Session 2533

Teaching Design for Energy Sustainability

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Abstract

"Increasingly, investors are diversifying their portfolios by investing in companies that set industry-wide best practices with regard to sustainability"[1]. Sustainability has become yet another universal trend, besides total quality management, six sigma and total customer satisfaction, that businesses and industries must adapt to remain competitive in the global market. Industries are adapting to Corporate Sustainability and, as a result, engineers must be trained to help their employers to stay in compliance with, and excel in, this investor-driven economic atmosphere.

Sustainability has everything to do with a harmonious co-existence of the economy, society and the environment [3, 4]. It is proposed that we view energy as the common thread that holds these three sectors together in an optimized fashion. A vision is cast in which the application of the principle of energy sustainability is incorporated into all engineering designs. Discussion is made on why sustainability should be considered as part of the design criteria much like that of economic feasibility of any acceptable engineering design projects[10].

Sustainability means different things to different groups,[4, 5, 6, 7, 8, 9, 16] in the context of this paper, energy sustainability is defined as the ability to fuel the world's economic engine in support of its economic growth by minimizing the use of fossil fuels to the extent that there is no associated environmental impact. A design for energy sustainability, therefore, is a design of inherent energy saving systems. This could take in the form of specifying renewable resources or taking into account measures to slow down the depletion of non-renewable resources or a combination thereof. This could mean design for energy effectiveness via fuel choice, conversion efficiency, operational controllability via either automatic or self-learning process, etc.

A course designed to teach energy sustainability is proposed. It embraces the philosophy that true energy sustainability must be a combined effort of end-of-pipe behavior and that at the command and control. A list of examples is made to cite lack of energy saving sensitivity in the real world both at the point of use as well as in the design process. Discussion is made concerning how they could have been designed differently had the principle of sustainability been invoked or practiced[17, 18]. It is concluded that true sustainability can only be achieved if energy sustainability can first be achieved.

Introduction

Businesses and industries are under intense pressure to embrace policy of sustainability or face economic reprisal by the investment community[1]. At the core, sustainability makes a lot of sense. It is the ability to sustain ourselves with respect to the utilization of natural resources, the ecology and the environment. It is meeting the needs of the present without compromising the ability of future generations to meet their own needs[2].

Sustainability has everything to do with a harmonious co-existence of the economy, society and the environment[3, 4]. The economic engine requires energy to run. The society depends on economic growth and a healthy and sustainable environment to thrive and the environment requires responsible energy harvesting and utilization to be inhabitable. In light of this interdependence, it is proposed that we view energy as the common thread that holds these three sectors together in an optimized fashion.

Many, if not most, publications[5, 6, 7, 8, 9] on the subject of sustainability, and its subset of engineering for sustainability, have been focused on the management aspects of the issue. Nothing is wrong with this approach except that it is philosophical and policy-oriented. Since sustainability is such a worldwide and urgent issue, a more concrete approach is needed—one that advocates practical actions. This paper is aiming at achieving this goal along the finite domain approach__solving a large and complicated problem one domain or element at a time. And the problem at hand is energy sustainability. Since sustainability means different things to different groups,[4, 5, 6, 7, 8, 9, 16] in the context of this paper, energy sustainability is defined as the ability to fuel the world's economic engine in support of its economic growth by minimizing the use of fossil fuels to the extent that there is no associated environmental impact.

If energy sustainability means engineering ability to design to the compliance of corporate sustainability policy, then future engineers (engineering students) must be trained and equipped with the know-how and creativity of engineering to explore new venues, to develop new methods and to enhance the existing efficiency. But all those could not be accomplished if the engineers being educated today are not aware of the immense responsibility expected of them concerning future generations.

