ME 432 Fundamentals of Modern Photovoltaics
Fall 2023 – Class Project Description

Class project: The class project is required for students who are enrolled in the 4-credit option only (usually graduate students). You should plan to work in teams of two, so please identify a partner but if you prefer to work alone please send a note to instructors on Campuswire. This year, I will give you a choice in the topic for the final class project. A list of possible topic ideas is given below, or you are welcome to design your own as long as you obtain instructor approval for your idea. Hint: make this relevant and helpful for your research! It is not ok to have the class project be something that you'd be doing for your research anyway (i.e., it should be something extra), but it's to your benefit to have it enhance/improve your research

Project Checkpoints:

- *A short proposal (paragraph) will be due Sept 29, so you should start thinking about your project soon. Include in the paragraph a description of (i) a specific question that you want to answer, (ii) why you think this question is important, and (iii) a strategy that you will apply to answer this question.*

- *During the week of Oct 30 – Nov 3, we will schedule 10 minute progress update meetings with each group. Please come prepared to your progress update meeting with slides showing where you are in your work, remaining steps to complete the work, and any questions that you have.*

- *Final Deliverables. The deliverables are (i) a 10 page report, and (ii) a 10 minute presentation during the scheduled final exam period. Be prepared to defend your conclusions to your audience – your classmates and perhaps some guests with expertise in PV. You will be assessed on your critical thinking, critical analysis, and use of sound and evidence-based reasoning.*

To accommodate the different backgrounds in the class, the project topics tend to fall into three categories. On your abstract and in your paper, please state which one you are doing.

(1) ***design projects*** *– design a system, scheme.*
(2) ***reports/analysis*** *– you've been commissioned by the UN to carry out an assessment, of say, the potential for nanoscale PV to help meets the electricity needs of the developing world. But wait …. Nanoscale PV cell efficiencies are around 2% on a good day. What is your assessment of this prospect? What would have to happen to make it work?*
(3) ***research proposal*** *– identify a current limitation to wide scale adoption of PV technology. It could be broad (PV manufacturing is too expensive), or focused (all-carbon photovoltaics). Do some background surveys and learn the state of the art. Suggest a research hypothesis to address the limitation, and describe how you would prove/disprove your hypothesis.*

(1) Design: Net Zero Mechanical Engineering Building

key question: Can the newly expanded Mechanical Engineering Building be a net-zero energy building?

The Sidney Lu Mechanical Engineering Building at the University of Illinois has recently undergone some renovations and an expansion. Your goal is to make this building "net-zero", meaning that over the course of one year it produces as much energy as it uses. The road to net-zero is long and winding, as prior to the renovation MEB was in the 90th percentile of all buildings for energy efficiency. Your mission: develop a roadmap that shows how (if) the newly-expanded MEB can make it to net-zero. If not, how close can we get?

As part of this work, your job will be to track down utility bills and relevant data to look at historical energy consumption for the building (). I can suggest faculty and staff to talk with to learn about green energy innovations introduced during the renovation. Your goal is to see how close we currently are to net-zero with the recent changes, and if we can get there by making additional improvements to the energy efficiency of the building (you will want to include estimates of potential energy savings via the incorporation of high efficiency heating/cooling systems, chilled water, etc.). By implementing the latest technologies, how much will can we cut our steam consumption? How much can we improve our heating/cooling/ventilation system? Finally, make an estimate of how much roof space is available for a solar installation, and assess how much of the electricity demands for the building a solar installation can provide. What is the best technology for the PV array?

(2) Analysis - Critical Minerals

Critical minerals, also known as critical raw materials, refer to a group of minerals and elements that are considered essential for modern technologies and industries, including electronics and renewable energy, amongst others. These minerals are characterized by their strategic importance and the potential risks associated with their supply chain disruptions. In this project, you will synthesize and evaluate various research articles, reports, and studies to identify key trends, knowledge gaps, and emerging issues in the critical minerals domain. Focus your work on understanding which minerals/materials are needed by different (emerging or established) renewable energy approaches. Some possible questions are:

- What are critical minerals, and why are they considered essential for renewable energy technology?
- What are the primary sources and extraction methods for critical minerals, and what are the associated environmental and social impacts?
- What innovative technologies and alternatives are being developed to reduce reliance on critical minerals in various industries?
- How can sustainable mining practices and recycling efforts be promoted to mitigate the environmental impact of critical mineral extraction?
- How do regulatory frameworks and international agreements impact the management and trade of critical minerals?

- What are the emerging research trends and future prospects in the field of critical minerals, particularly in terms of sustainable resource development and technological advancements?
- What case studies or examples from different regions or industries illustrate the challenges and opportunities associated with critical minerals?

(3) Decarbonization in the developing world.

