A Campus-Wide Course on Micro Renewable Energy Systems

This paper describes the intellectual and pedagogical issues, and results from two teachings of a campus-wide course dealing with a highly interdisciplinary topic: the possibility of developing renewable power generator devices that are suited to a single family. The course is set at the senior elective level in Engineering, but it is open to students at the junior level and above from any College on a campus that includes Colleges of Management, Architecture, and Sciences, and a unique college that includes Economics, Public Policy, International Affairs, Modern Languages and History of Science and Technology.

Introduction

The objective of this paper is to describe the development and initial experiences with a course-laboratory package suitable for students from all schools on a university campus on an issue of global importance. The intellectual challenge is in tackling the core learning issues for such a course across disciplines, and tailoring the contents to diverse interests and talents, integrating hands-on building and testing with high-level concept development. The course has to attract students all over campus, while ensuring excellent value to all.

Some believe that the Hubbert Peak Oil[1] Armageddon is upon us. Others hold that the recent rise in energy prices is one of numerous transient oil price spikes[2] driven by chance or even manipulation. Either way, the present situation is similar to the Sputnik launch in its potential to inspire concerted action towards the long-delayed dream of energy independence. Through most of 2008 in US cities, the price of a gallon of unleaded gasoline[3] exceeded the projected pump price of the energy equivalent in hydrogen. Coupled with growing fears of Global Warming[4] and the reality of carbon penalties[5] and credits[6], this poses an excellent opportunity to bring college students and faculty into a project-based learning environment where everyone wants to participate in achieving real results. The intellectual question is how to use this opportunity to demonstrate how well people can learn and integrate knowledge that will serve them for a lifetime.

Figure 1: High-intensity solar converter plus wind turbine. Courtesy Laura Hershberger.

Our course is based on the idea that enabling public participation is the fastest route to sustainable energy independence. For instance, a new 1GigaWatt renewable-power plant will take 10 years to go online, given the capital needs, policy issues, local permissions, environmental integration and infrastructure development. At the optimistic cost of $1 per installed watt[7], this takes at least $1B of capital. Though the sun may shine and the wind and water flow for all those years, not a watt will come out until the plant is switched on. In developing nations, such a plant may displace the homes and livelihood of a large community of people[8]. The same or better power capacity can be achieved with a fraction of that public capital investment and in much less time, if a million people installed 1KW renewable power devices on their own accord. This is the idea of micro renewable energy systems (MRES). A student's idea of such systems is shown in Figure 1.

MRES does not refer to one single technology. On the contrary, MRES integrate and use many technologies, and avoid irreversible choices as far as possible. Below we summarize why this is at once a down-to-earth application area, and an ambitious drive in technological advancement.

The system implementation challenge

It is neither easy nor economical today to build and use MRES, although brave entrepreneurs abound, advertising devices such as rooftop wind turbines and solar water heaters. Many such efforts are driven by the passion of good people with the desire to help others break free of energy monopolies, pollution, ecological devastation and grinding poverty. They are hindered by the poor efficiency of small devices, and the lack of technological and economic integration. We seek a reasoned, deliberate approach to make MRES happen on a global scale.

Power systems become economically attractive to a retail buyer at around $1 per installed watt, or roughly 10 cents per kilowatt-hour year-round (what we pay for grid-based electric power in much of the USA). We are far from achieving this level with kilowatt-sized devices, but a reasonable mass market may develop at about 2 to 3 times that price level among customers who value the grid independence and emergency usage potential of the devices. Increasing the efficiency of small devices requires leading-edge technologies that are extremely expensive today, because they come from national defence or space programs, and suffer from very small production size. A huge price drop can come from mass market efficiencies and integration of multiple devices, storage and uses if there is a large market. But getting the retail customer to buy enough such devices requires a *focused integration of economics, cultural understanding and market dynamics, with technology*. It also requires the facilities to reduce theory to field tests of practical devices usable by anyone in the world.