Practicing energy sustainability, however, does not mean that today's generation must sacrifice its life style so that the generations to come can live (it does not have to be that dramatic or traumatic although it would be noble if the situation so demands). Practicing energy sustainability, however, does mean significantly slowing down the rate of borrowing energy from tomorrow. This can be accomplished by enhancing current energy efficiency and transformability from fossil fuel resources as well as making options for renewable fuel resources more cost effective. How to impart the urgency of this sustainability message to today's generation of engineers is the topic that we will explore in this paper. The role of higher education was well highlighted, and rightly so, in connection with the subject of sustainability: "Higher education prepares most of the professionals who develop, lead, manage, teach, work in and influence society's institutions. It plays a critical role in creating and disseminating the knowledge, skills and values for society"[10]

An Engineering Vision

Who would have thought, even a decade ago, that oceanic oil tankers with double hull design could have become second nature to design engineers today? It may have required many oil spill catastrophes, culminating with the Exxon Valdez, to make design of double hull a second nature. But it has become second nature nonetheless. Who can today imagine any engineering designs or solutions done without economic analysis? It, too, has become second nature to engineers of this generation. Engineering solutions cannot stay aloof and be judged solely on their technological basis. Economic justification will set them apart. On the same bases of the above two examples, the author is casting a vision that engineers working on energy systems will, as a matter of second nature, take into accounts the strategies for energy sustainability in all facets of engineering design, purchase, installation and operation decision making.

First, the Energy Picture

On the front of global energy utilization, we, the people, are conducting ourselves in the most illogical manner that can be imagined. Not only are we using the most of what we have the least as shown in figure 1 and 2, we are subjecting the least available resources to the most accelerated depletion rate as shown in figure 3 and 4[12]. The only plausible explanation to this irrationality is expediency. A quick solution, albeit a solution, may ultimately be undesirable.

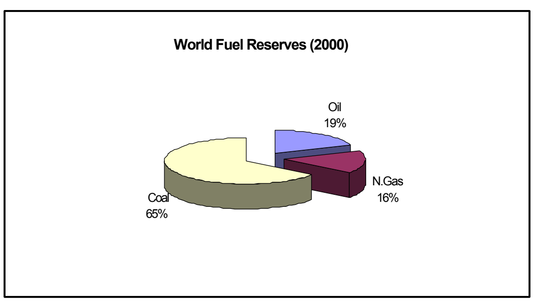

Figure 1—World Fuel Reserve.
Coal is most abundantly available.
(EIA Annual 2000)

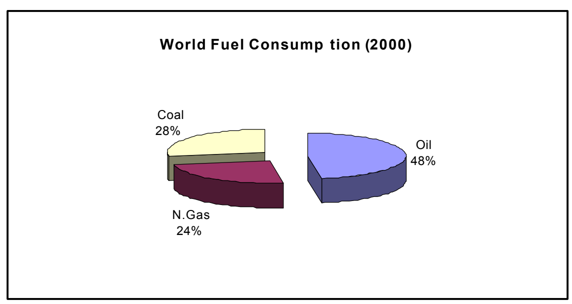

Figure 2—World Fuel Consumption
Coal is the least used fuel resource.
(EIA Annual 2000)

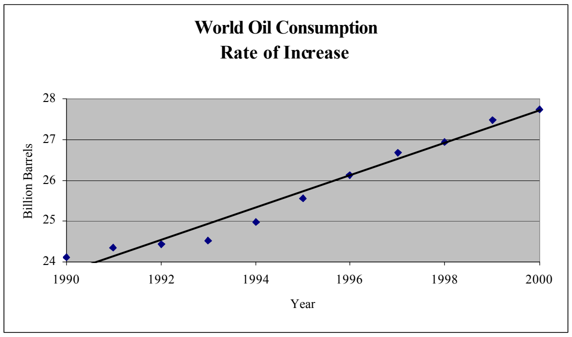

Figure 3—World Oil Consumption Rate of Increase (0.40 billion barrels/yr)

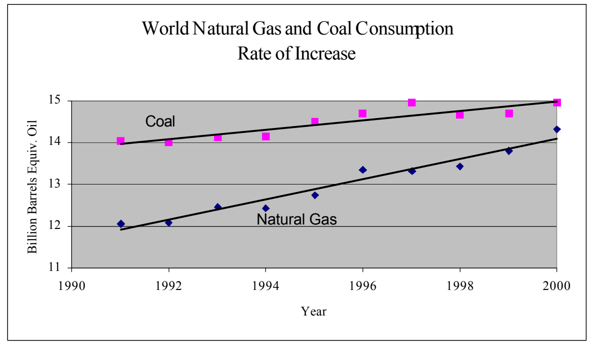

Figure 4—World Natural Gas & Coal Consumption Rates of Increase (0.25 and 0.11 billion barrels of equiv. oils/year, respectively)

