Sustainable Energy Sources and Systems: Course Description and Projects

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Abstract

In an effort to introduce engineering students to contemporary issues and life-long learning, a new technical elective, *Sustainable Energy Sources and Systems*, has been developed. The overall objectives of the course are to introduce students to energy sources and systems with an emphasis on sustainability and to expose students to economic, environmental, social and political issues related to energy. In this course, students apply material from thermodynamics, fluid mechanics, and heat transfer to analyze and/or design energy systems that utilize non-renewable energy sources such as fossil fuels and nuclear fission, as well as renewable energy sources such as solar, wind, biofuels, geothermal, and oceans. This paper presents an overview of the course and some of the novel pedagogical elements.

Introduction

Energy sources and energy conversion systems are important topics that are related to the well-being, health, and survival of individuals, nations, and even the planet. Because of their great importance and relevance, energy-related topics are in the news daily. New energy source extraction technologies and new energy conversion technologies are being developed and implemented for traditional (fossil) fuels, such as oil and natural gas. Moreover, due to environmental issues and limited fossil fuel resources, more and more attention is being given to renewable energy sources, such wind and solar power.

Energy-related topics are often complex. In addition to technical engineering and scientific analysis, energy-related topics often involve inter-related environmental, economic, social, and political issues. Several recent examples include:

- Hydraulic fracture or fracking
- Keystone pipeline
- Fukushima nuclear plant accident

Traditionally, engineering courses have focused on technical analysis, while environmental, economic, social, and political issues have been ignored.

Throughout history, technological advances and societal changes have made different energy sources more popular. Figure 1 shows the history of U.S. energy consumption from 1776 to the present day. Currently, the U.S. consumes approximately 97.4 quads of energy per year with the distribution by source and sector shown in Figure 2. Energy sources are dominated by fossil fuels (oil, coal, and natural gas). Nearly 40% of primary energy sources are being used to generate electricity. Overall, energy use is balanced among the residential, commercial, industrial, and transportation sectors. Conversion efficiency (and the second law of thermodynamics) shows over 60% of energy sources are being rejected (and mostly wasted).

While demand may be leveling off somewhat in the U.S. due to efficiency improvements and conservation efforts, the same cannot be said for the rest of the World, especially in the developing economies of China and India. Figure 3 shows the total world energy consumption by source. As in the U.S. fossil fuels dominate energy usage.

In order to understand energy-related issues, environmental and economic issues must also be understood. For example, the U.S. CO_2 (a greenhouse gas) emissions related to the various energy sources and sectors is shown in Figure 4. The combustion of fossil fuels produces CO_2, renewable energy generation source do not. However, advanced combined cycle plants fueled by natural gas are the least expensive electricity generation technology for new plants going online in 2018.

