abroad, and I grew up on the move. I lived in five countries in my first 18 years of life, most of those years in impoverished countries in Africa, specifically Zimbabwe. However, I never learned we were refugees until I was a teenager; that we were members of the ‘huddled masses yearning to be free.’

I inherited my love of academics from my parents. To them, excelling academically was not just getting straight A’s—it was understanding, then mastering the material you were taught. My 8th grade teacher in Jakarta, Indonesia sparked my love of science. I used to stop by her classroom multiple days per week and bombard her with questions; ‘how is light a particle and a wave?’, ‘why can’t we exceed the speed of light?’, ‘is time travel really impossible?’ The satisfaction of understanding why things happen, their underlying mechanism was immensely satisfying to me. I developed my strengths in chemistry and math for similar reasons; these were the subjects I found hardest to master, and thus the most rewarding. I decided to study chemical engineering at UC San Diego because it melded my love of chemistry and mathematics. Moreover, engineering to me means ‘building, inventing, creating’ based on scientific knowledge, and in turn enabling more scientific advances. So pursuing an engineering degree did not feel like I was forsaking my love of science. Instead, I have come to appreciate the symbiosis between the two.

Over the course of my academic career, I have experienced my fair share of adversity. Staying on track to graduate at 18 despite moving countries in my formative years was one hurdle to overcome. Besides this, in my first 2 years of undergrad, I fulfilled my classes, participated in service events I cared for, and conducted research, with my family able to foot the bill. However, my mother retired 2 years in, and suddenly I had huge out of state tuition bills to pay. I considered dropping out for a year and acquiring an in-state resident status, but I was enamored with my classes, with my research, with the environment. I decided to persevere. I took 1-2 jobs during the quarter, while maintaining the greatest research engagement I could. In the summer of my 3rd year, I was awarded the National Action Council for Minorities in Engineering (NACME) scholarship, and federal McNair scholarship for underrepresented minorities in academia. With that, I was able to conduct research throughout the summer without worrying about my bills. I thus managed to minimize my dependence on private loans, and graduate on time.

**Intellectual Merit:** Perhaps the second greatest source of adversity I overcame as an undergraduate would be becoming a qualified and competent researcher. I joined Professor Darren Lipomi’s research group in the Nano-engineering department as a freshman. This period of conducting research far beyond my classes forced me to teach myself physics significantly beyond my expertise, and take classes to catch up. For example, I learned about surface plasmon resonance modes before I learned about electric fields from my physics professors.

I worked in Professor Lipomi’s lab on three successful projects related to graphene and ultramicrotomy as a method of nanofabrication (also known as ‘nanoskiving’.) ‘Nanoskiving’ involves taking cross sections of thin films to produce wires, or cross sections of composite films to make ‘sandwich’ wires (\(\sim 100 \text{ nm}\times100 \text{ nm}\times400 \text{ µm}\)). I learned the somewhat complex task of nanoskiving from an outgoing undergraduate, and subsequently was the only member of the lab besides Professor Lipomi himself who could use the ultramicrotome. The first project involved nanoskiving of gold, graphene, gold composite films. My contribution involved demonstrating reproducibility in the fabrication of the nanowires, and imaging them by Scanning Electron Microscopy. The second project involved using graphene as a support and depositing metallic nanoislands as a thin film onto the...
graphene, then using this composite as a signal transducer. My contribution was to deposit metals on the graphene, and image the resulting sensors. In tandem, I worked on a personal project to produce graphene nanoribbons by ultramicrotomy, but this process was unsuccessful due to the extremely high specific strength of graphene. I briefly worked with Professor Kevin Corbett on projects related to structural biology as a lab technician, and helping with research projects to expand my horizons beyond engineering. However, I found that I preferred creating new fabrication schemes, or processes, and returned to full time research engagement in the Lipomi lab.

My final and most compelling independent project almost did not happen. Dissatisfied with our progress on graphene nanoribbon fabrication, I suggested a new project to use gold nanowires as a piezoresistive strain sensor. My graduate student advisor helped me theorize about the project, then graduated. Professor Lipomi offered me two options; stay on and publish the paper as a first author, or cut my losses and work with a new graduate student on a different project.

I worked relentlessly over the course of the summer, often upwards of 60 hours per week to revamp the fabrication process, upscale the rate of production of nanowires, and test them in a reliable manner. As the nanowires started working more consistently, Prof. Lipomi suggested I try a biomedical application. I consented, and with the help of an undergraduate I was mentoring at the time, affixed a nanowire to my wrist to measure the heartbeat pulse-pressure waveform. Learning to generate data only accounted for half of the hurdles, however; effective statistical analysis, scientific communication, and aesthetically pleasing figures became my new focus. Prof. Lipomi and graduate student Julian Ramirez were my sounding boards, but I was the main contributor, and accomplished much of the work independently. We submitted the manuscript in May of 2017, Sensors and Actuators A journal published it in August, with me as the first author. We determined that indeed nanowires fabricated in this new method could serve as strain sensors, and that they are more sensitive to strain than expected for bulk isentropic conductors, or even a metallic thin film (100 nm.)

This research experience in the Lipomi lab taught me a huge deal about conducting original research. Firstly, I learned to keep an eye on real genuine applications. Novelty is great, but it is not enough: rather a new technique or invention must also be useful in order to be of value to the scientific community and industry. I also learned that tenacity pays off, and I consider that to be a personal strength of mine. Finally, I acquired a love for the creation of new engineering knowledge. Thinking up new fabrication schemes, devices and potential applications is something I find visceral, breathtaking. This urge is what pushed me to pursue my education further in Materials Science and Engineering at Northwestern University.

**Broader Impacts:** As I see it, my research will benefit the scientific community and commercial sectors, as the engineering sciences are often highly translational. In particular, the research I have proposed will spur on nanoparticle catalysis as a primary application. Besides this, there are other interesting avenues to pursue, like room temperature superconductivity in nanoparticles. The properties of multi-metallic nanoparticles are largely unexplored, and non-comprehensively when they are. My research will aim to build interest in this field, and pursue new phenomena as I observe them.

Being able to pursue new phenomena, to pursue science has been humbling for me, as my chance to do so is extremely serendipitous. I learned in high school that several of the children orphaned by AIDS in Zimbabwe that I tutored loved math just like me. Homelessness, food insecurity, disability, these common nouns walk and talk on the streets of Addis Ababa or Kampala. My parents electrified my passion for service by reminding me that there is not much different between those who escape to more opportunity and those who cannot.

Holding onto that drive to provide for the underserved of Africa, I explored service in San Diego when I arrived in 2013. I was shocked to find that homelessness, food insecurity, and mental disabilities also plague the city,
although there is a difference in scale. That said, a shocking roughly 11,000 metro San Diegans are homeless.\footnote{C. Glynn, E. B. Fox, “Dynamics of homelessness in urban America.” arXiv:1707.09380 [stat.AP]}

Seeing an opening for someone with service interests like mine, I participated in various community service organizations, such as Revelle Community Outreach (RCO), National Society of Collegiate Scholars (NSCS), Humanities tutor program, Community Service Transport, and others. These are my main service commitments, which lasted a full 2 years or more. I am especially grateful for the chance to have worked in the Community Service Transport program as a driver. This program involved driving UC San Diego student volunteers to various community service opportunities, and then based on driver interest, participating with them. Working in this job, I participated in events like beach cleanups, retirement home visits, or ‘First Saturdays’, a program to collect donated clothes, then sort and distribute them to the homeless. Inspired by the service groups, I organized my own trip to Father Joe’s Village, a shelter for the homeless and displaced of San Diego. Despite only five people attending, I am happy to have increased awareness about homelessness amongst the students who accompanied me. I have only been in Evanston for a month or so at Northwestern University, but since arriving, I have begun participating in Junior Scientist Club. This program is designed to explore science experiments with kids in a downtown Chicago middle school that predominantly serves underrepresented groups. I hope my unique experiences as an immigrant can show the kids I meet that access to higher education is not barred, that the achievement gap between the genders and various races is theirs to close.

**Future Goals:** Upon graduation with a Ph.D. in Materials Science and Engineering from Northwestern University, I hope to pursue a career in industry, and or start-up companies. My dream is to conduct research full time, and perhaps in my own small way contribute both to the scientific community and to the economy. I see room for growth in the energy sector, where a great deal of innovation is to be had. On the long term, I plan to continue to inspire underrepresented groups to pursue advanced degrees by investing in creating chapters of junior scientist clubs at various universities. I also hope to give back to the National Action Council for Minorities in Engineering, and try to ensure that whichever company I pursue my industry career with is listed as a sponsor. With the aid of the NSF GRFP, I hope that I can achieve these goals and pursue my scientific ambitions unimpeded by financial concern. To that end, I submit this statement and proposal for your review.

Thank you for your consideration.
[Example 10]: Research Proposal

**Background and Motivation**: Metallic nanoparticles are of significant interest for catalysis applications such as new material synthesis, H\textsubscript{2} production, and fuel cells, or gas sensors and other energy systems. (1, 2) Although many unary and some binary nanoparticles have been well studied for these applications, there is a large number of nanoparticles incorporating alloys of multiple (3+) metals that may have enhanced performance for these applications. A new technique for the fabrication of multimetallic nanoparticles (NPs) has recently been explored by the Mirkin group at Northwestern University: scanning probe techniques used in tandem with specific metal binding via block copolymer lithography (SPBCL.) (3) With the advent of this technique, there are millions of combinations of nanoparticle composition, size, and oxide content, which can be screened for enhanced performance in specific applications, by forming gradients in composition or size. (4) Here, I propose to modify the substrate geometry and chemistry upon which catalytic nanoparticles are synthesized in order to improve control over nanoparticle formation. Metallic nanoparticle formation on a planar surface in SPBCL produces a singular particle of interest at the center of a single polymer dome, or ‘nanoreactor’, but also several smaller particles in the reactor’s periphery. The literature is clear that nanoparticle size directly influences catalytic activity. The catalytic activity can typically only be measured as an ensemble for the whole group of particles. Thus, it is critical to eliminate these ‘background’ particles that add noise to the signal of the large single particle. (5)

**Aim 1**: The first task is to evaluate the size distribution in a single polymer nanoreactor. Using scanning/transmission electron microscopy (S/TEM) the nanoparticle size distribution will be measured. **Hypothesis**: A range of nanoparticle sizes will form within each polymer dome nanoreactor on a planar surface, with a large nanoparticle at the center. These nanoparticles will have a Gaussian distribution around some average size, but most of the mass of the metal in each nanoreactor will agglomerate in the single large nanoparticle.

**Aim 2**: The second task is to attempt to direct the nanoparticle formation and squeeze the distribution, forming a single nanoparticle (i.e. eliminate background particles.) This will be attempted by selective etching of a single crystal silicon wafer according to a self-terminated anisotropic wet etch step using KOH, with arrangement determined by photolithography. (6) This treatment will define a new ‘anisotropic nanoreactor’ as compared to the planar surface nanoreactor. Characterization will be conducted by use of the S/TEM again to evaluate whether a directing effect occurs. **Hypothesis**: The patterned silicon surface will decrease the path length, and therefore the diffusion time, between the extremities of the nanoreactor and the geometric center. A decreased diffusion time will in turn confine and direct the nanoparticle towards the center of the well. This directing process will also help minimize auxiliary nanoparticles on the periphery (depicted in Figure 1). Plasma treatment and self-assembled monolayers can also be employed to increase the surface free energy of the substrate, and in turn guide the particle to the bottom of the well. However, if the surface free energy is too high, then there is a chance for small particles to dry on the sides of the anisotropic well reactor (similar to a ‘coffee ring’ effect). The surface energy that preferentially leads to single NP formation should be determined experimentally.

