Technology and Society Theme proposal: EE 1701 "Energy, Environment and Society"

Catalog Description: (3.0 credits)

Energy from renewables such as solar and wind to combat potentially catastrophic climate change resulting from our use of fossil fuels; electrifying our transportation; ways to increase energy efficiency and energy conservation; need for energy storage to increase the penetration of renewables; role of technology, societal benefits and the ethics.

Narrative Proposal

Course Overview:

The objective of this course is to discuss harnessing energy in the form of electricity from renewables such as solar and wind to combat potentially catastrophic climate change resulting from our use of fossil fuels. This course will describe the use of renewables-generated electricity in reducing/eliminating the use of fossil fuels in transportation by electrifying it and the industrial and the agricultural sector. We will discuss ways to increase energy efficiency and energy conservation, e.g., using LEDs for lighting and heat pumps for heating and cooling. Need for energy storage to increase the penetration of renewables into the utility grid will be discussed. In accomplishing the above, this course will describe the role of technology, the ethics and the societal benefits.

Climate change/global warming is the gravest threat facing humanity. Many scientists are sounding the alarm bell that unless the problem of greenhouse gases is addressed, a point of no-return will be reached soon, resulting in migrations and global conflicts like the world has never seen before. Nearly 97 percent of the scientists believe that it's caused by greenhouse gases due to human activities.

In this course, we will discuss that we have the means to combat this threat. Two low-hanging fruits to generate electricity are wind and solar resources that far exceed the need for our electricity demand; for example, just the rooftop solar can generate 40 percent of our electricity need in the U.S. Electricity generated from renewables can also be used to electrify transportation, thus greatly reducing carbon emission and leading to energy independence in a clean way.

The mission of this course is to make students go beyond the awareness of climate change; rather, it is to make them an advocate/champion and doers to utilize the latest technology to harness energy from renewables and for conservation. The course is designed so that students will learn the fundamentals related to harnessing energy from various sources (conventional and renewable), their environmental consequences and the impact on society. These sources of energy will be compared in terms of their costs, constraints, and environmental impacts - all within the context of social values and public policy.

Given that poorest of the poor are at the front line due to our use of energy, and the environmental consequences resulting from it, the importance of ethical thinking and our moral responsibility to adopt a sustainable behavior will be infused throughout this course.

This course will be based on the suggested prerequisite of high school physics that a majority of freshman take prior to entering the University of Minnesota. (According to the Director of Admissions, Rachelle Hernandez, in Fall 2015, the following had taken high school physics: 4,445 out of 5,771 admitted to the campus and 1,012 out of 1,076 admitted to CSE.)

Meeting the Guidelines for all Theme courses

- Thinking ethically about important challenges facing our society and world:

Throughout this course, we will discuss various topics in relation to using renewable sources and ways to conserve, pointing out the relevance to the environment and the ethics of doing so for the sake of future generations, including **1.4 billion people** worldwide (over one in six) that according to the United Nations have no access to electricity.

- Reflecting on the shared sense of responsibility required to build and maintain community:

  This course will constantly emphasize that protecting the environment is not only urgent but a shared responsibility. Doing so should not benefit one group over the other, without excluding anyone based on economic and social status. If there is pain, as there will be, it should be shared equitably.

  To find win-win policy solutions, we need to fully examine the value created for customers, utilities, and the grid energy system from the widespread adoption of renewable energy sources. For example, the Minnesota Value of Solar Tariff (VOST) is an excellent model, but it will need to be expanded and refined to put an accurate value on solar.

- Connecting knowledge and practice:

  Students will learn that the knowledge being imparted in this course is already being put into practice with a great deal of possibility of further innovations and breakthroughs. It will be an upbeat course in spite of the graveness of the subject matter. Various examples of successful projects such as the utility-scale 550 MW solar plant in California and the rising use wind energy in Colorado will be discussed.

- Fostering a stronger sense of our roles as historical agents:

  This course will foster the urgency of our role as a historical agent - we will all be judged by history if we understood the urgency and did not have the moral fortitude to act based on opportunities made possible by technologies at hand. Just as an example of this opportunity, according to NREL, the rooftop PV potential alone in the United States is 1,118 gigawatts of installed capacity and 1,432 terawatt-hours of annual energy generation, **which equates to 39% of total national electric-sector sales**, which is enormous. But if we are serious about combating climate change, we should aim for a much larger percentage – perhaps 100 percent that is possible [click here].

