Course Introduction

Larry Caretto
Mechanical Engineering 483

Alternative Energy Engineering II

January 20, 2010

California State University Northridge

Today's Class

- First class day items: roll, outline, etc.
- Class goals and learning objectives
- Assessment quiz
- Overview of energy
  - Basic vocabulary for discussing energy
  - Energy sources, alternative and otherwise
  - Energy consumption sectors
  - Costs and
  - Environmental effects

California State University Northridge 2

Basic Information

- Larry Caretto, Jacaranda (Engineering) 3333, lcaretto@csun.edu, 818.677.6448
- Office hours Monday and Wednesday 5 to 6 pm, Tuesday and Thursday 2 to 3 pm, and email, phone, drop-in, or appointment
- http://www.csun.edu/~lcaretto/me483
- B.K. Hodge, *Alternative Energy Systems and Applications*, Wiley, 2010.

California State University Northridge 3

Course Learning Objectives

- Have a good overview of conventional and alternative energy resources
- Understand the current and future potential for alternative energy sources, such as wind and solar
- Perform economic analysis of alterna-tive and conventional energy sources
- Understand environmental effects of alternative/conventional energy sources

California State University Northridge 4

Course Learning Objectives II

- Understand the important parameters involved in analysis and design of solar and wind energy systems
- Perform design calculations for solar collectors and solar photovoltaic systems
- Perform statistical calculations of wind energy systems and determine mean expected annual energy of wind systems

California State University Northridge 5

Class Operation

- Use slide presentations with copies available for download prior to class
- Use these to follow lecture instead of taking detailed notes
  - Ask questions and add your notes to the printed lecture presentation
- Questions during lecture with time for in-class solution by individuals or groups to enhance learning

California State University Northridge 6

Grading

- Weekly homework including questions requiring web/library research and short written responses (about one page)
- Two midterms
- Final exam
- Grading
  - Homework 10%
  - Midterms 50%
  - Final 40%

California State University Northridge 7

See Course Outline

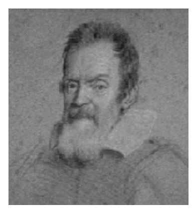
- Download from course web site
  - http://www.csun.edu/~lcaretto/me483
- Contains lecture schedule and web page for homework assignments and solutions
- Note information on the following items
  - Class participation and courtesy
  - Collaboration versus plagiarism: students found cheating receive F grade in course
- Students are responsible for changes to outline announced in class and via email

California State University Northridge 8

Course Outline Items

- Schedule
  - First midterm: Wednesday, March 17
  - Second midterm: Wednesday, April 21
  - Final exam: Monday, May 10, 3 – 5 pm
- Grading notes
  - Plus/minus grading will be used
  - Grading criteria in course outline
  - No make-up exams
  - Late homework accepted with 10% per week lateness penalty

California State University Northridge 9



Galileo Galilei

(1564-1642)

You cannot teach people anything; you can only help them find it within themselves.

http://space.about.com/od/astronomyhistory/a/galileoquotes.htm

California State University Northridge 10

Goals for this Course

- My goal is to help all students find within themselves sufficient knowledge of alternative energy so that they will all get an A grade in the course
- What is your goal for this course?
- What will you do to achieve that goal?

California State University Northridge

11

The posted lectures will usually be printed in this format showing extended notes below the slide.

In almost all cases, the extended notes will pertain only to the particular slide. However, for this initial lecture the notes have a large amount of detail and will actually start on slide 16, prior to the slide to which they refer.

Note that there is a homework assignment due on Monday, January 25. Download this assignment from the course web site. The assignment asks you to research energy data on web sites.

How to Get Your A

- Spend six to ten hours per week outside class studying for the course
- Prepare for lecture and be ready to ask questions
  - Read the assigned reading before class
  - Download, print, and review the lecture presentations before class
    - Use these as notes so that you can follow the lecture; write additional notes on these presentations

Notes below are for subsequent slides

California State University Northridge

12

What is energy?

Introduction

Dictionary definitions of energy[1] often list the personal meaning (“she has a lot of energy”) as the first meaning of the word. The scientific definitions, such as “usable heat or power”, “a source of usable power, such as petroleum or coal”, or “(Physics) the capacity of a physical system to do work” are subsidiary to the more common usages of the word. It is difficult to find a good definition of energy. In a Supreme Court opinion,[2] Justice Potter Stewart once said that he could not “succeed in intelligibly” in defining pornography, but, he added, “I know it when I see it…” That statement could serve as a definition of energy. It is hard to capture in an exact definition, but all of us have a general idea of what the topic means in the concepts used in science and engineering.

[1] Try a search for the work energy at http://www.dictionary.com/ to see various ways in which this term is used.

[2] Jacobellis v. Ohio, 378 U.S. 184 (1964)

How to Get you're A, Part II

- Study with fellow students and try to answer each other's questions
- Do the homework assignments
- Contact me by email, telephone or office visits to ask questions
- Develop a good working relation with other members the class
  - Participate in class discussions

California State University Northridge

13

Before the 1973 oil embargo, there was little public discussion of energy, energy cost, energy resources, energy conservation, or technology for improving the efficiency of energy use. The sharp rise in oil prices caused by the embargo and the potential impact on national lifestyles and national security has made energy a significant part of national policy for over thirty years. The importance of energy in the spectrum of issues facing the country seems to vary with the price of gasoline or electricity. However, there is an ongoing need for engineers who have good understanding of the technical issues about energy supply and the implication that these technical issues have on national policy.

Engineers and scientists first encounter the topic of energy in physics courses where the sum of the kinetic plus potential energy is defined as the negative of the work that is done in a "conservative" process (i.e., one without friction). This tells us that the dimensions of energy must be the same as those of work, name force times distance. Since force has the dimensions of mass times acceleration or mass times length divided by time squared, the dimensions of energy are mass times (length/time)-squared, written symbolically as ML^2T^{-2}. Power, which is the rate of energy change, has the dimensions of ML^2T^{-3}.

What I Will Do to Help

- Arrive at class a few minutes early to answer any questions you may have
- Give lectures that stress application of basics to problem solving
- Return homework and exams promptly so that you can learn from your errors
- Be available for questions in my office (visit or telephone) or email
  - Send entire class emails as appropriate

California State University Northridge

14

In the SI system of units the units of energy are joules, the amount of energy required to life a mass of one kilogram a distance of one meter. The power rate of one joule per second is called a watt. A joule is not very much energy. Electricity use is billed in units of kilowatt-hours; this is 3,600,000 joules (J) or 3.6 megajoules (MJ). A November 2005 electricity bill from the Los Angeles Department of Water and Power charged about 10.5 cents per kilowatt-hour for electricity delivered to a home in the San Fernando Valley. This is about $\$3\text{x}10^{-8}$/J.

The definition of energy as the amount of work done is expanded in thermodynamics to include processes with friction. In thermodynamics the internal energy, a property of the system, is defined such that the total work for any process change is the negative of the change in the energy sum. The energy sum is the sum of the kinetic energy, the potential energy, and the thermodynamic internal energy. Thermodynamics defines a new form of energy transfer, heat, which is defined as energy in transit due only to a temperature gradient.

Prior to the development of thermodynamics, there was no recognition that heat and work were both forms of energy, which means that they should have the same units. A separate set of units were developed for heat, the use of which persists today. These units, the calorie and the British thermal unit or Btu, are defined as the amount of heat required to raise a unit mass of water one unit of temperature. The exact definition of these energy units is considered further below.

Preliminary Assessment

- Designed to help instruction
- One set of questions on student background
- Second set of questions is ungraded quiz
- Take about 10 minutes for assessment
- Hand yours in when finished
  - Will call time when most students are done

California State University Northridge

15

Thermodynamics, the science of energy and its transformations, provides two broad laws for energy processes. The first law of thermodynamics states that energy is conserved. The second law states that some energy (work) is better than other forms (heat) because heat cannot be completely converted to work in a cycle. Thus, work is a more valuable form of energy than heat.

A practical example of the value of different forms of energy can be found by the comparison of their costs. The electrical energy charge of $3x10-8/J listed above is an example of the cost of energy in the form of work. In contrast, one can examine the utility charge for fuel as a cost of heat. An example of a heat energy charge can be found from a bill by The Gas Company that charges its customers for each "therm" they use. A therm is defined as 100,000 Btu, which is approximately the amount of energy in 100 cubic feet of natural gas. (The conversion factor between Btu and joules is 1 Btu = 1,055.056 joules.) A December 2005 gas bill for a home in the San Fernando Valley charged $0.92815 per therm[3] or $9.2815 per million Btu. This is a cost of \$9x10^{-9}/J or about 30% of the cost of electricity.

[3] This is the base cost. Use of more therms than allowed in a base allocation costs $1.109 per therm.

What Is Energy?

- Dictionary definition
- Capacity to do work
- Energy resources
- Energy and power (energy/time) units
  - Energy units: joules (J), kilowatt·hours (kWh), British thermal units (Btu)
    - 1 Btu = 1055.056 J
  - Power units: watts (W), Btu/hr
    - 1 W = 1 J/s = 3.412 Btu/hr

California State University Northridge

16

Energy Units

As we have seen above, the Joule, which is the basic unit for energy in the SI system of units as a very small amount of energy compared to typical energy use rates. Typically one uses units of kJ, MJ, GJ, etc. to express practical amounts of energy. In addition to the use of Joules for representing energy there are two systems of units – calories and British thermal units or Btus that data back to the early 19th century before the realization that heat and work were actually two different kinds of energy and could be measured by the same units. Both the Btu and the calorie were defied as the amount of heat required to raise a unit mass of water one unit of temperature. Thus, the Btu and the calorie were defined in such a way that the heat capacity of water would be 1 cal/gm·K or 1 Btu/lbm·R. Since the heat capacity of water changes with temperature, we have to specify the temperature at which the calorie or Btu is defined. Depending on the temperature selected, one can obtain different definitions of the Btu or calorie.