The original motivation for this came from opportunities identified at the interface between Space technology and Renewable Energy technology. However it was quickly seen that there are equally great challenges in the areas of understanding social and economic realities at the customer level in various nations, in public policy related to energy and climate change, in adopting innovations across disciplines within and outside science and engineering, and in aesthetics, public relations, and business models. Thus the course has to be truly cross-disciplinary and global in scope. It must be tailored to suit both the engineering student, and the student who is afraid of engineering and science, but has other valuable talents to contribute.

A grant from the Office of International Education funded acquisition of critical laboratory items to build demonstrations, hire student assistants, and travel to set up a joint project with a student team in another nation with very different realities. A one-year project was brought to successful completion in coordination with ongoing work at our lab, as that student team graduated. At our home institution, students in our Spring 2008 course developed a series of products, focusing on five projects in teams of two each. They did an initial comparison of realities in two very different regions, then selected projects, and did a Requirements Definition for their project. They then developed design analyses and presented them at the Institute's Undergraduate Research Opportunities Seminar midway through the semester. At the end of the semester, they submitted detailed reports as well as Business Plans for their projects. This exercise was repeated in Fall 2008, with a graduate section of the course added to focus on the issues where Space technology linked to renewable energy.

The course lecture material, evaluation methods, and course assessment comments from students, as well as the status of different projects are discussed, for both semesters. The unique challenges and exciting benefits of bringing in students from different colleges into such a class are also discussed. The subject area is one that generates genuine enthusiasm and awakens deeply-felt personal commitments to contribute to solving the energy and climate crises. The thrust of the paper is on the intellectual challenges in developing and presenting such a course, addressing the needs and expectations of students from various disciplines, while negotiating intricate and sometimes politically controversial issues across policy and economics.

Intellectual challenge: Content and methods for cross-discipline learning

1. The first problem that we have to keep addressing, is how to "sell" a campus-wide course to non-engineering majors who view an AE4xxx designation with horror, and to engineering students whose technical elective space is "owned" by their home departments.
2. The second problem is how to make sure that each type learns the issues across the domains of the other, rather than fall into the trap of many industrial cross-functional teams that degenerate into islands of insecurity. There is a bewildering array of technologies being pursued as part of the solution for energy independence. Even the small sampling of disciplines in Table 1 shows us why developing the abilities and experience of the learner has to be at the center of the curriculum.
3. The third challenge is to ensure that the result is a serious, rigorous learning experience, not a "party course". To summarize, we must walk a fine line between the extremes defined in the ancient saying: *"A jack of all trades is a master of none"* and the cartoon: *"I have learned a great many things in my 65 years, but most of them are about aluminum"*.

Previous work

Energy curricula are spread all over most campuses, though a few campuses have developed energy engineering as a new discipline. On our campus, we count 8 other (senior and graduate) courses on different aspects, spread between Mechanical, Electrical, Nuclear and Aerospace Engineering, Public Policy, Physics and Earth & Atmospheric Sciences. Environmental concerns are generally disconnected from energy. Economics of large plant designs are covered in textbook discussions that have not changed much since the 1980s. These practices are quite similar around the world, though some graduate level curricula on “non-conventional energy sources”[9] are offered, still exclusively in the large-plant context. Project-based courses such as those by Malte and Kramlich at U. Washington[10] are more appropriate for small-scale sustainable design and renewable energy, to deal with the plethora of issues. Grassroots community efforts recognize the need to integrate renewable energy with economics and sustainable development. “Permaculture” courses[11] combine ideas on energy flow, materials cycling, and appropriate technologies for self-reliant living, water and waste management, and how to organize local economies. International teams have worked on community projects, e.g., Engineers Without Borders[12] and MIT’s Solar Turbine lab[13].

