Market Penetration of Biomass Fuels for Electricity Generation

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Introduction

Today, biomass accounts for only about 1% of the fuel used for electricity generation in the U.S.; whereas coal alone accounts for more than 50%, and nuclear, natural gas, hydro and petroleum explain for about 20%, 16%, 7% and 3% respectively. Recently, interests in biomass for energy generation has arisen due to a number of factors such as, increases in crude oil prices, issues regarding the Middle East stability and concerns for climate change as combustion of fossil fuels is considered to be to be the largest contributing factor to the atmospheric release of greenhouse gases (GHG), which the Intergovernmental Panel on Climate Change (IPCC) proclaimed was the main cause of global warming. The use of biomass fuels for electricity generation can play an important role in reducing GHG emissions because biomass based fuels recycle atmospheric carbon, first absorbing it through photosynthesis then later releasing it through combustion. This reduces GHG emissions relative to fossil fuel use and hence the risk of global warming impacts can be reduced through the use of biomass fuels.

To determine what role biomass fuels can play in the future of electric power generation, this paper explores the influence of factors on future of biomass fuel consumption in the U.S. electric power sector: the price of fossil fuels such as coal, natural gas and petroleum, the rate of capital stock turnover for existing stocks of fossil power plants, and changes in technologies which could facilitate the use of biomass as fuels for electricity generation.

Background on Biomass Fuels

Biomass fuels as defined herein are any fuels that derive from agricultural and forestry biomass. There are many forms of agricultural and forestry biomass that can be used to create energy. Biomass can be used in creating electric power, heat, ethanol or biodiesel. Biomass fuels typically used for fueling electric power plants or heat producing processes include the following:

- Agricultural crop residues ─ corn stover, wheat straw, sugar cane bagasse, rice husks etc.
- Forest residues ─ logging residues and salvageable dead wood along with milling residues.

- Energy crops ─ switchgrass, willow and poplar.
- Urban wood wastes ─ wood pallets and products of demolition.
- Animal manure and associated methane emissions.

At present, residues from agriculture and forestry processing operations are the largest power related biomass sources. In terms of residues used most are employed to generate electricity or process heat in cogeneration systems (combined heat and power production) at industrial sites or municipal district heating facilities (Larson, 1993). Bagasse, and milling residues concentrated at industrial sites are the most common commercially used feedstocks. However, not all residues can be used for energy generation. Post harvest crop and forest residues help control erosion, sedimentation and flooding by maintaining soil fertility, organic matter content and structure. Complete removal of such residues would significantly increase erosion carrying away nutrients in the soil sediments reducing soil fertility (Pimentel, 1981).

Availability of Resources

The key to residue based biomass production of electricity is low cost dependable biomass feedstock availability. There are uncertainties associated with the availability of biomass residues. We are not sure how much biomass residues would be potentially collectible and useful as feedstocks for power production. A significant uncertainty is the value of competing uses of biomass residues. For instance, rather than utilizing them as power plant feedstocks, crop residues can be alternatively used as animal feeds, soil amendments and commercial products. With forest residues, the unknown factor is the impact of changes in forest fire prevention policies on biomass availability (Haq, 2002). Hauling cost is also an issue and a possible factor that prohibits use if low density residues cause excessive hauling distances and costs. Alternatively, dedicated energy crops such as switchgrass and willow can be used, (as discussed in Graham et al. 1995; Walsh et al. 1998; and Greene, 2004). Presently, dedicated energy crops are not commercially grown in the U.S. More future research and demonstrations will be needed to determine whether biomass energy crops can become a significant contributor to sustainable energy supplies for electricity generation.