Figure 1: Polymer Pen Lithography tip array provides SPBCL precursor to both unpatterned and patterned surfaces. i), ii) PPL Tip array deposits precursor. iii) Reduction in H\textsubscript{2} environment auses NP formation. iv) NPs aggregate. v) Polymer is burned, NPs coalesce
**Aim 3:** The final task in this project would be to evaluate the effect of the directed nanoparticle growth on catalysis in order to determine whether the smaller nanoparticles are affecting catalytic activity. In order to compare in a consistent fashion, the nanoparticles in the anisotropic nanoreactor will be normalized based on the exposed surface area. (The exposed nanoparticle surface area is smaller inside the patterned surface than on a planar surface.) In this case, a specific nanoparticle composition and reaction to be catalyzed must be chosen. A convenient starting point may be the catalysis of hydrogenation reactions by platinum in a hydrogen gas environment, or barring this, carbon nanotube formation. **Hypothesis:** The nanoparticles formed on the patterned surface will have a significantly smaller specific surface area (mm^2/g), and on a per mass basis will be less catalytically active than nanoparticles formed on a planar surface; an effect well examined in the literature. (7) By eliminating auxiliary particle formation, background catalytic turnover will be minimized, which will denote a significant improvement towards a reliable screening platform.

**Intellectual Merit:** This project will explore the fundamental limits of nanoparticle formation at the smallest scale possible. Reproducible production of extremely small nanoparticles is crucial to using the SPBCL technique as a robust screening platform for catalysis. **Anticipated Results:** Useful fundamental research will determine whether surface geometry and/or chemistry is a variable of interest in exploring the smallest scale of nanoparticle agglomeration, down to potentially single atoms in single wells. Electron microscopy techniques and electrocatalysis measurements will be acquired and compared to the literature to determine the effect of background nanoparticles on catalysis. **Potential pitfalls:** Measurement of the size distribution of nanoparticles by electron microscopy may be difficult, due to the smallest nanoparticles being below the resolution limit of the SEM. However, Northwestern University has recently acquired a high resolution aberration corrected TEM which can provide the size distribution.

**Broader Impact:** In 2015, roughly 90% of energy consumed in the U.S. came from nonrenewable sources. (8) Moreover, the energy demand is expected to climb ever higher. Screening of various catalysts may alleviate the energy crisis by rapidly exploring multi-metallic catalysts for enhanced performance in multiple reactions of interest. This also opens up a field of fundamental scientific interest, specifically ‘nanocombinatorics’; a method of exploring material dependent nanoscale phenomena in a massively parallel fashion. Besides catalysis, nanoparticles can be screened for enhanced plasmonic behavior, superconductivity, interesting metallic mixing behavior, and other size-dependent effects. All of this research relies on knowing that the nanoparticle being studied is indeed the sole contributor to its properties, and not background particles that often form in conventional SPBCL.

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3. P.-C. Chen et al., doi:101021/jacs.5b05139.
[Example 10]: Rating Sheet

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The proposed research has the potential to advance knowledge across multiple fields.

Broader Impacts Criterion

Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: The proposed research has the potential to benefit society.

Summary Comments: The applicant is well qualified to carry out the proposed research. The proposed activities have the potential to advance knowledge and benefit society. The research plan is well organized and based on sound rationale. The resources required are also available to the applicant.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The applicant shows a great academic record with three highly impact journal publications. The applicant has been a research assistant in Lipomi’s group since 2013. The applicant worked on three projects related to graphene and ultramicrotomy which not only resulted into publications but also prepared the applicant with necessary techniques and knowledge for the proposed research work. The research is based on multi-metallic nanoparticles in anisotropic nanoreactors. The proposal is well-prepared with detailed research plan and reasonable hypotheses.

Broader Impacts Criterion

Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: The applicant shows broader impacts on energy by understanding the multi-mettalic nanoparticles nanoscale phenomenon as catalyst. The applicant is active in social services and volunteer work. It helps the applicant for broader impacts.

Summary Comments: The applicant shows a great academic record with high impact research papers. The research experience prepares the applicant for the proposed research. The proposed research is well-prepared and shows broader impacts in energy and fundamental understanding of multi-metallic nanomaterials.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: This applicant has very good academic record and amazing research experience. He has continuously worked in a research group for over three years since freshman. As a undergraduate student, he worked on different projects including one project completely independent of a senior graduate student or postdoc. He has gained plenty of knowledge and techniques through his hard work. His intelligence, ambition, aptitude, and tenacity can be clearly seen from his research experience and achievement. He has already published three papers: one as the first author and the other two as co-author. His work also led to several presentations and awards.

Broader Impacts Criterion

Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: This applicant has very special experience before entering the university, so he cherishes the learning opportunity and understands the importance of education. His international background makes him care about people in impoverished situation. He has been a tutor in Africa for students whose parents were killed by the AIDS epidemic. He has participated several community service organizations for over 2 years, helping and organizing many events to help others. He is also in some program to explore science experiments with kids. His unique background is a good example for everyone, especially for disadvantaged students.

Summary Comments: It is inspiring to read this application, since the applicant is excellent in both intellectual merit and broader impacts. His great academic and research achievement is so much competitive that there is no need to consider his unique background. If he could win this fellowship, it is definitely because of his excellence instead of his background. His work led to several publications and awards, and his outreach activities show his love and leadership. He could have big impact in his future work.
On a wall of the Chicago Museum of Science and Industry, I once saw a quote by English author Eden Phillpotts: “The universe is full of magical things, patiently waiting for our wits to grow sharper.” These now-favorite words shaped the way I approached engineering as I progressed through my studies at Stanford University, seeking knowledge to allow me to examine concepts that once seemed “magical” and describe their underlying science. A freshman seminar called “Science of the Impossible” stimulated my desire to understand the detailed facets of material properties and use them for previously inconceivable applications. Now, after engineering coursework, internships, and undergraduate and graduate research, I realize that my job as a researcher is not only to create magic through science, but also to unweave the complexities that make science seem magical. Completing my PhD in Materials Science and Engineering at Northwestern University will lead, with “sharpened wits”, to a career that demystifies materials to develop innovative applications based on their properties.

My fascination with science began well before I read the Phillpotts quote – it has been ingrained in me for as long as I can remember. My parents are both in STEM fields; my mom fondly told me she often whispered “engineer” in my ear as a baby. So, whether nature or nurture, I never doubted that I would someday be a scientist or engineer. When I began my pursuit of an engineering degree in college, I expected to face challenges as a woman in STEM. However, in spite of being part of a noticeable minority, my undergraduate and graduate experiences have been overwhelmingly positive. I was particularly inspired by my academic advisor at Stanford, a female professor who motivated my decision to study materials science and offered valuable guidance in my academic goals, and my current co-advisor at Northwestern, Prof. Ramille Shah, who provides mentorship as an influential woman in academia and instills confidence in my pursuit of a career in engineering research. The support from my parents and mentors has inspired my dedication to sharing the enchantment of science with younger students, particularly those who might not have the same educational resources that I did.

**Research Experience and Intellectual Merit**

The summer after my freshman year in college, I volunteered as an intern with the National Enforcement Investigations Center of the Environmental Protection Agency (EPA) in Denver. At first, I was given basic tasks such as compiling images for reports, but finishing assignments quickly and accurately soon led to more autonomy. I was tasked with a more critical project to standardize and document procedures for the operation of “Next Generation” air-sampling techniques, and I performed chemical analysis to support legal cases. In addition to gaining lab experience, the EPA provided an introduction to the mechanics and myriad personalities of the work force. I independently studied theories on communication techniques, skills that are important to any successful team, and I appreciated the opportunity to grow in this area.

My first substantive materials science course on crystallography and characterization motivated me to join Dr. Robert Sinclair’s imaging-focused group at Stanford University for a sophomore summer research program. My goal as part of an interdisciplinary collaboration with medical researchers was to investigate the biodegradability of silica nanoparticles (NPs) in cells. I prepared cells for transmission electron microscopy (TEM) by conventional heavy metal staining methods and ultramicrotomy and worked extensively with TEM, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) to characterize the NPs. This experience helped me learn to adapt to challenges that can arise in microscopy – I needed to insert an aperture to perform accurate EDS, but the increased beam intensity caused significant sample damage, so I developed an efficient process to minimize the direct beam time. I co-authored my first publication through this work; after performing a statistical analysis, my contribution provided compelling TEM images and concluded that the NPs biodegrade within three weeks.
of injection in cells. My work demonstrated the capacity of silica NPs for controlled delivery of drugs or labeling agents for theranostic applications, as chemical agents to detect analytes, or for other load delivery applications. This project provided an introduction to the challenges and rewards of interdisciplinary collaboration, fostered my interest in soft materials imaging, and solidified my desire to pursue an advanced degree to support a career in research.

My junior year, I was selected for a competitive Krupp Foundation internship that allowed me to further explore soft material imaging as a researcher in Prof. Dr. Niels de Jonge’s Innovative Electron Microscopy group at the Leibniz Institute for New Materials in Saarbrücken, Germany. The goal of my project was to investigate the behavior of human epidermal growth factor receptor 2 (HER2), which allows cell proliferation in aggressive forms of cancer. I learned sterile cell culture techniques and maintained a breast cancer cell line, seeded cells onto electron-transparent microchips, and labeled them with an affibody-biotin conjugate and quantum dots to allow targeting of HER2 receptors. With little guidance, I performed fluorescence microscopy and environmental scanning transmission electron microscopy (ESEM/STEM) to image the cells in a liquid environment. Image analysis showed apparent localization of the receptors into lines. I am still performing a statistical analysis to confirm the observations and am lead author on a paper that is nearly complete. My work was unique in that it demonstrated the effectiveness of light and electron microscopy in comparing real-time behavior through live-cell fluorescence with high-resolution electron images; this method is widely pertinent to applications that require solution-based imaging. In addition to furthering my laboratory expertise, the internship was an opportunity to gain a global perspective through collaboration with Dutch and German colleagues, speaking in German, as part of an interdisciplinary team.

As a PhD student at Northwestern University, my interest and experience in microscopy and biomaterials led me to pursue a co-advised project with Prof. Vinayak Dravid, who investigates the applications of novel characterization techniques, and Prof. Ramille Shah, who specializes in extrusion-based additive manufacturing of a wide range of materials. During the first year of my doctoral study, I incorporated magnetic nanostructures with high T2-weighted MRI contrast into 3D-printed scaffolds, enhancing the potential for in vivo imaging of scaffold degradation. I learned to synthesize and print both hydrogel and particle-laden inks, a task that requires precision and meticulous attention to detail. Prior experience and the development of new skills allowed me to characterize the fabricated scaffolds by a variety of methods that will support my research proposal, including SEM, soft material TEM and fluorescence imaging, inductively coupled plasma mass spectrometry, and spectroscopic compositional analysis techniques.

**Broader Impacts**

I am passionate about supporting young women and other under-represented students who do not have the resources and encouragement that I’ve had. I want to be the voice, like my mom’s, in a young student’s ear that cultivates their interest in using science to unlock the “magic” in their world. This initial engagement must propagate through all stages of education to prevent attrition out of STEM fields. Therefore, I am engaged in mentorship and outreach programs that span the education spectrum, from elementary school through graduate school.

