

AC 2010-1702: ETIOLOGY OF THE ENERGY CRISIS IN ONE LECTURE

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Etiology of the Energy Crisis in One Lecture

Abstract

A dominant feature of the twenty-first century has been concerns over the costs, availability, economics, security, and environmental issues associated with energy in the United States and the rest of the world. This paper is an extension of presentations made by the author over the past few years to audiences as varied as freshmen-to-senior engineering students, practicing engineers, political leaders, and the general public. Using energy and cost data primarily from the DOE Energy Information Administration and the World Bank, a presentation can be crafted that suits various audiences and that can be readily updated as new information becomes available. Essentially all of the information is available in the public domain, but this paper assembles the information into a cogent sequence.

Purpose

The purpose of this paper is to provide to diverse audiences, especially engineering students, a concise (less than one hour) lecture that explains how we arrived at the current energy scenario and how we might mitigate the current energy problems (read “crisis”). Awareness and understanding of the United States energy situation is vital for tomorrow’s engineers—today’s students. Future engineers must interact with and advise the general public as well as political leaders on energy issues. The energy education of future engineers is especially important as neither of the major political parties has yet to champion a realistic and workable energy policy for the future. Using public domain energy and cost data from the DOE Energy Information Administration and the World Bank, a cogent presentation can be crafted that contains elements of the etiology of the energy crisis, that suits various audiences, and that can be readily updated as new information becomes available.

Introduction

Figure 1, a mosaic of satellites photographs at night of the United States, is a rather dramatic illustration of the population density and dispersion in the United States as indicated by the energy intensity distribution of night lighting (primarily electricity usage). Figure 1 is a visually eye-catching illustration to open a presentation on energy. This figure, as well as many of the illustrations in this paper, was taken from the U. S. DOE Energy Information Administration (EIA) document, *Annual Energy Report 2008*¹. Every June, the EIA issues a detailed report cataloging the energy usage of the previous year. The yearly issue thus provides an easy way to update energy usage and statistics. The current and previous editions of the *Annual Energy Report* (AER) are available at www.eia.doe.gov/aer.

An irrefutable fact is that the developed countries (the United States, Japan, the United Kingdom....) use more energy per capita than the less-developed countries (Mexico, Indonesia....). Figure 2, using World Bank data (2009)², dramatically illustrates the relationship between income and per capita energy use. High income countries, the “developed” countries,

with high standards of living use as much as eleven times more energy per capita than low income, third-world countries. This trend has held for a number of years. Figure 3, taken from



Figure 1. Mosaic of night satellite photographs of the United States¹.

Tester et al.³ (2005), but based on somewhat older data from the World Bank, graphically presents per capita energy consumption as a function of gross national product (GNP) per capita for a number of countries. The United States and Canada possess the highest energy consumption per capita. A number of reasons exist for the high energy consumption per capita in the United States; among the reasons are (1) historically cheap energy, (2) low population density, (3) large area, (4) historically an abundance of domestic energy, and (5) no ingrained ethic for conservation.

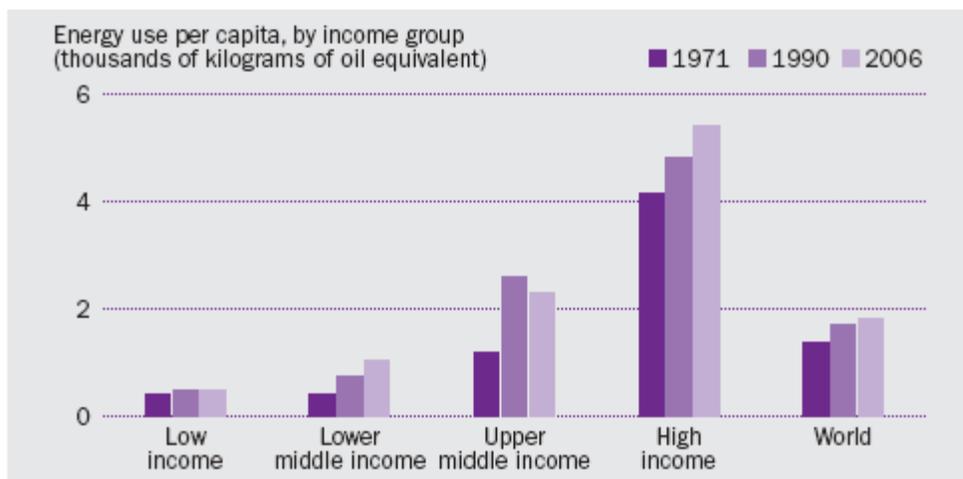


Figure 2. Energy use per capita as a function of country income level².