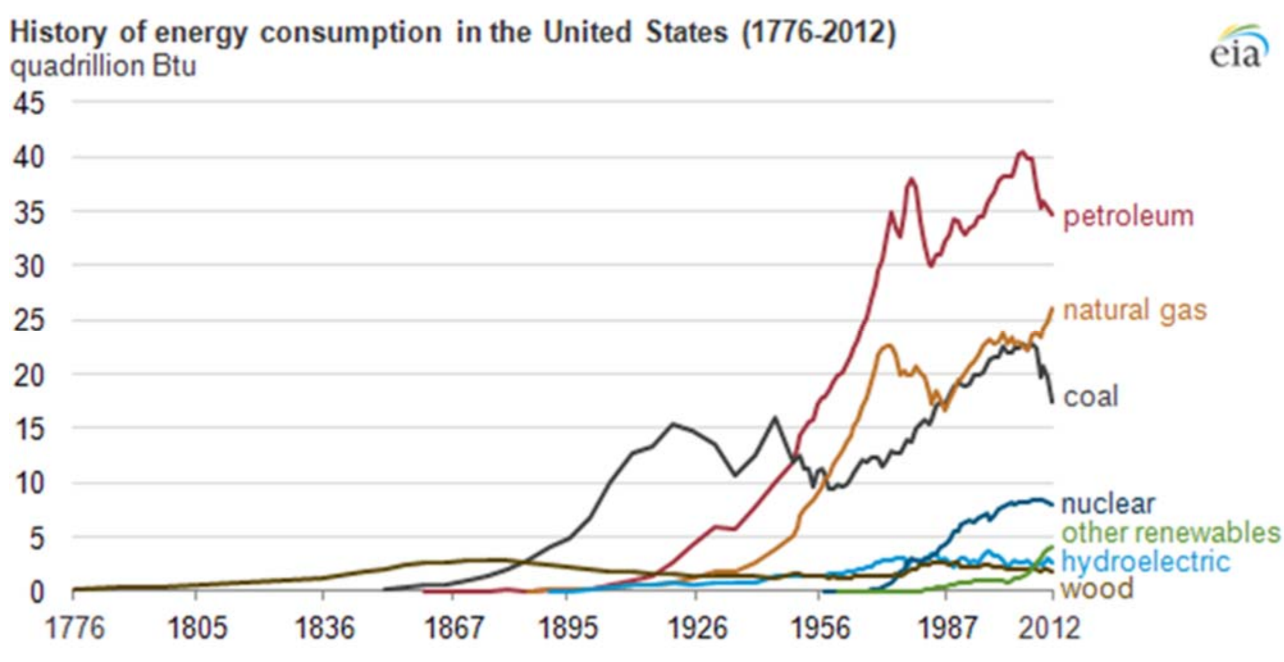


Figure 1. Historical U.S. energy consumption. (source: www.eia.gov)

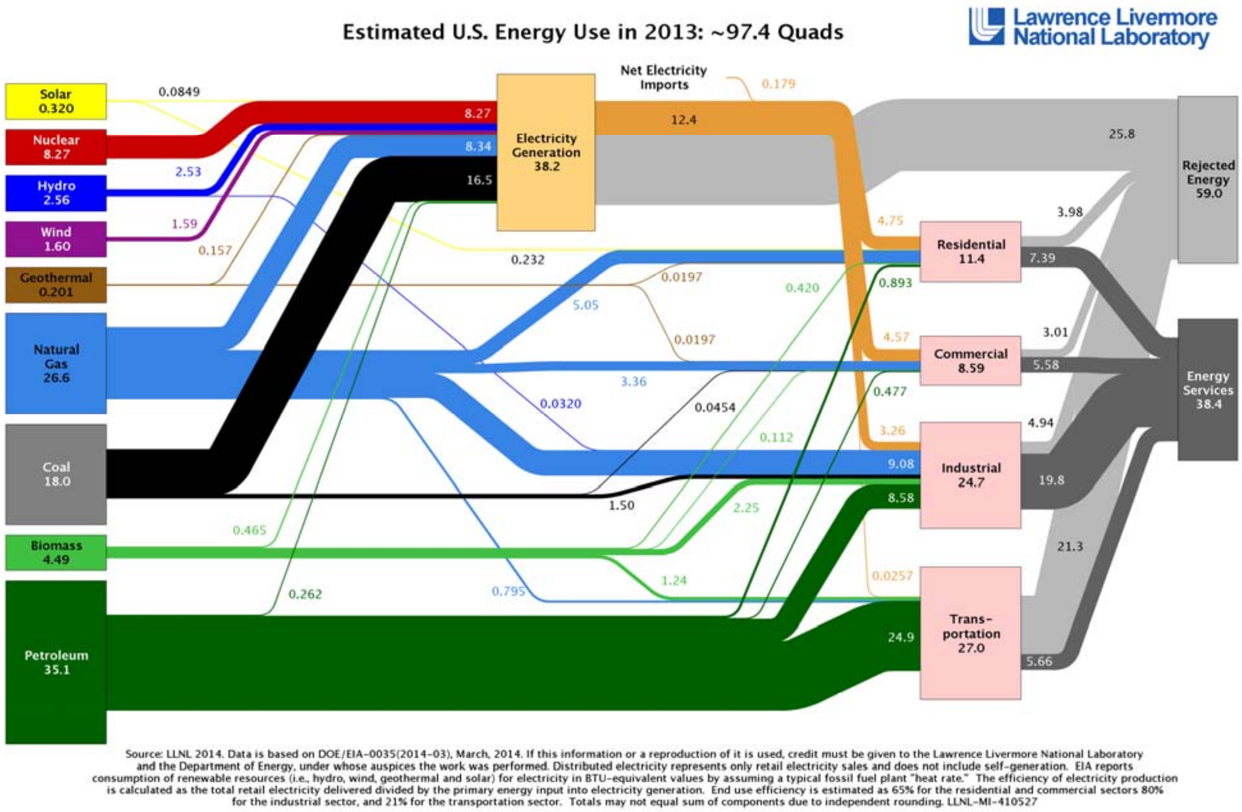


Figure 2. U.S. energy use by source and sector. (source: flowcharts.llnl.gov)

