INTRODUCING RENEWABLE ENERGY TECHNOLOGIES TO UNDERGRADUATE ENGINEERING AND TECHNOLOGY EDUCATION

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Abstract *— The need for efficient renewable energy technologies has been increased significantly during the last few years, especially with the dramatic unexpected changes in oil prices. As a matter of fact, renewable energy technologies would provide an increase of total energy supply diminishing the role of the oil. Additionally, these technologies provide green energy which would help reducing air pollution. Accordingly, introducing these technologies at the undergraduate level of engineering and technology education is vital. In this paper, an introductory comprehensive curriculum for renewable energy technologies is introduced. The curriculum covers energy collection, utilization, conversion, transmission and storage for renewable technologies such as solar, photovoltaic, wind, geothermal, hydropower, tides and waves, fuel cells and biomass. The course examines the environmental consequences of energy conversion including how renewable energy can reduce air pollution and global climate change. A thorough understanding about the economical side for using these technologies is also included.*

Index Terms— Renewable energy, curriculum, thermal energy storage, transmission.

INTRODUCTION

The renewable energy industry is expanding rapidly encompassed by rising concerns about oil reduction and global warming. Numerous innovations and applications are taking place [1] and some national governments have put programs in place to support the wider use of sustainable energy systems. On the other hand most engineers are not trained to use these renewable energy technologies and most are not aware of the principles of sustainability. This has led to a rapid increase in demand for renewable energy specialists who are able to design, install and maintain such systems [2]. There is therefore an urgent need to develop and implement new multidisciplinary courses that prepare engineers, scientists and energy planners to work with renewables to produce sustainable energy generation systems [2, 3].

The education and training of renewable energy specialists is based upon the knowledge usually taught in various disciplines and levels, but it needs specific complementary components. These are of two classes: firstly, a general knowledge able to create the understanding of the important role which the renewable energy has and will have in the future; secondly, a strengthened technical knowledge relevant to each technology which would offer the tools for efficient fieldwork under the specific utilization conditions of this technology [4].

Additionally, renewable energy education is a relatively new field and previously it formed a minor part of traditional engineering courses. These days it has an identity of its own, with special techniques, standards and requirements which are not normally encountered in other disciplines. Attempts to add one or two units of study on renewables into traditional science and engineering degrees are unlikely to produce graduates with sufficient knowledge or understanding to use renewables effectively. Furthermore, adding new techniques for renewable energy education is vital [5]. Modern renewable energy education includes a study of the technology, resources, systems design, economics, industry structure and policies in an integrated package. This prepares the graduates to design sound systems from amongst the range of options available [1]. Realizing the importance of imparting renewable energy education at all undergraduate engineering and technology education levels; it is quite likely that such attempt should be made simultaneously at several levels [6]. Conversely, it is necessary to ensure consistency and continuity in the inputs provided at different levels to maximize the overall efficiency and effectiveness of the renewable energy education strategy. Nowadays, several new approaches to renewable energy education have been introduced in the past decade. These are based on an assessment of the needs of industry and society [1]. Most of these approaches are undertaking specific individual renewable energy resource and they do not introduce a comprehensive approach to all of the other resources.

As an essential step to prepare undergraduates for further educational levels in the renewables; comprehensive introductory renewable energy technology courses should be introduced and taught at the undergraduate engineering and technology education.

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In this paper, an introductory curriculum for renewable energy technologies is introduced to the undergraduate engineering and technology education.

COURSE DESCRIPTION

This is an introductory comprehensive curriculum for renewable energy technologies with emphases on their resources and applications. In this context, the course covers energy collection, utilization, conversion, transmission and storage for renewable technologies such as solar, wind, geothermal, hydropower, tides, and waves, fuel cells and biomass. The course also examines the environmental consequences of energy conversion including how renewable energy can reduce air pollution and global climate change. A thorough understanding about the economical side for using these technologies is also included. Thermodynamics, heat transfer, and fluid mechanics concepts will form the basis for modeling the renewable energy systems. Accordingly, basics of thermodynamics, heat transfer, and fluid mechanics will be introduced.

PRE-REQUISITES

- This curriculum has been designed for the undergraduate engineering and technology education.
- Students from all majors are welcomed to attend.
- Junior standing: undergraduate engineering and technology education.

TEXT BOOK

There is no text book for the course. Instead, there will be references given and assignments to read current research papers and technical review articles that will be available on the web and through the university of Cincinnati library. Some of the material from the lectures will also be posted on the university of Cincinnati black board following the lectures.

