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Energy and Power Technology: A Perspective for the 21st Century

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Introduction

Energy and Power Technology in one manner, shape, or form was an integral part of many Industrial Technology curriculums during the 70's and 80's. In many programs, the structure of the course was automotive-based with an emphasis on engines, drive systems, and fluid power. It should be noted at this point that some progressive, proactive programs had transitioned away from the automotive emphasis into other areas that reflected the changing energy emphasis and increased automation in manufacturing (alternative energy, digital electronic, and electrohydraulics, etc). Industrial Technology programs of the 90's that still had the automotive-based Energy and Power course may have considered eliminating or shelving the course since it centered on topics areas that are better dealt with at technical institutes and community colleges. Energy and Power Technology, in my opinion, is still a viable course for Industrial Technology programs of the 2000's, if one considers an emphasis on energy and energy conversion systems (i.e., power plants—fossil fueled, nuclear-powered, and renewable/alternative-based—supplemented with a national and global perspective on environmental, economic, and social implications).

Over the last 50 years energy issues and concerns have been at the fore front of economic growth and prosperity. From the prices paid for a barrel of oil, a ton of coal, a gallon of gasoline, a cubic foot of natural gas, or a kilowatt of electricity to the supply and availability of energy resources, we have all been confronted with the reality that fossil fuels are a finite resource and that global consumption is outpacing the discovery and exploitation of new reserves. Alternative energy sources have been proven feasible but not economically viable as long as fossil fuel prices remain low and supplies remain abundant. Greater energy utilization efficiencies have proven to be effective conservation measures but cannot, and should not, be viewed as a long-term remedy or solution.

With this in mind, students in all degree programs, especially Industrial Technology, should be provided the opportunity to possess a greater measure of energy-related technological literacy—the ability to think critically about energy conversion technologies and technological advancements. This ability could be developed through an Energy and Power Technology courses within Industrial Technology programs, one that emphasizes several basic needs.

1) Students' need for a perspective on global energy resources with an emphasis on both renewables and nonrenewables.
2) Students' need for a perspective on the extraction and consumption levels of nonrenewables as well as the pollution, environmental degradation, global warming, and waste disposal aspects of their consumption.
3) Students' need for a perspective on global energy issues with respect to renewables energy resources, economic development, and a sustainable future.
4) Students' need for a perspective with respect to new energy technologies; for example, the proposed hydrogen-based economy and the issues relating to distributed power generation.
5) Students' need for a perspective on the paradigms for selecting,

evaluating, and adopting appropriate energy conversion technologies.

It is not the intent of this paper to suggest the replacement or restructuring of established industrial power and control curriculums with a fossil fuel and alternative energy focus but only to emphasize the need for students to possess a more in depth energy-related literacy and a possible path for developing this increased energy awareness. Whether this awareness should be provided to all university graduates through general education or cultural elective requirement is open to debate. What is important, however, is that Industrial Technology programs recognize the potential importance of this course and promote its incorporation as an elective or required course within their programs. As an example, our program (a department of about 110 students) recognized the importance of this course and incorporated it as a required course option (Energy and Power Technology or Fluid Power). Another possible incorporation approach that could be considered is the restructuring of the Technology and Society course that many larger programs already possess within their course inventories.

Global energy resources nonrenewables and renewables

According to Cassedy and Grossman (1998), 89% of US and 80% of the world's energy comes from fossil fuels (oil, natural gas, and coal). Consequentially, questions about who controls these resources, who benefits from their exploitation, and what are the environmental consequences of their exploitation and consumption have been raised repeatedly both globally and domestically. Overall estimates of current and future supplies of these resources have been given by energy industries but have been routinely challenged by consumer and ecology groups. Consumer groups have support the continued extraction in an unrestrained market with the intent that it will encourage lower energy. Ecology groups, on the other hand, have advocated the preservation of natural resources and the slow extraction of fossil fuels in hopes that higher prices would force greater conservation, increased energy utilization efficiencies, and a progressive movement toward renewable energy resources. One area of commonality between both groups is in their belief that industry-supplied data on fossil fuel reserves are self-serving and that any confidentiality of this information should be challenged. Industry responses to these claims have centered on the need to protect proprietary information from competitors. Issues such as these have raised fundamental questions for governments around the world, questions such as, (a) when and why should a private concern be forced to make public disclosures that may be against its own interests? (b) do energy resources belong to the people, to private companies, to the government, or to the world? (c) should domestic energy exploitation be monitored and controlled by governments? (d) is energy a natural security issue and concern? (e) should non-friendly governments with major oil reserves be overthrown in favor of more friendly governments? and (f) should a world organization be established to monitor and control energy extraction, production, distribution, and pricing?