Electricity Generation Using Different Fuel Sources

Historically, electricity generation from coal in the U.S. has been the highest. As shown in Figure 1, net electricity generation from coal in the electric power industry was about 155 billion kilowatt hours (kWh) in 1950. By 2004, it had increased to about 1,954 billion kWh. Power generation from nuclear and natural gas has also increased steadily over the past decade as indicated in the figure. On the other hand, the use of petroleum to generate electricity reached its peak in 1978, about 365 billion kWh. Since then power generation from petroleum fuel oil in the electric sector had declined dramatically due to the energy crisis in the 1970s and subsequently concerns over the costs and future supply of petroleum. Figure 1 also suggests that electricity generated by using biomass fuels has been historically insignificant. From 2000 to 2004 (see Table 1), average electricity generation from biomass was only about 29 billion kWh as compared to average electricity generation from coal which was about 1,929 billion kWh. Would biomass fuels be able to compete with fossil fuels in electricity generation in the future? What are the challenges that biomass fuels have to overcome?

Challenges from Fossil Fuels

The case of coal

Today, electricity generation accounts for more than 90% of the coal produced in the U.S. In terms of the quantity consumed in the electric sector, coal consumption has increased from 92 million short tons (about 2.2 quadrillion Btu) in 1950 to 1,015 million short tons (about 20 quadrillion Btu) in 2004.[1] Coal is relatively abundant and inexpensive compared with natural gas and petroleum. Also, increasing productivity in the mining ensures that coal will likely remain cost competitive with natural gas and petroleum. Coal prices went up during the 1970s as a result of the demand increase in response to fuel switching from oil and gas in the electric power and other sectors. Following the energy crisis of the 1970s, Figure 3 shows that coal prices have become relatively stable compared with the prices of natural gas and petroleum. In its Annual Energy Outlook, Energy Information Administration (EIA, 2006) predicts that during the

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[1] Source: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec7_9.pdf

period of 2006-2030, coal prices will likely remain to be stable and fluctuate around \$1 per million Btu.

Environmental consequences of using coal to generate electricity

Among the fossil fuels, coal contains the highest amount of carbon per unit of useful energy. Currently, the single largest source of carbon dioxide (CO_2) emissions comes from the electric power industry, representing 38% of the total U.S. CO_2 emissions from all sources (EPA, 2006). Coal-fired power plants are responsible for most of the CO_2 emissions in the U.S.'s electric power industry. Table 2 shows that CO_2 emissions from coal-fired power plants have been rising due to the demand increase for coal. The increased in CO_2 emissions is more pronounced after the oil price shocks of the 1970s, as electric power producers consumed more coal for electricity generation. The increasing volumes of CO_2 in our atmosphere are major concerns for the cause of human-induced global warming. In addition to emitting CO_2, coal-fired power plants emit a substantial amount of sulfur dioxide (SO_2) and nitrogen oxide (N_2O), both of which can produce acid rain and harm our environment.

Internalizing the external costs of coal

The current market price of coal does not reflect the pollution costs such as carbon abatement costs and the costs of compliance with the Clean Air Act. The price of coal could have been much higher if these external costs of coal were taken into account in the price scheme. The competitiveness of biomass fuels for electricity generation in the U.S. will very much depend on the willingness of government to impose stringent regulations aimed at reducing GHG emissions, especially CO_2. The higher the price for carbon[2] (i.e., the higher the future external costs of GHG emissions into the atmosphere); the more competitive the biomass fuels will be in generating electricity (see Schneider and McCarl, 2003). The future role of biomass for electricity generation is still uncertain due to the uncertainties in environmental policies and other factors discussed below. Would electric power producers switch to biomass fuels if coal becomes more expensive

[2] Assuming that the U.S. government has imposed stringent regulations on carbon emissions and that we are living in a carbon constrained world where carbon emissions are priced in the market place.

in the future? This would depend on the future of carbon price and also on the availability of other alternative fuels.