  This course is very much aligned with all of the following five grand-challenge research objectives that our land-grant university has embarked upon:

  1) How will we ensure just and equitable societies?
  2) How will we foster human potential and well-being across the life course in a diverse and changing world?
  3) How will we advance human health?
  4) How will we develop sustainable cities and resilient communities in a world of climate change?
  5) How will we provide secure food, water, and energy today and for the future?

- This course will be taught by a regular faculty.

Meeting the Technology and Society Theme objectives and criteria

Technology and Society Theme:

The backdrop of this course will be to briefly describe our use of energy sources at present and its climatic and geopolitical consequences. Given this, our ethical responsibility is to explore alternate ways so that our children and grandchildren have a future!

Energy systems underpin modern society and link critical food, transportation, health, and water infrastructures across multiple spatiotemporal scales. Driven by the goals of sustainability and resilience, our energy system is rapidly undergoing fundamental transitions in form and function. How we harness and use energy connects new technologies, societal values, policies, institutions, and laws. This course focuses on energy-harnessing opportunities, particularly electrical, using renewables, embedded within existing and future power systems infrastructure to be rapidly acceptable in societal and policy context. This course spans the management of the variability of renewable resources, explores the role of storage and demand, while ensuring economic and social sustainability.

This course will be optimistic and upbeat, and will show that we can meet this challenge by shifting to renewables for generating electricity and using it efficiently. In doing so, various possible sources and approaches will be discussed and compared in terms of their practicality, by which we can derive energy from renewables such as solar and wind, not only to confront global collapse but instead leading to a brighter future. In concrete terms, if such measures are implemented, it will mean using far less coal, less fracking and almost zero imported oil, and will have a profound impact on society, while making us energy independent. This sentiment will be constantly reinforced through lectures, classroom discussion, weekly homework assignments and guest speakers.

This course will result in students as informed and engaged citizens with the possibility of developing innovative technologies in their career by combining compelling ethical urgency raised by climate change and, with the underpinning of technological knowledge, making the difference by convincing communities, investors and policy makers that the changes are not only ethical but are sound business practices as well leading to "green" jobs in inner cities.

Meeting the following criteria:

- The course examines one or more technologies that have had some measurable impact on contemporary society.

  In this course, we will discuss a wide variety of renewable energy resources and the technology to harness electricity from them, along with their impact on the environment and society. It will explore their economic viability (click – here, here).

- The course builds student understanding of the science and engineering behind the technology addressed.

  This course, which is technical at its core, builds on the principles learned in high school physics and will provide students the understanding of science and engineering behind the technology.

- Students discuss the role that society has played in fostering the development of technology as well as the response to the adoption and use of technology.

  Students will learn concrete examples of success in using various resources and technologies (click here).

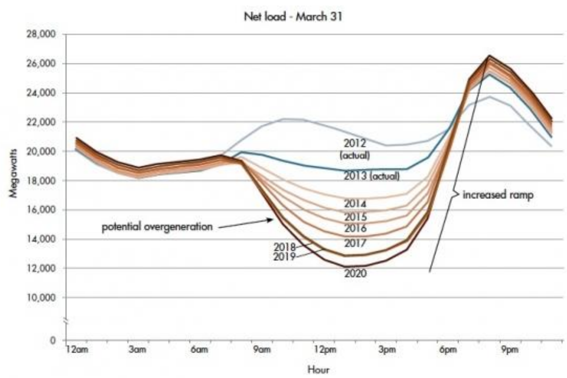
- Students consider the impact of technology from multiple perspectives that include developers, users/consumers, as well as others in society affected by the technology.

  In the qualitative question that will be asked in every homework set, students will be asked to consider various options from viewpoints of their economic viability and societal acceptability.

- Students develop skills in evaluating conflicting views on existing or emerging technology.

  There are always pros and cons in adopting these technologies. Students will be asked to consider them and evaluate them. There are many such topics where there is a great amount of effort and money being spent although the outcome is highly uncertain in solving our energy conundrum on a large scale. Some of these are the hydrogen economy, fuel from biomass, fuel cells, etc.

As an example, roof-top PVs is an extremely promising solution. However, there is a mortal threat to this promising solution. Utilities are looking at solar as detrimental to their survival for valid reasons. . This has to do with the “duck curve” shown here. It shows that during midday when the PV generation peaks, the utilities have a large over-generation capacity, even dipping into their base generation and they have to supply the peak power in the early evening hours when the demand is high as people return home and the solar output declines. Also, the ramp rate is very significant – projected in 2020 to be 14,000 MWs in just a few hours. Utilities buy the peak power from low-efficiency power pants using single-cycle gas turbines at almost twice the cost compared to the revenue they get from customers. Therefore, the utilities face a double whammy – losing revenue by not selling their product while having to maintain the infrastructure, and having to purchase electricity at much higher cost at peak hours. These so-called peaking plants are also very inefficient, resulting in a great deal of GHG emissions.



