

Final Report: Clean Energy Infrastructure Educational Initiative

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Executive Summary

The Clean Energy Infrastructure Educational Initiative represents a collaborative effort by the University of Dayton, Wright State University and Sinclair Community College. This effort above all aimed to establish energy related programs at each of the universities while also providing outreach to the local, state-wide, and national communities. The University of Dayton was the prime institution on the program.

At the University of Dayton, the grant aimed at: solidifying a newly created Master's program in Renewable and Clean Energy; helping to establish and staff a regional sustainability organization for SW Ohio. As well, as the prime grantee, the University of Dayton was responsible for insuring curricular sharing between WSU and the University of Dayton. Finally, the grant, through its support of graduate students, and through cooperation with the largest utilities in SW Ohio enabled a region-wide evaluation of over 10,000 commercial building buildings in order to identify the priority buildings in the region for energy reduction. In each of these areas, the grant has achieved success. First, through the grant, eight new graduate courses were created (RCL 590 - Building Energy Informatics, RCL 590 - Sustainable Energy Systems, RCL 590 - Wind Energy, RCL 590 - Solar Energy Engineering, RCL 590 - Geothermal EnePowerergy, RCL 590 - Thermal Systems Analysis, and RCL 550 - Special Project). One fledgling course was improved greatly (RCL 573 – Renewable Energy Systems). All of these courses were designed to include projects connecting to real clients in SW Ohio. These developments had contributed to growth of the the Master's in Renewable and Clean Energy program (established in Jan. 2009) to an enrollment to 54 students from 18 different nations. All early graduates (total since onset approximately 50) have ganed employment; with nearly 50% of these working within the state at salaries averaging over \$60,000. Females represent 25% of all graduates and current students. In fall 2012, the program will be hosting 4 international Fulbright Scholars – a sign of a growing recognition of quality. Second, the University of Dayton has been instrumental to the growth of a regional sustainability organization – Dayton Regional Green 3 (www.drg3.org). The UD PI serves as the co-Chair of the External Advisory Committee and, short of the leader of this group, all paid and voluntary staff are students in the UD Renewable and Clean Energy Masters program. The Univesity of Dayton has helped this organization establish a rapidly growing Green Business Certification Program (now with over 100 businesses certified) and now a monthly Sustainability Coordinators meeting. UD students have also developed residential and commercial building energy education outreach programs. Finally, through the grant support, and in cooperation with Dayton Power and Light and Vectren Inc., the primary electric and gas utilities for the Dayton region, the University of Dayton has through the use of a novel energy informatics approach identified among the entire commercial building customer base for these utilities those buildings having the most cost effective opportunities for energy reduction. In 2011-2012 on-site energy audits have been conducted for 50 commercial and light manufacturing buildings. These audits have identified energy cost savings of over \$3,000/year per customer, while helping to develop 12 energy engineers.

The main focus of Wright State was to continue the development of graduate education in renewable and clean energy. Wright State has done this in a number of ways. First and foremost this was done by continuing the development of the new Renewable and Clean Energy Master's

Degree program at Wright State¹. Development tasks included: continuing development of courses for the Renewable and Clean Energy Master's Degree, increasing the student enrollment, and increasing renewable and clean energy research work. The grant has enabled development and/or improvement of 7 courses. The program now includes a total of 22 courses. Collectively, the University of Dayton and WSU offer perhaps the most comprehensive list of courses in the renewable and clean energy area in the country. Because of this development, enrollment at WSU has increased from 4 students to 23. Secondly, the grant has helped to support student research aimed in the renewable and clean energy program. A quality graduate program is only possible if there is quality research. The grant helped to solidify new research in the renewable and clean energy area. The educational outreach provided as a result of the grant included activities to introduce renewable and clean energy design projects into the Mechanical and Materials Engineering senior design class, the development of a geothermal energy demonstration unit, and the development of renewable energy learning modules for high school students.

Finally, this grant supported curriculum development by Sinclair Community College for seven new courses and acquisition of necessary related instrumentation and laboratory equipment. These new courses, EGV 1201 Weatherization Training, EGV 1251 Introduction to Energy Management Principles, EGV 2301 Commercial and Industrial Assessment, EGV 2351 LEED Green Associate Exam Preparation, EGV 2251 Energy Control Strategies, EGV Solar Photovoltaic Design and Installation, and EGV Solar Thermal Systems, enable Sinclair to offer complete Energy Technology Certificate and an Energy Management Degree programs. To date, 151 students have completed or are currently registered in one of the seven courses developed through this grant. With the increasing interest in the Energy Management Degree program, Sinclair has begun the procedure to have the program approved by the Ohio Board of Regents.

Moreover, the effort aligns with Sinclair's college-wide energy initiative begun in fall 2007. The purpose of that initiative was to raise awareness in the Sinclair community and the surrounding community of the depletion of fossil fuel resources and other environmental issues related to consumption of fossil fuels. Courses such as Architectural Energy Analysis, Introduction to Alternative and Renewable Energy, and Introduction to Fuel Cells were developed and included in then existing programs. An Energy Education Laboratory was constructed with many displays and information kiosks to support community awareness. The Energy Technology Certificate and an Energy Management Degree programs were outlined and entered the approval process in 2010. The curriculums of both programs contained existing courses, but required additional courses in order to offer complete certificate and degree program.

¹ Students at UD and WSU are able to easily cross-register between institutions.

University of Dayton

Curriculum Development

The Renewable and Clean Energy program at the University of Dayton was initiated in January 2009. In the first class of students, there were 12 students. Course offerings were adequate – particularly given the cross-registration that was established from the onset between the University of Dayton and Wright State University. At the time of the establishment of the program, the program description is as summarized as shown in Figure 1. The existing courses at the University of Dayton time are highlighted in yellow. A new course in Renewable Energy Systems (highlighted in blue) had been developed – but it needed much work. Missing were courses providing greater detail in renewable energy – namely solar, wind, and geothermal energy and a course providing greater depth in building energy efficiency. Plus there was no real curriculum connected to a research strength at the University of Dayton in the area of Energy Informatics.

The program of study leading to the Master of Science in Renewable and Clean Energy degree, developed by the student in conjunction with her/his advisor, must include a minimum of 30 semester hours. The program requires that two courses be taken at DAGSI partner universities, Wright State University and the Air Force Institute of Technology. At least one-half of the courses must be taken at the University of Dayton. Both thesis and non-thesis options are possible. A thesis option would include 6 semester hours of MEE 599- Masters Thesis coursework in the program of study as part of the 30 semester credit hours.

The following specific requirements exist. WSU and AFIT respectively refer to Wright State University and Air Force Institute of Technology.

Required Core Courses (1 course from each area below)

Advanced Thermodynamics

- UD/MEE 511: Advanced Thermodynamics
- UD/CME 507: Advanced Thermodynamics
- WSU/ME 744: Advanced Thermodynamics
- WSU/ME 760: Thermodynamics of Solids
- AFIT/PHYS 635: Thermal Physics

Energy Materials

- UD/MEE 507: Energy Materials
- WSU/ME 890: Advanced Energy Materials

Required Renewable and Clean Energy Courses (3 courses; at least 1 in the Energy Efficiency area)

Renewable Energy

- WSU/ME 624: Solar Engineering
- Advanced Solar Energy - Photovoltaics (to be developed)
- WSU/ME 890: Hydrogen Energy
- UD/MEE 573: Renewable Energy Systems
- UD/MEE 590: Advanced Fuel Technology (including biomass)

Clean Energy

- AFIT/NENG 620: Nuclear Reactor Theory and Engineering
- WSU/ME 699: Fuel Cell Science and Technology
- WSU/ME 699: Energy Conversion
- UD/MEE/CME 524: Fuel Cell Fundamentals and Technology

<ul style="list-style-type: none"> ▪ UD/MEE/AEE 526: Advanced Fuels ▪ WSU/ME 890: Electrochemical Energy Systems ▪ Approved elective <p><i>Energy Efficiency</i></p> <ul style="list-style-type: none"> ▪ UD/MEE 568: Advanced Automotive Transportation Systems ▪ UD/MEE569: Energy Efficient Buildings ▪ UD/MEE571: Design of Thermal Systems ▪ UD/MEE 572: Design for Environment ▪ UD/MEE 578: Energy Efficient Manufacturing ▪ Approved elective

Figure 1. University of Dayton Renewable and Clean Energy program at its inception in 2009.

In this context, the grant helped to provide faculty support for the development and/or enhancement of eight courses. These courses are shown in Table 1 below. Table 1 indicates whether the course was a new course developed or simply improved. Summer funding was provided to three faculty (Dr. Kevin Hallinan, Dr. Andrew Chiasson, and Dr. Robert Brecha) to develop. A course release was also offered to Dr. Chiasson for one term to aid his development. To date all of these courses have been offered at least once since the initiation of the grant. All courses have addressed both on-campus and distance students. Course syllabi are included in the Appendix of the University of Dayton section of the final report.

Table 1. Courses developed / improved as a result of grant

Course / Faculty	Status	Rationale for Development
RCL 590 – Thermal Systems Analysis (Hallinan)	New	While the UD RCL program is an engineering program, growing out of an existing Mechanical Engineering program, a conscious decision was made to permit enrollment of all students with Bachelor's in all engineering and science fields. This course was developed to help provide the necessary background in thermodynamics and heat transfer to these students.
RCL 573 – Renewable Energy Systems (Chiasson)	Improve	A version of this course had been developed at the beginning of the program as an introduction to renewable energy for all RCL students; but the course needed work. Course re-development aimed at integrating computational tools for renewable energy (RESNET) in a way that augmented fundamental understanding. As well, re-development work focused upon integration of a project into the course.
RCL 590 – Sustainable Energy Systems (Brecha)	New	This course was developed both because the faculty expertise was there and because we believed that there was a need for students to understand the complex location of renewable energy and energy efficiency in the macroscopic world energy picture.
RCL 590 – Wind Energy (Hallinan)	New	Designed as a renewable and clean energy program, we were committed to offering courses in all renewable

		energy areas, with a particular emphasis on the physics of these systems and how to integrate them into the world). This course was developed to provide a deeper understanding of wind energy and to provide students an understanding of how to integrate wind systems into the world through a rich project-based experience.
RCL 590 – Solar Energy Engineering (Chiasson)	New	Designed as a renewable and clean energy program, we were committed to offering courses in all renewable energy areas, with a particular emphasis on the physics of these systems and how to integrate them into the world). This course was developed to provide a deeper understanding of wind energy and to provide students an understanding of how to integrate wind systems into the world through a rich project-based experience.
RCL 590 – Geothermal Power (Chiasson)	New	Designed as a renewable and clean energy program, we were committed to offering courses in all renewable energy areas, with a particular emphasis on the physics of these systems and how to integrate them into the world). This course was developed to provide a deeper understanding of geothermal energy and to provide students an understanding of how to design building geothermal heating and cooling systems through a rich project-based experience.
RCL 590 – Building Energy Informatics (Hallinan)	New	This new course was developed to align with research strengths in the building energy informatics at the University of Dayton. This course was designed to provide students knowledge and experience in utility analysis utilizing multiple approaches (regression, genetic algorithm, neural networks, and more). It was also designed to test informatic approaches to new research problems having relevance to commercial and residential buildings in the Dayton area.
RCL 550 – RCL Project – Building Energy Center (Hallinan)	New	One of the requirements of the program is enrollment in at least a 3 credit hour project. This project course was developed to engage students in the utility sponsored regional priority building energy reduction program managed by Dr. Hallinan in cooperation with Dayton Power and Light and Vectren – the primary electric and gas providers for the Dayton region. In this course, students learn the basics of an audit (utility analysis, HVAC evaluation, lighting and appliance evaluation, and client interactions) and then gain experience in administering the audit.

With these additions the program now offers a comprehensive grouping of courses in renewable energy and energy efficiency – with particular emphasis on applied engineering (e.g., how to design systems

and integrate into the world) and on project-based learning. Also, this program to our knowledge is the only distance program in the world focusing on renewable energy and energy efficiency. Figure 2 highlights the new schedule of offerings.

<p>Renewable and Clean Energy</p> <p>Typical Schedule of Courses (Revised July 3, 2011)</p> <p>Fall</p> <p>RCL 573 – Renewable Energy Systems (Classroom + Distance)</p> <p>RCL 590 – Thermal Systems Analysis (Classroom + Distance)</p> <p>RCL 578 – Energy Efficient Manufacturing (Classroom + Distance)</p> <p>RCL 590 – Solar Energy Engineering (Distance)</p> <p>RCL 568 – Internal Combustion Engines (Classroom)</p> <p>ENM 561 - Design and Analysis of Experiments (Classroom + Distance) (Satisfies Math)</p> <p>Spring</p> <p>RCL 569 – Energy Efficient Buildings (Classroom + Distance)</p> <p>RCL 590 – Geothermal Energy (Distance)</p> <p>RCL 590 – Wind Energy (Classroom + Distance)</p> <p>RCL 511 – Advanced Thermodynamics (Classroom)</p> <p>RCL 590 – Electric Utility Energy Management (Classroom + Distance) (Spring 2012 only)</p> <p>ECE 595 – Advanced Photo-voltaics (Classroom)</p> <p>ENM 561 - Design and Analysis of Experiments (Classroom + Distance) (Satisfies Math)</p> <p>Summer</p> <p>RCL 524 – Electrochemical Power (Classroom)</p> <p>RCL 590 – Building Energy Informatics (Classroom + Distance)</p> <p>RCL 590 – Sustainable Energy Systems (Distance)</p> <p>CME 595 – Biomass and Biofuels (Classroom)</p> <p>Fall, Spring and Summer</p> <p>RCL 550 – RCL 550 – Renewable and Clean Energy Project – Building Energy Center</p> <p>RCL 599 – Thesis (1-6)</p>

Figure 2. UD RCL Master's program of course offerings.

To date the program has been highly successful in terms of preparing graduates for renewable and clean energy jobs, both within Ohio, throughout the US, and internationally. The following shows a sampling of the recent graduates and where they are working. This list is not comprehensive

Roman Villoria-Siegert

Engineer, Direct Options

Joel Baetens

Energy Engineer, Michigan

Dustin Langille

Associate Engineer at Elara Engineering, Greater Chicago Area

Marissa Bernal

Associate Engineer at Rieck Engineering, Dayton, Ohio

Franc Sever

Graduate Assistant at University of Dayton, Dayton, Ohio Area
Design, Greater Chicago Area

Thomas Wenning

R&D Staff at Oak Ridge National Laboratory, Dayton, Ohio Area

Jessie Northridge

Mechanical Engineer at Heapy Engineering, Dayton, Ohio Area

Patrick Bruketa

Energy Engineer, Lansing, Michigan Area

Jessica Minor

Project Manager at Oberlin College, Columbus, Ohio Area

Han Nguyen

2013 MBA Candidate, Carnegie Mellon Tepper School of Business, Greater Pittsburgh Area

Autumn Nicholson

Application Engineer- Systems Analyst at Emerson Climate Technologies, Dayton, Ohio Area

Robert Lou

Graduate Researcher/Energy Engineer at University of Dayton, Dayton, Ohio Area

Jeremy Smith

Start-up industrial energy company, Davis, California.

Fiona Martin

Energy Engineer at Grumman/Butkus Associates, Greater Chicago Area

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Ying Zhou

Green Building Consultant, China

Xu Gong

Sustainability/Green Building Assistant Consultant at AECOM, China

[29 followers](#) | [Unfollow](#) | [See activity »](#)

T. Nathan Baldwin

Energy Engineer, Cleveland/Akron, Ohio Area

Graham Linn

Energy Engineer, Germany

Joshua Foor

Energy and Mechanical Engineer at Energy Optimizers, USA, Dayton, Ohio Area

Brendan Kellam

Energy Engineer at Baxter Healthcare, Greater Chicago Area

Shena Bailey, LEED AP O+M

Energy Engineer at KEMA, Lansing, Michigan Area

Brian Abels

Mechanical and Energy Engineer at Energy Optimizers, USA, Dayton, Ohio Area

Jarret Kelley

Energy Engineer at Plug Smart, Columbus, Ohio Area

Kevin Nichols

Energy Engineer at Plug Smart, Columbus, Ohio Area

Shijie Gu

LEED Engineer at Kendow Energy(Shanghai) Co.,Ltd, Dayton, Ohio Area

Scott Ulrich

Energy Engineer at CCG Energy Solutions, Cleveland/Akron, Ohio Area

Abinesh Selvacanabady

Engineer I at Resource Solutions Group, Dayton, Ohio Area

Carlos Martinez

Energy Efficiency and Renewable energy Engineer, Dayton, Ohio Area

Ajiri Ogbimi, LEED Green Assoc.

Energy Engineer at Vt-designs, Cincinnati Area

Gokul Murugesan

Energy Efficiency Analyst at ICF International, Washington D.C. Metro Area

Charles Ampong

Consultant at Navigant Consulting, Madison, Wisconsin Area

Brad Turnwald

Energy Engineer at CCG Energy Solutions, Cleveland/Akron, Ohio Area

Kirk Meekin

Energy Engineer, Dayton, Ohio Area

Robert Weber

PEJD-Engineering Services-Energy Efficiency, Bonneville Power Administration, Seattle, Wa

Rakesh Kaushik

PEJD-Engineering Services-Energy Efficiency, Bonneville Power Administration, Seattle, Wa

All early graduates (total since onset approximately 50) have gained employment; with nearly 50% of these working within the state at salaries averaging over \$60,000. Females represent 25% of all graduates and current students. In fall 2012, the program will be hosting 4 international Fulbright Scholars – a sign of a growing recognition of quality.

Outreach through the Dayton Regional Green 3 Regional Sustainability Organization

In 2007 an eight county regional sustainability organization was formed centered in the Dayton, Ohio area. The Dayton Regional Green 3 organization was created to:

- Become the regional resource for environmental sustainability and energy conservation through the Dayton Regional Green 3 website and Sustainability Center.
- Guide the region to become more energy efficient, integrate sustainability principles into daily operations and benchmark results.
- Develop a database for green standards.
- Introduce sustainability culture into the community.
- Reduce the region's carbon footprint through energy efficiency.
- Arrange workshops, seminars, and presentations to businesses and the community.

However, the organization was floundering through 2010. We looked at this organization as a vehicle for education to the community and the Clean Energy Infrastructure Educational Initiative grant enabled University of Dayton involvement in this organization on a large scale.

Grant PI – Dr. Kevin Hallinan – was appointed to the position of co-Chair of the External Advisory Committee for the organization. Graduate students funded from the grant, Thomas Blurton, Marissa Bernal, Alan Pilasrski, and Bart Sturm have been central to all developments in the sustainability organization.

Hallinan and the graduate students have been involved in numerous capacities, as detailed below.

Web – page development (Blurton)

Mr. Blurton has been the designer of content and the web page for drg3 itself (www.drg3.org). This web page. A screen shot of the drg3 home page is provided in Figure 3 below. The page links to all drg3 initiatives. It is intended to be a one stop shop for all sustainability initiative in the region. It provides links to all drg3 commercial and residential programs, all parks and recreation programs, utility energy reduction rebate programs, and all news related to sustainability in the region.



Figure 3. Home page for the Dayton Regional Green 3 site (drg3.org)

Commercial Building Energy Savings Estimator Tool (Blurton / Hallinan)

A commercial building energy savings estimator tool was developed for the drg3 web site. The intent of this tool was to provide an energy effectiveness grade for a building – basing the grade on EPA Energy Portfolio benchmarks for specific energy types. In addition to the grade, a building owner/occupant is provided a comparison of the energy cost of their building relative to an A rated building so that they can see the energy cost burdent for their building clearly.

Figure 4 shows the lead in to this page. Users are asked to enter one year's energy data (gas and electric) and some simple information about their building (square footage, number of employees, building use type, hours of operation, and number of computers/servers). An energy informatics approach is used to disaggregate the energy data into weather dependent and weather dependent terms in order to determine the annual heating energy, cooling energy, water heating/reheat energy, and lighting, appliances, and ventilation energy. These energy contributions are then compared to benchmarks available from the EPA Portfolio Manager program in order to establish energy effectiveness grades for each user; overall, and in each of the energy categories noted above.



A

Highest Performing Businesses
High performing businesses attract more employees, customers, and save money

B

High Performing Business
A high performing business with room to improve

C

Typical Performing Business
Typical buildings lose approx. 30% of their energy to waste and inefficiency

D

Low Performing Business
Low performing businesses have numerous opportunities for low cost energy savings

Welcome to Dayton Regional Green 3's Grade Your Energy Use Tool!

This tool will help you assess your energy use. You will be benchmarked against other businesses in your area and will be given a Green Rating.

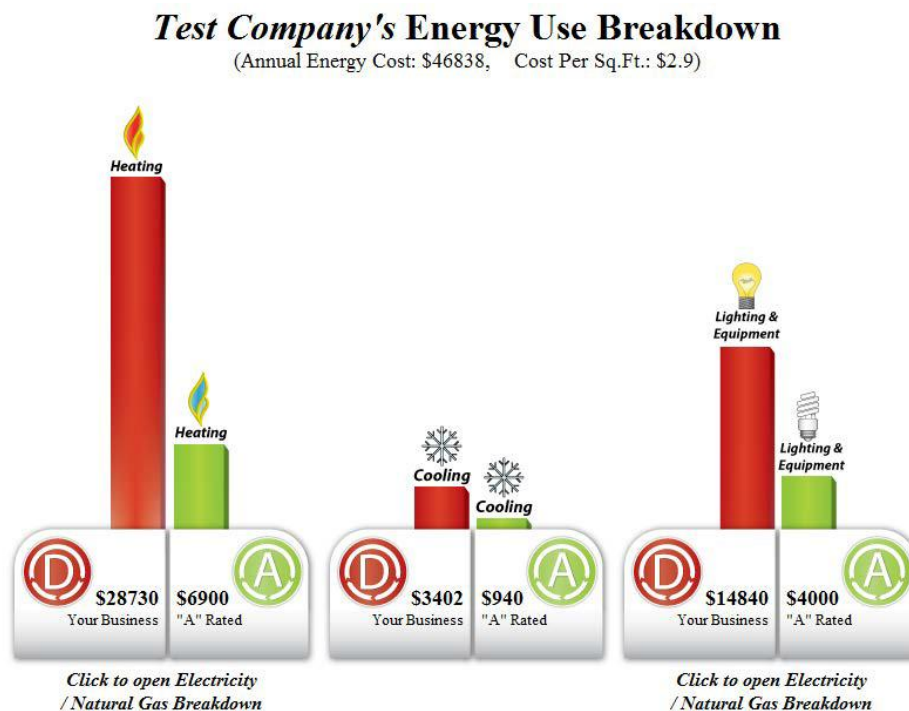
Before you continue, please make sure have the following information:

- 12 months of electricity bills
- 12 months of natural gas bills (if your business uses natural gas)
- The total heated and cooled square footage of your business

Important Note For Multi-use Buildings! This tool is for single use buildings only. If your business has a combination of manufacturing, assembly, warehouse, and/or office space linked to the same utility bill, this tool will not display accurate information. Please consider using a more advanced energy benchmarking tool such as the U.S. Department of Energy's (DOE) Portfolio Manager.
*Based on DOE's 2007 Portfolio Managers Calculation Engine

Figure 4. Building Energy Effective Rating Tool (<http://www.drg3.org/energy/>)

Figure 5 shows sample results for one building. Notable in this figure is that users are not only given a grade, but they learn how much lost income they have as a result of their energy ineffectiveness.





You lost over \$35050 due to inefficiencies!

- \$21830 in Heating. [Click for Tips!](#)
- \$2460 in Cooling. [Click for Tips!](#)
- \$10800 in Lighting, Water Heating, and Equipment Use. [Click for Tips!](#)
- Other Energy Efficiency Tips [Click for Tips!](#)

Figure 5. Sample energy effectiveness results for a participating building.

Green Business Certification Program

A Green Business Certification Program was selected as the inaugural activity for drg3 to gain visibility for the organization. A program was established. Graduate students Blurton, Bernal, and Pilarski have been instrumental in designing and implementing this program. The certification process basically requires:

- An on-site energy audit (drg3 provides small businesses an audit for a flat rate of \$100 which is waived if the building receives Green Certification status); and
- A web survey to evaluate a client's sustainability effectiveness relative to energy, solid waste, water, purchasing, and pollution prevention. See Table 2 for the rating requirements in these categories to achieve certification.

Table 2. Green Business Certification requirements

Certification Tabulation	Min Points Req'd for GBC	Actual Points Achieved	Min Points Req'd for BBC
1. General Standards for All Businesses	8		8
2. Solid Waste Reduction	12		12
3. Environmentally Preferable Purchasing	7		7
4. Energy Conservation	14		14
5. Water Conservation (Without Landscaping)	9		12
Water Conservation (With Landscaping)	10 or 18		13 or 23
6. Pollution Prevention	16		25
Total Without Landscaping:	66		78
Total With Landscaping:	67 or 75		79 or 89

The intent of the web-based survey instrument is as much about education than perfectly guaranteeing that each respondent is addressing each of the compents honestly. For example, relative to Energy Conservation the following questionnaire is administered. See Figure 5. Many of the businesses responding truly don't know what they can do to strive toward sustainability. The questionnaire itself was designed to inform as much as the measure.

As of May 2012, 58 businesses had received certification, with the program effectively beginning in September of 2011.

4 Energy Conservation		SCORE 14
A. ENERGY MANAGEMENT		REQUIREMENT YES NO
4A1. Conduct (or have a contract in place for) an ASHRAE Level 1 energy audit. Audit must be performed by a Registered Professional Engineer (PE) or a Certified Energy Manager (CEM). Not required for LEED or Energy Star buildings.	Mandatory	<input type="radio"/> <input type="radio"/>
4A2. Contact your energy provider and obtain gas/electricity consumption for 2 years	Mandatory	<input type="radio"/> <input type="radio"/>
4A3. Complete regularly scheduled maintenance on HVAC system	Mandatory	<input type="radio"/> <input type="radio"/>
4A4. Track and post monthly utility consumption (if >5 employees)	Mandatory	<input type="radio"/> <input type="radio"/>
B. ENERGY CONSERVATION (Choose at least 10 of 38 from items 4B1 thru 4B38)		REQUIREMENT YES NO
4B1. Use energy management system to control large mechanical loads		<input type="radio"/> <input type="radio"/>
4B2. Use lighting controls		<input type="radio"/> <input type="radio"/>
4B3. Implement indoor lighting efficiency		<input type="radio"/> <input type="radio"/>
4B4. Upgrade outdoor lighting to exceed IES standards for area wattage allowance		<input type="radio"/> <input type="radio"/>
4B5. Upgrade to T8 (or T5) fluorescent tubes with electronic ballasts		<input type="radio"/> <input type="radio"/>
4B6. Install programmable thermostats		<input type="radio"/> <input type="radio"/>
4B7. Set hot water heater between 120-140F		<input type="radio"/> <input type="radio"/>
4B8. Insulate major hot water pipes		<input type="radio"/> <input type="radio"/>
4B9. Use weather stripping to seal air gaps around windows and doors		<input type="radio"/> <input type="radio"/>
4B10. Use CFLs or LEDs in exit signs		<input type="radio"/> <input type="radio"/>
4B11. Use Energy Star for 50% of electrical equipment/appliances		<input type="radio"/> <input type="radio"/>
4B12. Use automatic power-down computer programs		<input type="radio"/> <input type="radio"/>
4B13. Convert hot water heaters to on-demand systems		<input type="radio"/> <input type="radio"/>
4B14. Use solar water heater or pre-heater		<input type="radio"/> <input type="radio"/>
4B15. Reduce number of lamps, install optical reflectors/diffusers		<input type="radio"/> <input type="radio"/>
4B16. Install ceiling fans for circulation		<input type="radio"/> <input type="radio"/>
4B17. Install timer to turn off office equipment after hours		<input type="radio"/> <input type="radio"/>
4B18. Install controls on vending and ice machines		<input type="radio"/> <input type="radio"/>
4B19. Use booster heater for hot water		<input type="radio"/> <input type="radio"/>
4B20. Replace refrigerators >10 years old with Energy Star model		<input type="radio"/> <input type="radio"/>
4B21. Use economizers on AC system		<input type="radio"/> <input type="radio"/>

Figure 5. Energy conservation questionnaire for Green Business Certification

DRG3 Regional Awareness

The University of Dayton has hosted the only two DRG3 regional events (October, 2011 and May, 2012). These events were used to invite businesses connected to regional Chambers of Commerce to learn about DRG3 and particularly the Green Business Certification. Additionally, the May 2012 event was organized to get next step ideas for growth and to get commitment of business leaders for participation in drg3 working groups.

DRG3 Educational Programs

University of Dayton graduate student Bart Sturm has developed educational programs for both residential and commercial building customers. A presentation has been developed for meetings with residential and commercial groups. Additionally, a hands-on self-guided tour based upon this presentation has been developed. This presentation can be accessed by users via a kiosk used for community events.

These presentations were also converted into web presentations at the drg3 site. The following url links to these web page presentation.

URL: www.drg3.org

DRG3 Grants

Through the grant period we have also assisted drg3 in the preparation of state and federal grants.

Research – Regional Priority Residential and Commercial Building Identification for Energy Efficiency

Introduction

Research is an integral component of a quality graduate program. Research that connects to the curriculum while also supporting the mission of educating the community about energy reduction is the ideal. A research strength of our faculty is in the energy informatics arena.

Initiated through this grant has been research aimed at working with the utilities to identify the commercial and residential customers in the area who have the greatest potential for energy reduction. Our research has aimed to meld historical building energy data, readily available building data from the county auditors, and weather data in order to disaggregate energy use data into heating, cooling, lighting and appliances, etc... These energy terms can be normalized relative to square footage and then compared to benchmarks available from the EPA and the U.S. Energy Information Administration for buildings of various use type.

In the midst of the grant period, a contract was established with Dayton Power and Light and Vectren to find the most likely buildings for energy reduction and then to conduct detailed energy audits of these facilities. These audits have been linked to the RCL curriculum, with RCL 550 – Special Projects (Building Energy Center) students involved educationally in the audits.

Thus this research:

- (i). educates building residents and the utilities in our region;
- (ii). helps to reduce energy use in the area; and
- (iii). educates and provides experiential learning to RCL graduate students

The following provides further details about the program.

Program Details

Pre-Assessment Activities

Identify Priority Buildings for Energy and Peak Demand Reduction

In order to identify priority buildings with energy savings potential, UD will:

- Gather energy usage data from DP&L and VEDO as well as building data from county building databases, and merge these three data sets. DP&L is responsible for providing 24 months of their commercial customers’ energy usage and peak demand data. DP&L is also responsible for providing customer peak demand information for each year;
- Analyze and disaggregate energy use into energy intensity (energy per square foot), for overall energy use as well as for all energy categories; namely heating, cooling, water heating, and lighting/appliances;
- Benchmark overall energy intensity and energy intensity in each energy category (heating, cooling, water heating, and lighting/appliances) per building use type;
- Benchmark customer peak demand intensity;
- Develop and implement algorithm for peak shaving potential based upon building use type;
- Evaluate the energy savings and peak load reduction potential of each building; and
- Identify the priority buildings having the most cost effective opportunities for energy and peak load reduction. The priority target building set will be those buildings with high end energy savings potential relative to both gas and electric energy use.
- Adhere to a strict data security protocol at all times in order to keep DP&L customer account data confidential.

Deliverable: A pre-assessment energy effectiveness report will be generated for all commercial building customers included in the study. A summary report showing the top 1,000 buildings for energy reduction will be generated and distributed to both DP&L and Vectren.

Develop Automated Reporting Capability for Energy Assessments

In order to speed the post-energy assessment process, an automated reporting system will be developed. All common analysis and plots will be automatically linked to the assessment report provided for each customer so that UD can easily provide recommendations for cost-effective energy saving opportunities.

Develop “Cloud-Based” Scheduling System

To simplify the process of scheduling assessments, UD will develop a “cloud-based” scheduling system. The site will detail available times for on-site assessments and have the functionality for a customer or DP&L/Vectren to reserve an appointment time. UD will work with DP&L/Vectren on the appearance of the site to ensure that it meets brand and quality standards. The scheduling system will be submitted to DP&L and Vectren for approval before any customer sees it.

Marketing to customers

DP&L and Vectren will be responsible for marketing the program to the top 1,000 customers. Marketing tactics may include mailings, emails, and phone calls. All marketing costs will be paid for by DP&L and Vectren, and are not included in the program budget provided in Section 5 of this agreement.

Conduct Energy Assessments

Conduct On-Site Energy Efficiency and Process Assessments

Detailed on-site building energy assessments will be performed on 36 buildings. This process will be led by UD faculty, Dr. Kevin Hallinan, with one or more energy efficiency trained graduate engineering students. DP&L and Vectren representatives may participate in any of these assessments. The team may also include other students who are participating for purposes of gaining experience or providing help in the post-assessment analysis.

The assessments will identify the most cost effective building energy system and process improvements for the building. Where appropriate the assessments will meter systems in order to improve the accuracy of savings recommendations. Metering specifically will be used to: measure % loading of a motor which may be under-powered; to monitor compressor power transients to diagnose compressor leaks; and to more accurately measure motor duty cycle for low efficiency motors where possible replacement may be in order.

At the end of each customer site assessment, UD will schedule a meeting with the program participant to share a follow-up report with the savings recommendations. This meeting will be scheduled for no more than two weeks after the energy assessment visit, unless metering is employed to measure the duty cycle of a building, where a three week span may be included. Additionally, complex geometry and multi-zoned buildings may require additional time between audit and follow-up.

The University of Dayton is responsible for ensuring safety of their faculty and students while performing site assessments. The University of Dayton will train students on safety hazards and accident prevention techniques, including providing students with site-appropriate personal protective equipment (PPE).

Conduct Energy Savings Analysis and Generate Energy Savings Reports

After the assessment, UD will calculate savings and identify the priority energy and peak demand savings opportunities. Cost savings and costs to implement recommended measures will be estimated. Finally, the appropriate DP&L and Vectren rebates, either prescriptive, custom or both will be identified².

² This assessment shall also serve as a qualifying "DRG3 audit" for customers interested in pursuing DRG3 Green Business Certification. Customers receiving DRG3 Green Business Certification may have access to "enhanced" DP&L rebates.

UD will generate a report which summarizes the priority measures, including the respective cost savings and cost to implement. Available rebate incentives will be highlighted. UD will work with DP&L and Vectren on the format of the report to ensure that it meets branding and quality standards. All reports will be submitted to DP&L and Vectren for approval before submitting to the customer. Included in the submission to DP&L and Vectren will be the energy savings calculations, to aid the review process.

Deliver Report to Customer

The report will be delivered and described to the customer by the university representatives and the energy conservation representatives of DP&L and Vectren. Utility incentives will be emphasized. The interest of the customer to respond will be gauged. If the customer has follow-up questions or needs, UD and DP&L/Vectren are jointly responsible for ensuring that the customer's needs are met.