The role of natural gas and petroleum in electricity generation

Natural gas is the least carbon-intensive fossil fuel. In terms of per unit of useful energy, combustion of natural gas results in 42% less CO_2 emissions than coal and 29% less than petroleum fuel oil (Sandor, 1999). Significant reductions in CO_2 emissions can be made through fuel switching from coal and petroleum to natural gas. Due to the recent changes in economic, environmental, and technological factors, Figure 3 indicates that natural gas consumption in the electric sector has been on the rise since the late 1980s, while the petroleum consumption has declined significantly since the late 1970s due to the oil price shocks. In fact, natural gas has become the fuel of choice for today's new power plants. Table 3 shows that the number of additional gas-fired power generating units has increased from 147 with total summer capacity of 10,919 megawatts (MW) during the 1995-1999 period to 1,176 with total summer capacity of 130,971 MW during the 2000-2004 period. On the other hand, Table 3 also shows that only 17 coal-fired generating units are added during the entire period of 1995-2004 with total summer capacity of 3,351MW. In addition, the table shows that petroleum does not add much capacity to the electric generating units during the entire period.

Could natural gas replace for coal in electricity generation in the future? Besides its use for generating power, natural gas has many other competing uses in the industrial, residential and commercial sectors. Industry is the biggest user of natural gas, accounting for more than 30% of natural gas consumption across all sectors. Natural gas has a multitude of industrial uses, including providing the base ingredients for such varied products as plastic, fertilizer, anti-freeze, and fabrics. In the residential and commercial sectors, natural gas is mainly used for heating purposes. If the demand for natural gas goes up in all sectors of the economy, the price of natural gas will certainly increase. Whether or not natural gas could replace for coal in power generation will depend on how cheap the gas is in the future.

Natural Gas and Petroleum Prices

Compared to coal, natural gas and petroleum prices have been volatile, fluctuating both up and down (see Figure 4). The price of natural gas will depend on the weather, stock inventory levels and fuel oil prices. For some electric industries, natural gas and petroleum fuel oil are substitutes. Although declining in number, these energy users are able to switch back and forth between these fuels quickly, depending upon which is cheaper (Brown, 2003). Rising oil prices push these energy users toward natural gas, and falling oil prices attracts them back to the fuel oil. Consequently, Figure 4 indicates that fuel oil and natural gas prices have tended to track each other over long periods of time.

History tells us that supply shocks and hence price will be the important factors that determine the future demand for natural gas in electric power sector. For example, due to the oil crisis of 1970s, demands for fuels in the electric sector has shifted toward coal, the fuel experiencing the smallest price increase and away from oil and gas; fuels experiencing the greatest price increase (Sweeney, 1984). Figure 4 indicates that the price of both gas and oil at the electric utilities have been increasing recently, while the price of coal still remains stable; its average price is below 2 $/million Btu. EIA (2006) predicts that between 2006 and 2030, natural gas prices at the electric sectors would likely be in the range of 5-6 $/million Btu. High natural gas prices could discourage the construction of new gas-fired power plants.

Would electric power producers build more new coal-fired power plants in the future in response to higher costs for natural gas? Again this would depend on how the carbon is valued at the market place in the future. High carbon prices in the future could discourage the construction of new coal-fired power plants. Given the above analyses, we may conclude that the market penetration of biomass fuels for power generation depends on two factors: 1) the future external costs of using coal, i.e., the future price of carbon and 2) the price of natural gas. Increase in both carbon and natural gas prices in the future would likely make biomass fuels competitive.

Analysis of Capital Turnover

The typical average economic lifetime of electric power plants is 40 to 60 years and these power plants will need to be replaced or renovated extensively when they reach the end of their useful life. In order to reduce carbon emissions and enhance environmental quality, old capital needs to turn over rapidly. There are more than 1,000 large fossil-fired power generating units operating in the U.S. with a total combined capacity of over 450 gigawatts (GW). The total annual carbon emissions from these plants exceed 2 billion tons (Dahowski and Dooley, 2004). The range of vintages for these existing electric generating units spans the period from 1940 to 2004. Figures 5 and 6 depict the U.S.'s fossil-fired power generation capacity for the electric utility and non-utility sectors[3] by unit vintage and fuel type.