Engineers typically use a reference temperature of 15°C or 59°F for the definition of the Btu and calorie. This is called the International Steam Table Calorie or IT calorie for short. One IT calorie is equal to approximately 4.1868 J. Another definition of the calorie, called the thermochemical calorie, is set be defining the calorie to be exactly 4.184 J, which is the heat capacity of water at about 17°C. The Btu is defined at a temperature of 15°C. Because the calorie and the Btu have been defined so that the heat capacity of water will be 1 Btu/lb_m·R or 1 cal/gm·K. These two unit combinations are equal.

Larger Units

- World energy production (2006) is 466×10^{15} Btu = 466 quads (quadrillion Btu) = 491×10^{18} J = 491 exajoules
- World electricity generation (2006) is 18,930 TWh (terawatt hours)
  - Shows that average worldwide power generation rate during the year was 2.16 TW or 0.33 kW per capita
  - http://www.onlineconversion.com/energy.htm

California State University Northridge

17

From the two definitions of calories, we can show that 1 Btu = 251.8272 (IT) cal. From the relationship between calories and joules we can also show that 1 Btu = 251.8272 cal. The approximate conversion factor that 1 Btu = 252 calories is correct (to three significant figures) for either definition of the calorie. Using the conversion factor that a Btu = 251.995 (IT) calories and one (IT) calorie = 4.1868 joules, gives the conversion factor that 1 Btu = 1,055.056 J.

The nutritional calorie used to measure the energy content of foods is actually 1000 (IT) calories. This is properly called a kilocalorie. Sometimes it is written as Calorie, with a capital C, to emphasize the difference between the original definition of the calorie and its use in nutritional applications.

The usual metric prefixes, kilo-, mega-, etc. are not typically used with Btu. In engineering applications the abbreviation M is often used to indicate a factor of 1000. Thus, the abbreviation MBtu would indicate one thousand Btu and the abbreviation MMBtu would indicate one million Btu. The unit of one million Btu is a common energy unit in engineering analysis and the cost of fuel at current prices ranges between $5 and $12 per million Btu.

Discussions of national and world energy use are often done in terms of quadrillion Btu, called quads for short, are used. World energy consumption in 2004 was 447 quads. A comparable unit is the exajoule; one exajoule is 1018 J. Because one Btu is about 1,055 J, the exajoule and the quad are approximately the same amount of energy. (Of course, the exact factor is that one quad is 1.055056 exajoules.)

Energy Costs

- Home costs (San Fernando Valley 2008)
  - Electricity: \$0.115/kWh = \$32/GJ
    - Increase from \$0.11/kWh to \$0.12/kWh
  - Natural gas: \$1.07/therm = \$11/GJ
    - One therm = 10^5 Btu is approximately the energy in 100 standard cubic feet of natural gas
    - Range was \$0.69 to \$1.22 per therm
  - Gasoline at \$3.00 per gallon (including taxes) costs \$26/GJ
    - Assumes energy content of gasoline is 5.204 MMBtu per (42 gallon) barrel
    - \$100/bbl oil costs \$6.20/GJ (5.80 MMBtu/bbl)
  - Energy cost without California gasoline taxes (\$0.585/gallon) is \$21/GJ

California State University Northridge 18

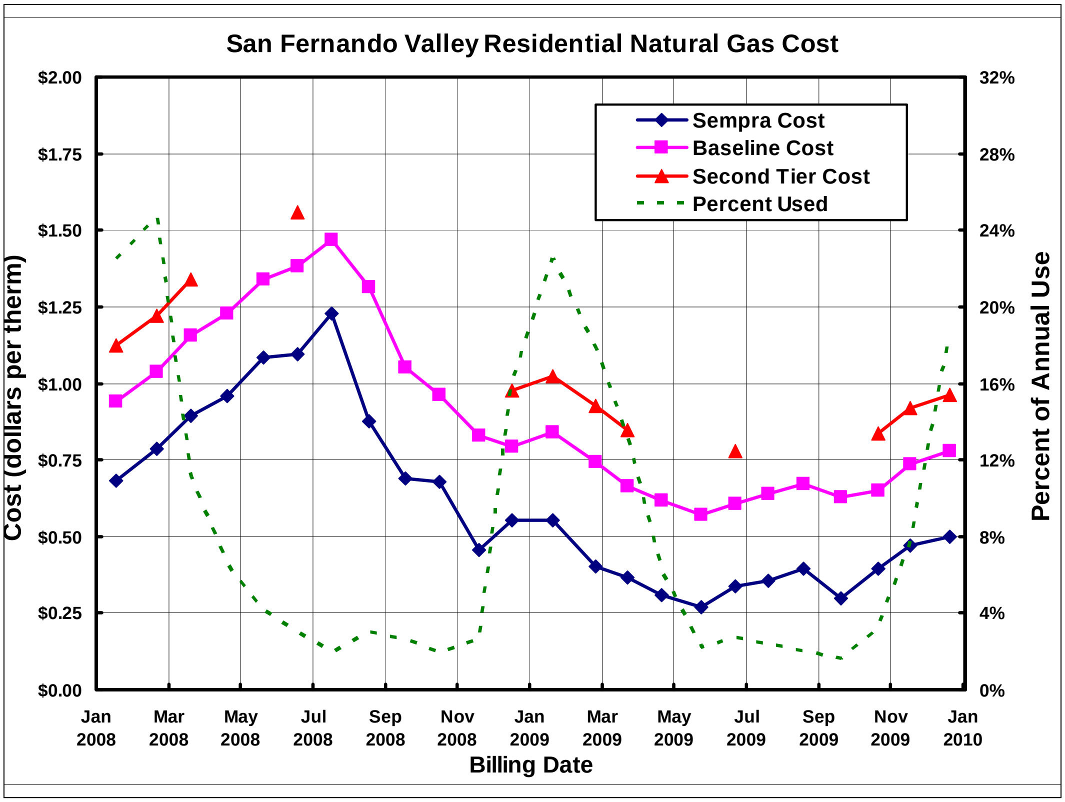
Large-scale electrical energy use is typically reported in units like terawatt-hours or terawatt-years (TWy). (One terawatt, TW, is 10^{12} watts; since there are 8,760 hours in the 365-day year, one terawatt year is 8.76×10^{12} kWh.) The annual world energy consumption is approximately 400 quads or 400 exajoules. The annual world consumption of electricity is about 2 TWy.

Another way of reporting large scale energy use is to equate it to a certain amount of fuel. For example the International Energy Agency reports all energy use statistics in million metric tons of oil equivalent. We will consider this measure further after first considering the energy content of fuels.

Energy content of fuels

In calculating costs of heat energy above, we said that The Gas Company charges for the heat energy in the gas it sells. This is the combustion energy, which is a thermodynamic internal energy due to chemical change. Heat content of fuels is usually expressed as the enthalpy change when a mass of fuel reacts form ultimate combustion products at the same temperature as the fuel and oxidizer. The amount of oxidizer in the reaction used for calculating the heat content is called the stoichiometric amount; this is exactly the amount required for the complete combustion of the fuel into the ultimate combustion products. For example, methane, which is the principal component of natural gas, has a stoichiometric complete combustion reaction given by the following chemical balance equation.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad \text{[Reaction 1]}$$



Energy content of fuels continued on next notes page

The chart above shows the monthly cost of natural gas. The homeowner is billed at two levels: the baseline unit, a lower consumer price, is allowed for a certain amount of gas. This amount depends on the climate zone and the month of the year. If a homeowner uses more than this baseline, a higher charge is made for the additional energy above the baseline.

The gas bills also show the wholesale energy cost paid by Sempra utilities, the parent company of The Gas Company. Of course, this cost is lower than the cost paid by the ultimate user.

In addition to the energy charges shown here and on the previous slide (the data on the previous slide were for baseline costs), the customer is also billed a use charge of $0.16438 per day. There are also various fees and taxes that are added to the final bill. With all these charges, the total cost ranged from $1.07 per therm to $2.20 per therm with an annual average of $1.39 per therm.

The electricity cost shown on a homeowner's bill from the Los Angeles Department of Water and Power simply gives a total cost per kilowatt-hour. During 2008 this cost increased as shown on the previous slide.

Energy content of fuels continued on next notes page.

Thermodynamics

- First law: Energy is conserved
- Second law: Cannot convert heat completely to work in a cycle
  - Work energy (including electricity) is more valuable than heat energy
  - Chemical energy in fuels is usually converted to heat then to work
  - Fuel cells that directly convert fuel energy to electricity are more efficient

California State University Northridge

20

The difference in enthalpy between the products – CO2 + 2 H2O (as liquid water) – and the reactants (CH_4 + $2O_2$), at 25°C and atmospheric pressure is -55,496 kJ/kg. This enthalpy change for the reaction is negative, indicating that heat is released, as expected. The value of the enthalpy change for combustion is equal to -23,859 Btu/lb_m. In the thermodynamic sign convention for heat, a negative heat transfer means that head is transferred from the system. Thus the combustion equation shown above has a heat release of 23,859 Btu per pound of methane when the product is liquid water.

The calculation when the water in the combustion products is a liquid is called the higher or gross heating value. If the water in the products is in the form of water vapor, a smaller amount of energy is released in the reaction. The resulting energy release is called the lower or net heating value. The difference between the gross and net heating value is simply the amount of energy released when the water vapor in the combustion products is condensed. The reaction in equation [1] produces two moles (2*18.01528 kg) of water for each mole (16.04246 kg) of methane. Since the latent heat of water at 25 C is 2,442.79 kJ/kg, the difference between the gross and net heating value is found as follows: (36.03056 kg H_2O / 16.04246 kg CH_4) * (2,442.79 kJ / kg H_2O) = 5486.38 kJ/kg CH_4.

Subtracting this energy from the gross heating value of 55,496 kJ/kg gives the net heating value as 50,010 kJ/kg or 21,500 Btu/lbm.