There are several parts of the planet where access to energy is currently limited, and by default much of the population uses much less energy than, say, here in the US. In the next twenty years, these areas are expected to grow their access to energy, resulting in energy needs comparable to developed nations. One of the bigger challenges with moving to a decarbonized energy infrastructure at global scales is not how we can decarbonize energy use in developed locations, but how to ensure that parts of the planet that currently have little access to energy can grow their energy usage in carbon neutral ways. In this project, you will carry out an extensive exploration of academic and scientific literature related to sustainable energy solutions tailored to the unique challenges and requirements of developing nations. Through this analysis, you will gain a comprehensive understanding of the evolving landscape of clean energy adoption in developing regions, offering insights to inform strategies, policy frameworks, and innovative solutions that can contribute to a more equitable and sustainable energy future for all. Some possible questions you may consider are:

- What are the specific energy needs and challenges faced by developing countries, and how do they differ from those in developed nations?
- What are the current trends and advancements in renewable energy technologies that are suitable for deployment in developing regions?
- How do policy frameworks and international agreements influence the adoption of carbon-neutral energy solutions in developing countries?
- How can decentralized and off-grid energy solutions help address energy access issues in remote and underserved areas?
- What case studies from different regions highlight successful initiatives and best practices in achieving carbon-neutral energy in developing countries?
- How can technology transfer and capacity building be promoted to accelerate the adoption of sustainable energy solutions in these regions?
- What are the environmental and health benefits associated with the transition to carbon-neutral energy in developing nations?
- What are the potential barriers and challenges that need to be overcome to ensure the equitable and inclusive distribution of clean energy solutions in the developing world?

(4) Report/Analysis: Solar Energy Technology Prospectus.

Key question: What is the potential for the solar technology of your choosing to solve the world's energy problems?

Choose a solar photovoltaic technology. It can be established (silicon wafer technology), up-and-coming (thin films CIGS), or research level (CZTS, quantum dot solar cells, hybrid perovskites). Your goal is not only to understand how it works and why it works, but also to understand how (if) this design can solve the world's energy problems. It's a lot of responsibility, but you've trained all semester for just this mission. Your tasks are: (i) calculate the maximum possible efficiency for this type of device, (ii) find what efficiencies people are getting today and for what cost, (iii) identify the processes that are causing the difference between the maximum and practical efficiencies, (iv) investigate how to improve these processes and provide a potential research plan. You may want to discuss other considerations: are the component materials readily found in the earth's crust? Is the processing straightforward? What has to happen to make this device economically viable versus standard Si cells and versus, say, coal electricity?

(5) Report/Analysis: Renewable Grid and Intermittency Project

key question: Can the weather report be used to predict power output from an ensemble of distributed PV systems (in other words, do local, less predictable intermittency effects "average out"?)?

Your goal is to evaluate the properties of PV intermittency (amplitude and frequency of electricity fluctuations) on large-scale grids and their stability. Although the unpredictability of the weather in a given location makes it difficult to rely fully on solar PV, it is possible that if we had enough perfectly interconnected, distributed PV systems scattered throughout the country, weather effects would average out and on the whole, a fairly steady electricity could be generated. A nice deliverable for this project would be to evaluate grid stability in the presence of distributed PV (for example, a plot of *mean time to failure vs. number of perfectly interconnected systems*).

(6) Report/Analysis: Evaluation of Nanoscale PV Technology

key question: Does nanotechnology-based photovoltaic designs as a whole have the opportunity to compete with established technologies such as crystalline silicon PV?

Over the past decade, a plethora of new PV technologies and device architectures have been proposed, under the umbrella of nanotechnology. Some examples of nanoscale PV technologies include quantum dot solar cells, hot carrier solar cells, and all-carbon photovoltaics. Most nanoscale PV devices characterized to date, however, show poor efficiencies and performance. With the quickly falling costs of conventional silicon PV, it is not clear whether nano-PV can play a role in the world's energy future. Honest assessment of these new developments in nanoscale PV has been complicated by the lack of a comprehensive set of guidelines to evaluate the new technologies. Little consensus has emerged regarding which nanotechnology-based schemes have the maximum opportunity. Your goals are: (1) to create a comprehensive set of guidelines to assess and evaluate nano-PV technologies, (2) to use this framework to assess nano-PV technologies, and (3) to use your models to identify the areas of greatest opportunity for large-scale deployment.

(7) Design: PV Transportation Solutions

Key question: what would be a well-designed approach to implementing wide scale PV-based transportation look like?

Approximately one third of primary energy in the United States is used for transportation. Gasoline's enormous energy density has traditionally been a decided advantage over other technology options. However, recent advances in energy storage technologies have enabled electric and/or hybrid vehicles, and open the possibility for a fully electric or plug-in hybrid technology solution combined with renewable energy.

