# AC 2010-2263: MICRO RENEWABLE ENERGY SYSTEMS AS A VEHICLE FOR INTERNATIONAL AWARENESS

**Narayanan Komerath, Georgia Institute of Technology**

# MICRO RENEWABLE ENERGY SYSTEMS AS A VEHICLE FOR INTERNATIONAL AWARENESS

## 1. ABSTRACT

The subject of Micro Renewable Energy Systems is explored as a medium for learning across disciplines, and for global knowledge exchange. Experience from 3 years of course offerings is distilled. Students in these courses came with their own strong motivation to help solve major global problems. Individual assignments revealed the differences between the constraints, resources and perspectives in the US and in places far removed. The course opened avenues for students with experiences in other countries, to contribute their perspectives. As a result, some innovations have been developed, along with a knowledge base to guide others.

## 2. INTRODUCTION

**Figure 1: NASA Mars Rover. An example of an intelligent, mobile, solar-powered multifunctional remote laboratory. Courtesy NASA**

Missions into deep space and to other heavenly bodies are designed to minimize mass and achieve long-duration reliability. Thus they must also have high efficiency and, in some cases, autonomous adaptation to harsh and varying local conditions, in order to extract resources available from their environment. The research related to these devices deals with the difficult problems that also plague most small-scale power extraction devices on Earth. The field of micro renewable energy systems (MRES), on the other hand, aims to solve problems in bringing family-sized power generators to mass-market consumers. The path towards solutions are typically at the interface between space technology and terrestrial energy issues. The philosophy adopted in MRES is that small devices cannot in the near term achieve thermodynamic efficiencies of scale that large, utility-scale power generators can achieve. However, efficiencies of scale do arise from mass production and iterative refinement, once a critical number of systems have been adopted by users worldwide. In addition, MRES devices enjoy the immense untapped potential of having a few billion human brains attending to them. This advantage puts MRES ahead of the best "artificial intelligence" that can be programmed into space resource extractors. In the long term, the best technologies and the vast experience of innovation from both application areas can help boost both areas. Thus for instance we reject the notion that "high intensity solar cells" which are very expensive, have no terrestrial market applications. In the longer term we expect to see these added to solar concentrators on urban roofs, at very low mass-produced cost. The technologies span numerous disciplines, posing a steep challenge to curriculum designers. The superficial contrasts and the inner similarities between extraterrestrial and terrestrial in situ resource utilization enabled by MRES are illustrated in Figures 1 and 2. The Mars Rover is an example of the best technology that we have been able to place on Mars. The ancient Dutch windmill, on the other hand was an element of a successful distributed power generation system, where the generators were placed at the point of use, and integrated human habitation, profitable trades and industry with easy access to their customers, using local materials, and with experienced maintenance and operational intelligence always at hand.