Fuel Energy

- Based on complete reaction of fuel to ultimate products using stoichiometric oxygen (exact amount required)
  - Enthalpy change for reactants and products at same temperature (typically 25°C)
  - E. g.: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ has enthalpy change of –55,496 kJ/kg CH_4 when product water is liquid
    - Negative Δh indicates heat removed from system of fuel plus oxidizer

California State University Northridge

21

As noted in the discussion of energy costs above, the therm, which is the unit used for natural gas sales, is approximately the energy content of 100 ft^3 of natural gas. The measure of 100 cubic feet (abbreviated as HCF or CCF) was the traditional billing unit for natural gas delivered to residential and commercial users prior to the 1970s. and it is still be basic unit in which domestic gas deliveries are measured. We can show this by using the density of methane, measured at a standard temperature of 60°F, which is 0.042269 lb_m/ft^3. Multiplying 23,859 BTU/lb_m by this density shows that the chemical energy content (higher heating value) of one cubic foot of methane (at 60°F and atmospheric pressure) is 1,008 BTU/ft^3.

Actual natural gas may have a slightly higher energy content than this due to amounts of higher molecular weight hydrocarbons that have a greater heating value per unit volume; the value may be also be lower due to the presence of inert gases with no energy content. Note that this equivalency is based on the use of the higher heating value.

Although we can compute the energy content of pure compounds exactly, the energy content of practical fuels such as oil, natural gas, and coal varies with the particular source of the fuel. Nevertheless, one often sees energy represented as an equivalent amount of fuel. This is based on some assumed average energy content of the fuel. (For actual calculations the energy content of the fuel is measured in a device called a calorimeter.)

Fuel Energy II

- Heat of combustion for methane is 55,496 kJ/kg = 23,859 Btu/lb_m
  - With product water as liquid, this is called the higher (gross) heating value, HHV
  - Product water as vapor gives the lower (net) heat of combustion or lower heating value (LHV) = 50,010 kJ/kg = 21,500 Btu/lb_m
    - Use of higher or lower heating value in efficiency and statistics based on convention
    - Use LHV in calculations with product water vapor

California State University Northridge

22

For example, the International Energy Agency (IEA) uses metric tons (tonnes) of oil equivalent as a unit for reporting energy statistics. The IEA defines this as 107 (IT) kilocalories heating value. This is 41.868 GJ or 39.6853 million Btu. Since one metric ton (or tonne) is 1000 kg, the implied heating value of the "equivalent" oil is 18,001 Btu/lbm. The IEA reports national energy use in national, regional and world statistics in Million Tonnes Oil Equivalent (Mtoe). One Mtoe is defined as 41.868×10^{15} J = 41.868 PJ, where 1 PJ = 1 petajoule = 10^{15} J. At a conversion factor of 1055.054 J/Btu, one Mtoe = 39.683×10^{12} Btu = 0.039685 quads. This is not a set conversion factor. The BP energy statistics workbook states the equivalence as 1 Mtoe = 40.4×10^{12} Btu, a discrepancy of about 2%.

Energy units are often listed on a per-unit-volume basis as well. This requires the knowledge of the fuel density. Typical hydrocarbon liquid fuels have a density of about 7 pounds per gallon (U. S.). Thus a crude oil with a lower heating value of 18,000 Btu/lbm would have 126,000 Btu/gallon. In the petroleum industry, one barrel contains 42 gallons. Thus, the energy in a barrel of this fuel would be 5.3 million Btu. The table below shows some date on the energy content of fuels; these data are based on the higher heating value. As a rule of thumb, the lower heating value is about 93% of the higher heating value of typical liquid hydrocarbon fuels.

Energy Information Administration Data on "Heat Rates"	
Coal MMBtu/ton Production: 21.070 Consumption: 20.753 Coke 27.426 Industrial: 22.489 Residential and Commercial: 23.880 Electric Utilities: 20.401 **Crude Oil MMBtu/bbl** Production: 5.800 Imports: 5.948 **Electricity Consumption: .** Btu per kilowatt-hour 3,412	**Petroleum Products MMBtu/bbl** Motor Gasoline: 5.204 Jet Fuel: 5.670 Distillate Fuel Oil: 5.825 Residual Fuel Oil: 6.287 Liquefied Petroleum Gas (LPG): 3.603 Kerosene: 5.670 **Natural Gas Btu/ft^3** Production, Dry: 1,027 Consumption: 1,027 Non-electric Utilities: 1,028 Electric Utilities: 1,019 Imports: Btu per cubic foot 1,022 Exports: Btu per cubic foot 1,006
Energy Information Administration (EIA), *Annual Energy Review 2000*, DOE/EIA-0384(2000) (Washington, DC, August 2001)	

Coal million Btu per short ton

Production: 21.070 Consumption: 20.753
Coke Plants: 27.426 Industrial: 22.489
Residential and Commercial: 23.880 Electric Utilities: 20.401
Imports: 25.000 Exports: 26.081

Coal Coke million Btu per short ton: 24.800

Crude Oil million Btu per barrel

Production: 5.800 Imports: 5.948

Electricity Consumption: Btu per kWh 3,412

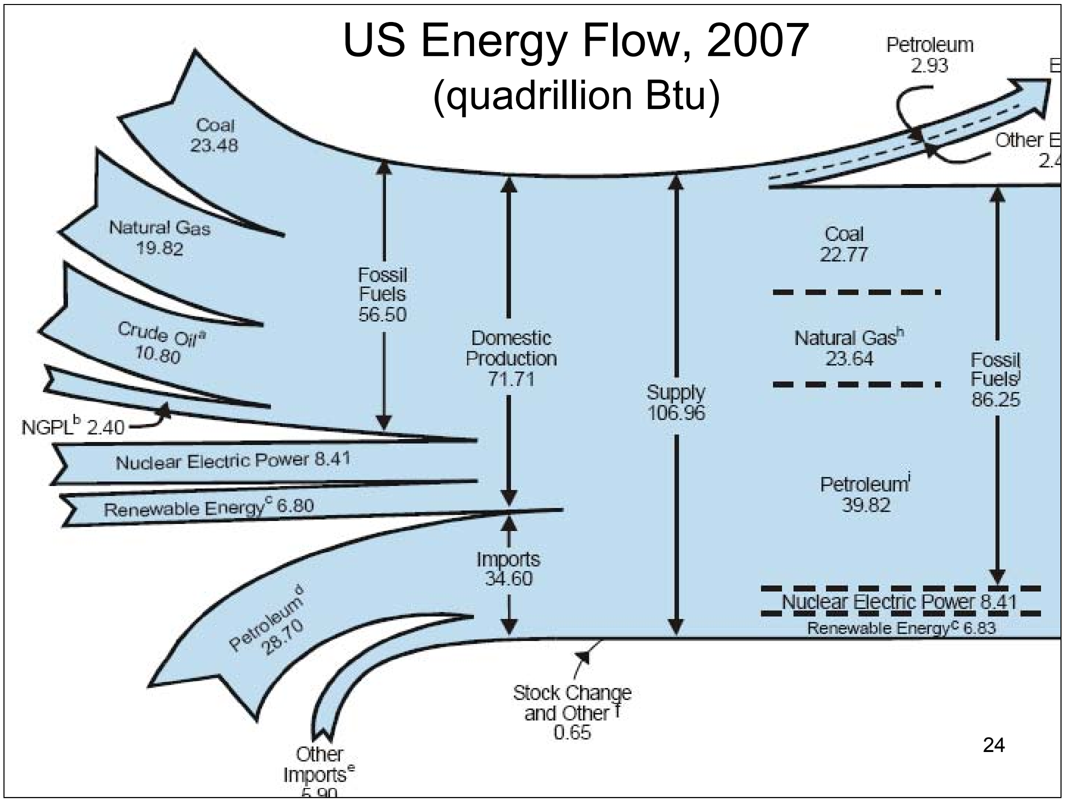
Petroleum Products million Btu per barrel

Consumption: 5.336 Motor Gasoline: 5.204
Jet Fuel: 5.670 Distillate Fuel Oil: 5.825
Residual Fuel Oil: 6.287 Liquefied Petroleum Gas: 3.603
Kerosene: 5.670 Petrochemical Feedstocks: 5.545
Unfinished Oils: 5.825 Imports: 5.326 Exports: 5.749

Natural Gas Plant Liquids Production million Btu per barrel: 3.887

Natural Gas Btu per cubic foot

Production; 1,027 Consumption: 1,027 Electric Utilities: 1,019
Non-electric Utilities: 1,028 Imports: 1,022 Exports: 1,006



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_3.pdf

Energy flow in the US in 2007 from EIA Annual Energy Review 2008 (1/2)

Footnotes:

(a) Includes lease condensate

(b) NGPL = natural gas plant liquids

(c) Conventional hydroelectric power, wood, waste, ethanol blended into gasoline, geothermal, solar, and wind.

(d) Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.

(e) Natural gas, coal, coal coke, and electricity.