While we may attempt to explain the anomaly of the energy picture politically, environmentally and economically, we cannot deny, from data in table 1 and 2 below, that simple math will show the imminent ends of the finite fuel resources at the current rates of utilization. In fact, there is a good chance for oil and gas to run dry during our lifetime. Coal will be exhausted in about two generations. It should be noted that predicting world reserve of fossil energy resources is far from being an exact science. For example, world oil reserve was thought to be 600 billion barrels in 1949 by Pratt[22]. Today, that number has significantly been increased to about 3000 billion barrels by the US Geological Survey[21]. There is no doubt the predicted reserves of fossil fuel resources will continue to be revised. The fact remains that the resources are finite and are being quickly depleted.

Table 1: World Fuel Resources and Consumption Rates[12]

	Reserve	**Annual Consumption**
Oil (billion barrels)	1,004	28
Natural gas (trillion cu ft)	5,450	87
Coal (million short tons)	1,083,259	5,146

Table 2: World Fuel Resources and Consumption Rates (in Equivalent Oil)

	Equiv. Billion barrels of oil reserve	**Annual equiv. billion barrels of oil consumption**
Oil	1,004	28
Natural Gas	865	14
Coal	3,439	16

And Now, Strategies for Energy Sustainability

The anomaly of the way global fuel resources are being used and their imminent ends, as shown above, give convincing argument that actions must be taken with genuine sense of urgency to achieve energy sustainability. It no longer is needed just for future generations. Energy sustainability is for the current generation, here and now. The author proposes that energy sustainability be achieved by the following action-oriented strategies to slow down the current consumption rates, use more of what are available the most, and use more of what are renewable. All are in that order of priority. As part of the proposed strategies for energy sustainability, the next 10 years be set aside for training on the concept of energy sustainability and energy engineering best practices. The training should be coordinated from several fronts: grass-root academic training for the future engineers (engineering students) by higher education institutes as well as professional training for the practicing engineers by technical societies and industries. After the 10 years of preparation and training, actions shall be taken as follow:

1. Slowing Down the Consumption Rates. This is not to advocate energy curtailment. Instead, this is to emphasize energy efficiency enhancement (demand side management philosophy). Engineers can contribute to this achievement by designing energy systems to decelerate the growth trends of any of the fuel utilization curves (figure 3 and 4) without cutting back on the economic machines. We can do this by "sharpening our pencils" (so to speak via design, controls, or operations) to gain on efficiency. This must be done before the established trend can be stopped and reverted. How much of an effort will it take to stop the troublesome trends in figures 3 and 4? About 1.3 % in overall efficiency enhancement would bring the acceleration rate of increase to a halt. Another 8.7 % would truly make a difference as shown in figure 5. Just being engineering elegant (a subject to be discussed in the next section) would truly be sufficient to get us over the hump and down the happy trail toward energy sustainability. *Proposed check-off design questionnaires: Highest achievable efficiency? Best control scheme? Energy supply to track the demand curve? Truly unusable waste?*

2. Using More of What Are Available the Most. The tasks at hand are challenging, which are enhancing coal gasification technology, specifying the right fuels for use, and using them more efficiently. Future engineers are key to the research and development effort in the area of coal gasification. While waiting for this technology to be rolled out[13], the design engineers have much to do to swap the percentage of oil and natural gas consumption. How can this be done? Engineers must, as second nature, specify natural gas as a fuel of choice. *Proposed check-off design questionnaires: Why oil? Why not natural gas? Is coal feasible?*

3. Using More of What Are Renewable. Having done the first two steps, energy sustainability can be achieved by using more of what we don't have to worry about the depletion. Here we are talking about renewable energy resources whose importance and benefits are unquestionably enormous and naturally understood. At the present time, however, the trend of using these resources is discouragingly downward[19]. It takes engineers to specify renewable resources and design them into actual applications. *Proposed check-off design questionnaires: Is fuel source, directly or indirectly, renewable?*

These three paths represent separate but complement solutions to energy sustainability. These are not new! What is novel about the strategies, however, is the accompanied grass-root academic training approach aiming at investing the time and effort at the higher education level where energy engineers are being molded. In this regard, the remainder of this paper focuses on how to teach the future engineers to think sustainability as a matter of second nature to impact the society on the global basis by helping to achieve energy sustainability through thoughtful and elegant engineering design.

