# Sustainable Energy Technology Curriculum Components: A Model Methodology for Engineering or Engineering Technology Programs

**Thomas W. Jenkins**[1]
Department of Engineering Technology (ET)
New Mexico State University (NMSU)
tjenkins@nmsu.edu,

**Craig I. Ricketts**[2]
ET NMSU crickett@nmsu.edu

**Robert Foster**[3]
Institute for Energy and the Environment, NMSU rfoster@nmsu.edu

[1,2,3] PO Box 30001, MSC 3566, Las Cruces, NM 88003-8001

## ABSTRACT

The authors present a model methodology for incorporating renewable energy technologies and sustainable engineering topics into an Engineering or Engineering Technology program's curriculum. The model is based upon the ongoing experiences of a four-year fully accredited Engineering Technology program in the Southwestern United States. Departments of Engineering Technology, with their characteristic multiple discipline structure, are uniquely suited for hosting a renewable energy program. The model appears to offer direct application to Engineering, Engineering Technology, and/or Environmental Engineering programs common to Latin American and Caribbean institutions of higher learning.

The need for adopting curricula in renewable energy technology will be presented, followed by an outline of the developmental approach taken to implement identified curriculum changes. Included will be a discussion of how the engineering theory can be complemented by service-oriented applications to develop a complete set of basic skills for the participants' entry into the regional workforce as well as assist the communities in which they serve.

It will be shown that the recommended step-by-step methodology permits the gathering and analysis of feedback data in order to evaluate the success of each phase, before the next phase is implemented and resources expended. It also illustrates how the outlined developmental approach is designed to reduce many of the prospective risks involved in making significant changes in program content. Finally, the potential benefits to be gained by the host department, the students, and other principal constituencies of the engineering institution are presented.

**Keywords:** Engineering and Engineering Technology, Sustainable Engineering, Renewable Engineering, Curriculum Improvement

## CURRENT LATIN AMERICA AND CARIBBEAN ENERGY SITUATION

According to the US Energy Information Administration (EIA), the Latin America and Caribbean Region (LACR) energy supplies are primarily dependent on fossil fuels - predominantly petroleum and natural gas. Although some countries have moderate to substantial fossil fuel resources to support their economies; the remainder of the region typically depends on imports that can have a significant effect on their economies and foreign currency reserves. The nations of Central and South America registered a combined 6% increase in GDP in 2004 (their best performance in 20 years) and increasing development in the region tends to forecast increasing demands on energy sources. The current reliance upon fossil fuels for energy production has increasing environmental, social and political, security, technical, and economic risks. (EIA 2007, WorldWatch 2007)

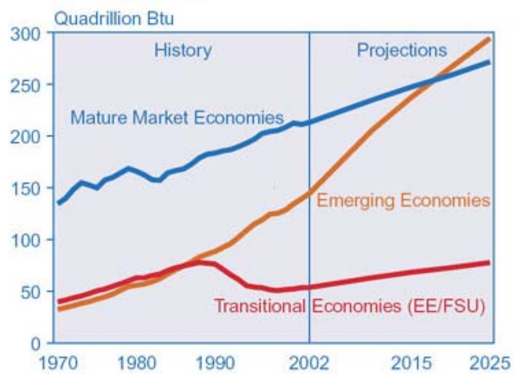


**Fig. 1: World Energy Use by Region – source EIA 2007**

In contrast to this situation, according to the EIA, all countries in the LACR have diverse levels of rich sources of renewable energy technologies (RET). Hydroelectric (not only large projects such as in southern Mexico but also the underutilized micro-hydro), geothermal (e.g. Guatemala), biomass (Brazil being a prime example), solar, wind, and ocean related sources (tidal, wave, and ocean thermal) exist in significant quantities.

RET offer significant economic development and modernization opportunities for rural areas in LACR that are not served by a conventional energy sector. Frequently the potentially important decentralized aspects and the inherent advantages of RETs are overlooked in favor of more traditional centralized large utility scale applications.

Of course, levels of each RET are dependent upon different geographic and meteorological variables particular to each country of the region, but all offer crucial opportunities to mitigate the risks of reliance on fossil fuels and contribute significantly to the LACR's sustainable energy mix. With global RET experiencing double-digit growth, it is envisioned that implementation of these technologies will continue to trend upward in the mid- and long-term thereby helping to address the changing political/social, environmental, economic, and national security issues (EIA 2004-2007, Martinot 2007, New Energy Finance 2008, Swain 2008).