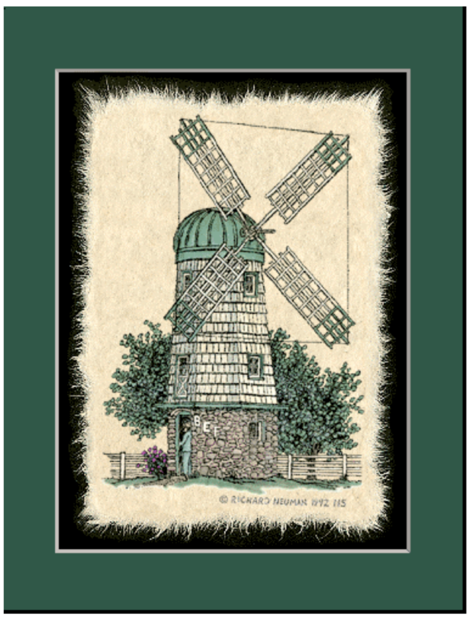

**Figure 2: Picture of a Dutch windmill. Published by kind permission from Mr. Richard Neuman, artist.**

In the context of MRES, we define "micro" as being less than 3 KW, which is enough to power a good-sized family home. "Renewable" includes sources that are "free", and inexhaustible, such as sunlight, wind, biomass and hydro power. The term "energy" is used to denote anything that produces useful work, not necessarily electric power. The term "systems" denotes the reality that isolated devices have not succeeded in penetrating this market to any great extent, despite many centuries of attempts. Success requires designing the system, taking into account local characteristics that go far beyond engineering, as indicated above in the context of the windmill. This last item demands that curricula in this area must include opportunities to learn about social and public policy issues in different parts of the world. To summarize, three important characteristics of MRES education are that it requires (a) the openness to ideas outside traditional approaches to renewable energy, (b) learning across many disciplines and (c) learning about social and public policy issues facing people all over the world. In past work, for instance a paper presented at the 2009 ASEE annual conference[1], the focus was on the cross-disciplinary aspect, trying to attract students campuswide into a course offered by an engineering school. In the process, the last issue, that of international education, turned out to be a much more interesting aspect. This is not entirely surprising, as the course development was originally funded through the Office of International Education as one suitable for approval as a Capstone course for students choosing the International Option in their engineering and science curricula.

The paper is organized as follows. First, the technical issues are presented. Next, the different concepts are explored. Thirdly, example student assignments are tabulated. Fourthly, observations of the instructor about student development are presented.

## 3. OUTLINE OF THE COURSE

The course is given a 4xxx designation, but invites students who have earned junior status to register as well. An 8xxx section is co-taught, in order to facilitate graduate student participation. The expectation is that the graduate students will complete much more sophisticated projects and business plans in the course, and provide guidance and leadership to the undergraduates. This arrangement has worked very well, since the graduate students who typically take the course are highly motivated, and see the course as an opportunity to ”let loose” according to one, on things that they have wanted to do all their lives. Students who sign up in the belief that as an elective course it would mean an easy ride, drop the course after they discover otherwise.

The course starts with a general exploration of MRES. It shows how to estimate the needs of a typical family, and how to turn that into a conceptual design estimate of the footprint of devices in this category. Thus the 1 to 3 KW range is translated into a 2 to 10 square meter footprint, suitable for backyards or flat rooftop “terraces” typical of homes in warm regions.

The ideas of conversion efficiency are next discussed, and related to rudimentary theromodynamics and laws of physics. This helps to place absolute upper limits on the power available, and then on the possibility of capturing that power for useful purposes. This then leads to the idea of a Figure of Merit, as the metric to use in improving device efficiency.

The concept of generation at the point of use is discussed next. For instance, a centralized plant may have much larger basic conversion efficiency than a small device. However, the efficiencies of fuel transport, conversion to and from line power, grid transmission efficiency, and final conversion from electric to mechanical work must be considered. Against this, the point-of use generator of mechanical power may achieve an overall efficiency of 3 to 4 times that of the utility solution. With secondary features such as local employment and free availability of renewable energy, the advantage factor may be up to 10.

Following these introductory discussions, students are asked to choose one US region, and one region abroad, and explore them to compare and contrast issues related to energy usage, sources and costs. This is an individual assignment, and starts them on a journey far from familiar grounds. It also sets the context for discussions between students from different parts of the world, on the similarities and differences in their experiences and expectations.

A broad range of ideas for energy extraction and conversion are then explored quickly, in order to convey perspective. Following this, a foray is made into public policy issues. A discussion on the issues of Climate Change reveals that few American students in engineering appear to have had any occasion to read or think about this debate, which is front-page news in the rest of the world. In the 3$^{rd}$ teaching of this course, the coverage of this topic was greatly expanded, in view of the then-imminent Copenhagen conference. This permitted the instructor to find and present viewpoints from three continents: North America, Europe and Africa. The thrust of our interest in this topic was to identify the economics and public policy potential to be used in developing strategies for various technical concepts, and so it was possible to introduce and discuss the contentious issues as being a diversity of perspectives, along with the deeper reasons behind each perspective, without making any judgements. In fact, our attitude is also that the engineer's challenge is to deal with uncertainty and present the public with options to solve problems, so we could be quite impartial in the debate over data quality and climate trends. Again, the winning strategy there was to simply look at the problems and opportunities through the eyes of people from different parts of the world. In a classroom where students from every populated continent are present, this is an interesting exercise, demanding a great deal of maturity from the students and alertness to nuances by the instructor. This exercise, which drove much discussion, set the context for cooperative problem-solving.