As shown in figure 5 below, if the current rate of increase in fossil fuel consumption is allowed without restraint, the resources will be depleted before 2065. If the only restraint is to put to a halt the rate of increase (or 0%) from now on, the combined fossil fuel resources will be depleted just before the end of the century. If, however, we implement the strategies of sustainability, the year 2080 is the turning point for sustainability. The strategies for sustainability allow us 10 years to get ready. During these 10 years, it is assumed the current rates of increase in oil, natural gas and coal are maintained. Beginning in the year 2013, however, we must be in a position to displace 5% in oil and natural gas consumption with elegant engineering for efficiency enhancement, coal gasification, and renewable energy resources. Use of renewable energy is expected to increase on an annual average of 2.1% until 2020[21] and, thereafter, 5% must be maintained if energy sustainability is to be achieved. Coal gasification and efficiency enhancements are expected to garner the much-needed time to accelerate the usage of renewable energy.

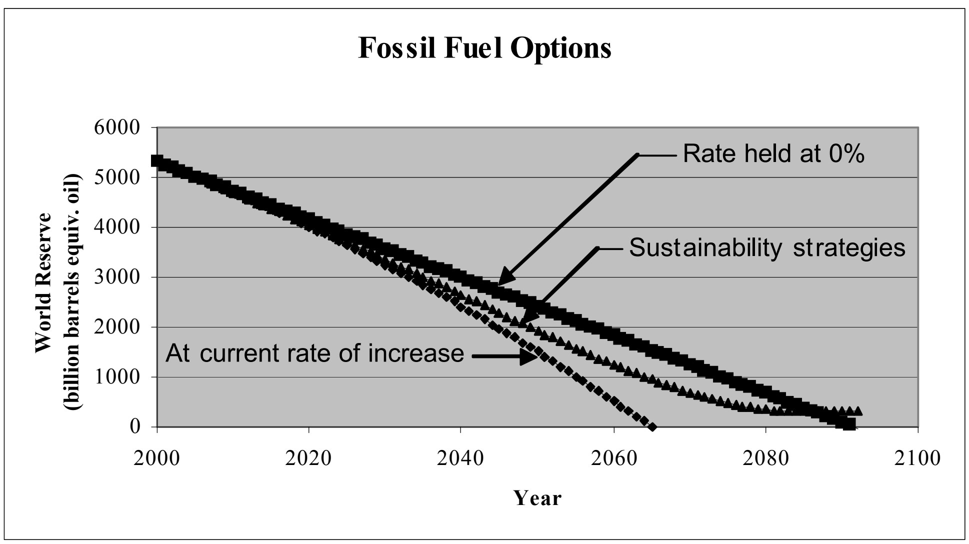

Figure 5—Options for the future of Fossil fuel Resources

Real-World Classic Cases of Inelegant Energy Engineering Design

It may be difficult to think of the inelegance of energy engineering because of its being inherently abstract. Perhaps we should first illustrate the concept of engineering inelegance by illustrating some of the cases that we can see and feel and then make a connection to energy engineering. For example, it is not considered engineering elegant to build a tripod structure for a light pole. Although it does the job, it costs too much more material and space. As another example, how about erecting a 50-foot high billboard with constant diameter steel post? Although it does the job, it is not elegant engineering because (1) it costs unnecessary material and energy to produce and install and (2) it requires much less engineering time to calculate the right moment, shear stress, and axial stress at the various points along the column. Not doing extra engineering calculations is precisely the reason why it is not elegant.

The real world around us is full of cases, which bring out the inelegance of energy engineering design. The following cases argue well for the strategies for energy sustainability as mentioned in the previous section:

