Open-Ended Problems: A Future Chemical Engineering Education Approach. J. Patrick Abulencia and Louis Theodore.

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Energy Management

This chapter is concerned with process energy management. As with all the chapters in Part II, there are several sections: Overview, several technical topics, illustrative open-ended problems, and open-ended problems. The purpose of the first section is to introduce the reader to the subject of energy management. As one might suppose, a comprehensive treatment is not provided, although several technical topics are also included. The next section contains three open-ended problems; the authors' solutions (there may be other solutions) are also provided. The final section contains 37 problems; *no* solutions are provided here.

16.1 Overview

This overview section is concerned with—as can be noted from its title—energy management. As one might suppose, it was not possible to address all topics directly or indirectly related to energy management. However, additional details may be obtained from either the references provided at the end of this Overview section and/or at the end of the chapter.

Note: Those readers already familiar with the details associated with this subject may choose to bypass this Overview.

Over the past four decades, an acute awareness of energy as a problem of impending critical magnitude on the national scene has arisen among informed leaders of industry, government, and the environmental movement. The energy crisis, or problem, or shortage, or dilemma, as it has been called, is created by the continually increasing demand for energy and a lack of management policy. This situation has resulted in two issues that are fast becoming pervasive concerns of this nation. One is the need for an adequate, reliable supply of all forms of energy, and the other, the growing public concern with the environment and social consequences of producing this much energy and further, of the environmental and social ramifications of its expenditure.

The solution to the energy problem amazingly *may* simply involve the application of meaningful conservation measures and the development of new, less problematic energy forms. Energy conservation may sharply reduce the terrible waste of resources that many have argued has also been at the very heart of the energy problem. Moreover, an extensive conservation program can be implemented in a very short period of time. Such an effort can play a major role in slowing the growth in the demand for energy and in causing energy to be used more efficiency and effectively. However, at the same time, new sources of energy must be developed to ensure the availability of adequate, long-term energy supplies. The *feasibility* of solar power, wind, tidal, geothermal, fusion, etc., and other unconventional sources of energy should continue to be investigated and developed.

In the final analysis, both society and the technical community can either accept or reject the grim projections for the future obtained by extending the energy consumption patterns and trends of the past that establish the basis for defining "energy demand". Once it has been determined that the demand exists, the choice among the various sources of energy and the means of energy conversion systems, either available at present or in some stage of development, can be made. This requires an evaluation for each means of power generation of the available fuel resources, including the environmental implications and their relation to relevant economic, political and social issues. However, all of these considerations are themselves influenced by assumptions regarding future demands for power; these, too, must be re-examined. For example, by analyzing the various components that presently constitute energy demand, resources, and transmission/transportation options, various alternatives can be devised to *maximize* the long-term social return per unit of energy consumed. In turn, such alternatives may have important implications for the economic system, social processes, and lifestyles. Topics (where applicable), such as resource quantity, resource availability, economics, energy quality, conservation requirements, transportation requirements, delivery requirements, operating and manufacturing, regulatory issues, political issues, environmental concerns, cost consequences, advantages and disadvantages, and public acceptance, need to be reviewed. A verifiable quantitative detailed review and practical evaluation of all viable energy options, categories, availability, cost, etc., has yet to be accomplished. These considerations define the energy issues and provide a means of solving and managing energy problems that exist today and defining the optimal course for future generations.

Regarding the future, are conservation and fossil fuels the answer? One of the authors believes that fossil fuels will dominate the energy landscape for at least the next two generations (50 years), if not longer. It is for this reason, that much of material in this chapter deal with fossil fuels.

Topics to be reviewed in this chapter include:

1. Energy Resources
2. Energy Quantity/Availability
3. General Conservation Practices in Industry
4. General Domestic Conservation Applications
5. General Commercial Real Estate Property Conservation Applications
6. Architecture and the Role of Urban Planning
7. The U.S. Energy Policy/Independence

16.2 Energy Resources

All the major energy resources may be classified into the following categories:

1. Natural gas
2. Liquid fuels (oil)
3. Coal
4. Shale oil
5. Tar sands
6. Solar
7. Nuclear (fission)
8. Hydroelectric
9. Wind
10. Geothermic

11. Hydrogen
12. Bioenergy
13. Waste

Extensive details on each of these energy resources are available on the Department of Energy (DOE) website and the Internet, as well as the work of Skipka and Theodore. [1]