As a consequence, the states like Nevada have rolled back the clock on net metering and PUC order tripled the fixed charges solar customers will pay over the next four years, and reduced the credit solar customers receive for net excess generation by three-quarters. As a consequence, most of the solar installers have left Nevada with job losses in thousands. A similar threat on a much larger scale may be looming. In California and other states with much bigger potential for roof-top solar, many utilizes have rulings similar to Nevada passed in their favor.

Students will consider if distributed battery-storage may be a solution to this conundrum. While remedying the situation that utilities despise, it may be possible to make solar their friend (at least in the eyes of public utilities commissions) with the help of distributed storage. First, there is no arguing that storage results in higher initial investment and if the problems caused by solar to the utilities were not there, net metering, without any connection charges and no storage, would result in the quickest payback for the installed solar. However, given the reality of the problems which if not addressed will “kill” solar in its infancy, we have to take the bull by the horn and propose a solution that is beneficial to all sides. This would be an excellent example to discuss that we need to consider every solution from various perspectives.

- Students engage in a process of critical evaluation that provides a framework with which to evaluate new technology in the future.

Students will be asked to develop a methodology to evaluate pros and cons in the context of the environment, economic viability, and the societal acceptance.

Students will learn about concerns, for example, the electric grid stability. Variable generation due to renewables such as solar can make the electric grid become unstable if a large amount of generation suddenly either comes-on or goes-off due to a fast-moving cloud cover, for example. A number often mentioned is that up to 20 percent renewables is manageable but no more. Solar-friendly **Germany**, Europe’s champion for renewable energy, hoping to slow the burst of new renewable energy on its grid, has eliminated an open-ended subsidy for solar and wind power and put a ceiling on additional renewable capacity. But if we are serious about combating climate change, we should aim at much larger percentage – perhaps 100 percent is possible.

Student Learning Outcomes

At the time of receiving a bachelor's degree, students:

- Can identify, define, and solve problems.

  Considering climate change as a problem, students will be able identify the source and understand and compare various solutions.

- Can locate and critically evaluate information.

  In the beginning of the course, students will be informed of the sources available to them for further investigation. Course activities throughout the semester, including the qualitative question each homework set will require them to look up information on their own and evaluate it.

- Have mastered a body of knowledge and a mode of inquiry.

  Students will certainly understand the available renewable energy resource, the basis of harnessing energy from them, importance of conservation and monitor continuing development and future breakthroughs.

- Understand diverse philosophies and cultures within and across societies. Can communicate effectively.

  The intent if this course is that with the technological underpinning, students will be able to communicate to policy makers in making the right decisions in energy-related policies.

- Understand the role of creativity, innovation, discovery, and expression across disciplines.

  Students will learn through their research that beyond technological innovation, the adaptation of any technology will depend on creativity and consensus building across disciplines (economics, policy, etc.) to succeed.

- Have acquired skills for effective citizenship and life-long learning.

  One of the goals of this course is to make students informed and engaged citizens with a passion for combating climate change. They will look for opportunities to accelerate the uptake of technology, design new institutions that promote and incentivize renewable energy use, align technology and policy, chart how incremental steps lead to an economy-changing vision, understand the drivers of behavior and behavioral change, and privilege economic development and the attainment of a sustainable future for a wide range of people and places.

Relationship to Student Outcomes:

In accordance with ABET accreditation criteria, all engineering programs must demonstrate that their students achieve certain outcomes. This list of outcomes may be found on the ABET.org website. Of the outcomes listed in the ABET criteria (enumerated as (a) through (k)), this course teaches skills which help the student achieve the following outcomes:

(a) an ability to apply knowledge of mathematics, science, and engineering

(e) an ability to identify, formulate, and solve engineering problems

(i) a recognition of the need for, and an ability to engage in life-long learning

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

How would this course be counted in students' graduation plan?

It will be counted as any other course and having the LE Theme of Technology and Society will be very beneficial.

Why would students be interested in taking this course?

Students will get a good overview of climate change, its drivers, and possible solutions. After taking this course, students will be in a better position to identify their own passion and pursue further studies accordingly.

Syllabus

Contact Hours: 3 hours of lecture per week.

Text: *None at present.* However, discussion has begun with Shane Nackerud of the Digital Library Development Lab to convert slides and notes used in this course to an open digital textbook.