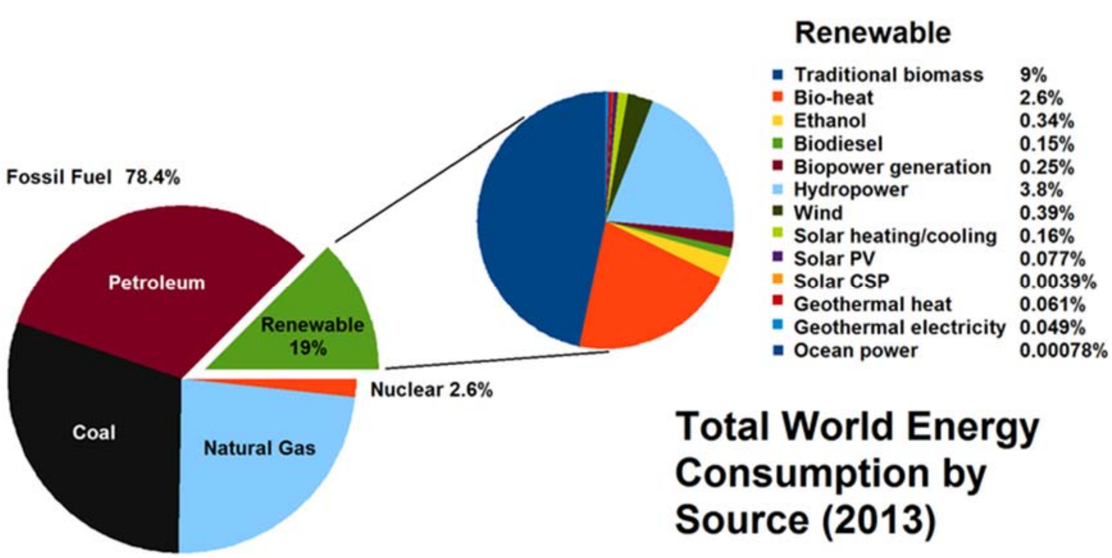


Figure 3. World energy use by source.
(source: www.ren21.net/ren21activities/globalstatusreport.aspx)

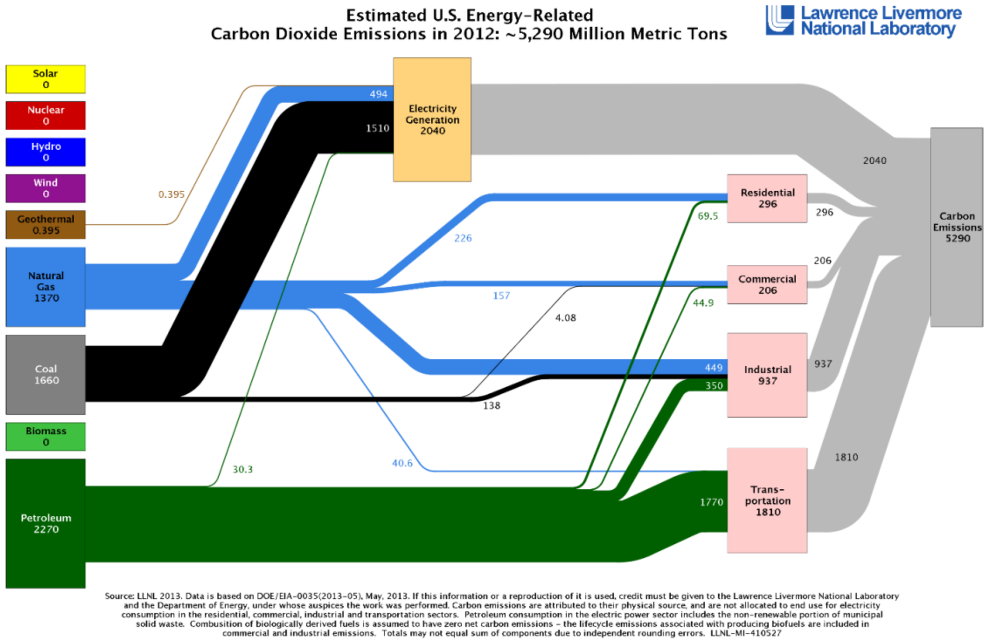


Figure 4. Energy related U.S. CO_2 emissions. (source: flowcharts.llnl.gov)