To gain a perspective on renewable, students need to develop an understanding of the advantages and limitations of renewable resources. One renewal resource, hydropower, is already being utilized and provides an important contribution to U.S. electric power generation (8.5% of annual electric production). According to Cassedy and Grossman (1998), hydropower is the largest and best developed of all renewable resources and accounts for almost 50% of the existing electrical generation in less-developed countries (LDCs); worldwide, only about 15% of the potential hydrocapacity in the developing world has been exploited. The major problem with hydropower projects, especially for LDCs, is the high investment cost, the potential requirement for long-distance transmission lines, and environmental and social impacts (loss of native species, the potential requirement to relocate large numbers of people, loss of productive agricultural lands). To counter these disadvantages, most hydroelectric project are undertaken with stated advantages and emphases in four basic areas: flood control, development of municipal water supplies, farmland irrigation, and electricity generation.

A second renewable resource is geothermal. This resource is used by some countries for electrical generation but worldwide its potential application is limited due to the limited availability of geothermal sites and the corrosive nature of geothermal sites on energy conversion systems. A third renewable resource is solar and wind energy. These two resources are sometimes treated as a single topic since both can only be used effectively in selective areas of the country and world. The major problem encountered with solar and wind technologies is the inconsistency of winds and sunlight within many areas (intermittent or inconsistent electrical generation). A fourth renewable resource, biomass, can only be produced in land areas where crops and trees can grow readily. According to Cassedy and Grossman (1998), wood provides about 7% of total world energy production, with an estimated 3/4 of this being consumed in less-developed countries (LDCs). While the world as a whole harvests less wood than it grows yearly, (LDCs) that depend on wood fuel are severely depleting their forest resources. There is hope for the expanded use of forest resources through forestry management and forest-based plantations.

Extraction and consumption of nonrenewables

For students to develop a perspective on the extraction and consumption levels of nonrenewables as well as the pollution, environmental degradation, global warming, and waste disposal aspects of their consumption, they need to possess an understanding of current estimates of fossil fuel reserves, current production and consumption rates, and the impacts associated with the utilization of fossil fuels. According to Cassedy and Grossman (1998), there is no proven method for making accurate and certain predictions of future fossil fuel reserves. One common survey method, the volumetric method, relies on surface reconnaissance and mapping to find geological formations. The most widely used method of large-scale resource estimation, the logistic curve, takes the historic pattern of extraction and extends it to fit classic shapes (S-curves for cumulative production and bell-shaped curves for production rates). An example of the bell-shaped production rate curve can be seen in Figure 1.

Cassedy and Grossman (1998) went on to indicate the existence of contradictory estimates of ultimate cumulative U.S. oil production. One estimate made in 1963 by A. D. Zapp, a geologist with the United States Geological Service (USGS), estimated ultimate cumulative production of U.S. oil reserves at 590 billion barrels (BBl) while another estimate made in 1969 by M. K. Hubbert estimated ultimate cumulative production of U.S. oil reserves at 165 BBl. Cassedy and Grossman concluded their assessment of U.S oil reserves by stating that the estimate made by A. D. Zapp, supported initially by the oil industry along with a desire for oil import quotas and higher domestic oil pricing, has lost fair by both the U.S. government and oil industry in support of M. K. Hubbert's estimate.

One of the most recent and controversial projections of world oil production came from Colin Campbell and Jean Laherrere. Their projections, published in Scientific American in March of 1998, predicted that world oil production would peak around the year 2004. An interesting aspect of the Campbell/Laherrere production curve is its regional breakdown of oil production and productions peaks (see Figure 2). Another aspect of the Campbell/Laherrere production curve occurs when curve units in billion of barrels (Y_1) are converted into units of quadrillion BTUs (Y_2) and then compared to the worldwide energy consumption projections in units of quadrillion BTUs shown in Figure 3. The principal conclusion that can be drawn from this comparison is that the rate of oil consumption is increasing over time such that the cumulative production timeline projected by Campbell/Laherrere will begin to shrink (in years) and that the rate of shrinkage will ultimately be influenced by the rates and levels of economic development and industrialization worldwide (increased production and consumption needed to support industrialization and rising standards of living worldwide).