1. Design a lighting system without regard for efficacy (12 instead of 79 lumens per watt) or power density.
<u>Discussion</u>: it is more involved in designing a lighting system than just delivering the needed lights. In addition to sizing the wires, specifying the fixtures, calculating the height of the installation and designing the layout, choosing the correct technology of light source is key to the success of the whole project. It is inelegant, therefore, to design a lighting system to satisfy the stated need by incandescent technology with an efficacy of 12. It must be second nature to the future engineers to endorse fluorescent technology, which provides a much-enhanced efficacy of over 550%. Obviously, endorsing technology with greater efficacy is a given, when available.
2. Design HVAC system without regards to controls (thermostats, switches) or economizers.
<u>Discussion</u>: it is not elegant to design a boiler plant for heating purposes (or chiller plant) without a lead-lag control. There is no reason, for example, for both boilers to be operating at the same time and at low load while only one boiler could be put on line running more efficiently at full load. A lead-lag control feature designed into the command module would be an engineering elegance. Elegant controls must be second nature to the future energy engineers for the success of energy sustainability.
3. Design energy system that allows dumping of excess and high quality steam to the environment during low demand period.
<u>Discussion</u>: it is extremely not elegant to design to waste 30,000 pounds per hour of high quality, high-pressure steam just because there is no load for it in the summer. Engineering elegance would be a design of a steam-driven turbine generator set to capture the wasted stream, transform it to electricity and reduce the plant's electrical demand. Somewhere in the electric grid system, less coal or natural gas or oil is being combusted because of this act of engineering elegance. Waste minimization must be made second nature in the life of future energy engineers.
4. Design a material transport or conveying system using compressed air.
<u>Discussion</u>: it may be expedient but inelegant to transport products by pushing them with compressed air knowing that compressed air is energy intensive to produce.
5. Design an energy system without auto shutoff features.
<u>Discussion</u>: It is not elegant to design a lighting system in a particular complex (say, a large warehouse) that has no way (or safe way or easy way) of being turned off. It would be truly engineering elegant to go a step beyond the capability of being turned on and off. And that is to design a system to automatically turn those lights significantly down when there is no motion being detected. The trick is how to turn those high-pressure sodium or metal-halide lights back on almost instantly upon demand. It should be second nature for the future energy engineers to design energy systems that tie supply to the demand curve.

6. Design a vacuum system by venturi effect.
Discussion: It is quite an inelegant way of creating a vacuum by flowing air at high velocity over an opening. Not only compressed air is energy intensive, generating a vacuum by this method is as non-engineering and inelegant as it can be.
7. Select oil over gas as primary fuel to use.
Discussion: it is inelegant to select oil over natural gas as a primary fuel to use in a boiler, for example, because natural gas is thought to be unsafe in case there is leakage. It is equally inelegant to select gas over oil because of its supposedly being cleaner. While waiting for coal gasification technology to be rolled out[13], it would be engineering elegant for engineers, as a matter of second nature, to select natural gas as a fuel of choice due to its abundance. It is assumed that natural gas is available in the area where the project is being designed for.
8. Design a cleaning system using compressed air.
Discussion: it is irresponsible and inelegant to design a cleaning system either to dust off personnel or equipment using compressed air. It would be elegant, however, to design instead a blower system to accomplish the same purpose. Proper use of compressed air should be second nature to the future engineers.
9. Design a constant flow HVAC system.
Discussion: to design a dual duct constant flow HVAC system is convenient but inelegant as far as energy engineering is concerned. It should be a matter of second nature to engineers to design such systems using the technology of variable speed or frequency drives. It is an engineering elegance because through such use, more sophisticated engineering knowledge is displayed and deployed.
10. Design HVAC system without heat recovery.
Discussion: It is engineering inelegant to design HVAC system to discharge conditioned cooled air or warm air to the atmosphere. It would be truly engineering elegant, however, to incorporate, as a second nature of engineering design, a run-around system, heat pipe for heat recovery, economizer or heat wheel technology.
11. Design a boiler plant whose thermal efficiency is 70^{+}%.
Discussion: there is a realistic limit as to how high thermal efficiency can reach. However, to have thermal efficiency of 70^{+}% is truly a reflection of inelegant engineering design. It must be second nature to engineers to maximize this number by optimizing insulation, feedwater preheat, and the amount of combustion air, etc.
12. Design an automobile with 15% energy efficiency.
Discussion: to say it is OK to live with 85% loss in energy transformation in today's vehicles is to accept a quite inelegant way of engineering. Much elegance can be achieved by working to reduce the substantial engine losses as well as losses due to idling and standby[14].
13. Design using rules of thumb.
Discussion: it is inelegant to rely on the rules of thumb for engineering design (this is not to say that such usage would lead to errors). Cost constraints on materials and high cost of energy over the life of the equipment demand that specific design and calculation be made to match the operating conditions of specific application.