Table 1. The cost of new electricity generation options going into service in 2018.[1]

		U.S. average levelized costs (2011 $/megawatthour) for plants entering service in 2018				
Plant type	**Capacity factor (%)**	**Levelized capital cost**	**Fixed O&M**	**Variable O&M (including fuel)**	**Transmission investment**	**Total system levelized cost**
Dispatchable Technologies						
Conventional Coal	85	65.7	4.1	29.2	1.2	100.1
Advanced Coal	85	84.4	6.8	30.7	1.2	123.0
Advanced Coal with CCS	85	88.4	8.8	37.2	1.2	135.5
Natural Gas-fired						
Conventional Combined Cycle	87	15.8	1.7	48.4	1.2	67.1
Advanced Combined Cycle	87	17.4	2.0	45.0	1.2	65.6
Advanced CC with CCS	87	34.0	4.1	54.1	1.2	93.4
Conventional Combustion Turbine	30	44.2	2.7	80.0	3.4	130.3
Advanced Combustion Turbine	30	30.4	2.6	68.2	3.4	104.6
Advanced Nuclear	90	83.4	11.6	12.3	1.1	108.4
Geothermal	92	76.2	12.0	0.0	1.4	89.6
Biomass	83	53.2	14.3	42.3	1.2	111.0
Non-Dispatchable Technologies						
Wind	34	70.3	13.1	0.0	3.2	86.6
Wind - Offshore	37	193.4	22.4	0.0	5.7	221.5
Solar PV[1]	25	130.4	9.9	0.0	4.0	144.3
Solar Thermal	20	214.2	41.4	0.0	5.9	261.5
Hydro[2]	52	78.1	4.1	6.1	2.0	90.3

Hodge[2] gives an overview of the current energy situation. Similar discussions can be found in sustainable engineering texts such as References [3]-[7].

In an effort to introduce engineering students to these topics, a new technical elective, *Sustainable Energy Sources and Systems*, has been developed. Descriptions of similar courses have been published.[8,9] The overall objectives of this course are to introduce students to energy sources and systems with an emphasis on sustainability and to expose students to economic, environmental, social and political issues related to energy. In this course, students apply material from thermodynamics, fluid mechanics, and heat transfer to analyze and/or design energy systems that utilize non-renewable energy sources such as fossil fuels and nuclear fission, as well as renewable energy sources such as solar, wind, biofuels, geothermal, and oceans. Economic, environmental, social and political issues related to energy are also considered. This paper presents an overview of the course and some of the novel pedagogical elements.

Course Overview

The catalog description of the course is:

> An introduction to energy sources and energy systems with an emphasis on sustainability. Students will apply material from thermodynamics, fluid mechanics, and heat transfer to analyze and design energy systems that utilize non-renewable energy sources such as fossil fuels, nuclear fission and fusion, and hydrogen, as well as renewable energy sources such as solar, wind, biofuels, geothermal, and oceans. Economic, environmental, social and political issues related to energy are also considered.

The current text book for the course is *Sustainable Energy* by Dunlap.[3] Other primary texts used for the course included Reference [4] and Reference [6]. Reference material used for the Fundamentals of Engineering (FE) Exam is used to provide students an additional resources for technical and economic analysis.

The specific topics covered in the course include:

1. Introduction to energy and sustainability
2. Review of thermal sciences and efficiency
3. Environmental effects of energy
4. Energy sources, systems, and storage
5. Economic analysis
6. Fossil fuels
7. Nuclear power
8. Hydrogen fuel cells
9. Solar energy
10. Wind energy
11. Biomass energy
12. Geothermal energy

13. Hydropower
14. Ocean energy (waves, tides, and thermal)

Topics 1-5 and fossil fuels are covered in approximately the first 40% of the course. Nuclear, solar, and wind are covered in the next 30%, while the balance of the course is devoted to the remaining topics.