16.3 Energy Quantity/Availability

An evaluation methodology was established by one of the authors [2] for a comparative analysis of energy resources. Its purpose was to provide an answer to the question, "Can a procedure be developed that can realistically and practically quantify the overall advantages and disadvantages of the various energy resource options?" A list of 12 categories/parameters that affect the answer to the question for each energy category was prepared by the author and are listed below. This analysis was applied to different sectors of the world, including the U.S. [1]

1. Resource Quantity
2. Resource Availability
3. Energy Quality
4. Economic Considerations
5. Conversion Requirements
6. Transportation Requirements
7. Delivery Requirements
8. Operation and Maintenance
9. Regulatory Issues
10. Environmental Concerns
11. Consumer Experience
12. Public Acceptance

16.4 General Conservation Practices in Industry

There are numerous general energy conservation practices that can be instituted at plants. Ten of the simpler practices are detailed below.

1. Lubricate fans
2. Lubricate pumps
3. Lubricate compressors

4. Repair steam and compressed air leaks
5. Insulate bare steam lines
6. Inspect and repair steam traps
7. Increase condensate return
8. Minimize boiler blowdown
9. Maintain and inspect temperature measuring devices
10. Maintain and inspect pressure measuring devices

Providing details on fans, pumps, compressors, and steam lines is beyond the scope of this chapter. Descriptive information [2,3] and calculation procedures [4] are available in the literature.

Eight energy conservation practices applicable to specific chemical operations are also provided below.

1. Recover energy from hot gases and/or liquids
2. Cover tanks of heated liquid to reduce heat loss
3. Reduce reflux ratios in distillation columns
4. Reuse hot wash water
5. Add effects to existing evaporators
6. Use liquefiers/gases as refrigerants
7. Recompress vapors or low-pressure steam
8. Generate low-pressure steam from flash operations

Providing details on distillation columns, evaporators, refrigerators is also beyond the scope of this chapter. Descriptive information and calculation procedures [4,5] are available in the literature. Additional details are available in several chapters in Part II.

16.5 General Domestic Conservation Applications

Domestic applications involving energy conservation are divided into 6 topic areas. These include:

1. Cooling
2. Heating
3. Hot water
4. Cooking
5. Lighting
6. New appliances

Specific details are provided in the literature [6].

Action by Congress and state legislatures, rulings by courts pronouncements by important people, or wishing alone cannot solve the energy problem. Individual efforts by everyone can make things happen and can help to win the battle against wasting energy. Each individual is important in that battle. An individual working alone or cooperating with neighbors, working with schools and colleges, with industry, with government, and with nonprofit organizations can make a difference. Here are specific suggestions that one can implement to help reduce energy waste.

1. Purchase energy-efficient automobiles
2. Purchase energy-efficient recreation vehicles
3. Purchase efficient appliances
4. Purchase energy-efficient toys
5. A well-tuned internal combustion engine makes a car, boat, lawnmower, or tractor more efficient and safer to both the individual and the environment
6. Carpooling, biking, walking, and using mass transit results in less pollution and energy savings
7. Use natural ventilation in the automobile whenever possible
8. Use natural ventilation in the home whenever possible
9. Avoid travel/trips that are not necessary
10. Do not waste food
11. Do not overeat
12. Make a conscious effort to operate on an energy efficient basis

16.6 General Commercial Real Estate Conservation Applications

Perhaps the major conservation measures in the future will occur in the commercial property arena since practitioners have come to realize the enormous financial investment possibilities that exist today. As a result, interest in this area has increased at a near exponential rate. The initial energy efficiency investments made in the commercial real estate (CRE) market have been associated with lower cost improvements having relatively short payback periods (less than 2-3 years) and involving low technology risk. As a result, the CRE industry now has the opportunity to move from this initial phase of low cost, short payback energy efficiency improvements to the multifaceted second phase of implementing deep energy retrofits where the capital need is much more intensive and the payback period is often longer. These technology changes range from minor changes that can be implemented quickly and at low cost, to major changes involving replacement of process equipment or processes at a very high cost. The challenge associated with these deeper, more capital-intensive energy efficiency retrofit improvements is complicated when internal financing is limited or not available. Fortunately, this is changing, and the market-ready, commercially-attractive financing mechanisms have arisen to meet these needs [7]. As noted above, energy conservation projects involving commercial properties are certain to increase in the future. This activity will be enhanced by:

1. convincing CRE properties to operate in a more efficient manner, and
2. providing incentives, e.g., underwriting loans, etc., to implement attractive energy efficient projects

This topic is reviewed in the next section, Problem 2.