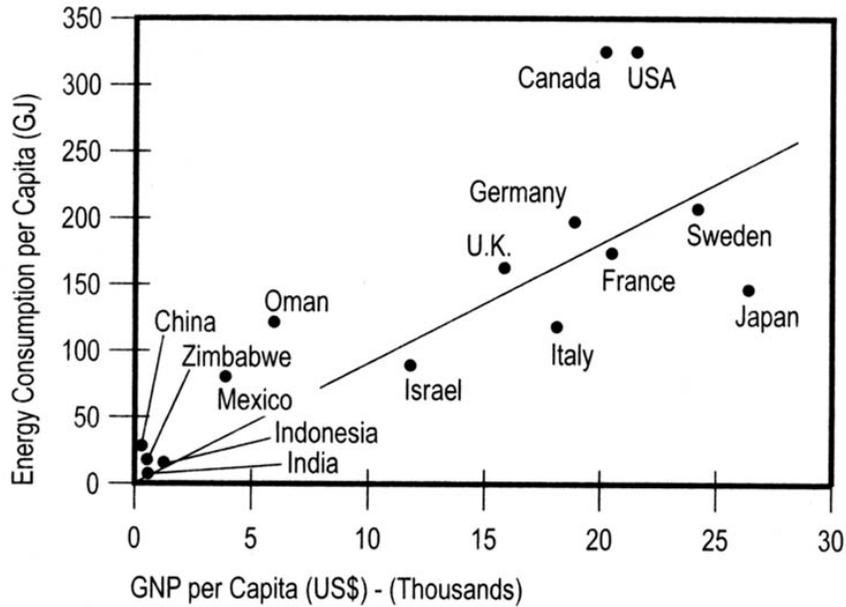


Figure 3. Per capita energy consumption versus gross national product (GNP) per capita for a number of countries (Tester et al.³ from World Bank data).

History of Energy Usage in the United States

Consider how the United States arrived at its current energy economy. Figure 4, from the EIA *Annual Energy Review 2001*¹, presents a graphical representation of the historical energy utilization. The energy usage unit used is the quad (quadrillion Btu = 10^{15} Btu). Until the mid-1800s, energy utilization was mostly wood, with coal becoming increasingly important after 1850. By 1900, coal usage was much greater than wood, and petroleum was becoming more important as an energy source. And in 1950, petroleum usage exceeded coal usage, and natural gas usage was dramatically rising. At the millennium, petroleum provided the most energy with natural gas and coal vying for second and third place. Nuclear power was in fourth place with hydroelectric and renewable energy (including wood) sources making the smallest contributions.

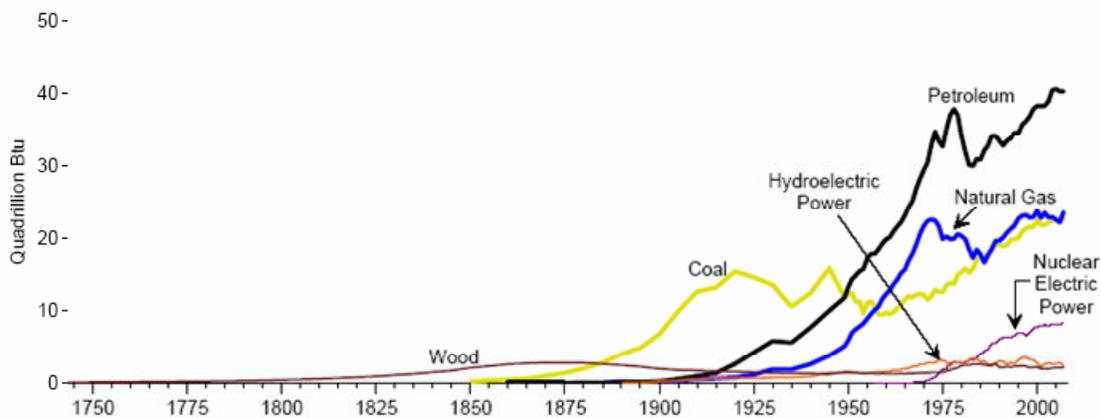


Figure 4. History of energy sources in the United States¹.

The genesis of the energy problem is illustrated in Figure 5. Until about 1950, the United States had little dependence on energy imports. However, with the post World War II prosperity, energy imports begin to increase since consumption increased faster than domestic production. The result has been a steady increase in energy imports. The increasing dependence of the United States energy economy on energy imports, much from politically unstable and/or marginally-friendly countries, has raised energy security and foreign policy issues.