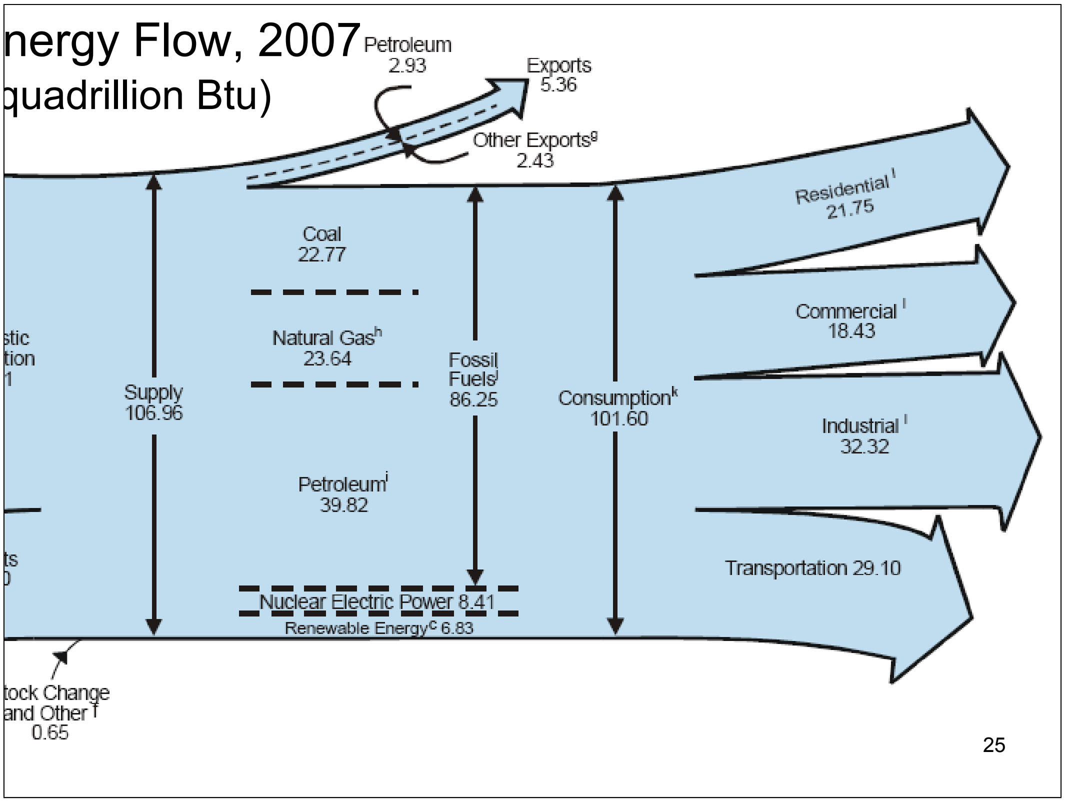
(f) Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.

(g) Coal, natural gas, coal coke, and electricity.

(h) Includes supplemental gaseous fuels.

(i) Petroleum products, including natural gas plant liquids.

(j) Includes 0.04 quadrillion Btu of coal coke net imports.



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_3.pdf

Energy flow in the US in 2007 from EIA Annual Energy Review 2008 (2/2)

Footnotes:

(c) Conventional hydroelectric power, wood, waste, ethanol blended into gasoline, geothermal, solar, and wind.

(d) Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.

(e) Natural gas, coal, coal coke, and electricity.

(f) Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.

(g) Coal, natural gas, coal coke, and electricity.

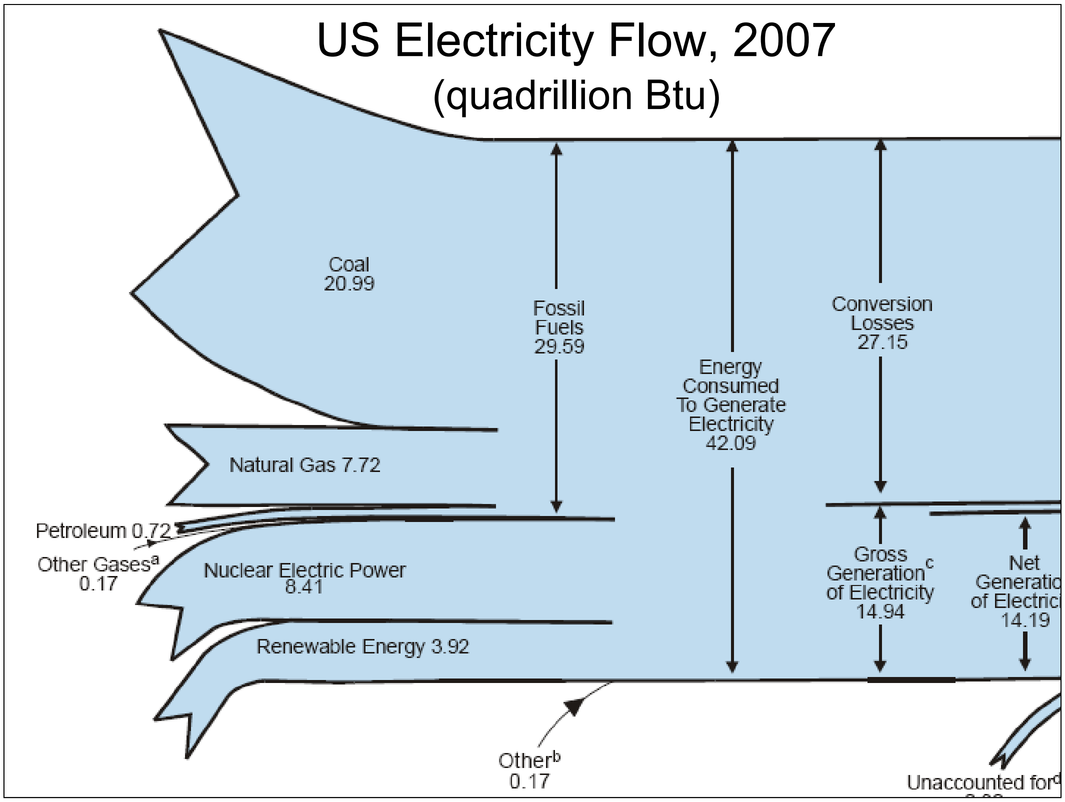
(h) Includes supplemental gaseous fuels.

(i) Petroleum products, including natural gas plant liquids.

(j) Includes 0.04 quadrillion Btu of coal coke net imports.

(k) Includes, in quadrillion Btu, 0.34 ethanol blended into motor gasoline, which is accounted for in both fossil fuels and renewable energy but counted only once in total consumption; and 0.08 electricity net imports.

(l) 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.



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec8_3.pdf, accessed January 2, 2009.

Electrical energy flow in the US in 2007 from EIA Annual Energy Review 2008 (1/2)

Renewable energy is mainly conventional hydroelectric power. Inputs of hydroelectric, wind, and solar photovoltaic power are adjusted by heat rates for steam-electric power to show energy that would be required if these direct conversion energies were not available. Nuclear input represents heat generated in nuclear reactors.

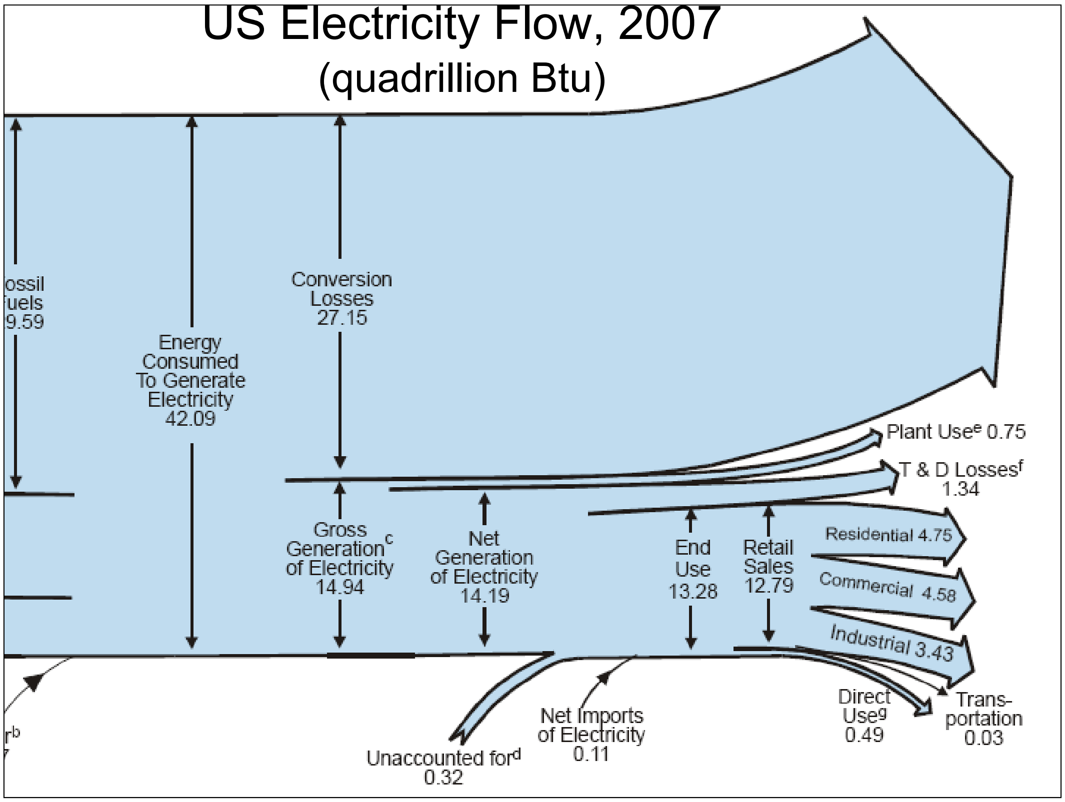
Footnotes:

(a) Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

(b) Batteries, chemicals, pitch, hydrogen, purchased steam, sulfur, and miscellaneous technologies.

(c) Estimated as net generation divided by 0.95.

(d) Data frame collection 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. (This is a quote; I am not really sure what these terms mean.)



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec8_3.pdf, accessed January 2, 2009.