16.7 Architecture and the Role of Urban Planning [6,7]

As energy concerns present some of the most pressing issues to the world, both professional and academic architects have begun to address how planning and *built form* affect society. Although the term *built environment* has come to mean different things to different people, one may state in general terms that it is the result of human activities that impact society. It essentially includes everything that is constructed or built, i.e., all types of buildings, chemical plants, utilities, arenas, roads, railways, parks, farms, gardens, bridges, etc. Thus, the built environment includes everything that one can describe as a structure or "green" space. Generally the built environment is organized into 6 interrelated components:

1. Products
2. Interiors
3. Structures
4. Landscapes
5. Cities
6. Regions

While "architecture" may appear to be one of the many contributors to the current environmental state, in reality, energy consumption and pollution affiliated with the materials, the construction, and the use of building contributes to most of the major environmental problems. In fact, architectural planning, design, and building can significantly contribute to the destruction of the rain forest, the extinction of plant and animal species, the depletion of nonrenewable energy sources, the reduction of the ozone layer, the proliferation of chloroflourocarbons (CFCs), exposure to carcinogens and other hazardous materials, and potential global warming problems. Where one chooses to build, which construction materials are selected, how a comfortable temperature is maintained or what type of transportation is needed to reach it—each issue decided by both architect and user—significantly impacts these overall conditions. Sadly, despite these opportunities to shape a healthier future, an analysis of American planning and building has in the past represented an assault on the existing energy ecological conditions.

Most architects today are committed to build "green". Most new buildings will incorporate a range of green elements including: radiant ceiling panels that heat and cool—saving energy and improving occupant comfort; a cogeneration plant that utilizes waste heat; a green roof that is irrigated exclusively with rainwater in order to mitigate the heat island effect; materials that are rapidly renewable and regionally manufactured, etc. Additionally, buildings are being designed to maximize weather patterns, day-lighting, and air circulation. For example a birds nest design has been emulated that is efficient, withstanding wind loads and wind shear, while simultaneously enabling light and air to move through it. Throughout the building process, construction, and demolition, energy is conserved and waste is recycled. Measurement and verification plans are also being employed to track utility usage for sustainability purposes.

Urban planners, who used to be called architects, are employing designs that operate like a wall of morning glories—adjusting to sunlight throughout the day, both regulating light and gathering solar energy. In effect, the design can often create an energy surplus that can be employed elsewhere in the system and/or process.

16.8 The U.S. Energy Policy/Independence [1,8]

Energy is central to all current and future human activities. That being said, this nation is approaching a crisis stage. Historically, the primary impetus for the emergence of the U.S. as a global leader has been its ability to satisfy energy needs independently. Without a strategy for determining the most beneficial path to achieve energy independence, the U.S. is positioning itself to be at the mercy of those that will control energy.

The current energy policy being pursued by the U.S. is disjointed, random, and fraught with vested interests. Achieving *energy independence* by pursuing current approaches will be costly, inefficient and disruptive, especially as resources diminish. In addition, environmental impacts will become greater concerns, and the consequences of continuing on the current course may be surprisingly difficult to correct.

Skipka [8] has suggested one approach to developing an energy policy that would achieve energy independence. He has proposed investigations and solutions that will be performed under a three-phase study program. The first phase will be devoted to finding sponsorship for: organizing research and analytical teams; defining team work scopes and objectives; and conducting literature reviews, outreach, matrix formulation, plan refinements, industrial/commercial/governmental coordination, and other tasks.

The second phase will involve: finalization of teams, work scopes and objectives; setting schedules; finalizing matrix criteria; coordinating teams; initiating work scopes, periodic reviews and realignments, cost/benefit and fatal/flaw analyses; draft findings/documents; industrial/commercial/governmental coordination; and other tasks.

The final phase will be implementation of the optimal energy strategy defined during the first two phases. The study group will be supplemented with industrial, academic, and business consultants.