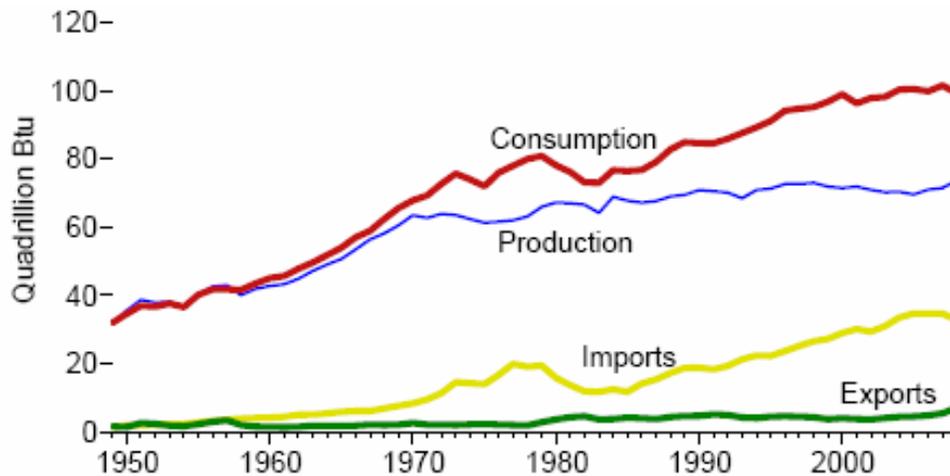


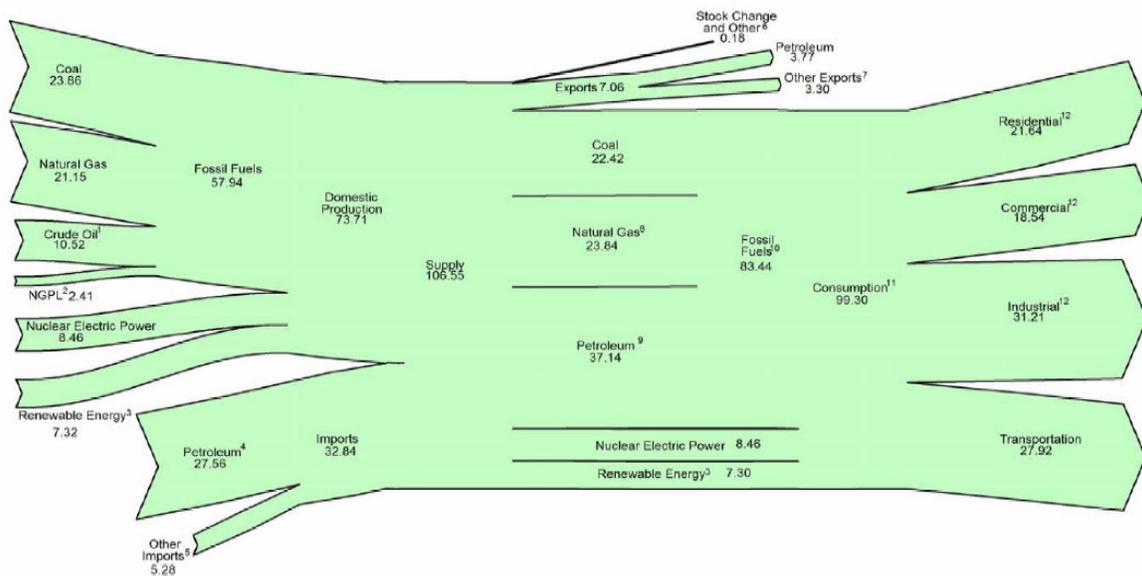
Figure 5. History of energy consumption, imports, and exports for the United States¹.

2008 Energy Usage in the United States

The EIA energy flow diagram, from the *Annual Energy Review 2008*¹, is arguably the most informative graphical representation in the *Review* and is reproduced as Figure 6. In this figure all energy usages are in quads (10^{15} Btu). Energy sources are delineated on the left-hand side of the diagram (coal at 23.86 quad, for example). The sources are then summed and expressed as domestic production (73.71 quad) and imports (32.84 quad). The total supply is 106.55 quad with exports of 7.06 quad which yields 99.30 quad for consumption. The end-point energy usages (categorized as residential, commercial, industrial, and transportation) are shown on the right-hand side of the figure. Thus, in 2008, the United States energy economy was 99.30 quad of which 32.84 quad was imported. The end-point energy usages are displayed on a pie chart in Figure 7. Industrial usage accounts for 31 percent of the total energy used, followed by 28 percent for transportation. The remainder is almost evenly split between residential and commercial. Since the energy used by no end-use sector is dominant, if significant reductions in energy uses are to be forthcoming all end-use sectors must be examined.

Figure 8 offers an informative breakdown of the data from Figure 6. The actual and percentage contributions of each of the supply sources (petroleum, natural gas, coal, renewable, and nuclear) to the actual and percentages of each of the end-point energy sectors (transportation, industrial, residential and commercial, and electric power) are delineated. The values are congruent with the energy flow diagram, Figure 6. For example, for transportation 95 percent of the energy is from petroleum, 2 percent is from natural gas, and 3 percent is from renewable resources.

Figure 9 is a diagram of petroleum flow in the United States for 2008. The format of Figure 9 is similar that of Figure 6 except that the numbers in the petroleum flow diagram are in millions of barrels per day (MMBD). Starting at the left-hand side, domestic crude oil production is a little less than that of the crude oil imported. The refinery output is cast in terms of motor gasoline, distillate fuel oil, liquefied petroleum, jet fuel, residual fuel oil, and “other.” Motor gasoline, at 8.96 MMBD, accounted for nearly one-half of the total utilization of petroleum products in the United States in 2008. The right-hand side of the petroleum flow diagram expresses the end-point petroleum energy usages. Transportation accounts for 70 percent of the total petroleum. Industrial usage is about 25 percent with residential, commercial, and electric power generation responsible for the remaining.



¹ Includes lease condensate.
² Natural gas plant liquids.
³ Conventional hydroelectric power, biomass, geothermal, solar/photovoltaic, and wind.
⁴ Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.
⁵ Natural gas, coal, coal coke, fuel ethanol, and electricity.
⁶ Adjustments, losses, and unaccounted for.
⁷ Coal, natural gas, coal coke, and electricity.
⁸ Natural gas only; excludes supplemental gaseous fuels.
⁹ Petroleum products, including natural gas plant liquids, and crude oil burned as fuel.
¹⁰ Includes 0.04 quadrillion Btu of coal coke net imports.
¹¹ Includes 0.11 quadrillion Btu of electricity net imports.
¹² Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.
 Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.
 Sources: Tables 1.1, 1.2, 1.3, 1.4, and 2.1a.

Figure 6. United States energy flow diagram for 2008¹.