NEEDED REFERENCES

- Renewable Energy: Power for a Sustainable Future; Godfrey Boyle, 2004 2nd ed., Oxford, University Press.
- Renewable Energy; Bent Sorensen, 2004, 3rd ed., Elsevier Academic press.
- Renewable Energy Conversion, Transmission and Storage; Bent Sorensen, 2007, Elsevier, Academic press.
- Principles of Solar Engineering, Goswami, Kreith and Kreider.
- Fluid Mechanics and Thermodynamics of Turbomachinery, S. Dixon, 2005, 5th ed., Elsevier.
- Handouts (provided by the Instructor).
- National Renewable Energy Laboratory (NREL)- http://www.nrel.gov/
- Office of Energy Efficiency and Renewable Energy (EERE)- http://www.eere.energy.gov/

GOALS/OBJECTIVES

- To appreciate the importance of energy and renewable energy to our society.
- Understand and analyze energy conversion, utilization and storage for renewable technologies such as wind, solar, biomass, fuel cells and for more conventional fossil fuel-based technologies.
- To acquire the knowledge and skills to model and design renewable energy systems.
- To improve the students' ability to solve engineering problems through the application of heat transfer, fluid mechanics, thermodynamics and economic principles.

CLASSROOM PROCEDURE

- The course is ten weeks in duration and consists of three lecture hours per week.
- Students are expected to attend all class periods and contributed to discussion.
- A significant part of the final course grade will rest on participation, determined by attendance at the class sessions or lectures and on actual contributions to class discussions.

STUDENTS' OUTCOMES

- In-class, assignments solutions.
- The students will be subdivided into groups; three students in each one of them. Each group will choose one of the renewable energy resources and is expected to deliver three presentations:

* First one: should cover; the nature, a brief history, and the collection of the chosen renewable energy resource.
* Second one: should cover; conversion, utilization, energy estimation and storage of the chosen renewable energy resource.
* Third one: should cover; transmission, environmental effects, and economics of the chosen renewable energy resource.

- Research project: each group is expected undertake a small research project to explore the state of the art in the chosen renewable energy resource.
- In-class final exam.

GRADING SCALE

- In- class participation and assignments solutions 30%
- In-class, short presentation 30%
- Research project 20%
- Final exam 20%

COURSE OUTLINE

The detailed course outline is shown in Table I.

TABLE I
Course outline

Week #	Topic
Week#1	**Introduction**, course mechanics and motivation. Fundamentals of thermodynamics and fluid mechanics.
Week#2	**Fundamentals of heat transfer** by conduction & convection. Radiation heat transfer: introduction, emissivity, absorbitivity, Stefan-Boltzmann law. Spectral intensity, emissive power, relation to irradiation and radiosity. Blackbody radiation; Plank distribution. Surface emission, absorption, and transmission. Band emission
Week #3	**Solar fundamentals**; wavelengths of solar radiation, Spectrum of solar power density, direct & diffuse radiation. Availability of solar radiation.
Week #4	**Solar collectors**; flat collectors, evacuated tubes, concentrators and solar ponds. Solar architecture; exposure control, heat storage, circulation and insulation. Measurement of time; the Julian's day number.
Week #5	Solar Energy Conversion. Photovoltaics. Nanosolar. Solar Energy Storage
Week #6	**Wind energy**; energy and power in the wind, wind turbines; horizontal and vertical axes wind turbines. Effect of the number of blades and tip speed ratio. Aerodynamics of wind turbines; airfoils.
Week #7	**Geothermal energy**; physics of geothermal resources; aquifer, cap rock, and heat source. Darcy's law for porous medium. Relation between pressure and depth. Vertical thermal gradient and heat flow. High pressure steam fields, single flash steam power plant, binary cycle power plant, and double flash power plant.
Week #8	**Hydropower energy**, hydroelectricity; world resources, water turbines; Francis turbine, propellers, impulse turbines, Turgo and cross flow turbines. Selecting of best turbine; effective head, water speed, and flow rate. Specific speed and ranges of applications.
eek #9	**Wave energy**; phase velocity of the wave, duration time, height, wavelength and fetch. Wave energy converter; offshore and shoreline wave energy converters. Tidal energy; energy from currents; marine current turbine system, horizontal forces, power transmission, and turbine farms.
Week #10	**Fuel cells**, concept of electrochemical cells; oxidation and reduction processes, fuel cell reactions and configurations, and applications. **Biomass**; composition of biomass, biomass as fuel; wood gasifiers, ethanol production. **Integration** between renewable energy resources.

CURRICULUM SNAPSHOTS

A summery for chosen parts of the proposed curriculum [7], will be introduced in the following sections.

Solar Fundamentals

The spectrum of electromagnetic radiation is shown in Figure 1.