Topics 6-14 deal with the different energy sources and the related conversion technology. The prerequisites for the course are ME 301-Thermodynamics II and ME 321-Heat Transfer; accordingly, the typical student in the course is a senior-level mechanical engineering student. Thus students are expected to have a fairly high-level of technical knowledge and problem solving ability, and are required to perform technical, environmental, and economic analysis for topics 6-14. Samples of the types of analyses required are given in the questions, taken from exams and homework, included in Figures 5-7.

The technical analysis is heavily weighted towards resource availability and mechanical conversion processes. For example, in the study of wind energy, the focus is on wind energy resource availability, mechanical conversion efficiency, and generation capacity. Important issues such as electrical conversion, power electronics, and electricity transmission are only mentioned briefly.

The course has four stated student learning outcomes, i.e., students who successfully complete this course will have demonstrated an ability to:

1. Evaluate and compare non-renewable and renewable energy sources for energy content and environmental impact. (a, e)

2. Perform thermal, environmental, and economic analyses of energy systems. (a, e)

3. Design energy systems (including economic analysis) and communicate results either orally and/or in writing. (c, g)

4. Understand some of the ethical, economic, environmental, social, and political issues associated with energy and energy systems**.** (f, h, i, j)

The letters after the outcomes refer to ABET program outcomes. Outcomes 1 and 2 are assessed through traditional homework assignments and exams. Samples of typical homework and exam questions are provided in Figures 5-7. Outcome 3 is assessed primarily through the design project, and outcome 4 is assessed primarily through the article summaries and the research project.

The rest of this paper summarizes some of the more novel activities of the course such article summaries, a design project that makes use of energy system simulations software tools, and a research project.

2. A gas turbine power plant produces 50 MW of shaft power from inlet air at 100 kPa and 30°C. The compressor has a compression ratio of 9 and an isentropic efficiency of 0.8. The outlet temperature of the combustion chamber is 1100°C. If the turbine has an isentropic efficiency of 0.9 and an exhaust pressure of 100 kPa, determine the air flow rate and power plant thermal efficiency. Assume air standard cycle analysis and constant specific heats.

3. For the gas turbine power plant described in Problem 2, methane gas (CH_4 with a HHV = 55.5 MJ/kg) is the source of fuel.

   Assume that complete combustion takes place with excess air so that the balanced reaction is

$$CH_4 + 3\,(O_2 + 3.76\ N_2) \rightarrow CO_2 + 2\,H_2O + O_2 + 3(3.76)\ N_2$$

   (a) What is the percentage of excess air?
   (b) What is the air-to-fuel ratio on a mass basis?
   (c) How much methane gas, in m^3, is required to run the plant for one day?
   (d) How much CO_2, in kg, is produced in one day?

4. The capital cost of the gas turbine power plant described in Problem 2 is $700 per kW. The plant has a load factor of 60 percent and life of 20 years with a salvage value of 10 percent.

   (a) Assume the initial investment could have been invested at an annual rate of 6 percent. Find the cost of energy in cents per kW-h associated with the capital investment.
   (b) Assume fuel costs are $3.00 per million kJ. Find the cost of energy in cents per kW-h associated with the fuel.

Figure 5. Sample questions related to the energy, environmental, and economic analysis of a fossil fuel system.

4. A small industrial complex is considering producing its own electricity–either most of it or all of it. Two technologies are being considered: wind turbines and gas-turbine generators. Compare systems that make use of the following technologies to provide power at a rate of at least 50 kW_e for 12 hours per day. The following conditions apply:

system	power (kW_e)	load factor	initial cost	annual maintenance	annual operating cost
wind turbine	15	50	$20000	$2000	$0
gas-turbine generator	35	75	$50000	$2500	$10000

Assume a 20 year life and an interest rate of 6%. Determine the energy cost in $/(kW-hr) for the systems. Discuss the characteristics (economic, environmental, and reliability, etc.) of the two systems, i.e. advantages and disadvantages. Which system would recommend? Explain. How would future uncertainties affect your recommendation?

Figure 6. Sample questions related to the energy, environmental, and economic analysis comparing two electrical generation options—one a renewable energy source, the other using a fossil fuel.