Early intervention can spark enthusiasm for science and introduce the creative thinking and problem solving that science and engineering demand. I am a mentor in Letters to a Pre-Scientist (LPS), which pairs professionals with elementary school students from under-represented communities to encourage scientific communication as pen-pals. I am always excited to see responses that demonstrate genuine curiosity and an eagerness to learn, and the letters help me think about how I can most effectively convey science to students and the community. I am encouraged that programs like this can motivate students to think about futures in STEM.
While very rewarding, LPS does not allow in-person contact with students, so I pursued additional outreach opportunities such as the Evanston Engineering Grand Prix. At this annual event, volunteers lead middle school students from an under-resourced community through engineering challenges. I worked with middle school girls on various engineering projects and was amazed by their creativity and intuition in problem-solving. This event inspired me to further engage in Science In your Community Center, which aims to improve access to science and engineering for under-represented groups in Evanston. Each month, I work one-on-one with middle school students to perform fun and exciting engineering tasks. The program allows me to make a lasting connection with my students and support their interests as they progress in their education, and also offers the opportunity to develop teaching skills.

Although I never questioned whether I would go to college, many Chicago-area students do not have the same level of support from parents, teachers and peers. I was honored to be selected for the iMentor program, which strives to increase the percentage of Chicago students who attend and graduate from college. iMentor pairs a college graduate with a same-gender high school junior for three years. Mentors correspond weekly, attend monthly meetings, and serve as a resource through the student’s first year of college. This experience has been challenging; my first task was to convince my mentee that going to college is likely to improve her quality of life. I am thrilled that we are now making plans for her future after high school.

While academia has made great strides toward gender equity in STEM, most disciplines still face significant disparity by the graduate level. For this reason, I was very active in the recruitment of women to the incoming Materials Science PhD class at Northwestern, and I was delighted to see that half of the 2017 cohort is female. In my current capacity as President of Northwestern’s Materials Science Student Association, I am able to support all incoming MSE students by planning events that foster a community of inclusion and diversity. As an active member of the Society of Women Engineers (SWE), I cultivated communication between incoming students and SWE by bringing about 15 first-year students to this year’s SWE kickoff event; last year, I was the only MSE first-year attendee. SWE has given me the opportunity to mentor a new MSE PhD student and an undergraduate student, allowing me to both provide support and have enlightening conversations about their experiences as women in STEM.

Another difficult task in improving STEM diversity is increasing representation in academic faculty and high-ranking government and industry positions. Support from the NSF GRFP will help pave the way for my PhD and a successful career in materials science; I plan to use my platforms and resources to advocate for women and other underrepresented groups, across the age spectrum, in science and engineering fields.

**Future goals**

My fascination with the science that seemed “magical” when I was young has led me to a career in Materials Science, a field that strives to unravel the complex properties of materials and harness them for a broad and growing range of applications. I decided to pursue a PhD because I want to lead research and innovation, particularly in biomaterials and their characterization through novel imaging methods. A PhD will also provide an avenue to pursue my passion for mentorship, teaching, and making science accessible to the community. Support from the NSF GRFP will afford me the academic freedom to conduct adventurous and novel research, allow me to seek dynamic, interdisciplinary, and potentially international collaborations, and provide a platform for mentoring and improving diversity in science and engineering.
Seeing the invisible: Novel staining methods for liquid-cell electron microscopy

Keywords: Form-function, liquid-cell electron microscopy, contrast enhancement, nucleic acids

Introduction/Motivation: The study of materials is governed by the relationship between form and function; a quintessential example of this phenomenon is DNA, in which molecules assemble in a particular pattern at the nanometer scale and consequently constitute the basis of life at the macroscale. The visualization of nucleic acids and proteins is essential to our understanding of the human body, but DNA in particular has additionally proven useful in applications beyond biology, such as templating, functionalization, and programmed assembly. In order to fully control how DNA and other macromolecules may assist in these applications, we must observe the mechanisms by which they operate in their functional environment.

The 2017 Nobel Prize in Chemistry for the development of cryo-electron microscopy (EM) demonstrates the importance of imaging in our understanding of the physical and biological world. Although groundbreaking in establishing a method to obtain high-resolution images of phenomena in solution, cryo-EM is limited to a snapshot frozen in time. Liquid cell EM, on the other hand, has the potential to provide the same quality of in situ imaging and also break the temporal barrier, making it an ideal platform to observe solution-based mechanisms like DNA assembly and binding events based on bio-recognition principles.

Background: The primary challenge in soft EM is achieving reasonable contrast while avoiding sample damage. Traditional staining methods to overcome signal-to-noise issues require heavy metal contrast agents, which are effective for visualizing the cell membrane but do not provide adequate staining of nuclear material. A DNA staining method recently developed by Ou et al.\textsuperscript{1}, chromatin electron microscopy tomography (ChromEMT), allows for positive staining of DNA in the nucleus of human cells. This method first labels cells with a fluorescent molecule that selectively binds to DNA, and then bathes the cells in diaminobenzidine (DAB). Upon photobleaching, excited fluorescent molecules generate a reactive oxygen species that catalyzes DAB polymerization localized to DNA. Cells are then stained with osmium, which binds to DAB with high affinity. The ChromEMT staining technique with tilt-tomography is particularly useful in observing DNA structure across an entire nucleus, a previously unrealized concept.\textsuperscript{1}

Objective: The aim of this project is to develop a platform technology for macromolecule staining in fluidic cell EM by a ChromEMT-based method, allowing for the direct imaging of nucleic acids and proteins both in a cellular environment and in their capacity for functionalization and assembly.

Preliminary Work: I have prepared cells for transmission EM (TEM) using conventional staining methods and sectioning by ultramicrotomy, developing required skills for soft EM. I applied the ChromEMT method to stain DNA in mitotic and resting cells; Figure 1 shows co-localized fluorescence and scanning-TEM (STEM) images of ovarian cancer cells, demonstrating that the method was successful for imaging DNA and that photobleached nuclei were more heavily stained than neighboring cells without photobleaching.

Research Plan: (1) Broaden capabilities of in-cell staining: The Ou study\textsuperscript{1} tested only DNA-specific fluorescent dyes; I will expand this technique to other nucleic acids and proteins in cells to broaden
applications. I plan to develop a ChromEMT-based method using an RNA-targeted dye, which will be used to analyze the comparative quantities of DNA and RNA for the first time via direct imaging. This would allow me to evaluate differences in nucleic acid organization of healthy versus diseased cells and determine how disease impacts nuclear structure.

(2) Develop liquid EM staining method: By re-engaging in my prior collaboration with Prof. Dr. Niels de Jonge at the Leibniz Institute for New Materials (INM) in Germany, I plan to stain and image membrane proteins using in situ EM. Prof. Dr. de Jonge’s extensive experience in protein labeling and correlative fluorescence microscopy with in situ STEM will facilitate development of a liquid-cell microscopy method for direct protein imaging. At the INM, by extending techniques derived during my internship, I will label cells seeded on electron-transparent chips with a protein-specific fluorescent dye and DAB, perform fluorescence microscopy and photobleaching on live cells, fix the cells, and then stain with osmium tetroxide by direct deposition on the cell layer. To confirm that DAB selectively stains the correct protein, I will perform two experiments: (1) a control experiment without the fluorescent dye, and (2) an experiment with a quantum dot labeling step that follows our previously established method for protein labeling.2 This technique offers the possibility of correlating the real-time movement of live cells with high-resolution EM of the proteins and receptors in specific areas of the same cells. This will be the first instance of direct protein imaging in liquid EM and could provide unprecedented insight into the distribution and behavior of membrane proteins in diseased cells.

(3) Perform in situ imaging of DNA-assisted assembly: Once this staining method is applied to liquid EM in cells, I will adapt it to observe DNA in solution. This will involve collaboration with Prof. Chad Mirkin’s group at Northwestern, which specializes in the synthesis of spherical nucleic acids (SNAs) and other DNA-assisted assembly. In SNA formation, oligonucleotide strands attach to the surface of gold nanoparticles.3 I plan to stain the oligonucleotides and incorporate them and the nanoparticle solution into a fluidic chip for TEM. My goal is to directly image the mechanism by which the strands adhere to the surface, resulting in a new method that can be applied to numerous systems that use DNA for assisted patterning onto a substrate.

Intellectual Merit: The NSF GRFP would support a unique opportunity for an interdisciplinary, international collaboration that spans the fields of biology, chemistry and materials science. My experience in EM and preparatory methods and my connection to a highly respected global research partner make this proposal feasible within my PhD timeline. This project will provide a platform technology to advance our knowledge of DNA and protein behavior in their functional environments, lead nearly immediately to methods with practical significance for direct imaging of macromolecules in solution, and facilitate future discoveries through liquid-cell EM.

Broader Impacts: In my personal statement, I described how I strive to improve diversity in STEM fields by encouraging young scientists in under-resourced areas. I plan to demonstrate microscopy methods to students and share accessible images of previously opaque concepts such as DNA with the community, particularly through Northwestern’s Career Day for Girls and Chicago’s Junior Science Club. I am also excited to mentor undergraduate students with this research through REUs and SWE to encourage female representation in STEM at the graduate level. The project’s potential impacts to scientific discovery have broad applicability, which I hope to present at global conferences; imaging DNA in theranostic materials such as SNAs will lead to improved disease therapy, and the imaging of macromolecules in cells will significantly improve our understanding of biological function and the ways this function can be manipulated.

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Very Good
Explanation to Applicant: Author has had research experiences both at Stanford as an undergraduate and with Dr. Niels de Jonge in Germany as part of a Krupp Foundation Internship. She has a strong GPA and is a co-author on a 2015 publication. She has another publication in process and has 1 poster presentation. Her proposed research was clearly explained and a logical extension of current research.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: Author is passionate about supporting young women and under-represented students and is involved in engagement with students of all ages through a variety of outreach programs. Notably, she is the president of Northwestern's Materials Science Student Association.

Summary Comments: According to reference writers, Author is driven, intelligent, experimentally savvy, and has tremendous potential. Her proposed research at Northwestern takes advantage of expertise both at Northwestern (with Dr. Chad Mirkin's group) and in Germany (with Dr. Niels de Jonge, who she worked with previously).

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Excellent
Explanation to Applicant: The intellectual merit of the proposed research is in developing a novel in situ staining/imaging method for cells within their contextual environments, which would enable a better understanding of the biological processes in normal and diseased cells. Through previously established collaborations during undergraduate study, the applicant bridges prior research with the proposed project. Resources for successful research are available to the applicant. The applicant has an impressive academic record and letters are supportive of a top-tier creative, independent learner.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Excellent
Explanation to Applicant: The broader impacts of this research could be in improved diagnostic techniques, basic studies of biology, and better design of therapeutic molecules. The applicant is dedicated to improving diversity in STEM, particularly among women. A specific plan to incorporate demonstrations of research into outreach and recruiting activities is a strength of the application. Previous activity in publication and presentation of research confirm a drive for successful sharing of research results with the scientists and the community.

Summary Comments: Statements and letters support a top-tier level student with impressive global collaboration opportunities and solid plan for outreach.

Intellectual Merit Criterion
Overall Assessment of Intellectual Merit: Very Good
Explanation to Applicant: This is a very good research project. The author has two publications (one as first author). Project has potential to significantly advance the field of liquid-cell electron microscopy.

Broader Impacts Criterion
Overall Assessment of Broader Impacts: Very Good
Explanation to Applicant: The societal impacts of the project can be high if successful since they can advance the field of electron microscopy leading to a number of enabling applications.