Students were then introduced to the ideas of System Design. The next assignment was a Requirements Definition, working in teams of two. Student teams were to define the requirements for systems to be offered as solutions in regions of their choice. In many cases, students went with their original choices of regions, but they also had freedom to choose other regions. Table 1 thus captures the different regions that students have chosen in 3 semesters. Some of the students have been natives of the regions that they chose, but others are not, and chose the regions purely out of interest in learning about them.

The textbook for the course is a non-traditional one, as befits such a highly cross-disciplinary course. It is written by a journalist[2], albeit expert in energy topics and economics. His key postulates are that the Grid is not indispensable, that transportation should be integrated with power generation, and that these provide a viable route to an eventual hydrogen-based economy. Thus automobiles or two-wheelers can provide the dual role of being power generators when connected to the home.

The course then goes on to cover the concept of distributed generation, and its importance in bringing renewable energy plants on line. Examples from Denmark and US communities are cited. The possibility of going to micro distributed generation is then explored, and the nascent treatment of such topics in the literature is explored. Some students had already volunteered as testers of Smart Meters at home, and were thus excited to learn of the prospective advantages of the Smart Grid, and employment opportunities in its various aspects. This topic again brought out discussions from international students, as such technologies are spreading faster in Europe and Southeast Asia.

Following this, individual technologies are covered. This coverage, contrary to initial expectations, had to be enhanced in depth, as students proved thirsty for this depth and willing to do the reading to enable it. Thus, reading material assigned in the course was voluminous, but appeared to be used quite well in developing project work.

At the culmination of the course, and in fact through the latter third of the semester, students were developing team project reports. In two earlier teachings of the course, the class was smaller, and included several students from the instructor's research group. As such, there was a substantial hands-on / experimental component to the course. In the latest teaching, in Fall 2009, the classroom was on the far side of campus from our MRES laboratory, so the lab component was limited to one afternoon of explorations.

## 4. GEOGRAPHICAL COVERAGE

Over 3 teachings of the course, the first assignment, to compare the realities in two regions has collected a diverse set of results. The original assignment was to select one US State or part of a state, and compare that with a place in an undeveloped nation. This evolved into a broader definition of the regions, so that we could learn from places outside the US better. For instance, Israel, France and Iceland are by no means undeveloped nations, but have their own advanced usage of renewable energy. On the other hand, not all US regions have the same state of development. Table 1 presents the regions. Obviously the choice is driven in many cases not only by students' curiosity about different places, but by the experience that they bring from at least one of the regions that they select. It is this aspect that opens up the dialog between students on the different ideas. The numbers shown in the table are the number of times each region has been chosen by students.

Table 1: Regions chosen by students to explore for energy-related issues and realities

| Developed / US region | "Different realities" region |
|---|---|
| Greece(2) | Egypt |
| Bahamas | Belize |
| Northern California | Malaysia(2) |
| New Jersey (2) | Canada |
| Colorado | Tanzania |
| Georgia(2) | Singapore |
| Florida | China |
| Southern Brazil | Zimbabwe |
| New Zealand | Karnataka, India |
| Hudson Valley, NY | Haiti |
| Germany | Maharashtra, India |
| Japan | Jamaica |
| Montana | Dhaka, Bangladesh |
| Ireland | Namibia |
| Missouri(2) | Iceland (2) |
| United Kingdom | Taiwan |
| Massachussetts | Bolivia |
| Detroit, MI | Baghdad, Iraq |
| Virginia(3) | Republic of Korea (2) |
| Pennsylvania | Israel |
| Arizona | Sarawak (Malaysia) |