Figure 1. Production rate curve and curve components where X-axis is based on years and Y-axis is based on units of production.

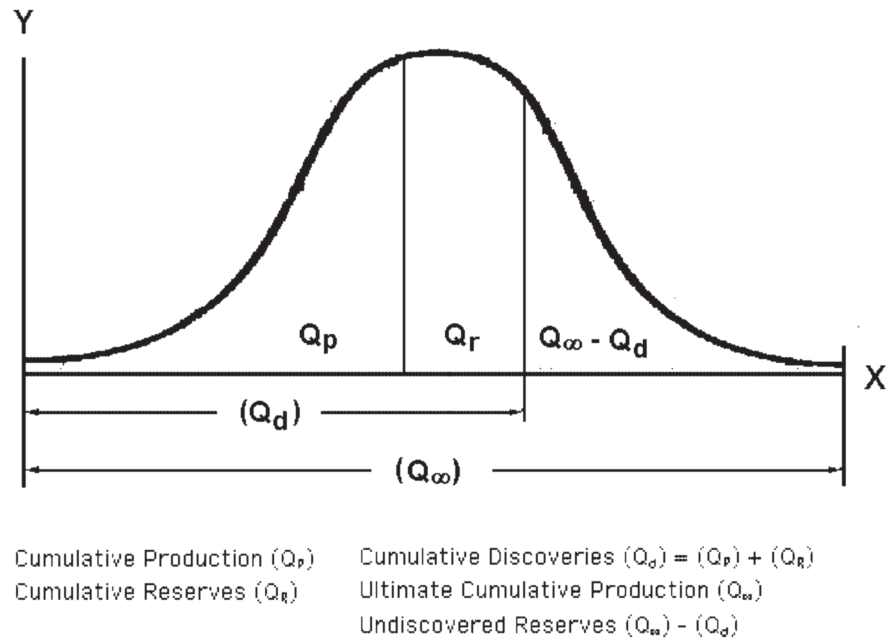
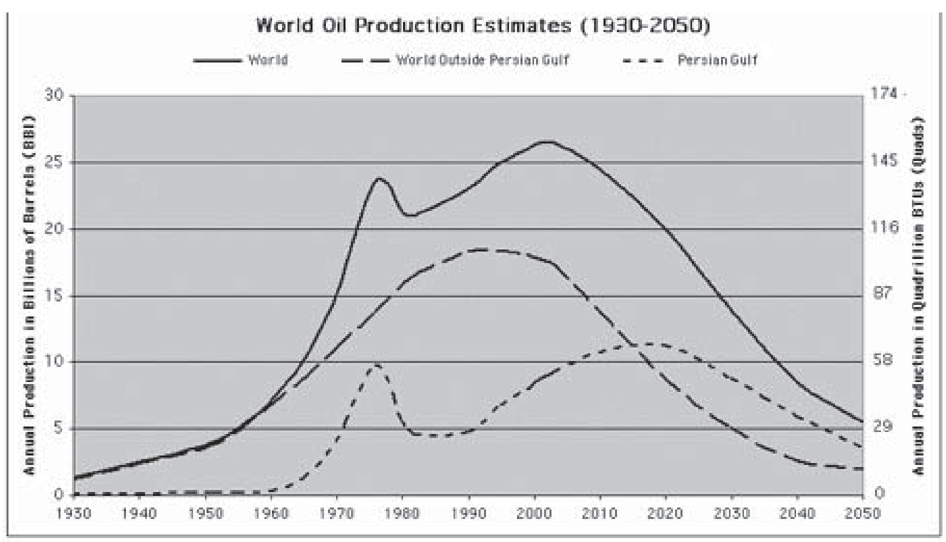


Figure 2. World oil production estimates between 1930 and 2050 in billions of barrels (Y_1) and in quadrillion BTUs (Y_2). Adapted from: Campbell-Laherrere World Oil Production Estimates (1930-2050), Slide 11 of 20, Long Term World Oil Supply (A Resource Base/Production Path Analysis), U.S. Department of Energy, Energy Information Administration, (Available Online: http://www.eia.doe.gov/puboil_gas/petroleum/2000/long_term_supply/sid012.htm