Summary Comments: This is a well thought out project that can advance knowledge about electron microscopy methods. The candidate has a good research track record and can have significant potential in the research field.
I believe that advanced materials will shape the future. Regardless of the engineering discipline, material properties play a crucial role. Whether engineers are designing computer chips, medical implants, or car parts, the materials that are available limit what can be achieved. Advanced materials give engineers the ability to move beyond current limitations and achieve what was previously impossible. Materials science and engineering is the spearhead of innovation, and I found polymer science and nanotechnology to be two of the most exciting areas of research. As an engineering student, I want to be on the cutting edge of research and innovation, and pursuing a graduate education provides me the opportunity to accomplish that goal.

I became interested in materials at a young age when I first learned that all matter was made up of atoms. I thought it was incredible that everything was made up of what I imagined to be tiny building blocks. After taking introductory science classes in elementary school and middle school, I became fascinated with chemistry. In high school, I performed chemistry experiments for the first time, and I was enthralled. If I finished a quiz or test early, I would hand in my paper and ask if there were any experiments I could do in the extra time. My teacher would smile and say, “As long as you tell me what happens and why.” This made me realize that experiments weren’t just interesting, they were a challenging puzzle that could be explained. I was hooked. During my first year at Case Western Reserve University, I took the course Chemistry of Materials with Professor David Schiraldi, a course that bridged my interest in materials with my enthusiasm for chemistry. After taking this course, I began to seek out materials courses in other departments and disciplines including materials science and engineering, polymer science and engineering, and biomedical engineering. After taking these courses, I decided to pursue a bachelor’s degree in polymer science and engineering.

The classes I took provided me with valuable fundamental knowledge. The next step was to apply that knowledge. I had always enjoyed laboratory courses, and I believed that working in a research lab would be the next step in developing myself as a scientist. During the spring of my sophomore year, I began working as a research assistant in the Laboratory for Cancer Nanotechnology at Case Western Reserve University under Dr. Efstathios Karathanasis. My research was primarily focused on using nanoparticles for the imaging and treatment of metastatic cancer tumors. I performed chemistry for nanoparticle synthesis, and I also participated in both in vitro and in vivo studies. While I joined a lab for the opportunity to do ground breaking research, I also found that working in a research laboratory provided me with the opportunity for great personal and academic growth. Every day provided a new challenge and a new skill to learn. Due to my work in the Karathanasis Lab, I was a coauthor on the paper “Vascular Targeting of a Gold Nanoparticle to Breast Cancer Metastasis” in the Journal of Pharmaceutical Sciences.

After working in the Karathanasis group for a year, I began working as a research assistant in Dr. LaShanda Korley’s laboratory in the Department of Macromolecular Science and Engineering at CWRU so that I could conduct research on polymeric materials. I focused on developing and thermally testing films of polymer blends with the goal of incorporating graphene oxide nanoparticles that could function as compatibilizers. In addition to investigating these blends, I researched low molecular weight gels that were designed to be thermally responsive. Throughout this process, I gained experience in thermal testing and analysis of materials. Additionally, I had the opportunity to manage and design my own experiments and tests. Experimental design proved to be both challenging and gratifying. I learned the importance of managing variables and drawing meaningful conclusions from experimental results. Setting a research objective, devising and refining a plan, executing that plan, and ultimately achieving the objective was incredibly fulfilling.
By the end of my junior year, I had three semesters of research experience. However, I had only been able to contribute ten to fifteen hours a week towards research because I was taking classes at the same time. I wanted to experience what it would be like to work in a research lab full time. I decided to pursue this goal by attending a research experience for undergraduates at the Macromolecules and Interfaces Institute at Virginia Tech. I worked under the guidance of Professor Richey Davis from the Department of Chemical Engineering. I was tasked with encapsulating rosmarinic acid, a naturally occurring active pharmaceutical ingredient, in a polymeric nanoparticle. I learned about new areas of polymer science and different methods of particle synthesis and characterization. After I completed my research at Virginia Tech, I presented a poster of my summer research at the American Chemical Society workshop, Polymers in Medicine and Biology, in Santa Rosa, California in September 2015. At the workshop, I presented my work to scientists from across the world. I connected with people from different scientific backgrounds and gained valuable insight into the field of polymer science. Participating in this conference confirmed that materials research is the correct career path for me.

During my undergraduate classes and research, my scientific curiosity grew. I became increasingly interested in materials science. I was especially interested in soft matter research. I decided that the best way to continue to pursue my passion for soft matter research was to go to graduate school and seek a PhD. I began this journey in the Department of Materials Science and Engineering at Northwestern in the fall of 2016. Because my undergraduate degree was in polymer science and engineering, the classical materials science courses broadened my knowledge significantly. I learned about defects in metals, transmission electron microscopy of crystallographic materials, Ostwald ripening, and many other fascinating topics. These topics gave me a new perspective on the field of materials science and engineering.

In the fall of 2016, I began working in the laboratory of Professor Samuel Stupp so that I could pursue my interests in supramolecular chemistry and biomaterials. During my time in the Stupp group I have focused on making hybrid materials that incorporate the beneficial properties of both polymeric and supramolecular materials. Specifically, my work focuses on making new biomaterials that incorporate peptide amphiphiles and biocompatible polymers. Peptide amphiphiles have a wide variety of potential medical applications due to their incredible self-assembly and tunable bioactivity. My experience in the Stupp group has been incredibly rewarding because I have had the opportunity to do both materials synthesis as well as materials characterization. I have been able to apply the research skills I gained during my undergraduate research as well as develop new skills. Working in the Stupp group also gives me the ability to work with scientists from fields including chemistry, biology, biomedical engineering, and material science. Because of the multidisciplinary nature of the Stupp group, every discussion with colleagues is an amazing learning opportunity.

In addition to personally conducting research, I strive to motivate others to be interested in science. While I was a junior at CWRU, I was Undergraduate Representative in the Society for Biomaterials. As Undergraduate Representative, I engaged students to increase interest and participation in academic research by organizing laboratory tours for undergraduates to show the myriad of research opportunities on campus. In the spring of 2014, I participated in the Biomaterials Education Challenge. My team and I visited a Cleveland area middle school to conduct hands on educational activities with students. We assisted the students in designing artificial knee replacements using household supplies in order to teach them about the fundamentals of science, medicine, materials, and engineering. I also designed educational materials distributed at three Cleveland area schools. My team achieved second place at the National Society for Biomaterials conference in the education challenge for our work. During this experience, I found that I loved teaching. In the summer of 2015 I had the opportunity to be a mentor for a group of children as part of the Youth Experiencing Science program at Virginia Tech. During this program, I
designed experiments and activities to teach the children about medicine, materials science, and the scientific method. Additionally, I helped them present their findings at the Blacksburg community street fair “Steppin’ Out.”

After participating in several education outreach programs while I was an undergraduate, I decided I wanted to gain more teaching experience. In the spring of 2016, I was a teaching assistant for the course Polymer Properties and Design in the Department of Macromolecular Science and Engineering at Case Western Reserve University. While I was a TA, I led review sessions to reinforce understanding of the lectures. I also held office hours where I taught course content during one on one conversations with students. In addition to teaching scientific and engineering content, I also led writing sessions in order to improve students’ technical writing and communication. I learned that I have a strong interest in teaching after my experience as a teaching assistant.

During my graduate education, I continue to be involved in educational outreach so that I can show students of all ages how exciting science can be. During the fall of 2016, I was a science mentor in the Junior Science Club where I mentored elementary and middle school students at a Chicago Boys and Girls Club to encourage interest in science and engineering. Additionally, I have become involved in the Materials Science Student Association as the Volunteer and Outreach Chair. I organize fundraising and charity events to help both the local and national community. I also coordinate our department’s affiliation with Letters to a Prescientist, a program in which scientists become pen-pals with young students interested in science. In order to further help this cause, I plan fundraising events for Letters to a Prescientist so that the organization can continue its amazing work. My experiences with educational outreach have been rewarding because I have been able to teach children about subjects I am passionate about and motivate them to be interested in science. Through these programs I learned that I enjoy teaching and sharing my love of science with others. By participating in these programs, I can reach underprivileged and underrepresented students and encourage them to take an interest in science and engineering.

During my undergraduate and graduate education I found that I greatly enjoy performing research and teaching others. I aim to become a professor so that I can pursue these passions even further. This career path will give me the opportunity to take part in cutting edge research on advanced materials that will shape the world. Being a professor will give me the ability to do much more than scientific research. I will be able to pass down all the knowledge I gained throughout my career. I will teach courses that reach hundreds if not thousands of students, mentor young scientists in how to perform research and communicate their results, and perform educational outreach in the surrounding community. Attending graduate school at Northwestern University is a great opportunity to broaden my academic knowledge, improve my research skills, and grow as a person. The NSF-GRFP provides amazing academic freedom to conduct research at a high level in my areas of interest so that I can achieve my goals. Furthermore, by seeking a PhD I will be able to emerge as a leader both scientifically and in my community.
**Composite Covalent and Supramolecular Hydrogel for Wound Therapy**

**Summary:** The goal of this proposal is to study the formation and optimization of composite hydrogels, produced by the polyelectrolyte complexation of covalent polymers and supramolecular fibers, that are designed to assist wound healing.

**Aim #1:** Develop design principles of hydrogel fabrication using parameters such as ionic strength and pH to tune the hydrogel morphology and properties.

**Aim #2:** Study antibacterial properties using *Staphylococcus aureus in vitro* and mouse *in vivo* using models to determine how hydrogel morphology affects antibacterial efficacy.

**Background:** Polyelectrolyte complexes (PECs) are an interesting class of hydrogels formed via the complexation of a polycation and a polyanion. PECs have many useful biomedical applications, including dermal wound therapy.¹ For dermal wound treatment, it is desirable to keep the wound moist because a hydrated environment can result in epithelialization faster than a dry environment, resulting in accelerated tissue repair.² However, hydrated environments also allow for bacterial proliferation which can result in infection. A hydrogel that can keep the wound area hydrated, but also incorporates an antibacterial component would be very desirable for wound healing applications.³ A peptide amphiphile (PA) has been developed that has shown promising antibacterial properties *in vitro* with *Staphylococcus aureus* in unpublished work by collaborators at Nanyang Technological University (NTU) in Singapore. This PA (Figure 1a) also has the ability to form self-assembled fibers. Despite having fortuitous antibacterial properties, the PA fibers on their own do not have sufficient structural integrity to be used for wound healing. A hydrogel made with these peptide amphiphile fibers could hydrate a wound as well as maintain a bacteria free environment. The peptide amphiphile fibers being used are negatively charged, so the PA fibers can be crosslinked using polycations. This results in a hydrated polyelectrolyte complex. PECs do not require catalysts or initiators (which are often toxic) to form, while covalent hydrogels typically do.¹ Chitosan (Figure 1b) is a positively charged polyelectrolyte that is commonly used in biomedical applications because it is biocompatible, inexpensive, and has good wound healing properties.¹,⁴

In order to incorporate the antibacterial PA into a hydrogel of sufficient structural integrity for wound healing applications, I propose to develop a precise understanding of how molecular interactions of PAs and chitosan determine the properties of PECs. Unpublished work I have performed using a model PA shows that PECs are formed after mixing solutions of negatively charged PA nanofibers and chitosan. The complexation of these materials results in a fibrous network with nanoscale and microscale features (Figure 1c). PECs are sensitive to changes in pH, ionic strength, molecular weight, charge ratio, and mixing order.³ How these parameters affect the material properties as well as the biomedical properties of covalent polymer-supramolecular polymer PECs is of high interest. Studying this system could lead to improved wound healing methods as well as provide important information on the science of polyelectrolyte complexes.