The project will attempt to maximize long-term social return per unit of energy consumed. As such, other alternatives may also have important implications for the economic system, for social processes, and for lifestyles. Topics (where applicable), such as resource quantity, resource availability, economics, energy quality, conservation requirements, transportation requirements, delivery requirements, operation and manufacturing, regulatory issues, political issues, environmental concerns, cost consequences, advantages, disadvantages, and public acceptance, will be studied. Another feature of the project will include an analysis that provides a rated, quantitative detailed review and practical evaluation of all viable energy options, categories (see earlier sections), and corresponding weighting factors that are contained in this analysis. These considerations presently define the energy issues and can provide a means of solving and managing energy problems that exists today while at the same time defining the optimal course for future generations.

A detailed and expanded treatment of energy management is available in the following two references:

1. K. Skipka and L. Theodore, *Energy Resources: Past, Present, and Future Management*, CRC Press/Taylor & Francis Group, Boca Raton, FL, 2014 [1].
2. L. Theodore, *Chemical Engineering: The Essential Reference*, McGraw-Hill, New York City, NY, 2014 [9].

16.9 Illustrative Open-Ended Problems

This and the last section provide open-ended problems. However, solutions *are* provided for the three problems in this section in order for the reader to hopefully obtain a better understanding of these problems, which differ from the traditional problems/illustrative examples. The first problem is relatively straightforward while the third (and last problem) is somewhat more difficult and/or complex. Note that solutions are not provided for the 37 open-ended problems in the next section.

Problem 1: Discuss the general subject of energy conservation from a layman's perspective.

Solution: Many still remember the fuel shortages of the 1970s with long lines at filling stations, and buildings under-heated or closed in the winter. Others remember, more nostalgically, gasoline prices of 25 cents per gallon and spending the evening driving around on a dollars worth of gas. Gasoline at that price is long gone, probably never to return. And a return to the days of fuel shortages may be lurking just around the corner. In a highly industrialized society, Americans are by far the largest energy users in the world and must seek ways to conserve energy. Small improvements in the efficient use of energy translate into the release of large amounts of coal, fuel oil, and gasoline to be used for other purposes or that may be banked for future generations. Such increased efficiency also reduces the production of air pollutants, such as the greenhouse gas, carbon dioxide, which may contribute to global warming. Emissions of sulfur and nitrogen oxides, which are involved in the production of acid rain, are also reduced when energy is conserved.

Whatever the reasons, energy conservation should be an important part of any energy-planning strategies. There are many things, both small and inexpensive and large and costly, which can be done to improve the manner in which one uses this valuable resource.

Problem 2: Discuss why the commercial real estate (CRE) market is "ripe" for energy conservation activity in the future.

Solution: The commercial real estate (CRE) market in the U.S. consists of approximately 4.8 million office, retail, service, lodging, multifamily, warehouse, and storage buildings, representing a significant opportunity for building owners to reduce energy use and monetize their energy savings. Moreover, it is now evident to CRE owners and lenders that a building's energy performance can impact property value. As a result, less energy-efficient buildings are at a growing competitive disadvantage and in danger of accelerated obsolescence.

The above market developments have stimulated a number of retrofit projects designed to increase energy efficiency on any projects involving properties that still rely on original mechanical and electrical equipment often near the end of their useful life; this has resulted in a substantial demand for equipment upgrades and replacement. Assuming this to be true, the floodgates holding back the demand for equipment replacement and upgrading may finally be at the cusp of opening. This dynamic will represent a significant opportunity for replacing or upgrading dated energy-consuming equipment with more efficient units. The end result of this powerful business driving force will likely result in rapid acceleration of the deep energy efficiency retrofit market.

As noted earlier, the initial energy efficiency investments made in the CRE market have been associated with lower-cost improvements having relatively short payback periods (less than 2-3 years) and involving low technology risk. As a result, the CRE industry now has the opportunity to move from this initial phase of low-cost, short-payback energy efficiency improvements to the multifaceted second phase of implementing energy retrofits (defined as resulting in at least a 30% reduction in whole-building energy use) where the capital need is much more intensive and the payback period often longer.

The execution challenge associated with deeper, more capital-intensive energy efficiency retrofit improvements is complicated when internal financing is limited or not available. While some financing for energy efficiency upgrades has been available to CRE owners, the availability of "commercially-attractive" financing often has not. Fortunately, this is changing, and market-ready, commercially attractive financing mechanisms have arisen to meet the need.

Problem 3: It would normally seem that the thicker the insulation, the less the heat loss; i.e., increasing the insulation should reduce heat loss to the surroundings. But, this is not always the case. There is a "critical insulation thickness" above which the system will experience a greater cost to prevent heat loss due to an increase in insulation thickness. This situation arises for "small" diameter pipes when the increase in area increases more rapidly than the resistance opposed by the thicker insulation. Provide a technical analysis of this phenomenon.