- To use "doubling the pipe size will increase the flow by 5 times" rule of thumb will give an overestimation by 25% which in turn will overestimate the size of the motor of the pump or fan—an unnecessary use or misuse of energy. It should be second nature to the future engineers to avoid the use of rule of thumb.

- To use "1% increase in horsepower for every 2 psig in compressor's outlet pressure" rule of thumb is inelegant because it does not take into account the range of pressure of interest. It may end up with over-estimating the size of the motor for unnecessary waste of energy capital. This is yet another example as to why the use of rules of thumb should be avoided in seeking elegant solutions to engineering work.

14. Design too much material into the packaging of certain product.
Discussion: Too much wood for crating or too thick aluminum in foiling or too much paper for packing involves extra energy to produce and transport. It would be engineering elegant to make foiling as thin as possible but not thinner or crating as securely as possible but not excessively.
15. Design heating and cooling system for using traditional fuels as applicable.
Discussion: it would be engineering elegant to design such system using non-traditional geothermal resource and do it as a matter of second nature.

What are the Future Engineers' Teachers to Do?

In light of the above cases of engineering inelegance in practice, what can engineering educators do to impart second nature training to a new generation of engineers to stay in tune with energy sustainability? Because energy sustainability is a global and complex issue, it suits the philosophy of the finite element method well. We need to impose the prescribed general solution on one element at a time – in this case one project at a time by one engineer at a time. To achieve this end goal, future engineers must be trained

1. To be technically elegant as a matter of second nature in engineering design! There is a gold mine underneath the vast inefficiency of the energy engineering ground that we are standing on. It is estimated that, of the 58 billion barrels of equivalent oil consumed every year, about 38 billion barrels of equivalent oil are wasted as losses. While some of those losses naturally pertain to thermodynamic limits, most are preventable through elegant and careful engineering design. Energy engineers can literally change the world one project at a time by working to fine tune the efficiency, select gas over oil, work to make coal a preferred fuel source over gas or oil, and design more renewable energy resources into the specifications.
2. To add an extra step in the formal engineering design process[15] to consider energy sustainability in the following manner:
   - Understand the need
   - Define the problem
   - Research and Investigate
   - Understand the constraints
   - Establish the design criteria
   - Propose alternative solutions
   - Analyze each solution
   - *Apply the strategies of sustainability*
     - *Can energy consumption rate be slowed down by other design consideration?*
     - *Is fuel source renewable? If not, can natural gas or coal be an alternative fuel source for oil?*
   - Select the optimal solution
   - Write specifications
   - Communicate

Let's hope that the new generation of engineers being educated in, and equipped with knowledge of, energy sustainability will make the engineering reflected in the above 15 energy cases, and many others, better by being more engineering elegant. In a world where we admire beauty and value etiquette, engineering inelegance really presents the unpleasant face of engineering. The new generation of engineers must be trained not only to detect waste but also to quantify it and to articulate why the alternatives make sense, financially, socially and environmentally.

Expectations of engineering performance must change. No longer is it adequate for the engineers to be able to design alone (say, a power plant), it must be expected that the finished product (say, a power plant) be environmentally clean and socially sustainable. This expectation must be fulfilled not because of the environmental movement of the time, which is changeable, but because of the elegant way of doing engineering, which must become second nature in the life of the sustainability-conscientious engineers. After all, one of the positive images society has of the engineers is that of a trusted innovator (NSF survey 1998).

How Can This Be Accomplished Through Engineering Education?

Education takes time but, fortunately, it is the most effective way available to train the makers of energy technology to always seek sustainability alternatives and to look at the long-term effect of the engineering solutions in a global and societal context. It is recommended that energy sustainability be included in energy engineering practice through the culture of teaching the thermal sciences. One of the many ways of doing this is the offering of some specific courses.

The following course syllabus is recommended for a Mechanical/Electrical engineering course entitled ***Design for Energy Sustainability.*** The primary course objective is to train the future engineers to think sustainability as a matter of second nature by seeking engineering designs (1) that slow down the rate of energy consumption, (2) that use more of the resources most available, and (3) that use more of the resources renewable. This course is being planned to offer at Union University to graduating seniors during the fall 2004 or spring 2005 semester.