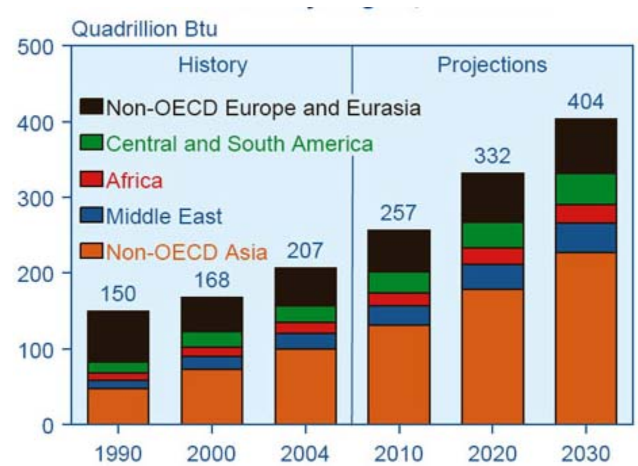


**Fig. 2: Energy Mix Use by Region 1990-2030 – source EIA 2007**

## EDUCATIONAL CHALLENGES

Based upon their jointly published data, the National Science Board and the National Science Foundation (NSF) conclude that "*we have observed a troubling decline in the number of … citizens who are training to become scientists and engineers, whereas the number of jobs requiring science and engineering training continues to grow*". Indications are that without active intervention, these flat or downward trends can be expected to continue.

An increasing focus of the private and public sectors for RET present added challenges to Engineering and Engineering Technology (EET) educational institutions which are tasked with providing graduates who have knowledge and skill sets relevant to present and future environments; i.e. an educated and skilled workforce that will provide the bridge between the theory/research of energy technologies and the application of these technologies. If EET programs do not move to adapt their curricula accordingly, then these dynamic educational challenges pose a growing risk that EET programs could fall short of fulfilling their responsibilities toward important constituencies. Some of these constituencies include: employers of the institutions' graduates who are seeking personnel with specific qualifications; students seeking a quality education relevant to today's issues and employment environments; and the citizens in the community served by the institution (Goswami 2001, NSF 2005 & 2007, Grose 2003, Guy 2008).

## OPPORTUNITIES

"*Increasing global competition for energy resources, growing concern over global climate change, questions about the long-term stability of the Middle Eastern energy supplies and the tremendous progress in new energy technologies all suggest a rapidly changing landscape of energy needs, vulnerabilities, and opportunities*"**-** (US National Commission on Energy Policy, 2006)

"*With emerging energy technologies there will be a demand for qualified technologists who can assist engineers in practical application of renewable energy*," (Pecen 2004).

Minorities and traditionally under-represented populations provide a great pool of untapped potential students for engineering and engineering technology departments. Evidence is beginning to develop that suggests that a RET program has the potential to attract socially conscious students, especially female and indigenous students, to an engineering program. "*Young women are drawn to disciplines that have an obvious altruistic quality to them, such as environmental engineering*" (Guy 2008, Singh 2006). Based upon the demographics of the RET courses offered to date, the authors have observed that a majority of their students consist of self-identified minorities or other traditionally under-represented students. This data supports the above hypothesis.

These above noted challenges offer opportunities for EET programs to develop and incorporate curricula that include RET and sustainable engineering topics. These topics may assist in addressing these challenges and the direct needs of the programs' constituencies, as well as aid in institutional recruitment of engineering, science, and technology students by offering programs that appeal to today's students.

## A MODEL METHODOLOGY OF CURRICULUM CHANGES TO INCLUDE RET AND SUSTAINABLE TOPICS

When planning modification of an established curriculum within an existing EET program, it is prudent to take a phased approach. The following recommended step-by-step methodology permits the gathering and analysis of feedback data toward evaluating the success of each phase, before the next phase is implemented. This mitigates many of the prospective risks involved in making significant and rapid changes in program content. Risks to EET programs in making significant changes to a curriculum are many and sometimes subtle; however, the most critical are the expenditures in resources (faculty, training, equipment, time, overhead, etc) to support changes that in the end, may not provide a commensurate return on that investment. In a staged approach, resources are allocated in each stage or phase and each phase must prove its success before the program proceeds to the next stage. In the topic model methodology, a three phase (four part) approach is recommended.

In the **FIRST PHASE**, a single course is developed and offered with smaller modifications to existing courses. This first, or flagship course, which in the beginning will most often be a "technical elective"[1], will be a broad overview of the technologies of Renewable Energy including Solar, Wind, Biomass, Hydro (Tides, Waves, Hydroelectric, Ocean Thermal, and Ocean Currents), Geothermal, Hydrogen – fuel cell, etc. Lectures and discussions will also involve cost/benefit and economic analyses of the various technologies on large and small-scale applications. A broad initial course offers the added benefit of potential early involvement of several cross-discipline faculty. The course could initially be offered once a year and be open to all students with appropriate backgrounds. The technical level will be suitable to the junior level of Engineering or Engineering Technology.