2. If a motor vehicle gets 30 miles per gallon on gasoline, what gas mileage could be expected from E-85? How much CO_2 is produced, in kg, on a 100 mile trip from a gasoline powered vehicle compared to a vehicle powered by E-85?

fuel	formula	MW (kg/kmol)	heating value (kJ/kg)	density (kg/m^3)	compression ratio
gasoline	C_7H_{17}	101	47300	783	10
ethanol	C_2H_5OH	46	29700	750	12

Note: Assume complete combustion with 100% theoretical air, e.g.

$$C_2H_5OH + 3\,(O_2 + 3.76\ N_2) \rightarrow 2CO_2 + 3\,H_2O + 3(3.76)\ N_2$$

Figure 7. Sample questions related to the energy, environmental, and economic analysis comparing two fuels sources.

Class Activity: Article Summary and Discussion

Throughout the course, students are required to locate, summarize, and lead in-class discussions on current articles related to energy sources or energy-related technologies. The articles are selected from a variety sources, including newspapers & popular magazines, trade journals, and scholarly journals.

As part of this activity, information literacy is introduced as life-long learning skill. The librarians at IPFW have defined information literacy as:

> "Information literacy enables an IPFW student to recognize an information need, develop a strategy to locate, evaluate, and synthesize information, and cite sources of information accurately."[10]

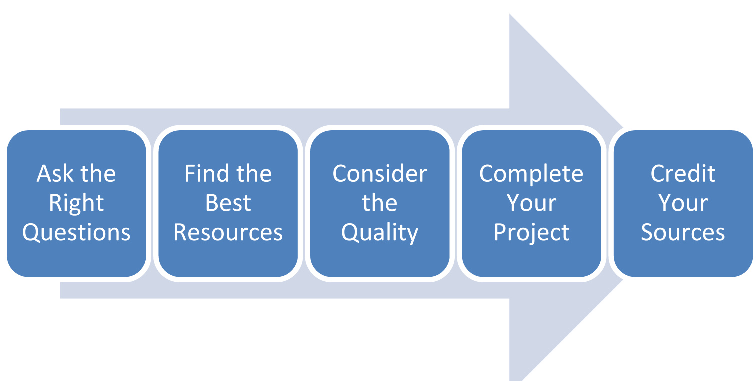


Figure 8. A schematic of steps required information literacy.

This definition of information literacy is presented to the class, along with information about scholarly vs. popular reference materials and ways to determine the credibility of web sites.

At various times throughout the semester, the instructor or a student chooses an article and presents it to the class. Near the start of the semester, newspaper or magazine articles are preferred. Closer to end, students are required to read at least one journal article. An example of each type of article is given in Table 2.

Table 2. Types of articles used for in-class discussion

article type	citation
newspaper	Justin Gillis. "A Tricky Transition from Fossil Fuel." New York Times. 11 Nov 2014.
magazine	Frank Keith. "Bang for the Buck." *Mechanical Engineering*, American Society of Mechanical Engineers. May 2012. John Reilly and Allison Crimmins. "Myth vs. Fact." *Mechanical Engineering*, American Society of Mechanical Engineers. January 2011.
journal	Mark Z. Jacobsen and Mark A. Delucchi. "Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials." *Energy Policy*. 39, 1154-1169 (2011).

Class Activity: Renewable Energy Design Project

Description

The objective of this project is to design an electrical power system for a private, residential unit. The system must include at least one renewable energy technology. The system can be off-grid or grid-connected and may include energy storage.

You may work in teams of three or four and should use one of the three software packages SAM, RET Screen4, or HOMER to simulate your system.

Specifically answer the following questions:

1. Describe your power system requirements.
2. Identify the primary components for your system.
3. Determine approximate cost data for the components of your system.
4. Estimate the available resources, i.e., wind and solar. You may be able to use data files available on the web.
5. Perform a system simulation using one (or more of the above) software packages.
6. Describe the operating characteristics of your system including an economic analysis.