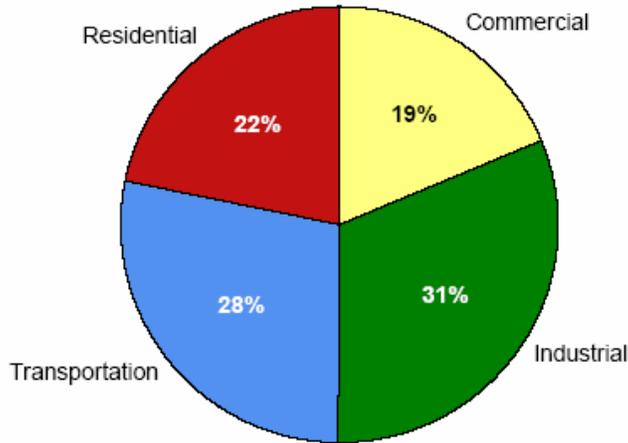
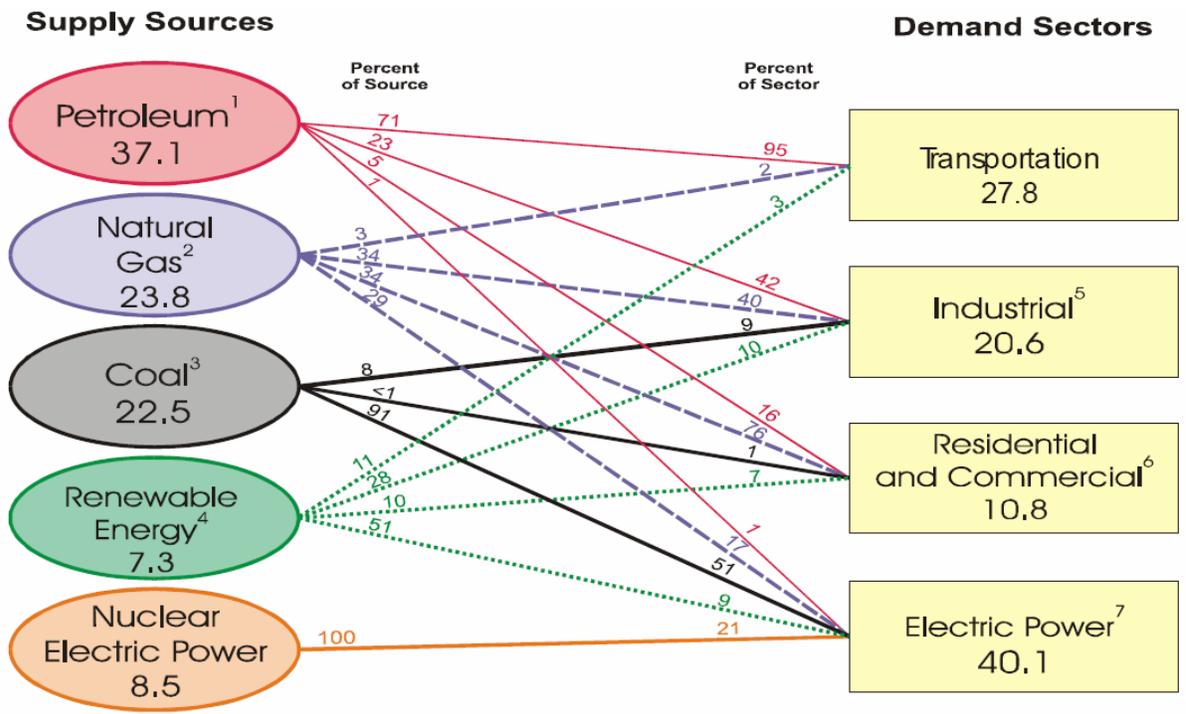


Figure 7. End-use energy utilizations in 2008¹.



¹ Does not include the fuel ethanol portion of motor gasoline—fuel ethanol is included in "Renewable Energy."
² Excludes supplemental gaseous fuels.
³ Includes less than 0.1 quadrillion Btu of coal coke net imports.
⁴ Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
⁵ Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
⁶ Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
⁷ Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.
 Note: Sum of components may not equal 100 percent due to independent rounding.
 Sources: Energy Information Administration, *Annual Energy Review 2008*, Tables 1.3, 2.1b-2.1f, 10.3, and 10.4.

Figure 8. Energy sources to end-use energy sector utilizations in 2008¹.

The coal flow diagram for 2008 is shown in Figure 10 and is expressed in millions of short tons. In a fashion similar to the other energy flow diagrams (Figures 6 and 9), information proceeds from the left-hand side (sources) to the right-hand side (end-point usages). All coal is produced

domestically with a small amount exported. Virtually all of the coal usage (93 percent) in the United States is for the generation of electricity, with some, about 7 percent for industrial use. Coal is the one energy source that does not have to be imported. The extensive use of coal for electric generation poses significant environmental issues. However, significant research efforts are under way to mitigate environmental issues associated with coal-fired electrical generating facilities.

Figure 11 itemizes the percent contribution of renewable energy sources in the United States for 2008. In 2008, renewable energy from all sources contributed about 7 percent of the total energy utilized in the United States. Perhaps the most amazing statistic is that wood and conventional hydroelectric power accounted for 62 percent of the total renewable energy that year! Solar and wind contributed only 8 percent of the total renewable energy (or about 0.6 percent of the total energy consumption) in 2008. Hence, in spite of much interest and media hype, the penetration of solar and wind energy into the energy mix has not made much progress. Indeed, the allocation of research funding for renewable energy is still an unsolved issue. A recent article in *Mechanical Engineering* (Winters⁴, 2009) suggests that research investments should be directed to wind and geothermal rather than solar thermal and photovoltaic.

