Research Statement

Introduction and Vision

My research vision is to engage students in creating clean energy solutions by linking fundamental science to practical implementation. I propose a research program that moves fluidly from computational simulations at the atomic scale to real-world energy applications in the field. This approach not only addresses pressing scientific and environmental challenges, but also provides rich educational experiences for students. By participating in every step – from theoretical modeling to hands-on deployment – students will learn how scientific innovation can drive sustainable progress. My expertise in density functional theory (DFT) and related computational methods, combined with my experience in experimental techniques like Raman spectroscopy and device fabrication, uniquely enables this full-spectrum approach. All projects will be designed to align with Deep Springs College's mission of self-sufficiency and service: the ultimate goal is to contribute to a net-zero clean energy future, which is especially relevant given Deep Springs' remote desert environment and self-sustaining infrastructure. Below, I outline four interconnected research thrusts (a–d) that illustrate this vision, each involving students at every stage:

a. Atomistic Simulations for Advanced Energy Materials

The first pillar of my research involves atomistic simulations of materials to discover and optimize properties critical for energy applications. Using *first-principles calculations* (DFT and beyond), I will investigate materials' electronic, optical, and mechanical properties in search of candidates for next-generation solar cells, thermoelectrics, and other clean energy devices. For example, I plan to computationally evaluate semiconductors and nanomaterials for key parameters such as band gaps, electrical conductivity, and elastic constants under various conditions. These properties determine how a material might perform in a solar photovoltaic cell or as a thermoelectric generator. Students will be deeply involved in these simulations: I will train undergraduates to use computational tools like Quantum ESPRESSO or VASP (for DFT) and the GW-BSE approach (for excited-state calculations) on accessible high-performance computers. Through these projects, students will learn to analyze theoretical results (such as interpreting a density of states or a band structure) and connect them to practical material performance. The educational payoff is significant – students gain skills in computational physics and an atomic-level understanding of how material properties impact macroscopic energy systems. Moreover, their simulation results can feed directly into experimental plans (for instance, identifying a promising new solar absorber material for further testing).

b. Photovoltaic System Optimization in Desert Environments

The second thrust moves from the atomic scale to the level of solar energy systems, focusing on photovoltaic (PV) optimization in real-world conditions. Deep Springs College, situated in an isolated sunny valley, is an ideal living laboratory for solar energy research. (In fact, the college already operates its own solar array as a renewable energy source.) My plan is to involve students in maximizing the efficiency and output of solar panels, particularly under desert conditions. This includes projects on optimizing the tilt angle of panels throughout the year, mitigating losses from soiling (dust accumulation), and determining effective cleaning cycles and technologies. Students could, for example, design experiments to measure how different tilt adjustments seasonally affect energy generation, or study how quickly dust buildup reduces panel efficiency on the college's array. We will use a combination of simulation and empirical data collection: tools like PVsyst (photovoltaic simulation software) or Python models can predict optimal tilt and cleaning schedules, which we will then compare against on-site measurements. I have a strong background in solar energy research – at UC Merced I studied solar cell performance theoretically, and in Nepal I worked on solar thermal energy storage and even installed one of the first solar simulators in the country. I also mentored a project in Nepal where high school students analyzed solar panel tilt optimization, reflecting my commitment to student-led inquiry in this area. At Deep Springs, students engaged in PV optimization research will not only learn about solar physics and engineering, but will also contribute tangible improvements to the college's energy system. The outcome of this work could be a set of best practices for maintaining off-grid solar installations in dusty, arid environments – knowledge beneficial to many rural communities and consistent with Deep Springs' ethos of practical self-reliance.

c. Building Energy Efficiency and Simulation-Based Audits

The third research area expands into building energy efficiency, bridging computational modeling with campus sustainability. Even in a small community like Deep Springs, optimizing energy usage in buildings (dormitories, classrooms, dining hall, etc.) can significantly reduce environmental footprint and serve as a blueprint for efficient living. I propose to conduct simulation-based energy audits of campus facilities, involving students in both the virtual modeling and real-world data gathering. Using building energy simulation software (such as EnergyPlus or similar tools), we will model the thermal and electrical behavior of structures on campus. We will evaluate strategies like improved insulation, smart thermostats, or efficient lighting and HVAC upgrades, quantifying their impact on energy consumption. Projects could include optimizing load scheduling (for example, running power-intensive equipment at times that align with peak solar generation), or simulating the effect of different equipment upgrades on the college's overall energy use. Students will take the lead in these investigations: one team might collect data on how often generators run or how temperatures fluctuate in a dorm, while another team creates a computer model to test energy-saving interventions. Through this, students learn valuable skills in data analysis, coding, and systems engineering, all within a liberal arts context that demands clear communication of technical results. They also witness firsthand how theory translates into practical policy – if our simulations identify a measure that could save energy or costs, the students could help propose its implementation to college decision-makers. This participatory research not only educates students about sustainable technology, but also empowers them to improve their own living environment, embodying the Deep Springs principle of self-governance in a very concrete way.