Table 1:Sampling of issues and disciplines, showing opportunities for campuswide participation

MRES issue	Discipline/skill	Home schools
Wind turbine aerodynamics Wind turbine generator Distributed Energy Systems Transmissions Closed-cycle thermal generator Biodiesel from Algae Home energy savings Small farm economics	Aerodynamics, Electric motors/generation. Policy, economics, electric power Fluid and Thermo dynamics Biology, chemistry, physics Spacecraft thermal systems Economics; system engineering	Physics, Chemistry, Environmental Sciences, AE, ME, EE, Bio Engg., Automotive Engg., Systems Engg., Public Policy, Economics, Management

Haynes et al[14] used the preparation of environmental impact statements on real-life projects as a theme of their project, to converge the interests of students and faculty from various disciplines on problems of common interest into a set of Workshops for faculty on instructional techniques in science. They used these projects to develop pedagogically sound curricula for learning the methods and skills of science. Education researchers helped them to develop assessment techniques that captured learning status before, during and after project exposure. This is relevant here in that it contains several lessons and years of diverse experience related to educating both students and the public about MRES, and conducting field tests and assessment.

Isaacs sought[15] to *“discover whether technology-based learning was more appropriate for a diverse student population and whether the introduction of concepts through group game play fostered deeper understanding of interdisciplinary material.”* Their project experience[16] provides valuable guidance in that they sought to *“bring together the growing concerns of environmental awareness and diverse learning styles in an innovative model aimed at educating future engineering leaders”*. Fruchter and Emery[17] discuss a *“new metric, cross-disciplinary learning, as a journey from the state of island of knowledge (discipline-centric) to a state of understanding of the goals, language, and representations of the other disciplines"* along with a 4-tiered evolution from "islands of knowledge", to *"awareness, appreciation, and understanding.”* Bell et al[18] discuss facilitating cross-disciplinary learning using WebCT with examples of *“student-centered strategies such as debates, case analyses, and class presentations, combined with multimedia ..to increase student participation."* Fazzolari[19] deals with web-based delivery of a course on solar and wind energy, but no lab component is evident. Russell et al[20] have discussed the problem of integrating basic content from several courses into a curricular core suitable for lower-division students. This provides several items of thought relevant to our problem of creating a course, distilled from several disciplines, but note that our problem ranges across a far wider spectrum of disciplines and student talents.

Schaffer[21] *et al* analyzed 70 cross-disciplinary student design teams. A point of interest to us is their observation that the highest confidence ratings by students were for the "Problem Identification" phase near the start of the project. This reflects the philosophy taught in our course that the "Requirements Definition" is the real core of the project design, and involves the greatest thinking and learning of issues. They confirmed the importance of providing feedback, and setting clear and high expectations, rewards and incentives. These findings reinforce our course structure, especially aspects such as the midterm public poster presentation. This sets up a very focused and probably scary event, from which students come back exhilarated by the finding that they do very well in explaining their ideas to an outside audience.

Learning Resources

The search for good learning resources on this complex area took us far and wide. There are many resources, but they are spread out over the internet, and in research and project reports. Many good books exist on specific technologies[22,23], but the best coverage of the many issues that we found is in a book[24] by a well-known writer for the Economic Times. There are many excellent web-based resources[25,26,27] , but these have to be found for specific parts of a course on MRES. Reports from Think Tanks and the Congressional Research Service are valuable summaries of issues.

Course Content

1. General discussion lectures: Summarized in Table 2, these lecture topics each had a large Microsoft PowerPoint presentation and a set of reading materials associated with it. They introduce general philosophy and issues in several areas, and show how to estimate engineering and cost parameters in new situations.
2. Demographics assignment of the student's choice: Each student focuses on one area outside the US, and one US state or locality for a comparative assessment of needs, realities, opportunities, and apirations. This is as much for motivation as for knowledge. In Spring 08, the diverse class chose (and were eager to talk about) Iceland, UK, India, East Africa, Canada, Australia, and several US states. In Fall 08, the list expanded to Hungary, Haiti, Jamaica, Singapore, Bangladesh, Patagonia, Japan, and other places.