Post-Assessment Activities

Correlate Results from On-Site Assessments with Pre-Assessment Reports

In order to improve the process of prioritizing buildings based upon the pre-assessment utility analysis, the pre-assessment results will be correlated with the recommendations made from the on-site assessments. This effort will seek to identify the most important pre-assessment indicators for the most cost effective energy reduction.

Measure Savings

UD may measure energy usage in commercial buildings where program participants implement at least one of the recommended energy savings measures. Accurate measurement of savings requires a year of post-improvement data. This is not a program activity required by DP&L and Vectren. If UD wishes to measure post-improvement energy savings, UD will need to make arrangements separately with the program participant.

Syllabi of New Course Developments

Course syllabi are included for all new or updated courses on the following pages.

MEE 590 / RCL 590 – Wind Energy Engineering

Syllabus

Instructor: Dr. K. Hallinan, Professor of Mechanical Engineering/Renewable and Clean Energy, kevin.hallinan.ud@gmail.com

Office Hours: As needed. Virtual office hours as well.

Course Website: isidore.udayton.edu....When you log-in, you will see the class displayed as MEE 499 – Wind Energy.

Textbooks: D. Spera, Wind Turbine Technology, 2nd Ed., ASME Press, 2009.

Course Description: Introduction to wind energy engineering, including wind energy potential and application to power generation. Topics include wind turbine components; turbine aerodynamics; turbine structures; turbine dynamics; wind turbine controls; fatigue; connection to the electric grid; maintenance; wind site assessment; wind economics; and wind power legal, environmental, and ethical issues.

Prerequisite: Undergraduate Fluid Mechanics and Strength of Materials Course are essential.

Course Objectives

1. To develop an understanding of historical and societal perspectives regarding the demand for mechanical and electrical power generation from wind using land/offshore turbines.
2. To develop an understanding of the physics behind the design of wind turbines.
 - Students will be able to estimate the available power for conversion, the impact of turbine blade design, size, and location relative to the ground on power generation
 - Students will be able to analyze the structural mechanics of turbine blades and structures
 - Students will be able to predict vibration concerns based on a given design
3. To help students gain the knowledge and experience needed to site a wind farm
4. To help students gain knowledge of wind turbine installation
5. To help students analyze the economics of wind energy.
6. To give students an understanding of the environmental, political, and ethical issues associated with wind energy.

Course Grading:

Midterm Exam	20%
Homework	30%
Design Project with Presentation	30%
Final Examination	20%

Grading Policy:

~~~~~A 92-100

A- 90-92

B+ 88-90

~~~~~B 82 -88

B- 80-82

C+ 78-80

C < 78

Course Dynamic:

A flipped classroom experience will be utilized. There will be no live lectures by the faculty. All lectures will be recorded and expected to be reviewed before each class. At times students will be asked to prepare a mini-lecture on a topic. A student will be called on randomly to deliver. Most often, the classroom will be a time to work problems and projects.

Midterm & Final Exam:

There will be one test and no final exam for the course. Absence from the tests will be excused only for medical reasons or serious immediate family problems. A student who anticipates missing these tests for legitimate university or professional activities should talk with the instructor at least one week prior and discuss a resolution.

Homework:

Homework is important in learning and understanding key principles. No late homework will be accepted. The homework should be done in a professional manner.

Project:

A semester long project will be assigned during the first week of class. The project will ask students to site a wind farm on a facility relatively close to the University of Dayton.

Computer Usage:

The software package MATLAB (The Mathworks) may be used in the assignments and project.

Topics:

| Week | Topic |
|-------------|----------------------------------------------------------------------------------------------------|
| Week 1 | Overview of Course; Wind Energy History; Wind Energy Potential; Overview of Wind Energy Technology |
| Week 2 | Overview of power generation availability; Wind potential estimation |
| Week 3 | Wind Turbine Power Curves; Estimation of Power Capacity |
| Week 4 | Wind Turbine Fluid Mechanics Foundation |
| Week 5 | Wind Turbine Turbomachinery / Aerodynamics |
| Week 6 | Wind Turbine Structures/Failure/Reliability |
| Week 7 | Wind Turbine Controls / Electrical Aspects |
| Week 8 | Wind Farm Siting |
| Week 9 | Wind Farm Siting |
| Week 10 | Wind Turbine Economics (Distributed) |
| Week 11 | Wind Turbine Economics (Central) |
| Week 12 | Wind Turbine/Farm Environmental & Ethical Issues |
| Week 13 | Project |
| Week 14 | Project |
| Week 15 | Project Presentations |

RCL 590 Z2 – Building Energy Informatics

Course Description: The core concept for this course is that energy + information yields reduced energy. The focus of the course is on the collection and analysis of energy data sets, processes and approaches to optimize energy distribution networks, and optimization of energy consumption systems. This course addresses the information needed, provides tools for analysis of the information, and provides an understanding of the feedback which can be used to reduce energy, using information to persuade customers to change. Students will monitor real time and monthly energy data of large multi-building sites, aggregate information into actionable information, prioritize aggregate information into potential savings, estimate savings priorities for each building and among the network of buildings, and develop and present information which can be used to persuade customers to change. Significant programming required. One major project. Pre-requisite: MEE 569 – Energy Efficient Buildings or MEE 578 – Energy Efficient Manufacturing or permission of instructor.

Instructor: Kevin P. Hallinan, 229-2835, kevin.hallinan@udayton.edu, KL 361

Computer Usage: Matlab, Excel

Course Website and Team Spaces: <https://isidore.udayton.edu/portal/site/025bf9fe-1158-4e13-9e1e-f86a2e3b3d00/page/9c32f08b-3c2f-4270-bc60-7a8f33ebc65e>

Course Elluminate Site (synchronous and asynchronous presentations):

Synchronous (Real Time):

<https://sas.illuminate.com/m.jnlp?sid=2009171&password=M.C122F987F37C2217476FB6EE190942>

Asynchronous (Off-line):

<https://sas.illuminate.com/mrtbl?suid=M.28A928D829BF8D6B50F380F2D6317C>

Grading:

Homework – 20%

Project Midterm Report – 30%

Project Final Report – 50%

Syllabus

- I. Overview Energy Informatics
- II. Strategic Energy Management
- III. Baseline Energy Characterization
- IV. Building Sensors/Energy Data Management Systems
- V. Baseline Building Energy Data Analysis
- VI. Time Analysis of Building Energy Data

- VII. Sensitivity Analysis with Multiple Parameters (Genetic Algorithms and Neural Networks)
- VIII. Effecting Occupant Behavior
- IX. Prioritizing Possible Energy Reduction/Production Actions
- X. Projects

MEE 590 Sustainable Energy Systems - Summer 2012

Instructor: Robert Brecha, Ph.D.,

Physics Dept. + Renewable and Clean Energy Program, and

Sustainability, Energy and Environment (SEE) initiative

Campus office: Science Center 25

rbrecha1@udayton.edu

Class: During the first week I will hold class "live" in a classroom for those able to be present. I do this so that I can get to know some of you. After that, the course will be online only; typically T – Th 9:00-10:15. Other times to chat can be arranged, and I am always available through e-mail.

MEE 590 is a course intended to be an overview of energy systems at the graduate level. My working assumption is that all students in the course have chosen to be here because of interest in the subject matter, and that you have a sufficient scientific and engineering background to tackle concepts and approaches to energy and environmental science that may involve some fairly sophisticated mathematics. By registering for this course (or any other course for that matter), you are effectively signing a contract to both do the work required in the course and to actively participate in class discussions during the semester. **I will expect everyone in the class to be prepared for class by doing all assigned readings and assignments ahead of time.** If you have questions about the reading material, or have trouble answering questions that are assigned, please contact me by email before class or raise questions during class.

There are several broad themes that will be covered in this class. We will take time to look at some basic characteristics of the current energy system, along with limitations and objections to further growth in that system in a "business-as-usual" fashion. Questions to be examined include the availability and consequences of finite fossil fuel resources and anthropogenic climate change. We will examine predictions of impending "peak oil", as well as estimates for other fossil fuel resources. As for climate change, we will have to understand how energy is transported from the sun to the earth, and how that energy is exchanged between the earth's surface, the atmosphere, the oceans, and ultimately, with space. As an introduction, we will investigate a simple energy balance model of the earth-sun system. We will also look at some alternative energy sources and discuss the feasibility of making changes from stored solar energy (fossil fuels) to current solar energy. As renewable energy sources become more prominent, care must be taken to address issues of sustainability, a term that will require some consideration. For example, we will touch on issues of intergenerational and international responsibility. An overarching theme is that the energy system is becoming more complex – simple equations like "oil = transportation" and "coal = electricity" will need revision. Furthermore, there will likely be increases in the linkage between energy, water and food systems. Because of the combination of driving factors, a virtually complete re-build of the energy system will take place in the next few

decades. You will be an instrumental part of that process and should have an understanding of not only the details of certain technologies, but also a picture of links and interactions between energy sources and impacts.

The text for the course is Energy Systems Engineering – Evaluation and Implementation, by F.M. Vanek and L.D. Albright. The text can be purchased as a used book (I am still using the first edition for this course; a new edition has just been published, but not in time for me to take advantage of it) and will be available through the UD Isidore site on a chapter-by-chapter basis. In addition, the Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Renewable Energy Sources last year; this document (~1000 pages) will be made available as a useful reference and compilation of some of the most recent information about renewable energy capacity, progress, economics, etc. The course will follow (mostly) an online lecture format, with lectures recorded and available to students. Powerpoint presentations will also be made available. I do not expect to have to cover all material in the text for you; repeating what you can already read would be an insult to your abilities. However, all assigned reading material is part of what I expect you to master for the purpose of homework and other assignments. For this to work, you must keep up with the reading and be prepared to ask questions. I will also be using other sources of information for the course, some of which will be made available as handouts or electronic links, as the emphasis I will be placing on some material is slightly different from that in the texts.

On the Isidore course webpage I will be posting homework assignments *to be submitted on* the posted due date, generally on Monday. The course outline will provide a list of readings *to be done before coming to class* with essentially one reading assignment for each class period. The general idea is that the readings are to prepare you for the material to be covered in class. The problems are to be done after we have covered material in class, and serve as practice for your newly-acquired skills and knowledge. There will be homework problems and exercises due every week. I encourage you to work together on homework problems, but the work you do must be your own.

Homework will be turned in as a Word document, including all plots, equations, etc. You should learn to become proficient with the equation editor in Word, and it is expected that you will know how to use Excel and/or MatLab to examine data, make plots, etc. Think of your homework assignments as a simplified form of a scientific paper. You must always present complete work, and not just final answers. Your work must be understandable to me; I will not engage in guesswork about what you perhaps meant to convey in your homework solutions. Homework will be submitted and given an understandable document name in the form: *your_family_name_HWxx*.

In addition to homework problem sets, there will be at least one additional written assignment.

| | | |
|---------------------|---------------|-----|
| Grade distribution: | Homework | 85% |
| | Final paper | 10% |
| | Participation | 5% |

A 92-100%; A- 88-92%; B+ 85-88%; B 82-85%; B- 78 – 82%; C 65-78%; F <65%

Support for Your Learning in This Class

The LTC’s Office of Student Learning Services (SLS) is a learning resource for all students at the University of Dayton. SLS offers a wide variety of services to assist you in achieving academic success at the university, including study skills classes and workshops, tutoring and consultations, disability screenings, and a web site with many resources

(<http://learningsupport.udayton.edu>). Please contact SLS at 937-229-2066 or visit their office on the ground floor of Roesch Library (LTC 023) if you would like to talk about how you could be a more effective learner.

Students with Disabilities

I would like us to discuss ways to ensure your full participation in this course. If you feel you need an accommodation based on the impact of a disability, please contact me privately to discuss your specific needs. Formal disability-related accommodations are determined through the Learning Teaching Center’s Office of Student Learning Services (SLS). It is very important that you be registered with SLS and notify me of your eligibility for reasonable accommodations with a signed SLS Self-Identification Form. We can then plan how best to coordinate your accommodations. For more information, please contact SLS at 937-229-2066, by email at disability.services@notes.udayton.edu or stop by the SLS office in LTC 023.

Topics

| Date | Topic | Text Assignment | Notes and other exercises |
|---------------------------------------|-----------------------------------------|-----------------|---------------------------|
| Week 1 | | | |
| Mon. May 14 | Introductory material | Chap. 1 | |
| Tue. May 15 | Systems Tools | Chap. 2 | |
| Wed. May 16 | Systems Tools | Chap. 2 | |
| Thur. May 17 | Economic Tools | Chap. 3 | |
| Week 2 | | | |
| Mon. May 21 | HW Problems due – systems and economics | | |
| Tue. May 22 –
Thur. May 24 | Discussions – Prompts to be provided | | |
| Week 3 | | | |
| Tue. May 29 | Fossil fuel resources | Chap. 5 | |
| Wed. May 30 | Climate change | Chap. 4 | |
| Thur. May 31 | Climate modeling | Chap. 4 | |
| Week 4 | | | |

| | | | |
|---------------|--------------------------------------------------------|----------------|--|
| Mon. June 4 | HW Problems due - resources | | |
| Tue. June 5 | Climate scenarios | Add'l. reading | |
| Wed. June 6 | Climate economics | Add'l. reading | |
| Thur. June 7 | Stationary combustion systems – GHG and LCA | Chap. 6 | |
| Week 5 | | | |
| Mon. June 11 | HW Problems due – climate | | |
| Tue. June 12 | Economics and impacts of stationary combustion systems | Chap. 6 | |
| Wed. June 13 | Carbon sequestration and geoengineering | Chap. 7 | |
| Thur. June 14 | Nuclear energy | Chap. 8 | |
| Week 6 | | | |
| Mon. June 18 | | | |
| Tue. June 19 | Nuclear power, economics and impacts | Chap. 8 | |
| Wed. June 20 | Solar resource | Chap. 9 | |
| Thur. June 21 | Solar photovoltaics | Chap. 10 | |
| Week 7 | | | |
| Mon. June 25 | HW Problems due – Stationary, including nuclear | | |
| Tue. June 26 | Solar thermal systems | Chap. 11 | |
| Wed. June 27 | Wind energy | Chap. 12 | |
| Thur. June 28 | Challenges and analysis of fluctuating renewables | | |
| Week 8 | | | |
| Mon. July 2 | | | |
| Tue. July 3 | Energy storage technologies | Add'l. reading | |
| Wed. July 4 | Independence Day – no class | | |
| Thur. July 5 | Heat transfer and buildings | Add'l. reading | |
| Week 9 | | | |
| Mon. July 9 | HW Problems due – solar, wind, storage | | |
| Tue. July 10 | Residential building modeling | | |
| Wed. July 11 | Transportation systems | Chap. 13 | |
| Thur. July 12 | Transportation scenarios | Chap. 14 | |
| Week 10 | | | |
| Mon. July 16 | HW Problems due – buildings and transportation | | |
| Tue. July 17 | Energy and the food system | | |
| Wed. July 18 | Energy and water | | |
| Thur. July 19 | Conclusions | Chap. 15 | |
| Fri. July 20 | Final paper due | | |

Geothermal Energy Systems

MEE 499; MEE/RCL 590, Spring 2012

Course Information

| | |
|--------------------|---------------------------------------|
| Class Days/Time: | Two (usually) class sessions per week |
| Classroom: | Web |
| Pre/Co-Requisites: | Thermodynamics, Heat Transfer |
| Instructor: | Andrew Chiasson, Ph.D., P.E. |
| Email Address: | Andrew.Chiasson@udayton.edu |

Course Mechanics and Web Page

This is a web-based course with all course materials such as the syllabus, recorded lectures, lecture notes, major assignments, and handouts located on the course web site on Isidore.

The URL for Isidore is: <http://isidore.udayton.edu> . You will be prompted for your UD login and password.

Recorded class sessions can be found under the *Collaborate Classroom* link in the Isidore course website. There will be usually two recorded lectures per week that will be posted on Isidore generally on Tuesdays and Thursdays, except on holidays observed by the University of Dayton.

Course Description

This course will cover the theory and design of the three broad uses of geothermal energy: (i) heat pump applications, (ii) direct uses, and (ii) electrical energy generation. The majority of the course will focus on heat pump applications, with emphasis on ground heat exchanger simulation and design for buildings and other systems. Closed-loop, open-loop, and hybrid geothermal heat pump systems will be examined. Heating, cooling, and electricity generating applications using hot geothermal reservoirs will also be discussed.

The course will expose students to the development and use of geothermal design and simulation tools. Most of the tools will be implemented in Excel, but students are welcome to use other software tools such as Engineering Equation Solver (EES) or MATLAB. Some of the class time will be devoted to demonstrating the development and use of these tools, which will be used to solve homework problems.

Graduate students will be expected to review and submit a written critique of two journal articles or scientific publications of their choice.

Overall Course Goals or Student Learning Objectives

- To appreciate the importance of alternative energy sources and uses to our society.
- To acquire the knowledge and skills to model and design geothermal energy systems.
- To improve our ability to solve engineering problems through the application of economic, heat transfer, fluid mechanic, and thermodynamic principles and the use of computers.
- To improve our ability to communicate technical information.

Course Content Learning Outcomes

Upon successful completion of this course, you will be able to:

- Identify and clearly describe intended end use(s) of conventional energy and geothermal counterparts.
- Develop mathematical models for design and simulation of closed- and open-loop geothermal systems.
- Compute and compare end use consumption of conventional and alternative energy for a given application.
- Evaluate economic life-cycle cost of geothermal energy systems relative to conventional energy systems.
- Select/recommend preferred energy systems option (conventional, geothermal, hybrid).
- Communicate (both orally and written) technical information to both technical and non-technical audiences in a clear and concise manner.

Required Texts/Readings/Equipment

Textbook: None required.

Reference Books and Sources:

- **ASHRAE Handbooks**
- **Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings; S.P.Kavanaugh and K. Rafferty; www.ashrae.org.**
- **www.geokiss.com (information and tools for ground-source heat pumps)**
- **<http://geoheat.oit.edu> (information for direct-use high-temperature geothermal)**

Grading

Your grade for this course will be determined by homework assignments and a final project. In addition, graduate students will also submit two journal article critiques.

Homework will be assigned on a weekly basis. **Assignments shall be submitted through Isidore only. Late homework will not be accepted.** A comprehensive project will be assigned midway through the course and will be due prior to the last day of classes.

| | |
|----------------|------------|
| Homework: | 80% |
| Final Project: | <u>20%</u> |
| | 100% |

The following scale will be used to determine your final grade:

| | | | | | | | | | |
|-------|------|------|------|------|------|------|------|------|------|
| F | D | C- | C | C+ | B- | B | B+ | A- | A |
| <60.0 | 60.0 | 70.0 | 73.0 | 76.0 | 80.0 | 83.0 | 86.0 | 90.0 | 93.0 |

University Policies

Intellectual Property Statement

The materials shared with you during this course are authored by and owned by the instructor, the department, the school and/or the book publisher. Copyright laws must be respected in using these materials. For example, unless authorized to do so, do not share course materials with anyone outside the course.

Academic Honesty

I encourage you to talk with each other about the readings and ideas brought up in class. But in all assignments to be graded as individual work you are expected to do your own written work. In the case of group work, all members of a group will be held responsible for the content of work turned in to satisfy group assignments. The instructor will keep a healthy eye out for possible plagiarism when reading your work. Here is some advice to help you avoid plagiarizing:

It is best to express the ideas you use in your own words. In the case of both individual and group work, words or ideas that come from someplace or someone else must be cited: "A good rule of thumb is this: Whenever you consciously borrow any important element from someone else, any sentence, any colorful phrase or original term, any plan or idea—say so, either in a footnote, bibliography, or parenthesis" (from "Academic Honesty in the Writing of Essays and Other Papers," Carleton College, 1990).

For specific university policies concerning academic honesty, see the University's [Academic Honor Code](http://bulletin.udayton.edu/content.ud?v=29&p=3286&c=3313) in the Bulletin <<http://bulletin.udayton.edu/content.ud?v=29&p=3286&c=3313>>.

Dropping the Course

You are responsible for understanding the university's policies and procedures regarding withdrawing from courses. And you should be aware of the current deadlines and penalties for dropping classes. Information on [withdrawal from courses](http://bulletin.udayton.edu/content.ud?v=29&c=3312&p=3286) (<http://bulletin.udayton.edu/content.ud?v=29&c=3312&p=3286>) is available in the Bulletin under Grades and Scholarship and from your Dean's Office.

Tentative Course Schedule

Geothermal Energy Systems; MEE 499; MEE/RCL 590; Spring 2012

| Week | Date
(Monday starting week) | Topics to be Covered |
|------|--------------------------------|-------------------------------------------------------------------------------------------------------|
| 1 | Jan. 16 | Course Mechanics; Geothermal Energy Overview; Heat Pump Fundamentals |
| 2 | Jan. 23 | Heat Pumps Fundamentals (<i>cont.</i>) |
| 3 | Jan. 30 | Heat Pumps Fundamentals (<i>cont.</i>) |
| 4 | Feb. 6 | Heat Pumps & Outdoor Air; Selecting a Heat Pump |
| 5 | Feb. 13 | Ground-Coupled Heat Pump Systems |
| 6 | Feb. 20 | Vertical Bore Ground-Coupled Heat Pump Systems |
| 7 | Feb. 27 | Vertical Bore Ground-Coupled Heat Pump Systems (<i>cont.</i>); NO CLASS Thurs. (Mid-Term Break) |
| 8 | Mar. 5 | Vertical Bore Ground-Coupled Heat Pump Systems (<i>cont.</i>); Laying out the Ground Heat Exchanger |
| 9 | Mar. 12 | Final Project Assigned; Multi-Borehole Systems and Simulation |
| 10 | Mar. 19 | Horizontal Ground-Coupled Heat Pump Systems; Earth Tubes |

| Week | Date
<i>(Monday starting week)</i> | Topics to be Covered |
|-------------|----------------------------------------------|------------------------------------------------------------------------------------------------|
| 11 | Mar. 26 | Surface Water Heat Pump Systems |
| 12 | Apr. 2 | Inside the Building Considerations; NO CLASS Thurs., Apr. 5 (<i>Easter Break</i>) |
| 13 | Apr. 9 | Inside the Building Considerations (<i>cont.</i>); Groundwater (open-loop) Heat Pump Systems |
| 14 | Apr. 16 | Groundwater (open-loop) Heat Pump Systems(<i>cont.</i>); Direct Use Geothermal |
| 15 | Apr. 23 | Geothermal Power Plants; Geothermal Resource Development |
| Finals Week | Apr. 30 | End of Course |

Solar Energy Engineering

MEE 590-04, RCL 590-01, Fall 2011

Course Information

| | |
|--------------------|------------------------------------------------------------|
| Class Days/Time: | Two (usually) class sessions per week |
| Classroom: | Web |
| Pre/Co-Requisites: | Renewable Energy Systems; Heat Transfer;
Thermodynamics |
| Instructor: | Andrew Chiasson, Ph.D., P.E. |
| Email Address: | andrew.chiasson@udayton.edu |

Course Mechanics and Web Page

This is a web-based course with all course materials such as the syllabus, recorded lectures, lecture notes, major assignments, and handouts located on the course web site on Isidore.

The URL for Isidore is: <http://isidore.udayton.edu> . You will be prompted for your UD login and password.

Recorded class sessions can be found under the *Illuminate Classroom* link in the Isidore course website. There will be usually two recorded lectures per week that will be posted on Isidore generally on Tuesdays and Thursdays, except on holidays observed by the University of Dayton.

Course Description

This course will cover the theory, design, and application of the two broad uses of solar energy: (i) direct thermal uses and (ii) electrical energy generation. The majority of the course will focus on thermal applications, with emphasis on system simulation and design for buildings and other systems.

The course will expose students to the development and use of solar design and simulation tools. Most of the tools will be implemented in Excel and TRNSYS, but students are welcome to use other software tools such as Engineering Equation Solver (EES) or MATLAB. Some of the class time will be devoted to demonstrating the development and use of these tools, which will be used to solve homework problems.

Overall Course Goals or Student Learning Objectives

- To appreciate the importance of alternative energy sources and uses to our society.
- To acquire the knowledge and skills to model and design solar energy systems.
- To improve our ability to solve engineering problems through the application of economic, heat transfer, fluid mechanic, and thermodynamic principles and the use of computers.
- To improve our ability to communicate technical information.

Course Content Learning Outcomes

Upon successful completion of this course, you will be able to:

- Identify and clearly describe intended end use(s) of conventional energy and solar counterparts.
- Apply mathematical models for design and simulation of solar energy systems.
- Compute and compare end use consumption of conventional and alternative energy for a given application.
- Evaluate economic life-cycle cost of solar energy systems relative to conventional energy systems.
- Select/recommend preferred energy systems option (conventional, solar, hybrid).
- Communicate technical information to both technical and non-technical audiences in a clear and concise manner.

Required Texts/Readings/Equipment

Textbook: None required.

Reference Books and Sources:

- **Solar Engineering of Thermal Processes, 3rd Ed., by J.A. Duffie & W.A. Beckman, 2006.**
- **ASHRAE HVAC Applications Handbook**
- **RetScreen e-textbook (<http://retscreen.net>)**

Grading

Your grade for this course will be determined by homework assignments and a final project.

Homework will be assigned on a weekly basis. **Assignments shall be submitted through Isidore only. Late homework will not be accepted.** A comprehensive project will be assigned midway through the course and will be due during finals week or before.

| | |
|----------------|------------|
| Homework: | 80% |
| Final Project: | <u>20%</u> |
| | 100% |

The following scale will be used to determine your final grade:

| | | | | | | | | | |
|-------|------|------|------|------|------|------|------|------|------|
| F | D | C- | C | C+ | B- | B | B+ | A- | A |
| <60.0 | 60.0 | 70.0 | 73.0 | 76.0 | 80.0 | 83.0 | 86.0 | 90.0 | 93.0 |

University Policies

Intellectual Property Statement

The materials shared with you during this course are authored by and owned by the instructor, the department, the school and/or the book publisher. Copyright laws must be respected in using these materials. For example, unless authorized to do so, do not share course materials with anyone outside the course.

Academic Honesty

I encourage you to talk with each other about the readings and ideas brought up in class. But in all assignments to be graded as individual work you are expected to do your own written work. In the case of group work, all members of a group will be held responsible for the content of work turned in to satisfy group assignments. The instructor will keep a healthy eye out for possible plagiarism when reading your work. Here is some advice to help you avoid plagiarizing:

It is best to express the ideas you use in your own words. In the case of both individual and group work, words or ideas that come from someplace or someone else must be cited: "A good rule of thumb is this: Whenever you consciously borrow any important element from someone else, any sentence, any colorful phrase or original term, any plan or idea—say so, either in a footnote, bibliography, or parenthesis" (from "Academic Honesty in the Writing of Essays and Other Papers," Carleton College, 1990).

For specific university policies concerning academic honesty, see the University's [Academic Honor Code](http://bulletin.udayton.edu/content.ud?v=29&p=3286&c=3313) in the Bulletin <<http://bulletin.udayton.edu/content.ud?v=29&p=3286&c=3313>>.

Dropping the Course

You are responsible for understanding the university's policies and procedures regarding withdrawing from courses. And you should be aware of the current deadlines and penalties for dropping classes. Information on [withdrawal from courses](http://bulletin.udayton.edu/content.ud?v=29&c=3312&p=3286) (<http://bulletin.udayton.edu/content.ud?v=29&c=3312&p=3286>) is available in the Bulletin under Grades and Scholarship and from your Dean's Office.

The last day to drop a course in Fall 2011 with a grade of W is: **Monday, November 7, 2011.**

Tentative Course Schedule

Solar Energy Engineering; MEE/RCL 590; Fall 2011

| Week | Date
(Monday starting week) | Topics to be Covered (two classes per week) |
|------|--------------------------------|---------------------------------------------------------------------------------------------------------|
| 1 | Aug. 22 | Course Mechanics; Solar Energy Overview |
| 2 | Aug. 29 | Definitions, fundamentals, solar radiation on surfaces |
| 3 | Sep. 5 | Selected heat transfer topics |
| 4 | Sep. 12 | Solar Collectors |
| 5 | Sep. 19 | Energy Storage; Solar Process Loads |
| 6 | Sep. 26 | Thermal Applications: Solar Water Heating |
| 7 | Oct. 3 | Thermal Applications (<i>cont</i>): Solar Water Heating (<i>cont.</i>) |
| 8 | Oct. 10 | Thermal Applications (<i>cont</i>): Space Heating;
NO CLASS Thurs., Oct. 6 (Mid-Term Break) |
| 9 | Oct. 17 | Thermal Applications (<i>cont</i>): Passive Solar Heating;
Final Project Assigned |
| 10 | Oct. 24 | Thermal Applications (<i>cont</i>): Solar Cooling |

| Week | Date
<i>(Monday starting week)</i> | Topics to be Covered (two classes per week) |
|-------------|----------------------------------------------|-------------------------------------------------------------------------------------------------------|
| 11 | Oct. 31 | Thermal Applications (<i>cont</i>): Solar Combisystems |
| 12 | Nov. 7 | Thermal Applications (<i>cont</i>): Solar Ponds |
| 13 | Nov. 14 | Thermal Applications (<i>cont</i>): Electrical Power Systems |
| 14 | Nov. 21 | Solar Photovoltaics
NO CLASS Thurs., Nov. 24 (<i>Thanksgiving</i>) |
| 15 | Nov. 28 | Solar Photovoltaics (<i>cont</i>). |
| 16 | Dec. 5 | Final Project Wrap-up;
NO CLASS Thurs., Dec. 8 (Immaculate Conception, Christmas on Campus) |
| Finals Week | Dec. 12 | Project Due Monday Dec. 12 by 5:00 PM |

Renewable Energy Systems

RCL 573, MEE 473/573, Fall 2011

Course Information

| | |
|--------------------|-----------------------------------------|
| Class Days/Time: | M W / 3:00 – 4:15 PM |
| Classroom: | KL 221 |
| Pre/Co-Requisites: | Thermodynamics, Heat Transfer |
| Instructor: | Andrew Chiasson, Ph.D., P.E. |
| Office Location: | KL 363A |
| Telephone Number: | 937-229-2892 (Off.) |
| Email Address: | andrew.chiasson@udayton.edu |
| Office Hours: | (T Th, 3:00-4:00 PM, or by appointment) |

Course Web Page

<https://quickplace.udayton.edu/mee473573>

This site will contain all course materials: syllabus, lecture notes, assignments, recorded lectures, and handouts.

Virtual Classroom Live Link

Offsite students can view the lectures at:

<https://sas.illuminate.com/m.jnlp?password=M.A3437642CAEB3386DB403C97F131BF&sid=2009171>

(Recorded lectures will be posted on the QuickPlace site).

Course Description

The energy challenges facing our society today are not news anymore. The sources and technologies we use for energy today stem from the Industrial Revolution, some 200 years ago. With growing world population (in addition to increased rates of urbanization in developing countries) and corresponding expected growth in energy demand, our current energy practices are not sustainable; fossil fuel resources are finite and are attributed to negative environmental impacts. Energy from clean, renewable sources promises to have an increasing role in meeting future energy needs.

This course takes a practical approach to introduce students to various sources and uses of renewable energy, and its economic feasibility. In general, this course will examine energy sources and uses in the context of: (1) generation of electrical energy, (2) thermal uses of energy, and (3) alternative fuels for transportation. Some of the specific areas that will be discussed include conventional energy production and uses, solar energy utilization, wind

energy utilization, biomass, combined heat and power (CHP), run-of-river hydro applications, geothermal energy utilization, fuel cells, and alternative fuels for vehicles. The course will make use of RETScreen, a software tool for conducting preliminary design and economic feasibility of renewable energy projects. This software tool will be used for solving in-class and homework problems.

Overall Course Goals or Student Learning Objectives

- To appreciate the importance of energy and renewable energy to our society.
- To acquire the knowledge and skills to model and design renewable energy systems.
- To improve our ability to solve engineering problems through the application of economic, heat transfer, fluid mechanic, and thermodynamic principles and the use of computers.
- To improve our ability to communicate technical information.

Course Content Learning Outcomes

Upon successful completion of this course, for a given situation, you will be able to:

- Identify and clearly describe the intended end use(s) of energy.
- Identify *conventional* sources of energy and *renewable* energy counterparts.
- Identify the technologies for energy conversion or generation, and distribution to end uses.
- Diagram/design the conventional and renewable energy system from source to end use.
- Compute and compare end use consumption of conventional and renewable energy.
- Evaluate economic life-cycle cost of renewable energy systems relative to conventional energy systems.
- Select/recommend preferred energy systems option (conventional, renewable, hybrid).
- Communicate (both orally and written) technical information to both technical and non-technical audiences in a clear and concise manner.

Required Texts/Readings/Equipment

Textbook: *Alternative Energy Systems and Applications* by B.K. Hodge, 2010, John Wiley & Sons, Inc., ISBN: 978-0-470-14250-9

Other Reference Books: e-textbook at: <http://retscreen.net>

Other equipment / materials requirements : RetScreen software is required for in-class problems and homework. This is freeware available at: www.retscreen.net

Grading

| | |
|----------------|---------------------------------------|
| Exam #1: | 20% |
| Exam #2: | 20% |
| Homework: | 40% (<i>late penalty = 33%/day</i>) |
| Final Project: | <u>20%</u> |

100%

The following scale will be used to determine your final grade:

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------|------------|------------|----------|-----------|------------|-----------|------------|------------|----------|------------|------------|-----------|-----------|------------|-----------|-----------|------------|----------|-----------|------------|-----------|-----------|------------|-----------|-----------|------------|----------|
| F | --- | --- | D | -- | --- | C- | --- | --- | C | --- | --- | C+ | -- | --- | B- | -- | --- | B | -- | --- | B+ | -- | --- | A- | -- | --- | A |
| <60.0 | 60.0 | | 70.0 | | | 73.0 | | | 76.0 | | | 80.0 | | | 83.0 | | | 86.0 | | | 90.0 | | | 93.0 | | | 100 |

Classroom Protocol

All electronic devices including cell phones must be turned off and are not to be visible at any time during class unless specifically directed by the instructor.

Notebook computers may be used in class for taking notes and specified in-class activities, not for instant messaging, email or other distractions.

All email messages will be sent to you via your Lotus Notes Account, so you should be in the habit of checking that account every day or you should ensure that Lotus Notes forwards messages to another account of your choice.

In addition, as a student in this class, you are expected to:

- Take ownership and responsibility for the conduct of the class.
- Always treat class members with respect.
- Be considerate and limit materials or actions that others might find distracting, such as conversations, work from other classes, newspapers, video games, etc.
- Be prepared to contribute to group and class discussions in a courteous, substantive, and thoughtful manner.
- Bring necessary materials to every class.