U.S. and world fossil fuel reserves can also be viewed in respect to the ratio of perceived reserves versus production. In this way, reasonable projections can be developed to forecast the number of years remaining of a given fossil fuel. According to information provided by Cassedy and Grossman (1998) and the International Energy Annual 2000, the breakdown of US and world fossil fuel reserves can be viewed through the following analysis:

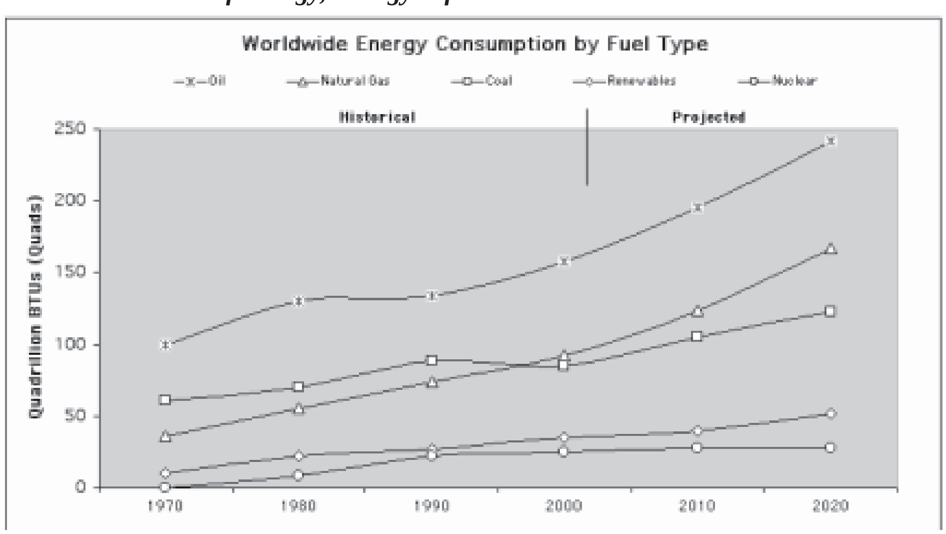
1a) U.S. oil — the current reserve/production ratio (R/P) for oil is about 10 years and the remaining undiscovered reserves was estimated to be about 41 billion barrels (BBl) in 1994 (17 years of additional consumption potential provided production levels of 2.4 BBl/yr are maintained).
1b) World oil — the current R/P ratio for oil is about 50 years and the remaining undiscovered reserves was estimated to be about 471 BBl in 1994 (22 years of additional consumption provided production levels of 22 BBl/yr are maintained).
2a) U.S. natural gas — the current R/P ratio for natural gas is about 9 years and the remaining undiscovered reserves was estimated to be about 580 trillion cubic feet (TCF) in 1994 (34 years of additional consumption if production levels of 17.4 TCF/yr are maintained).
2b) World natural gas — the current R/P ratio for natural gas is about 68 years and the remaining undiscovered reserves was estimated to be about 4,980 TCF in 1994 (64 years of additional consumption provided production levels of 73 TCF/yr are maintained).
3a) U.S. coal — the current R/P ratio for coal is about 279 years and the remaining undiscovered reserves was estimated to be about 980 billion metric tons (Bmt) in 1995 (1,050 years of additional consumption provided current production levels of 0.93 Bmt/yr are maintained). Peak production on coal (4 Bmt/yr) is almost 4 times larger than current production rates and is not expected to occur until the 23rd century.
3b) World coal — the current R/P ratio for coal is about 294 years and the remaining undiscovered reserves was estimated to be about 5,400 Bmt in 1995 (1,542 years of additional consumption provided production levels of 3.5 Bmt/yr are maintained).

Industrial energy use and electric power generation accounts for more than 50% of all fossil fuel consumed in the U.S. Coal does not supply all of this need, but could, given the vastness of this resource. How quickly coal demand rises depends on several factors: growth in overall energy demand, the price of oil and gas, environmental restrictions and pollution control requirements, limitations on the use of land and water, and transportation costs constraints.

From a consumption standpoint, a typical 1,000 MW power plant operating for a day burns about 10,000 tons of coal and generates about 1,000 tons of solid waste that must be disposed of in an environmental sound manner. In addition to the disposal of coal ash, scrubber sludge and particulate dust must also be disposed of. From an extraction standpoint, water seepage into underground mines reacts with the coal and forms acids that can leech into underground aquifers. Surface mining and the exposed overburden produces acids that can leech into rivers and streams as well as more noticeable environmental damage. The use of natural gas and fuel oil for electrical generation has less environmental impact than coal combustion but does contribute to fossil fuel depletion and increased carbon dioxide levels worldwide.