## 5. CONCEPTS EXPLORED

5.1 Old Lady of the Gobi: Solar concentrator
An interesting twist on solar thermal collectors was provided by a student who found the story of an old lady who lives in the Gobi desert. She had pieced together a solar collector from discarded aluminum cans and other sources of metal foil, and was using it to heat water and do cooking. This provided the inspiration to design concepts for inexpensive solar thermal systems. Such concepts have been studied for the urban roof terrace market.

5.2 Woodstove
Smoke from smouldering leaves and other biomass is a major source of pollution in many tropical areas where there are no rules against outdoor burning. An efficient biomass reactor would thus be of use in several applications. One project in Fall 2009 studied the design of a biomass reactor, from the expert point of view of a PhD candidate in Combustion, working with undergraduates. The target markets were in Massachussetts and in Bolivia. In the former, heating oil costs are an extreme problem for residents. In the latter, outdoor burning is more of an issue. On the other hand, the link between the two regions is that Bolivia holds much of the world's known deposits of Lithium[3], essential for efficient storage batteries, and Massachussetts has a concentration of industry that would like to use those resources.

5.3 Woodstoves with thermoelectric generation
Other students have done projects on small woodstoves for kitchen use, and collected sources of information on the heating value of low-grade wood fuels consisting of twigs, leaves etc. Thermoelectric generation from woodstoves has been shown by Phillips Corporation[4], with "rocket stoves"[5] designed for use in the Sudanese desert and other such locations.

5.4 Solar PV
Photovoltaic systems were advanced as the best choice for residents of South Korean cities, especially the island communities in the south. The grid in South Korea is highly sophisticated, with power failures being very rare. Thus the main motivation for residents would be to reduce grid power costs and have more power available at peak times for air conditioning. A team of students looked at a combination of solar panels and rooftop wind turbines.

5.5 Vertical Axis wind turbine
Though more complex and less efficient than horizontal axis machines, the Vertical Axis Wind Turbine (VAWT) offers a compact and safe design suitable for crowded places. There are many commercial offerings of these devices. Students learned the hard way, however, that the advertised specifications for such devices are generally not realistic, and often exceed the absolute theoretical limits set by the laws of physics.

The student team looking at systems for South Korea ploughed on bravely, but it appeared that a combined solar PV/VAWT system would be too cumbersome and not worth the expense to residents of Korean cities[6]. Figure 3 shows a conceptual device combining a solar concentrator and a vertical axis wind turbine, built to a scale suitable for portability.

**igure 2: Concept for hybrid MRES comprising a solar PV plus concentrator heat engine and a vertical axis wind turbine.**

5.6 Bioreactor One student looked at developing a system consisting of a robotic lawn mower, and a small grass compost reactor to produce and collect methane. The idea was that the lawn mower would be partially powered by methane collected from its grass cuttings. The robotic lawn mower used lunar rover technology. The target in that case was the US suburban homeowner, who is faced with an annual race to prevent weeds from overgrowing her lawn and garden. Only a part of the fuel needs of the robotic mower would be met by the compost methane collection, however, since methane is 20 times as bad as CO2, eliminating the methane is in itself a worthwhile effort. A follow-up project[7] looked at a biomass reactor on a larger scale.

5.7 Algae Biodiesel microfarming, land co-use
An interesting offshoot of the course is the development of a scheme for synergistic algae-mushroom cultivation, tuned to the needs of small farmers and families, with the model customers being in rural India or urban US[8]. This process has gone ahead to a "Patent Pending" status.