Syllabus
Engineering Course: Design for Energy Sustainability
Prerequisites: Heat transfer, Thermodynamics

Educational outcomes: at the end of the course, each student will demonstrate to have

- an ability to apply knowledge of math, science and engineering in solving the energy problems
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve energy engineering problems
- a broad education necessary to understand the impact of engineering solutions in global and societal context
- a knowledge of contemporary issue
- an ability to communicate the justification of added cost for the design of energy sustainability

Measurement Techniques:
- Exit interview
- Project design
- Public defense

Introduction and Background

Week 1:
- Sustainability development and the role of energy.
- What is sustainability development? What is energy sustainability?
- History of the sustainability movement.
- The global picture of sustainability. The international fiber of sustainability program.
- Energy as the common thread for the co-existence of the Society, Economic, and the Environment.
- The finite resources. The renewable resources.
- The state of the energy of the world.
- The state of the energy of the US. The state of the energy future.

Week 2:
- Strategies for energy sustainability.
  - Key for success
    - Engineering elegance
    - Second nature engineering practice
- Energy economics
- Energy accounting.
- Life cycle cost analysis.

Strategy No. 1*: Energy Sustainability by Slowing down the Current Energy Consumption Rates*

Week 3:
- Energy conversion.
- The processes.
- The efficiency.
- Why is energy efficiency important?

Week 4: Engineering efficiency
- The efficiency limit, thermodynamically, technologically and operationally.
- The efficiency limit and engineering inelegance.

Week 5: Engineering the future by reengineering the past
- Equipment
- Methods of design
- Methods of operation and replacement

Week 6: Energy calculation.
- Cost calculation.
- Saving calculation.
- Waste calculation (steam leakage, compressed air leakage, trap failures, improper insulation, excessive blowdown, excess air boiler control)

Week 7: Energy conservation devices. Energy codes and programs. Energy star building, Green lights, EPA programs. DOE programs, Federal programs, International programs, etc.

- Heat pipes and heat recovery systems
- Co-generation/ combined heat and power
- Controls and energy management systems
- Humidification. Lighting. Motor

Week 8: Energy clinic—a hands-on workshop to emphasize second nature training in energy waste identification, energy waste quantification and energy waste remediation via technology. Role-play for discussion.

Strategy No. 2*: Energy Sustainability by Using More of What Are Available the Most.*

Week 9: Fuel sources selection—the technologies, the regulations, the safety aspects.

- Energy from waste incineration
- Co-generation
- Fuel selection
- Heat pumps. Geothermal energy
- Gas-fired air conditioning design (via absorption process)
- Coal gasification
- Fuel cells

Week 10: Energy clinic—a hands-on workshop to emphasize second nature training in fuel sources selection. Role-play for discussion and articulation of choices.

Strategy No. 3*: Energy Sustainability by Using More of What Are Renewable Resources*

Week 11: the Green movement (energy, chemistry, lights, buildings, steam, etc) [20]

- Geothermal energy
- Solar energy
- Wind energy
- Energy from the oceans
- Biomass energy
- Hydrogen energy
- Hydroelectric energy

Week 12: Energy clinic—a hands-on workshop to emphasize second nature training in renewable fuel sources selection. Role-play for discussion and articulation of choices.
Week 13 -14: Practical real-world project assignment*
Week15: Project presentation*

*** Note**: for this course project, the class is divided into several teams. Each team is to conduct an energy-engineering audit for a selected manufacturing facility or industry in the area. The objectives are (1) applying the engineering method to come up with energy saving proposal for the plant, (2) recommending, quantifying and designing alternative energy projects to realize savings, (3) presenting implement-able plan to the plant with proper economic and sustainability justification, (4) seeking alternative energy options as second nature.

Conclusion

Energy sustainability must be achieved and can best be done through engineering education where potential makers of energy technologies and designers of energy consuming systems are being molded. Not only is it ethically responsible for engineers as a profession to do[6], it is inelegant for the engineers not to seek the best solution taking into accounts the strategies for energy sustainability. The suggested course in Design for Energy Sustainability is practical in that it contains three energy clinic sessions for problem solving and illustration and a real-world project calling for interaction with the industries. Design for sustainability must become second nature to the future engineers if the future is to be taken care of today. Due to the interdependence of the economy, society and the environment on energy, we can safely conclude that true sustainability can only be achieved if energy sustainability can first be achieved.

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