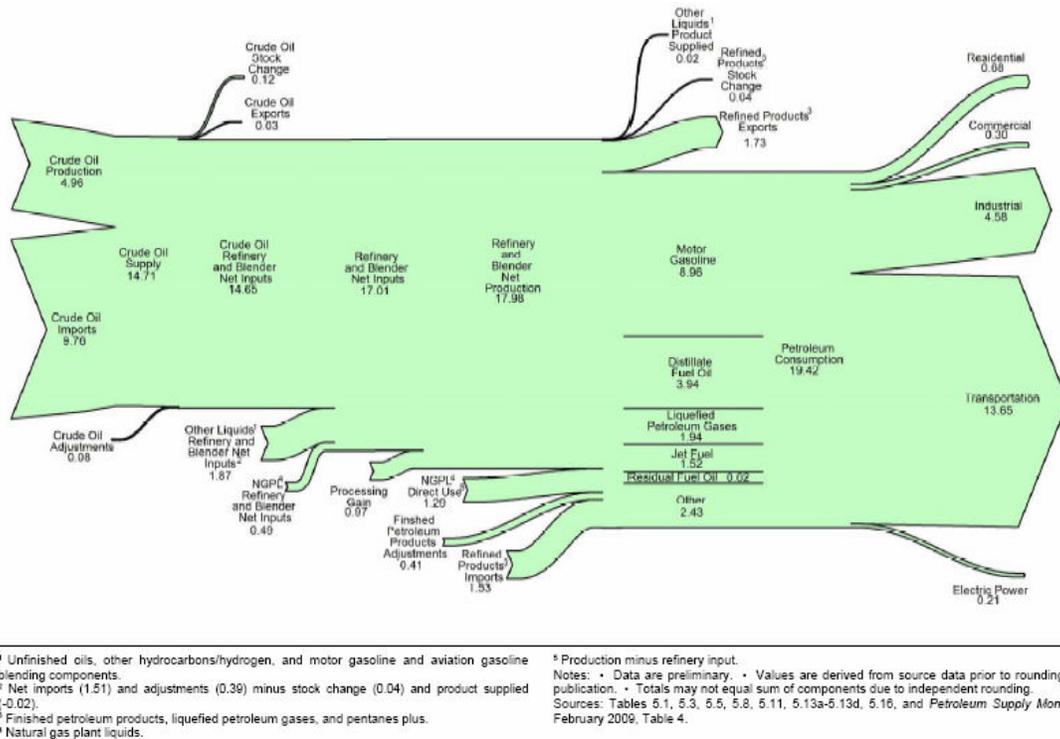
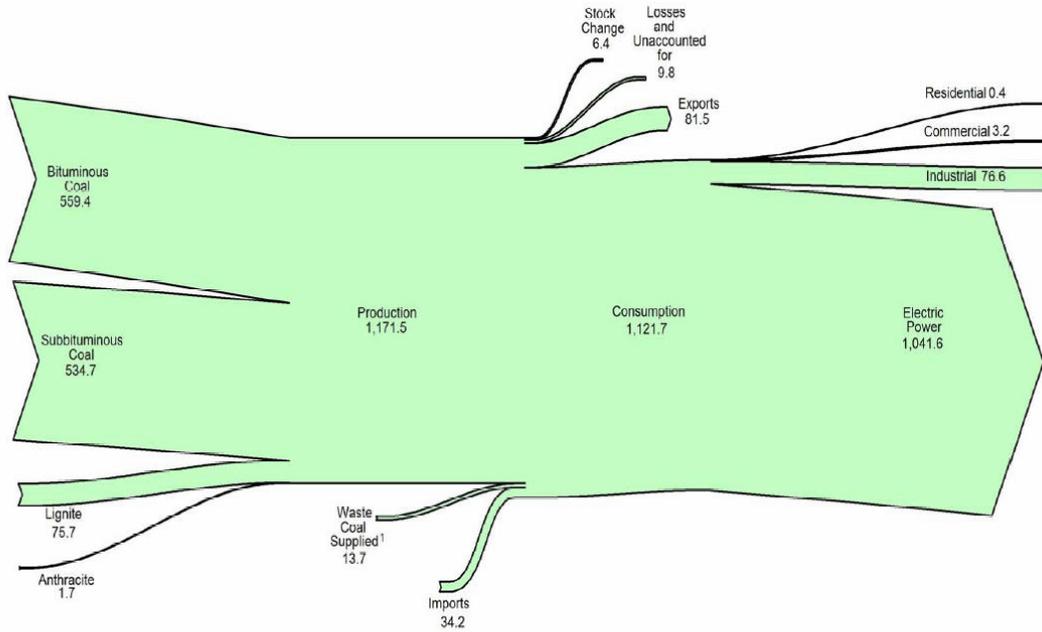
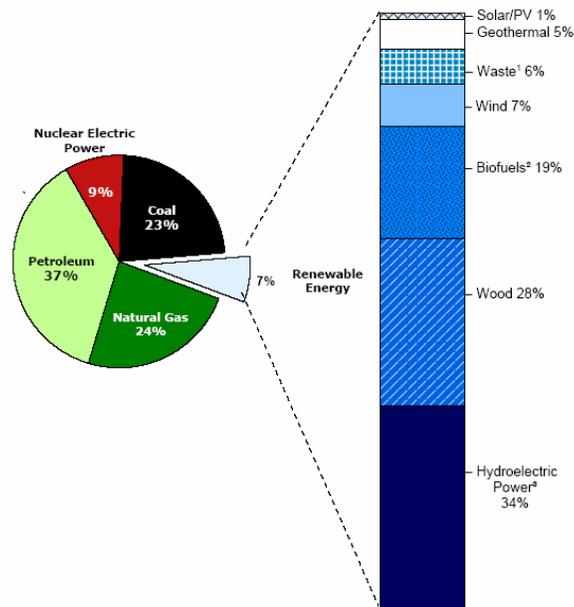


Figure 9. United States petroleum flow diagram for 2008¹.