**Figure 1:** (a) Antibacterial PA (b) Chitosan (c) SEM image of PA-chitosan PEC, 500 nm scalebar (d) Confocal image of a PEC formed by mixing PA (red) and chitosan (green), 10 micron scalebar
**Proposed Approach:** *Aim #1:* The formation of hydrogels during polyelectrolyte complexation is dependent on numerous parameters including the pH of the polyelectrolyte solutions, ionic strength of the polyelectrolyte solutions, ratio of polycation to polyanion, concentration of the polycation solution, and concentration of the polyanion solution. These parameters control the resulting hydrogel structure and properties. Because of these numerous parameters, this is a highly tunable gelation system. The parameters will be systematically varied to produce hydrogels with varying morphologies and properties. Morphological analysis will be performed using scanning electron microscopy (SEM). Additionally, confocal microscopy experiments will be performed in which the anionic supramolecular nanofibers (PA) will be labelled with a different fluorescent dye than the cationic covalent polymer (chitosan). Using different dye labels for the anionic and cationic components of the PEC allows for the discovery of phase separation and/or colocalization of the anionic and cationic components. By conducting these experiments, a comprehensive empirical understanding of composite hydrogels formation and morphology will be gained. The mechanical properties of the hydrogels will be probed using small angle oscillatory rheometry.

*Aim #2:* Because wound healing is the application for the proposed hydrogel, I will assist collaborators in the design of *in vitro* and *in vivo* experiments. *In vitro* studies will be performed with *S. aureus* because it is a leading cause of infection, especially infections that are resistant to conventional antibiotics. After these studies, *in vivo* studies will be performed using a mouse model to test the ability of the PA-chitosan hydrogel to function in biological environments. Small dermal wounds will be made, and *S. aureus* will be administered to the wound site. The proposed PA-chitosan hydrogel will then be applied to the wound site. By performing these tests, it will be determined whether this material will have promise in animal models as well as in cell culture. Our collaborators at NTU have expertise in biophysics and membrane science, and our joint studies seek to explain the mechanism by which the antibacterial PA works.

**Conclusions:** A composite covalent and supramolecular hydrogel produced using polyelectrolyte complexation could be capable improving healing in dermal wounds. Knowledge gained through this study will improve understanding of polyelectrolyte complexes.

**Broader Impact:** The proposed study seeks to develop, examine, and optimize composite hydrogels produced through the ionic complexation of covalent and supramolecular components. This will assist researchers in understanding and developing ionic hydrogels with high complexity and functionality. Furthermore, the proposed hydrogel could have the ability to assist in the treatment of dermal wounds and infections. By utilizing the method studied in this proposal, and incorporating different polycations and polyanions as the supramolecular and covalent components, the formation of this interesting class of hydrogels can be explored. Additionally, by changing the bioactive epitopes on the PA component, the lessons learned in this study could be used to develop gels for a variety of biomedical applications.

In addition to performing scientific research, I seek to share the lessons I learn with the next generation. I have a passion for teaching young students about scientific principles and research. During graduate school, I continue to be involved in educational outreach through Junior Science Club and Letters to a Prescientist by organizing programs and activities for young students. By teaching these students about science, I can reach underrepresented students who might otherwise not consider a career in science or engineering fields.

[Example 12]: Rating Sheet

**Intellectual Merit Criterion**

Overall Assessment of Intellectual Merit: Excellent

Explanation to Applicant:

With a strong academic record and work experience, this candidate appears extremely well-suited to take on the tasks of graduate work and academic life. He has experience in his area of work and exceeds standards expected by a beginning graduate student.

**Broader Impacts Criterion**

Overall Assessment of Broader Impacts: Excellent

Explanation to Applicant:

The candidate has worked in several research arenas. This in combination with his outreach efforts and the intellectual merit of the proposal increased this reviewers enthusiasm for long-term broad impact success.

**Summary Comments:** Through a strong intellectual merit and broader impact statement, this applicant receives high praise. He will undoubtedly continue to be a successful graduate student. Through strong mentorship, scientific support, and previous work in this space, the applicant is well-suited to carry out experiments and shows the ability to place his work among others.

**Intellectual Merit Criterion**

Overall Assessment of Intellectual Merit: Excellent

Explanation to Applicant:

The PI proposes to develop a precise understanding of how molecular interactions of peptide amphiphiles and chitosan determine the properties of polyelectrolyte complexes. The proposed study is supported by preliminary data based upon unpublished research conducted by the PI. The research plan is carefully thought through, well organized, based upon a sound rationale and clearly written. The PI has the expertise from prior research experience to successfully deliver on the proposed work plan. In addition, PI has adequate resources (in his current institution along with collaborations) to successfully deliver on the plan.

**Broader Impacts Criterion**

Overall Assessment of Broader Impacts: Excellent

Explanation to Applicant:

The broader impacts include developing gels for a variety of biomedical applications, and attract and engage students about STEM.

**Summary Comments:** The PI has proposed a well-reasoned research project and plan which has the potential to impact a variety of biomedical applications.

**Intellectual Merit Criterion**

Overall Assessment of Intellectual Merit: Very Good

Explanation to Applicant:

Although the proposal looks good, the tile and content may not be closely related. Research plan is to understand how molecular interactions to determine the properties of polyelectrolyte complexes, but it is not clear to show how to design the polymer for wound therapy applications. the proposal need to have more input of background introduction of wound therapy and polymer design principles for wound therapy application.

**Broader Impacts Criterion**

Overall Assessment of Broader Impacts: Excellent

Explanation to Applicant:

The research plan will assist researchers in understanding and developing ionic hydrogels with high complexity and functionality, which is important for materials science community.

**Summary Comments:** This is a well thought out project that can advance knowledge about electron microscopy methods. The candidate has a good research track record and can have significant potential in the research field.
National Defense Science and Engineering Graduate Fellowship (NDSEG)

Suggested Anatomy of a NDSEG Fellowship Application

Purpose of NDSEG: As a means of increasing the number of U.S. citizens and nationals trained in science and engineering disciplines of military importance, the Department of Defense (DoD) plans to award fellowships in April 2019, subject to the availability of funds. The National Defense Science and Engineering Graduate (NDSEG) Fellowship is highly competitive. Since its inception in 1989, NDSEG has awarded nearly 3,600 fellowships from over 58,000 applications to U.S. citizens and nationals who pursue a doctoral degree in one of fifteen supported disciplines at a U.S. institution of their choosing.

Format:

1. Personal Statement- Will be typed in a Form (500 words) No special formatting required - What are your short and long-term professional goals? How did these goals develop? How have you already begun to lay the foundation for these goals? How does this fellowship fit into these goals?

2. Research Proposal [New Format, 2018-2019 Cycle]: 3 Page, Single line space, 1 Page Max Cited Work, 12Pt. Times New Roman Font, Graphics and Charts may be included - a smaller font size may be used to label charts and graphics

Criteria: Proposed research relevant to the DoD. The research proposal should capture How well the proposal responds to one of the BAAs listed on the website under the DOD menu.

Academic Achievement. This is based on your academic transcript, Major GPA, and GREs/MCATs.

Reference Evaluation Forms. These forms should capture professional assessment of the applicant, a testimony to your scholarly excellence. References should be provided by an Advisor or Instructor.

Personal Statement. Describe your academic or other interest, and personal achievements.

Tips from Emily Hoffman (before research statement length increase): The structure of your essay will obviously change from person to person, but they will all have certain aspects.

- Very small background section/sentence
- Project statement
- Elaboration of project
- Implications for DoD
- How you will achieve the goals of your project
- Project wrap up
- Brief "Broader impact" (stolen from NSF, but they care about this too)
- Future plans
- Conclusion/ summary

Example NDSEG Award-Winning Applications

Example 1 NDSEG (Award Winner 2020): Only example with 3-page research statement

[Example 1]: Personal Statement
My goal for graduate school is to develop skills that prepare me to accomplish my long-term visions of i) improving performance and reducing costs of sustainable energy technology to reduce anthropogenic CO2 emissions and mitigate climate change, and ii) bridging the gap between the scientific community and lawmakers through effective communication.

I started thinking about energy challenges in middle school by imagining ways to harvest wasted energy in cities, e.g. capturing excess heat or harnessing unused light. During my first year at the University of Michigan, I became interested in materials science and its intersection with energy technology through coursework and student design teams. Furthermore, a wind energy class I took in Australia introduced me to economic and policy challenges that must be overcome to compete in the complex energy market. With a deepened interest in policy and the evolution of the energy landscape, I decided to minor in Energy Science and Policy. The ensuing economics and policy classes I took led to my goal of influencing energy policy in the future.

I discovered my love for research through my R&D internships at Axalta and 3M, which hooked me on the concept of expanding human knowledge and developing technology for the collective good of current and future generations. These internships led me to pursue a PhD at Northwestern to prepare for a career in research.

The adoption of sustainable energy technology relies on effective energy storage. Storing renewable energy in the form of H₂ allows intermittent sources to more reliably meet demand and compete with fossil fuels. In the Seitz Lab, I develop catalysts that improve efficiency of electrochemical H₂ production from water. In addition to storage for renewables, the ability to produce lightweight fuel directly from water allows for easy transportation and use in the most demanding conditions. Through my work in the Seitz Lab, I am gaining expertise in the fields of materials science, catalysis, and electrochemistry, all of which continue to be key drivers in the push toward sustainable energy.

To address my goal of advocating for inclusion of science in policy, I have involved myself with the Science Policy Outreach Taskforce at Northwestern. I plan to write one-pagers to inform politicians about science issues that have societal impacts and join the American Association for the Advancement of Science later in my career.

To achieve my long-term goal of reducing costs of sustainable energy technology, I plan to go into industrial research after graduate school. My educational experiences have made it clear that the limiting factor for widespread adoption of “green” technologies is cost. Industry research is the most direct way for me to reduce these costs.

Being awarded the NDSEG fellowship would allow me to continue researching better catalysts for H₂ production from water. Manpower for this project is currently funded by my advisor’s lab startup package but will need a secure funding source to continue. Supported by this fellowship, I can develop the skills necessary to meet my long-term goals.
Ir-based Perovskite Oxynitride Catalysts for Efficient Electrochemical Water Splitting

Research Goal: The rapid adoption of renewable energy technologies is crucial for reducing CO2 emissions and combating climate change, which the Department of Defense has identified as an issue of national security. Coupling wind and solar energy with electrochemical H2 production enables effective use and storage for these intermittent sources. To improve the efficiency of this process, we need improved catalysts for the Oxygen Evolution Reaction (OER), the more complex half-reaction for water splitting. I plan to test whether improved catalytic performance of Ir for electrochemical water splitting can be achieved through the stabilization of high oxidation states of Ir via incorporation into perovskite oxynitride materials.

Motivation: In efforts to improve the OER, iridium compounds have proven to be highly active catalysts. Though iridium’s scarcity presents an obstacle for widespread deployment, its compounds are useful for high performance applications. Moreover, understanding the fundamental causes for its exceptional activity will help lead to higher intrinsic activities for precious and non-precious catalysts. Expanding on this theme, Seitz et al. presented SrIrO3 as the most active OER catalyst to date.\[1\] During catalyst evaluation, an unknown motif of IrOx was formed on the surface. Theoretical studies predict that this motif stabilized higher than typical oxidation states of Ir, leading to the high observed activity.\[2\] If I can substitute N3- for O2- in SrIrO3 to experimentally access and prove the presence of higher Ir oxidation states (via charge balance) in this structure, I would be able to directly link changes in the Ir bonding environment and electronic structure to significant observed activity improvements.