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University Services (free for all students)

Support for Your Learning in This Course

The LTC's Office of Student Learning Services (SLS) is a learning resource for all students at the University of Dayton. SLS offers a wide variety of services to assist you in achieving academic success at the University, including study skills classes and workshops, tutoring and consultations, disability screenings, and a web site with many resources (<http://learningservices.udayton.edu>). Please contact SLS at 937-229-2066 or visit their office on the ground floor of Roesch Library (LTC 023) if you would like to talk about how you could become a more effective learner.

Students with Disabilities

Your learning in this course is important to me. I invite you to come and talk with me about ways to ensure your full participation in the course. If you feel you need an accommodation based on the impact of a disability, please contact me privately to discuss your Self-Identification Form as provided by the LTC's Office of Student Learning Services (SLS). It is important that you be registered with SLS and notify me of your eligibility for reasonable accommodations in a timely manner, and, when appropriate, that we make special arrangements in case of an emergency building evacuation. For more information about disability services at the University of Dayton, please contact SLS at 937-229-2066, by email at disabilityservices@udayton.edu or stop by SLS in the LTC, room 023.

Tentative Course Schedule

Renewable Energy Systems; MEE 473/573; Fall 2010

| Week | Date
(<i>Monday starting week</i>) | Topics to be Covered |
|------|-----------------------------------------|---------------------------------------------------------------|
| 1 | Aug. 23 | Course Mechanics; Renewable Energy (RE) in Context |
| 2 | Aug. 30 | Overview of RE Technologies; Energy Engineering Economics |
| 3 | Sept. 6 | NO CLASS Mon. (<i>Labor Day</i>); Solar Energy Fundamentals |
| 4 | Sept. 13 | Active & Passive Solar Thermal Systems |
| 5 | Sept. 20 | Solar Thermal Systems (continued) |
| 6 | Sept. 27 | Solar Photovoltaic Systems |
| 7 | Oct. 4 | Wind Energy Utilization |
| 8 | Oct. 11 | Final Project Assigned ; Wind Energy Utilization (cont.) |
| 9 | Oct. 18 | EXAM #1 (Mon. Oct. 18); Final Project Discussions |
| 10 | Oct. 25 | Combined Heat and Power (CHP); Biomass Applications |

| Week | Date
<i>(Monday starting week)</i> | Topics to be Covered |
|-------------|----------------------------------------------|-------------------------------------------------------------------------------|
| 11 | Nov. 1 | Run of River Hydro Applications; Geothermal Energy Utilization |
| 12 | Nov. 8 | Geothermal Energy Utilization (<i>cont.</i>) |
| 13 | Nov. 15 | Alternative Fuels for Transportation and Fuel Cells |
| 14 | Nov. 22 | Emerging Energy Technologies; NO CLASS Wed., Nov. 24 (<i>Thanksgiving</i>) |
| 15 | Nov. 29 | Combining / Integrating Multiple Source Technologies |
| 16 | Dec. 6 | Final Project Presentations; NO CLASS Wed., Dec. 8 (Holiday) |
| Final Exam | Dec. 13 | EXAM #2 Mon. Dec. 13; 2:30-4:20 PM (Final Project Report Due) |

Wright State University

Sinclair Community College

Introduction

This report covers the work performed at Sinclair Community College under the Department of Energy grant entitled "Clean Energy Infrastructure Educational Initiative". The University of Dayton led the collaboration with Wright State University and Sinclair Community College on this one year project to improve the education of students in renewable and clean energies. Sinclair participated as a subcontractor to the University of Dayton. The work at Sinclair concentrated on developing curriculum and furnishing laboratories with supporting instrumentation and equipment necessary to complete programs to offer an Energy Technology Certificate and an Energy Management Degree at the associate's level.

Curriculum Development

The curriculum development process focused on designing instructional programs, certificate and associate's degree, which would prepare the workforce to analyze, design, and/or make retrofit recommendations for residential, commercial, and industrial buildings and facilities to increase their energy efficiency and reduce their energy use. The curriculums address the building's envelope, mechanical systems, and the operational procedures. Also included in the programs is the design and installation of renewable energy systems.

The Energy Technology Certificate program was officially initiated in 2011 and the Energy Management Degree program was officially initiated in 2012. Enrollment in the courses has been a function of the timing of the development and offering of each course.

| Course | Enrollments |
|----------------------------------------------------------|-------------|
| 1. Weatherization Training | 35 students |
| 2. Introduction to Energy Management Principles | 24 students |
| 3. LEED Green Associate Exam Preparation | 50 students |
| 4. Energy Control Strategies (pilot offering) | 4 students |
| 5. Commercial and Industrial Assessment (pilot offering) | 4 students |
| 6. Solar Photovoltaic Design and Installation | 23 students |
| 7. Solar Thermal Design and Installation | 11 students |

ENERGY MANAGEMENT DEGREE PROGRAM DESCRIPTION:

This program is intended for students who are interested in an entry-level position in the field of energy services. This program consists of HVAC, energy analysis and management, energy services and renewable energies courses.

PURPOSE:

To prepare student for careers in the Energy Management Field to conduct energy audits and analysis and prepare economic analysis of energy use and management in buildings and institutions to recommend cost saving corrective action

SPECIFIC NEEDS:

There exists a high priority of solving global environmental problems such as climate change, air pollution, and habitat and resource depletion as well as the labor market demand for new employees in the arena of energy efficiency and renewable energy.

PROGRAM OUTCOMES:

The following outlines the five program outcomes and lists the specific courses which address the outcomes.

1. Demonstrate the ability to collect and analyze pertinent energy-related data and to render findings, conclusions and recommendations.
 - a. Introduction to HVAC Systems
 - b. Basics of Heating & Heating systems
 - c. Basics of Cooling & Cooling Systems
 - d. Basics of Electrical Circuits & Controls
 - e. Mechanical Systems Blueprint Reading
 - f. Introduction to Physics
 - g. HVAC Loads & Distribution for Small Buildings
 - h. Energy Management Principles
 - i. Architectural Energy Analysis
 - j. Weatherization Training
2. Demonstrate the proper operation of the components of heating, air-conditioning, and air handling systems and subsystems.
 - a. Introduction to HVAC Systems
 - b. Basics of Heating & Heating systems
 - c. Basics of Cooling & Cooling Systems
 - d. Basics of Electrical Circuits & Controls
 - e. Mechanical Systems Blueprint Reading
 - f. Introduction to Physics
 - g. HVAC Loads & Distribution for Small Buildings
3. Demonstrate the basics concepts of heat transfer through building envelopes.
 - a. Introduction to Physics
 - b. Energy Management Principles
 - c. Architectural Energy Analysis
 - d. Weatherization Training
4. Demonstrate the basic concepts of energy conservation and the purposes, objectives and mechanics of energy auditing processes.
 - a. Alternative and Renewable Energy Sources
 - b. Introduction to Physics
 - c. Energy Management Principles
 - d. Architectural Energy Analysis
 - e. Weatherization Training
5. Demonstrate the specification, use and calibration of measuring devices such as blower door, duct blaster, infrared camera and combustion analyzer.
 - a. Introduction to Physics

- b. Energy Management Principles
- c. Architectural Energy Analysis
- d. Weatherization Training

RATIONALE:

The purpose of the program is to prepare students for entry-level positions in the field of energy services. This program will give the students the information of envelope, mechanical systems, and operational procedures in buildings to analyze energy use, describe energy saving opportunities and prepare energy management plans and reports.

ENERGY MANAGEMENT DEGREE CURRICULUM

| Course Number and Title | # of Credits |
|----------------------------------------------------------------------------|--------------|
| CAT1111 - Mechanical Systems Blueprint Reading | 1 |
| COM2211 - Effective Public Speaking | 3 |
| EET1120 - Introduction to DC & AC Circuits | 2 |
| EGV1101 - Alternate & Renewable Energy Sources | 2 |
| EGV1201 - Weatherization Training | 2 |
| EGV1251 - Introduction to Energy Management Principles | 3 |
| EGV1301 - Architectural Energy Analysis | 2 |
| EGV1351 - Building Performance Training | 2 |
| EGV2101 - Solar Photovoltaic Design & Installation | 3 |
| EGV2151 - Solar Thermal Systems | 3 |
| EGV2201 - Electrical Lighting & Motors | 2 |
| EGV2251 - Energy Control Strategies | 2 |
| EGV2301 - Commercial & Industrial Assessment | 3 |
| EGV2351 - LEED Green Associate Exam Preparation | 2 |
| EGV2780 - Energy Management Technology Capstone | 4 |
| ENG1101 - English Composition I | 3 |
| HVA1201 - Basic HVAC Systems with Cooling | 3 |
| HVA1221 - Heating Systems | 3 |
| HVA1261 - HVAC Loads & Distribution for Small Buildings | 3 |
| HVA1351 - Building Psychrometrics & Load Calculations | 4 |
| MAT1280 - Technical Mathematics I | 4 |
| MAT1290 - Technical Mathematics II | 4 |
| MET1131 - Personal Computer Applications for Engineering Technology | 1 |
| MET2711 - Ethics for Engineering Technology Professionals | 1 |

| | |
|------------------------------------------------------------------------|-----------|
| PHY1131 - Technical Physics | 3 |
| SCC1101 - First Year Experience | 1 |
| Ohio Transfer Module: Social & Behavioral Sciences Elective | 3 |
| Ohio Transfer Module: Arts & Humanities Elective | 3 |
| TOTAL NUMBER OF CREDITS | 72 |

ENERGY TECHNOLOGY CERTIFICATE PROGRAM

The certificate program is intended for the entry level workforce position. The certificate program is designed such that all the credits count toward the Energy Management Degree if the student wishes to pursue that degree.

ENERGY TECHNOLOGY CERTIFICATE CURRUCLUM

| Course Number and Title | # of Credits |
|----------------------------------------------------------------------------|---------------------|
| CAT1111 - Mechanical Systems Blueprint Reading | 1 |
| HVA1221 - Heating Systems | 3 |
| EET1120 - Introduction to DC & AC Circuits | 2 |
| EGV1101 - Alternate & Renewable Energy Sources | 2 |
| EGV1301 - Architectural Energy Analysis | 2 |
| HVA1201 - Basic HVAC Systems with Cooling | 3 |
| PHY1131 - Technical Physics | 3 |
| EGV1251 - Introduction to Energy Management Principles | 3 |
| EGV1201 - Weatherization Training | 2 |
| HVA1261 - HVAC Loads & Distribution for Small Buildings | 3 |
| MET1131 - Personal Computer Applications for Engineering Technology | 1 |
| TOTAL NUMBER OF CREDITS | 25 |

COURSE DEVELOPMENT AND RATIONAL

Table 1. Courses develop / improved as a result of grant

| Course | Status | Rationale for Development |
|--------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EGV120 Weatherization Training | Improved | This course will provide the student with the information and skills to perform a residential energy audit and resulting weatherization actions. This course will provide the student with the skills to operate a blower door, duct blaster, infrared camera, and a combustion analyzer. |

| Course | Status | Rationale for Development |
|-------------------------------------------------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EVG2351 LEED Green Associate Exam Preparation | Developed | This course will prepare the student for the first of the LEED AP exams, the LEED Green Associate Exam. This course will give the student the necessary prerequisites, as required by the U.S. Green Building Council, to take the exam. This course will include all the topics as listed in the LEED Green Associate Candidate Handbook. |
| EGV1251 Introduction to Energy Management Principle2 | Developed | This course will provide students with information and skills necessary to work in the energy efficiency, energy auditing workplace. This course will give the student the skills to prepare energy management plans to offer building owners and operators. |
| EGV2251 Energy Control Strategies | Developed | This course will provide students with information and skills necessary to work in the energy efficiency, energy auditing workplace. This course will give students knowledge of mechanical control systems in residential, commercial, and industrial buildings and the skills to develop energy efficient control strategies. |
| EGV2301 Commercial and Industrial Assessment | Developed | This course will provide the student with the information and skills to conduct energy assessments on commercial and industrial facilities. The course will give the student the information to determine energy saving opportunities and prepare reports. |
| EGV2101 Solar Photovoltaic Design and Installation | Improved | This course will prepare the student to take the North American Board of Certified Energy Practitioners Entry Level Exam. This course will prepare the student to enter the solar photovoltaic industry at the entry level position. This course will cover solar resource, solar panels, system components, system and component sizing, and system installation and maintenance. |
| EGV2151 Solar Thermal Design and Installation | Improved | This course will prepare the student to take the North American Board of Certified Energy Practitioners Entry Level Exam. This course will prepare the student to enter the solar thermal industry at the entry level position. This course will cover solar resource, solar thermal panels, site assessment, system components, system and component sizing, and system installation and maintenance. |

Table 2. Sinclair Community College program of course offerings

Renewable and Clean Energy Typical Schedule of Courses

Semester 1

Technical Mathematics
PC Applications for Engineering Technology
Basic HVAC Systems with Cooling
First Year Experience
Alternative and Renewable Energy Sources
English Composition I
Mechanical Systems Blueprint Reading

Semester 2

Technical Math II
Heating Systems
Weatherization Training
Introduction to Energy Management Principles
Introduction to DC and AC Circuits
Architectural Energy Analysis

Semester 3

Public Speaking
Technical Physics
OTM SOC
OTM HUM

Semester 4

Commercial and Industrial Assessment
LEED Green Associate Exam Preparation
Electrical Lighting and Motors
Energy Control Strategies
Solar Photovoltaic Design and Installation
HVAC Loads and Distribution for Small Buildings

Semester 5

Building Psychrometrics and Load Calculations
Energy Management Capstone
Building Performance Training
Ethics for the ET Professional
Solar Thermal Systems

Since both the Energy Technology Certificate and the Energy Management Degree programs are new, only three students have completed the certificate. However, it is clearly demonstrated that the enrollment of students in the programs is substantial which will lead to a number of students

completing both the certificates and degrees. A number of students in the courses are already working in the industry and are taking courses to increase their skills at their current jobs.

Laboratory Improvements

The blower door, duct blaster, and combustion analyzer are used in the new Weatherization Training course as well as an existing Architectural Energy Analysis and Building Performance course. The data logging equipment, ultrasonic compressed air leak detector, and VFD, motor and coils are used in the new Commercial and Industrial Assessment course. The wind turbine is used to power much of the Center for Energy Education Laboratory and will be used in the Wind Turbine course when developed. The solar photovoltaic system and Solar Pathfinder are used in the Solar Photovoltaic Design and Installation course. The batteries store the energy from both the wind turbine and the solar PV system to power the off-grid laboratory components. The software, Trane Trace, is used in the Energy Control Strategies course. That particular software was selected because it is popular with the mechanical and assessment contractors in the area.

Outline outreach initiatives and industry certifications

Sinclair Community College has many community partners, both nonprofit and for profit, which provide locations for the students in the Energy Management program for internships, service learning, and other job experiences. For example, students designed and installed a solar thermal system for County Corp, a local nonprofit. Students also participated in the 1.1MW solar PV installation by Dayton Power and Light as well as the 40kW system at the Miamisburg Mound. Students have also performed energy and indoor air quality assessment for nonprofits such as County Corp and Habitat.

Outline pre-college initiatives

Sinclair Community College has an active outreach program to educate high school and middle school students about energy conservation, energy efficiency, and renewable energy. A portion of the Center for Energy Education Laboratory is dedicated to this outreach program with solar racers. Many tours are conducted through the laboratory for both school students and high school teachers. Sinclair also participates in many community activities such as the Dayton Air Show. The solar racer activities conducted at these events create awareness in the community of alternative and renewable energy.

Syllabi of New Course Developments

Course syllabi are included for all new or updated courses on the following pages.

1. EGV1201 Weatherization Training

COURSE DESCRIPTION:

The Weatherization Certification course will give the student a depth of knowledge necessary to perform energy assessments of single or multifamily dwellings by identifying weatherization issues. The course covers the operation of equipment; blower door, duct blaster, infrared camera, combustion analyzer and heat transfer principles and fundamental building science theories. This course consists of classroom lectures and laboratory projects.

COURSE OUTCOMES:

1. Demonstrate a working knowledge of energy movement through a building's shell and insulating properties of building materials.
2. Demonstrate a working knowledge of thermal bypass.
3. Demonstrate a working knowledge of air barrier.
4. Demonstrate a working knowledge of residential heating and cooling systems.
5. Demonstrate an understanding of residential "life style" energy use.
6. Demonstrate the proper operation of the blower door, duct blaster, infrared camera, and the combustion analyzer.
7. Demonstrate proper weatherization procedures.

OUTLINE:

1. Introduction
2. Principles of Energy and Energy and the Building Shell
3. Air Leakage and Thermal Bypass
4. Insulation and Windows and Doors
5. Residential Heating and Cooling Systems
6. Lighting and Appliances and Water Heating
7. Health and Safety
8. Energy Audit and Reporting

2. EGV1251 Introduction to Energy Management Principles

COURSE DESCRIPTION:

The course introduces the principles of energy management and provides an overview of the energy industry. The history of energy production and costs, the dynamics of

worldwide energy consumption and growth, the principle methods by which energy is used, and its environmental and financial impacts and consequences are covered. Objectives and components of an effective energy management program are discussed.

COURSE OUTCOMES:

1. Describe global energy production and consumption and energy uses historically and current.
2. Describe different types of fossil, nuclear and renewable fuels, and the environmental, economic and political impacts of their use.
3. Explain the need for and the components of an effective energy management program.
4. Describe how energy management is integral to the architecture, building, and HVAC/R industries.
5. Describe long-term energy management objectives and trends for the future.

OUTLINE:

1. Components of An Effective Energy Management Plan
2. Heating and Cooling Systems
3. Control System Overview
4. Distribution and Process Equipment
5. Lighting and Electrical Distribution Systems
6. Overview of Building Envelope
7. Implementation Strategies

3. EGV2351 LEED Green Associate Exam Preparation

COURSE DESCRIPTION:

This course helps prepare the student for the first of the LEED AP exams, LEED Green Associate Exam and meet the requirement of the student to have involvement on a LEED-register project, or employment in a sustainable field of work, or completion in an education program that addresses green building principles in LEED, to qualify to take the first of the LEED AP exams, the Green Associate Exam.

COURSE OUTCOMES:

1. Demonstrate understanding of Synergistic Opportunities and LEED Application Process
2. Demonstrate understanding of Project Site Factors; Community Connectivity, Zoning Requirements, Development
3. Demonstrate understanding of Water Management; Types and Quality of Water, Water Management
4. Demonstrate understanding of Project Systems and Energy Impacts; Environmental Concerns, Green Power

5. Demonstrate understanding of Acquisition, Installation, and Management of Project Materials; Recycled Materials, Locally (regionally) Harvested and Manufactured Materials, Innovative and Regional Design
6. Demonstrate understanding of Project Surroundings and Public Outreach; Codes

OUTLINE:

1. Synergistic Opportunities and LEED Application Process; Project Requirements, costs, Green Resources, Standards that support LEED Credit, Credit Interactions Interpretation Rulings/Requests, Components of LEED Online and Project Registration, Components of LEED Score Card, Components of Letter Template, Strategies to Achieve Credit, Project Boundary; LEED Boundary; Property Boundary, Prerequisites and/or Minimum Program Requirements for LEED Certification, Preliminary Rating, Multiple Certifications for Same Building, Operations & Maintenance, Occupancy Requirements, USGBC Policies, Requirements to Earn LEED AP
2. Project Site Factors; Community Connectivity, Transportation, Pedestrian Access, Zoning Requirements, Development, Heat Islands
3. Water Management; Types and Quality of Water, Water Management
4. Project Systems and Energy Impacts; Environmental Concerns, Green Power
5. Acquisition, Installation, and Management of Project Materials; Recycled Materials, Locally (regionally) Harvested and Manufactured Materials, Construction Waste Management
6. Stakeholder Involvement in Innovation; Integrated Project Team Criteria, Durability Planning and Management, Innovative and Regional Design
7. Project Surroundings and Public Outreach; Codes

4. EGV2251 Energy Control Strategies

COURSE DESCRIPTION:

The course pertains to all devices used to regulate and/or control energy use in buildings and building systems.

COURSE OUTCOMES:

1. List, recognize, and describe the control systems and energy control strategies used in the commercial sector.
2. Explain the basic principles of control system design.
3. Describe commissioning of an energy control system in buildings.
4. Synthesize the relationship between energy control and indoor air quality.
5. Install and operate data acquisition equipment and verify data.
6. Select testing equipment.

OUTLINE:

1. Electrical Control Diagrams
2. Pneumatic Control Systems
3. Electronic Control Systems
4. Indoor Air Quality: Outdoor air requirements and optimizing efficiency
5. Proportional and Programmable Controllers
6. Building Automation Systems
7. Energy Control Strategies
8. Complete Control Systems

5. EGV2301 Commercial and Industrial Assessment

COURSE DESCRIPTION:

This course covers methods of collecting data; utility, envelope, mechanical systems, and operational procedures, for both commercial and industrial facilities and analyzing the data with statistical procedures and simulation software to develop energy saving management plans.

COURSE OUTCOMES:

1. Demonstrate proficiency in analyzing energy use utility data.
2. Demonstrate proficiency in the operation of energy simulation software.
3. Demonstrate the operation of data collection equipment such as data loggers.
4. Demonstrate an understanding of the operation of HVAC equipment in commercial and industrial buildings and the data collection procedures.
5. Describe industrial processes and equipment such as heat exchangers.
6. Prepare an energy management plan and report.

OUTLINE:

1. Analyzing Utility Data
2. Introduction to Data Logging Equipment
3. Data Logging Air Systems
4. Analyzing Air Systems Data and Making Recommendations
5. Data Logging Electrical Systems
6. Analyzing Electrical Data and Making Recommendations
7. Commercial Assessment Format
8. Industrial Assessment Format
9. Energy Simulation Software
10. Preparing an Energy Manage Report

6. EGV2101 Solar Photovoltaic Design and Installation

COURSE DESCRIPTION:

This course covers components of solar PV systems and the sizing of PV systems and components. This course is designed to prepare the student to take the NABCEP PV Entry Level Exam.

COURSE OUTCOMES:

1. Demonstrate an understanding of solar energy fundamentals.
2. Demonstrate an understanding of solar PV modules.
3. Know the components of both stand-alone and grid connected PV systems.
4. Demonstrate the sizing of PV system and all components.
5. Demonstrate an understanding of performance analysis, maintenance and troubleshooting.

OUTLINE:

1. PV Markets and Applications
2. Safety Basics
3. Electricity Basics
4. Solar Energy Fundamentals
5. System Components
6. PV System Sizing Principles
7. PV System Electrical Design
8. PV Mechanical Design
9. Performance Analysis, Maintenance and Troubleshooting

7. EGV2151 Solar Thermal Design and Installation

COURSE DESCRIPTION:

This course covers some of the basic cognitive materials needed to install and maintain Solar Thermal Systems. This course is designed to help individuals better prepare for the NABCEP solar thermal installer examination but does not provide all of the materials needed to completing the certification examination.

COURSE OUTCOMES:

1. Demonstrate an understanding of solar energy fundamentals.
2. Identify solar thermal system and their components.
3. Demonstrate ability to conduct a site assessment.
4. Knowledge of installing solar collectors, water heaters and storage tanks.
5. Knowledge of installing mechanical/plumbing equipment, electrol control systems and their operation.
6. Demonstrate an understanding of maintaining and troubleshooting a solar thermal system.

OUTLINE:

1. Working Safely with Solar Thermal Systems
2. Identifying Systems and Their Components
3. Adapting a System Design
4. Conducting a Site Assessment
5. Installing Solar Collectors
6. Installing Water Heaters and Storage Tanks
7. Installing Piping
8. Installing Mechanical/Plumbing Equipment
9. Installing Electrical Control
10. Installing Operational and Identification Tags and Labels
11. Performing a System Checkout
12. Maintaining and Troubleshooting a Solar Thermal System

Budget Expenditures

| Project Budget | | Actual Expenditure |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| \$29,600 | Salary-Administrative/Professional
Faculty Salary Reallocation | \$29,655.33 |
| | Five were developed and delivered and revised. Two were Developed and delivered and need revisions. One course remains to be developed. List of courses are below. | |
| \$4,737 | Fringe Benefits | \$2,532.96 |
| \$3,956 | Out of state travel | \$1,153.80 |
| | Due to scheduling, only one workshop and/or conference was attended in Wisconsin. | |
| \$15,688 | Indirect costs | \$15,717.32 |
| \$43,485 | Equipment, materials and supplies | \$44,629.17 |
| | A complete list of equipment, materials and supplies is listed below. | |
| \$0.00 | Outside services | \$2,444.18 |
| | Building Performance Institute Proctor status was obtained for one Sinclair faculty to provide testing for Sinclair students for the certification of Building Analyst Professional. Verbal permission was obtained before expenditure. | |
| Totals | \$97,466 | \$96,132.76 |

Courses Developed:

1. Weatherization Training
 - i. With revisions
2. LEED Green Associate Exam Preparation
 - i. With revisions
3. Introduction to Energy Management Principles
 - i. With revisions
4. Energy Control Strategies
 - i. First generation
5. Commercial and Industrial Assessment
 - i. First generation
6. Solar Photovoltaic Design and Installation
 - i. With revisions
7. Solar Thermal design and Installation
 - i. With revisions

Out of State Travel:

Trip to Midwest Renewable Energy Association in Custer, Wisconsin, for workshop in Site Assessment Certification to be included in both Solar Photovoltaic and Solar Thermal Design and Installation courses.

Materials and Equipment:

1. Southwest Windpower Whisper 500: 3 KW Wind Turbine w/Charge Controller
2. Materials for Turbine Tower
 - a. Linear feet 5" steel Pipe Schedule 40
 - b. PC 5" RD CF C1018 12 inch long
 - c. PC 5" RD CF C1018 12 inch long
 - d. PC 2 X 7 CF C1018 7 Inch
 - e. PC 2 X 9 CF C1018 9 Inch
 - f. PC 3/4 X 18 CF1018 18 Inch
 - g. PC 2" RD 15 Inch
3. HOBO Sensors & Accessories
 - a. 3-P-AC-1 AC Adapter – universal input volt power
 - b. 1- T-MAG-SCT-200 Trans,0-200A,333mV Out CT,SCT-1250-200
 - c. 3- S-THB-M008 Temp/RH Sensor (12-bit) w/8m Cable S/N 9990777, 9990778, 9990779
 - d. 3- T-MAG-0400-10 AC Split-Core CT Mini, 10 amp, 333mV out
3- ADAPT-SER-USB CABLE-USB232 with CABLE-PC3.5
 - e. 3- TEL-7001 Telaire 7001 CO2 Sensor
 - f. T-MAG-0400-75 AC Split-Core CT Mini, 75 amp, 333mV out
 - g. 3- S-UCC-M006 Pulse Input Adapter – Electronic Switch S/N 9943384, 9943385, 9943386
 - h. 9- S-TMB-M017 Smart Temp Sensor 12-bit w/ 17m Cable S/N 9955649, 9955650, 9955651, 9955652, 9955653, 9955654, 9955656, 9955656, 9955657

- i. 6- S-FS-CVIA Flex Smart Analog Module S/N 9994789, 9994790, 9994791, 9994792, 9994793, 9994794
 - j. 3- T-VER-E50B2 Power Meter 600VAC 3 pulse output
4. ULTRAPROBE 100 SCANNER KIT
5. SW 235 Solar World 235 Watt Mono-Crystalline Solar PV Module
 - a. UniRac Solar Mount Racking System. INCLUDED
 - b. BOS-PV Wire/Connectors, Outback Combiner Box & Breakers (15ampDC), Outback MATE-3, OutBack Breaker (10ampAC), OutBack HUB-4, Grounding Lugs, INCLUDED
6. CABLE-2070 Cable-Telaire CO2 Sensor to Analog Mod
7. GE Telaire Hobo Datalogging Kit for 7001
8. Calib 8002 CO2 Monitorsaration Kit for GE Telaire models 7001,8001
9. SOLAR PATHFINDER
 - a. TELESCOPE ALUMINUM TRIPOS
 - b. SOLAR PATHFINDER ASSISTANT 5 SOFTWARE CD
 - c. PV PLUG IN FOR ASSISTANT 4 OR HIGHER
 - d. THERMAL PLUG IN FOR ASSISTANT 4 OR HIGHER
10. Lumber Package for PV Roof Mockup
11. Canon Vixia HF R20 Flash Memory 1080p HD Digital Video Camcorder
12. Transcend 32 GB Class SDHC 10 Flash Memory Card TSGSDHC10E
13. Bacharach Fyrite Tech 60 24-8217 Residential Combustion Analyzer
14. Storage Cabinet
15. 8-85 Ah Batteries
16. Set Battery Cables
17. TraneTrace software
18. #KR001-2 KRENDL 475 ALL FIBER MACHINE W/1 LARGE BLOWER (14AMP), 150' REMOTE CORD
 - a. #H0102 MKII 3"X50' CLEAR HOSE
 - b. #PT018 REDUCER TUBE 3"TO2"
 - c. #HO100MKII 2"X50' CLEAR HOSE
 - d. #PT020-3 2"-1 1/4" NOZZLE 2"HOSE ONLY
 - e. #HO109 SUMMER BRAIDED TUBE 1 1/4" ISD
 - f. #DV103-1 MC4ZW METAL WORM 4" CLAMP (MC4ZW) 50 PER
19. 10-retrotec AC 107 Air Current Testers
20. 12T598 VFD 1.5HP 6A 230V 1 or 3 Ph
21. 1N541 PUMP CENTRIFICAL 1/2 HP MANUFACTURER # 1BF10534
22. HOT WATER COIL 18 in X 24in 11.7 GPM MANUFACTURER # W1021824H
23. HOT WATER COIL 18 in X 24in 11.7 GPM MANUFACTURER # W1021824H
24. 2- IDEAL 44-789 WALL LOCKOUT 4/CARD
25. IPAD II

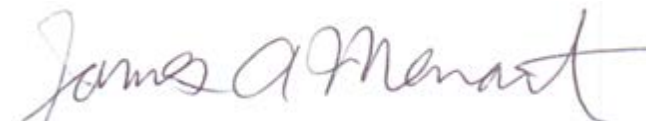
June 22, 2012

Dr. Kevin Hallinan
University of Dayton Research Institute
300 College Park
Dayton, Ohio 45469-0172
Kevin.Hallinan@notes.udayton.edu

Dear Dr. Hallinan:

Attached to this letter is the final report for work done on the DOE grant entitled "Clean Energy Infrastructure Educational Initiative." The prime grant number is DE-SC005734 and the sub-recipient agreement number is RSC11006. The principal investigator at Wright State University is Dr. James Menart., the Technical Officer and overall principle investigator for this grant is Dr. Kevin Hallinan, and the contracting officer at the University of Dayton Research Institute is Ms. Amy Davidson. If you have any questions, my contact information is given below.

Sincerely,

A handwritten signature in dark ink, reading "James A. Menart". The signature is fluid and cursive, with the first name "James" and last name "Menart" clearly legible.

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Final Report

For the Grant Entitled
Clean Energy Infrastructure Educational Initiative

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PI Signature and Date: ____James A. Menart, July 30, 2011____

Period Covered by Report: March 1, 2011 to May 31, 2012

Duration of Project: March 1, 2011 to May 31, 2012

Funding & Duration

Year One: \$177,767

Total Requested Funding: \$177,767

Subrecipient Agreement No.: RSC11006

Prime Grant Number: DE-SC005734

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ABSTRACT

This report covers the work that was performed at Wright State under the Department of Energy grant entitled “Clean Energy Infrastructure Educational Initiative”. This project is a collaboration between the University of Dayton, Wright State University, and Sinclair College. The lead on this project was the University of Dayton and Wright State is a subcontractor to the University of Dayton. Essentially this was a one year grant to improve the education of students in renewable and clean energies. Wright State’s focus in this endeavor was at the graduate level, but they also performed work at the undergraduate and high school levels.

At Wright State work was carried out in three different areas. These areas are

- Renewable and clean energy master’s degree program development,
- Renewable and clean energy research, and
- Renewable and clean energy undergraduate and high school education.

In each of these three areas a number of projects were carried out as a result of this funding. While the second area listed above may not seem like an area that falls under the title of “Clean Energy Infrastructure Educational Initiative”, it really is quite important to graduate education. At the graduate level, research is critical to improving the quality of the programs education. This is especially true for the students who chose to do the master’s thesis option, but also for the students who chose to do the non-thesis master’s degree option. A strong research program and a strong educational program for graduate engineering programs go hand-in-hand. In addition to this, funding research projects provide financial support to students to be in Wright State’s Renewable and Clean Energy Master’s Degree Program.

At the present time Wright State’s Renewable and Clean Energy Master’s Degree Program has 23 students. This is a 475% increase from Wright State’s starting number of 4 students. The program is relatively young, 3.5 years old, and has had good growth over this period of time. At the present time the Renewable and Clean Energy Master’s Degree Program offers 22 courses in different types of renewable and clean energy. It is believed that this is one of the most comprehensive offerings of renewable and clean energy courses in the country. This master’s degree program is a collaboration between four universities and the Dayton Area Graduate Research Institute. This collaboration has served to strengthen this program. The Renewable and Clean Energy Master’s Degree Program has come a long way in its relatively short life and this grant from the Department of Energy has enhanced this advancement.

This report provides details of the work performed as a result of this Department of Energy funding. This report is broken down into the three major areas listed above. A number of projects were undertaken in each of these areas as a result of this funding and these projects are discussed in this report.

INTRODUCTION

This Clean Energy Infrastructure Educational Initiative is a collaborative effort between the University of Dayton, Wright State University, and Sinclair Community College to advance education at a number of levels in clean energy. The University of Dayton is the lead on this project and Wright State and Sinclair are collaborators. The focus of Wright State’s efforts have been at the graduate level; however we have done some important work at both the undergraduate and high school levels.

The main focus of Wright State was to continue the development of graduate education in renewable and clean energy. Wright State has done this in a number of ways. First and foremost this was done by continuing the development of the new Renewable and Clean Energy Master’s Degree program at Wright State and the University of Dayton. Development tasks included: continuing development of courses for the Renewable and Clean Energy Master’s Degree, increasing the student enrollment, and increasing renewable and clean energy research work. It is our belief that the Renewable and Clean Energy Master’s Degree program is necessary to help advance Ohio’s dream of becoming the “Silicon Valley of Renewable Energy”. Wright State and the University of Dayton share this dream and realize that this dream is going to require a highly educated engineering workforce to make it become a reality. Wright State and the University of Dayton are hard at work producing this engineering workforce. In addition to the main focus of this work, Wright State also expended resources to enhance renewable and clean energy education at the undergraduate level and at the high school level.

In the sections that follow descriptions of the work done under this grant are given. This discussion will be broken into three major sections: Master’s Degree Program Development, Research, and Undergraduate and High School Program Development. Note that the research work is one means used to enhance the Renewable and Clean Energy Master’s Degree Program at Wright State University. Having a strong research program increases the stature and the quality of any engineering master’s degree program. In addition, providing a variety of research project enhances the student’s learning and it adds to the knowledge base in renewable and clean energy. Lastly, having strong funding for master’s thesis projects provides financial support for students to go through the program.