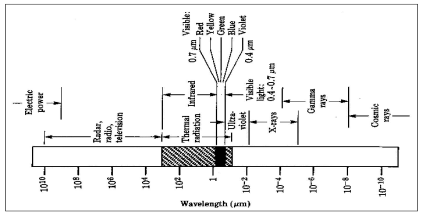

FIGURE. 1
SPECTRUM OF ELECTROMAGNETIC RADIATION.

Energy estimations

Spectral Intensity: The rate at which radiant energy is emitted at wavelength "λ" in the (θ,φ) direction per unit area of emitting surface normal to this direction per unit solid angle about this direction and per unit wavelength dλ.

$$I_{(\lambda,T)} = \frac{2hc_o}{\lambda^5\left[e^{\left(hc_o/\lambda KT\right)} - 1\right]} \quad \text{.....} \quad (1)$$

Hemisphere emissive power [ref incropera], Figure 2

$$E = \iiint_{0,0,0}^{\infty,2\pi,\pi/2} I_{\lambda,e} cos\theta \; sin\theta \; d\theta \; d\varphi \; d\lambda \quad \text{.....} \quad (2)$$

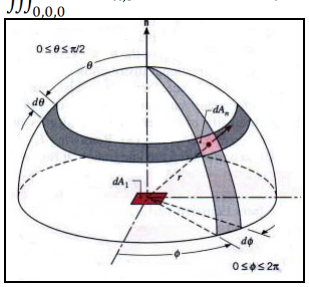

FIGURE. 2
EMISSION FROM A DIFFERENTIAL ELEMENT INTO A HEMISPHERE.

Photovoltaic cells

Photovoltaic cells made with a non-reflective coating doped material called a semiconductor. Solar irradiation strikes the semiconductor. Electrons freed and directed to an outside source; which would be a battery, Figure 3.

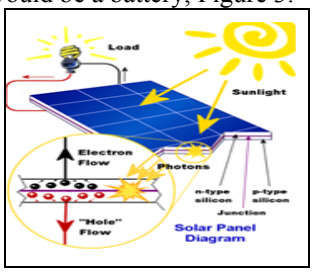

FIGURE. 3
PHOTOVOLTAIC SOLAR PANEL DIAGRAM.

Nanosolar

Two of the hot-button fields of scientific study: Nanotechnology & Solar Energy. They are being combined by many researchers to find a cheap efficient source of energy for the nation's future. A solar coating based nanoparticle ink has been developed with the ability to transfer sunlight to power at amazing efficiency [8], Figure 4.

FIGURE. 4
NANOSOLAR PANEL BASED NANOPARTICLE INK.

Solar energy storage in improved phase change materials

Nanofibers with high thermal conductivity were added with different ratios into a phase change material to enhance its thermal performance as a solar energy storage medium. The PCM can be used as energy storage medium as shown in Figure 5.

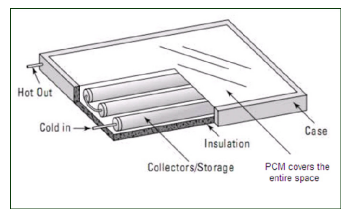

FIGURE. 5
SOLAR ENERGY STORAGE SYSTEM BASED IMPROVED PCM.

Wind energy

The energy available in wind is proportional to the area it is passing through, and the cube of its velocity. Wind turbines are used to convert wind energy into electricity by use of a generator attached to the turbine. A wind turbine consists of: Rotor; consists of two or three blades that extends out of the hub, Nacelle; sits behind the rotor and houses the main mechanical components such as the drive train, gearbox, transformer and generator, and Tower; supports the nacelle and rotor, generally made of steel, Figure 6. The rotor blade directs lift force, generated by the airflow over its airfoil cross-section, tangential to its rotation direction – causing the rotor to rotate. To optimize the use of the lift force, in large wind turbines there is a mechanism in the rotor that allows the blades to rotate and change the angle that the wind contacts the blades.

Aerodynamics of wind turbines

The performance of a wind turbine depends mainly on the design of its blades. Figure 7 shows the main characteristics of an aerofoil.

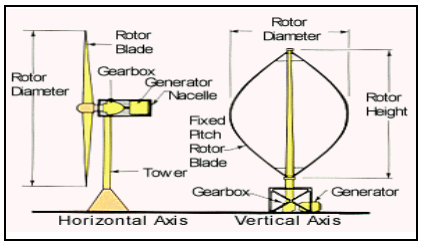

FIGURE. 6
WIND TURBINE CONFIGURATIONS

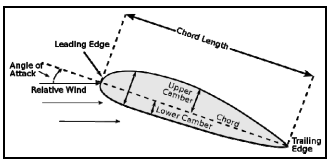

FIGURE. 7
MAIN CHARACTERISTICS OF AN AEROFOIL.