Table 2: List of Course Modules

- Introduction to Micro Renewable Energy Systems.
- General process of System Design
- Global energy needs and usage in different sectors
- Kyoto Protocol, Carbon credits and other incentives
- Distributed Generation
- Thermodynamics survey
- Economics of renewable energy and case for micro-renewables
- Technology surveys (several modules)
- Project discussions and presentations

3. Readings from Think Tanks and Congressional Research Service Reports: Besides being templates for student reports, these provided an excellent learning experience, not least because it posed a surprising challenge, revealing gaps in present curricula.

4. Requirements definition: This exercise followed lectures and discussion on the basic conceptual system design process. This formalizes knowledge and emphasizes customer and market early in the project.

5. Team project selection: In the first teaching of the course (Spring 2008) each student was assigned to two projects, one as leader and one as supporter, so that each team will had two members. Projects are listed in Table 3.

6. Developing Project Documents: The main progress reporting mechanism is a formal Project Document for each project, adapted from industry/DARPA formats to track fast-paced projects. These track schedules and critical paths to continually reduce project risk. Since the 1990s, Prof. (Author's) teams have demonstrated the use of such documentation to collect relevant information and organize complex off-site projects, with diverse (freshman-to-PhD) teams.

7. Interspersed lectures on different topics: Once the projects were determined, lectures were provided on each technology in a "time-sharing" manner, to keep all projects moving. Extensive Resources were provided on the course website, and the instructor helped by distilling the essence of each project area into lectures staged in levels.

8. Lab experience with testbeds: Two testbeds were developed in Spring and Fall 2008, namely, a vertical axis wind turbine at our 42-inch low speed tunnel, and a solar collector/heat engine.

9. Project meetings: Given the small class size in Spring 08, the students decided that the professor's office which is arranged as conference room, was much better for discussion. Everyone participated in animated, productive team discussion. In Fall 2008, we had a far worse classroom in the basement of an ancient building; however, the discussions were just as lively.

10. Feedback discussions on presentations: Students were asked to list questions and discussion as a course assignment. Based on experience from April 2008, we expect that questions from the Judges and visitors will sharpen thought. Students exclaimed that this worked so well because it was several weeks before the end-of-semester crunch - a lesson to be emulated instead of the usual "end-of-course presentation" that we usually assume. In April 2008, the campus student newspaper published two comments from students in this class at the Undergraduate Research Opportunities Symposium, reproduced here by permission. The first was[28]: *"Presenting at this symposium is more engaging than class presentations because everyone in the class knows what you are talking about already. Here, it feels like you're disseminating and informing others outside your field of research", said Kamalakannan Radharaman, a fourth-year Biomedical Engineering major'.* His classmate from aerospace engineering was shown explaining her 1KW solar collector project designed for the home "terrace" (flat concrete roof) in rural India.

11. Business plan development: The final exam is the development of a concise Business plan by each student. Business Plan guidance and resources are available on the internet for students

to download templates. In Spring 2008 the students were given a copy of the Lunar Ventures Business Plan that was developed by Prof. Komerath's student team the previous year, as a source of information and formats.

Not all MRES are for "developing economies". Matthew Layfield's concept integrated a suburban solar-accelerated compost methane generator with a robotic lawn mower. It simultaneously attacks the growing yard waste problem of suburban US homes, cuts leakage of methane into the atmosphere (methane is 20 times as bad as CO2 per unit mass in global warming), and promises the miracle of robotic lawn-mowing based on Mars Rover technology.

Table 3: Projects in AE4883

Vertical axis wind turbine
EduKitchen: Clean woodstove power generator
1KW solar thermal-power
Venkat: Land co-use for Algae biodiesel and dairy farming
Solar—biogas lawn mower

Assessment

Lessons from the first teaching of the course in Spring 2008 are summarized in Table 4. A prototype assessment plan was approved by our institution's IRB for approval of protocols. This plan focuses on first informing the students that the course is a subject of study and research, and an open-format survey inviting thoughtful discussion on the course and the area (not on the instructors). The usual Institute Course-Instructor Survey gives students the opportunity to comment on the instruction, but the effectiveness of this tool has come under serious question in the engineering education community, and we share those concerns.