5.8 Agricultural Energy Use Planner
One team[9] set up a software package that would enable farmers to determine an optimal strategy to invest in renewable power of various types. The software would not do the decision-making for the farmer, but would provide comparative evaluations and do the numbers for given data entered by the farmer based on their current and projected costs and opportunities. At the end of the term, they were going to develop this into a business opportunity.

## 6. STUDENTS' OBSERVATIONS

Israel, like Pennsylvania, depends largely on coal, but does not have the additional benefit of a large nuclear power plant. In Israel the use of solar water heaters is nearly universal, but there are additional opportunities to incorporate biomass, wind and low-grade geothermal sources at the kibbutz level[10]. A secondary observation is that because of the prevalent use of solar water heaters, there may be little roof ideal space left to install photovoltaic or other rooftop collectors. Pennsylvania has potential wind resources in the Erie, Scranton and Lancaster areas, and is already the $18^{th}$ among US states in installed wind power. Israel on the other hand, appears to have little potential for wind energy extraction near the most populated areas.

A comparison between Egypt and California[11] provides interesting observations. Egypt is currently dependent on fossil power (from natural gas reserves) to a large extent, followed by hydroelectric power, mainly from the Aswan dam on the Nile, which is used mainly for industries in the Nile valley. Energy demand from agriculture is very small, because farming practices have not changed much from ancient times, and depend primarily on manual or animal labor. There are plans to bring a 1-GW nuclear plant on line to meet some of the demands of growth. However, the coastal areas, especially the Mediterranean coast with its steady winds, provide excellent potential for wind farms, and this is seen as a major new source. A tough issue in Egypt is how to reach the outlying communities, where the electric power grid is not well developed. In these regions, small-scale solar converters provide an excellent alternative. The provision of water heating can help alleviate problems due to unsanitary water sources. In comparison, California is much advanced in using renewable sources, but can take advantage of integrated solar-wind solutions at the micro level.

A comparison of southern Brazil and Zimbabwe[12] provides some stark observations. In Zimbabwe, hyperinflation and deprivation or disruption of many services that were nominally available, provides extreme challenges. Southern Brazil, on the other hand, has had to depend on local sources, mostly privatized. Brazil does have massive natural resources and a developed economy in the densely populated coastal regions, but there are vast areas with virtually no development. The dependence on annual rainfall is heavy, and causes major problems when there are sharp variations in rainfall. These include disruption of hydroelectric power supply and the power grid. The Brazilian example of recovery from economic collapse and shifting to local self-reliance provides an encouraging prospect for recovery in Zimbabwe. Major sources of untapped power are the vast biomass reserves in both nations, as well as the micro hydel power potential from the mountainous regions.

Ireland provides sharp contrasts with Namibia[13]. Ireland (at least until recently) was one of the wealthier nations of Europe, but had to import 91% of its energy. Residential energy usage is 36% above that of the EU average. CO2 emissions from home energy use is a concern. Two major untapped sources are the strong winds and the abundance of water, along with hydroelectric potential at a micro level. In addition, Ireland also has some of the best wave energy sources on the planet.

Namibia is relatively poor and mostly rural, with a low population density and a large desert area. Biomass resources are scarce, and so is water. However, solar energy is abundant, and offshore wind and shoreline wave resources are some of the best in the world – though of course not suitable for exploitation at a micro level.

The Bahamas and Florida[14] posed an attractive comparison problem, since both have some unique features due to the annual hurricane season, and similar climates.  The Bahamas import all their energy supplies, so solar and wind resources are attractive options for micro power generation.

# 7. INSTRUCTOR'S OBERVATIONS

7.1 Opportunity for students to contribute their own experience
A unique aspect of such a course is that it draws out the international students, who are generally very quiet in engineering classes. Here they are able to speak from deeply held ambitions to bring energy independence to their native lands, and from in-depth knowledge of the constraints and opportunities that only a native can convey. In this course, they see that their knowledge is valued, and this encourages them to contribute to discussions.