Geothermal energy

Geothermal resources commonly have three components: heat source, relatively high permeability reservoir rock, and water to transfer the heat. Hot water, warm water, or steam is pumped from underground reservoirs to the surface. Energy is extracted via a turbine or heat exchanger. Cooled water / steam is then either used in subsequent operations or pumped back underground. Figure 8 shows a schematic diagram for a dry steam power plant.

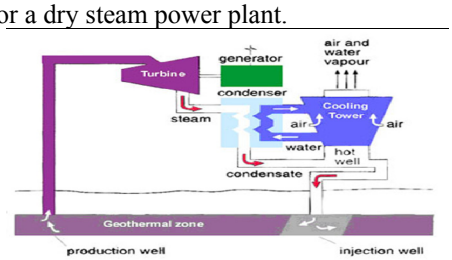

Figure. 8
DRY STEAM POWER PLANT.

Waves and tides energies

Waves in the ocean are caused by the wind blowing across the ocean surface and pushing the water ahead. These waves contain natural energy that can be harnessed and used for many different purposes, Figure 9. The wave energy can be estimated using the following formula:

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T \approx \left(0.5 \frac{\mathrm{kW}}{\mathrm{m}^3 \cdot \mathrm{s}}\right) H_{m0}^2 \, T \qquad \text{..... (3)}$$

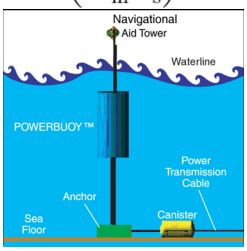

Figure. 9
BLOCK DIAGRAM OF CYLINDRICAL STEEL BUOY.

Tidal energy is used to produce electricity and is more predictable than wind and solar. Moon's gravitational force pulls the water towards it. Tide energy has the same timeline to wave energy. As the tide comes into shore and leaves shore it spins turbines that generate electricity, Figure 10. Energy from a tidal barrage can be estimated using the following formula:

$$E = \tfrac{1}{2} A \rho g h^2 \qquad \text{..... (4)}$$

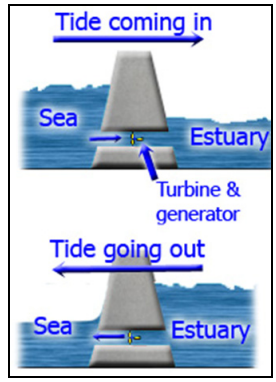

Figure. 10
BLOCK DIAGRAM OF GENERATING ELECTRICITY USING TIDES.

Fuel cells

A fuel cell is an electrochemical conversion device. It produces electricity from fuel (on the anode side) and an oxidant (on the cathode side), which react in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate virtually continuously as long as the necessary flows are maintained.
Proton exchange membrane, (PEM), fuel cells are the type typically used in automobiles. A PEM fuel cell uses hydrogen fuel and oxygen from the air to produce electricity, Figure 10.

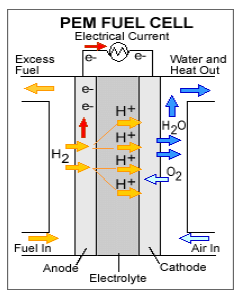

FIGURE. 10
PROTON EXCHANGE MEMBRANE, (PEM), FUEL CELLS.

Biomass energy

Biomass is biological material derived from living, or recently living organisms, such as wood, waste, and alcohol fuels. Biomass is commonly plant matter grown to generate electricity or produce heat. Conversion technologies may release the energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid biofuel or

combustible biogas. Fermentation process combines innovations in pre-treatment, state-of-the-art enzyme technology, and advanced fermentation technology. Pre-treated fiber is converted to sugars using enzymes; sugars are subsequently fermented to ethanol; and ethanol is purified to fuel.

CURRICULUM SHORTCOMINGS

The main shortcoming for the proposed curriculum is that it does not include lab sessions. The following lab sessions would be included:

- Solar energy/photovoltaic labs.
- Measurement of aerodynamic forces using a wind tunnel.
- Measurement of the calorific value of biomass materials using combustion Calorimetry.

CONCLUSIONS

The contribution of renewables to world energy supply is increasing significantly. It is necessary to prepare undergraduate engineering and technology students to face the challenges presented by renewables. As an essential step to prepare undergraduates for further educational levels in the renewables; comprehensive introductory renewable energy technology courses should be introduced and taught at the undergraduate engineering and technology education.

In this context, an introductory curriculum for renewable energy technologies is introduced to that level of education. The main goal of this introductory course is to motivate the students to understand and analyze energy conversion, utilization and storage for renewable technologies such as wind, solar, biomass, fuel cells, and for more conventional fossil fuel-based technologies. Lab sessions would be included to the proposed curriculum for more perception.

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