Table 4: Lessons from first teaching of MRES

Aspect	Lesson
Learning resources	Students were pleased to be able to learn as needed, with proper introductory lectures and posted reading materials on the course website. They liked the provision of very basic material to help in the design process, applying concept already "learned" elsewhere.
Skills	Generating estimates from physical laws and common sense, and refining them through benchmarking, is a critical skill. Students swiftly picked up the "knack" of this, as the key to innovating across disciplinesStudents had a surprising amount of difficulty in reading Congressional reports and other resources that dealt with policy issues. Engineering students need more guidance on economics and cost modeling.
Teams and reporting	Presentations in the middle of the semester work better than "final presentations". Getting others to understand the thrust of the effort was difficult until students made their poster presentations. Then everyone was talking about "MRES" as if it were a household term. Interactions with other universities are slow, since each set has their own pressing priorities, but being aware of their projects is of great value.

A post-course survey was emailed to students, requesting thoughtful expert comments. This was not anonymous, and respondents provided permission to use their names as appropriate. The questions and responses to-date are given in Table 5. Several more are awaited and will be included in the final version of this paper.

Table 5: Alumni Assessment (edited/ paraphrased for conciseness)

1	Question: Why did you take the course, and how did those reasons and expectations compare with what you found in the course? Responses: • To learn more about the development of different renewable energy systems and recent technologies being used. Enjoyed the opportunity to focus on researching wind energy. I expected a bit more background (more comments on this in later questions) • Renewable energy is a growing field with career opportunities. Micro-renewable energy is often overlooked. Interested in local, non-grid solutions, particularly in developing countries. Micro renewable energy is a way to "design for the other 90%" of the world without typical western resources. • To learn more about the rapidly expanding subject of renewable energy systems. The course opened me to many options that I was able to use in my research in developing applications using green energy. • Lot of interest in the field of Renewable Energy and found the concept of learning more about small scale systems and developing our own ideas very attractive. The course more than exceeded my expectations and forced me to actively think and come up with solutions, one of which (biofuels) I am currently researching in much more depth.
2	Question: What would you like to see added/deleted from this course? Responses: • Like to see more background given to the individual technologies before splitting off into individual projects. I believe we ended up spending only about 2-3 weeks before each person got focused on their own project. Also, as an alternative to going into more detail, have the class present their updated findings in a way to explain the technology to the others, rather than more individual focus on development. • The class should include hands-on experience with devices. Get a solar oven, parabolic mirror, simple wind turbine (or just a propeller on an axle) and develop tactile learning. Maybe build a few devices from plans without the research and write ups. Just to get a feel for construction and energy balances. • Also provide a survey of contemporary commercial solutions so students can see what is being done. Maybe also reference E. F. *Schumacher, Buckminster Fuller, etc.* • Able to gain a lot of hands of experience with the course and would like to see more. • Could perhaps investigate a wider range of modern energy concepts to more depth but quite a few were covered extensively in the course.
4	Question: Please comment on the balance between class lectures, class discussions, assigned readings, outside readings for assignments, discussions with people outside the class. Should this balance be altered? Responses: • When taking this Spring 08, there were a few lectures in the beginning, and then it shifted to mainly discussions on individual projects. I would've enjoyed further readings and background available. Perhaps not assignments in terms of reports, but more reference readings to learn more information or discussion of those topics: Ex. A report on solar and then discussion on that, a report on wind and then a discussion on that.