Prior Work: Thus far, I have extensively synthesized and characterized various materials at Northwestern’s shared-user facilities. I have frequently used the pulsed laser deposition (PLD) facility, which allows for controlled film growth. Crystal Truncation Rod (CTR) measurements confirm that I can consistently deposit SrIrO3 films, a necessary precursor for my proposed research. (Figure 1).

I have also attempted to synthesize the oxynitride SrIrON2 by heating SrIrO3 powder to 850°C under flowing NH3 gas. The X-ray Photoemission Spectrum (XPS) reveals the absence of N in the material, though X-ray diffraction (XRD) suggests that a structural change occurred. X-ray Absorption Spectroscopy (XAS) measurements from beamtime at the Advanced Photon Source (APS) complement these results with information on the Ir bonding environment, which along with XPS identifies the formation of metallic Ir (Figure 1). This result suggests that stabilization of this oxynitride requires alternative methods. I have concurrently collaborated with theorists in the Wolverton group (part of the IRG) to predict the stability of my target perovskite oxynitride materials. I plan to continue this collaboration as I investigate more combinations of cations and anions in the SrIrO3 structure.

Figure 1: CTR measurements confirm correct phase of SrIrO3 (left), XPS of Ir4f (center) and Fourier transform of Ir L3 edge from XAS (right) confirm transformation to metallic Ir SrIrO3 powder.
Research Plan: Multiple groups have published theoretical formation energies of various oxynitride compounds, from which I identified tungsten as a promising additive for stabilizing a Sr-Ir oxynitride.\[3\] Synthesis of this material will resemble the method for SrIrO\textsubscript{3} films, using PLD and alternating between SrIrO\textsubscript{3} and SrWO\textsubscript{4} targets to form sandwiched layers of Sr-Ir and Sr-W oxides. The film will be annealed in air to create a uniform structure, and then heated under flowing NH\textsubscript{3} to substitute nitrogen into the material (see Figure 2). Composition and structure information will be taken via XPS and XRD, respectively, to determine if the oxynitride was successfully synthesized. In addition, XAS and XPS will allow us to track changes in the bonding environments and verify the stabilization of higher Ir oxidation states. Normalizing the catalytic activity (measured using cyclic voltammetry) to the iridium content will indicate if the modified structures have improved the intrinsic activity compared to other Ir-based materials.

Should nitrogen incorporation into the material prove challenging, I have identified alternate plans. For example, I can deposit films in the presence of pulsed NH\textsubscript{3}, another technique for synthesizing oxynitrides.\[4\] Other promising cation species (La, Sc) can be used in combination with Sr and Ir to help stabilize the structure. This research lays the groundwork for future studies in photoelectrochemical water splitting due to the optimal band positions of oxynitride materials. In addition, advanced reactor design would allow for in situ spectroscopy of the catalyst during electrochemical operation to determine structure changes as a function of environment.

I am well positioned to conduct this work in the Seitz Lab at Northwestern University. My advisor is an expert in electrocatalysis and spectroscopy; our lab has excellent tools to perform electrochemical measurements for catalytic activity assessments and in situ spectroscopic studies. My co-advisor, Professor Sossina Haile, is head of the Interdisciplinary Research Group (IRG) for “Functional Heteroanionic Materials via the Science of Synthesis” at the Northwestern University Materials Research Science and Engineering Center (MRSEC). This IRG consists of several faculty focused on computation, synthesis, characterization, and application of these novel materials. I intend to leverage this network of distinguished researchers to help achieve my research goals.

The proposed work directly relates to specific phrases from section II.A.1.a.i.(2) of the pertinent Broad Agency Announcement.\[5\] For example, the relation of Ir bonding environment to catalytic activity closely aligns with the focus toward “investigations into the effect of microenvironment on chemical reactivity.” Synthesizing a new material via addition of new cationic and anionic species improve probes “how material and morphology affect electron transfer and electrocatalysis” and is an effort to “to tailor electrocatalysts at a molecular level.” The use of in situ XAS also addresses “spectroscopic techniques that selectively probe electrode surfaces and electrode-electrolyte interfaces.” Thus, the proposed work falls well within the Army Research Office’s intended scope of research in the field of electrochemistry.

Further, production of H\textsubscript{2} fuel from water presents opportunities uniquely attractive to the Department of Defense. Firstly, the coupling of renewable sources of electricity with effective energy storage addresses intermittency issues, helping wind and solar to displace fossil fuel-based sources of electricity. These sources are primary sources of atmospheric CO\textsubscript{2} and contribute to climate change, an issue that the Department of Defense has repeatedly identified as a threat to national security. Secondly, decreased use of fossil fuels in the U.S. would help reduce dependence on foreign oil and positively contribute to the nation’s energy security. Thirdly, H\textsubscript{2} can be easily
generated, transported, and used in remote conditions, either in a fuel cell or by combustion. Unlike batteries which have a fixed mass even when depleted, H2 fuel has no mass once depleted.

**Notable Impacts:** Improved OER catalysts are essential for enabling the economic feasibility of H2 production from water. Natural gas reforming accounts for 95% of U.S. H2 production; this process is extremely CO2-intensive and dependent on fossil fuels, whose extraction is environmentally hazardous. H2 is also vital for producing agricultural fertilizers due to its importance in ammonia synthesis. Improving electrochemical water splitting technology provides a path for the agriculture and energy industries to help fight against global climate change.

In addition to reducing emissions, the discovery of new oxynitride compounds contributes to the growing field of heteroanionic materials research. Unlike mixed-cation compounds, mixed-anion compounds are relatively unexplored. Introduction of nitrogen and sulfur into oxide materials can stabilize these compounds and introduce beneficial optical properties.[6] Thus, the addition of N to SrIrO3, in combination with altered cationic composition, presents an opportunity to stabilize higher Ir oxidation states, improve intrinsic catalytic activity, and contribute to exciting possibilities for materials discovery. In addition to presenting at conferences, I also plan to share this work at the Joint Undertaking for an African Materials Institute (JUAMI) 2020 meeting in Nairobi, Kenya where I hope to guide hands-on lab activities.[7]

Thus, the stabilization of Ir-based oxynitride materials through altered cation composition will deepen our understanding of how atomic environment affects catalytic activity of water-splitting, contributing to developments in energy storage that help mitigate climate change while advancing efforts of the science and defense communities.

**References:**


Example 2 NDSEG (Award Winner 2016)

Coming from an immigrant family, my first exposure to science was a biography on Albert Einstein. It was a window into a world that I had never seen outside the dilapidated, converted garage I called home, one where science could both explain and shape the world. In college, I dived into research that addressed world issues, like solar cells or battery electrodes. Because of these experiences, I am pursuing a materials science PhD and hope to become a professor. My desire is to continue using research as a tool to better the world while inspiring disadvantaged groups to participate in science.

At Northwestern, I joined Prof. Mark Hersam’s group studying layered 2D materials. These materials offer exciting layer-dependent properties, and the Hersam group has helped create a rich library of 2D materials of differing electronic properties. These materials form the building blocks for novel electronic devices such as gate-tunable heterojunction p-n diodes or memristors and will usher in a new generation of bandgap-tunable devices for high-speed electronics and computer memory. These advances can improve high-frequency wireless and satellite communications, or enable smaller, faster, low-powered computers, areas of research that are of great interest to the DoD.

To obtain atomically thin 2D materials, researchers employ processing techniques such as chemical vapor deposition, micromechanical exfoliation, and solvent exfoliation. Out of these techniques, solvent exfoliation, combined with solution-based separation, provides a high-throughput method to isolate monodisperse 2D materials, critical for any commercial device fabrication. However, due to aggressive sonication conditions, the process results in low yields with small lateral flake sizes, limiting performance.

I propose two modifications to processing steps. The first is to employ alternative surfactants, such as water-soluble thiol compounds, to effectively separate the layers during sonication, resulting in higher monolayer yields. The second modification is to utilize exfoliation pretreatments such as shear mixing and ball milling to exfoliate material before sonication. Both steps would allow for reduced sonication conditions, increasing exfoliation yield and flake sizes.

The Hersam group is well-equipped to make significant progress due to their expertise in this field. Furthermore, Northwestern’s user facilities provides access to microscopy and spectroscopy equipment. I will leverage access to this wide suite of resources to improve solvent exfoliation, then integrate 2D materials into heterostructure devices.

My work in the Hersam group will improve my abilities as a researcher and scientist, preparing me to lead my own group. It will also empower me to train future scientists and engineers while creating opportunities for underrepresented groups in science. My hope is that I can inspire the next generation of scientists to pursue a rewarding career in science.
Example 3 NSDEG (Award Winner 2015)

Experiencing the value of engaged faculty, participating in community outreach, and partaking in undergraduate research have shaped my career goals toward pursuing a PhD in materials science and working toward a tenure track professor position at a research university. A career in academia will allow me to give back to the environment that is responsible for my continued interest in science and engineering. As a professor, I plan to provide research opportunities to both graduate and undergraduate students. From personal experience, the combination of course work and hands-on laboratory involvement during the undergraduate career impacts the decision to continue with formal education. In addition, I am overjoyed by the prospect of influencing and encouraging hundreds of students throughout their scientific careers and being able to discuss scientific advances daily.

Progressing toward my career goals, I started my PhD program at Northwestern University in September. I joined the research group led by Prof. Mark Hersam and will be working on heterojunction devices using 2D transition metal dichalcogenides with other low-dimensional semiconducting materials for electronics and optoelectronics.

The successful isolation of graphene in 2004 has led to the availability of other 2D crystals of varying structure and electronic type, enabling the fabrication of a variety of heterostructure devices such as tunneling transistors, memory devices, inverters, and sensors. While the realization of functional devices using atomically thin heterostructures is significant, current demonstrations do not yet present definitive advantages over existing silicon-based technology. Therefore, there is a need to determine unique device geometries that will take advantage of the novel properties resulting from the 2D nature of these structures. A pertinent example is the 2D p-n heterojunction diode, first fabricated using monolayer molybdenum disulfide and semiconducting single-walled carbon nanotubes in the Hersam Laboratory. Unlike bulk counterparts, a 2D p-n heterojunction diode exhibits gate-tunable rectification and a unique anti-ambipolar transfer behavior. Still, the partially lateral device geometry and large electrical contacts restrict high-speed operation due to parasitic elements. Therefore, further innovation is required to realize truly vertical p-n heterojunctions to overcome the aforementioned limitations. The novelty of these heterostructures will allow for a new generation of devices and circuits that will revolutionize high frequency wireless and satellite communication technology which is of high relevance to the DoD.

My time in the PhD program will provide the necessary foundation upon which I can continue to build my scientific career in electronics and optoelectronics, mold me into a more effective researcher and communicator, expand my network of potential collaborators, and provide me with an opportunity to increase my scientific understanding.
The National Graduate Education for Minorities (GEM) Fellowship

Julia Downing, 2021

About the GEM Fellowship

From the official website:

“GEM offers MS and Ph.D. level students an outstanding opportunity and access to dozens of the top Engineering and Science firms and Universities in the nation. The GEM Fellowship was designed to focus on promoting opportunities for individuals to enter industry at the graduate level in areas such as research and development, product development, and other high level technical careers. GEM also offers exposure to a number of opportunities to a number of opportunities in academia.”

Candidates are targeted for participation who are members of the following under-represented groups in science and engineering as defined by the United States Bureau of Labor Statistics:

- American Indian/Native
- African American/Black
- Hispanic American/Latino

Applicants must be a U.S. citizen or U.S. permanent resident at time of application.