The main educational goals and objectives of the flagship course are for students to:

- Acquire the technical terminology associated with renewable energy technologies;
- Learn the fundamentals of basic engineering theory that underlie the generation of power from renewable energy sources;
- Gain an understanding of the cost-benefit ratios and economics of various energy technologies as compared to traditional sources;
- Understand the constraints associated with economic implementation of production and distribution of renewable energy facilities in both large and small scales;
- Be introduced to the social and environmental issues related to basic human needs and to the concept of sustainability.
- Be exposed to an applied laboratory section (optional) that will provide opportunities for multidisciplinary hands-on group projects useful for reinforcing deeper understanding of these technologies.

At the same time, existing courses may be modified during this first phase to include RET topics and applications. Some traditional EET courses that would lend themselves to introduction of RET basic topics and/or applications within the standard course content are:

- In the electronics area: "*AC/DC Electronics"; "Electric Power Distribution*"; "*Electric Machines*"; "*Instrumentation"; "Motors"*
- In the mechanical area *"Building Utilities"; "Heat Transfer"; "Thermodynamics"; "Fluid Mechanics or Fluid Technology"*
- In the civil area *"Construction Methods"; "Building Design"; "Water Treatment"*
- In the chemical area "*Fuels";"Fuel Cell Technology",* etc.
- In the agricultural area "*Crops for Fuels*"; etc.

Topics of RET and their applications could be included in a plethora of common EET courses, thereby introducing concepts via augmentation within existing content and cross-pollination with other disciplines. The most straightforward method is to chose homework or laboratory exercises with RET

[1] A technical elective is a technically challenging course that a student may select from an approved set of electives. This type of course is used to fulfill the requirements toward their degree and permits the student to direct a focus to a particular area of interest in their field of study.

concepts that are relevant to the course topic. An Engineering Technology department, with its multidisciplinary content, would typically find it easier to administratively manage these changes within one academic department.

This first offering and the modification of existing courses could be implemented within a calendar year time period with little disruption of workloads or schedules, and a modest investment in resources. A simple feedback assessment loop could be implemented to determine student and faculty member satisfaction with this first phase. Student enrollment statistics represent another prospective indicator of success.

Once the success of phase one is determined via the feedback, the second phase may be implemented. The **SECOND PHASE** of the curriculum evolution is to design and develop the courses required to meet the institution's requirement of an emphasis/concentration or a minor. An emphasis or concentration is an optional topic area within which a student can use electives and existing courses to "concentrate" their studies – in this case RET or sustainable engineering. By using electives judiciously, this format traditionally does not require students to take additional courses beyond their degree requirements. On the other hand, a minor commonly requires 18 additional credits focused in an area outside a student's major, nine of which must be upper division. Courses oriented toward a minor would be more specialized, technically rigorous, and have optional accompanying laboratories to permit application of theory to "real-world" scenarios. Multi-disciplinary group projects could be utilized in courses, but especially in a one or two-semester "Capstone" style project course. This second phase allows the student to complement a bachelor's degree with a minor in RET or other descriptive designation. If students choose courses in a prudent manner, a minor may only add an additional semester to the student's graduation date.

In addition to the phase-one flagship course and the above noted augmentations of existing courses; follow-on courses that are envisioned as candidates to be developed during this second phase might include:

- Solar Energy: Photovoltaic Theory, Design, and Technologies;
- Solar Energy: Active and Passive Solar Thermal Theory, Design, and Technologies;
- Wind Energy;
- Electric Power Engineering with emphasis on RET applications
- Geothermal Energy;
- Ocean Energies (Wave, Tidal, Ocean Thermal, Ocean Currents, et. al.);
- Hydroelectric including micro-hydro;
- Fuel Cell and Hydrogen Technologies;
- Biofuel Technologies;
- Sustainable Building Design;
- Water Resource Technologies;
- Any of a variety of environmental, pollution, economic, governmental, etc. type topics – (with typically a lesser amount of engineering and math content)
- Advanced topics and standards and procedures – e.g. the *National Electrical Code* (NEC);
- Internship – that is the work-phase of a co-operative education plan during which the student works in the industry under supervision of professionals and for which college credit is earned; or
- A one or two-semester Capstone styled Senior Project course where multidisciplinary teams of students analyze, design, implement/install a renewable energy technology at an appropriate site.