d. Field Deployment of Clean Energy Technologies

The capstone of my research agenda is the field deployment of clean energy solutions, which brings together insights from the previous areas and gives students hands-on engineering experience. In this thrust, we will work on designing, prototyping, and testing small-scale clean energy technologies appropriate for Deep Springs' context. Potential projects include: building a solar water heater or solar-powered irrigation pump for the ranch, experimenting with energy storage solutions (like a battery bank or even a thermal storage using phase-change materials for the farm), or creating a simple weatherization retrofit for old buildings to improve efficiency. Another exciting avenue is exploring magneto-thermoelectric devices (an area I have worked on during my postdoc) for power generation from temperature gradients on the farm – though high-tech, this could involve students in assembling and measuring a device that converts waste heat to electricity. I have extensive fabrication and lab experience (from cleanroom micro-fabrication of sensors to assembling solar gadgets in Nepal) that I will share with students as we build these projects. Crucially, each project will be approached as a *research and learning experience*: students will formulate the problem (e.g., "How can we reduce diesel generator use at the farm by storing solar energy at night?"), brainstorm and design a solution, then construct and test it in the field. We will measure outcomes – for instance, does the solar water heater provide enough hot water, or how much fuel does a battery system save? This iterative, hands-on process teaches students engineering design principles, teamwork, and the resilience needed in real-world problem solving. It also reinforces the mission of service: solutions we develop at Deep Springs could be models for other off-grid or sustainable communities. By working on practical implementations side by side with theoretical studies, students gain a 360-degree view of scientific innovation. They learn that making a difference requires both understanding fundamental science and mastering the art of applying that science to improve lives.

e. Agrovoltaics Research at Deep Springs College

My agrovoltaics research will focus on integrating photovoltaic (PV) solar energy systems with the existing cattle-and-alfalfa ranch at Deep Springs College, capitalizing on the college's unique geographic and climatic conditions. Students will lead hands-on projects to systematically study how different configurations of solar panel arrays influence agricultural productivity, including impacts on alfalfa crop yields, plant health, soil moisture retention, and livestock behavior. Specifically, students will design controlled field trials comparing shaded and unshaded plots, install environmental sensor networks (soil moisture sensors, temperature loggers, spectral irradiance meters), and conduct seasonal analyses of plant growth and forage nutritive values. They will also evaluate various panel designs—such as varying height, spacing, tilt angles, and use of bifacial modules—to optimize sunlight utilization for both electricity generation and agriculture. Additionally, the research will include exploring sustainable weed management strategies using sheep or cattle grazing under the PV arrays, potentially reducing maintenance costs and improving overall ecosystem health. The anticipated outcomes from these projects will include comprehensive datasets on microclimatic conditions beneath PV installations, quantitative assessments of the optimal agrovoltaic layouts for desert agriculture, and guidelines for integrating PV infrastructure within active ranching environments. Students will gain valuable skills in experimental design, data collection, computational modeling, and systems-level optimization. Results will not only contribute original, publishable knowledge to the growing field of agrovoltaics but also offer practical, evidence-based recommendations for Deep Springs and similar rural communities aiming to enhance land productivity sustainably. Ultimately, the project aims to establish Deep Springs College as a leading example of dual-use agricultural and renewable energy innovation, equipping students with interdisciplinary expertise to contribute effectively toward global sustainability and net-zero emission goals.

Student Engagement and Broader Impact

In all the above projects (a–e), student involvement is the linchpin. I plan to involve students in every phase, from literature review and experimental design to execution and analysis. This apprenticeship model aligns with the college's intimate academic setting, where faculty and students collaborate closely. The research activities will often double as educational modules: a student might receive academic credit for an independent study on DFT simulations, or a group of students might turn the solar panel cleaning schedule study into a class project. The outcome I seek is twofold: new scientific insights and technologies for sustainable energy, and more importantly, the development of young scientists and leaders. Students who engage in this research will emerge with concrete skills (like programming, experimental techniques, data analysis) and a deeper motivation to pursue science in service of society. Furthermore, our focus on clean energy positions Deep Springs as a microcosm for global challenges. By striving for energy self-sufficiency and innovation at Deep Springs, we contribute to broader efforts to achieve net-zero emissions and combat climate change. This work can elevate Deep Springs College's profile as not only an educational pioneer but also a contributor to sustainability research. I foresee sharing our findings through student-coauthored publications and presentations – for instance, a student team could present the results of the solar optimization study at an undergraduate research conference or even publish in a sustainability journal. Such accomplishments would be incredibly empowering for students and demonstrate the value of Deep Springs' educational model.

Conclusion

In summary, my research program aspires to blend academic rigor with meaningful real-world impact, mirroring Deep Springs College's own integration of scholarship, labor, and service. By guiding students through computational material discovery, solar energy optimization, energy-efficient systems, and field-based innovation, I will leverage my background to foster a culture of inquiry and purpose. We will tackle the practical energy needs of our immediate community while training students to solve problems that extend far beyond our valley. I am thrilled by the opportunity to undertake this work at Deep Springs – a place where the frontier spirit and commitment to self-sustenance provide an ideal backdrop for clean energy research. Together with Deep Springs students, I aim to build not only devices and models, but also build up the next generation of scientists prepared to lead and serve in creating a sustainable future.