MASTER’S DEGREE PROGRAM DEVELOPMENT

The Renewable and Clean Energy Master’s Degree program at Wright State University and the University of Dayton was signed into existence by the Chancellor of the Ohio Board of Regents on November 24, 2008. The first students entered the program in January of 2009. This program is a collaborative effort among a number of schools in the Dayton, Ohio region. These schools include Wright State University, The University of Dayton, The Air Force Institute of Technology, and Central State University. In addition the Dayton Area Graduate Schools Institute has provided support for the program. This program is the first of its kind in the state of Ohio and one of a few in the country. It is my belief that programs in renewable and clean energy are important to the United States’ energy future and Wright State is proud to be a part of this endeavor.

With the help of this Department of Energy grant the enrollment at Wright State in the Renewable and Clean Energy Program has increased from 4 students in January of 2009 to 23

students at the present time. This is a large improvement in the short history of this program, 3.5 years. Up to this time Wright State has graduated 10 students who have taken jobs at such places as:

- Energy Systems Group
- Habegger Corporation
- Tri Tech
- Department of Veteran's Affairs
- Dayton Superior
- Third Millennium Metals

In addition 3 of the 10 graduates from the program have went on to pursue Ph.D. degrees in engineering, and we do not have employment information for one of our graduates. While 10 graduates is not a huge number it must be remembered that the program is only 3.5 years old and the average time students spend in the program is 2 years. Thus the graduate numbers depend on the enrollments for the first 1.5 years.

Course Development

With the financial help of this grant the Renewable and Clean Energy Courses offered by Wright State have grown and improved substantially. The current Renewable and Clean Energy courses offered at Wright State University are:

- WSU/ME623 – Energy Conversion
- WSU/ME624 – Solar Engineering
- WSU/ME626 – Wind Power
- WSU/ME627 – Electrochemical Energy Systems
- WSU/ME628 – Fuel Cell Science and Technology
- WSU/ME642 – Vehicle Engineering
- WSU/ME750 – Photovoltaics
- WSU/ME752 – Hydrogen Energy
- WSU/ME780 – Advanced Energy Materials

In addition a nuclear engineering course entitled

- AFIT/NENG620 – Nuclear Reactor Theory and Engineering

is taught at Wright State by a professor from the Air Force Institute of Technology and the two courses

- CSU/ME699 – Environmental Advances in Coal Based Power Plants
- CSU/ME699 – Hydropower

are taught at Wright State by two faculty members from Central State University. When you add the 12 plus renewable and clean energy classes taught at the University of Dayton it can be seen that our program is quite impressive. This makes for a total of 24 renewable and clean energy classes which degree students at Wright State or the University of Dayton may take. As best I can tell this is the widest selection of renewable and clean energy courses for any program like this in the country.

Of these 12 Wright State renewable and clean energy courses the following were benefactors of this grant:

- WSU/ME623 – Energy Conversion
- WSU/ME624 – Solar Engineering
- WSU/ME626 – Wind Power
- WSU/ME628 – Fuel Cell Science and Technology
- WSU/ME750 – Photovoltaics
- WSU/ME752 – Hydrogen Energy
- WSU/ME780 – Advanced Energy Materials

Details on each of these courses are given below.

WSU/ME623 – Energy Conversion

Energy Conversion is a fundamental course for the Renewable and Clean Energy Master's Degree program. In this course students are given some basic concepts about converting one form of energy to another. In addition to giving the students basic information on converting one form of energy to another, we try to look at several examples of energy conversion. As part of this grant work a number of additions and improvements were made on the way we teach the basic principles of energy conversion. A detailed categorization study of the different forms in which energy appears is undertaken. The idea that energy can be defined as "the ability to cause change" is stressed over the traditional idea that energy is "the ability to do work". This subtle change in the definition of energy may not seem like much, but to me it is an important one. Trying to identify how energy could produce work makes it very difficult to identify all of the varied forms in which energy appears. It is much easier to identify change than it is to identify a potential work production. From my stand point the traditional definition of "energy is the ability to produce work" comes from the early days of thermodynamics and needs to be replaced by what is a more general, more to the point, and more useful definition of energy. We have also updated the general energy topics of the first and second laws of thermodynamics for this class. After talking about the general principles of energy conversion, a number of examples of energy conversion are given. These are carefully chosen examples of the conversion of energy from one form to another. These examples help the student to cement the concepts of energy conversion into their minds and provide the student exposure to a number of energy conversion processes.

In addition to looking at energy and energy conversion, this course presents material on two topics that are very important to present day energy conversion. These two topics are energy's effect on the environment and energy economics. Both of these issues will have major influences on how energy is produced and used in the future; thus students in the Renewable and Clean Energy Program need to have information on these topics. The major topic discussed in regards to the environment is global warming and in terms of energy economics the students are taught the time value of money. In terms of global warming, a few of the simpler models are discussed and what some of the consequences could be. In regards to the energy economy, the students have to use economic analysis to weigh the economic benefits of one energy system against another.

The topics covered in Energy Conversion are:

- Introduction to energy and discussion of what is energy?
- Our energy situation in both the United States and the world.
- Economic analysis of energy systems.
- Heat transfer review.
- Energy's effect on the environment.
- Mechanical to electric energy conversion. An electric generator, magneto-hydrodynamic generator, and ocean energy are used as examples here.
- Thermal to electric energy conversion. A gas turbine combined with an electric generator and a thermoelectric device is used as an example here.
- Chemical to electric energy conversion. Biofuels are used as the example here.
- Nuclear to electric energy conversion. A nuclear power plant is used at the example here.

- Electromagnetic to electric energy conversion. Photovoltaic panels are used as the example here.

A syllabus for this course can be found in Appendix A. Electronic notes for the Energy Conversion course have been developed and are available to the students via Wright State's PILOT web instructional system.

This course is offered every year at Wright State. The enrollment varies between 8 to 25 students. Both Renewable and Clean Energy graduate students and undergraduate students are welcome in this course.

WSU/ME624 – Solar Engineering

The Solar Engineering course teaches students about the solar resource and how to calculate the amount of energy present in this resource for any location on the earth for any time of day for any day of the year. There is detailed coverage of this topic. This course then goes on to discuss solar flat panel collectors, solar concentrating collectors, and solar photovoltaics. The solar photovoltaic topic is only meant to introduce the students to this very important means of capturing solar energy. At Wright State we feel that photovoltaics are such an important topic that we have developed a whole class on photovoltaics. The Wright State photovoltaics course will be discussed latter in this report. At Wright State we have a two course sequence on solar energy: Solar Engineering and Solar Photovoltaics. The Solar Engineering course is meant to cover the fundamentals of solar energy and the thermal collection of solar energy. The Solar Photovoltaics course deals with capturing solar energy with solar cells and converting the solar energy directly to electrical energy.

For this class a unique homework sequence was developed. The students write an EXCEL program that calculates the amount of solar energy impinging on a surface as a function of time, location, and orientation. They then go on to calculate how much of this energy is captured and converted to thermal energy of a fluid by a flat plate solar collector. Next they program how much solar energy is captured and converted to thermal energy by a concentrating solar collector. This program is a course long project that continues to build on itself. By the end of the quarter, the students have a program that can be used to design or analyze thermal solar collectors.

The topics covered in Solar Engineering are:

- Review of radiative heat transfer.
- Solar radiation resource available on a surface located at any specified location on the earth with any specified orientation without atmospheric effects.
- Effects of the atmosphere on the solar radiation resource.
- Flat plate solar collectors.
- Solar concentrators.
- Solar hot water heating.
- Introduction to photovoltaics.

A syllabus for this course can be found in Appendix A. Out of a 10 week course 1 week is spent reviewing radiative heat transfer which is the means by which we receive energy from the sun, 3 weeks are spent on the solar resource, 3 weeks are spent on flat plat solar collectors, 2 weeks on solar concentrators, 1 week on solar hot water heating, and 1 week on solar photovoltaics. Electronic notes for the Solar Engineering course have been developed and are available to the students via Wright State's PILOT web instructional system.

This course has about 20 to 30 students in it. About half of these students are Renewable and Clean Energy Master’s Degree students and half of the students are undergraduate engineering students.

WSU/ME626 – Wind Power

Wind Power is a popular renewable and clean energy class at Wright State University. I believe the reason for this is that electricity generated with wind power is cost competitive with fossil fuel generated electricity in some regions of the country and nearly cost competitive with fossil fuel generated electricity in a number of other regions of the United States. Wind power has made good in-roads into the power production process and its future looks good. I believe students are attracted to this class because they see the potential of wind generated electricity.

The Wind Power class at Wright State provides our students with a great deal of information on generating electricity using wind energy. The class starts out with a short introduction to wind power and a brief history on humankind’s efforts at extracting useful energy from the wind. Many lessons in regards to renewable energy can be learned by looking at the history of wind power. After this, just like in the Solar Engineering class, time is spent studying the wind resource. The students learn how to calculate the energy stored in the wind, how to deal with the statistical nature of wind energy, and how to site wind turbines. After studying how to model the wind resource students begin studying at the individual parts of the wind turbine and how to design the different parts of the wind turbine. The first component studied is the wind turbine rotor since this is the part that initially takes the kinetic energy of the wind and converts it into rotational mechanical energy. The rotor is looked at from both an aerodynamic and strength perspective. Detailed models are discussed. After the rotor the class progresses through the electric generator, the gearbox, and the tower. These are the main components studied in detail. The other components of the wind turbine are mentioned, but time does not allow a detailed mathematical treatment of any more than the four components mentioned above.

The topics covered in Wind Power are:

- Introduction to wind power.
- The wind resource.
- Aerodynamics of wind turbine rotors.
- Mechanics of wind turbine rotors.
- Generators used in wind turbines.
- Gear boxes used in wind turbines.
- Wind turbine towers.
- Other components used in wind turbines.
- Overall wind turbine design.

A syllabus for this course can be found in Appendix A. Electronic notes for the Wind Power course have been developed and are available to the students via Wright State’s PILOT web instructional system.

This course has 30 students attending. Over half of the students are Renewable and Clean Energy Master’s degree students and the remainder are undergraduate engineering students.

WSU/ME628 – Fuel Cell Science and Technology

The Fuel Cell Science and Technology course is focused on teaching the students the operating principles of the fuel cell. Students are introduced to fuel cell technology, applications, and the current research and development in the fuel cell field. By the end of this course students understand fuel cell advantages over batteries or heat engines and technological challenges that

remain with fuel cell technology. This is a very popular course and had an enrollment of 36 students in the Fall of 2011. There were 13 graduate students in the course and 23 graduate students.

In this course the students receive five homework assignments and three exams. In addition, graduate students are required to turn in one research paper on a fuel cell related topic. Students can choose any topic from materials development or system design to fuel cell simulation. To the undergraduates, a more hands on project is offered and the undergraduate students are allowed to work in groups of 2 or 3 students. Undergraduate students can select between writing a MATLAB code or working on an operating manual for a commercial fuel cell testing station used at Wright State. In the near future, it is hoped that students have the opportunity to operate the testing station and acquire actual fuel cell data for analyses. The MATLAB programming project can be a project such as modeling the open circuit voltage for different operating conditions of a fuel cell, modeling the I-V characteristics of a fuel cell, modeling the fuel cell's electrolyte conductivity as a function temperature or humidity, or other modeling activity related to the fuel cell.

The topics covered in Fuel Cell Science and Technology are:

- Introduction to fuel cells.
- Thermodynamics of fuel cells.
- Activation loss in fuel cells – electrochemical kinetics.
- Ohmic loss in fuel cells – charge transport.
- Concentration loss – mass transport.
- Fuel cell characterizations.
- Fuel cell technologies.
- Fuel cell development and applications.

A syllabus for this course can be found in Appendix A.

WSU/ME750 – Photovoltaics

The photovoltaics class at Wright State delves into the intricate workings of solar panels. It does this from both the macroscopic and microscopic perspectives. The macroscopic perspective looks at the operating characteristics of solar panels from the electrical perspective. A circuit model is developed and techniques for solving the resulting coupled, highly nonlinear, algebraic equations are given. The students are asked to write a computer code or to use EXCEL to solve different versions of these equations. The effects of cell temperature and the solar irradiation are also considered. This discussion impresses upon the students that matching the load with the panel output is important for efficient operation. After discussing the operation of solar panels from the macroscopic viewpoint, we discuss their operation from the microscopic viewpoint. The only way to understand how solar panels convert electromagnetic energy from the sun into electrical current is to look at the molecular structure of the materials which make up the solar panels. In addition, this microscopic look at solar panel materials helps the students to understand the macroscopic behavior of the solar panels studied in the first part of the class. After studying solar cells at the microscopic level, a number of types of solar cells are discussed.

The topics covered in Photovoltaics are:

- Basic principles of photovoltaic cells.
- Photovoltaic circuits.
- Electrons and holes in semiconductors.
- Generation and recombination of free electrons.
- p-n junction.

- Mono-crystalline photovoltaic cells.
- Thin film amorphous photovoltaic cells.
- Managing light intake and increasing efficiency of photovoltaic cells.

A syllabus for this course can be found in Appendix A. Electronic notes for the Photovoltaics course have been developed and are available to the students via Wright State’s PILOT web instructional system.

This course has from 4 to 10 students. Only graduate students are allowed in this course and thus the enrollment is smaller. Many of the 700 level courses, graduate student only courses, at Wright State have enrollments of about 10 students. Another issue limiting enrollments is that the students have to complete the Advanced Thermodynamics course, WSU/ME744, before entering the photovoltaics course. This prerequisite course is important because of the microscopic viewpoint that is required to understand photovoltaics.

WSU/ME752 – Hydrogen Energy

The purpose of this course is to provide the students with essential knowledge on hydrogen production and storage, as well as an overview of hydrogen energy conversion. Learning about recent advancements in hydrogen conversion and storage and performing related computer simulations are additional goals of this course. Access to renewable and clean sources of energy is one of the highest priorities among the scientific and technological challenges that face us in the 21st century. The conventional sources of energy, in particular carbon-based sources, have limited reserves and pollute the environment with catastrophic consequences for the whole planet. Hydrogen is one of the desirable substitutes whose combustion generates water, an absolutely harmless and recyclable end product. This course discusses different aspects of hydrogen energy. For hydrogen production, chemical, electrolytic, thermolytic, photolytic, and photobiologic methods are discussed. For hydrogen storage, the methods include chemical, compressed gas, liquid, hydride, cryogenic, and adsorption. The role of hydrogen in future energy systems is also discussed.

The topics covered in Hydrogen Energy are:

- Introduction to energy from hydrogen.
- Hydrogen production by chemical, electrolytic, thermolytic, photolytic, and photobiologic methods.
- Computer simulations of hydrogen production.
- Experiments in hydrogen production.
- Hydrogen storage by chemical, compressed gas, liquid, hydride, cryogenic, and adsorption techniques.
- Computer simulations of hydrogen storage.
- Overview of hydrogen energy conversion.
- Role of hydrogen in future energy systems.

A syllabus for this course can be found in Appendix A.

This enrollment in this course is similar to that in the Photovoltaics course.

WSU/ME780 – Advanced Energy Materials

The Advanced Energy Materials course is one of the two required courses for the Renewable and Clean Energy Master’s Degree program at Wright State University. The other course required is Advanced Thermodynamics, WSU/ME 744. Both the Advanced Energy Materials and the Advanced Thermodynamics course are offered once a year at Wright State University. From the beginning, this course was intended to teach students, from different engineering or science

disciplines, who are in pursuit of the Renewable and Clean Energy Master’s Degree, the fundamentals of materials including metals, ceramics, polymers and composites. The influences of crystal structure, defect chemistry, and atom mobility on the physical and chemical properties of materials are emphasized in this course. This course uses this knowledge of physical and chemical properties and applies it to renewable energy systems such as fuel cells, batteries, hydrogen storage, solar cells, wind turbines, etc.

The materials for this course were compiled from several books and journal review papers. Examples of the reference books are “Materials Science and Engineering: an Introduction”, “Introduction to Ceramics”, “Fuel Cell Fundamentals”, “Lithium Batteries: Science and Technology”, “Nanotechnology for Energy Challenge”, “Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications”, and “Nanostructured Materials for Solar Energy Conversion”. Carbon-based nanomaterials, including graphene, are taught in the class because of the emergence and interest in supercapacitors for electric vehicles and the mechanical properties of composite materials is taught because of their application to wind turbines. Another topic discussed in the course is thermoelectrics because this is an energy conversion device that is only understood by understanding the characteristics of the material.

Throughout the quarter, there are four to five homework assignments given to the students. By the end of quarter, each student is required to give a presentation on any topic in relation to materials for renewable energy applications. Students are also required to submit a literature review paper in relation to materials for renewable energy applications. The topic is the student’s choice with the approval of the instructor. The homework practice and exams ensure the students master the fundamentals of materials knowledge. The presentation and paper provides the graduate student an opportunity to explore their own interest in the renewable energy field and apply the knowledge they have learned in the course to the practical world.

The topics covered in Advanced Energy Materials are:

- Crystal structures of metals and catalytic activity in fuel cells.
- Crystal structures of ceramics and their applications in batteries and fuel cells.
- Defect chemistry and atom diffusion.
- Ion conduction in the materials of solid oxide fuel cells.
- Semiconductor and band gap basics and their applications in solar cells and thermoelectrics.
- Introduction to polymers and ionic electrolyte in batteries and fuel cells.
- Carbon-base materials and their applications in batteries and supercapacitors.
- Composites materials and their application in wind turbines.

A syllabus for this course can be found in Appendix A.

Since this is a graduate student only course, the enrollment is in the 5 to 10 student range.

Web Site Development

Another large initiative that was done as part of this research funding was the development of a web site for the Renewable and Clean Energy program. This web site can be found at

<http://www.engineering.wright.edu/mme/rce/>

This web site has been developed by Meg Wiltshire and her team located in the College of Engineering and Computer Science at Wright State University. We have developed a new web site that will be more attractive to potential students. It is believed that the internet is the number

Wright State Final report for "Clean Energy Infrastructure Educational Initiative." Prime grant number is DE-SC005734 and the sub-recipient agreement number is RSC11006.

one means by which students learn about Wright State's Renewable and Clean Energy Master's Degree Program; thus this initiative was carried out to help increase the enrollment. Our new site contains more information than our prior site and it has pictures and videos to make it more appealing to today's internet generation. The homepage for this website is shown in Figure 1 and additional pages of the web site are shown in Figures 2 -4.

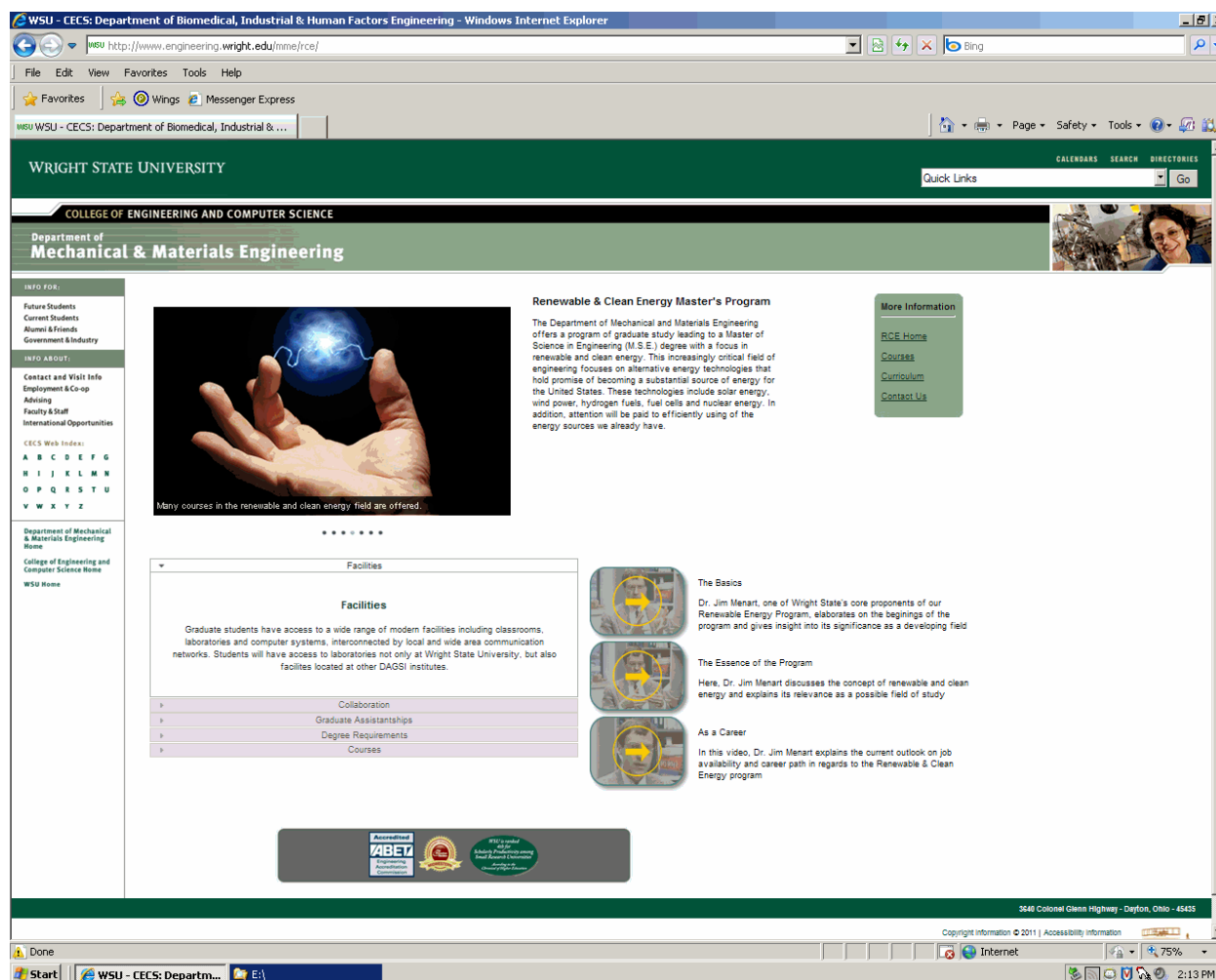


Figure 1: Home page of Wright State's Renewable and Clean Energy Master's Degree Program web site.

The home page (see Figure 1) contains links to the all the Renewable and Clean Energy web materials. The main links are to the program requirements, course information, and contact information. So that potential students can obtain a verbal description of the program, a number of videos of the Program Director discussing the Renewable and Clean Energy Program are given. To make the site more attractive a number of photos of renewable and clean energy systems are provided on the web page. The photograph shown in the upper left-hand corner of Figure 1 changes on a set time interval.

Wright State Final report for “Clean Energy Infrastructure Educational Initiative.” Prime grant number is DE-SC005734 and the sub-recipient agreement number is RSC11006.

The curriculum page (see Figure 2) contains information on all the requirements for the Renewable and Clean Energy Master’s Degree Program. The program requirements are categorized according to prerequisite courses, core courses, required renewable and clean energy courses, required math course, elective courses, thesis and non-thesis requirements, and collaborative university requirements. By clicking on each one of these categories of requirements the user is given more information.

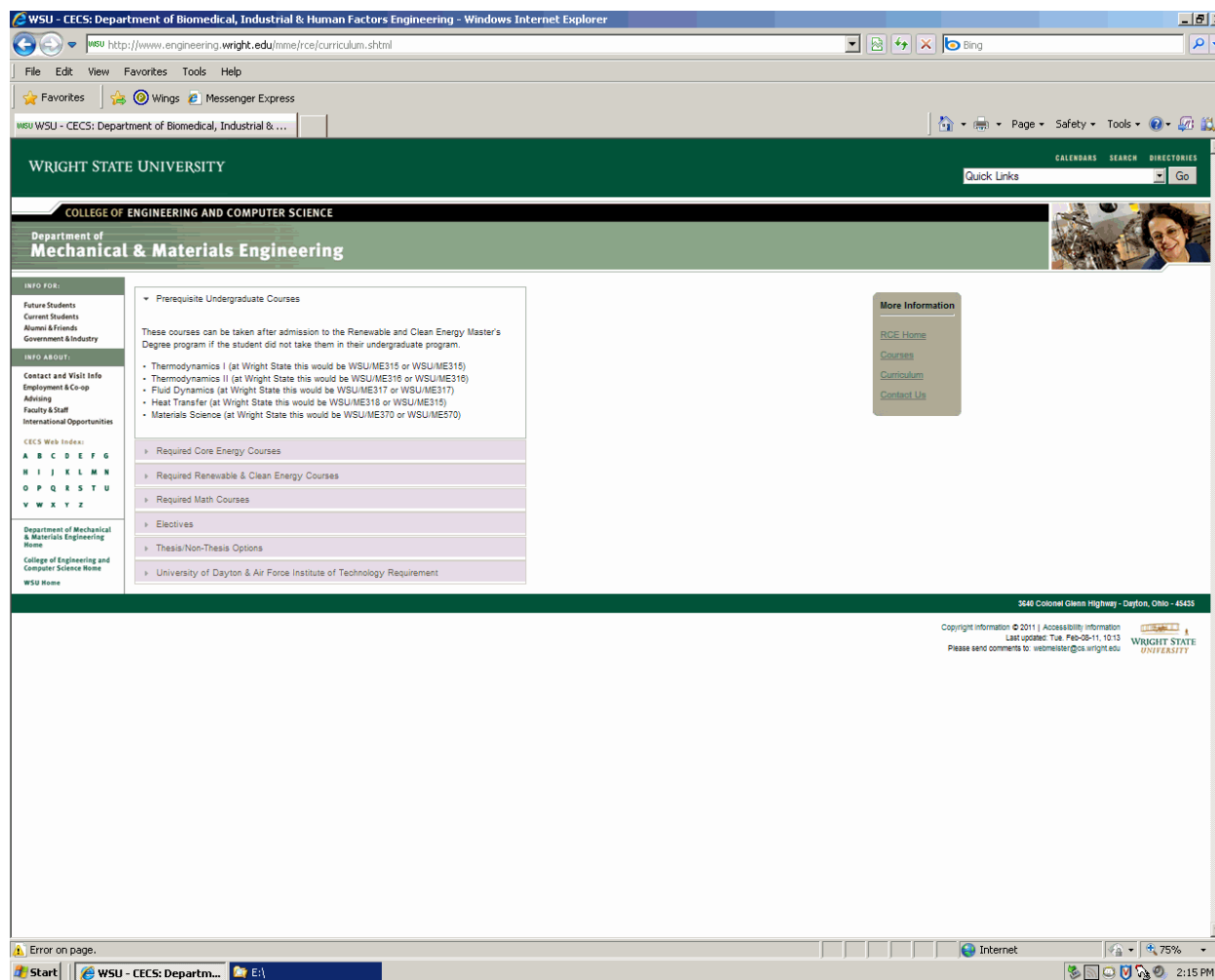


Figure 2: Curriculum page of Wright State’s Renewable and Clean Energy web site.

The course page shown in Figure 3 provides a two to three line description of each course in the Renewable and Clean Energy Master’s Degree program. These descriptions are those that are published in Wright State’s Course Description catalog. The course descriptions are arranged according to the curriculum requirement categories shown in Figure 2. This makes it easy for students to locate the course information that satisfy each requirement of the program. The Renewable and Clean Energy courses are broken into Renewable Energy courses, Clean Energy courses, and Energy Efficiency courses.

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The contact information page (see Figure 4) list the names, pictures, and e-mail addresses of the two individuals at Wright State who are responsible for providing more information on the Renewable and Clean Energy program. These two individuals are the program director, Professor James Menart, and the student advisor, Angela Griffith.

The screenshot displays the website for the Department of Mechanical & Materials Engineering at Wright State University. The page is titled "WRIGHT STATE UNIVERSITY" and "COLLEGE OF ENGINEERING AND COMPUTER SCIENCE". The main navigation bar includes "Department of Mechanical & Materials Engineering". The page is organized into several sections:

- INFO FOR:** Future Students, Current Students, Alumni & Friends, Government & Industry.
- INFO ABOUT:** Contact and Visit Info, Employment & Co-op, Advising, Faculty & Staff, International Opportunities.
- CEES Web Index:** A-Z index for navigation.
- Department of Mechanical & Materials Engineering Home** link.

The main content area is divided into five columns of courses:

- Core Energy Courses:**
 - WSU/ME 744: Advanced Thermodynamics (4 quarter credits). Description: Thermodynamics is studied from both the classical (macroscopic) and statistical (microscopic) viewpoints with emphasis on statistical thermodynamics. Property relationships, Maxwell relations, partition functions, distribution functions, kinetic theory and the Boltzmann transport equation are discussed. Prerequisites: ME310 or ME510. Links: WSU/ME 700, UD/ME 511, UD/CME 507, AFIT/PHYS 035, WSU/ME 780, UD/MAT 590.
- Renewable Energy Courses:**
 - WSU/ME 623: Energy Conversion (4.5 quarter credits). Description: This course will study the fundamentals of energy and energy conversion, our energy resources, direct energy conversion, heat to work energy conversion, fossil fuel energy conversion, and alternative energy conversion. Prerequisites: ME310 or ME510. Links: WSU/ME 624, WSU/ME 626, WSU/ME 623, WSU/ME 750, WSU/ME 752, UD/ME 573.
- Clean Energy Courses:**
 - WSU/ME 628: Fuel Cell Science and Technology (4.5 quarter credits). Description: Fundamentals, technologies, applications of various types of fuel cells. Thermodynamics prediction, electrolyte conduction, electrode kinetics. Polymer electrolyte fuel cells, solid oxide fuel cell, fuel cell stack. Prerequisites: ME 315 or ME 515 and ME 370 or ME 570. Links: WSU/ME 627, CSU/WSU/ME 699, UD/ME/CME 524, AFIT/ENEG 620.
- Energy Efficiency Courses:**
 - WSU/ME 642: Vehicle Engineering (3.0 quarter credits). Description: Develops students' abilities to derive and solve vehicle equations, and introduce dynamic analysis in vehicle design. Various performance criteria, control concepts, and HEVs will be studied. Prerequisites: ME 213. Links: UD/ME 569, UD/ME 571, UD/ME 572, UD/ME 576.
- Math Courses:**
 - WSU/MTM 504: Advanced Engineering Mathematics I (3 quarter credits). Description: Topics may include ordinary differential equations, linear algebra orthogonality, Fourier series and integrals, multivariable calculus, and partial differential. Prerequisites: MTH232 and MTH235 or MTH233 and MTH253. Links: WSU/MTM 505, WSU/MTM 517, WSU/MTM 532, WSU/MTM 533, WSU/MTM 606, WSU/MTM 607, WSU/MTM 616, WSU/MTM 631, WSU/MTM 655.

On the right side, there is a "More Information" section with links to "ECE Home", "Courses", "Curriculum", and "Contact Us". At the bottom, there is a footer with the address "3640 Colonel Glenn Highway - Dayton, Ohio - 45435", copyright information "Copyright Information © 2011 | Accessibility Information", and contact information "Please send comments to: webmaster@cs.wright.edu".

Figure 3: Course detail page of Wright State's Renewable and Clean Energy web site.

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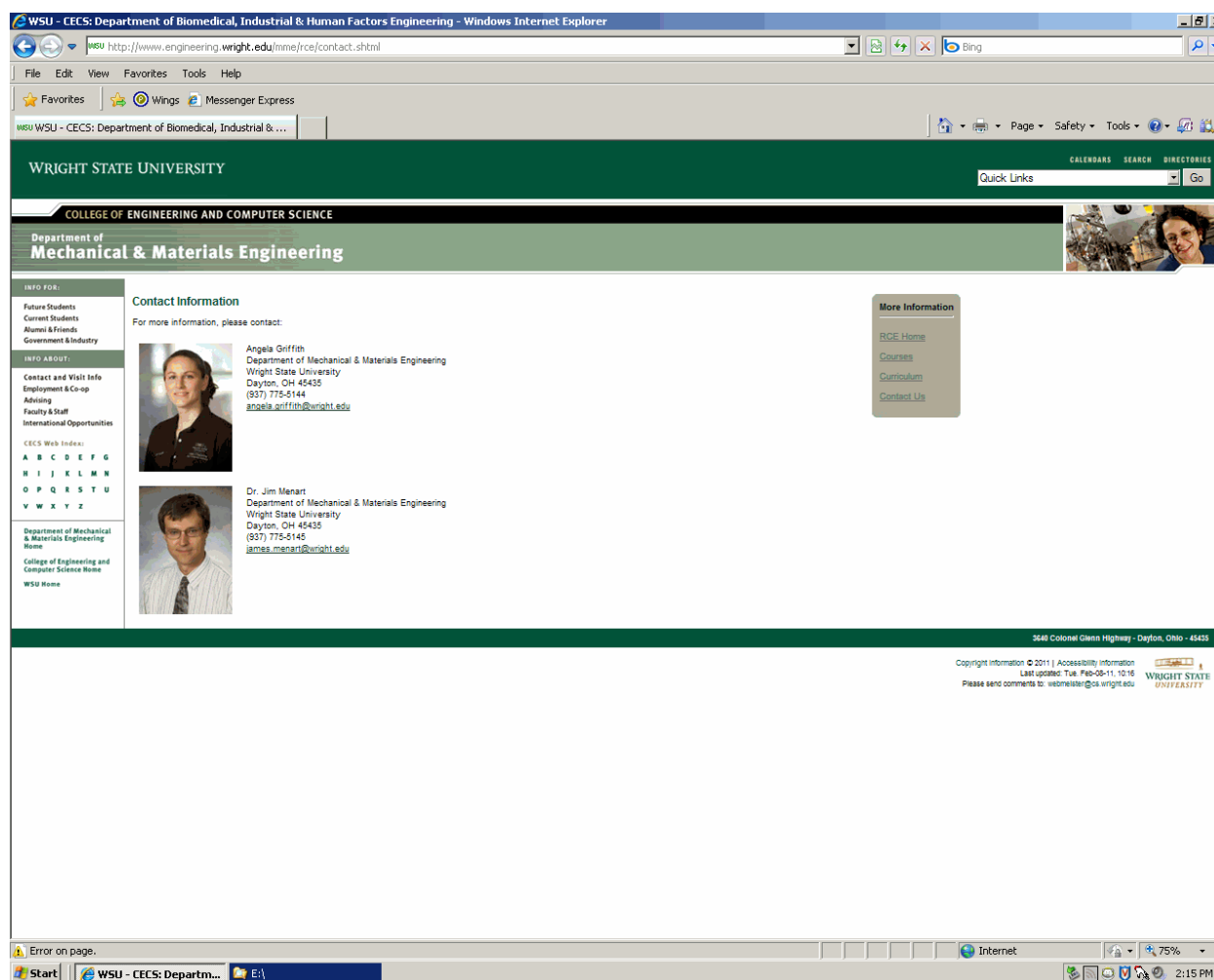


Figure 4: Contact page of Wright State’s Renewable and Clean Energy web site.