Electrical energy flow in the US in 2007 from EIA Annual Energy Review 2008 (2/2)

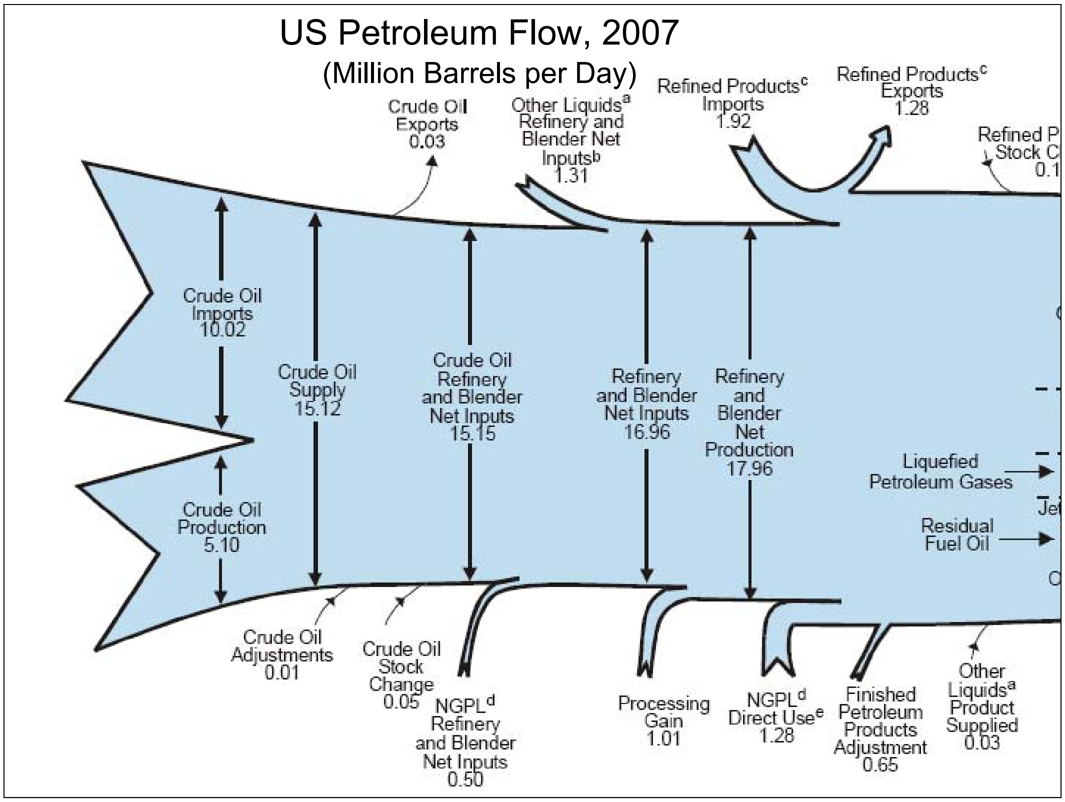
Renewable energy is mainly conventional hydroelectric power. Inputs of hydroelectric, wind, and solar photovoltaic power are adjusted by heat rates for steam-electric power to show energy that would be required if these direct conversion energies were not available. Nuclear input represents heat generated in nuclear reactors.

Footnotes:

(e) Electrical generation used in operation of power plants estimated as 5% of gross generation.

(f) Transmission and distribution losses (between generation and delivery to customer) as estimated as 9% of gross generation.

(g) 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.



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec5_3.pdf, accessed January 2, 2009.

Petroleum energy flow in the US in 2007 from EIA Annual Energy Review 2008 (1/2)

Note that the units here are volume units (million barrels per day or MMBPD) not energy units. (1 MMBPD crude oil = 2.12 quads/yr.) The “processing gain” of 1.00 MMBPD shown at the bottom near the center of the figure is due to the lower densities of finished products compared to crude oil; there is actually an energy loss due to the processing of the crude.

Footnotes:

(a) Unfinished oils, other hydrocarbons/hydrogen, and motor gasoline and aviation gasoline blending components.

(b) Net imports (1.41) and adjustments (-0.05) minus stock change (0.02) and product supplied (0.03).

(c) Finished petroleum products, liquefied petroleum gases, and pentanes plus.

(d) Natural gas plant liquids.

(e) Production minus refinery input.

Notes:

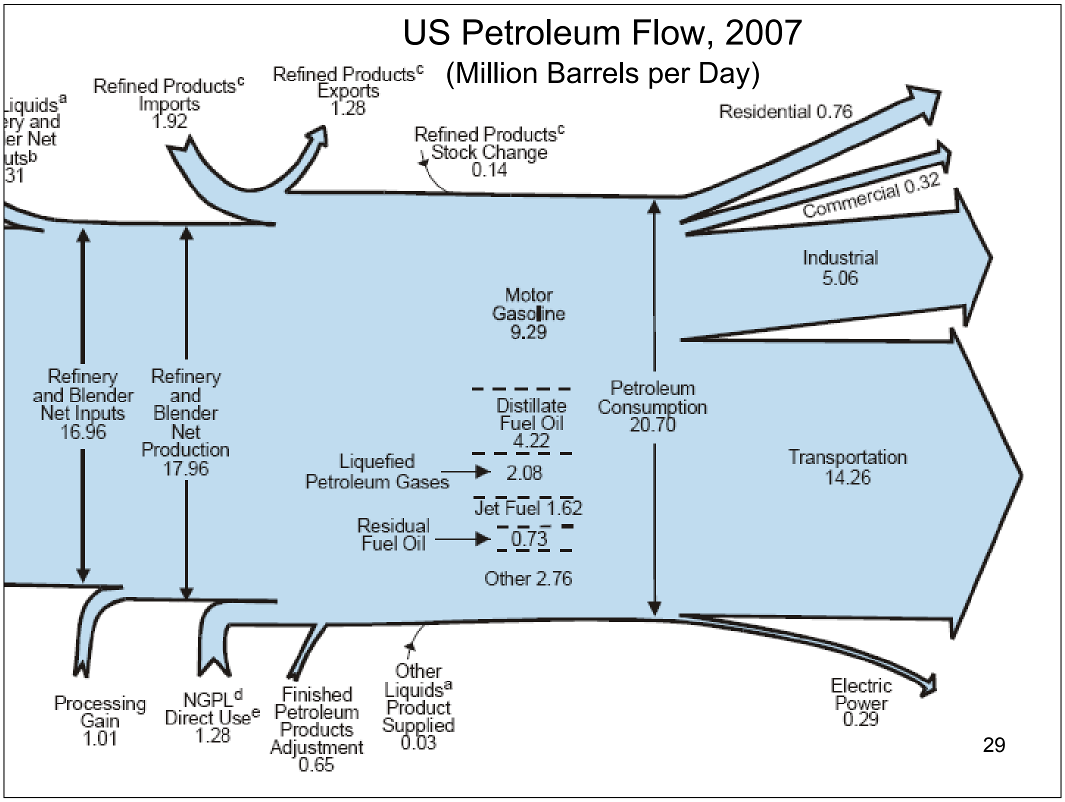
• Data are preliminary.

• Values are derived from source data prior to rounding for publication.

• Totals may not equal sum of components due to independent rounding.

Sources: Tables 5.1, 5.3, 5.5, 5.8, 5.11, 5.13a-5.13d, 5.16, from 2008 *Annual Energy Report* and *Petroleum Supply Monthly,*

February 2008, Table 4.



http://www.eia.doe.gov/emeu/aer/pdf/pages/sec5_3.pdf, accessed January 2, 2009.

Petroleum energy flow in the US in 2007 from EIA Annual Energy Review 2008 (2/2)

Note that the units here are volume units (million barrels per day or MMBPD) not energy units. The “processing gain” of 1.01 MMBPD shown at the bottom near the center of the figure is due to the lower densities of finished products compared to crude oil; there is actually an energy loss due to the processing of the crude.

Footnotes:

(a) Unfinished oils, other hydrocarbons/hydrogen, and motor gasoline and aviation gasoline blending components.

(b) Net imports (1.41) and adjustments (-0.05) minus stock change (0.02) and product supplied (0.03).

(c) Finished petroleum products, liquefied petroleum gases, and pentanes plus.

(d) Natural gas plant liquids.

(e) Production minus refinery input.

Notes:

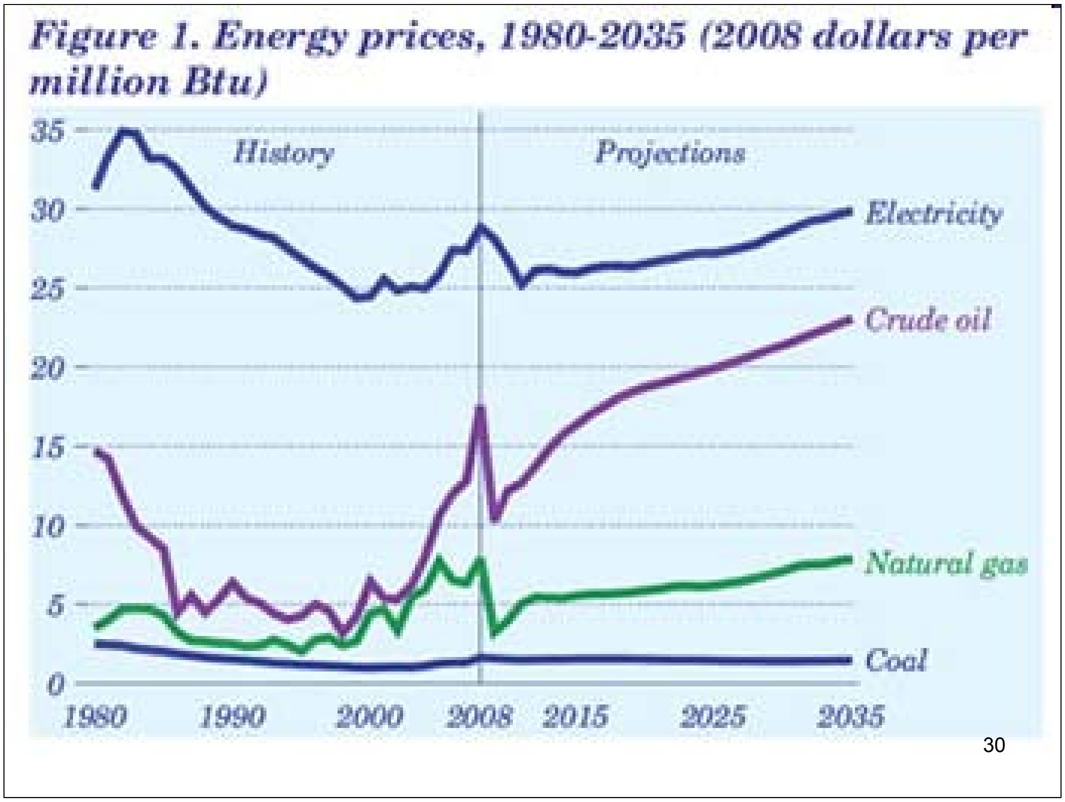
• Data are preliminary.