The fellowship is administrated through Northwestern directly, as a GEM “member” institution, though the funding itself is comprised of contributions from NU, GEM, and the industry sponsor. New GEM employers are added every year; past employers for MSE fellows have have included MIT Lincoln Laboratories, 3M, Lam Research and more. Other employers include Apple, ComEd, ExxonMobil, and almost all of the DOE National Laboratories (Argonne, PNNL, Brookhaven, etc.)

At the “full” fellow level, GEM provides up to 5 years of support, including full tuition and stipend, thus making it one of the most lucrative graduate fellowships. If sponsored by a GEM employer, M.S. students are contractually obligated to complete two summer internships at the company, and Ph.D. students are contractually obligated to complete one summer internship (beginning the summer after sponsorship). This fellowship is also stackable and can be awarded along with with NSF, NDSEG, etc.

Preparing an application for the GEM Fellowship

The application has two parts. For early consideration, it is best to submit Part I (application form, which includes a one-page resume) by October 1st, 2021.

The second part of the application includes a Statement of Purpose (~800 words) with a high degree of flexibility in terms of content must submit at least a one-page statement of purpose that outlines your academic, research and/or career goals by 11:59 PM Eastern on November 15th. The application also includes a Supplemental Remarks section where the applicant can provide additional information about themselves, their background, and their future goals.

The largest companies tend to recruit fellows early, so it’s important to complete Part I as soon as possible to get on the list. Employers will contact you directly for an interview during the application cycle.
Example GEM Award-Winning Applications (Full Fellows)

Example 1 GEM (2021) – Ph.D., Applied as an undergraduate at NU

[Example 1] Statement of Purpose

The National Academy of Engineering keeps an ongoing list of 10 grand engineering challenges including 1. Affordable solar energy, 2. Energy from fusion, 3. Food, 4. Water, etc. Upon review, it seemed peculiar to me that energy acquisition was a more pressing challenge than necessities like food or water. However, I soon learned these challenges are interconnected, and the way engineers can have real impact on the lives of others is to find alternative energy and advance technology to store it. This pressing problem motivated me to join the Hersam group at Northwestern University where I work on improving nickel-rich cathode materials for lithium-ion batteries (LIBs) via two-dimensional nanomaterial coatings.

I have taken on the challenge of applying these coatings to nickel-rich cathodes which have proven to be the best candidate towards improving LIBs and realizing revolutionary technologies such as long-range electric vehicles and grid-level storage, due to their high specific capacities of 200 mAh/g. However, based on literature findings and my own studies, nickel-rich cathode chemistries are known to react with atmospheric moisture and CO2, producing lithium impurities that increase cell impedance, reduce the first cycle efficiency, and decrease high-rate performance. Therefore, the incumbent solution is to produce and store Ni-rich cathode materials in expensive dry rooms or inert environments, substantiating the need to find other methods to preserve Ni-rich cathode materials.

My current work focuses on studying humidity-exposed NCA with a graphene ethyl cellulose (GrEC) coating. So far I have proved a GrEC protected LiNi0.8Co0.15Al0.05O2 (NCA) electrode subjected to relative humidity for two months has superior capacity retention, cycling stability, a lower surface impedance, and less Li2CO3 impurity present on the cathode surface than uncoated NCA, a promising result. Through this process, I not only learned experimental techniques, but built a background by which to hypothesize the kinds atom level kinetic processes producing the data I see. For my senior year, I am focusing on tuning the GrEC coating hydrophobicity to achieve the best ambient protection and performance. Additionally, I am using varied techniques to document the effect of humidity. Specifically, I use X-ray photoelectron spectroscopy, Raman spectroscopy, titration, and Fourier-transform infrared spectroscopy to elucidate the presence and intensity of organic and inorganic impurity species formed due to reaction with ambient conditions. I also use Time of flight-secondary ion mass spectrometry is used to assess the lateral and depth distribution of impurity species at or near the NCA surface. I plan to foster collaborations with the Northwestern University Atomic and Nanoscale Characterization Center (NUANCE) to help elucidate surface reconstruction layers due to high nickel reactivity.

This research will significantly improve the performance of nickel-rich cathodes exposed to ambient conditions, minimizing the need for expensive dry rooms during cathode production and storage. I strive to create a strategy that can be easily modulated to protect and improve the performance of any cathode material.

Ultimately, I hope to use my research experience in industry. To prepare myself to do so, I interned remotely this past summer at AbbVie, working on building chemical process simulation models to produce a pipeline active pharmaceutical ingredient (API). My models optimized manufacturing by maximizing throughput, lowering production cost, and decreasing equipment downtime through various debottlenecking processes. In addition to my project, I held 25+ informational interviews with AbbVie colleagues and learned how intricate it is
to bring any product to market. It requires the proven technology, but also scientists investigating human factors, regulatory, packaging, quality assurance, and cross functional collaboration on each front. I also gained presentation experience through communicating my computational project and its results to many groups, including a diverse steering committee, engineers in my area, and all scientists working on the same API as myself.

My fascination and appreciation of battery science has only grown with each opportunity that I have to understand it, including in fundamental graduate physics classes I have taken such as quantum mechanics and solid-state physics. I hope to continue this growth in Professor Lynden Archer’s lab at Cornell working on the challenges inhibiting metallic anodes as safe, high energy, cost effective alternatives to graphite. LIB research is unique because academia and industry are solving the same problems from different backgrounds. This makes my material science perspective powerful in companies working on the next generation electrode material, solid state battery, or scale up process, which I strive to join. My various academic and research experiences across startups and industry have helped me gain a holistic understanding of how to envision, build, and execute multiple projects from the ground up, and how research is motivated and completed in industry. Support from a GEM fellowship would afford me the opportunity to conduct exploratory and novel research, foster interdisciplinary collaborations, and pursue my goal of creating energy storage to tackle the world’s grand engineering challenges.

Example 2 GEM (2020) – Ph.D., Applied as an undergraduate at another institution

[Example 2] Statement of Purpose

Confucius said, “When you find a job you love, you don’t have to work a single day in life.” This is how I feel about research. I have spent long hours in the lab during the summer and winter breaks instead of going on vacation and have squeezed out every single minute I can find for research during the semesters. It is because of the delight I get from learning materials science, chemistry, and research techniques and the invigorating projects that I have the opportunity to work on with others that I have the energy to do it all.

Within the Wang Lab, I am responsible for two independent projects: (1) developing a direct-ink write (DIW) extruder to expand the material choices of 3D printing and (2) building a two-wavelength digital light processing (DLP) 3D-printer, which will not be discussed due to space constraints. The first project was initiated as part of our effort to broaden the educational impact of our research on organic electronic materials. Even though most high schools and universities now have 3D printers (mostly fused deposition modeling (FDM) printers), the material profile is very limited as it is based on melt/solidification process. In order for students to experience working with non-conventional materials such as conducting polymers, polydimethylsiloxane (silicone) or even Nutella that can greatly expand their hands-on scientific learning, a DIW extruder needs to be added to the FDM printer. However, each DIW extruder can cost >$1,000, not always budget-friendly for schools. I proposed to Prof. Wang that I can use a 3D printer to 3D print components for an auger-based DIW extruder, and couple them with some low-cost commercial parts to build our own for ~$300. She enthusiastically encouraged me to pursue this project.
The extruder is currently in the final stages of its development, after overcoming challenges in the redesign of countless components, mathematical descriptions of the extruder’s function and design, optimization of printing parameters, and troubleshooting of printing consistency. This project has elevated my critical thinking skills and run me through the gamut of research challenges, of which the exposure will be invaluable during my graduate research. Above all the technical skills I have learned from this project, the most valuable lesson has been the importance of tenacity. It has been my continued persistence that has progressed the project to this extent and it will be this effort that will drive the project to completion. We plan to publish all the details on J. Chem. Ed. so that anyone with an FDM printer can build their own DIW printer.

I present my research progress for both projects at group and subgroup meetings alongside graduate students on a regular basis. Additionally, I aid the rest of the Wang Lab with any hardware problems. I have machined custom thin-film molds, developed fixtures for 3D-printing apparatuses, created an oscillatory thin-film elongation instrument, rendered 3D illustrations of conceptual material science phenomena, and run chemical syntheses of silica sol-gels.

Over the summer of 2019 I participated in the summer undergraduate research experience (SURE) program at UW-Madison, working on a collaboration between Prof. Roderick Lakes and Prof. Jacob Notbohm. My independent project explored the relationship between synthetic fibrous networks and the reduction in stress around a punched hole that occurs due to the rotation of individual fibers, known as micropolar elasticity. I prepared samples with a speckle pattern for tracking with digital image correlation (DIC), pulled the samples with tensile-testing equipment, utilized DIC software in Matlab, and developed scripts to quantify strains in certain regions. Taking this project from the conceptual stage all the way to the final steps of the experimental stage gave me a more comprehensive view of research. Additionally, I am now applying these DIC techniques for research projects back in the Wang Lab.

[Example 2] Supplemental Remarks

As I move forward in my career, I will continue to develop my research, critical thinking and communication skills while continuing my involvement in science outreach and education. I hope to join Professor Hayden Taylor’s nanomanufacturing design group at UC Berkeley, where I can use my research experience in additive manufacturing and machine building with my formal training in materials science and engineering to develop novel additive manufacturing technologies that reduce the environmental impact of manufacturing. After earning my Ph.D. in materials science, I would like to work at a national laboratory or in industry. I would enjoy highly collaborative and fundamental research of national labs, but the commercial and fast-paced environment of industry is similarly enticing. Both workplaces utilize fundamental knowledge to solve practical problems, in alignment with my career aspirations. I also intend to get involved with summer internship programs and local outreach centers to continue my effort of raising awareness of MSE and mentor students to instill enthusiasm for research in the next generation of youngsters.
Growing up, I dreamed about not only engineering the futuristic devices I saw and read about in my sci-fi novels and TV shows, but also exciting the public with my scientific discoveries. Years later in pursuit of this goal, I enrolled in a PhD program in materials science and engineering at Northwestern University. After completing multiple undergraduate projects spanning topics from device nanofabrication to additive manufacturing and formulation of nanomaterial inks for roll-to-roll printing substrates, I wanted to pursue an interdisciplinary thesis that combined these research areas. I was drawn to Northwestern for its strong legacy in materials science and engineering, its interdisciplinary research centers, and its impressive suite of instrumentation to enable cutting-edge research. I eventually joined Prof. Mark Hersam’s research group, which has close relationships with industrial partners (Millipore Sigma, Exelon, Tesla) and commercial startups (Nanointegris, Volexion). For my doctoral research, I am focusing on scalable manufacturing of electronic nanomaterials for novel devices.

In the Hersam laboratory, I learned that the growing field of two-dimensional (2D) nanomaterials has led to increasing demand for the production and integration of graphene, molybdenum disulfide (MoS2), and hexagonal boron nitride (h-BN) into electronic and optical devices. Our lab had previously demonstrated gram-scale production of the aforementioned 2D nanomaterials via liquid phase exfoliation utilizing the stabilizing polymer ethyl cellulose (EC). However, a grand challenge in the field of nanotechnology involves transitioning from lab-scale production to industrial-scale production of 2D materials. Due to size-dependent properties at the nanoscale, this high-volume production must be achieved in a manner that results in monodisperse flake size that is preserved throughout downstream additive manufacturing processes (e.g., screen printing, gravure printing and blade coating).

