ME 432 Fundamentals of Modern Photovoltaics
Fall 2020 – Class Project Ideas

Class project: The class project is required for graduate students only. You will work in teams of two, so please identify a partner. This year, I will give you a choice in the topic for the final class project. I will provide a list of possible topics, 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 Fri Oct 2, so you should start thinking about your project soon.*
- *During the week of Nov 2-6th, we will schedule 10 minute progress update meetings with each group.*

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 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 Mechanical Engineering Building of the University of Illinois now undergoing 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 currently, MEB is in the 90^{th} percentile of all buildings for energy efficiency. Your mission: develop a roadmap that shows how (if) MEB can make it to net-zero. If not, how close can we get?

I can provide you with utility bills and relevant data to look at historical energy consumption for the building. I can also suggest faculty and staff to talk with to learn about the status of the current plans for the renovation. Your goal is to see how close we can get to net-zero, by making 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? Is BIPV worth consideration? You may consider the possibility of adding panels not neccesarily to the roof itself, but also consider adding an expansion to the universities solar farm to offset MEB's electricity consumption.

(2) 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?

(3) 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*).

(4) Research Proposal: Earth-Abundant Module Reliability.

Key question: What new testing methods and protocols, different from the testing methods and protocols used for crystalline silicon modules, should be implemented for the newer thin film solar modules?

Reaching terawatts of power requires some 40,000 square kilometers of modules manufactured annually, simply to offset the modules being decommissioned every year. Of all the stardust on the planet, only 29 elements are believed to exist in abundant enough quantities to enable terawatt-scale manufacturing. Novel, earth-abundant PV materials have been proposed, as a means to overcome this resource constraint. Modules manufactured from these materials will need to withstand the same rigorous 20-year lifespans of traditional technologies. It is an outstanding question, whether existing module testing protocols actually stress the failure modes of modules manufactured from these novel materials. After carrying out a literature search on thin-film module reliability, develop a series of tests on mini-modules of Earth-abundant materials to diagnose relevant failure modes. Think of your deliverable as a testing methods guidebook, outlining additional failure modes that are unique to thin film earth-abundant systems, and describing new stress-tests to expose these failure modes during accelerated testing that should be performed in addition to standard protocols.

(5) 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.

(6) 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.

(7) 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?

(8) 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.

(9) 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 IPCC [2]? 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

[2] IPCC, 2014: Climate change 2014: Synthesis Report. Contri- bution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

(10) Report/Analysis: New solar module tariffs and their effect on the industry.

Key question: How will the new tariff's imposed starting January 2018 effect the recent growth of the solar industry?

Solar panel prices have fallen significantly since 2010, which has helped inspire the growth of the solar energy industry in the United States. In January 2018, President Donald Trump signed an executive order placing tariffs on imported solar panels, with the intent of encouraging module manufacturers to open plants in the United States. On the other hand, the Solar Energy Industries Association fought the tariffs tooth and nail, and had projected tens of thousands of job losses, claiming that the tariffs will undermine the economics of renewable energy as a whole. What effect have the tariffs imposed on solar modules and on the growth of the solar industry since their implementation in 2018? What will they mean for the long term deployment of solar at global scales? For this project, you should consider in detail several historical cases: what have been the results of tariffs imposed on manufactured goods in the past, and why might you expect the results to be similar or different in this case?

(11) Report/Analysis: Net Metering.

Key question: What role has net metering played in the promotion of the solar industry? What costs and benefits does it introduce? Consider several case studies in detail.

'Net metering' refers to a general set of billing mechanisms by which solar energy system owners are credited for the electricity that they add to the grid. Net metering rules vary from state to state, you can find out the individual state policies using the online Database of State Incentives for Renewables & Efficiency (DSIRE). These policies increase demand for solar energy systems, which promotes their adoption. This further creates jobs for installers, electricians, and manufacturers across the full solar supply chain. Additionally net metering helps to create a smoother demand curve for electricity and allows utilities to better predict and manage their peak loads. On the other hand, some utilities perceive net metering policies as lost revenues and argue that they present burdens on non-solar electricity customers. Indeed the original net metering policies (largely based on paying providers back at retail rates) were indeed designed for areas with low solar adoption. With rapid increases in solar capacity in places like California, Arizona, and New York, it is very likely that we will see changes to net metering rules in the next few years. California has already instituted changes to the state's original net metering scheme that will soon take effect. There are currently many discussions taking place on how to evolve the current programs, to consider factors such as accurate valuation of the solar energy flowing into the distribution grid, rate structures that charge more for electricity at certain times of the day, consider where on the grid the excess electricity is being generated, credits at a wholesale rather than retail rate, and the impact of residential solar energy storage batteries. Your task is to consider several case studies: what were the net metering rules, what effects did they have, and how should they be changed?

(12) 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.

(13) Report/Analysis: Tesla Solar Roof vs. conventional solar panel roof installation.

Key question: Is the Tesla Solar Tile Roof more economical than installing conventional solar panels on a regular roof? You may wish to consider both a home being built from scratch, and an existing home.

Tesla released its new solar energy generating roof tiles and boasts of their superior durability and economic/environmental draw. Flashy and innovative, Tesla's products continue to change the market in all sorts of different areas. Will residential solar energy be next? Currently residential solar energy consists of installing solar panels on existing rooftops, while Tesla replaces your existing roof with a new solar roof. The lifetime of these panels and installations is said to be about 25 years, while Tesla offers a 30 year warranty. Is the pleasing aesthetic and Tesla hype worth the money? Will Tesla's solar roof offer a quicker return on investment than conventional solar? Is investing in new technology worth it in order to fund the innovative side of the solar market?

(13) 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.

(15) 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.

(16) 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.