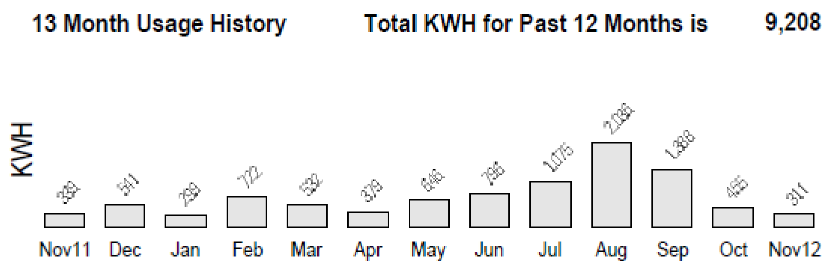
Deliverables

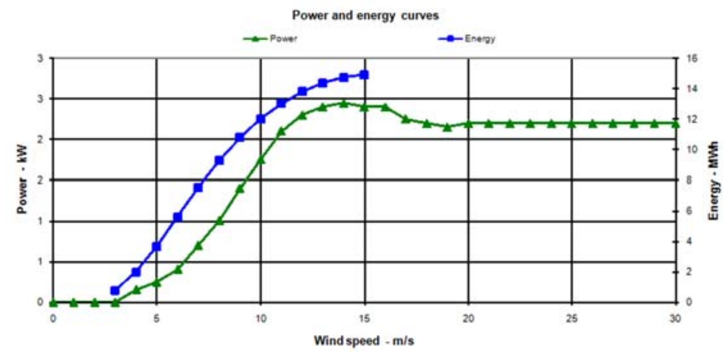
As a group, you will submit a brief technical memo, approximately 4 - 5 pages, detailing your system. As an individual, you will be required to answer questions on your project, either in writing on the final exam or orally during finals week.

Figure 9. Assignment statement for the renewable energy design project.

Similar projects have been proposed by others in the literature, see e.g. [11]-[13].

Figure 10 shows some typical project results. First, typical demand data is required for the project. Based on this data, a Southwest Windpower's Skystream 3.7 wind turbine is selected for analysis. This wind turbine is designed for to be used is grid-connected homes and businesses.





Financial Analysis

Financial parameters			
Inflation rate	%	2.8%	
Project life	yr	15	
Debt ratio	%	50%	
Debt interest rate	%	4.00%	
Debt term	yr	7	
Initial costs			
Power system	$	11,000	94.0%
Other	$	700	6.0%
Total initial costs	$	11,700	100.0%
Incentives and grants	$	3,300	28.2%
Annual costs and debt payments			
O&M (savings) costs	$	75	
Fuel cost - proposed case	$	604	
Debt payments - 7 yrs	$	975	
	$		
Total annual costs	$	1,654	
Annual savings and income			
Fuel cost - base case	$	889	
Electricity export income	$	532	
	$		
Total annual savings and income	$	1,421	
Financial viability			
Pre-tax IRR - equity	%	8.1%	
Pre-tax IRR - assets	%	-1.3%	
Simple payback	yr	11.3	
Equity payback	yr	10.7	

Cumulative cash flows ($)

Emission Analysis

Base case electricity system (Baseline) Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh	
United States of America	Coal	0.941	36.0%	1.470	
Electricity exported to grid	MWh	1	T&D losses	36.0%	
GHG emission					
Base case	tCO2	15.4			
Proposed case	tCO2	1.9			
Gross annual GHG emission reduction	tCO2	13.4			
GHG credits transaction fee	%	0.0%			
Net annual GHG emission reduction	tCO2	13.4	is equivalent to	2.5	Cars & light trucks not used
GHG reduction income					
GHG reduction credit rate	$/tCO2	0.00			

Figure 10. Generation prediction, economic analysis, and emission analysis from RETScreen4.

Class Activity: Research Project

Description

Each student will be assigned an energy source or issue to investigate and on which to report. The objective of this project is for the student to become an "expert" on the energy source or issue and some of the associated technology. The student will develop a one-page synopsis and an annotated bibliography to distribute to the class. A 15-minute presentation to the class will also be required.

Specifically answer the following questions:

- Estimate and discuss the capacity of your energy source or the background/scope of your issue.
- Discuss some of the technology currently used to transform your energy source into a more useful form. What are the technological issues involved? Are innovations required to make your technology viable?

or

- Discuss some of the technology currently related to your energy issue. What are the technological issues involved? Are innovations required to make your technology viable?
- What role does government have with your energy source or issue and the related technology?

Deliverables

To be submitted:

- One-page synopsis
- Annotated bibliography with statements related to the quality of your sources
- Presentation consisting of 18-24 slides printed with 6 slides per page
- One-page "position" paper describing your thoughts on the role of government as it relates to your topic and your prediction as to how this energy source/issue and related technologies will exist in the future.