The objectives of this project are: (1) to design a solar charging station for a fleet of 10-20 neighborhood electric vehicles, (2) to compare solar system mounted on top of the vehicle with stand alone charging station, and (3) to compare the full-system efficiency of the neighborhood charging station relative to other technology options (conventional vehicles, electric vehicles charged from the grid). You should identify solar PV system specifications (W_{peak}, type, direction, cost ....), energy storage system specifications (what to optimize for transportation, what technology solutions are available, and what works best with different PV systems), and how to interface with the solar system and the batteries of the different electric vehicles.

(8) Report/Analysis: The Energy Storage Challenge

key question: what emerging technology will provide much needed capabilities in energy storage to enable adoption of solar PV technology on a global scale?

Many people believe that the key technical challenge that must be overcome to enable wide scale adoption of solar PV technology is in energy storage. Since the sun doesn't always shine, we need a way to generate electricity when the sun is shining, and convert the energy into a form in which it can be stored for later use. There are several candidates to consider: batteries, solid oxide electrolysis, pumped hydro, and chemical liquid fuels are a few. What are the merits and shortcomings of each? Can any of these meet the energy storage challenge? If not, what needs to be overcome?

(9) Report/Analysis: Making solar PV become cost competitive with traditional fossil fuel based electricity generation – the role of policy.

Key question: Today solar energy is almost, and possibly already, cost-competitive with traditional fossil fuel based electricity generation. When will we get there? How should we get there?

The solar industry has seen remarkable growth in the last ten years, due to a combination of factors including mass production and economics of scale, dedicated R&D efforts (see: DOE SunShot initiative), and at least in part due to incentives offered at the federal, state, or local levels to support growth. Considering several metrics such as capital costs, operating costs, and levelized costs of electricity (LCOE) production, how far away is solar PV from being cost competitive with coal burning power plants? Where are the opportunities for the most improvement? The module cost has dropped substantially over the last ten years, but so-called "soft costs" have not. Today, solar PV is still supported by incentives – local or federal programs and financing schemes designed to support the development of the technology. But many of these incentives are being lowered. This is what should happen – as the technology matures, its dependence on incentives reduces. What current policies are in place at federal, state, and local levels to promote the growth of solar, and what role have they played in the last ten years? Are they still necessary? What are some possible policy-oriented paths forward and their expected outcomes.

(10) Report/Analysis: The Paris Climate Agreement.

Key question: The Paris Climate Agreement was adopted in 2015 and went into effect in 2020. How will countries achieve these new standards? If these countries do achieve their goals, will they accomplish the mitigation of climate change?

The target set by the Paris Agreement within the United Nations Framework Convention on Climate Change [1] is to hold the global average temperature to well below 2 C above pre-industrial levels. Where does this fall, in comparison to the climate futures scenarios outlined by the latest IPCC report? How will the goal of the agreement be met and what needs to be done to reach these goals? You may think about a particular country, a group of countries, or the agreement as a whole.

[1] Paris Agreement, Decision 1/CP.21, UNFCCC secretariat. Online; accessed 26-May-2017 (2015). URL http://unfccc.int/resource/docs/2015/ cop21/eng/10a01.pdf

(11) Report/Analysis: Large-Scale PV Adoption in Illinois.

Key question: what will solar farms look like on the county or state map between now and 2030?

Consider goals of 15% and 25% electricity generation via solar PV for the state of Illinois. How much land area would this require? The land here is prime farming land, and is probably currently being used for crop farming – corn and soy. What are the consequences of trading this land for solar farms? What is the best way to deploy the solar farms with minimal impact on the farming community? What is the economic worth per acre of such land, and what happens if it is diverted to solar PV generation instead? You may wish to compare on a map the visual impact of compact solar farms, vs. spread out wind farms. Consider the wind farm map here: https://eerscmap.usgs.gov/uswtdb/viewer/#6.59/40.036/-89.326, and produce a static comparison map to generate equivalent MW using solar farms.

(12) Report/Analysis: Transparent Solar Panels.

Key question: How do they work and how well do they work? Is it worth it to install them in place of house windows?

One of the new technologies in solar energy is the transparent solar panel, of interest for solar-integrated windowing for instance. This raises the question of how these devices actually work, given they are transparent to visible light. Transparent solar panels also offer new ideas in building a truly carbon neutral home. Using these panels instead of windows in strategic areas of the home could help offset one's fossil fuel energy usage. However, windows in many buildings are not in the optimum position to harness the incoming light from the sun. Are installing transparent solar panels in buildings economical? In what other ways can these panels be used? Can you come up with a building design that makes the best use of this new technology while also capitalizing on the natural light the windows would allow for.

(13) Design: Create the first Mars mission's solar energy generation plant.

Key question: The first Mars colony will require energy production of some kind and solar energy makes the most sense. Design the system that will be packed into a rocket and taken to Mars to power the first ever (human) Mars colony.

Good luck.

(14) A Solar Project of Your Own Choosing.

As far as class project ideas go, you are always welcome to roll your own. Feel free to contact me to discuss or talk about any ideas that you are interested in pursuing.