• Values are derived from source data prior to rounding for publication.

• Totals may not equal sum of components due to independent rounding.

Sources: Tables 5.1, 5.3, 5.5, 5.8, 5.11, 5.13a-5.13d, 5.16, from 2008 *Annual Energy Report* and *Petroleum Supply Monthly,*

February 2008, Table 4.

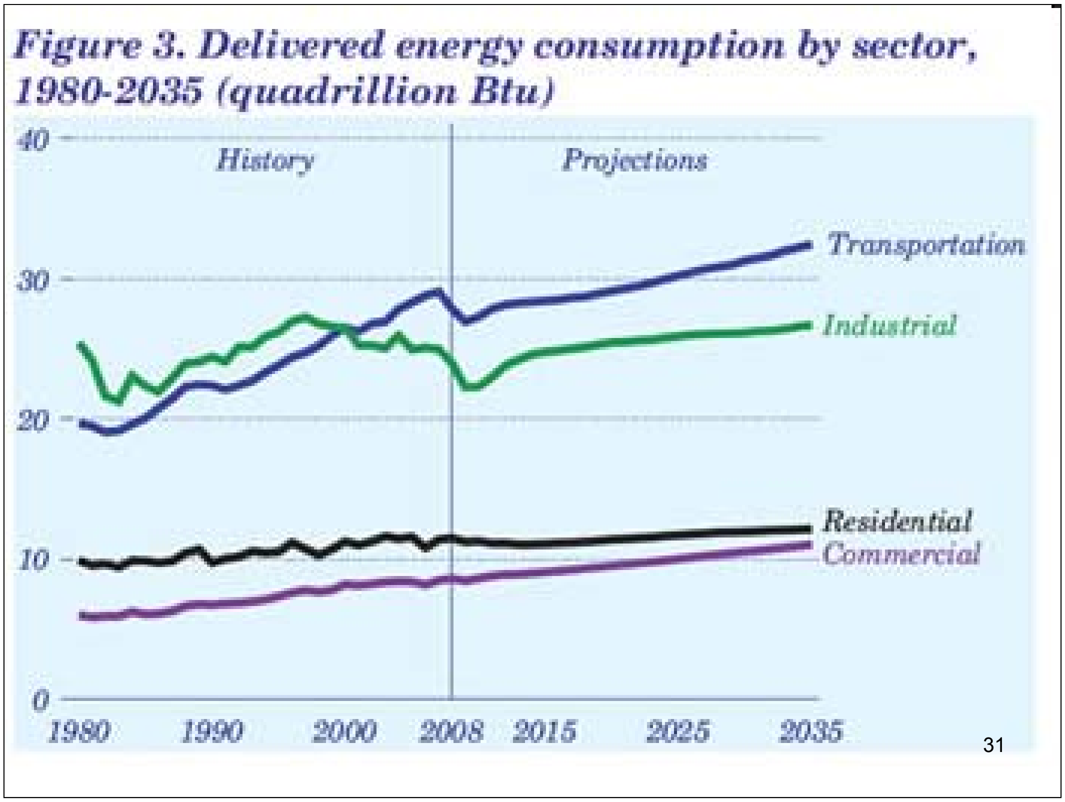


Energy Information Agency – Annual Energy Outlook 2010 Early release data http://www.eia.doe.gov/oiaf/aeo/overview.html

Use of cost per unit energy allows comparison of different fuels.

Electricity has highest cost because of second law efficiency limitations. Declining electricity costs between 1980 and 2005 were due to improvements in efficiency while fuel costs (mainly natural gas and coal) were generally the same.

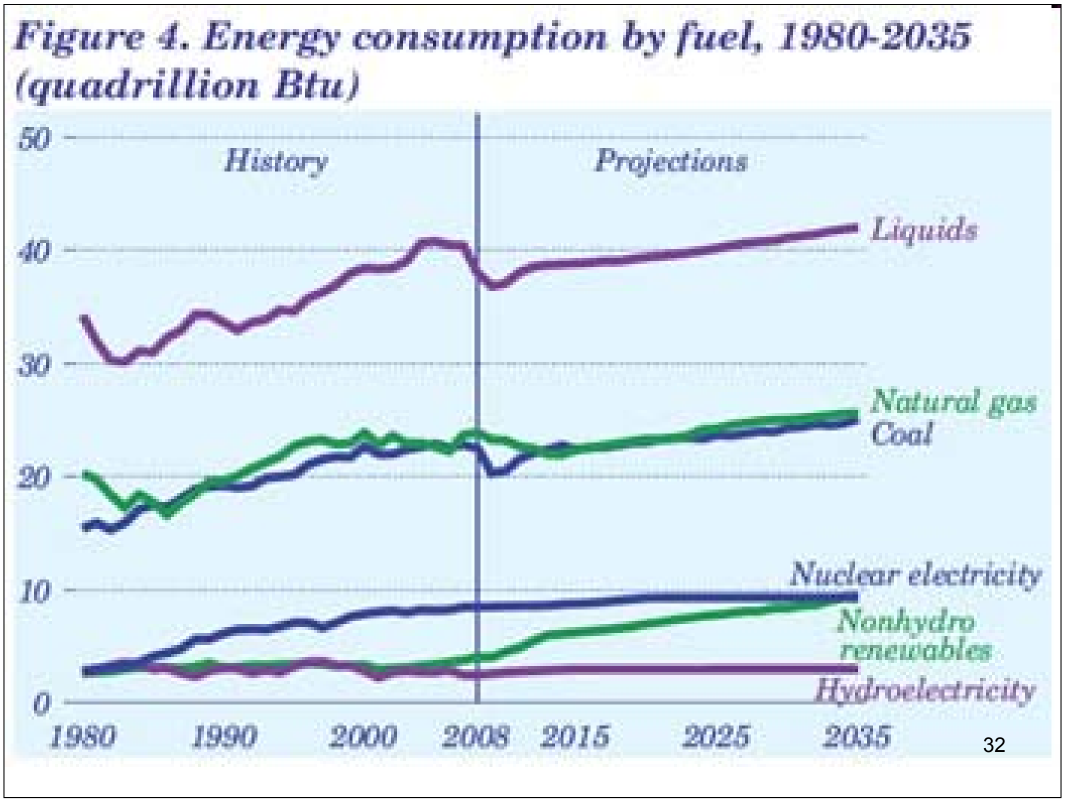
How valid do you think the long-term projections are? Note the smoothness of the projections compared to the sharp fluctuations in cost in recent years.



Energy Information Agency – Annual Energy Outlook 2010 Early release data http://www.eia.doe.gov/oiaf/aeo/overview.html

These are the same end-use sections that we have seen on previous charts. Note that all such charts consider electrical energy as a pass-through. The electricity consumption of the various sections includes the direct fuel-energy use and the fuels used to generate the electricity for each sector.

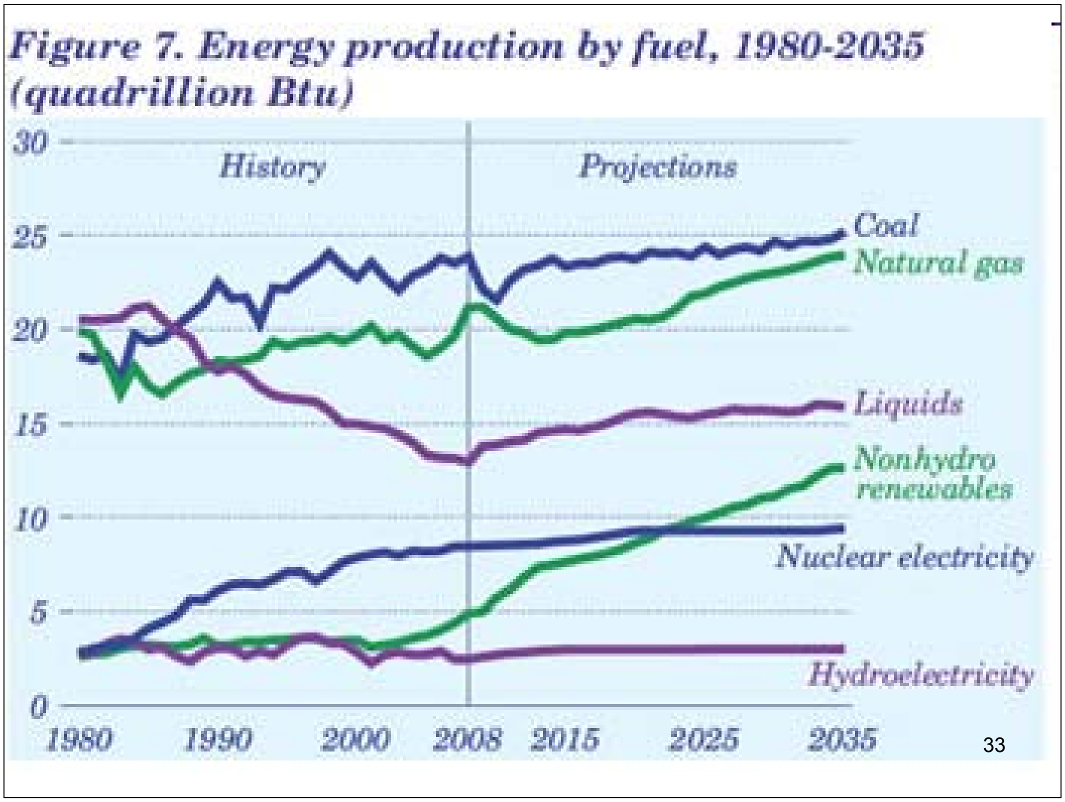
The forecast for transportation fuels is much less than the forecast in the 2007 Annual Energy Outlook. This is due to new regulations proposed for motor vehicle fuel economy since the 2007 Annual Energy Outlook.