Figure 5 shows that coal plays a major role in the U.S. electric power generation. Most of the coal-fired power plants operating today were built throughout the 1950s-1980s. The average plant sizes ranges from 10 MW per unit to 1,300 MW per unit over that time period. Beginning in the 1990s, the combination of lower prices, reduced capital cost and improved efficiency has made natural gas the economic choice for new generating capacity in most regions of the U.S. (Ellerman, 1996). As can be seen in Figures 5 and 6, gas-fired generating capacity in the recent period of 2000-2004 alone has increased tremendously from the previous decade of the 1990s. This is especially pronounced in the electric non-utility sector illustrated in Figure 6. There is no doubt that environmental regulations have some effect on the choice between coal and natural gas.

A large portion of existing coal-fired power plants is more than 30 years old and is still capable of operating for many years to come. Moreover, these plants have fairly high capacity factors and the investments in SO_2, N_2O and other emissions controls that many owners have already made in these plants suggest that they (owners) have significant interest in keeping them operating for decades to come (Dahowski and Dooley, 2004). Furthermore, empirical studies (see Maloney, 1988 and Nelson et. al., 1993) have shown that environmental regulations could create an incentive for firms to

[3]The electric utility sector consists of privately and publicly owned establishments that generate, transmit, distribute, or sell electricity primarily for use by the public. Non-utility power producers are not included in the electric sector. In the electric non-utility sector, electricity is generated by end-users, or small power and independent power producers to supply electricity for industrial, commercial, and military operations, or sales to electric utilities.

delay the retirement of old power plants because these plants receive the grandfather rights. Hence, the capital turnover rate for existing old coal-fired power plants is likely to be slow. In any case, old and inefficient power plants will turn over in the future offering the opportunity to increase biomass contribution in electricity generation.

Technologies for Electricity Generation

The technologies for using fossil fuels to generate electricity are well established. At present, steam turbines, internal combustion engines, gas combustion turbines, water turbines, and wind turbines are the most common methods to generate electricity. A list of the major technologies for using fossil fuels to generate electricity is given below (Hansen, 1998):

- Pulverized coal firing with steam cycle
- Fluidized bed combustion with steam cycle
- Oil or gas fired boiler with steam cycle
- Oil or gas fired gas turbine
- Combined cycle with gas and steam turbine
- Pressurized fluidized bed combustion with combined cycle
- Integrated coal gasification with combined cycle (IGCC)

Most of the electricity in the U.S. is produced in steam turbines. Fossil fuel is burned in a furnace to generate pressurized high temperature steam. The pressurized steam is then expanded through a turbine that turns a generator to produce electricity. The steam exhausted from a turbine is then cooled in a condenser and returned to a boiler to begin the cycle once again (Joskow, 1987). The primary measure of the efficiency of an electric power plant's operation is its heat rate which is defined as the amount of Btu's fuel energy input required to produce a kilowatt hour (kWh) of electricity. The lower the heat rate, the greater the power plant's efficiency. As fossil-fired power plants gain more efficiency, CO_2 emissions could be reduced since less amount fossil fuel input is used to produce the same amount of electric power.

The heat rate can be converted to an efficiency factor by taking the ratio of the heat equivalent value of a kWh to the heat rate of the plant (Thompson et al., 1977). For example, the ratio of the heat equivalent value of 3,412 Btu/kWh to a heat rate of 10,107

Btu/kWh can be calculated and translated into an operating efficiency of 34%, the U.S. average efficiency for fossil-fired power plants. An operating efficiency of 34% means that for every 100 Btu of energy that go into a power plant, only 34 Btu is converted to usable electrical energy. Gas-fired combined cycle technology is the overwhelming choice for today's new power generating units. Combined cycle plants offer extremely high efficiency, clean operation, low capital costs and shorter construction lead times. The operating efficiency of combined cycle units is now approaching 60% compared with 34% efficiency for traditional boiler units.[4] Due to the technological improvements in these gas-fired combined cycle units, virtually all new generating capacity being added today relies on gas, as shown in Figures 5 and 6.