In short, oil and natural gas resources worldwide are on a path toward eventual exhaustion. Timelines for predicted production shortfalls for these fuels are a few decades and higher prices caused by dwindling supplies will eventually begin to have a significant impact on the rates of economic development in industrialized countries and LDCs unless steps are taken to reduce our fossil fuel dependence. One negative aspect of higher oil and natural gas prices is that the demand and price for coal will begin to rise worldwide—a fuel that accounts for the majority of the sulfur dioxide emissions, an emission that leads to acid rain formation and acute respiratory ailments. Some positive aspects of higher fossil fuel prices

Figure 3. Historic and projected energy consumption worldwide between 1970 and 2020 in quadrillion Btu (10^{15} Btu). Adapted from: Figure 6. World Energy Consumption by Fuel Type, 1970-2020, International Energy Outlook 2002, U.S. Department of Energy, Energy Information Administration.



include the incentive it will provide for greater utilization efficiency; a net reduction in carbon dioxide emissions, a greenhouse gas that is believed to cause global warming; and the technological and economic practicality of renewable resources utilization.

The hydrogen economy and distributed generation

Decarbonization is a term that is widely used to reference the changing ratio of carbon to hydrogen atoms between succeeding energy sources. According to Rifkin (2002), wood has the highest ratio of carbon to hydrogen atoms—ten carbon atoms per hydrogen atom. Among fossil fuels, coal has the highest carbon-to-hydrogen ratio, about one or two carbon atoms to each hydrogen atom. Oil, on the other hand, has one carbon atom for every two hydrogen atoms, while natural gas has only one carbon atom to four hydrogen atoms. Although each successive energy source has emitted less CO_2 than its predecessor, CO_2 emissions have continued to rise due to the increased consumption of carbon-based fuels. It was also stated that "Hydrogen completes the journey of decarbonization. It contains no carbon atoms. Its emergence as the prmary energy source for the future signals the end of the long reign of hydrocarbon energy in human history" (Rifkin, 2002, p 179).

Hydrogen is found everywhere on Earth, in water, in fossil fuels, and in all living things. It rarely exists as a free-floating element. In essence, hydrogen is an energy carrier, a secondary form of energy that has to be produced like electricity. According to Rifkin (2002), half of all the hydrogen currently produced in the world is derived from natural gas via a steam-reforming process (a reaction of natural gas with steam in a catalytic convertor). In the steam-reforming process, hydrogen atoms are extracted from natural gas leaving carbon dioxide as a by-product. Coal can also be reformed thorough gasification to produce hydrogen but is more expensive than natural gas-based production. Hydrogen can also be processed from oil or gasified biomass.

The real question in the development of a hydrogen economy is whether it is possible to use renewable forms of energy, like photovoltaics, wind, hydro, and geothermal, to generate the needed electricity for the mass production of hydrogen using electrolysis. A growing number of energy experts indicate the electrolysis process is feasible, but qualify that the cost of employing renewable forms of energy for hydrogen extraction would need to decline considerably before the process could competitive with the natural gas steam-reforming process. Rifkin (2002) that "the most important aspect of using renewable resources to produce hydrogen is that the sun's energy and wind, hydro, and geothermal energies, will be convertible into "stored" energy that can be applied in concentrated forms whenever and wherever needed, and with zero CO_2 emissions" (p. 191).

Creating an infrastructure to store, transport, and dispense hydrogen, however, raises additional cost and safety concerns. Rifkin (2002), indicated that proponents of renewable energy sources are pinning their hopes on breakthroughs being made in the development of small stationary and portable fuel cells and on the fast growing market for them as mini-power plants for use in factories, offices, retail stores, homes, and automobiles. Fuel cell technology is not a new invention. In actuality, fuel cell development predated the internal combustion engine but lacked commercialization until NASA decided to incorporate them in spacecrafts during the 1960s. Principal advantages of fuel cells is that they do not require any recharging and will generate electricity on a continuous basis as long as an external fuel and an oxidant are inputted into the system. It was also indicated that "fuel cells powered by hydrogen could potentially produce enough electricity to meet our energy needs far into the future. Moving beyond the fossil-fuel era, however, will not be easy. It is still expensive to produce hydrogen. Moreover, at present, most fuel cells use natural gas and other fossil fuels as fuel stock" (Rifkin, 2002, p. 193).