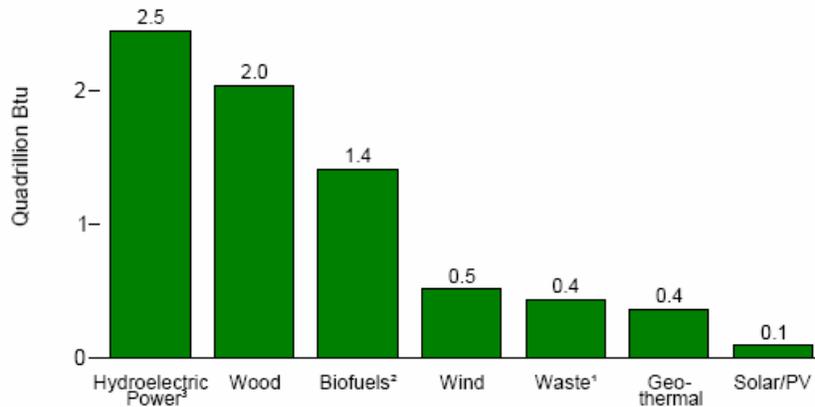
¹ Includes fine coal, coal obtained from a refuse bank or slurry dam, anthracite culm, bituminous gob, and lignite waste that are consumed by the electric power and industrial sectors. Notes: • Production categories are estimated; other data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding. Sources: Tables 7.1, 7.2, and 7.3.

Figure 10. United States coal flow diagram for 2008¹.



¹ Municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural by-products, and other biomass. ² Fuel ethanol and biodiesel consumption, plus losses and co-products from the production of fuel ethanol and biodiesel. ⁴ Includes small hydroelectric power.

(a) Percentages



(b) Actual (quad)

Figure 11. Percentage and actual contributions of renewable energy in 2008¹.

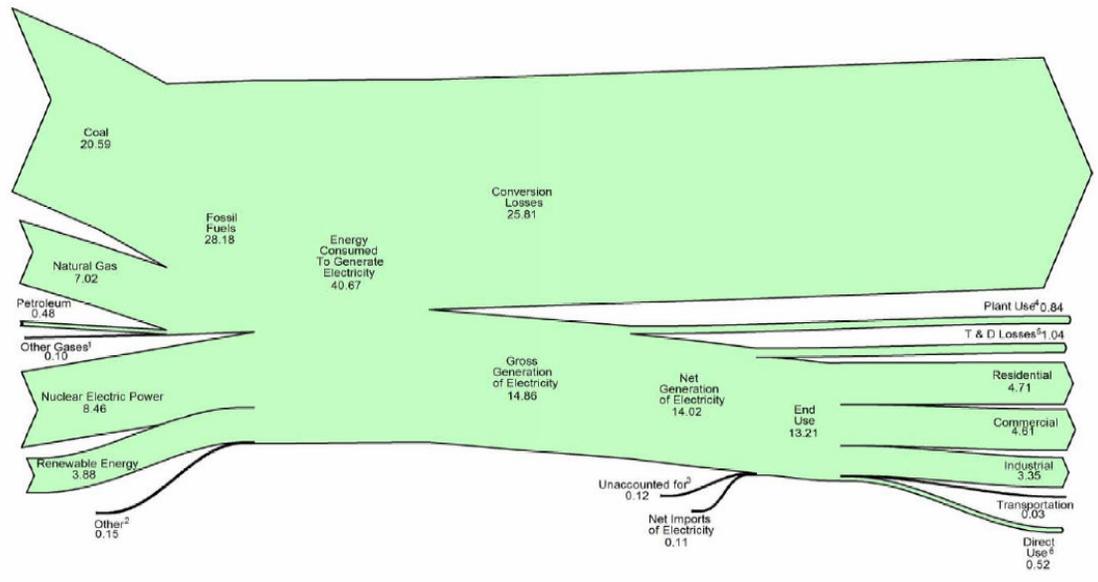
Although an end-point energy use rather than an energy source, an examination of the electricity flow in the United States is appropriate. Figure 12 presents the electricity flow diagram for 2008; the numbers in the figure are in quad (10^{15} Btu). The conversion factor is $3412 \text{ Btu} = 1 \text{ kWh}$. The left-hand side delineates the input energy including nuclear electric power. Coal is the dominant fossil fuel (73 percent) source of energy for electricity generation in the United States. The right-hand side of the diagram breaks down the end-point energy usages including transmission and distributions losses (about 9 percent). With 40.67 quad consumed to generate 14.86 quad of electricity, the overall thermal efficiency of electricity generation is 37 percent. Hence, of the 40.67 quad of energy used to generate electricity in the United States in 2008, 25.81 quad represents conversion losses.

Lost Opportunities and Why

Much insight can be gained by tracking the cost of a kWh of electricity in terms of “real” and “nominal” dollars. Real dollars are the chained dollars based on the dollar in 2000 while nominal dollars are the actual cost during a given year. Real dollars thus account for inflation. Figure 13 tracks the “real” and “nominal” cost (in cents) of a kWh from 1960 until 2008. In 1960, the real cost of a kWh of electricity was about 8.5 cents compared to about 9.25 cents in 2008. Indeed, until 2006, the real cost of a kWh has been less than in 1960. From 1980 until 1998, the real cost of a kWh of electricity monotonically declined. The declining real cost of electricity during the prosperous years of the 1980s and 1990s, relative to inflation, provided little economic impetus for conservation or alternative energy sources.