The future market penetration of biomass fuels for electricity generation will critically depend on developments in biomass generation technologies. The cost of power generation from biomass can be greatly reduced if the conversion technologies are developed or improved. There are four classes of technologies for the conversion of biomass for electricity generation: direct combustion, co-firing, gasification and pyrolysis. Similar to most conventional fossil-fired power plants, most of today's biomass power plants are direct combustion systems which use steam generation technology to produce electricity. Biomass power plants can be in the 10-80 MW range compared with coal-fired power plants which can be anywhere in the range of 100-1500 MW. The heat rate for biomass power plants may range from 12,000-20,000 Btu/kWh, with average operating efficiency of about 22% (see NREL, 2000), as compared to average heat rate of 10,107 Btu/kWh for coal-fired power plants with average operating efficiency of about 34%. Due to their low efficiency and the uncertainty over the availability of biomass fuels, biomass-fired power plants tend to incur more costs than fossil-fired power plants.

Currently, the most feasible and lowest cost option for the use of biomass is co-firing with coal in existing boilers. Since, the capital costs for co-firing are less than those associated with standalone biomass power projects. Further, co-firing projects capitalize on existing generating units and can be operated at the plant's discretion. Hence the risks associated with co-firing projects are rather low (Hughes, 2000; and Bain and Overend,

[4] Source: http://www.fuelingthefuture.org/contents/NaturalGasPowersUp.asp

2002). The future market for biomass power and thus biomass fuels will depend on how these power generation technologies evolve over time.

Concluding Remarks

Most of the world's electricity is generated by using fossil fuels such as coal, natural gas and petroleum fuel oil. Burning fossil fuels remains the most cost effective way of producing electricity at least for now. In the U.S., fossil fuels account for about 70% of the fuels used for electricity generation, while biomass only accounts for about 1%. There are many reasons why biomass-based energy is not economically competitive with conventional fossil fuel-based energy. Biomass fuels are bulky often with high water content. Fuel quality may not be predictable. Physical handling of the material can be challenging. Hauling can be expensive. These characteristics drive up the cost of biomass energy, as additional land, labor and equipment is required for feedstock planting, harvesting, transport, storage and processing compared to conventional fuels (Hall and Scrase, 1998). Moreover, biomass-fired power plants are relatively small in size and capacity, thus they tend to have a high fixed capital cost to generated electricity ratio. Hence, relative to electricity generated from fossil fuels, biomass-based power is more expensive on average given current prices.

The electric power sector in the U.S. is a major source of CO_2 emissions which contribute to global climate change. A substantial amount of CO_2 emissions could be reduced if the electric sector uses biomass fuels rather than fossil fuels to generate electricity. However, electricity producers do not have incentives to switch from fossil fuels to biomass fuels simply because biomass fuels are not cost competitive, as mentioned above. The question we are interested in is: how do we make biomass fuels economically competitive with fossil fuels? This paper explores the factors which may influence the market penetration of biomass fuels for power generation. We argue that market penetration of biomass fuels depend on two important factors: 1) the future price of carbon, and 2) the natural gas price. Increase in both of these prices will make biomass fuels competitive. In addition, we also discuss the issues related to the capital turnover rate for existing fossil power plants and the changes in electric power generation technologies which may affect the future market penetration of biomass fuels.

References

Bain, R. and R. P. Overend. 2002. "Biomass for Heat and Power." *Forest Products Journal* 52(2): 12-19.

Brown, S. P. A. 2003. "U.S. Natural Gas Markets in Turmoil." Available at: http:// www. dallasfed.org /news/speeches/03brown_testimony.pdf.

Dahowski, R. T. and J. J. Dooley. 2004. "Carbon Management Strategies for US Electricity Generation Capacity: A vintage-based approach." *Energy* 29:1589-1598.

Ellerman, A. D. 1996. "The Competition between Coal and Natural Gas: The Importance of Sunk Costs." *Resources Policy* 22: 33-42.

Energy Information Administration (EIA). 2006. "Annual Energy Outlook 2006 with Projections to 2030." Available at: http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html.