The above list is a sampling of the potential courses. Each institution when choosing their combination of courses, must take into account its own areas of expertise, the local RET resources (access to rivers or oceans, wind, solar, geothermal, etc.) and its constituencies – (for example, is there a solar or biofuels industry which could partner with the institution?). The NMSU RET example curriculum may be viewed by visiting the university web site – see references.

During this second phase, the flagship course may also evolve from an elective into a "required" course and existing courses could be more substantially modified from phase one to include more comprehensive and in-depth RET topics, while yet remaining within the pre-existing course content structure. Simple examples might include: in a "Heat Transfer" course, exercises could be developed using solar gain on indigenous rock storage – often used in passive solar architecture; in a "Fluids" course, exercises or laboratory experiments could be developed around a "micro-hydro electric" system or solar assisted water pump system; or in an "Instrumentation" course, a data acquisition system could be developed for a solar, wind, or meteorologic station.

The criteria used to indicate success of the first two phases will initially be based upon feedback from students in the end-of-semester evaluation and eventually upon whether the new courses have enough student interest to sustain them. The secondary measure-of-success criteria will be results from surveys of graduates and/or employers at the one-and three-year periods after the student has graduated; feedback for an Industrial Advisory Committee (see below); and, a tracking of employment and graduate school admissions statistics for graduates.

Through focused efforts, the authors were able to develop a minor in RET using a grant for $13,000US. About two-thirds of the funds were used to purchase necessary laboratory equipment with the remainder utilized for student support.

**PHASE THREE** implementation will be dependent upon success of phases one and two and implemented only if the preceding phases have demonstrated success based upon the evaluation criteria. Thus, only after phases one and two have demonstrated sufficient student interest, reliable job placement of graduates, and industry support, does phase three of the plan begin. This third phase involves designing, developing, and offering courses such that students can obtain a Bachelor of Engineering or Engineering Technology in Renewable Energy Technology or some variation on this title, such as Sustainable Engineering, Alternative Engineering, etc**.**

## APPLIED SERVICE ORIENTED APPROACH – PART FOUR

Designed into each phase of the model are opportunities for applied "hands-on" instruction. This can take the standard format of a typical laboratory exercise; or may be an internship or a co-operative educational work-phase with industry partners; or can take a community service oriented project approach; or, could be a combination of these.

Educational programs in renewable energy technology can give students a good general background about the different options that are available for extracting, transforming, and using energy in efficient and responsible ways. Just as important as learning theory and developing a marketable skill set, is participation in community outreach activities that help educate regional residents, as well as energy stakeholders such as builders, contractors, and governmental entities.

When a populace becomes more conscious of how sustainable energy management can benefit the community, awareness of the finite limits and conservation of energy resources are elevated. The populace in then more likely to become active promoters of efficient and sustainable living practices while making intelligent use of available energy resources.

In the proposed RET program, students and faculty will have the opportunity to promote alternative and sustainable energy use throughout the community by participating in research, design, and application projects in schools, under-developed communities, indigenous communities, etc. and disseminate information and training through well-advertised workshops to the communities. These activities will generally be through for-credit courses such as group multi-disciplinary senior projects, Capstone projects, internships, co-op, and participation in service oriented clubs or fraternal organizations such as student chapters of "Engineers Without Borders". Students will also take this information and skills into the community after graduation.

**Fig. 3: NMSU engineering and business students installing 6 kWp photovoltaic array on the Southwest Environmental Center in Las Cruces, New Mexico.**

The NMSU Institute of Energy and the Environment (IEE), which serves as the extension arm of the College of Engineering and is a partner (see below) with the ET Program in the development of the renewable energy curriculum, has conducted numerous renewable energy workshops and seminars involving student and community participation. NMSU-IEE is a renewable energy education leader in Latin America. Since 1992, NMSU has conducted over 120 Spanish or Portuguese language renewable energy education workshops throughout the region, training over 5,500 participants in courses lasting from one day to seven weeks. Indeed, many of the key renewable energy developers, engineers, and planners in Bolivia, Brazil, Chile, Dominican Republic, Guatemala, Honduras, Mexico, Nicaragua, and Panama have attended in-country IEE renewable energy educational workshops. Many of these educational activities have taken place under the auspices and in support of development programs of the U.S. Agency for International Development, the U.S. Department of Energy, and the World Bank.

## INVOLVEMENT OF PARTNERS

As is typical, the contributing courses in all phases of this plan will have a principal professor or coordinator who is responsible for that curricula component. Strong support and administrative control from the institution and department are also needed. Additionally, significant program support can come from the development of internal and external institutional partners for this program. These partners may provide technical expertise, mentorship to students, equipment and other tangible resources, training to faculty, staff, and students, and potential guest instructors.