Transportation, the dominant end-point petroleum energy usage, also warrants examination. Much insight can be gained by tracking the cost of a gallon of motor gasoline in terms of “real” and “nominal” dollars. Figure 14 presents the real and nominal cost per gallon of motor gasoline from 1978 to 2008. In real dollars gasoline was \$2.25/gallon in 1980, a price not reached again until 2004. As of the spring of 2010, gasoline is just over \$2.50/gallon, reflecting the rapid increase since 2004. Indeed, only after 2000 has the rate of increase of the price of gasoline exceeded that of inflation. The argument could be made that in 1998, the inflation-adjusted price of gasoline was cheaper than it had ever been! During the prosperous years, relative to inflation,

gasoline prices declined. No wonder that conservation, higher gas mileage vehicles, and alternative energy sources possessed little appeal or aroused much interest in the public or public officials.



¹ Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.
² Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, miscellaneous technologies, and non-renewable waste (municipal solid waste from non-biogenic sources, and tire-derived fuels).
³ Data collection frame differences and nonsampling error. Derived for the diagram by subtracting the "T & D Losses" estimate from "T & D Losses and Unaccounted for" derived from Table 8.1.
⁴ Electric energy used in the operation of power plants.
⁵ Transmission and distribution losses (electricity losses that occur between the point of generation and delivery to the customer) are estimated as 7 percent of gross generation.
⁶ Use of electricity that is 1) self-generated, 2) produced by either the same entity that consumes the power or an affiliate, and 3) used in direct support of a service or industrial process located within the same facility or group of facilities that house the generating equipment. Direct use is exclusive of station use.
 Notes: • Data are preliminary. • See Note, "Electrical System Energy Losses," at the end of Section 2. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.
 Sources: Tables 8.1, 8.4a, 8.9, A6 (column 4), and Energy Information Administration, Form EIA-923, "Power Plant Operations Report."

Figure 12. United States electricity flow diagram for 2008¹.

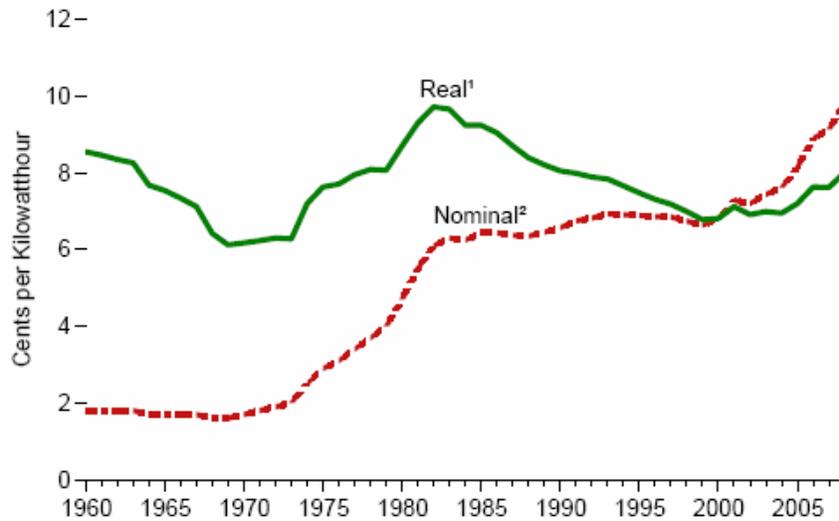


Figure 13. Electricity prices from 1960 to 2008¹.

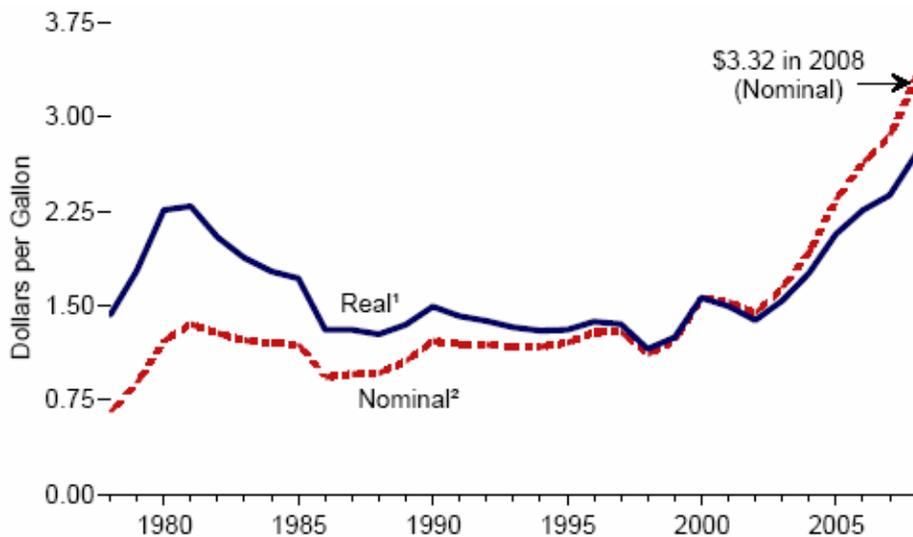


Figure 14. Motor gasoline prices from 1978 to 2008¹.

It's Worse Than We Think

Although this paper has concentrated on the energy scenario in the United States, an examination of energy usage on a worldwide basis will enhance understanding of the global nature of the energy problem. Figure 15 depicts the energy utilization of the world and the countries with the most energy consumption from 1994 to 2006. All data are presented in quads. The increases in energy use worldwide and by China are evident in the figure. The energy usage in Russia declined slightly, and the energy used by the United States remained essentially constant. China's energy usage has increased dramatically. The energy problems of the United States are exacerbated by the increasing demand for energy worldwide, especially in countries with rapidly expanding economies. As the economies of more developing countries evolve toward modernization and manufacturing, the world energy supply problems will be exacerbated.