Distributed generation (DG) generally refers to integrated or stand-alone small electricity-generation power plants that are located near or at the site of end-users—factories, commercial businesses, public buildings, neighborhoods, and private residences. Currently, most DG power plants are used as backups to the main grid and are only turned on during emergencies or when power disruptions are expected. If these power plants could be effectively integrated into the main power grid, they could become producing assets that supply power to power companies during peak load periods, ones whose own capacities may be too stretched to meet unexpected energy demands.

According to Rifkin (2002), the combined output of fuel cell-based, mini-power plants via an "energy web" could eventually exceed the power generation by the utility companies at their own central plants (energy web is short for distributed generation coupled with web-based integration to the main power grid). If this was to happen, it could constitute a revolution in the way energy is produced and distributed; power companies may be forced to redefine their mission if they are to survive. The distributed web would integrate state-of-the-art computer hardware and software that transforms the centralized grid into a fully interactive intelligent energy network. Sensors and microprocessors embedded throughout the system would provide moment-by-moment information on energy conditions, allowing current to flow where and when it was needed at the cheapest price. For example, if the system was at peak demand, customer's thermostat settings could be changed automatically and selected appliances shut down using a single command. A downside of a distributed web would be its reliance on computer integration and sophicated sensors whose failure could cause a cascade of failures and ripple effects throughout the entire system. This effect could also be generated through cyber attacks on the electrical infrastructure by "hackers" playing games with the web-based systems or by cyber warriors (terrorists) whose sole intention is be to bring all or parts of the elecrical power grid down.

Economic development and a sustainable future

A key question for industrialized countries is how to sustain economic growth in the face of dwindling supplies of conventional energy resources. A key question for LDCs, is how to create industrial economies, not just sustain them. Additional questions and concerns for LDCs include:

1) How do they afford the energy resources and technologies they need for economic growth and development?
2) If they cannot afford to import the needed energy resources and technologies, how do they exploit the resources they do possess?
3) What policies should be adopted by LDCs to achieve sustainable economic development?
4) What policies should the industrial world adopt to encourage and support economic development in LDCs?

The plight of the LDCs has both moral and political implications. Lesser-developed countries differ widely and their needs and problems differ in important ways. Some are industrializing rapidly and will probably join the ranks of the industrialized world in the near future. Some have little hope of any significant advancement while others are actually becoming more impoverished. Regardless of their individual plights, consumption of energy will have to increase in LDCs if they are to achieve and sustain any type of economic development.

Reliance on non-commercial energy sources, such as wood, underscores the reason why the demand for conventional energy sources in LDCs must grow. Other reasons for increased consumption of conventional energy sources include: (a) conventional technologies for power plants or industrial processing are geared toward the use of fossil fuels and (b) technologies for agricultural production, raw material extraction, and manufacturing depend on commercial energy resources; without them LDCs cannot compete with industrialized countries.

Prospect of growth in commercial energy demand in the LDCs can have disquieting implications. According to Cassedy and Grossman (1998), the rate of growth in energy demand in the 73 poorest countries between 1965 and 1985 was about 4% per year. If a 3.5% per year growth rate in energy demand is projected for all LDCs, by the year 2020, given current population growth trends, per capital energy consumption will be 1/3 that of industrialized countries. This forecast was further supported by the U.S. Department of Energy when they stated " . . . world energy consumption is projected to increase by 60 percent over a 21-year forecast horizon, from 1999 to 2020. Worldwide, energy use grows from 382 quadrillion British thermal units (Btu) in 1999 to 612 quadrillion Btu in 2020 " (Energy Information Administration, 2002, p. 1). The historic and projected trends in energy consumption worldwide can be seen in Figure 3.

Implications presented by projected growth in energy demand within LDCs is alarming for several reasons. First, meeting these new levels of demand will impact the predicted longevity of world fossil fuel reserves. Second, most of the poorest nations already spend 30 to 50 percent of their export income on imported energy. The more LDCs can meet their own energy needs with indigenous resources, the better off they will be (i.e., hard currency can be spent on economic growth and social concerns rather than the importation of oil and gas). If LDCs can be given access to more efficient energy conversion technologies or alternative energy technologies, the rate of fossil fuel consumption may not grow at the expected level of 3.5%.