Partnerships will need to be sought internally from within the institution and externally from industry, trade associations, private support groups, governmental agencies, secular organizations, nongovernmental organizations (NGOs), etc. and should complement both the RET resources in the region and the second phase curriculum course mix. A secondary form of cooperative assistance will come in the formation of an active "Industrial Advisory Committee" (IAC) with members from these groups. The traditional function of an IAC is to advise on curricular issues and content, industry changes, employment opportunities and required skill sets, etc., as well as provide opportunities for faculty member exchange, guest lecturers, student internships or co-op opportunities, along with other resource support.

The internal partnership concept applies within the overall university campus. NMSU is now beginning a college wide cross disciplinary sustainability degree with various departmental partners from Agriculture, Engineering, Social Work, and Government, among others. Renewable energy programs are a natural fit for this type of cross-disciplinary sustainability degree. Not every engineering class will be applicable, but some of the introductory topic classes can be appropriate to students from other disciplines, just as some classes on sustainable business development or agricultural practices, economics, etc. can be valuable skills for engineering students to learn.

Partnerships between "sister" international institutions provide excellent opportunities for collaboration. From 2006 to present, the NMSU College of Engineering and the Office of International Programs has collaborated with three Mexican institutions (Universidad Autónoma de Cd. Juárez, Tecnológico de Monterrey, and Centro de Investigación de Materiales Avanzadas) on a National Science Foundation Partnerships for Innovation Program emphasizing wind energy and also new water purification technologies.

**Fig. 4: NMSU and Monterrey Tech (Mexico) engineering students participating in joint NMSU and National Renewable Energy Laboratory wind energy training symposium in Colorado.**

The NMSU-IEE renewable energy educational and service oriented focus has been on wind and solar energy technologies for water pumping, village power, water purification, and other rural applications. These are the natural market niches for these technologies that are economically competitive without government subsidies. Participants have learned how to assess renewable resources, select appropriate projects, determine energy demands, select appropriate systems, and conduct acceptance tests of installed power systems. Often, hands-on installation and acceptance testing of renewable energy systems has been incorporated into the educational seminars to further the capabilities and confidence of students. To augment private sector capabilities, participation of local vendors of solar and wind energy systems has been especially encouraged. In some cases, such as the Programa de Energía Renovable para Zonas Aisladas (PERZA) in Nicaragua, NMSU has trained and qualified PV installers for the World Bank.

**Fig. 5: Honduran engineers attend NMSU-IEE PV engineering course conducted in Tegucigalpa for the Government of Honduras (Proyecto de Infraestructura Rural) and World Bank, June 2007**

Principal goals of NMSU-IEE renewable energy educational programs in Latin America have been to:

- Build the confidence and enthusiasm of decision-makers, engineers, faculty, and students for using renewables through fostering in them an increased understanding of the capabilities and benefits of renewable energy technologies;
- Develop and improve local educational and technical capabilities;
- Improve the knowledge base of Latin America academic institutions, industry and project developers regarding the appropriate application of renewable technologies; and
- Strengthen relationships among U.S. and Latin America renewables industries, universities and development agencies.

NMSU-IEE emphasizes coordinated international education with local academic institutions and industry. This both strengthens the overall material, effectiveness, and links between U.S. and Latin American universities. NMSU has conducted Spanish or Portuguese courses in coordination with a variety of Latin American universities, including the Universidade de Amazonas in Brazil; the Instituto Católica Tecnólogico de Barahona and Instituto Dominicana de Tecnologia in the Dominican Republic; the Universidad del Valle in Guatemala; and in Mexico there are many including the Universidad Nacional Autónoma de México, Universidad de Quintana Roo, Universidad Autónoma de Ciudad Juárez, Universidad de Sonora, Universidad Autónoma de Querétaro, Universidad Michoacana, among others.

## CONCLUSIONS

Some of the contemporary challenges confronted by EET institutions also present opportunities specific to renewable energy technology and sustainable engineering education. The step-by-step methodology toward curriculum changes presented here, permits the gathering and analysis of feedback data on the success of each phase, before implementing the next phase in the process. This developmental approach has been designed and proven to reduce many of the prospective risks involved in making significant changes in program content.

Education provides an essential contribution during any successful widespread realization of new technologies. A comprehensive and cohesive education program in the renewable energy area not only provides the awareness and knowledge needed for selecting and applying renewable technologies, but has been shown to help develop the local capabilities and networks necessary for the long-term successful understanding and application of these technologies. Finally, the potential benefits to be gained by the host department and its constituencies from the evolution of curriculum content have been observed to be substantial.

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