Solution: The reader is first referred to Chapter 6 for a solution to this problem. Consider the system shown in Figure 16.1. The area terms for the heat transfer equations in rectangular coordinates are no longer valid and cylindrical coordinates must be employed. Applying the energy equation to a pipe or cylinder leads to

$$q = \frac{T_i - T_o}{\frac{1}{2\pi r_i L}\left(\frac{1}{h_i}\right) + \frac{\Delta x_w}{k_w 2\pi L r_{\text{lm},w}} + \frac{\Delta x_i}{k_i 2\pi L r_{\text{lm},i}} + \frac{1}{2\pi r L}\left(\frac{1}{h_o}\right)}$$

$$= \frac{2\pi L(T_i - T_o)}{\frac{1}{r_i h_i} + \frac{\ln(r_o / r_i)}{k_w} + \frac{\ln(r / r_o)}{k_i} + \frac{1}{r h_o}} = \frac{2\pi L(T_i - T_o)}{f(r)} \tag{16.1}$$

where

$$f(r) = \frac{1}{r_i h_i} + \frac{\ln(r_o / r_i)}{k_w} + \frac{\ln(r / r_o)}{k_i} + \frac{1}{r h_o} \tag{16.2}$$

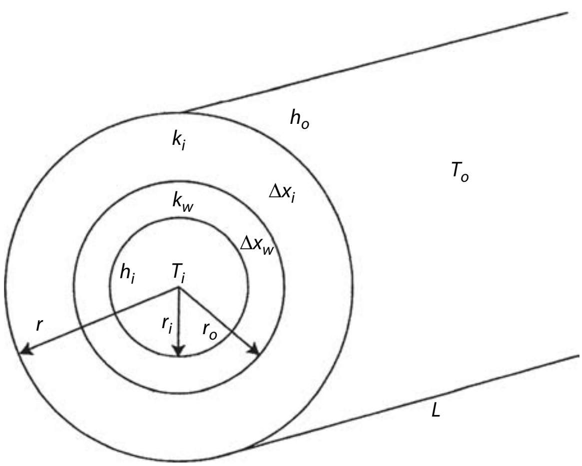

Figure 16.1 Critical insulation thickness for a pipe

The development presented applies when r is less than r_c. If r_o is larger than r_c, the above analysis again applies, but only to the results presented for $r > r_c$, i.e., r_c will decrease indefinitely as r increases. Note that there is *no* maximum/minimum (inflection) for this case since values of $\ln(r/r_o)$ are indeterminate for $r < r_o$. Once again, g approaches zero in the limit as r approaches infinity.

As noted earlier in Chapter 6, as the thickness of the insulation is increased, the cost associated with heat lost decreases, but the insulation cost increases. The optimum thickness is determined by the minimum of the total costs. Thus, as the thickness of the insulation is increased, the heat loss reaches a maximum value and then decreases with further increases in insulation. Reducing this effect can also be accomplished by using an insulation with low thermal conductivity.

16.10 Open-Ended Problems

This last section of the chapter contains open-ended problems as they relate to energy management. No detailed and/or specific solution is provided; that task is left to the reader, noting that each problem has either a unique solution or a number of solutions or (in some cases) no solution at all. These are characteristics of open-ended problems described earlier.

There are comments associated with some, but not all, of the problems. The comments are included to assist the reader while attempting to solve the problems. However, it is recommended that the solution to each problem should initially be attempted *without* the assistance of the comments.

There are 37 open-ended problems in this section. As stated above, if difficulty is encountered in solving any particular problem, the reader should next refer to the comment, if any is provided with the problem. The reader should also note that the more difficult problems are generally located at or near the end of the section.

1. Describe the early history associated with energy management.
2. Discuss the recent advances in the general field in energy management.
3. Select a refereed, published article on energy management from the literature and provide a review.
4. Provide some normal everyday domestic applications involving the general topic of energy management.
5. Develop an original problem on energy management that would be suitable as an illustrative example in a book.

6. Prepare a list of the various technical books which have been written on energy management. Select the three best (try to include a book written by one of the authors) and justify your answer. Also select the three weakest books and, once again, justify your answer.
7. List and discuss the various life expectancies for the following fuels:
   - Coal
   - Oil
   - Natural gas
   - Solar
   - Fission
   - Fusion

   Comment: Refer to the literature [1] for some assistance.
8. Provide at least a dozen energy conservation measures that can be implemented at home.