World Commission on Environment and Development (Brundtland Commission, 1987) looked into the concept of sustainable development and concluded with a recommendation that development should meet the needs of the present without compromising the ability of future generations to meet their own needs. The commission went on to indicate that economic growth is possible, but an economy should exist in equilibrium with the earth's resources and its natural ecosystem. According to Pearce and Turner (1990), sustainability with respect to resources could begin with renewables and that renewable resources should be used at rates less than or equal to the natural rate at which they can be regenerated, while non-renewables could be depleted but with optimal efficiency. The principle of sustainability suggests the creation of policies that emphasize more efficient energy conversion technologies, careful management of renewable resources, and the continued development and integration of renewable resources.

Paradigms for selecting and adopting appropriate energy conversion technologies

The potential for rising prices of conventional sources of energy gives the strongest economic argument in favor of the development of alternative technologies sooner rather than later. Energy substitution will begin in earnest when the costs of energy production by alternative methods are lower than prevailing prices of conventional sources and when consumers are convinced there will be no reversal in price and supply trends. The evolution of any new energy technology has a choice between two paths, each of which has social, ethical, and technological implications.

The first choice is the hard path. This path entails the construction of large-scale, centralized power plants that take advantage of economies of scales. Centralized power plants (mass production of electricity) is seen as a way to generally improve the condition of all society and spillovers (unintended ecological and social impacts) are regarded as solvable through the further application of technology; large-scale coal-fired, natural gas-fired, and nuclear power plants normally fall into this pathway. Critics of the hard path detail acid rains in the northeast attributal to coal-fired power plants in the midwest and disposal problems associated with coal ash and chemical debris from scrubber systems. The second choice is the soft path. This path entails energy production that is small-scale, decentralized, and emphasizes technologies that have a low environmental impact. In short, this path envisions the use of renewables—hydroelectric, solar, wind, and biomass. Proponents of hard and soft technologies have debated the issue from two major perspectives: industrialized countries and less-developed countries (LCDs). Utilities companies have

According to Cassedy, E. and Grossman, P. (1998), each technology under development can be grouped into one of three categories:

1) Near term. These technologies have reached the stage of commercialization; technical feasibility has been proven; pilot plants have been operated successfully; and costs are close to that of conventional or competitive technologies; expected impact of these is within 5 to 10 years.
2) Medium term. Technical and scientific feasibility has been proven, prototypes have been developed, and proof of economic viability will be forthcoming; expected impact is within 10 to 15 years. Direct and indirect substitution characteristics influence their overall adoption. In direct substitution, new capital equipment is not needed to distribute and use new energy technology; synfuels, ethanol, and natural gas are good examples. Indirect substitution requires new capital equipment; for example, solar energy replacing the market for conventional fuels.
3) Long term. Technologies that are still in the research stage; scientific feasibility has yet to be proven. Technologies at the research phase need continuous financial support even though no assurances can be given as to when or if the basic principles will be proven; fusion technology is a prime example. Unfortunately, basic research has increasingly come under attack as too expensive and unnecessary and has repeatedly been cut from the governmental budgets.

Summary

Our energy infrastructure is based on the consumption of fossil fuels and very little has been done to reduce our dependence on these energy resources. Nuclear power, at one time, was believed to be a replacement energy source but incidents at Three Mile Island and Chernobyl have created a greater awareness of the social costs and environmental consequences associated with this technology. Renewable energy resources can make a difference but should not be expected to support all of our energy needs. Consequently, we as a society should expect energy-related challenges and crises to arise; ones that could impact our wealth, our health, our life styles, and our children. Since any proposed solutions will ultimately center around social, philosophical, and technological issues, people who possess a greater measure of energy-related literacy will be in a position to offer constructive criticism and direct or indirect support. The ability to think critically about energy and energy-related issues could be enhanced through an Energy and Power Technology course, one that places an emphasis on energy conversion systems supplemented with a national and global perspective on environmental, economic, and social interests and concerns.

It should also be noted that what has been presented in this paper is just a sampling of the issues, concerns, and topics areas that could be incorporated into an Energy and Power Technology course, one specifically structured to address energy-related issues and literacy development. As a final note, any course that is structured with an emphasis in energy and energy conversion systems, should be supplemented with energy data and technical reports that are available online from the U.S. Department of Energy, Energy Information Administration, http://www.eia.doe.gov.

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