As Ring⁵ points out, if the per capita energy consumption in the developing world were to reach only 50 percent of that of the industrialized nations and if the industrialized nations per capita energy consumption were to be reduced by 50 percent, then the world energy requirement would more than double. If 100 percent were considered, then a more than four-fold increase would be required—in excess of 2000 quad/year. Considering the world energy economy is 400 quad/year, such an increase is impossible. Ring also points out that while the United States requires about 12,000 Btu/\$ GNP, developing countries such as China and India require 46,000 Btu/\$ GNP and 31,000 Btu/\$ GNP, respectively. The implication is that unless developing countries are able to dramatically reduce their Btu/\$ GNP consumption, the world's energy requirements may be significantly underestimated.

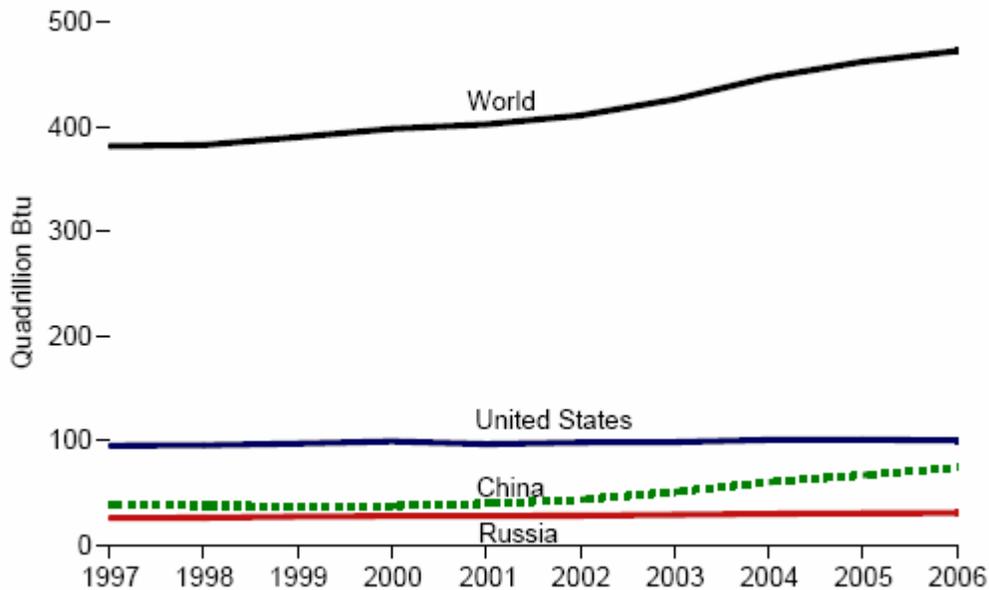


Figure 15. World energy utilization from 1997 to 2006¹.

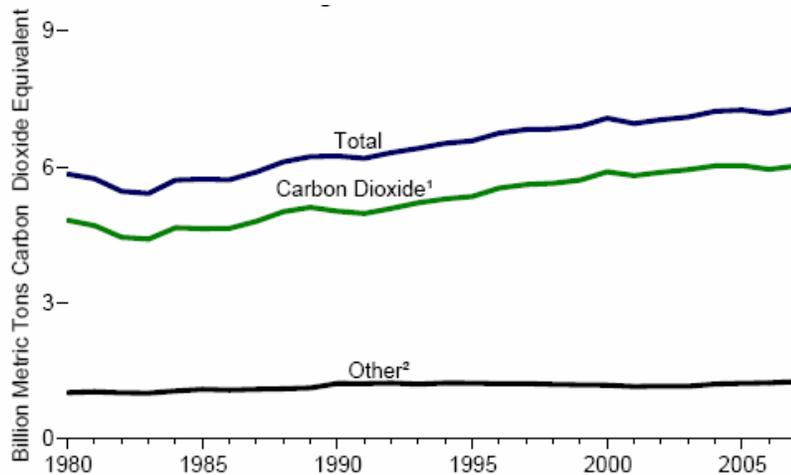
A corollary issue is the production of greenhouse gases. Figure 16 illustrates the long term effect: a monotonic increase in the production of carbon dioxide.

Where Do We Go From Here

The energy crisis is real and is likely to get worse. If we are to meet the increasing United States and world energy demands, then conservation, more efficient use of existing resources, the use of alternative energy sources, and the alternative use of existing energy sources must be aggressively pursued. Three of the fourteen Grand Challenges for Engineering⁶ (www.engineeringchallenges.org), as promulgated by the National Academy of Engineering in 2008, are directly associated with finding solutions to the energy dilemma and many of the remaining have future implications for energy. Petroski⁷ presents a unique perspective on the difficulties in solving such energy-related challenges and cites examples of prizes as fiscal inducements. As several reviewers pointed out, and as the author concurs, nuclear power is likely to, and perhaps must, play an increasingly important role for electricity generation in the United States. Hodge⁸ provides a survey of alternative energy sources and alternative uses of existing energy resources including nuclear energy.

References

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- [2] World Bank, 2009, *World Development Indicators 2009*, ISBN: 08213-7829-5, Washington, D.C.



¹ Metric tons of carbon dioxide can be converted to metric tons of carbon equivalent by multiplying by 12/44.

² Methane, nitrous oxide, HFCs, PFCs, and SF₆.

(s)=Less than 0.005 billion metric tons of gas.

-- = Not applicable because these gases cannot be summed in native units.

Figure 16. Carbon dioxide equivalent production from 1980-2007 [1].

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