RESEARCH

A number of graduate student research projects were partially supported with money from this grant. As part of this grant seven graduate students were supported. These students are Kyle Hughes, Paul Gross, Michael Gustafson, Jayme Carpenter, Cory Knick, Zhuo Yao, and Chuang Guan. The research work that these students performed includes geothermal energy, solar energy, lithium ion batteries, and hydrogen storage. Because it generally takes two years to finish a Master’s degree and this grant was only applicable for one year, these Master’s thesis projects were only partially funded by this grant. This grant money helped to keep these projects alive and was important to the success of the Renewable and Clean Energy Program at Wright State University.

In the sections below descriptions of the research occurring in each of the topical areas listed above are given. The descriptions are not complete, but are meant to give the reader a flavor of the type of research that was performed as a result of this grant.

Geothermal Work

The purpose of this work is to produce guidelines, or a rule-of-thumb, for the proper length of tube needed for a horizontal geothermal ground loop system to provide effective performance for residential heating and cooling applications. The loop length in a ground source heat pump system is important to determine because an undersized loop can result in a system that is unable to handle the required heating and cooling loads; and an oversized loop increases the cost of installation. Providing guidelines for tubing per ton of heating and cooling will aid in reducing installation costs of ground source heat pump systems, making them more cost competitive to traditional heating and cooling options.

This work is a numerical exploration of a horizontal geothermal ground loop to see what length it should be for efficient operation. This investigation is carried out using the Wright State developed finite volume code called GEO2D. GEO2D is a geothermal ground loop simulation tool which was developed under a grant from the Department of Energy in 2011. This is a detailed two-dimensional, unsteady analysis of the ground loop that is coupled to analysis of the heat pump and the heat loads of the residence or building being heated or cooled. This is a complete simulation of ground loop geothermal systems.

Tubing per ton of heating and cooling guidelines will be determined by performing a computational study that includes the effects of location and soil type. For this work three locations are surveyed: Dayton, OH; Orlando, FL; and St. Paul, MN. Heating and cooling loads appropriate for an average 2000 ft² home in these locations are used. To study the effects of soil, three different soil types with different thermal conductivities are investigated. The soil types used are dry silty clay, moist silty clay, and wet sandy soil with thermal conductivities of 0.4 W/m-K, 0.8 W/m-K, and 2.8 W/m-K respectively. The primary interest is how the different locations and soil types affect the required ground loop length. The "proper" ground loop length is largely determined by the desired COP for the heat pump used in the geothermal system. For this research, lengths that satisfy the criteria of having a minimum COP of 2.0 and 2.5 after a 20 year period are recorded. With three locations, using three different soil types, nine lengths are reported in which the COP of the system did not drop below 2.0 and nine more lengths are reported for the case where the COP does not drop below 2.5. This yields nine plots which are shown below.

Figure 5 through Figure 7 display the graphs of COP versus length for the thermal conductivities of 0.4 W/m-K, 0.8 W /m-K, and 2.8 W/m-K in Dayton, Ohio. A similarity all three graphs share is that as the length of the ground tube increases, the change in COP decreases. It is crucial to find the minimum length at which the COP does not increase significantly; a system built with that loop length will cost less than a system with a longer loop length, but will still deliver comparable performance. Figure 5 through Figure 7 demonstrate that thermal conductivity plays a significant role in the performance of a geothermal heat pump. For example, looking at the length of 150 m of tubing, the system surrounded by soil with a thermal conductivity of 0.4 W/m-K has a COP of approximately 1.8. Stepping up to the next thermal conductivity tested, 0.8 W/m-K, yields a COP of around 2.4 for 150 m of loop length. At a thermal conductivity of 2.8 W/m-K, 150 m of loop length yields a COP of 3.1. The heat pump performance is significantly impacted by a change in thermal conductivity.

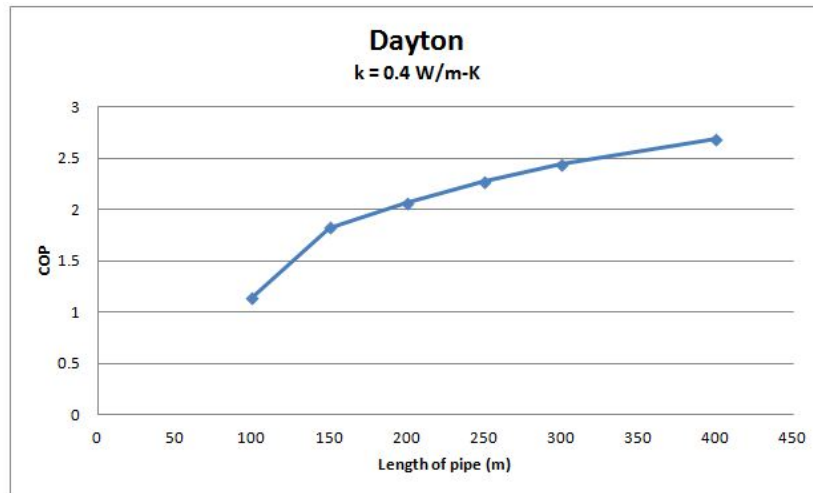


Figure 5: COP for Dayton length study at a thermal conductivity of 0.4 W/m-K.

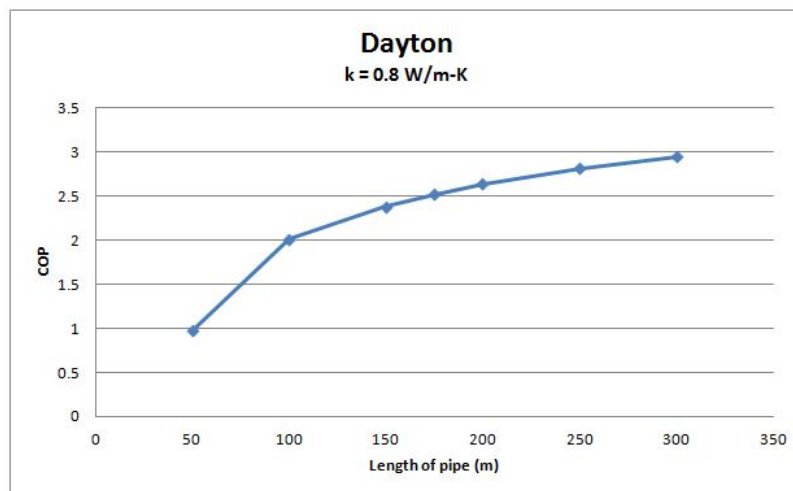


Figure 6: COP for Dayton length study at a thermal conductivity of 0.8 W/m-K.

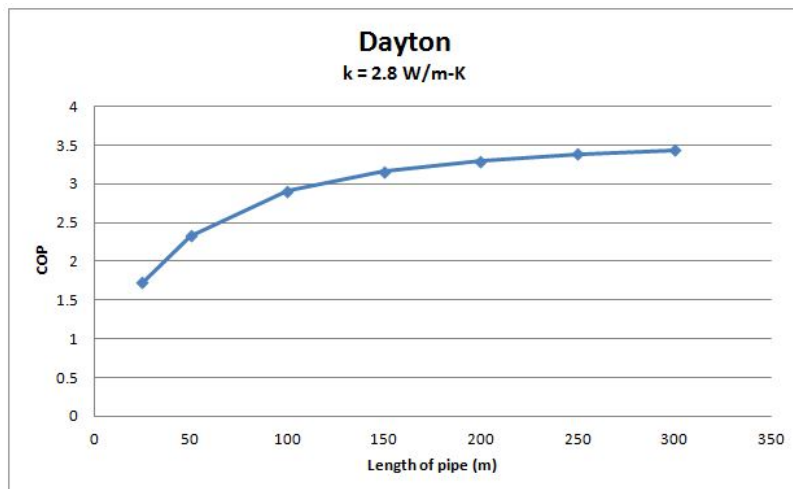


Figure 7: COP for Dayton length study at a thermal conductivity of 2.8 W/m-K.

The plots of COP versus length for the Orlando location are shown in Figure 8 through Figure 10. In comparison to the plots for the Dayton area, these plots increase more sharply. Figure 8 and Figure 9 show that more tubing is needed in the Orlando location than the Dayton location to reach the same COP; this occurs because the Orlando location does not have a balanced heating and cooling load and more tubing is needed to adequately bring the heat exchanger fluid down to a temperature conducive to good system performance. As the thermal conductivity of the soil increases, a leveling off of COP performance within the surveyed tube lengths can be seen.

Figure 11 through Figure 13 show the plots of COP versus loop length for St. Paul, MN. The St. Paul system results show a smaller slope than the Orlando system; this means that the performance is not significantly increased by increasing tube length. From this observation, it can be predicted that a shorter length of tubing per ton of heating and cooling is better for St. Paul because the cost of additional tubing will more quickly outweigh the benefit of the small increase in heat pump performance. Figure 11, the COP plot at 0.4 W/m-K for St. Paul, does not appear to level off over the lengths tested in this study. However, the plots with higher thermal conductivities, such as Figure 12 and Figure 13, show a definite leveling off of performance for the longer lengths.

Figure 5 through Figure 13 can be used in conjunction with the building heat loads to find suitable lengths of tubing per ton heating and cooling for a given COP. Values may be interpolated from the plots, but not extrapolated. For quicker reference, the guidelines for tubing per ton heating and cooling for COPs of 2.0 and 2.5 have been calculated and compiled in Table 1 and Table 2. The of tubing per ton heating and cooling was found by selecting the corresponding loop length for the desired COP from the COP plots in Figure 5 through Figure 13. This value was then divided by the maximum building load. To ensure that outlying values were not selected for the maximum building loads, the maximum heating and cooling loads that were not present in at least 1% of the population (approximately 88 times) were disregarded.

When a COP of 2.0 is desired, Table 1 indicates that the Dayton heat loads require the least amount of tubing per ton heating and cooling and Orlando requires the most tubing per ton heating and cooling. The St. Paul location results are very similar to the Dayton results, suffering only a small amount from the slightly uneven heating and cooling loads in St. Paul.

For a desired COP of 2.5, Dayton heat loads require the least amount of tubing per ton heating and cooling. According to Table 2, Orlando requires the most tubing per ton heating and cooling at a given thermal conductivity and St. Paul falls between the two. When examining Table 2, the effect of ground thermal conductivity to heat pump performance can be seen. For example, looking at Dayton, the location with the most favorable heat loads for GHP performance, at the lowest thermal conductivity, tubing per ton heating and cooling of 226 m/ton is recommended. Orlando, with the same parameters, recommends 264 m/ton, yielding a 58 m/ton difference. However, at the next highest thermal conductivity tested in Orlando, 0.8 W/m-K, the tubing per ton heating and cooling suggested length is 149 m/ton. In comparison with Orlando at a thermal conductivity of 0.4 W/m-K, this is 135 m/ton better; more improvement is seen with a higher thermal conductivity rather than changing to more favorable heat loads.

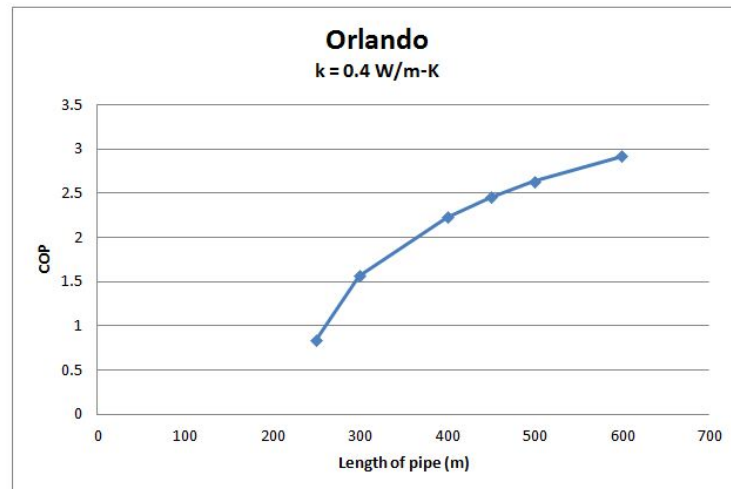


Figure 8: COP for Orlando length study at a thermal conductivity of 0.4 W/m-K.

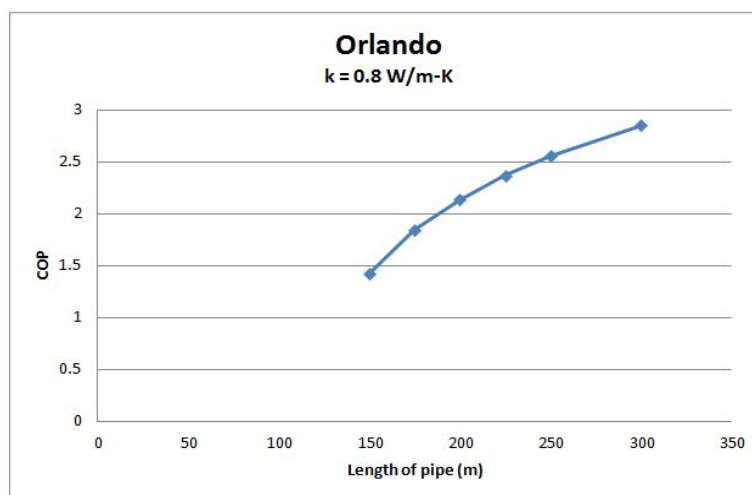


Figure 9: COP for Orlando length study at a thermal conductivity of 0.8 W/m-K.

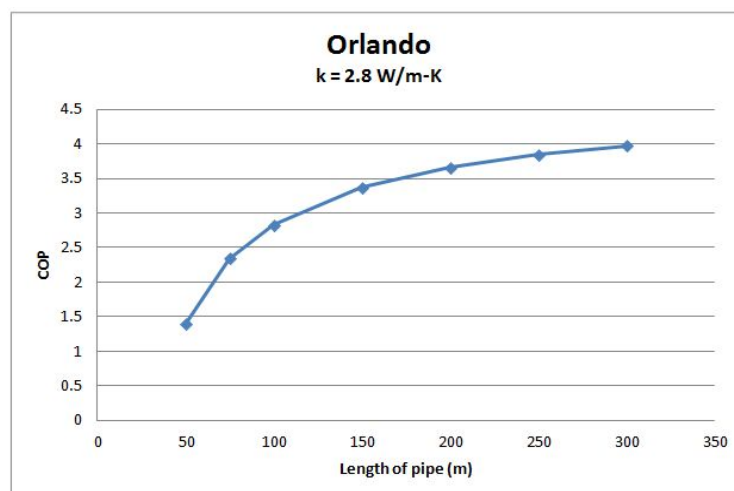


Figure 10: COP for Orlando length study at a thermal conductivity of 2.8 W/m-K.

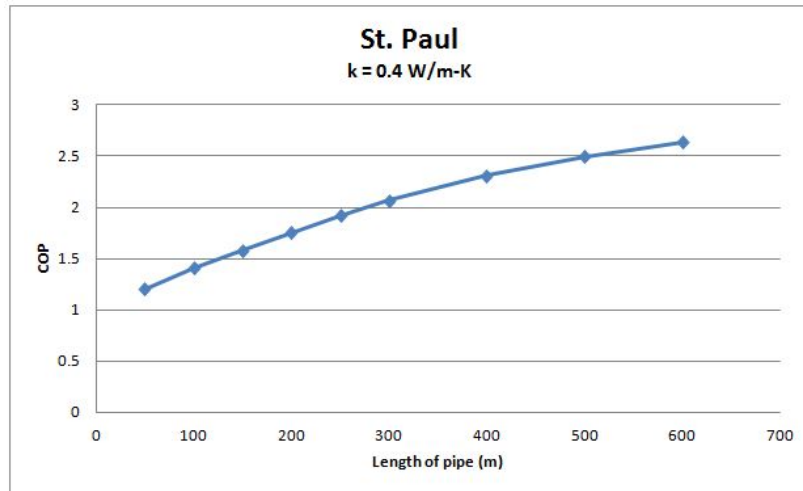


Figure 11: COP for St. Paul length study at a thermal conductivity of 0.4 W/m-K.

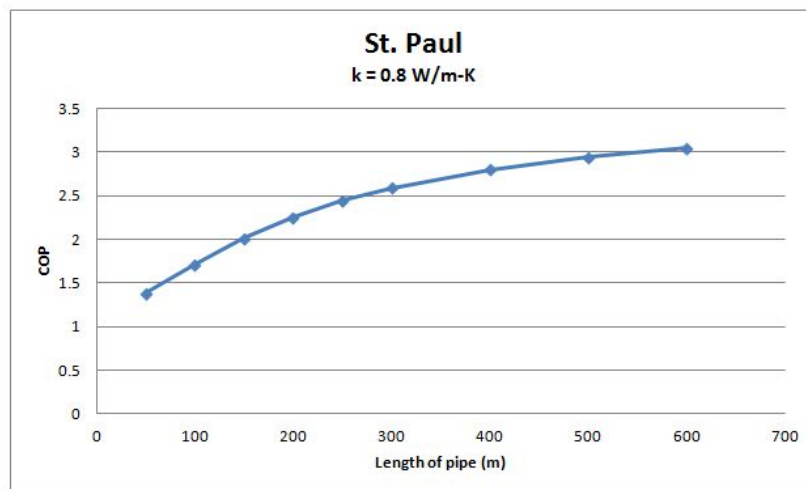


Figure 12: COP for St. Paul length study at a thermal conductivity of 0.8 W/m-K.

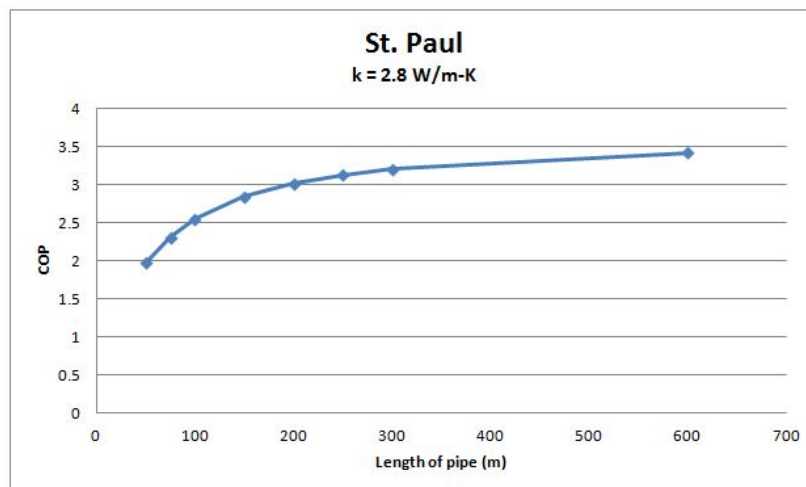


Figure 13: COP for St. Paul length study at a thermal conductivity of 2.8 W/m-K.

Table 1: Tubing Per Ton Heating and Cooling for a COP of 2.0.

| COP = 2.0 | | |
|-----------|---------------------------------|-------------|
| Location | Thermal Conductivity
(W/m-K) | L/Q (m/ton) |
| Dayton | 0.4 | 130 |
| | 0.8 | 70 |
| | 2.8 | 33 |
| Orlando | 0.4 | 224 |
| | 0.8 | 115 |
| | 2.8 | 40 |
| St. Paul | 0.4 | 139 |
| | 0.8 | 74 |
| | 2.8 | 36 |

Table 2: Tubing Per Ton Heating and Cooling for a COP of 2.5.

| COP = 2.5 | | |
|-----------|---------------------------------|-------------|
| Location | Thermal Conductivity
(W/m-K) | L/Q (m/ton) |
| Dayton | 0.4 | 226 |
| | 0.8 | 120 |
| | 2.8 | 45 |
| Orlando | 0.4 | 284 |
| | 0.8 | 149 |
| | 2.8 | 51 |
| St. Paul | 0.4 | 253 |
| | 0.8 | 136 |
| | 2.8 | 48 |

A number of other plots were produced as part of this work for each of the nine combinations of location and thermal conductivity. In addition to loop length results, the bulk exit temperature of the liquid from the geothermal ground loop and the heat transfer rate between the fluid and the ground were produced. These plots provide a geothermal system designer with more information on the performance of the ground source heat pump system as a function of location and soil type.

Solar Work

The title of the solar project that was partially fund with this grant is "Modeling a 24 hour Solar Power Plant". The idea behind this project is to write a computer program that simulates a solar power plant that can deliver power to the grid over a 24 hour period. Of course the only way that this can be done is using some sort of energy storage. The storage mechanism used in this work is hydrogen. Solar panels are used to capture energy from the sun and convert it to electricity. Part of the electricity from the solar panels is delivered directly to the electrical grid to supply the current demand for power. The remaining electricity from the solar panels is run through a fuel cell that is running as an electrolyzer to produce hydrogen. This hydrogen is then stored in an underground storage tank for use at night. After the sun has set hydrogen is taken from the storage tank and run back through the fuel cell, operating in forward mode, to produce electricity that can be supplied to the electrical grid.

Technically this type of solar power plant is possible to build and operate. However, at the present time, this type of electric power plant is not cost competitive. The costs of all the components used in this system are high. Expensive parts would be the hydrogen storage tanks and the fuel cells. Solar panels are also expensive, but the price has come down considerably in the past three years; and in some parts of the country solar generated electricity is close to being cost competitive to that being generated with fossil fuels. The rapidly declining cost of solar generated electricity is one of the exciting aspects of this project.

One of the goals of this project is to obtain estimates on the costs of a 24 hour solar electric power plant. The entire plant will be modeled and then reasonable cost estimates of each component in the system will be obtained so that the initial capital costs can be determined. Next, the income generated by the power station will be determined by using locally determined costs of electricity. Maintenance costs will also be estimated on a yearly basis. The maintenance costs will be subtracted from the yearly income providing a net income for the 24 hour solar electric power plant. Using the time value of money, with an appropriate interest rate, the payback period for the plant will be determined. This payback period is expected to be very long.

A second goal of this project is to find ways to reduce the cost of such a solar electric power plant. There are a large number of ways to store and generate hydrogen. For example, instead of storing hydrogen in high pressure tanks, in a metal hydride, as a liquid using cryogenic techniques, or by using some other type of absorption technique. Thus it is believed that a computer model such as this will lead to ideas for cost improvements. In addition, maybe fuel cells are not the best way to produce hydrogen and then use the hydrogen to produce electricity. It may be that some general electrolysis technique should be used and then a gas turbine in conjunction with an electric generator can be used to produce electricity by burning the hydrogen.

A third goal of this project is to have a tool that can manage the production and storage of energy in such a plant. This is a very complicated process. This will be a function of the power produced and the power loads placed the plant. Managing a power plant such as this is a complex problem. Some of the times during the day all of the power produced by the solar panels will be delivered directly to the grid. At other times during the day only part of the power from the solar panels will be delivered to the grid and the remaining power will be used to generate hydrogen. Some times during the day hydrogen will have to be taken from storage and used to produce power, because the solar panels will not generate enough electricity. Of course during the night all of the power will come by running the stored hydrogen through the fuel cells. A very crude initial computation in this regard is shown in Figure 14. This plot shows the solar resource, the amount of power generated by the fuel cells, the amount of power used by the fuel cells to produce hydrogen, and the electricity demand. The solar resource shown in this plot is for Yuma, Arizona in the summer. Arizona is a high sun state and one of the better locations to utilize solar energy. This plot is for one week. Figure 15 shows the amount of hydrogen in storage at a given time. When the hydrogen is declining it means that it is being used to generate power. When the hydrogen is increasing, this means it is being generated by the extra solar power. The goal of the project is to generate a plot for an entire year including many more details than are included in the plots shown in Figure 14 and Figure 15.

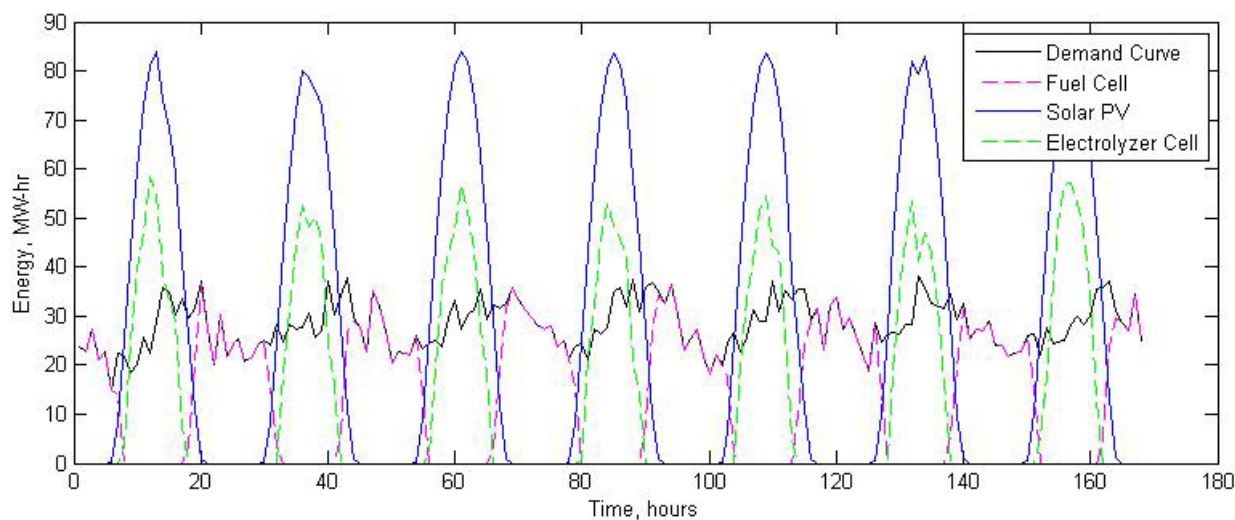


Figure 14: Solar resource, energy used by fuel cells to produce hydrogen, electricity generated by fuel cells, and the electricity demand curves for one week for a 24 hour solar electric power plant in Yuma, Arizona.

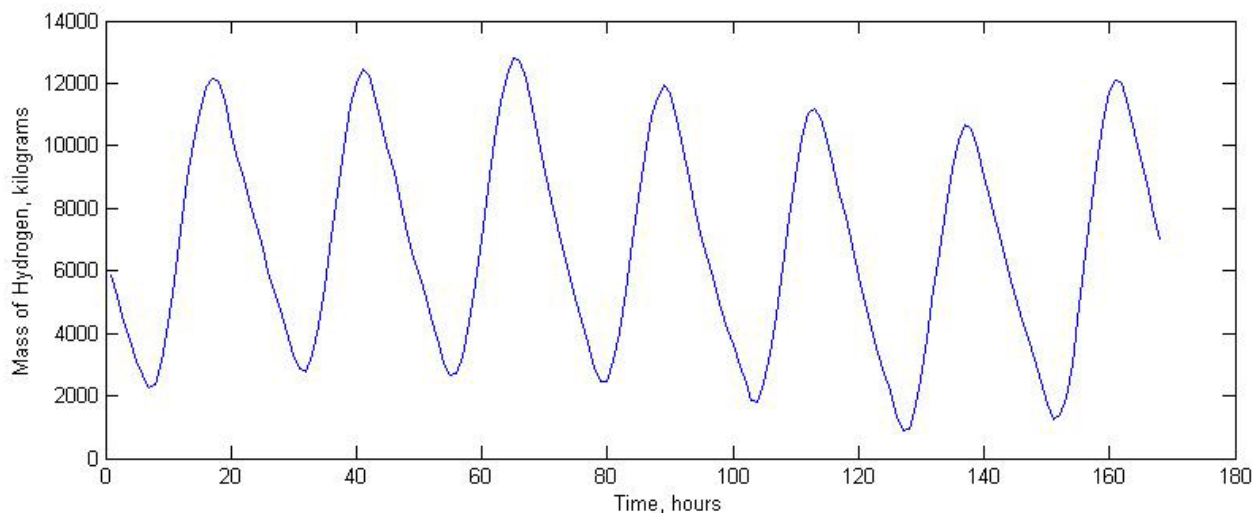


Figure 15: Amount of hydrogen in storage as a function of time for one week for a 24 hour solar electric power plant in Yuma, Arizona.

Lithium Ion Battery Work

Electric vehicles, medical equipment, military equipment, and space technology require electric power systems with features like high energy density, safety, long life, low maintenance, etc. This demand provides a strong driving force for the development of electrochemical power technology. Many high performance electrochemical power sources have been developed in the past several decades. The lithium-ion battery attracts a great deal of attention due to its advantages in terms of high energy density, rechargeability, and long cycle life. At present, most portable devices like mobile phones, laptops, and digital cameras are powered by lithium-ion batteries.

A lithium-ion battery consists of a cathode and an anode separated by a macro porous polymer separator soaked in a lithium-ion conducting electrolyte. The cathode material is generally a high redox potential transition metal oxide or phosphide. Typical cathode materials include layer structured LiMO_2 , spinel-structured LiM_2O_4 , and olivine-structured LiMPO_4 , where M can be iron, cobalt, nickel, manganese or other transition metals. Typical anode materials, in most cases, are carbon-based materials which can store large amounts of lithium at low redox potentials such as graphite, coke, and carbon microspheres. Tin and silicon based metals can also serve as the anode. Lithium-ion battery electrolytes are generally a lithium salt (mostly fluorine-containing organic lithium salt) like LiClO_4 , LiPF_6 , LiBF_4 , LiAsF_6 , LiCF_3SO_3 dissolved in appropriate organic solvent combination such as propylene carbonate, ethylene carbonate, dimethyl carbonate, and diethyl carbonate.

Two lithium ion battery projects were funded as part of this work. The first project involved improving the cathode and the second project involved improving the anode. Both of these projects involve looking at the materials used for these two components of the battery. Advancement of high-capacity lithium-ion batteries, especially for the demand in electric vehicles, relies on novel electrode materials with high reversible lithium storage capacities. That

is what these two lithium-ion battery projects are about. Below the cathode work is described first and the anode work is described second.

Cathode Work

The cathode work involves studying olivine LiFePO_4 . Olivine LiFePO_4 has the advantage of low cost, being environmentally friendly, being safe, and having a high electrochemical performance; thus it has attracted a great deal of attention in recent years. However, improvement in LiFePO_4 's electronic conductivity and lithium ion diffusion coefficient is still a challenge and a key problem with this technology. These problems must be overcome so that LiFePO_4 can be applied to large-scale industrial applications. Previous research provides a rough guidance on a high-performance LiFePO_4 cathode applicable for Li-ion batteries. Nanoparticles of LiFePO_4 coated with a thin layer of carbon, i.e. LiFePO_4/C nanocomposite, facilitate increased electrical conduction and ionic diffusion.

The goal of this work is to improve the electrochemical performance of LiFePO_4 for cathodes in lithium-ion batteries. This is done by synthesizing LiFePO_4 at the nanoparticle size and studying the effects of different parameters on this synthesizing process. This research work could lead to improvements in the capacity, cycle life, and kinetic performance of lithium-ion batteries. This work uses a sol-gel method to synthesize carbon coated LiFePO_4 material for use as a cathode material in lithium-ion batteries. As part of this work the parameters of the sol-gel process that affect the LiFePO_4 are systematically studied including the influence of the carbon and iron sources, the carbon content, and the sintering temperature. All these items affect the LiFePO_4/C morphology and structure which have an effect on the electrochemical performance of LiFePO_4 . How these factors affect the electrochemical performance are tested and analyzed in hopes that they reveal a means to improve the kinetic performance of LiFePO_4 as a cathode material in lithium-ion batteries.

The specific research content of this work is listed below:

1. Citric acid is used as a complexing agent and carbon source to synthesize carbon coated LiFePO_4/C . The influence of sintering temperature on the electrochemical performance of LiFePO_4 is studied and the optimized sintering temperature determined. The influence of non-stoichiometric lithium content on the electrochemical performance of LiFePO_4 is also studied. The synthesis techniques and parameters that provide the best LiFePO_4/C electrochemical performance are then used to study the effects of citric acid content. Next the best carbon content is studied.
2. Next, ethylene glycol is used as a complexing agent and carbon source, $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ or $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ are used as an iron source to synthesize LiFePO_4/C . The influence of the iron source and the content of ethylene glycol on the structure and electrochemical performance are studied. Using the optimized iron source and carbon content the influence of PH value on the structure and electrochemical performance are then studied. Efforts are made to understand the relationships among synthesis techniques, structure, and electrochemical performance.
3. Using the optimal procedures and parameters found in the first and second parts of this research listed above, a study is done using a citric acid plus

- ethylene glycol two compound complexing agent to synthesize LiFePO_4/C and determine the influence of the compound complexing agent on the electrochemical performance of LiFePO_4/C . Further a de-agglomeration pretreatment on the dry gel is studied to determine its influence on the structure and electrochemical performance of LiFePO_4/C .
4. Lastly, the influences of different complexing agents on the performance of LiFePO_4 according to the coordination chemistry theory are determined. The coordination chemistry theory is used to reduce the number of experiments that need to be done in order to find an effective basis for the choice of complexing agent using the sol-gel method.

The effect of different material processing techniques and parameters on the lithium-ion battery discharge capacity are shown in Figure 16 through Figure 20. Figure 16 shows the effect of sintering temperature, Figure 17 shows the effect of relative molar fraction of lithium to the stoichiometric amount of lithium, Figure 18 shows the effect of amount of ethylene glycol used, Figure 19 shows the effect of carbon rate, and Figure 20 shows the effect of PH value. From these figures is seen that the optimum discharge capacity is obtained at a sintering temperature of 700°C , a molar fraction of lithium of 1.25 or 25% above stoichiometric, at the lowest ethylene glycol content tested, at the highest carbon rate tested, and a PH value of 6.8. All of these discharge capacities were obtained from charge/discharging curve such as that shown in Figure 21. Note that the charging/discharging cycle was performed a number of times to obtain the plotted discharge capacities shown in Figure 16 through Figure 20.

From this research, it has been found that different chelating agents have significant impacts on the performances of LiFePO_4 when used in lithium-ion batteries when all other experimental factors are controlled. In general, ethylene glycol is better than citric acid and a combination of ethylene glycol and citric acid is better than just citric acid. On the other hand, researchers have submitted that different valence of iron sources play an important role on the electrochemical performance, carbon content, and morphology of LiFePO_4 , no matter what kind of chelating agent is utilized. We hypothesized that other parameters such as PH value in the sol precursor will vary the ferrous ion content during the sol-gel preparation, although the starting raw material is ferric oxalate, which eventually affects the properties of the LiFePO_4 . During the sol-gel processing, the iron ions react with the chelating agent and form complex compounds. There are three states in the whole process, a sol, a gel, and a sintered product. The particle size and uniformity of the sintered product LiFePO_4 determines the electrochemical performance of the lithium ion battery. The sol is dispersed in the solution; it keeps good uniformity by continuous stirring. The gel is different when different iron sources and complexing agents exist in the sol precursor. Thus, the formation of the middle state gel is important to the process, it directly determines the properties of the sintered product. In this work we set out to understand the possible sol-gel mechanisms on the impacts of iron sources and complexing agents, as well as iron valence state, on the eventual product of LiFePO_4 . Basic concepts about complexing reactions in coordination chemistry were considered and the influences of using different iron sources and complexing agents on the properties of LiFePO_4 were interpreted according to coordination theories.