European students of today come with considerable knowledge about Global Warming issues, and gladly share their observations. Students raised on US farms, on the other hand, find that they have truly unique perspectives to convey on the technological and cultural issues of farm life, something that people brought up in cities have no opportunity to learn otherwise.

7.2 Opportunity for students to learn about other regions
The other side of the coin is that all the students are eager to learn about other regions, and in this course, the saying "learning through the eyes of classmates" is very true indeed. Discussions brought out the point that MRES are better suited than the large-plant approach, for nations that are short on capital and land, but have high population density. In such regions, public participation through mass-marketed, family-sized power generation at the point of use, is an effective route to sustainable energy independence. The macro-plant approach requires many years of preparation, and gaining the sources for a large infusion of capital. It causes major community disruption, which has become a national and even an international issue in several nations such as Egypt (the Aswan dam and hydroelectric project), China (the Three Rivers project), India (the Narmada project, and the earlier Koyna Dam which was blamed for triggering a large earthquake which in turn breached the dam and caused flooding), and nuclear and fossil-burning thermoelectric plants all over the world. Students see that through the long gestation period, not a watt of energy would be delivered from the resources available.

7.3 Strategy Difference Based on Population Density

Once a project is finally operating, it is capacity-limited, so that as the population rises, supply, and wealth creation by the project, are inversely proportional to population. In fact, it may even be proportional to the negative nth power of population, with n larger than one. This is because of the constraints placed by rising demand, such as rolling blackouts.

In contrast, the MRES approach allows each new person to participate, in purchasing and installing, or in maintaining and operating, the systems. Capital comes mostly from individuals. An additional, crucial point is that in most such densely populated regions, land is at a premium. So the only hope to capture a substantial fraction of the sunlight, rain or wind in such regions, is to be able to place the collectors on the land owned by families in rural and in urban areas. This requires their participation. Thus, in the MRES approach, the supply of power and the creation of wealth from this power, are proportional to population, and in fact may be proportional to the positive nth power of population, n again being greater than one.

**Macro-Plant / Grid Approach:**
Supply and Wealth $\propto$ **1/(Population)$^n$, n>1**

**MRES Approach:** Supply and Wealth $\propto$ **(Population)$^n$ n>1**

**Figure 4: Contrast between the long-term implications of macro and micro power generation approaches, as the population in the served area changes.**

Against these advantages are stacked the massive obstacles to developing MRES. These are the very poor present-day efficiency of such systems compared to large-scale plants, the highly intermittent and occasional availability of power from isolated devices, and the cost per unit installed power, which is typically 5 to 10 times that of grid-supplied utility power. It takes quite a lot of faith for students to believe that such disadvantages can be overcome through good design and advanced technology, but this is an exciting challenge.

## 8 OPPORTUNITY TO COLLABORATE WITH STUDENTS IN OTHER REGIONS

The next stage in this course is to set up real collaborations with students in other countries. This was attempted in the first teaching of the course. An undergraduate team in another nation had been developing an electrical generator to operate with a small wind turbine with discussions with our research team, and guidance from their local faculty. They had been using a magneto from a moped for tests, and had designed a larger version that was optimized for a lower rotational speed, as a demonstration. An attempt was made to engage them in discussions related to the projects being done in the Spring 2008 teaching of this course. However, with the differing semester schedules and the graduation pressures on the foreign team, this attempt did not work. A second attempt has been started with a presentation given by the instructor in January 2010.

## 9 CONCLUSIONS

a. A new cross-disciplinary course on Micro Renewable Energy Systems, offers opportunity for students to share local and international experience
b. International students get an opportunity to express their experience.
c. US students gain knowledge about conditions in other countries through experience of technical colleagues, in joint projects.
d. Several reports of comparative experience between different regions have been collected from 3 teachings of the course.
e. We find that the international aspects have more potential than the cross-disciplinary aspect of the course.

## 10 ACKNOWLEDGEMENTS

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