Syllabus (topics and learning outcomes):

1. Evidence of Climate Change, Causes and Contributors, Consequences (1 week):
    - Show the incontrovertible evidence of climate change and its seriousness
    - Fossil fuels producing CO_2 as the cause of it
    - Mission: create a mindset to be sustainability conscious

    Videos by NASA on changing climate, melting in Greenland and Antarctica; snippet from "Racing Extinction" on melting of permafrost; animations from NREL/DOE on Greenhouse effect.

    Sustainability – what does it mean, what is its significance in the generation and distribution of electricity and understanding of our present energy overview: Energy Consumption in various forms, Global Warming and Climate Change, Impact of Fracking, Role of Electricity.
2. Electricity as a possible solution to combat climate change (1 week,):
    - Consider our energy use and sources to produce electricity in the United States
    - Show the possibility of shifting our energy use to electricity in various sectors and then producing it by renewables
    - Overview of the technologies at hand and intense research being conducted

Papers by Mark Z. Jacobson, “100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States” and “I was wrong about Solar” by Prof. David Keith of Harvard.

3. Energy from Conventional Fossil Fuel Source (1 week)

   An understanding of Traditional sources of electricity generation: coal, natural gas, hydro, nuclear, Renewable Sources of Generating Electricity – Availability of Resources and an Introduction: Wind and Solar. Environmental impact of conventional sources of electricity generation, how these compare to renewable sources, e.g.: wind versus natural gas in producing greenhouse gases

4. Nuclear Power (1/2 week)

   - Role of existing nuclear plants in the interim without producing carbon
   - Fission versus fusion
   - How do nuclear plants work (BWRs, PWRs and Advanced Reactors)
   - The problem of storing radioactive waste – will it ever be solved?
   - New designs to make nuclear power plants modular and safer

   Animations explaining the difference between BWR and PWR plants; video on advanced nuclear reactors from U.S. NRC

5. Hydroelectric systems (1 week):

   - Principle of hydro in generating electricity and its potential
   - Do run-of-the-river hydro plants have the potential to generate electricity
   - Can many of the dams in the United States produce electricity (e.g., only 3 percent of the nation’s 80,000 dams now produce electricity)

   Demo of harnessing potential energy; electric generators

6. Wind: on-land and offshore (2 weeks):

   - Fundamentals of harnessing energy from wind – Betz’s Law
   - On-land and offshore resources
   - Structure and efficiency of wind turbines
   - Correlation between wind and utility load
   - Cost of wind electricity in relation to other sources
   - Challenges to the grid because of wind variability
   - Wind forecasting in day-ahead and real-time markets
   - Success examples like in Colorado

   An understanding of Harnessing Energy from the Wind: Physics, Maximum Power Point at various wind speeds, Various electrical structures, Various type of generators and their operating principles. Costs and constraints related to wind energy: economics, infrastructure, environmental, limitations (shadow effect, migration patterns, etc., global perspectives, public policy due to variable nature, social values)

Demos on wind turbines and generation of electricity; operating at the maximum coefficient of performance

7. Solar: PVs: Residential, Community Solar and Utility-Scale (2 weeks):

   An understanding of Generating Electricity using Photovoltaics (PVs): Physics, i-v Characteristics and Maximum Power Point of PV Cells, Interconnecting to a single-phase utility grid by a power-electronics converter, Interconnecting it to a three-phase utility grid by a power-electronics converter. Costs and constraints related to solar energy: economics, infrastructure, environmental, current limitations, future potential and expectations, public policy given its variable nature, social values, for example reduction on greenhouse gases.

   - Fundamentals of harnessing electricity using PVs
   - Structure and efficiency of solar cells
   - Cost of solar cells and the balance-of-system
   - Cost of solar-electricity in relation to other sources
   - Solar gardens
   - Correlation between PV-generated electricity and utility load
   - Challenges to the grid because of PV variability
   - PV forecasting in day-ahead and real-time markets
   - Success examples in Hawaii, California, New Jersey, etc.