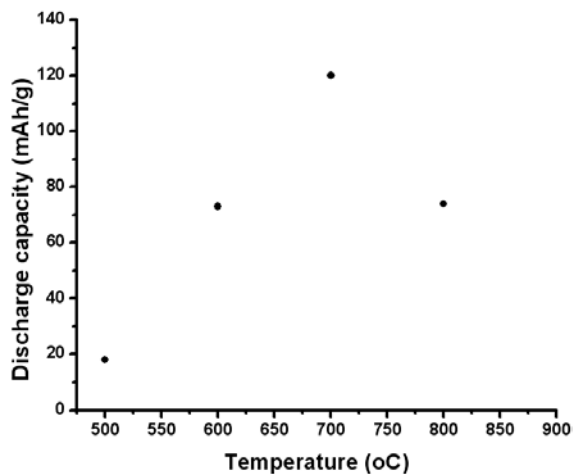


Figure 16: Discharge capacity of LiFePO4/C versus sintering temperature.

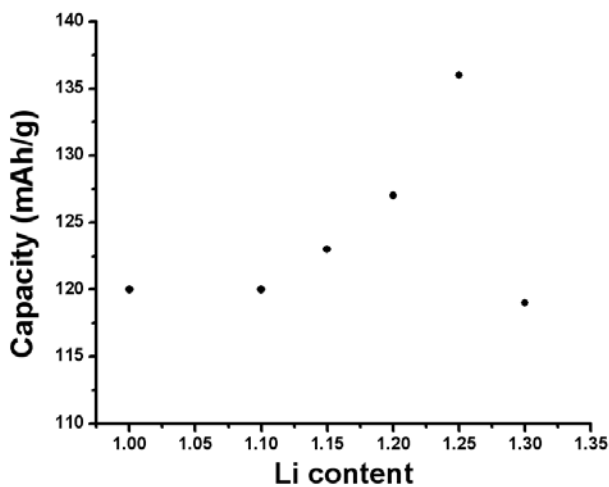


Figure 17: Discharge capacity of LiFePO4/C utilizing different lithium contents in the sol-gel process.

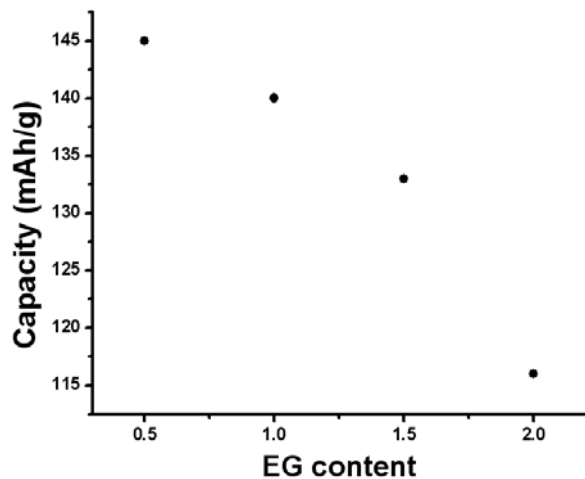


Figure 18: Discharge capacity of LiFePO4/C utilizing different ethylene glycol (EG) contents in the sol-gel process.

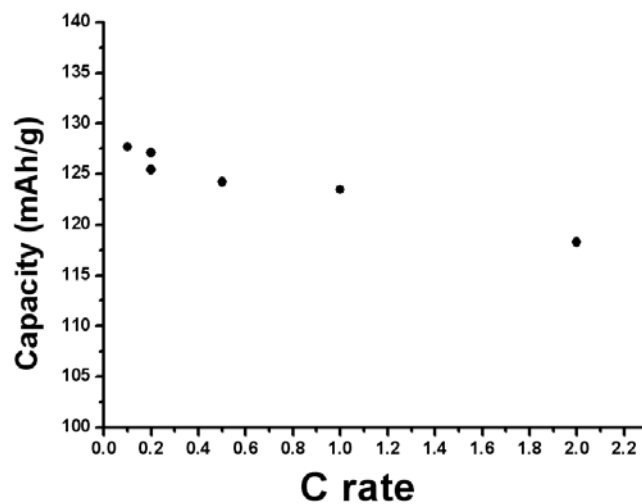


Figure 19: Discharge capacity of LiFePO4/C for different carbon rates.

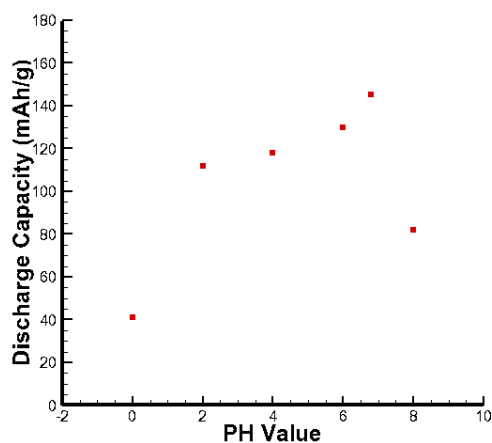


Figure 20: Discharge capacity of LiFePO4/C for different PH values.

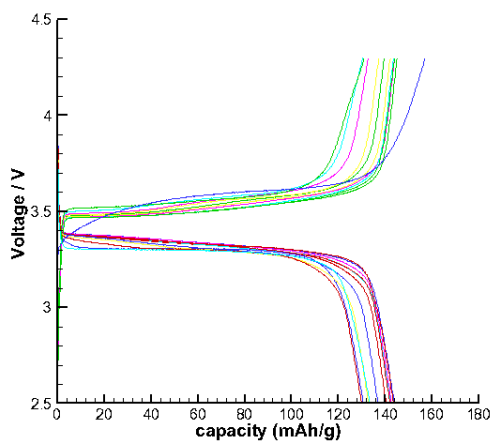


Figure 21: Typical charging/discharging curves of a lithium-ion battery.

When metal ions in two oxidation states are coordinated with the same kind of ligand, in general, the coordination complex formed by the higher valence metal ion has higher stability. The complex compounds formed by Fe^{2+} and complex agents have small stability constants compared with Fe^{3+} . Therefore, the Fe^{2+} containing complex is easily decomposed during the sintering process. Consequently, the formed LiFePO_4 exists in the form of small particles, contains less carbon originated from the ligand, and hence, exhibits good discharge ability. In consideration of the complex agents, stability constants of the complex compounds formed by ethylene glycol or citric acid are different under the condition of using the same metal ion. The complex compounds formed by ethylene glycol have small stability relative to citric acid. Similarly, the gel complex is decomposed faster during the sintering process leading to less carbon content and high discharge ability. Therefore, based on this work, two suggestions are proposed on the aspects of selecting iron sources and complex agents for the sol gel preparation of LiFePO_4 :

1. For the iron source: select a salt composed of Fe^{2+} such as $\text{FeC}_2\text{O}_4\cdot\text{H}_2\text{O}$ and $\text{Fe}(\text{CH}_3\text{COO})_2$.
2. Select the complex agent that contains the smaller number of carbon atoms that are in small molecules. The formed complex compounds will have small stability constants, such as ethylene glycol and oxalic acid.

The selections of precursors and complex agents also have some reference values for the preparation of the LiMPO_4 series of cathode materials, or other cathode and nano-functional materials.

Anode Work

The second lithium ion battery project involves studying carbon fiber supported silicon nanowires for use as anodes in lithium-ion batteries. Silicon is a possible alternative for negative electrode materials because of its high electrical capacity; it has a theoretical electrical storage capacity of up to 4200 mAh/g. However, a problem with this material is the progressively large volume expansion of the parent silicon lattice when lithium atoms are inserted into the silicon. This results in cracking and disintegration of the electrode. Silicon nanowires have been demonstrated to be capable of mediating this problem, because the nanowire structure can accommodate large strain without pulverization. Since silicon nanowires are intrinsic electronic semiconductors, growing silicon nanowires on electrical conducting substrates can provide intimate electrical connections and fast electron transport. This work has obtained results on the morphological, structural, and electrochemical characterizations of silicon nanowires grown on the surface of carbon fibers.

Carbon fiber supported silicon nanowires were grown at 700°C using high-purity hydrogen gas and saline gas at a ratio of 1:2 using silver catalyst-assisted chemical vapor deposition. Lithium storage performances were assessed using the half-cell configuration. Lithium-metal foil was used as the counter electrode, silicon nanowires materials as the working electrode, and 1 M $\text{LiPF}_6/\text{EC}+\text{DMC}$ (1:1 in volume) as the electrolyte. The cells were subjected to galvanic discharge and charging cycles in the potential range from 0.01 – 3.0 V at a current density of 50 $\mu\text{A}/\text{cm}^2$.

Experimental results indicate that the density, length, and diameter of silicon nanowires primarily depend on the growth time and catalyst coating. It was found that a significant increase

of length occurred after 5 minutes. Figure 22 shows a high resolution scanning electron microscope image of silicon nanowires grown for 10 minutes. A large quantity of silicon nanowires was obtained. The average length reached was over 100 μm and the diameter was about 300 nm.

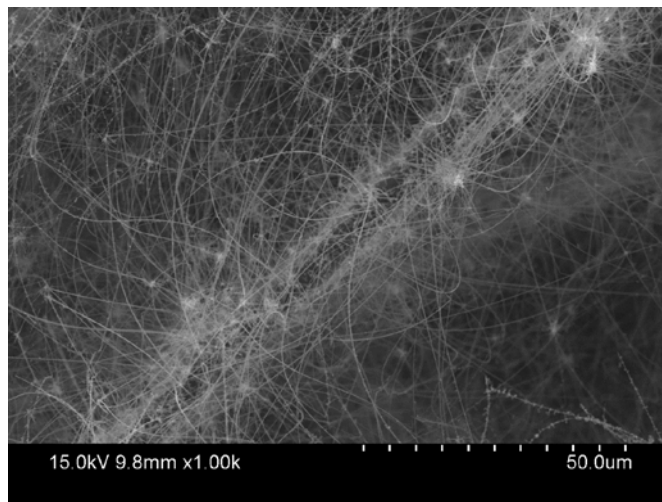


Figure 22: High resolution scanning electron microscope image of silicon nanowires grown on carbon fibers after 10 minutes.

Figures 23 (a) and (b) show the first five discharge/charge profiles of pure carbon fiber and carbon fiber supported silicon nanowires, respectively. Bare carbon fibers were tested as a baseline case at the same conditions used for the determination of the net lithium storage in silicon nanowires. For bare carbon fibers the first discharge capacity was about 350 mAh/g and the charge capacity was 200 mAh/g with a columbic efficiency of 57%. From Figures 23b, on a weight percent basis of silicon nanowires, it can be seen that when silicon nanowires grow on the carbon fibers, the first discharge capacity increases to 1540 mAh/g and the charge capacity grows to 980 mAh/g, giving a columbic efficiency of 64%.

The irreversible capacity mainly occurred above 0.3 V during the first discharge. Comparing Figures 23 (a) and (b), an irreversible slope centered around 1.3 V is the consequence of an irreversible lithium and electrolyte reaction with the functional groups of carbon fibers and the native silicon oxide layer on the silicon nanowires. The following progressive decrease of the voltage between 1.0 and 0.3 V can be attributed to solid electrolyte interphase formation. Based on capacity results, the first gravimetric discharge and charging capacity per gram of silicon nanowires can be determined leading to a value of 4500 mAh/g of silicon and 3800 mAh/g of silicon, respectively. Recently, in-situ experiments on an individual silicon nanowire anode indicated that the fully lithiated phase at room temperature was $\text{Li}_{15}\text{Si}_4$ corresponding to a capacity of 3579 mAh/g. Our measured reversible charge capacity is very close to the reported theoretical value.

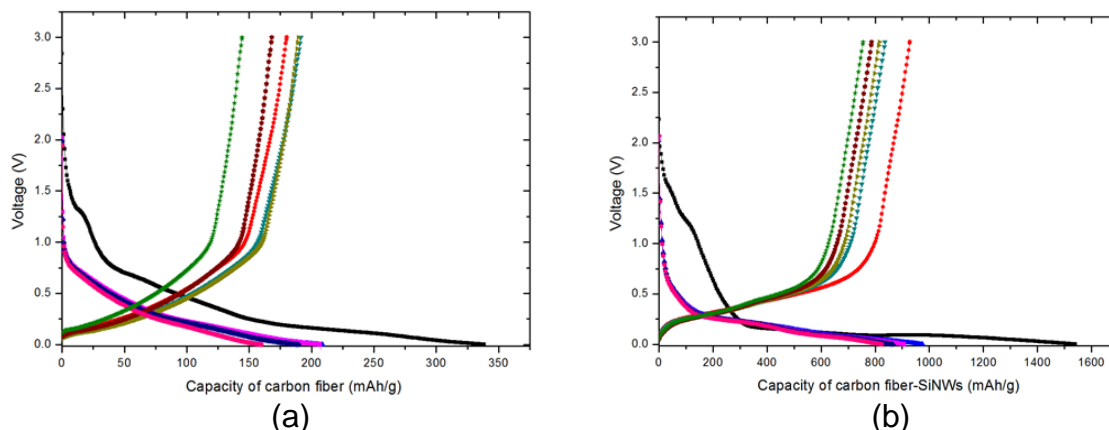


Figure 23: Galvanostatic charge-discharge profiles of a) carbon fiber (substrate), b) carbon fiber-silicon nanowires, obtained at a current density of 50 mA/cm².

Figure 23b, shows a long flat plateau during the discharge process. It is believed that during the first discharge, crystalline silicon reacted with lithium to form amorphous Li_xSi. The following discharge and charge process showed the different characteristic of amorphous silicon. During the second cycle, the capacity had a remarkable drop. The high capacity fading was due to the brittle property of the sample and the problem of pulverization. The capacity fading was also caused by the volume change after the first cycle.

A carbon fiber veil, silicon nanowire, anode material was prepared through chemical vapor deposition for this study. After 10 minutes of growth, there was a 25% weight increase and the diameter of the nanowires was about 300 nm. After 5 charge-discharge cycles a discharge capacity of 825 mAh/g was obtained, much higher than that of commercial lithium-ion batteries using graphite (372 mAh/g). Also, the cycling performance was significantly enhanced over the pure silicon anodes. We believe that the carbon fiber veil, silicon nanowire anodes are a promising method to enhance the performance of the lithium-ion batteries.

Nano-materials for Hydrogen Storage Work

This project involves developing a process to produce a material that can be used for hydrogen storage. The material being considered is graphene and the process being studied for its production is ultrasonication. This project is of utmost importance, given the unique status and potential of graphene as the basis of a whole new class of nanomaterials, and considering the mysteries that still exist in connection with graphene production, as well as the unique potential of graphene-based materials for hydrogen storage. Our preliminary results revealed the exfoliation mechanism and the active role of surfactants. Specifically, we have calculated the energetics of the final stages of graphene exfoliation. A snapshot of an exfoliation stage is shown in Figure 24.

The energy variations during exfoliation, an example of which is presented in Figure 25, allows one to calculate exfoliation rate, i.e., the production rate of graphene. These results are essential for understanding the details of the exfoliation process, and allow for optimization of relevant parameters.

For hydrogen storage, the exfoliated graphene platelets are doped with various metals, and their capacity for hydrogen storage is assessed through accurate computational modeling. One example of the resulting nanocomposites is shown in Figure 26. Preliminary results show promising hydrogen storage characteristics of graphene-based nanocomposites.

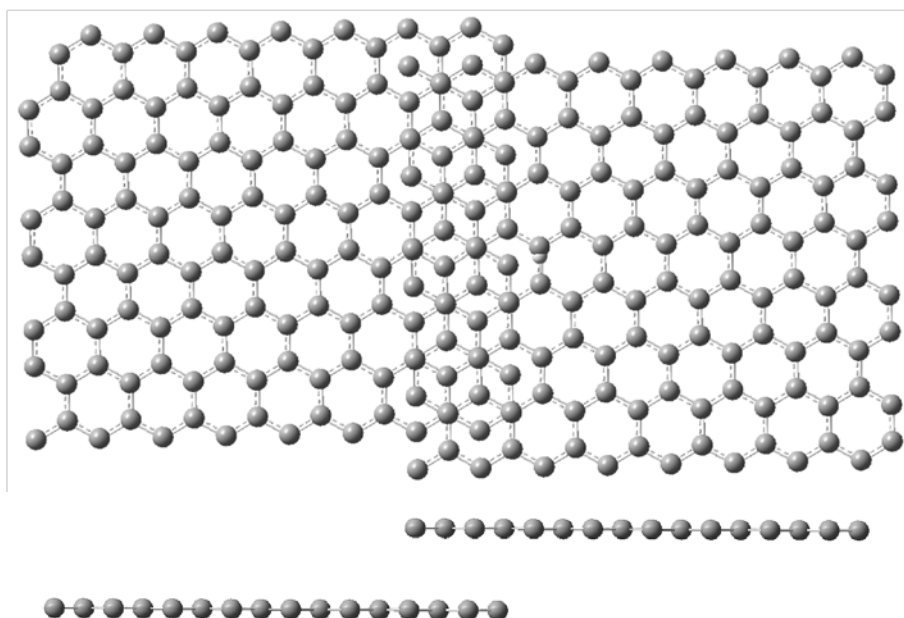


Figure 24: Two graphene nanoplatelets at the final stage of exfoliation (top view on the top and side view on the bottom).

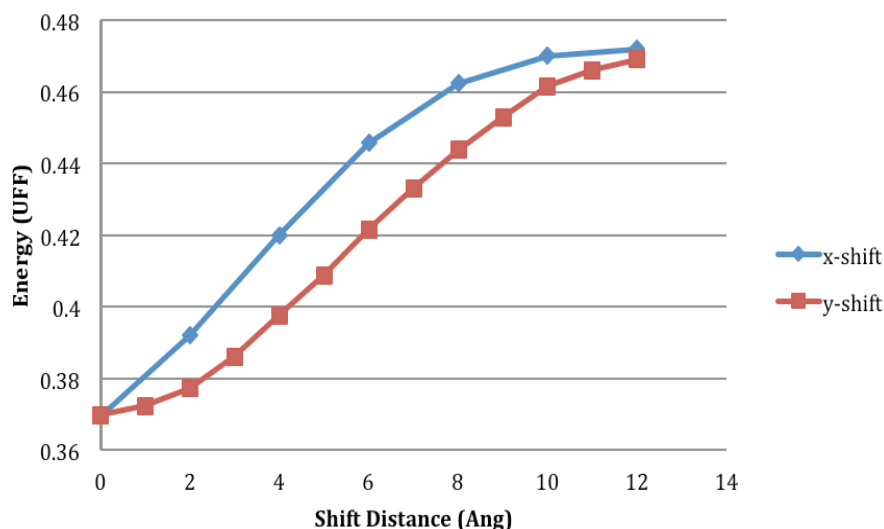


Figure 25: Energy variations for the parallel shift of one graphene layer (side length ~1 nm) in between two fixed layers of the same size, along armchair (x) and zigzag (y) edges.

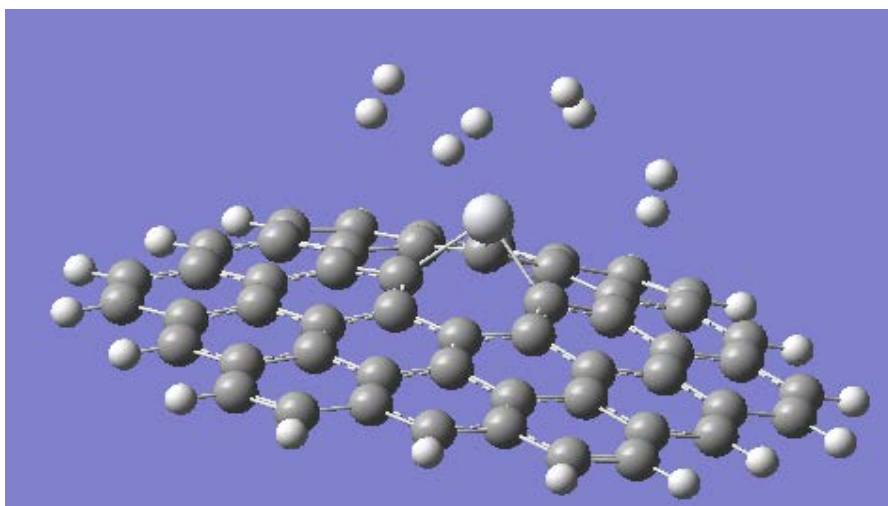


Figure 26: Four hydrogen molecules adsorbed on titanium-doped graphene.

UNDERGRADUATE AND HIGH SCHOOL PROGRAM DEVELOPMENT

At the undergraduate and high school level of renewable and clean energy education two activities were carried out by Wright State as part of this grant. The first activity was to introduce renewable and clean energy design projects into the Mechanical and Materials Engineering senior design class. The second activity was to build a geothermal energy demonstration unit and develop learning modules for high school students.

Senior Design

As part of this grant efforts were put into adding more renewable and clean energy projects to the undergraduate senior design course at Wright State University. It turns out that renewable and clean energy projects are good senior design projects. In the 2011-2012 senior design class there were four renewable and clean energy projects. These were

- Solar Irrigation Project
- Einstein Refrigeration Demonstration Unit
- Lithium-Sulfur Battery Project
- Electric Car Eco Project

Each of these projects involved 3 to 5 seniors in Mechanical or Materials engineering and one faculty advisor. They are all exciting projects that the students enjoyed working on and I believe they learned a great deal about engineering and renewable and clean energy.

Solar Irrigation Project

The Solar Irrigation Project involved the use of solar panels and a rain water collection system to irrigate a small plot of land. The system is completely renewable in that it obtains all its water from rain and all its power from the sun, all consumables are naturally replenished. Two photovoltaic panels are used to run a pump that delivers captured rain water from an underground tank and to the plants in the field. This system is only a demonstration unit and thus is small, but it could easily be scaled-up for large scale use. There is a nice match to using solar energy for irrigation because the most irrigation is required when the sun has been burning brightly drying the ground. When the sun is burning brightly the solar panels are capable of

delivering their maximum power. This system is not economically viable for locations that have easy access to electricity, but could prove to be beneficial in remote locations that do not have access to power lines or in third world countries where electrical power is scarce.

The most recent group of senior design students working on this project designed and installed a complete set of diagnostic equipment. This was done so that we could check how well the system is working. This will provide information on the performance of such a system and how the performance of the system can be improved. A picture of the farm area to be irrigated with the solar irrigation system is shown in Figure 27, a picture of the solar panels used to produce electricity for the pump is shown in Figure 28, and schematic of the complete system is shown in Figure 29. Note that the rainwater capture occurs on the 960 ft² roof shown in Figure 27.



Figure 27: Farm where solar irrigation system is located.



Figure 28: Solar panels used in solar irrigation system.

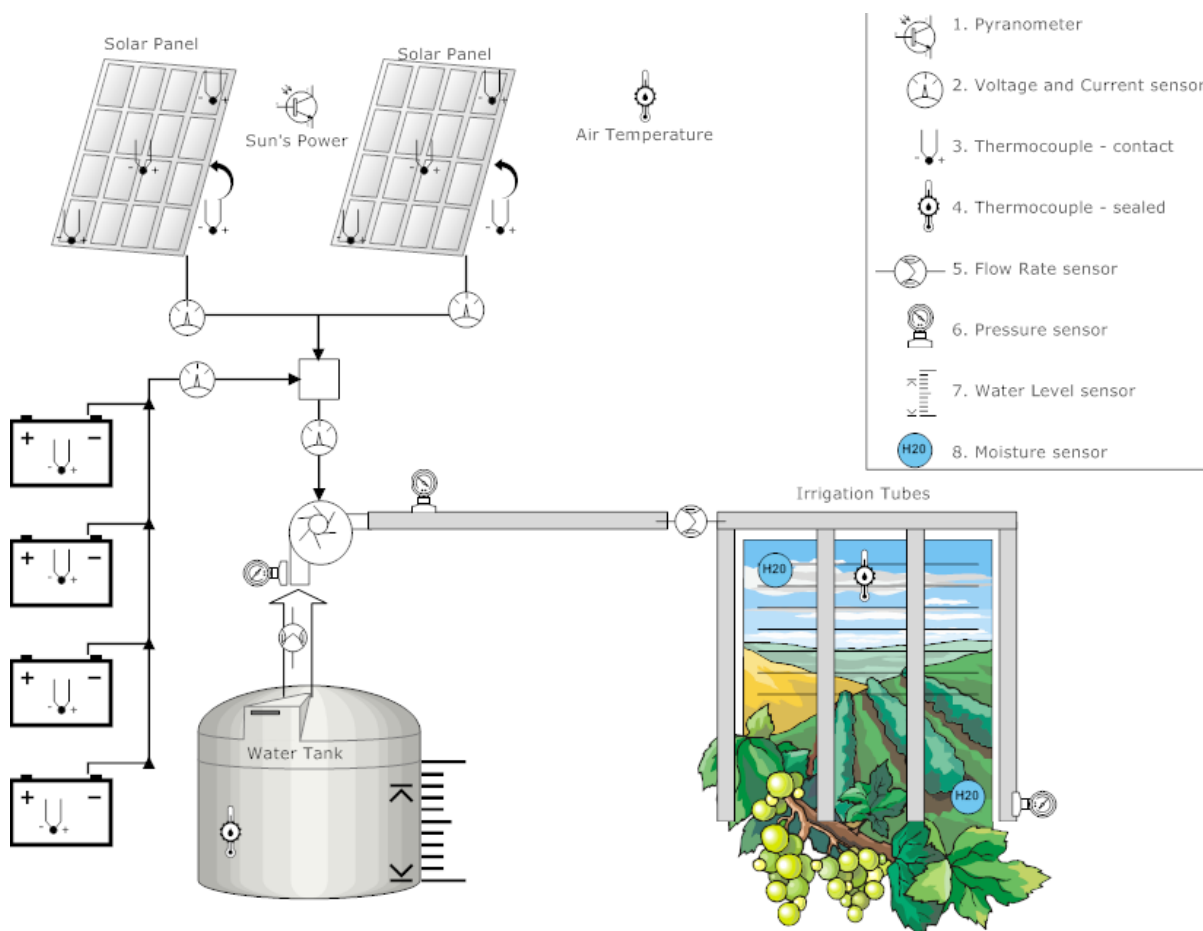


Figure 29: Schematic of solar irrigation system.

Einstein Refrigeration Demonstration Unit

The purpose of the Einstein Refrigeration Demonstration Unit Project was to build a demonstration absorption refrigeration system that works off the Einstein cycle. This is a refrigeration cycle that can use heat instead of electricity to produce refrigeration. Since an Einstein refrigeration unit only requires low temperature heat as a power source, a number of free energy sources can be used, such as waste heat from an industrial process or solar energy. Using solar energy for refrigeration is a nice match between energy need and energy supply. When the sun is burning hot the most solar energy is available and this is generally when the most home air-conditioning is required. The coefficient of performance of such a refrigeration cycle is small, but since free energy can be used, this is not detrimental to the economics of such a refrigeration system.

A picture of the absorption refrigeration system built by the senior design students is shown in Figure 30 below. The actual refrigeration system is the stainless steel tubes located in an enclosed plastic case. The refrigeration system is enclosed for safety considerations. The refrigerant used in this system is a mixture of ammonia, butane, and water and thus some containment was desired if the refrigeration system should develop a leak.

A cycle diagram for the system is shown in Figure 31. As shown in Figure 31 the heat from the house, or the area to be cooled, is absorbed in the evaporator and the heat is rejected out the condenser, just like a traditional vapor compression refrigeration system. The major difference is no compressor is required in an adsorption refrigeration cycle. To drive the cycle low temperature heat is injected into a device called the generator. The generator separates the ammonia and the water so that the refrigeration cycle can be continuous. The generator is also used to drive the ammonia/water/butane refrigerant mixture around the cycle.



Figure 30: Absorption refrigeration system.

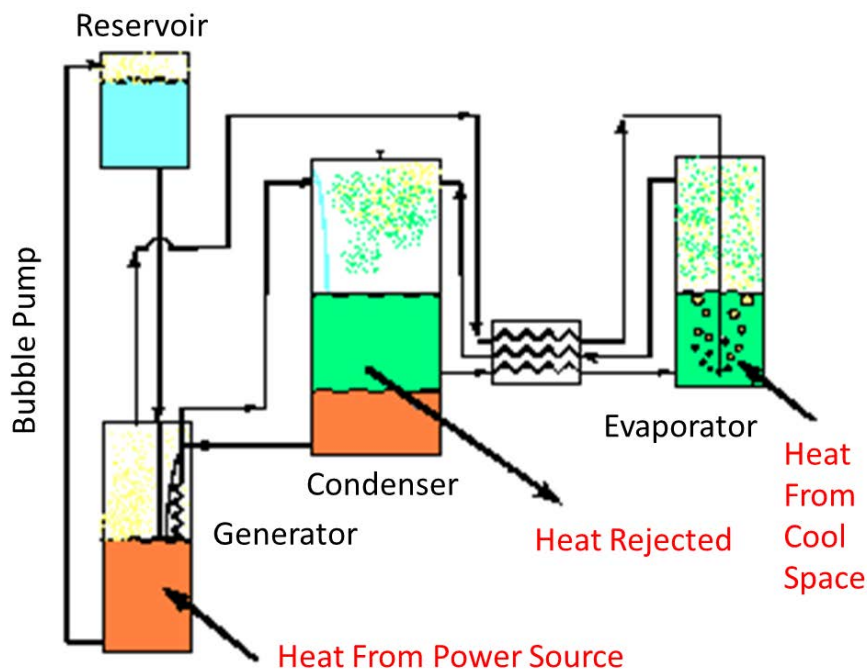


Figure 31: Einstein cycle for an absorption refrigeration system.

Lithium-Sulfur Battery Project

The goal of the Lithium-Sulfur Battery Project was to solve the current problems of the lithium sulfur battery, and set up a foundation for future research at Wright State University. One problem with the lithium-sulfur battery is elemental sulfur's lack of conductivity; this creates a need for a conductive cathode material to be combined with the sulfur. A second problem is lithium-sulfide precipitates and collects in anode pores. Specifically, poly-sulfides form that are a result of the sulfur reducing into the lithium. This drastically reduces the capacity of the battery, resulting in a lack of rechargeability. By trying multiple electrolytes and using different cathodic conductors, this problem will hopefully be resolved by controlling the positive lithium ions. Also by testing different variables, such as composition, rechargeability will hopefully be gained. Using different liquid electrolytes and different cathodic conductors, the following characteristics were explored as part of this senior design project: rechargeability, high voltage capacity, and high specific capacity. If a lithium-sulfur battery containing these characteristics can be built, it could ultimately change all of the current technology used in everyday lives.

The main concern with the lithium-sulfur battery in this project is the effectiveness of various cathodes, with focus on determining the best scenario in four different areas to obtain the best results possible. These include optimum sulfur particle size for spreading the cathode layer, base material of the cathode, the optimum sulfur content, and control of poly-sulfides via the type of electrolyte used. The impact of these four important factors on the battery performance were determined as part of this design project.

In order to control these factors, a design of experiments was devised to limit the number of tests that had to be run. Table 3 and Table 4 outline the different cathode creation techniques and materials used in each process.

Table 3: Design of experiments legend.

| Assignments | Variable | High Range (+) | Mid-Range (°) | Low Range (-) | Additional (*) |
|----------------------|-------------------|---------------------------------------------------|--------------------------------------------------------|--------------------------------|---------------------------------------------------|
| A | Graphite-S-Al | - | - | - | - |
| B | Carbon Felt | - | - | - | - |
| C | Grinding Time | 15 minutes | - | 10 minutes | - |
| D₁ | Sulfur Percentage | 30 wt % | 20wt % | 10 wt % | - |
| D₂ | Sulfur Percentage | 60 wt % | 50wt % | 40 wt % | - |
| E | Electrolyte | TEGDME with LiN(CF ₃ SO ₂) | TEGDME-DOXL with LiN(CF ₃ SO ₂) | TEGDME with LiClO ₄ | ethylene carbonate dissolved in diethyl carbonate |

Table 4: Graphite/sulfur-aluminum design of experiments.

| Trial Number | AC | AD ₁ | AD ₂ | AD ₁ E |
|----------------|-----|-----------------|-----------------|-------------------|
| Trial 1 | + | + | + | + |
| Trial 2 | + | + | + | + |
| Trial 3 | ° | N/A | N/A | ° |
| Trial 4 | ° | ° | ° | ° |
| Trial 5 | - | ° | ° | - |
| Trial 6 | - | N/A | N/A | - |
| Trial 7 | N/A | - | - | * |
| Trial 8 | N/A | - | - | * |

The computer controlled battery testing station is shown in Figure 32. This is the system used to determine the output from each of the batteries produced. The batteries are small disks that have the red test leads coming out of them. There are several batteries connected to the system in Figure 32 so that a multiple number of battery configurations can be tested at one time.



Figure 32: Lithium-ion battery testing system.

A large number of results were obtained as part of this work. In this report only the results as a function of sulfur content are presented. These results are shown in Table 5. Optimization of the sulfur content in the battery is crucial for obtaining the highest discharge capacity possible for the lithium-sulfur battery. Considering the results obtained from testing with an 80 weight percent sulfur cathode, it was determined that the sulfur content within the cathode should be varied from 10 weight percent to 60 weight percent in 10 weight percent increments. Results presented in Table 5 show that discharge capacity is increased with a reduction in sulfur. Optimal sulfur content was determined to be 20 weight percent, with discharge capacities over 130 mAh/g of sulfur. These values are well below the values predicted in the literature, but are a significant improvement over previous testing. All batteries tested with this electrolyte demonstrated no rechargeability.

The results obtained during testing were surprising, as the optimal weight percentage of sulfur was dramatically lower than reported in the literature. Based on the literature, lower sulfur content within the cathode should have fewer pathways for the sulfur and graphite to conduct during discharge. Ideal compositions for a fully dense cathode should be a 50/50 ratio of sulfur and graphite particles. Since cathodes cannot be fully dense, the literature reports that a 30% porous cathode is acceptable with the sulfur content around 50 to 60 weight percent. The lower sulfur content within the cathode slurry can contribute to the morphology of the graphite and sulfur particles used in preparation and the porosity of the cathode.