   Comment: Refer to the literature [1,6] for some assistance.
9. Provide at least a dozen energy conservation measures that can be implemented at the office.

   Comment: Refer to the literature [1,6] for some assistance.
10. Provide at least a dozen energy conservation measures that can be implemented at a chemical plant.

    Comment: Refer to the literature[1,6] for some assistance.
11. Discuss the role insulation plays in energy management.

    Comment: See Problem 3 in the previous section
12. List and discuss the various types of insulation currently available. Outline how one might go about developing a new insulation.
13. Discuss the benefits of including an entropy/exergy analysis in energy conservation analyses.
14. For the purposes of implementing an energy conservation strategy, process changes and/or design can be divided into four phases, each presenting different opportunities for implementing energy conservation measures. These include product conception, laboratory research, process development, and mechanical design. Discuss each of these measures.
15. Discuss the present state of the nuclear power industry in the U.S. Extend the discussion to that of the world.
16. Provide a layman with a definition of fission and fusion, and detail the difference.

17. Provide a technical definition of fission and fusion, and detail the difference.
18. Ivory Tower University runs its own coal-fired power plant, consuming Utah bituminous coal with an energy content (in the combustion literature, energy content is defined as the lower heating value, LHV) of 25,000 kJ/kg. The coal contains, on average, 1.0 wt% sulfur and 1.2 wt% ash (based on the total mass of the coal). The power plant is 35% efficient (indicating that 35% of the energy in the coal is actually converted to electrical energy), and is operated at a 2.0 megawatt average daily electrical load (ADL). Assume that the coal is completely burned during combustion, and also that the power plant captures 99% of the ash and 70% of the sulfur dioxide produced during combustion. The current coal price is $120/ton delivered to the university. Ash-hauling charges to the regional landfill are $40/metric tonne (1 metric tonne = 1,000 kg = 2,205 pounds = 1.1025 US tons).

    After a US EPA Green Lights energy audit, Ivory Tower finds that it can install energy-efficient lighting and reduce its average daily electrical generation. The materials and labor costs for the energy-efficient lighting upgrades are $350,000, which Ivory Tower will pay from cash on hand.

    Using the information given above, calculate the average reduction in electrical load, and the new average daily load for the power plant. Base the calculations on reductions (due to the justification of energy-efficient lighting) in the 10-50% range. Comment on the results.
19. Refer to the previous problem. Using the efficiency of the power plant, the heating value of the coal, and the results from Problem 18, calculate the daily reduction in the quantity of coal (kg/d) consumed by the university's power plant for each percentage range value. Again, comment on the results.
20. Using the results from the two previous problems, calculate the daily reduction in the quantity of ash (kg/d) produced when the university implements this energy-saving lighting program. Comment on the results.
21. Using the results from the previous problems, calculate the annual reduction in cost of coal supplied to the power

plant when the university implements this energy-saving lighting program. Comment on the results.

22. Using the results from the previous problems, calculate the annual reduction in cost of ash hauled to the landfill when the university implements this energy-saving lighting program. Comment on the results.
23. Refer to the previous problems. Sulfur dioxide (SO_2) is produced from the coal's sulfur during combustion. Using this information, calculate the annual reduction (metric tonnes/year) of SO_2 emissions that will result from the various reduction possibilities in average daily electrical generating needs. Comment on the results.
24. It took about 20,000 Btu fuel input to produce 1kW·h of electricity in 1900. Estimate the efficiency of conversion and compare it with a typical value for today's power industry.

    Comment: Refer the to the utility industry literature for conversion efficiency values.
25. A steam turbine in a power plant operates between the temperatures of 300 and 900 K. The efficiency has already been increased to the maximum by mechanical changes, and the plant is now trying to improve the efficiency thermodynamically. One can increase the operating temperature of the heat source by 30 K or decrease the temperature of the heat sink (the cool reservoir) by 30 K. Which is most effective? Do you think it would be a significant improvement to use water from the bottom of a lake rather than the top for cooling water? Repeat the above calculating for temperature increases/decreases in the 20-40 K range.
26. Even with an aggressive energy conservation program, the Earth's growing population will continue to demand increasing amounts of electricity. Identify and describe the environmental impacts, both positive and negative, of the following alternative means of power generation: coal-fired steam boilers; nuclear power; photovoltaic solar panels; and hydroelectric dams.
27. The opportunity for energy conservation in the field of transportation is enormous. Forty-five million gallons of gasoline could be saved for future generations *each day in the U.S. alone* with an increase in fuel efficiency of only 2 mpg. And, as has been stressed by many, this is a "win-win"