   Animation on how PV cells work; Demos of i-v characteristics of PVs; operating at the maximum power point; PVs in series but one or more panels shaded; PVs for charging batteries

   An understanding of Delivering Electricity to Consumers over Transmission Lines, Fundamentals of ac in contrast to dc, Phasor Analysis to make it simpler: Power, Reactive Power, PF, Efficiency, Single-phase and three-phase circuits, Transforming voltages (efficiency/waste/loss in each system, comparisons between the two, and therefore connection to environmental/economic impacts)

8. Electric Power Grid and its Stability (1 week)

   - Its structure and how it works
   - How does variable generation affect its stability
   - Demand-side Management – Load following Generation

   Demo using PowerWorld software

9. Need for Storage (1/2 week, slides under development)

   - Various types of batteries and battery fundamentals
   - Pumped-hydro
   - Flywheels

Animation of how batteries work; demo of their charging and State of Charge measurement

10. Electrifying transportation (1 week):
    - Possibility of Electrifying Transportation powered by renewables
    - Electric and Hybrid-electric vehicles
    - Batteries and Supercapacitors for automotive application
    - Fuel cell fundamentals and types of fuel cells: pros and cons
    - How does the efficiency of fuel-cell systems compares with natural-gas turbines

    Animation of how fuel cells work; demo of fuel cells
11. Conservation through LEDs (1/2 week):
    - LED fundamentals and their comparison to incandescent and CFLs

    Demo of LEDs and their dimming
12. Efficiency Improvements in Motor-Driven Systems (1/2 week):
    - Efficiency improvements by using adjustable-speed drives in motor-driven systems

    Demo of adjustable-speed drives
13. Conservation in the Agriculture sector (1/2 week)
    - Greenhouse gases from various agricultural sectors
    - Effect of various diets on the environment
    - Making vegetables affordable by growing them in greenhouses, using LEDs powered by renewables
    - Vertical greenhouses – future of urban farming?

    Video on various agricultural/diet-related greenhouse gas emissions
14. Air-conditioning in a hotter world (1/2 week):
    - How heat pumps work
    - Practicality of central air conditioning versus zonal air conditioning
    - Can air-conditioning be minimized through architecture
    - Do ground-source heat pumps make sense?

    Video on how heat pumps and air-conditioners work
15. Miscellaneous (2 week)
    - Electricity Management Apps – weather forecasting for resources and loads – using the Internet of Things and Bluetooth technology
    - LEED Certification, Architectural Design and Urban sustainability
    - Net-zero electricity homes and communities
    - Electricity Policy Issues, RES in Minnesota), Carbon Trading, Windsource, Tax Depreciation for Solar Gardens/Community Solar, etc.

16. Guest Speakers (1 week – spread throughout the semester)
    - wherever appropriate – e.g., examples: Matt Schuerger from PUC to allow independent power producers, Mouli V. on tax structure for PVs, Jeff Johnson on ethics and the environment, Michelle Rosier on Sierra Club's view of the Clean Power Plan, Mark Ahlstrom on rates for renewable-generated electricity

All through the course, critical thinking and decision making on socio/economic impact of electricity usage and possible solutions for sustainability will be promoted.

Animations: Animations that can be manipulated will be used throughout to provide a visual conceptualization to improve learning. Some of these animations are developed and they will be supplemented with excellent animations available through various organizations. For example, https://phet.colorado.edu/en/simulations/category/new and http://www.physicsclassroom.com.

Hardware Demos: The development of hardware setups for in-class demonstration purposes. After demonstrating them in the classroom, they will be available in the EXCEED lab (https://sites.google.com/a/umn.edu/exceed/). Some of these demos are as follows:

1. PVs
    - i-v characteristics;
    - MPP in PVs with grid interface
    - PVs in series but one or more panels shaded
    - PVs for charging batteries
2. Battery characteristics and measuring SoC through Texas Instrument's Fuel-Gauge IC
3. Fuel Cell Characteristics
4. operating a wind turbine at MPP either in simulation or by using two very small dc-motors coupled to each other where one emulates a wind turbine and the other a wind generator,
5. Wind turbine kits commercially available
6. LEDs, LEDs in greenhouses (?)
7. Basic principles of how voltage is generated and how force/torques is produced in electric machines
8. Show how motors/generators work with small kits
9. Use of a very low-cost real-time controller being developed by ONR funding in energy-saving applications and to replace expensive measuring equipment

Assignments, nature of assessments, student projects

1. There will be a weekly homework assignment that will be collected and graded. Solutions will be provided subsequently. These assignments will count **25%** towards the grade.

   The homework assignments will have 4-5 numerical problems to promote and assess the comprehension of the course material. In addition, there will be a descriptive/qualitative question that will ask students the relevance of the material covered in that week and the ethics of doing so. It will ask how they can personally contribute to advancing the goal of sustainability.

2. There will be two mid-term exams, each **20%** of the grade.

3. The Final Exam will be comprehensive of all the material discussed in the course and will determine **35%** of the grade.