Overall, through varying sulfur content, grinding time, base material and electrolytes, this project created a solid foundation for future lithium-sulfur battery research at Wright State University. With the collected results and previous work, the next design team can use the methods discussed and expand the current research. Results have shown that longer grinding times of the slurry, low weight percentage of sulfur in the cathode, and electrolyte composition lead to longer discharge times and higher discharge capacity. Batteries featuring optimal combinations of the

three previously defined variables showed the best results. It can be said that having a longer grinding time, low sulfur weight percentage, and correct electrolyte composition will lead to a successful lithium sulfur rechargeable battery.

Table 5: Lithium-sulfur battery discharge capacity as a function of sulfur content of the cathode.

| Cathode | Sulfur wt % | Graphite wt % | Mixing Time (min) | Total Cathode mass (g) | Electrolyte | 1 st cycle discharge capacity (mAh/g S) |
|---------|-------------|---------------|-------------------|------------------------|---------------------------------------------------|----------------------------------------------------|
| 10-1 | 10% | 15% | 10 | 0.002 | ethylene carbonate dissolved in diethyl carbonate | 67.37 |
| 10-2 | 10% | 15% | 10 | 0.0026 | ethylene carbonate dissolved in diethyl carbonate | 176.92 |
| 40-3 | 40% | 15% | 10 | 0.003 | ethylene carbonate dissolved in diethyl carbonate | 61.58 |
| 40-4 | 40% | 15% | 10 | 0.0029 | ethylene carbonate dissolved in diethyl carbonate | 62.52 |
| 20-5 | 20% | 15% | 10 | 0.0029 | ethylene carbonate dissolved in diethyl carbonate | 138.29 |
| 20-6 | 20% | 15% | 10 | 0.0021 | ethylene carbonate dissolved in diethyl carbonate | 236.84 |
| 30-7 | 30% | 15% | 10 | 0.0027 | ethylene carbonate dissolved in diethyl carbonate | 62.77 |
| 30-8 | 30% | 15% | 10 | 0.0032 | ethylene carbonate dissolved in diethyl carbonate | 41.12 |
| 50-9 | 50% | 15% | 10 | 0.0037 | ethylene carbonate dissolved in diethyl carbonate | 43.53 |
| 50-10 | 50% | 15% | 10 | 0.0035 | ethylene carbonate dissolved in diethyl carbonate | 30.86 |
| 60-11 | 60% | 15% | 10 | 0.0027 | ethylene carbonate dissolved in diethyl carbonate | 33.14 |
| 60-12 | 60% | 15% | 10 | 0.0029 | ethylene carbonate dissolved in diethyl carbonate | 30.37 |

Electric Car Eco Project

The goal of the Electric Car Eco Project was to design and build a car that has the highest miles per gallon equivalent possible. The phase miles per gallon equivalent is used because this car was an electrically driven car. Thus, based on the electrical energy used and the amount of energy in a gallon of gasoline, a miles per gallon equivalent can be determined. The miles per gallon equivalent can simply be found by taking the miles per kilowatt-hour value and multiplying it by 34.02.

This project had a unique aspect to it in that the students competed at the national level in the Shell Eco-Marathon in Huston, Texas from March 29 – April 1, 2012. The purpose of this competition was to help spark innovation in fuel efficiency. At the competition, the Wright State team placed 13th out of 20 teams in the battery plugin division with a best mileage of 77 miles per kWh, or around 2620 MPGe.

As part of this project the students designed an electric car that is shown in Figure 33. While some of the parts for this car were obtained by purchasing off the shelf components a number of the components were designed and built by the students. In addition the overall design of the car was done by the students.



Figure 33: Wright State electric eco car and design team.

A key part of this project was the electric motor. Two sizes of electric motors were used on this project. The first was a 1000 watt motor and the second was an 800 watt motor. Both of these electric motors were of the electric hub design for a 20 inch wheel. The motor located in the wheel is shown in Figure 34. The wheels used on the car are bicycle tires with swing arms as seen in Figure 34. With the 1000 watt hub motor installed, the team conducted a test on rollers in the lab. With a four minute data log at 15 mph the team got a calculated mpg of 74 miles per kWh or around 2518 MPGe. Another data log test was conducted on the smaller motor, but results were not recorded due to computer issues. Results using the smaller motor in actual competition conditions were 77 miles per kWh, or around 2620 MPGe. Thus the smaller motor produced higher mileage. Judging by the highest mileage cars at the Shell Eco-Marathon it seems that smaller electric motors provide higher mileage. For this reason the senior design group calculated the size motor that would be required to get their car up a 2% grade. The results are shown in Figure 35 below. It is recommended that future Shell Eco-Marathon design teams use the smallest motor possible in their car.

After the competition the students had time to redesign the car frame. They made the frame lighter and stronger than the one used at the competition. To do this they used the computer software COSMOS to determine the von Mises stresses throughout the structure. The results from this stress analysis are shown in Figure 36 and the actual frame is shown in Figure 37. This frame will be used by students in next year's senior design class.



Figure 34: Wheel, electric motor, and rear swing arm for the Wright State eco car.

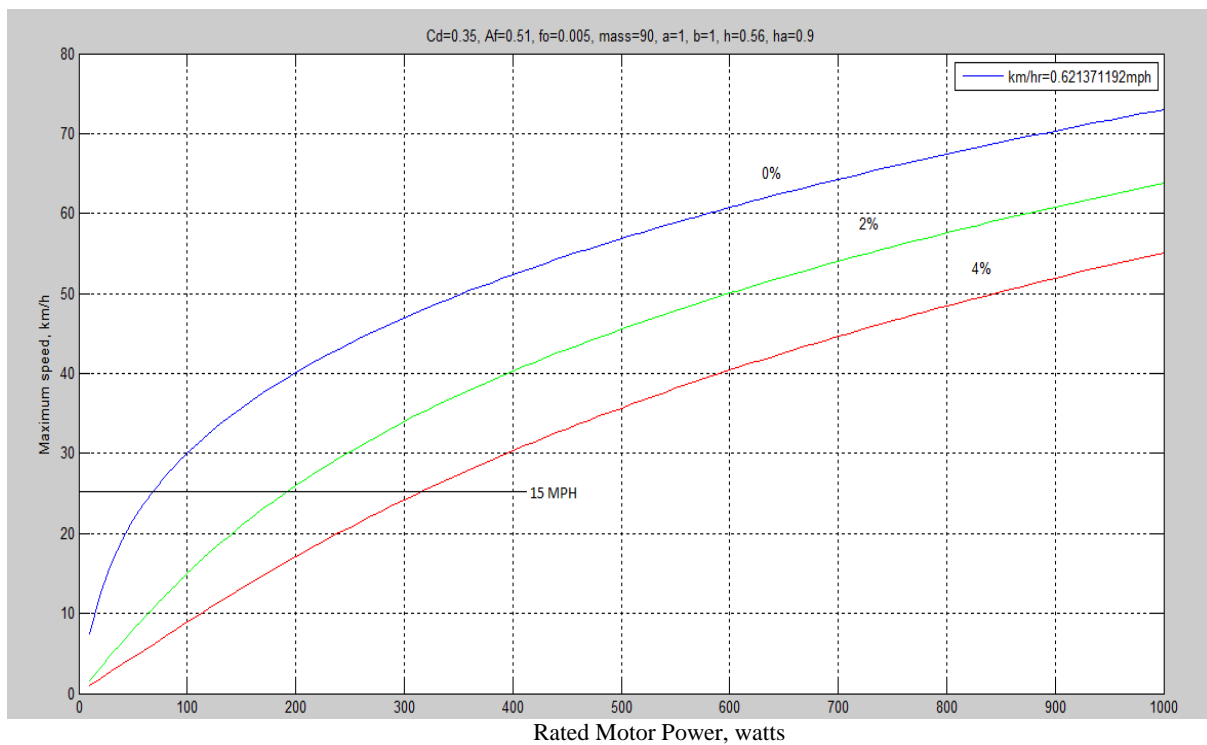


Figure 35: Calculated motor speeds as a function of the motor rated power in watts.

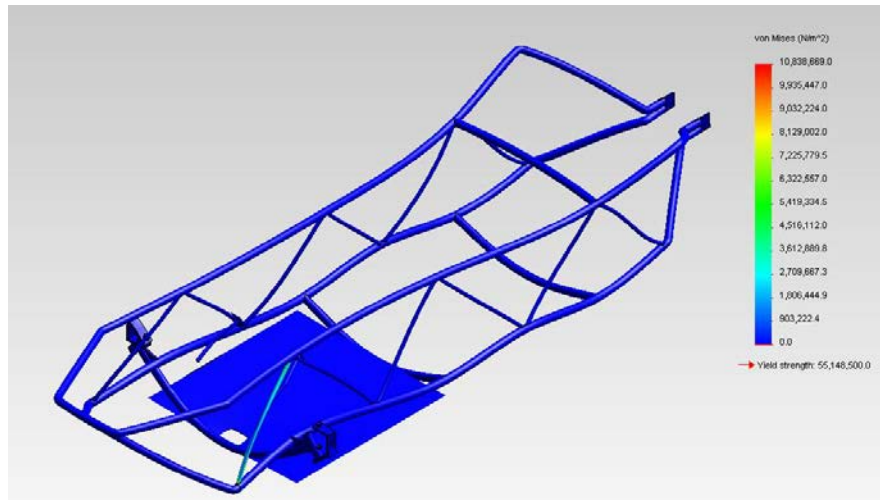


Figure 36: COSMOS determined von Mises stresses throughout the frame.



Figure 37: Actual frame for eco car.

Geothermal Energy Demonstrator and Lesson Modules

As part of this grant a geothermal energy high school course was developed. This course consists of ten, 1 hour lesson modules and a geothermal demonstration unit (see Figure 38). The goal of the Geothermal Energy Demonstrator and Lesson Modules Project is to expose high school students to geothermal energy. In particular, a specific goal was to try and get high school students to understand the working principles of geothermal heating and cooling for homes and commercial buildings. A two pronged approach was used to teach this topic. The first prong was to develop power point lesson modules, and the second prong was to produce a low temperature geothermal demonstration unit.

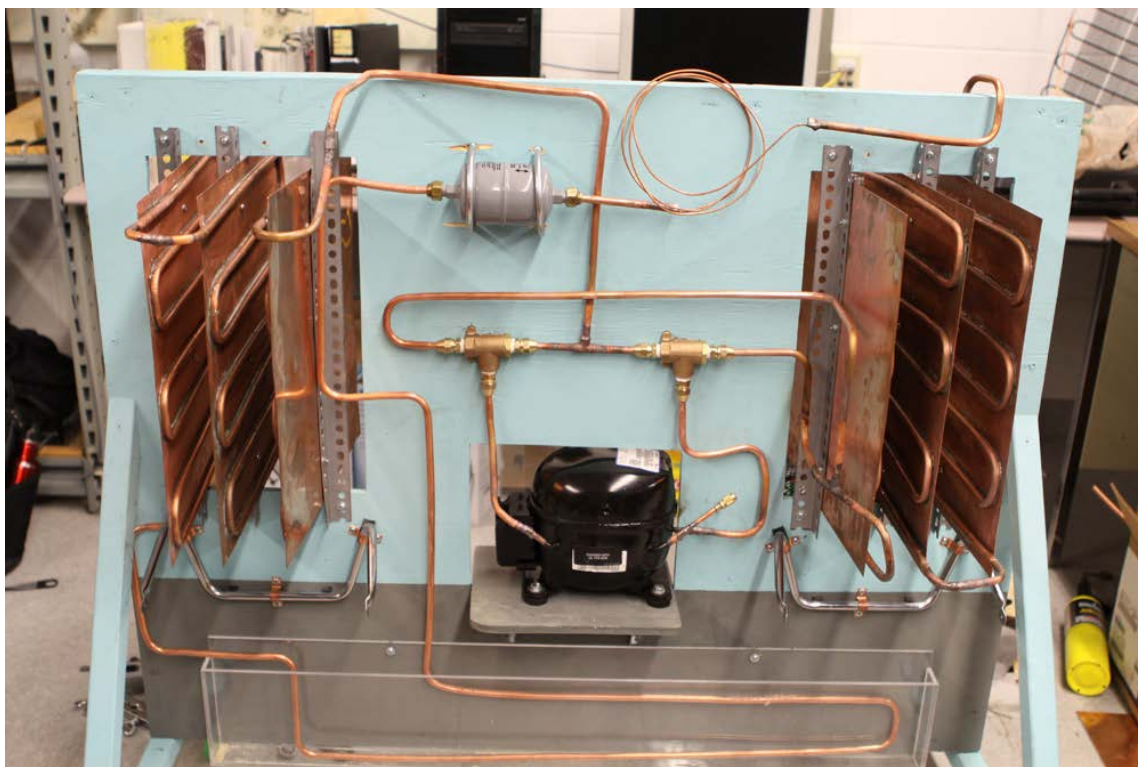


Figure 38: Geothermal demonstrator.

An outline of the ten power point lesson modules is shown in Figure 39. The entirety of geothermal energy usage is covered by these modules. Each module is designed for a one hour lesson and generally includes 10 to 15 slides. The slides have a large number of pictures to make them interesting and to give the students a visual perspective on geothermal energy systems. Great efforts were taken to make the slides interesting, while at the same delivering technical content. An example of one of the lessons is given in Appendix B.

The first lesson module talks about geothermal energy in general and why we should be considering it. It explains what geothermal energy is and the two general categories of geothermal energy; hot and cold geothermal. Hot geothermal is energy from the earth at temperatures above about 200°F and cold geothermal is energy from the earth below this temperature and usually at temperatures around 50°F. It is important to distinguish between hot and cold geothermal because of what they can be used to do and the techniques that are used to harvest the energy are different.

After this introduction there are two lesson modules on thermodynamics and one lesson module on the refrigeration cycle. Thermodynamics is the science behind geothermal systems, both hot and cold. It was felt that it is important for high school students to tie the application of utilizing geothermal energy to the underlying science of thermodynamics. If high school students see the connection between basic science and application they will appreciate their science classes more and study harder in these classes. We also want the students to see math in use. Again, we want to show the students that math is useful, hoping that this will encourage them to pursue this subject with gusto.

After presenting some of the science and mathematical basics, we introduce the basics of systems used to harness geothermal energy. After covering some basics there are two lessons that cover hot geothermal energy, one lesson that covers heat pumps, and one lesson that covers cold geothermal energy. The reason heat pumps are covered in a separate lesson before covering cold geothermal energy is heat pumps are the reason we can obtain useful energy out of the ground at 50°F to heat a house to 70°F. Heat pumps are also the reason we can speed up the heat flow from a 70°F home to 50°F ground to cool the home in the summer. The heat pump is critical to cold geothermal and I believe it is the most difficult component for the students to understand. For this reason we have one full lesson on heat pumps. It is also for the reason that we have chosen to make a heat pump demonstration unit. This will be discussed in the following paragraphs.

1. General overview of what will be learned
 - a. Why is Geothermal important?
 - b. Examples of systems that will be looked at—what do they do?
 - c. Basic overview of SI units.
2. Thermodynamics
 - a. Energy, heat, and temperature.
 - b. $Q=m \cdot c \cdot \Delta T$, $Q=m \cdot L$.
 - c. Heat transfer.
 - d. Work.
3. Thermodynamics
 - a. Properties of fluids.
 - b. Gas laws.
 - c. Lookup tables.
 - d. P-h diagrams.
4. Refrigeration cycle
 - a. Purpose.
 - b. State points.
 - c. Different components and what they do to reach each state.
5. Geothermal system basics
 - a. Connect geothermal to refrigeration cycle as well as other taught material.
6. Hot geothermal.
 - a. Introduction of new components (turbine instead of compressor, etc.).
 - b. Continuing comparison to refrigeration cycle.
 - c. COP—explain and give basic formulas.
7. Hot geothermal.
 - a. Specific ways geothermal energy is gathered.
 - b. Qualitative information: figures of geothermal energy usage, etc.
8. Heat pump (leading to cold geothermal).
 - a. Concept of reversing—again compared to refrigeration.
 - b. Several examples—heating/cooling at home, in car, etc.
 - c. Efficiency of ground over air.
9. Cold geothermal.
 - a. Specifics on ground loops.
10. Cold geothermal and demonstrator.
 - a. Demonstrator explained thoroughly. Open time for questions.

Figure 39: Outline of ten geothermal lesson modules.

The last lesson in this course on geothermal energy is the geothermal demonstrator. There are only a few slides in this lesson, because the idea is to have the students see and feel the

geothermal demonstrator in action. While the demonstrator is running the instructor will explain the operation of the unit and the principles of cold geothermal energy harvesting. This geothermal demonstrator is essentially a heat pump. With this demonstration unit we want the students to be able to feel the evaporator getting colder and the condenser getting hotter. We want these high school students to see that a compressor is required to make this happen. To run this compressor electric current or work is required. The means by which a heat pump moves thermal energy from a low temperature body to a high temperature body is by the use of work, in this case the work comes in the form of electricity. Essentially by changing the pressure of the refrigerant we are changing the temperature of the refrigerant. Reducing the pressure lowers the temperature of the refrigerant and increasing the pressure raises the temperature of the refrigerant. This gives us the ability to move heat into the refrigerant at a low temperature and to move heat out of the refrigerant at a high temperature.

The geothermal demonstrator designed for this project is shown in Figure 38. As mentioned above this system is essentially a heat pump, even though we call it a geothermal demonstrator. This heat pump consists of the four main components of any heat pump: a compressor, a condenser, an expansion valve, and an evaporator. The compressor is used to increase the pressure of the refrigerant and thus to increase the temperature of the refrigerant. The compressor is the black object in the lower middle of the display shown in Figure 38. The condenser and the evaporator are the copper objects on the left and right side of the board. These are essentially finned tubes with fans at the bottom. The fans have not yet been attached to the system and are not shown in Figure 38. The fans are needed to enhance the heat transfer between the air and the refrigerant. Since this heat pump is mimicking a geothermal heat pump, the evaporator and condenser can be reversed. This is done by means of a couple of three way valves which are located on the back side of the display board. The back sides of the valves are the two tee joints shown just above the compressor. These two valves allow the operator to make the left-hand side heat exchanger the evaporator or the right-hand side heat exchanger the evaporator. Thus the condenser also switches sides. This is the process used in a geothermal heat pump so that the same system can be used to either heat or cool the home. The expansion valve for this system is the thin copper tube located at the upper center of the board. The expansion valve is coiled because of its long length. Essentially the frictional forces present in this small tube are used to reduce the pressure of the refrigerant from a high value to a low value; thus decreasing the temperature of the refrigerant. Another component of the geothermal demonstrator is the filter dryer shown as the gray cylinder in the upper middle, left-hand side in Figure 38. This device is used to remove water and other impurities from the refrigerant. While not done yet the plastic basin at the bottom of the demonstrator will be filled with dirt and used to mimic the ground. We could not rely solely on ground heat transfer in this demonstrator because an extremely long length of tube would be required. Thus the ground is just for show, while the heat transfer is occurring in the finned, copper heat exchangers on each side of the board. All pieces of the heat pump are plumbed together with copper tubing that has been silver soldered.

This geothermal demonstrator was designed to fit in the back of a van so that it could easily be transported to different high schools. The demonstrator is on wheels and can easily be rolled on smooth surfaces. In addition, the only power needed for operation is a 120 volt, typical wall outlet. This is needed to run the compressor and the fans.

BUDGET BREAKDOWN BY PROJECT

A breakdown of the money spent on this program at Wright State by each of the three fundamental areas is tabulated below. Some final expenses for this project have not hit the Wright State budget system yet, so there may be small changes to these numbers.

| | |
|---------------------------------------------------------------------------|-----------------|
| Renewable and clean energy master's degree program development | \$37,383 |
| Renewable and clean energy research | \$83,187 |
| <u>Renewable and clean energy undergraduate and high school education</u> | <u>\$16,197</u> |
| Total Spent | \$136,767 |

The total spent of \$136,691 is \$41,000 below the \$177,767 allocated amount for Wright State. It was hoped that a no-cost extension would have been granted for this money so that graduate students currently being funded by this grant could have continued funding under this grant. This no cost extension was denied.

SUMMARY

A great deal of advancement in the Renewable and Clean Energy Master's Degree Program, and in renewable and clean energy education in general, has been made because of this Department of Defense funding. This funding was used in three general areas:

- Renewable and clean energy master's degree program development,
- Renewable and clean energy research, and
- Renewable and clean energy undergraduate and high school education.

In each of these three areas a number of projects were carried out as a result of this funding.

In the renewable and clean energy master's degree program development great efforts were made to improve the new Renewable and Clean Energy Master's Degree Program at Wright State University and the University of Dayton. This was done by course development, web site development, student advising, and student recruitment. From the beginning of this degree program until now, the enrollment at Wright State has increased from 4 to 23 students. This is a 475% increase in enrollment. While we desire many more than 23 students in the program, we think that our growth has been reasonable over the short life span of the Renewable and Clean Energy Master's Degree Program. Our hopes are to double this number over the next three years.

The second thrust area for this project, renewable and clean energy research, is really a thrust to increase the enrollment and stature of the Renewable and Clean Energy Master's Degree Program. By increasing the funding for thesis research in this master's degree program enrollment numbers are increased. By increasing the research happening in the Renewable and Clean Energy Master's Degree Program the stature of the program is raised and the education received by the students in the program is enhanced. At the master's level high quality education and research go hand-in-hand. As part of this grant a seven graduate students were supported working on renewable and clean energy research projects that fell into four general areas of renewable and clean energy: geothermal energy, solar energy, lithium ion batteries, and

hydrogen storage. This is a broad cross section of projects supported. A large number of results were obtained as a consequence of this funding, as well as a number of graduate students trained.

The third thrust area for this research, undergraduate and high school education was advanced by injecting a number of renewable and clean energy projects into Wright State’s Mechanical Engineering senior design class and by developing a geothermal energy demonstrator and lesson modules for high school students. Four renewable and clean energy projects were carried out in this year’s senior design class. While the primary motive for injecting these projects into the undergraduate senior design class was to spur student interest in renewable and clean energies, a secondary motive was to encourage them to enter the Wright State / University of Dayton Renewable and Clean Energy Master’s Degree Program. The primary motive of the geothermal energy demonstrator and lesson modules for high school students was to increase high school student’s interest in science and math. It is hoped that this type of course will encourage more high school students to enter the engineering field. Of course the strongest desire is to have them enter a renewable and clean energy discipline, but any engineering or science discipline is considered a success.

In the future work on the Renewable and Clean Energy Master’s program at Wright State University and the University of Dayton will continue. It is believed that this is an important program for the United States and for the State of Ohio. We believe that there is a great need for engineers with specific knowledge in renewable and clean energy systems. Wright State is proud to be supporting this field and wants to supply many engineers to this important discipline.

ACKNOWLEDGMENTS

Wright State University would like to thank DOE for supporting this work under grant number DE-SC005734. This funding has been extremely helpful to the advanced of the Renewable and Clean Energy Master’s Degree program at Wright State University and to renewable and clean energy education in general. We would also like to thank Dr. Hallinan and the University of Dayton for taking the lead on this project.

APPENDIX A – RENEWABLE AND CLEAN ENERGY MASTER'S DEGREE PROGRAM SYLLABI

SYLLABI

WSU/ME623 – Energy Conversion

SYLLABUS

ME 623 Energy Conversion

4.5 credit hours

WRIGHT STATE UNIVERSITY

Department of Mechanical and Materials Engineering

INSTRUCTOR: Dr. J. Menart, Room 125 RC, Phone 775-5145 E-mail: james.menart@wright.edu

WEB SITE: See PILOT site. Homework solutions, notes, and other materials are located here.

CLASS TIME AND LOCATION: M & W 2:45 – 3:50 p.m. Room 146 RC and F 2:45 – 4:15 p.m., Room 154 RC

OFFICE HOURS: M 1:00 – 2:00 pm, W 5:00 – 6:00 pm, F 4:30 – 5:30 pm, or by appointment

2011 CATALOG DATA: ME 423/623: This course will study the fundamentals of energy and energy conversion, our energy resources, direct energy conversion, heat to work energy conversion, fossil fuel energy conversion, and alternative energy conversion.
4.5 Credit hours Prerequisites: ME 316 with minimum grade of D.

TEXTS: Vanek, F and Albright, L, *Energy Systems Engineering*, McGraw Hill, New York, 2008.
Y. Cengel and M. Boles *Thermodynamics - An Engineering Approach*, 6th Edition, 2008.
Weston, K., *Energy Conversion*, out of print but obtained online at <http://www.personal.utulsa.edu/~kenneth-weston> accessed August, 2009.
Hau, E., *Wind Turbines: Fundamentals Technology, Application, and Economics*, Springer, New York, 2006 (Electronic book on Ohio Link).
Goldsmid, J. G., *Introduction to Thermoelectricity*, Spring, New York, 2010 (Electronic book on Ohio Link).
Demirbas, A., *Biofuels: Securing the Planet's Future Energy Needs*, Springer, New York, 2009 (Electronic book on Ohio Link).
Kaltschmitt, M., Streicher, W., and Wiese, A., *Renewable Energy: Technology, Economics, and Environment*, Springer, New York, 2007 (Electronic book).

REFERENCES: H. A. Sorensen, *Energy Conversion Systems*, Wiley, New York, 1983.
Sieniutycz, S. and Vos, Alexis, *Thermodynamics of Energy Conversion and Transport*, Springer, New York, 2000.
El-Wakil, M. M., *Powerplant Technology*, McGraw Hill, New York, 2002.
Ghosh, T. K. and Prelas, M. A., *Energy Resources and Systems: Volume 1: Fundamentals and Non-Renewable Resources*, Springer, New York, 2009 (Electronic book).
Goldsmid, H. J., *Introduction to Thermoelectricity*, Springer, New York, 2010 (Electronic book).
Annaratone, D., *Steam Generators: Description and Design*, Springer, New York, 2008 (Electronic book).
Cruz, J., *Ocean Wave Energy: Current Status and Future Perspectives*, Springer, New York, 2008 (Electronic book).
Hodge, B. K., *Alternative Energy Systems and Applications*, Wiley, New York, 2010.
Wood, B. D., *Applications of Thermodynamics*, 2nd Edition, Addison-Wesley, Philippines, 1982

OBJECTIVES: To understand the basics of energy and energy conversion. To be exposed to a number of energy conversion methods. These energy conversion methods will include both traditional and alternative methods of energy conversion.

PREREQUISITES: The prerequisite course is ME316-Thermodynamics I. Incoming students are expected to have knowledge of:

- I. How to determine thermodynamic properties for a substance
- II. Control volume analysis
- III. Heat and work
- IV. Entropy
- V. Conservation of mass
- VI. Zeroth, First, and Second laws of Thermodynamics
- VII. Steady state steady flow and uniform state uniform flow processes
- VIII. Thermodynamic cycles

TOPICS COVERED IN COURSE:

- I. Energy and energy conversion
- II. Exergy.
- III. Major energy classifications.
- IV. Economic analysis.
- V. Energy's effect on the environment.
- VI. Energy conversion between major energy classifications
 1. Chemical to thermal
 2. Thermal to mechanical
 3. Mechanical to electrical
 4. Nuclear to thermal
 5. Electrical to mechanical
- VII. Energy conversion within a major energy classification
 1. Mechanical to mechanical
 2. Thermal to Thermal
 3. Electromagnetic to electrical
- VIII. Many renewable energy types will be used as examples of the conversions above.

HOMEWORK: In general there will be 7 or 8 homework sets with 4 or 5 problems per set. The student will generally have 1 week to complete the homework. Late homework will receive a 50% grade reduction and late homework that is a duplicate copy of the posted solutions will receive an 80% grade reduction. Students may work together on their homework, but each student must contribute to the process and individually write out their solution. Use of a solution manual or student work from a prior quarter is not allowed for homework until after the due date. Problems may be done such that there is a Given, Find, and Solution. The Given should contain all the information stated in the problem in abbreviated form. Many times it is best to make a sketch of the problem and place the given information on this sketch. Do not recopy the problem statement! The Find section should briefly state the quantities being sought. Lastly, the Solution section should contain an orderly display of how you solved the problem. The solution should be such that it is easy for someone else to understand how you deduced your answers. All important equations should be written out in symbolic form, as well as showing the substitution of numbers into the equation. Assumptions should be clearly stated and any additional figures required should be shown. Put a box around your final answers. The use of commonly used symbols to state the Given, Find, and Solution information is encouraged.

EXAMS: Two midterms and one final will be given. On a test the student is responsible for the material discussed in class, as well as the assigned reading. Makeup exams will be given only under exceptional circumstances. All exams are to be the student's own work and no collaboration is allowed. The exams come in two parts. For the first part the student is only allowed to use a pencil and a calculator. For the second part of the test the student can use a pencil, a calculator, and a crib sheet. For the first exam the student is allowed to use an 8.5 inch by 5.5 inch piece of paper as a crib sheet. For the second test the student can use two of these sized crib sheets. For the Final the student is allowed to use three of these sized crib sheets. The first part of the test will be definitions, conceptual questions, and some short

analytical problems. For the most part the first part of the test is evaluating your conceptual and qualitative knowledge of the material. The second part of the test will be substantial engineering problems that the student must solve. This will test your quantitative understanding of the material.

GRADING: The grading for the course is as follows:

Homework - 15%

Exam I - 25%

Exam II - 25%

Final - 35%

The student will be awarded the highest grade according to the following scale:

A - 90% or more of the total points

B - 80% or more of the total points

C - 70% or more of the total points

D - 60% or more of the total points

F - less than 60% of the total points

GRADUATE STUDENTS: In addition to the work described above, graduate students must do an energy conversion project. This will count as 10% of the graduate student’s grade in place of 5% of the homework grade and 5% of Exam 1 grade.

ATTENDANCE POLICY: Attendance for lecture class is not mandatory; however, the student is responsible for all the material presented in class, as well as the assigned reading.

ACADEMIC INTEGRITY: All work in this course must be completed in a manner consistent with WSU Policy or Code of Academic Responsibility and Conduct. Violation of this code will result in a penalty to be determined by the instructor to fit the gravity of the offense and the circumstances of the particular case. The instructor may: 1) fail the student for the particular assignment or test, 2) give the student a failing grade in the course, 3) recommend that the student drop the course, or 4) bring the case in front of the University Student Honesty or Discipline Committee.

TENTATIVE SCHEDULE

| <u>PERIOD</u> | <u>DATE</u> | <u>TOPIC</u> | <u>READING</u> |
|---------------|-------------|-------------------------------------------------------|-------------------------------------------|
| 1 | 9/5 | Labor Day Holiday | |
| 2 | 9/7 | Topic 1 - Introduction, What is Energy | Chapter 2 Cengel and Boles |
| 3 | 9/9 | Topic 1 - Introduction, What is Energy | Chapters 4, 5, 6, 7, & 8 Cengel and Boles |
| 4 | 9/12 | Topic 2 - Our Energy Situation | Chapters 1 Vanek and Albright |
| 5 | 9/14 | Topic 3 - Economic Analysis | Notes |
| 6 | 9/16 | Topic 3 - Economic Analysis | Notes |
| 7 | 9/19 | Topic 4 - Heat Transfer Review | Notes |
| 8 | 9/21 | Topic 5 - Energy’s Effect on the Environment | Chapter 4 Vanek and Albright |
| 9 | 9/23 | Topic 5 - Energy’s Effect on the Environment | Chapter 4 Vanek and Albright |
| 10 | 9/26 | Topic 6 - Mechanical to Electric (Electric Generator) | Chapter 9 Hau, |
| 11 | 9/28 | EXAM – I | |
| 12 | 9/30 | Topic 6 - Mechanical to Electric (Electric Generator) | Chapter 9 Hau |
| 13 | 10/3 | Topic 6 - Mechanical to Electric (Electric Generator) | Chapter 9 Hau |
| 14 | 10/5 | Topic 6 - Mechanical to Electric (MHD) | Chapter 11 part 2 Westin |

Wright State Final report for “Clean Energy Infrastructure Educational Initiative.” Prime grant number is DE-SC005734 and the sub-recipient agreement number is RSC11006.

| | | | |
|-------|-------|--------------------------------------------------------------------|------------------------------|
| 15 | 10/7 | Topic 6 - Mechanical to Electric (MHD) | Chapter 11 part 2 Westin |
| 16 | 10/10 | Topic 6 - Mechanical to Electric (Ocean) | Notes |
| 17 | 10/12 | Topic 6 - Mechanical to Electric (Ocean) | Notes |
| 18 | 10/14 | Topic 7 - Thermal to Electric (Turbine and generator) | Notes |
| 19 | 10/17 | Topic 7 - Thermal to Electric (Turbine and generator) | Notes |
| 20 | 10/19 | Topic 7 - Thermal to Electric (Thermoelectric) | Chapters 1 & 2 Goldsmid |
| 21 | 10/21 | Topic 7 - Thermal to Electric (Thermoelectric) | Chapters 1 & 2 Goldsmid |
| 22 | 10/24 | Topic 8 - Chemical to Electrical (Bio Fuels) | Chapter 5 Demirbas |
| 23 | 10/26 | EXAM – II | |
| 24 | 10/28 | Topic 8 - Chemical to Electrical (Bio Fuels) | Chapter 5 Demirbas |
| 25 | 10/31 | Topic 9 - Nuclear to Electric (Nuclear Reactor) | Chapter 10 Westin |
| 26 | 11/2 | Topic 9 - Nuclear to Electric (Nuclear Reactor) | Chapter 10 Westin |
| 27 | 11/4 | Topic 10 - Electromagnetic to Electric (Photovoltaics) | Chapter 6 Kaltschmitt et al. |
| 28 | 11/7 | Topic 10 - Electromagnetic to Electric (Photovoltaics) | Chapter 6 Kaltschmitt et al. |
| 29 | 11/9 | Topic 10 - Electromagnetic to Electric (Photovoltaics) | Chapter 6 Kaltschmitt et al. |
| 30 | 11/11 | Veterans Day | Notes |
| Final | 11/16 | FINAL EXAM 3:15 – 5:15 p.m., all material covered in course | |

WSU/ME624 – Solar Engineering

SYLLABUS ME 624 Solar Engineering Spring 2011

4 credit hours

WRIGHT STATE UNIVERSITY
Department of Mechanical and Materials Engineering

INSTRUCTOR: Dr. J. Menart, Room 125 RC, Phone 775-5145, E-mail: james.menart@wright.edu

WEB SITE: WebCT

CLASS TIME AND LOCATION: 4:10 – 5:50 p.m. MW, Room 399 Millet

OFFICE HOURS: M 3:00 – 3:50 p.m., W 3:00 – 3:50 p.m., F 4:00 – 5:00 p.m., or by appointment

2007 - 09 CATALOG DATA: ME 424/624: Solar Engineering. (Credits 4) Fundamentals of solar radiation and how it can be utilized as an energy source. Flat plate collectors, concentrating collectors, solar hot water heating, photovoltaics, and thermal energy storage will be discussed. Prerequisites: ME 318.