situation, since a reduction in pollution is proportional to the reduction in fuel use. One partial solution to the production of combustion pollutants is the addition of gasoline additives to increase the amount of oxygen in the fuel. Methyl-*tert*-butyl ether (MTBE) is currently used as an oxygenating fuel additive, providing more power per gallon as well as more complete gasoline combustion in internal combustion engines. This is achieved at a cost of about 1 cent per gallon of fuel.

Assuming that the average fuel usage rating for automobiles in the U.S. is 18 mpg and that the increase in efficiency with the MTBE additive is 5%, calculate the savings in gallons of fuel in the United States per year if MTBE were used in every car. Repeat the calculation for various mpg and additive values. Also analyze the results.

28. An important consideration for the use of the MTBE fuel additive described in the previous problem is the "break-even" point. This occurs when the cost of the additive equals the savings in gasoline. Given that the use of MTBE costs 1 cent per gallon and the cost of gasoline averages at $3.20 per gallon nationwide, calculate the "break-even" point for its use. Use any relevant data from the previous problem in the solution. Comment on the results.
29. Discuss the use of the MTBE fuel additive in light of the results of the two previous problems.
    Comment: Two additional factors have been recently added to the arguments against MTBE addition. First, MTBE is thought to be a possible health threat to consumers as they pump their own gas, and secondly, MTBE is highly mobile in groundwater, has generated large groundwater plumes below a number of leaking underground storage tank sites, and poses a potential health threat due to contamination of drinking water supplies.
30. A good plan for energy conservation can include a variety of strategies. One of these should be recycling of materials. Most recycling efforts have multiple positive benefits, including reducing energy demands and landfill space, as well as reducing the pollution of land, air and water.

    Society continues in its transition from a "throw-away" society to one that is giving more thought to each consumer product and its containers. This change has been brought about by a variety of pressures, including dwindling landfill space and the increased cost of solid waste disposal. Incentives in the form of bottle deposits and recycling efforts of communities have helped in this transition. The engineers at the Steincke Quality Container Corporation have designed three new containers and are making a presentation to the Vice President of Marketing. She will make the choice of which container to use to package a new product. Differences in appearance of the three options are negligible and none has an effect on the product in any way.

Using the data below, Table 16.1 help the Vice President make the energy-conscious decision with regard to this container.

Table 16.1 Container Information, Problem 30

	Container A	Container B	Container C
E_1	200 J/unit	450 J/unit	650 J/unit
E_2	0 J/unit	250 J/unit	150 J/unit

Note: E_1 = energy to produce the container, and E_2 = energy to manufacture the container from recycled materials.

Assume that the raw materials cost to produce the item are the same for each container. The only difference is in the amount of energy needed to improve the structure of the container to make it more durable. Container A cannot be recycled, while containers B and C can be recycled. However, Container B can only be recycled five times, on average; Container C can be recycled up to 20 times without deterioration of performance.

- Create a table for each container showing the number of units required for each recycle and the associated costs, E_1, E_2, and Total E. Calculate the energy costs for one million unit-uses at a recycle rate of 25%.
- Which container would you advise the Vice President to select, based only upon these energy considerations? Justify your answer.

31. Using the data from the previous problem, calculate the number of times Containers B and C would have to

be recycled to make them competitive with Container A, assuming a recycle rate (RR) of various values in the 75-95% range. Comment on the results.

32. The authors have often stated that most technical individuals believe that the world's energy problems will be solved by either the nuclear or solar route. Express your position on this issue.
33. The authors of this book have voiced a concern that employing windmills to recover the energy of the wind for useful purposes may adversely affect the rotation of the Earth. Comment on this concern.
34. Develop an energy policy for the U.S.
    Comment: Refer to the literature [1] for some assistance.
35. Develop an energy policy for a third world country.
    Comment: Refer to the literature [1] for some assistance.
36. Develop an energy policy for China.
    Comment: Refer to the literature [1] for some assistance.
37. In terms of future activities, discuss whether energy management or water management will be more important. (See also Chapter 17).

References

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