	• I thought this was fine. Maybe provide more readings as noted above. • There was a good balance between class lectures, class discussions and projects. Every class gave the opportunity for us to learn something from the instructor than discuss is amongst our peers. We also worked in teams of two on two projects that allowed us to use the classroom knowledge to gain some hands on experience. • No, the format was ideal. The course began with more of an emphasis on lectures, shifted to discussions and then required us to read outside material as we began working on our projects and finally lead to discussions and work outside of class.
5	Question: Should the course go to a "3-hour lecture" format while retaining the projects? (we would like to hold the credit hours to 3) Responses: • There should be more lecture, but don't know if the full 3 hours/week is necessary. Perhaps 2 of the 3 classes as lecture, other for project discussion (if 3 1-hr classes). Otherwise, 1 of the 2 classes for lecture, other for project discussion (if 2 1.5-hr classes). • More lecture/discussion time in class would be good. • The course required a lot of work and was definitely worth 3 credit hours. • No but it might be feasible to have two 1 hour lectures and a sort of half-lab session. We could use a 1.5-2 hour session to actively work on our projects in a lab like situation. We could use this time to do outside research and formulate solutions to problems posed to us. It would perhaps focus the attention of the students better.
6	Question: How did the workload compare to other (graduate or undergraduate?) 3-hour course at (your institution)? Responses: • The workload was manageable. I think with some additional readings, it would've matched a typical elective class. Definitely less than a typical AE core class however. • Pretty typical • The work is comparable to the 3 credit hour capstone courses that seniors in Aerospace Engineering major have to take. The course layout and workload required is almost identical to the senior space design course I took in Fall 2008. • The workload was very light at the start but increased quite exponentially during project completion time. However, the workload was never overwhelming and on the whole, probably comparable if not lower than most AE courses.
7	Question: How did the intellectual demands / demand on critical thinking and exploration compare with other courses at the same level? Responses: • The project/research emphasis provided greater opportunity for critical thinking and exploration. Presented a format that allows students to stay interested in material by developing their project. • I appreciated the focus on real-world market conditions. It was good to design for manufacture in a developing country. Too many courses are purely theoretical; this was a refreshing application of the practical. Surveying commercial applications would help, too. (The professor)'s experience and stories of how things are really done was of great value. I wish more courses would tell students what it is really like out there. I use this

	aspect of the course when writing cover letters or talking to recruiters. • The course required a lot of research and creativity because the subject material is not frequently touched upon by many classes. • I thought that this course challenged me to think a lot more than most other courses at this level. I loved the concept of actively coming up with a new solution to problems in our assigned fields. I loved this creative aspect of the class and feel it was one of its strongest points. It did not merely attempt to teach us about present advances but also improved our problem solving and professional presentation methodology. We learnt how to research and create professional reports also.
8	Question: Please comment on depth vs. breadth in the course. Is the balance right? If not, how would you like to see it changed? Responses: • Depth vs. breadth balance was fine, except again further background references would be helpful before splitting up into projects. Perhaps better with continued depth throughout the semester in the individual technologies/applications. • More of both is always better. I thought it was a good balance. Maybe add a little about application of off-grid technologies in America. Talk about zoning, expectations of power availability, materials. I see America as a potential test bed for technology to be developed for areas with fewer resources. • We went into a lot of depth into our selected project topics and got an overview of the others. While this is ideal, I would have maybe personally liked to explore more extensively in 2-3 topics as well as have the overview. This might however make the workload too big.
9	Question: Any other questions that should have been asked / comments Responses: • The class discussion were helpful because the topic is so contemporary. I would encourage informal groups to meet outside of class. As mentioned, I would encourage/provide opportunities to actually build devices from plans in addition to the projects we worked on.

Conclusions

1. Micro Renewable energy systems (MRES) are seen as a worldwide means of moving towards energy independence and controlling global warming.
2. Implementing MRES requires integration of knowledge on climate change, economics, international cultural issues and various branches of science in addition to engineering.
3. Introducing MRES to students thus requires a multidisciplinary approach.
4. A course has been developed where students from all across a campus can contribute.
5. The course has been tested through two semesters.
6. A suite of five concepts has been selected for development.
7. Outcomes assessment and alumni opinions show that the initiative, independent study and teamwork aspects of the course are effective and well-received, and that the alumni are comfortable in giving thoughtful opinions and assessments.

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