TEXTS: Duffie, J. A. and Beckman, W. A., *Solar Engineering of Thermal Processes*, 3rd Edition, Wiley, New York, 2006.

REFERENCES: Goswami, D. Y., Kreith, F., and Kreider, J. F., *Principles of Solar Engineering*, 2nd edition, Taylor & Francis, 2000.
Tiwari, G. N., *Solar Energy: Fundamentals, Design, Modeling and Applications*, Narosa Publishing, New Delhi, India, 2002.

GOALS: To develop the students understanding of the energy we get from the sun and how to utilize this renewable source of energy. To develop abilities in the student to analyze different types of solar energy conversion systems as well as the fundamentals of solar energy.

PREREQUISITES: The prerequisite course is ME318 – Heat Transfer. Incoming students are expected to have knowledge of:
I. Heat Transfer
II. Fluid Dynamics
III. Thermodynamics

TOPICS COVERED IN COURSE:

- I. Radiation
- II. Solar Radiation
- III. Flat Plate Collectors
- IV. Solar Concentrators
- V. Solar Hot Water Systems
- VI. Photovoltaic Systems

HOMEWORK: Homework will be assigned in class and on most occasions is due one week after it is assigned. Late homework will receive a 50% grade reduction and late homework that is a duplicate copy of the posted solutions will receive an 80% grade reduction. Students may work together on their homework, but each student must contribute to the process and individually write out their solution or write their own program. Use of the solution manual is not allowed for homework until after the due date. Problems should be done such that there is a logical and orderly solution to the problem. In this class it will be required that a number of homework problems will have to be worked out in an EXCEL spreadsheet. There are some long calculation procedures that will be nice to have easy access to later in the course.

Wright State Final report for "Clean Energy Infrastructure Educational Initiative." Prime grant number is DE-SC005734 and the sub-recipient agreement number is RSC11006.

EXAMS: Two midterms and one final will be given. On a test the student is responsible for the material in the lecture session as well as the reading. All exams are to be the student's own work and no collaboration is allowed.

ATTENDANCE: Attendance will not be taken nor is the grade based on attendance; however, the student is responsible for all the material presented in class. If the student misses class it is the student's responsibility to obtain the material presented in class.

GRADING: The grading for the course is as follows: Note the different homework percentages for graduate students and undergraduate students.

Exam I - 20%

Homework -20% undergraduate students
10% graduate students

Exam II - 25%

Project - 10% graduate students only

Final - 35%

The student will be awarded the highest grade according to the following scale:

A - 90% or more of the total points

B - 80% or more of the total points

C - 70% or more of the total points

D - 60% or more of the total points

F - less than 60% of the total points

GRADUATE STUDENTS: In addition to the course work described above, students taking the course for graduate credit will also be required to complete a 20 page report on a solar energy topic of their choosing or a 10 page project. The reports should use a 1.5 line spacing and a 12 point font. The topic must be cleared with the instructor by the 6th week of class. This report will count for 10% of the graduate students grade.

ACADEMIC INTEGRITY: Cheating will not be tolerated. In this class students are encouraged to work together on the homework. On the tests and the project the students are to work alone. In addition, the student is not allowed to use any work from prior quarters of Solar Engineering. Therefore no homework or projects from prior quarters of this class should be used. Students are encouraged to use the library, internet, and other course books on solar engineering to help them complete their studies. Of course, the library, internet, and other course books cannot be used on a test. All work in this course must be completed in a manner consistent with WSU Policy or Code of Academic Responsibility and Conduct. Violation of this code will result in a penalty to be determined by the instructor to fit the gravity of the offense and the circumstances of the particular case. The instructor may: 1) fail the student for the particular assignment or test, 2) give the student a failing grade in the course, 3) recommend that the student drop the course, or 4) bring the case in front of the University Student Honesty or Discipline Committee.

TENTATIVE SCHEDULE

| <u>Period</u> | <u>Date</u> | <u>Topic</u> | <u>Assigned Reading</u> |
|---------------|-------------|-------------------------------------------------|-------------------------|
| 1 | 3/28 | Radiative Heat Transfer | 3-5 |
| 2 | 3/30 | Radiative Heat Transfer | 3-5 |
| 3 | 4/4 | Available Solar Radiation – no atmosphere | 1 |
| 4 | 4/6 | Available Solar Radiation – no atmosphere | 1 |
| 5 | 4/11 | Available Solar Radiation – atmospheric effects | 2 |
| 6 | 4/13 | Available Solar Radiation – atmospheric effects | 2 |
| 7 | 4/18 | Available Solar Radiation – atmospheric effects | 2 |

Wright State Final report for “Clean Energy Infrastructure Educational Initiative.” Prime grant number is DE-SC005734 and the sub-recipient agreement number is RSC11006.

| | | | |
|-------|------|--------------------------------------------------------------------------------|----|
| 8 | 4/20 | Flat Plate Collectors | 6 |
| 9 | 4/25 | Flat Plate Collectors | 6 |
| 10 | 4/27 | Exam - I , Chapters 3 – 5, 1, and 2 | |
| 11 | 5/2 | Flat Plate Collectors | 6 |
| 12 | 5/4 | Solar Concentrators | 7 |
| 13 | 5/9 | Solar Concentrators | 7 |
| 14 | 5/11 | Solar Hot Water Heating | 12 |
| 15 | 5/16 | Solar Hot Water Heating | 20 |
| 16 | 5/18 | Photovoltaics | 23 |
| 17 | 5/23 | Exam - II , Chapters 6, 7, 12, and 20 | |
| 18 | 5/25 | Photovoltaics | 23 |
| 19 | 5/30 | Memorial Day Holiday | |
| 20 | 6/1 | Photovoltaics | 23 |
| Final | 6/6 | Final Exam 5:45 – 7:45 p.m., Room 399 Millet, Chapters 1- 7, 12, 20, 23 | |

WSU/ME626 – Wind Power

SYLLABUS ME 626 Wind Power

4.5 credit hours

WRIGHT STATE UNIVERSITY

Department of Mechanical and Materials Engineering

INSTRUCTOR: Dr. J. Menart, Room 125 RC, Phone 775-5145, E-mail james.menart@wright.edu

WEBSITE: Use the Pilot website. The link is on your Wings, Academics page in the upper left-hand corner (<http://wings.wright.edu/cp/home/displaylogin>). Homework solutions, notes, and other materials are located here.

CLASS TIME AND LOCATION: 6:00 – 7:53 p.m. T & Th, Room 153 Medical Sciences

OFFICE HOURS: T 4:00 p.m. – 5:00 p.m., W 4:00 – 5:00 p.m., F 4:30 – 5:30 p.m., or by appointment

2009 -10 CATALOG DATA: ME 426/626: Wind Power. Credits 4.5
Power in the wind, the wind turbine and its parts, performance of wind turbines, and economics of wind turbines are studied. Credit Hours: 4.500 Lecture hours: 4.500 Lab hours: 0.000. Prerequisites: ME 317 or ME 517

TEXT: Manwell, J. F., McGowan, J. G., and Rogers, A. L., Wind Energy Explained: Theory Design and Application, 2nd edition, Wiley, 2009.

REFERENCES: Erich, H., *Wind Turbines: Fundamentals, Technologies, Application, Economics*, 2nd Ed., Springer, Berlin, 2006.

Mathew, S., *Wind Energy: Fundamentals Resource Analysis and Economics*, Springer Press, Netherlands, 2006.

Golding, E., *The Generation of Electricity by Wind Power*, Halsted Press, New York, 1976.

Fox, R. W. and McDonald, A. T., *Introduction to Fluid Mechanics*, 5th Ed., Wiley, New York, 1998.

Tong, W., ed. by, *Wind Power Generation and Wind Turbine Design*, WIT Press, Boston, 2010.

Sorensen, J. D. and Sorensen, J. N., *Wind Energy Systems: Optimising Design and Construction for Safe and Reliable Operation*, Woodhead Publishing, Oxford, 2011.

Eggleston, D. M. and Stoddard, F. S., *Wind Turbine Engineering Design*, Van Nostrand Reinhold Company, New York, 1987.

GOALS: To develop the student's understanding of the energy we can get from the wind and how to utilize this renewable source of energy. To develop abilities in the student to analyze and design wind turbines, as well as fostering growth in the student's understanding of the fundamentals of wind power.

PREREQUISITES: Incoming students are expected to have some knowledge of:

- IV. Conservation of mass as applied to fluids
- V. Conservation of momentum as applied to fluids
- VI. Conservation of energy
- VII. Lift
- VIII. Drag

TOPICS COVERED IN COURSE:

- I. Power available in wind
- II. Basic concepts of wind turbines
- VII. Rotor aerodynamics and design
- VIII. Mechanical drive train
- IX. Electrical system
- X. Control system
- XI. Towers
- XII. Performance of wind turbines
- XIII. Economics of wind energy

HOMEWORK: In general there will be 7 or 8 Homework sets with 4 or 5 problems per set. The student will generally have 1 week to complete the homework. Late homework will receive a 50% grade reduction and late homework that is a duplicate copy of the posted solutions will receive an 80% grade reduction. Students may work together on their homework, but each student must contribute to the process and individually write out their solution. Use of the solution manual is not allowed for homework until after the due date. Problems should be done such that there is a Given, Find, and Solution. The Given should contain all the information stated in the problem in abbreviated form. Many times it is best to make a sketch of the problem and place the given information on this sketch. Do not recopy the problem statement! The Find section should briefly state the quantities being sought. Lastly, the Solution section should contain an orderly display of how you solved the problem. The solution should be such that it is easy for someone else to understand how you deduced your answers. All important equations should be written out in symbolic form, as well as showing the substitution of numbers into the equation. Assumptions should be clearly stated and any additional figures required should be shown. Put a box around your final answers. The use of commonly used symbols to state the Given, Find, and Solution information is encouraged.

EXAMS: Two midterms and one final will be given. On a test the student is responsible for the material discussed in class and the material in the assigned reading. Makeup exams will be given only under exceptional circumstances. All exams are to be the student's own work and no collaboration is allowed.

ATTENDANCE: Attendance in class is not required; however, it is strongly encouraged. The student is responsible for all that happens in class.

ACADEMIC INTEGRITY: Cheating will not be tolerated. In this class students are encouraged to work together on the homework. On the tests the students are to work alone. Use of solution manuals is not allowed. Students are encouraged to use the library, internet, and other course books on wind power and fluids to help them complete their studies and homework. Of course, the library, internet, and other course books cannot be used on a test. All work in this course must be completed in a manner consistent with WSU Policy or Code of Academic Responsibility and Conduct. Violation of this code will result in a penalty to be determined by the instructor to fit the gravity of the offense and the circumstances of the particular case. The instructor may: 1) fail the student for the particular assignment or test, 2) give the student a failing grade in the course, 3) recommend that the student drop the course, or 4) bring the case in front of the University Student Honesty or Discipline Committee.

GRADING: The grading for the course is as follows:

| | |
|----------------|---------------|
| Homework - 20% | Exam II - 25% |
| Exam I - 20% | Final - 35% |

The student will be awarded the highest grade according to the following scale:

- A - 90% or more of the total points
- B - 80% or more of the total points
- C - 70% or more of the total points
- D - 60% or more of the total points
- F - less than 60% of the total points

GRADUATE STUDENTS: In addition to the work described above graduate students must write a 20 page, double spaced, report on some aspect of wind energy. This will count as 10% of the student's grade in place of 5% of the homework grade and 5% of Exam I grade.

TENTATIVE SCHEDULE

| <u>Period</u> | <u>Date</u> | <u>Topic</u> | Assigned Reading
<u>Chapter</u> |
|---------------|-------------|--------------------------------------------------------------------------------|------------------------------------|
| 1 | 3/27 | Introduction | 1 |
| 2 | 3/29 | Introduction | 1 |
| 3 | 4/3 | Wind Resources | 2 |
| 4 | 4/5 | Wind Resources | 2 |
| 5 | 4/10 | Wind Resources | 2 |
| 6 | 4/12 | Rotors | 3 |
| 7 | 4/17 | Rotors | 3 |
| 8 | 4/19 | Exam - I , Chapters 1 – 3 | |
| 9 | 4/24 | Rotors | 3 |
| 10 | 4/26 | Rotors | 4 |
| 11 | 5/1 | Rotors | 4 |
| 12 | 5/3 | Rotors | 4 |
| 13 | 5/8 | Electrical System | 5 |
| 14 | 5/10 | Electrical System | 5 |
| 15 | 5/15 | Other Components | 6 |
| 16 | 5/17 | Exam - II , Chapters 3 - 6 | |
| 17 | 5/22 | Other Components | 6 |
| 18 | 5/24 | System Design | 9 |
| 19 | 5/29 | System Design | 9 |
| 20 | 5/31 | System Design | 9 |
| Final | 6/7 | Final Exam 8:00– 10:00 p.m., Room 153 Medical Sciences, Chapters 1-6, 9 | |

WSU/ME628 – Fuel Cell Science and Technology

Syllabus: ME 428/628

ME 628 Fuel Cell Science and Technology

4.5 credit hours

Wright State University

Department of Mechanical and Materials Engineering

Class Time and Location: MWF 8.22am – 9.35am, Russ 153

Instructor: Dr. Hong Huang, Office: Room 259, Russ Center,
Phone (937)-775-3982, Email: hong.huang@wright.edu

Office Hour: Office Hours: 10.00 – 11.30 am, MWF

Prerequisite: ME 570, ME 515 or equivalent

Goals: Students will understand how fuel cell differs from battery or heat engine. Emphases are on thermodynamics, electrochemical kinetic principles, charge and mass transfer in fuel cells. Students will be also introduced fuel cell technology, applications, and the current research and development in fuel cell fields.

Contents and Topics:

1. Introduction to fuel cells
2. Thermodynamics in fuel cells
3. Activation loss in fuel cells - Electrochemical kinetics
4. Ohmic loss in fuel cell – charge transport
5. Concentration loss – mass transport
6. Fuel cell characterizations
7. Fuel cell technologies
8. Fuel cell development and applications

Course Text: course will be based on the textbook and some reference books as well as journal papers.

Textbook: O'Hayre, R., Cha, S-W., Colella, W., and Prinz, F.B., Fuel Cell Fundamentals, 2nd edition, John Wiley & Sons, 2009

Below are the reference books used in this course:

1. Wolf Vielstich, Arnold Lamm, and Hubert A. Gasteiger, Handbook of Fuel Cells: Fundamentals, Technology, Applications, Wiley, 2003
2. Gregor Hoogers, Fuel Cell Technology Handbook, CRC, 2003
3. National Energy Technology Laboratory and U.S. Department of Energy, Fuel Cell Handbook, University Press of the Pacific, 2005

Grades: The final grade will be based on participation, three exams, presentation, and final overview papers

Scoring and Grading:

A: 90-100%; B: 80-89 %; C: 70-79 %; D: 60-69 %; F: less than 60%

Undergraduate:

Attendance (3%), Homework (15%), Matlab modeling/presentation (12%),
Exam – I: 15%; Exam – II: 25%; Final Exam: 30%.

Graduate:

Attendance (3%), Homework (15%), presentation (12%),
Overview papers (10%), Exam – I: 15%; Exam – II: 20%; Final Exam: 25%.

Matlab: use MATLAB to model one fuel cell problem

Presentation: one selected topic (fuel cell material, system, subsystem)
15min including 2-3 min Q&A

Paper requirement: literature review on one selected topic (fuel cell modeling, material, system, subsystem) 15 pages, 1.5 spacing, max 5 figures, at least 10 references

Tentative Schedule

| Week | Lecture | EVENT |
|------|-----------------------------------------------------------------------------------------------------------|--------------------------------------------|
| 1 | Introduction: chapter 1
Thermodynamics: chapter 2 | |
| 2 | Thermodynamics: chapter 2
Nernst equation, fuel cell efficiency | Homework 1 |
| 3 | Chapter 1&2 HW Review
Chapter 3 Kinetics Introduction | Homework 2
Exam-I (chapters 1,2) |
| 4 | Chapter 3: Kinetics
Butler-Volmer equation, Tafel equation
Chapter 4: Charge transport Introduction | Homework 3 |
| 5 | Chapter 4: Charge transport
Ionic conduction in liquid, solid, polymer | Homework 4 |
| 6 | Chapter 4: Charge transport
Ionic conduction in liquid, solid, polymer
Chapter 3&4 HW Review | Exam-II (chapters 3, 4) |
| 7 | Chapter 5: Mass transport
Convective transport, flow structure | Homework 5 |
| 8 | Chapter 6: fuel cell modeling
Chapter 7: fuel cell characterization | Homework 6 |
| 9 | Chapter 5 & 6 HW Review
Chapter 9: fuel cell materials | |
| 10 | Chapter 8: fuel cell types
Chapter 10: fuel cell systems
Chapter 11,12: fuel cell subsystems | Homework 7 |
| 11 | 8.30-10.30, Nov 18, 2011 | FINAL EXAM (comprehensive) |

WSU/ME750 – Photovoltaics

SYLLABUS
ME 750 Photovoltaics
4.5 credit hours
WRIGHT STATE UNIVERSITY
Department of Mechanical and Materials Engineering

INSTRUCTOR: Dr. J. Menart, Room 125 RC, Phone 775-5145 E-mail: james.menart@wright.edu

WEB SITE: Pilot site – the link is on your Wings Academics tab in upper left-hand corner (<http://wings.wright.edu>). Homework solutions, notes, and other materials are located here.

CLASS TIME AND LOCATION: M 4:05 pm – 5:58 p.m., W 4:05 pm – 5:58 p.m., Room 155 RC

OFFICE HOURS: M 2:00 –3:00 p.m., W 3:00 –4:00 p.m., F 4:30 –5:30 p.m., or by appointment

2011 - 12 CATALOG DATA: ME 750 - Photovoltaics. Basic principles of solar cells will be covered including semiconductors, electrons and holes, and p-n junctions. Different types of solar cell materials including crystalline and amorphous cells as well as techniques for increasing their efficiency will be presented. Credit Hours: Lecture hours: 4.500, Prerequisites: ME 744 or ME760 or equivalent

TEXTS: Nelson, J., *The Physics of Solar Cells*, Imperial College Press, Wiley, London, 2003.

REFERENCES: Markvart, T, ed, *Solar Electricity*, 2nd edition, Wiley, 2000.
Goetzberger, A. and V.U. Hoffmann, V. U., *Photovoltaic Solar Energy Generation*, Springer, 2005.
Möller, H. J., *Semiconductors for Solar Cells*, Artech House, Boston, 1993.
Duffie, J. A. and Beckman, W. A., *Solar Engineering of Thermal Processes*, 3rd Edition, Wiley, New York, 2006.

GOALS: To understand the physics of different types of solar cells and to be able to work with the mathematical models of solar cells.

PREREQUISITES: Incoming students are expected to have some knowledge of:
IX. Molecular Structure
X. Statistical Thermodynamics
XI. Quantum mechanics

TOPICS COVERED IN COURSE:

- I. Basic Principles of photovoltaic cells
- II. Photovoltaic circuits
- II. Electrons and holes in semiconductors
- XIV. Generation and recombination of free electrons
- XV. p-n junctions
- XVI. Monocrystalline photovoltaic cells
- XVII. Thin film amorphous photovoltaic cells
- XVIII. Quantum dots
- XIX. Cell arrays
- XX. Managing light intake and increasing efficiency of photovoltaic cells

HOMEWORK: Homework will be assigned in class and on most occasions is due one week after it is assigned.

EXAMS: Two midterms and one final will be given. On a test the student is responsible for the material in the lecture sessions as well as the reading. All exams are to be the student's own work and no collaboration is allowed.

ATTENDANCE: Attendance will not be taken nor is the grade based on attendance; however, the student is responsible for all the material presented in class. If the student misses class, it is the student’s responsibility to obtain the material presented in class.

GRADING: The grading for the course is as follows:

- Homework – 20%
- Exam I – 20%
- Exam II – 25%
- Final – 35%

ACADEMIC INTEGRITY: All work in this course must be completed in a manner consistent with WSU Policy or Code of Academic Responsibility and Conduct. Violation of this code will result in a penalty to be determined by the instructor to fit the gravity of the offense and the circumstances of the particular case. The instructor may: 1) fail the student for the particular assignment or test, 2) give the student a failing grade in the course, 3) recommend that the student drop the course, or 4) bring the case in front of the University Student Honesty or Discipline Committee.

TENTATIVE SCHEDULE

| <u>Period</u> | <u>Date</u> | <u>Topic</u> | <u>Assigned Reading</u> |
|---------------|-------------|--------------------------------------------------------------------------|-------------------------|
| 1 | 1/4 | Introduction and Circuit Representation | 1 |
| 2 | 1/9 | Basic Principles | 2 |
| 3 | 1/11 | Basic Principles | 2 |
| 4 | 1/16 | Martin Luther King Holiday | |
| 5 | 1/18 | Electrons and Holes | 3 |
| 6 | 1/23 | Electrons and Holes | 3 |
| 7 | 1/25 | Generation and Recombination | 4 |
| 8 | 1/30 | Exam - I , Chapters 1 - 3 | |
| 9 | 2/1 | Generation and Recombination | 4 |
| 10 | 2/6 | Generation and Recombination | 4 |
| 11 | 2/8 | p-n Junctions | 5 |
| 12 | 2/13 | p-n Junctions | 5 |
| 13 | 2/15 | p-n Junctions | 6 |
| 14 | 2/20 | p-n Junctions | 6 |
| 15 | 2/22 | Monocrystalline Solar Cells | 7 |
| 16 | 2/27 | Monocrystalline Solar Cells | 7 |
| 17 | 2/29 | Exam - I , Chapters 1 - 6 | |
| 18 | 3/5 | Thin Film Solar Cells | 8 |
| 19 | 3/7 | Managing Light | 9 |
| 20 | 3/12 | Increasing Efficiency | 10 |
| Final | 3/15 | Final Exam 5:45 – 7:45 p.m., Room 155 RC, Chapters 1-10, handouts | |

WSU/ME752 – Hydrogen Energy

Syllabus

ME752 HYDROGEN ENERGY

4.5 credit hours

Wright State University

Department of Mechanical and Materials Engineering

Instructor:

Dr. Amir A. Farajian

258 RC, Phone: 2619, amir.farajian@wright.edu

Office Hours: T and Th: 4:00-5:00 PM, or by appointment

Texts:

-- A. V. Da Rosa, *Fundamentals of Renewable Energy Processes*, 2nd Edition, Academic Press, 2009

-- Additional class handouts

Additional References:

-- B. Sorensen, *Hydrogen and Fuel Cells*, Elsevier Academic Press, 2005

-- D. A. J. Rand and R. M. Dell, *Hydrogen Energy*, Royal Society of Chemistry (RSC) Publishing, 2008

Goals and Scope:

The purpose of this course is to provide the students with essential knowledge on hydrogen production and storage, as well as an overview of hydrogen energy conversion. Learning about recent advancements and performing related computer simulations are other goals of the course. Access to renewable and clean sources of energy is one of the highest priorities among scientific and technological challenges in 21st century. The conventional sources of energy, in particular carbon-based sources, have limited reserves and pollute the environment with catastrophic consequences for the whole planet. Hydrogen is one of the desirable substitutes whose combustion generates water, i.e., an absolutely harmless and recyclable “waste”. This course discusses different aspects of hydrogen energy. For production, chemical, electrolytic, thermolytic, photolytic, and photobiologic hydrogen production methods are among the methods that are considered. For storage, the methods include chemical, compressed gas, liquid, hydride, cryogenic, and adsorption storage procedures. The role of hydrogen in future energy systems is also discussed.

Course Contents Include:

- Introduction to hydrogen energy
- Comparison with other sources of energy
- Hydrogen production
 - chemical
 - electrolytic
 - thermolytic

- photolytic
- photobiologic
- Computer simulations of hydrogen production
- Experiments on hydrogen production
- Hydrogen storage
 - chemical
 - compressed gas
 - liquid
 - hydride
 - cryogenic
 - adsorption
- Computer simulations of hydrogen storage
- Overview of hydrogen energy conversion
- Role of hydrogen in future energy systems

Course Project:

The students are required to study recent advancements in hydrogen production and storage. Formal report and presentation are expected. In addition, using state-of-the-art simulation packages, the students perform basic computer modeling on hydrogen production and/or storage.

Exam Schedule:

First Exam: Feb. 8

Second Exam: March 17

Grading:

Homework 25%, Project 25%, First Exam: 25%, Second Exam: 25%

Grading scale:

A course average within each of the following ranges will guarantee *at least* the corresponding letter grade: A: 85-100, B: 70-85, C: 55-70, F: <55.

WSU/ME780 – Advanced Energy Materials

Syllabus

ME 780 Advanced Energy Materials

4.5 credit hours

Wright State University

Department of Mechanical and Materials Engineering

Instructor: Dr. Hong Huang, Office: Room 259, Russ Center,
Phone (937)775-3982, Email: hong.huang@wright.edu

Class Time: 6.05 – 7.58 pm, Mon. & Wed.; **Class Location:** Russ Center 155
Office Hours: Mon. Wed. 9.00-11.00am.

Prerequisite: ME515 or ME 575 (or equivalent thermodynamics)
ME570 (or equivalent intro to materials)

Goals: This course will focus on principles and materials in advanced energy conversion and storage systems. Through the journey in this course, students are anticipated to understand have general knowledge on materials including metals, ceramics, polymers, composites as well as advanced nanomaterials, and their applications in energy systems.

Contents and Topics: Fundamentals of materials, crystal structure, defect chemistry, and atom mobility in relation to application in renewable energy systems, such as solar cells, hydrogen storage, fuel cells, lithium-ion batteries, and supercapacitors. Specifically, the following topics will be addressed:

1. Crystal Structures of metals and ceramics
2. Defect chemistry and atom diffusion
3. Ion Conduction and fuel cells
4. Ceramic thermal properties
5. Semiconductor and bandgap basics
6. Solar cells and Thermoelectrics
7. Polymers, composites, and carbon-based materials and their applications in Li-ion batteries and supercapacitors

Reference books and literatures:

4. O'Hayre, R., Cha, S-W., Colella, W., and Prinz, F.B., Fuel Cell Fundamentals, John Wiley & Sons, 2005
5. Chiang, Y-M., Birnie, D.P., Kingery, W.D., Physical Ceramics: Principles for Ceramic Science and Engineering, John Wiley & Sons, 1997
6. Nazri, G-A., Pistoia, G., Lithium Batteries: Science and Technology, Kluwer Academic Publishers, 2004
4. Kingery W.D., Bowen H.K., and Uhlmann D.R. Introduction to Ceramics, 2nd Edition, John Wiley & Sons, 1975
5. Callister W. D. and Rethwisch D.G. Materials Science and Engineering: an introduction, 8th edition, John Wiley & Sons, 1975

Scoring and Grading:

A: 90-100%; B: 80-89 %; C: 70-79 %; D: 60-69 %; F: less than 60%

Attendance (3%), Homework (15%), Presentation and Paper 20%

Exam – I: 15%; Exam – II: 20%; Final Exam: 27%.

Presentation: (15 min, Q&A 5 min):

Introduction, materials and structure, synthesis, characterization, performances, conclusion

Paper (Literature Review): (15 pages, at least 20 ref.)

Abstract, introduction, materials and structure, synthesis, characterization, performances, discussion, conclusion, reference

Tentative Schedule

| Week | Lecture | EVENT |
|------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| 1 | Introduction of Renewable Energy
Review of ME 570 contents | |
| 2 | Crystal structures of metal and catalytic properties,
Imperfection, Atom Diffusion, and Hydrogen
separation | Homework 1 |
| 3 | Bandgap and semiconductor
Solar cell and thermoelectric devices | 0116 MLK holiday
Homework 2 |
| 4 | Solar cell and thermoelectric devices
Exam I | Exam I |
| 5 | Ceramics Crystal Structures
Imperfection in ceramics | Homework 3 |
| 6 | Ionic conduction
Mixed conduction in ceramics | Homework 4 |
| 7 | Fuel Cells and materials functionalities
Exam II | Exam-II |
| 8 | Exam II
Polymer and composites | |
| 9 | Polymer electrolyte in fuel cells
Carbon-based materials for lithium-ion batteries
and supercapacitors | Homework 5 |
| 10 | Nanomaterials for renewable energy
Presentation | presentation |
| 11 | Mar 12, last day of the class, review
Mar 14, Final Exam 8-10pm | Final Exam, comprehensive
Paper Due on Mar 19 noon |

APPENDIX B - EXAMPLE LESSON FOR GEOTHERMAL PROJECT

Lesson 9

Cold Geothermal

Lesson IX

Ground Loops

- ▶ Ground loops are heat exchangers as explained in a refrigeration cycle.
- ▶ Ground loops can act as an evaporator, transferring heat from the ground into the fluid when the system is in heating mode. The ground is used as a heat source.
- ▶ They can also act as a condenser transferring heat from the fluid into the ground when the system is set for cooling. The ground is used as a heat sink.



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Ground Considerations

- ▶ The temperature of the ground remains relatively constant below the frost line at a depth of about 6 feet and is approximately 50°F.
- ▶ Heat exchange is best in moist soil because of its increased conductance.
- ▶ A water source (such as a pond) can be used instead, but loops would need to be buried much deeper.



Piping

- ▶ The piping used for ground loops is usually Polyethylene.
- ▶ It is very flexible and has a high life expectancy.
- ▶ Needs to be sufficiently spaced as to not affect other sections of pipe and heat transfer.



http://geoghegan.com/1ad-00-23-14

Fluid

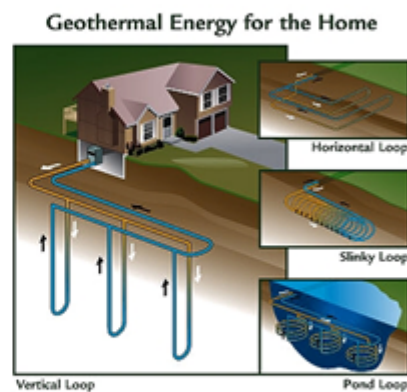
- ▶ The fluid typically used in ground loops is water or a water antifreeze mixture. Sometime an environmentally friendly refrigerant.
- ▶ Antifreeze is used so that the fluid does not freeze when near the ground surface.
- ▶ A certain flow rate and length of pipe are needed for the desired heat transfer.



<http://buschurand.com/2011/01/01/5-million-rental-advantage-of-a-solar-thermal-system/>

Types of Ground Loops

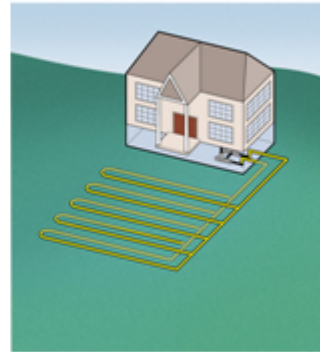
- ▶ Three options are available for a ground source heat loop: straight horizontal, vertical (borehole) and spiral horizontal ("slinky").
- ▶ Choosing a type depends on cost and land area available.



<http://industrialgeothermal.com/2011/01/01/5-million-rental-advantage-of-a-solar-thermal-system/>

Horizontal Loops

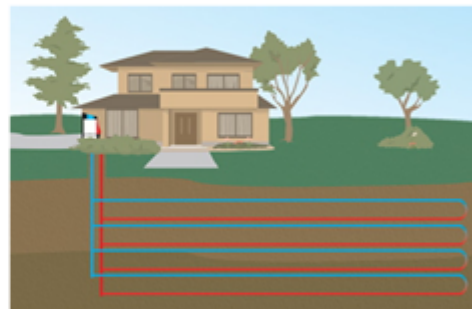
- ▶ A number of trenches are used, the piping can be configured in the trenches in several ways:
 - ◊ single pipe
 - ◊ multiple pipes in a narrow trench
 - ◊ multiple pipes in a wider trench
- ▶ The trenches are normally four feet deep or more, and vary in length depending on the number of pipes to be buried.



http://www.geothermal-energy.com/geothermal-energy.html

Horizontal Loops

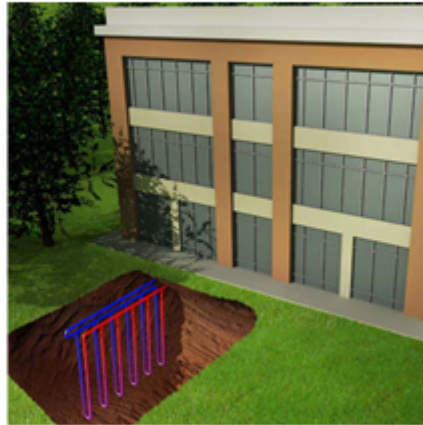
- ▶ Installation is usually the most economic
- ▶ Often used for newly constructed homes and commercial buildings
- ▶ Need larger land area without hard rock



http://www.bobcatshills.com/geothermal-energy.htm

Vertical Loops

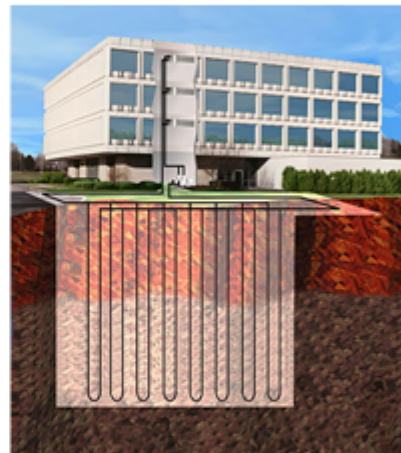
- ▶ Good to use if land area is limited
- ▶ Can be used where the land is too rocky for trenching
- ▶ Easier to install for existing buildings, large commercial buildings, or educational facilities



http://www.thp-m.com/?p=earth_coupling

Vertical Loops

- ▶ To install, a contractor will bore holes into the ground.
 - Long, hairpin-shaped loops of pipe are inserted
 - pipes are connected to headers in a trench leading back to the building.
- ▶ Drilling depth is determined by the lowest cost based on the conditions of the job site. Typically borehole depth is 150 to 250 feet.
- ▶ The objective of a vertical borehole is to install a specific amount of pipe, not to reach a certain depth.



<http://www.earthcoupling.com>

Slinky coils

- ▶ A "slinky" is a coil of plastic tubing spread out and overlapped in a trench and buried.
- ▶ Installed horizontally at the bottom of a three-foot-wide trench.
- ▶ This method concentrates the heat transfer surface into small volume, requiring less land area and shorter trenching.



Image by: www.geothermalinc.com/images/geothermal2014back-of-slinky-coil.jpg

Slinky coils

- ▶ Popular approach, especially in residential systems.
- ▶ A compact slinky will reduce trench length by about two-thirds; an extended slinky will reduce trench length by about one-third.
- ▶ Specific design lengths will vary with the climate and soil.



<http://geothermalinc.com/geothermal-slinky-ground-loop/>

References

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- <http://oee.nrcan.gc.ca/publications/residential/heating-heat-pump/7158>
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