Energy Information Agency – Annual Energy Outlook 2010 Early release data
http://www.eia.doe.gov/oiaf/aeo/overview.html

Here is our first view of alternative energy sources. Note the relatively small contribution compared to all other sources. However, a dramatic increase in nonhyrdo renewable energy is forecast in this chart. The forecast value for 2030 is about twice the amount forecast in the 2007 Annual Energy Outlook.

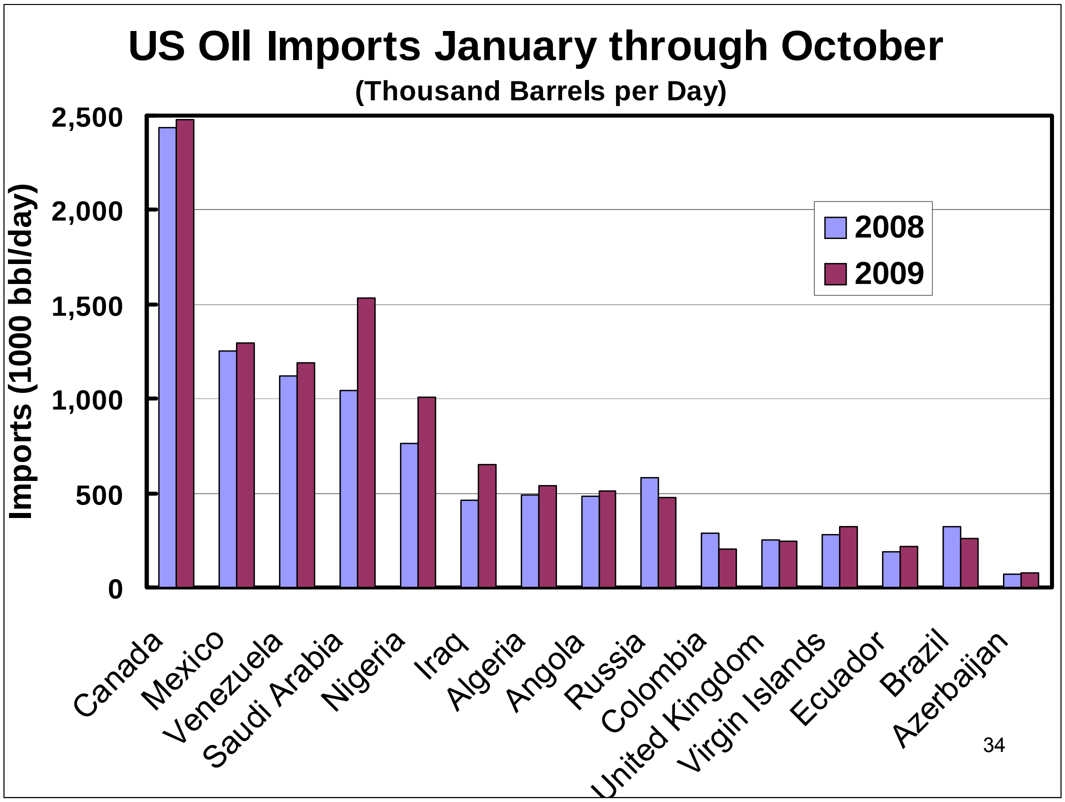
There are additional differences between the two forecasts. Liquid fuel use in the outlying years is forecast to be much lower in the 2010 AEO than it was in the 2007 AEO. Again, this is due to the expected regulations on motor vehicle fuel economy. The 2007 AEO forecast for natural gas and coal is similar to the one in the 2010 forecast (shown in the chart) for coal and natural gas up to 2025. Beyond that time the use of coal was forecast to increase (compared to natural gas). The 2010 AEO forecast (shown here) predicts similar use rates for coal and natural gas in the final years of the forecast.



Energy Information Agency – Annual Energy Outlook 2010 Early release data http://www.eia.doe.gov/oiaf/aeo/overview.html

A comparison of chart with the previous one shows the impalance in the US energy production and consumption. This is most apparent in the liquid fuels. Here the production is seen to decrease. The pervious chart shows that the consumption, already higher than production, is forecast to increase. Despite the projected reductions in liquid fuels from new fuel economy standards, there will be an increase in oil imports in the future. However, this increase is less than it would be without the new fuel-economy standards.

The projected production and consumption of hydroelectric power and nuclear energy are the same. The production of renewable energy are higher than the consumption, indicating that some of the renewable energy will be exported.



Plotted from Energy Information Agency data downloaded January 11, 2010 http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/company_level_imports/current/import.html

Although people often think that oil imports come from the Middle East, this chart shows that much of the US imported oil comes from countries outside the Middle East. Our nearest neighbors, Canada and Mexico are the main sources of imported oil. Venezuela, whose president, Hugo Chavez, demonizes the US, is one of the leading importers of oil to the US

IEA 2006 Energy Data

Region/ Country/ Economy	Popu-lation (million)	GDP (billion 2000$)	GDP (PPP) (billion 2000$)	Energy prod. (Mtoe)	Net imports (Mtoe)	TPES (Mtoe)	Elec. cons.[a] (TWh)	CO_2 emissions[b] (Mt of CO_2)
World	6536	37759	57564	11796	-	11740[c]	17377	28003[d]
OECD	1178	29169	31158	3842	1845	5537	9872	12874
Middle East	189	838	1456	1529	-990	523	599	1291
Former USSR	284	568	2266	1610	-577	1017	1274	2395
Non-OECD Europe	54	162	477	64	45	108	171	271
China	1319	2315	8916	1749	161	1897	2716	5648
Asia	2120	2139	7661	1187	176	1330	1414	2718
Latin America	455	1796	3425	704	-169	531	808	972
Africa	937	773	2207	1110	-489	614	522	854

California State University Northridge

35

Reference: http://www.iea.org/textbase/nppdf/free/2006/key2006.pdf

Abbreviations:

GDP = Gross Domestic Product: The final value of all goods and services produced in a country or region. GDP data are expressed in US dollars adjusted for inflation to the year 2000.

GDP (PPP) = GDP at Purchasing Power Parity = GDP adjusted to account for the cost of living in a country or region. Areas with a lower cost of living will have a higher ratio of GDP(PPP) to GDP

Mtoe = Million tonnes of oil equivalent. 1 Mtoe = 41.868×10^{15} J = 41.868 PJ = 39.685×10^{12} Btu = 0.039685 quads

TPES = Total primary energy supply = indigenous production + imports – exports – international marine bunkers ± inventory changes.

Footnotes:

(a) Electricity Consumption = Electricity Production + Imports – Exports – Transmission and distribution losses; units are terawatt·hours

(b) CO_2 emissions from fuel combustion only; units are megatonnes = 10^9 kg

(c) TPES for world includes international marine bunkers

(d) CO_2 emissions for world include international aviation and international marine bunkers

IEA 2006 Energy Ratios

TPES/ pop (toe/capita)	TPES/ GDP (toe/000 2000$)	TPES/ GDP (PPP) (toe/000 2000$ PPP)	Elec. cons./pop (kWh/ capita)	CO_2/ TPES (t CO_2/ toe)	CO_2/ pop (t CO_2/ capita)	CO_2/ GDP (kg CO_2/ 2000$)	CO_2/ GDP (PPP) (kg CO_2/ 2000$ PPP)	Region/ Country/ Economy
1.80	0.31	0.20	2659	2.39	4.28	0.74	0.49	World
4.70	0.19	0.18	8381	2.32	10.93	0.44	0.41	OECD
2.76	0.62	0.36	3163	2.47	6.82	1.54	0.89	Middle East
3.58	1.79	0.45	4481	2.35	8.42	4.22	1.06	Former USSR
2.02	0.67	0.23	3199	2.51	5.07	1.67	0.57	Non-OECD Europe
1.44	0.82	0.21	2060	2.98	4.28	2.44	0.63	China
0.63	0.62	0.17	667	2.04	1.28	1.27	0.35	Asia
1.17	0.30	0.15	1777	1.83	2.14	0.54	0.28	Latin America
0.66	0.79	0.28	557	1.39	0.91	1.10	0.39	Africa

California State University Northridge

36

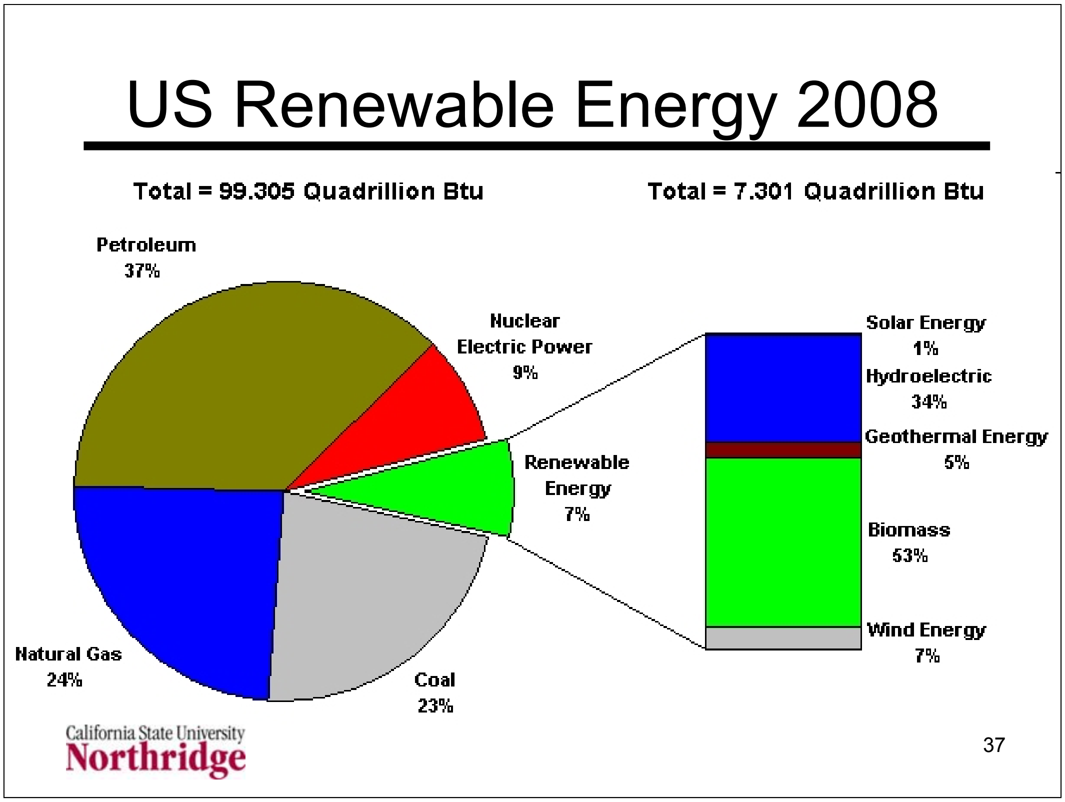
Reference: http://www.iea.org/textbase/nppdf/free/2008/key2008.pdf