To fully realize scalable production of graphene/EC powder, I automated a pilot-plant scale shear mixing process to improve graphene ink production output by nearly an order of magnitude. I also formed a collaboration with the General Electric Co. to investigate cross-flow filtration (CFF) as an effective, innovative method for graphene/EC sorting that bypasses the limitations of centrifugation in nanomaterials processing. CFF as integrated with pilot plant-scale shear mixing in the Hersam Laboratory will lead to a fully continuous, scalable and liquid-based scheme for producing and sorting 2D nanomaterials with clear scalability advantages compared to incumbent approaches. My research adapts methods common to chemical and biological engineering to create a new paradigm of nanomaterial exfoliation and processing with the potential to become a staple processing tool for 2D material researchers and manufacturers alike. Furthermore, this project seeks to promote an unprecedented shift from batch processing to continuous production of 2D nanomaterials, a highly impactful contribution to the field of nanotechnology. If these scalable manufacturing methods are adopted by major chemical companies, the production of tons/yr. of conductive graphene inks will enable novel technologies such as electrodes for lithium ion batteries, photodetectors, and energy storage devices at low cost. There is also significant commercial interest in the success of the proposed work; once completed, the proposed system and associated findings will be patented and may contribute to a start-up.

In my first year in the Hersam Laboratory, I have built a broad portfolio of skills and experimental techniques that enable me to pursue cutting-edge projects at the intersection of materials science, chemical engineering, electrical engineering and automation, and biological engineering. My work has given me exposure to techniques for 2D nanomaterial production (shear mixing, sonication), additive manufacturing (inkjet printing,
aerosol jet printing, blade coating), processing (centrifugation, vacuum filtration and thermal annealing), physicochemical characterization (scanning electron microscopy, atomic force microscopy, X-ray photoelectron spectroscopy, Raman spectroscopy, thermogravimetric analysis and rheometry), and electrical characterization (four-point probe, ambient IV measurements). I have also made progress towards my dissertation, contributing to a completed manuscript for peer review (topic: functional properties of boron nitride inks) and a first-author publication that is currently in preparation (topic: cross-flow filtration as a continuous, scalable sorting methodology for 2D nanomaterials).

My primary career goal is to lead a team in materials research and development at a multinational company or at my own startup at the intersection of nanotechnology and novel manufacturing technologies. I am building strong industry partnerships as part of my graduate training (i.e. manufacturing conductive ink products for Millipore Sigma and conducting proof-of-concept nanomaterial sorting studies with General Electric) but I want to build my industrial experience further in the form of a summer internship. Finally, by expanding my network to include leaders in industry and other young professionals engaged in multidisciplinary research, I hope to leverage my connections to forge exciting new research partnerships.

[Example 3] Supplemental Remarks

As an ethnically mixed, Latino woman in STEM, I felt intimidated throughout my academic career when I did not see many engineers who looked like me in the classroom. I was born in the United States to a mother who fled the communist regime in Cuba with her family seeking political asylum. At the Cuban Refugee Center in Miami, FL they were redirected to begin a new life in Washington Heights, New York City, NY. My mom, her three brothers, parents and grandparents cohabitated between two tiny apartments while my grandfather worked as a janitor and my grandmother taught kindergarteners in New York’s public school system. Though my grandfather only has a seventh-grade education, he labored until all four of his children got a college degree despite their limited income. My family’s experiences have taught me that education is one of our most precious, hard-won rights. I went on to attend the University of Maryland on a full academic scholarship, and now I am proud and determined to earn a PhD – the first in our family to do so - in honor of their efforts.

Meanwhile, my family’s refugee story is still unfolding. Just recently, my cousin Juan Carlos and his wife Maribel were finally reunited in Florida after years apart while trying to emigrate from Cuba. JC was a computer programmer for Castro’s government and Mari was a physician; they were frequently forced to travel to South America for their jobs. JC defected on an assignment to Chile and made his way to the US, but it was years before Mari could follow. Now, they are living in Boca Raton, FL with two beautiful American-born children. JC and Mari’s story constantly reminds me that there are countless people from underrepresented or oppressed populations taking enormous risks every day for their children to have the opportunities that I have had. As a result, I am humbled, grateful, and determined to bring up underrepresented youth along with me on my journey as a researcher.

To this end, I am dedicating my efforts outside of the lab to connect with youth who are just as talented or more talented than I am but were not afforded the same opportunities due to their country of origin, race, sex, or financial situation. During my first year at Northwestern, I participated in Letters to a Pre-Scientist (LPS), a mentorship program that pairs career scientists with K-12 students in disadvantaged areas who are interested in becoming scientists themselves. Similarly, I volunteer biweekly for the Junior Science Club (JSC) at Pedersen-
McCormick Boys and Girls Club in Chicago with elementary school students from underrepresented groups. I also planned and taught a course for Splash, a weekend-long symposium for local high schoolers, focused on a manned mission to Mars. Finally, I took a leading role in a student organization when I joined the board of officers of the newly-assembled Graduate Society of Women Engineers (GradSWE) at Northwestern. I have planned campus-wide events with 100+ attendees, coordinated mentorship programs and organized a group trip to a play about the challenges of women of color in STEM fields.

Next year, I plan to expand GradSWE’s initiatives as Vice President to include activities with local K-12 students, specifically young girls from minority groups. My hope is that by recruiting more underrepresented youth to pursue a STEM education, I am paying forward the support and the opportunities that my family and my country gave me.

Example 4 GEM (2014) – Ph.D., applied as a 2nd year graduate student at NU

[Example 4] Statement of Purpose

Given my previous research experience, I chose to attend Northwestern University because of the rigor of its academic program and the chance to work with my current advisor, Prof. Manijeh Razeghi, a pioneer in the development of III-V compound semiconductors and optoelectronic devices. As a member of her graduate research group at the Center for Quantum Devices (CQD), I now have access to the outstanding facilities and knowledge that has placed this group at the forefront in the field of wide-bandgap III- Nitrides. The CQD places a strong emphasis on a full understanding of device development, all the way from material growth to full systems. Therefore, during my graduate research I will focus on device modeling, material growth, material characterization, processing, fabrication and device characterization of AlGa(In)N optoelectronics. My specific goal is to use the AlGa(In)N material system to develop high-efficiency ultraviolet (UV) light-emitting diodes (LEDs), UV laser diodes and UV focal plane arrays (FPAs).

In order to achieve these goals, we will implement novel approaches to growth and fabrication. To accomplish the UV laser diode, we will first develop high efficiency UV LEDs by reducing the dislocation density and increasing the doping using new growth techniques and improving on existing ones such as lateral epitaxial growth, pulsed atomic layer epitaxy, and reduced area epitaxy. These LEDs will serve as a basis for our laser diodes, which will be created by adding waveguides and an etalon. To accomplish high performance solar blind FPAs we will augment the ROIC by implementing new processing techniques that add visible light rejection, and we will reduce layer cracking and non-uniformity by implementing inter-layers, strain- compensating super lattices, and selective area epitaxy. Commercial applications can greatly benefit from these solid-state UV emitters and detectors. For example, UV emitters can be used for portable food/water/air purification or for improving existing LED lighting. UV laser diodes would allow for higher density optical data storage and higher resolution laser printing. UV FPAs are ideal for fault monitoring power lines, flame detection, and astronomy imaging. Additionally, there are a number of military applications. UV FPAs can be used for portable early missile threat warning systems.

Combinations of emitters and detectors would provide systems for rapid detection of biological agents. Therefore, through my graduate research I will help develop new technologies valuable to both government and industry.
In the short time that I have worked at CQD, I have already gained significant technical experience in III-Nitride material growth (MOCVD), material characterization (SEM, AFM, XRD, PL, Hall) and analysis, processing (photolithography, laser bar etching, contact metallization, thermal annealing, flip-chip bonding and wire bonding), and device characterization (IV, CV, Output power, EL). I have also made substantial progress towards my dissertation, resulting in one peer-reviewed publication (topic: high-performance UV FPAs), and a first-author publication that’s in preparation (topic: epitaxial growth optimization of device templates for high power LEDs and other optoelectronic devices).

Due to the CQD’s strong ties with industry, the DoD and the DoE, the group focuses on creating practical devices with clear commercial applications. Because of this, in addition to pursuing research, I will take advantage of the CQD’s industry and government partnerships to establish my own connections. I plan to do this through collaboration and research internships at national laboratories and/or industry in order to carry out meaningful research both during and after my graduate studies. An industry partnership through the GEM Fellowship program would be ideal in achieving these goals.

Due to my group research experiences, technical ability, and effective communication skills, I plan to pursue a career as a research scientist within industry or the government. With the financial support of the GEM fellowship, I will be able to continue the graduate studies and experimental research that are necessary to further hone my skills and prepare me for a future career in R&D. More importantly, thanks to the industry partnership and summer internship, I will use my technical talent to contribute to my employer by demonstrating my ability to succeed in a professional environment.

Thus, the GEM fellowship program would not only be an ideal way to launch my professional career, but it would also connect me with the right network of science professionals that I will need for future career development.

[Example 4] Supplemental Remarks
Beyond building my professional career, I continuously strive to help others by sharing the lessons I have learned, both in and out of the classroom. I was born in Cali, Colombia, but at age ten my family was forced to flee our homeland and move to the United States seeking political asylum. The terrorist group known as the FARC directly targeted my family because my father worked as a photographer for the government.

During my early years I endured many difficulties while trying to succeed in my education, such learning a completely new language, adapting to a foreign culture, working janitorial jobs after school to help support my family, and in general facing the societal pressure that came with trying to succeed as a low-income minority when others expected me to fail. Nonetheless, through hard work and the support of my parents, I earned a full-ride scholarship to MIT and became the first generation of my family to go college.

While the financial and cultural stresses I endured presented a continuous challenge, I am very thankful for the insight they provided me. In turn, I have provided support to many underprivileged minorities who were struggling with financial, academic, or social pressures. While at MIT, for example, I had the privilege of mentoring Suan Tuang through the Questbridge program. Although he was born in Myanmar, our paths were very similar. His family escaped persecution and had fled to America for political asylum. While going to high school in Florida, he excelled and was admitted to MIT. During his freshman year, he experienced similar
challenges to those that I faced, and I was thankful to be there to support him. Suan’s time at MIT was marked by continued success, and he is now part of the MD/PhD program at Harvard Medical School. Helping Suan realize his potential despite the challenges presented by his underprivileged background was an inspiring experience, and drove me to pursue additional outreach opportunities.

Unfortunately, Suan’s story of success is an exception. Because of our lack of resources and mentoring as high school students, both Suan and I realized that many of the circumstances that led to our success were in part luck. We also realized that other underprivileged students might not be as lucky. During my time as a graduate student, I have witnessed first-hand the lack of diversity in the academic STEM population that results from this achievement gap. In order to address this issue, I have continued my educational outreach at Northwestern through a number of different organizations. In the Illuminate program, for example, I serve as a mentor by providing individualized assistance with college admissions; as a curriculum development officer, I help develop the materials and strategy necessary to best assist mentees in the program; and as a teacher I provide bi-weekly ACT prep classes. Besides Illuminate, I am currently a member of the Northwestern chapter of the Questbridge scholars network, a member of the Research Engagement, Awareness and Conversations program, a group leader for the Kits’n’Cats program, and the educational outreach officer for the Northwestern chapter of SPIE. These programs seek to reach out to high school students through lectures, campus tours, and STEM workshops. While I may have different roles in these programs, my goal is the same: to inspire underprivileged students to pursue a higher education in STEM by helping them realize their potential and available opportunities.

In order to bridge the achievement gap, I will use my experiences to further the goals of the Minorities in Energy Initiative by developing new educational outreach programs and supporting existing ones, such as the HMTech summer program led by the Sandia National Laboratory's Black Leadership Committee. As a grateful refugee, I pursue these goals with the hope that I can repay America for the shelter, care and countless opportunities it has provided my family.