This work will be graded but not returned.

Figure 11. Assignment statement for the renewable energy design project.

Examples of recent topics include:

transportation - electric vehicles	transportation - hydrogen power
algae energy	energy storage
hydroelectric power	wind energy
ocean energy	ethanol
nuclear energy - fusion	natural gas - hydraulic fracturing
transportation - natural gas	nuclear energy - fission

Concluding Remarks

A new technical elective, *Sustainable Energy Sources and Systems*, has been developed that introduces students to energy sources and systems with an emphasis on sustainability and exposes students to economic, environmental, social and political issues related to energy. Research projects and in-class discussions expose student contemporary issues and life-long learning. A design project requires the student to use an energy system simulation tool and perform an energy and economic analysis of a system that includes a renewable energy component.

This course was taught for the first time in 2010. Assessment results for the second time teaching the course (fall semester 2012) are included in Table 3. Overall, students are satisfied with the course and feel that outcomes are being achieved.

Table 3. Student learning outcome assessment for the fall semester 2012

Students who successfully complete this course will have demonstrated an ability to:	Agree	Disagree
Evaluate and compare non-renewable and renewable energy sources for energy content and environmental impact. (a, e) Selected student comments: *Helped to understand impacts of fossil fuel and renewable energy sources.* *Dismisses myths gives fact*	11	0
Perform thermal, environmental, and economic analyses of energy systems. (a, e) Selected student comments: *Understood levelized cost of different system, their CO2 and greenhouse gas emission.* *Certain energy systems were more applicable to thermal/environmental/economic analyses in terms of weighted complexity* *Environmental should have been covered more. Thermal needed a review.*	11	0
Design energy systems (including economic analysis) and communicate results either orally and/or in writing. (c, g) Selected student comments *Individually conducted projects were extremely useful* *I feel this could have used more attention. More in-class examples would have been beneficial* *It would be nice if design projects were assigned early and more time was given to work on them* *Projects are useful in this area*	10	1

Understand some of the ethical, economic, environmental, social, and political issues associated with energy and energy systems. (f, h, i, j)		
Selected student comments *The research project was very useful and where I probably learned the most.* *Understood government and industrial position* *Discussions regarding these issues were also extremely useful and relevant* *More current issues would be good.*	11	0

References

1. U.S. Energy Information Administration. (April 2014) "Levelized Cost and Levelized Avoided Cost of New Generation Resources." *Annual Energy Outlook 2014.*
2. B. K. Hodge. (2010) "Etiology of the Energy Crisis in One Lecture." *American Society for Engineering Education*.
3. R. A. Dunlap. (2015) *Sustainable Energy*. Cengage Learning.
4. F. Kreith and J. F. Kreider (2011) *Principles of Sustainable Energy*. CRC Press.
5. B. K. Hodge. (2010) *Alternative Energy Systems and Applications*. John Wiley & Sons.
6. J. W. Tester, E. M. Drake, M. J. Golay, and W. A. Peters. (2005) *Sustainable Energy: Choosing Among Options.* MIT Press.
7. G. Boyle, B. Everett, and J. Ramage, eds. (2004) *Energy Systems and Sustainability: Power for a Sustainable Future.* Oxford University Press.
8. J. Riddell and A. Sala. (2010) "Alternative Energy, an Introduction for Engineers." 2010 ASEE Annual Conference & Exposition. *American Society for Engineering Education.*
9. O. D. Momoh. (2014) "Developing a Renewable Energy Technology Course for a Master of Technology (MTECH) Program." 2014 ASEE Annual Conference & Exposition. *American Society for Engineering Education*.
10. See http://guides.library.ipfw.edu/librarybasics and related links.
11. K. T. Aung. (2011) "Simulation Tools for Renewable Energy Projects." 2011 ASEE Annual Conference & Exposition. *American Society for Engineering Education*.
12. K. T. Aung. (2013) "Economic and Life Cycle Analysis of Renewable Energy Systems." 2013 ASEE Annual Conference & Exposition. *American Society for Engineering Education.*
13. R. G. Belu, R. Chiou, K. Ghaisas, and T. B. Tseng. (2014) "Teaching Renewable Energy System Design and Analysis with HOMER." 2014 ASEE Annual Conference & Exposition. *American Society for Engineering Education*.

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