This chart shows the differences between industrialized countries in the OECD and regions with a large number of developing countries or regions such as Asia and Africa. Even within these regions there are significant differences among countries. In Africa, Eritrea has a TPES/Population ratio of 0.15 Mtoe per capita and South Africa has a ratio of 2.74. In Asia, Bangladesh has a TPES/Population ratio of 0.16 Mtoe per capita and Chinese Taipei (Taiwan) has a 4.74 ratio.

The largest ratio is 22.07 Mtoe per capita in Qatar. The world's two largest countries, China and India, have ratios of 1.43 and 0.51, respectively.

A random selection of Mtoe per capita ratios for various countries is shown below:

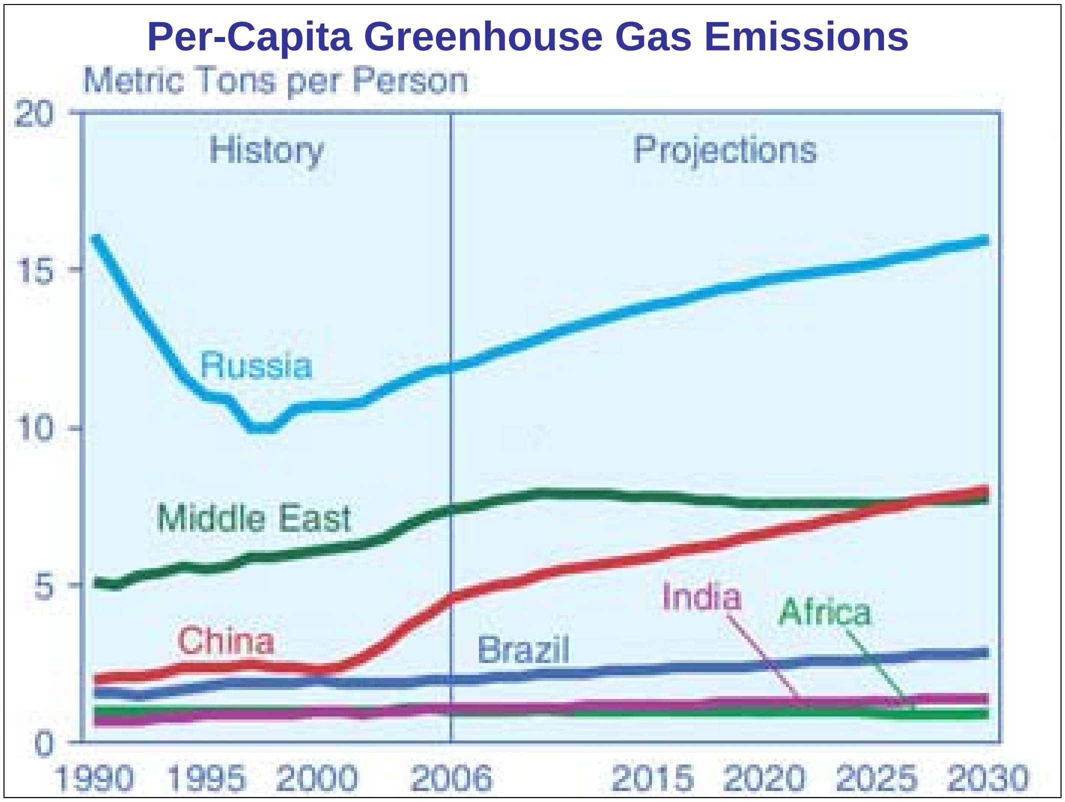
United States	7.74
Haiti	0.27
Japan	4.13
Canada	8.27
France	4.31
Germany	4.23
Luxembourg	9.96
Singapore	6.84
United Kingdom	3.82



Data from Energy Information Agency web site downloaded january 11, 2009 http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html

Renewable energy consists mainly of two long time energy sources: hydroelectric power and biomass fuels. Biomass fuels include alcohol fuels for gasoline engines, biodiesel, industrial waste (the largest component) agricultural waste and municipal waste.

Note that although renewable energy was 7% of the total US comsumption in 2008, solar energy was only 1% of that 7% or 0.07% of the total energy consumed in the US in 2008. Wind energy was seven times that amount or about 0.5% of the US energy consumption for 2008.



Data from Energy Information Agency downloaded January 11, 2010:

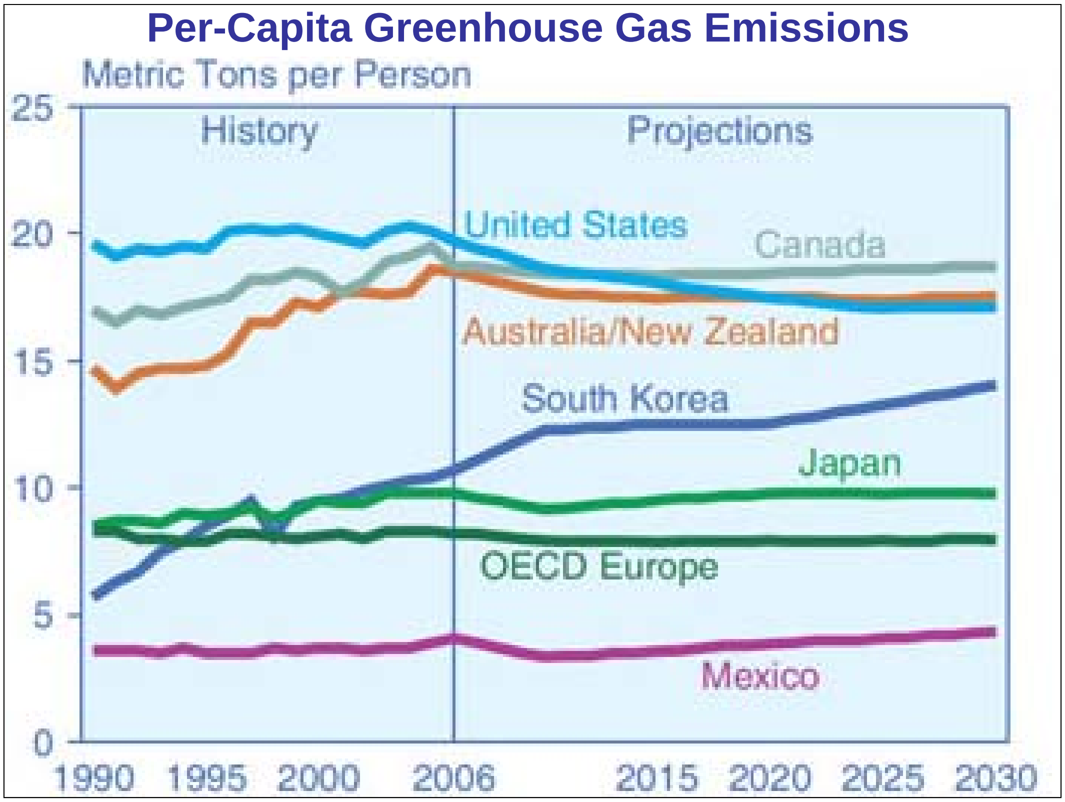
http://www.eia.doe.gov/oiaf/ieo/emissions.html

These data are all for non-OECD countries that have lower economic output than the US and Europe.

The data are tor total greenhouse gas emissions expressed as equivalent mass oc CO_2. Although CO_2 is the most significant greenhouse gas, other important greenhouse gases are methane and nitrous oxide (N_2O). The mass of various greenhouse gases are multiplied by the ratio of the greenhouse gas potential of the gas divided by the greenhouse gas potential of CO_2.

Although a country that has a low per-capita emission rate can claim that it las a low impact relative to its population, it can have a significant impact if tis population is large. For example, China, with a population of 1.326 billion people would have total greenhouse gas emissions of 8 billion metric tons per year in 2035 if it reaches a forecast emission level of 6 metric tons per person per year.

Note that all these non-OECD countries have per-capita emissions below 10 metric tons per person per year.



Data from Energy Information Agency downloaded January 11, 2010:

http://www.eia.doe.gov/oiaf/ieo/emissions.html

These data are all for OECD countries that have economic outputs similar or slightly less than the US and Europe.

The data are tor total greenhouse gas emissions expressed as equivalent mass oc CO_2. Although CO_2 is the most significant greenhouse gas, other important greenhouse gases are methane and nitrous oxide (N_2O). The mass of various greenhouse gases are multiplied by the ratio of the greenhouse gas potential of the gas divided by the greenhouse gas potential of CO_2.

Note that all these OECD countries have per-capita emissions about10 metric tons per person per year or more. Contrast this with the emissions for non-OECD countries on the previous chart.