Environmental Protection Agency (EPA). 2006. "Inventory of the U.S. Greenhouse Gas Emissions and Sinks: 1990-2004." Available at: http:// yosemite.epa.gov/oar/ globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Graham, R. L., E. Lichtenberg, V. O. Roningen, H. Shapouri and M. Walsh. 1995. "The Economics of Biomass Production in the United States." Available at: http://bioenergy. ornl.gov/papers/bioam95/graham3.html.

Greene, N. 2004. "Growing Energy: How Biofuels Can Help End America's Oil Dependence." Available at: http://www.nrdc.org/air/energy/biofuels/biofuels.pdf.

Hall, D. O., and J. I. Scrase. 1998. "Will Biomass be the Environmentally Friendly Fuel of the Future?" *Biomass and Bioenergy* 15: 357-367.

Hansen, U. 1998. "Technological Options for Power Generation." *The Energy Journal* 19(2): 63-87.

Haq, Z. 2002. "Biomass for Electricity Generation." Available at: http://www.eia.doe. gov/oiaf/ analysispaper/ biomass/index.html.

Hughes, E. 2000. "Biomass Cofiring: Economics, Policy and Opportunities." *Biomass and Bioenergy* 19: 457-465.

Joskow, P. L. 1987. "Productivity Growth and Technical Change in the Generation of Electricity." *The Energy Journal* 8(1): 17-38.

Larson, E. D. 1993. "Technology for Electricity and Fuels from Biomass." *Annual Reviews Energy Environ* 18: 567-630.

Maloney, M. T. and G. L. Brady. 1988. "Capital Turnover and Marketable Pollution Rights." *Journal of Law and economics* 31(1): 203-226.

National Renewable Energy Laboratory (NREL). 2000. "Lessons Learned from Existing Biomass Power Plants." Available at: http:// www.nrel.gov/docs/fy00osti/26946.pdf.
Nelson, R. A., T. Tietenberg and M. R. Donihue. 1993. " Differential Environmental Regulation: Effects on Electricity Utility Capital Turnover and Emissions." *The Review of Economics and Statistics* 75(2): 368-373.

Pimentel, D., M. A. Moran, S. Fast, G. Weber, R. Bukantis, L. Balliett, P. Boveng, C. Cleveland, S. Hindman, and M. Young. 1981. "Biomass Energy from Crop and Forest Residues." *Science* 212: 1110-1115.

Sandor, R., M. Walsh, and A. LeBlanc. 1999. "Creating a Market for Carbon Emissions: Gas Industry Opportunities." Available at: http://www.envifi.com/Bios/natgas.htm.

Schneider, U. A. and B. A. McCarl. 2003. "Economic Potential of Biomass Based Fuels for Greenhouse Gas Emission Mitigation." *Environmental and Resources Economics* 24: 291-312.

Sweeney, J. L. 1984. "The Response of Energy Demand to Higher Prices: What Have We Learned?" *American Economic Review* 74(2):31-37.

Thompson, R. G., J. A. Calloway and L. A. Nawalanic. 1977. *The Cost of Electricity: Cheap Power vs. A Clean Environment*. Houston, Texas: University of Houston.

Walsh, M. E., D.G. De La Torre Ugarte, S. Slinsky, R.L. Graham, H. Shapouri, and D. Ray. 1998. "Economic Analysis of Energy Crop Production in the U.S. - Location, Quantities, Price and Impacts on Traditional Agricultural Crops." Available at: http:// bioenergy.ornl.gov/papers/bioen98/walsh.html.

Table 1. Electric Power Industry's Electricity Net Generation from Various Sources of Fuels (All units are in billion kilowatt hours)

Year	Coal	Nuclear	Natural Gas	Hydro	Petro-leum	Biomass	Geo-thermal	Wind	Solar
2000	1,943.11	753.89	517.98	271.34	105.19	29.22	14.09	5.59	0.49
2001	1,882.83	768.83	554.94	213.75	119.15	27.78	13.74	6.74	0.54
2002	1,910.61	780.06	607.68	260.49	89.73	29.19	14.49	10.35	0.55
2003	1,952.71	763.73	567.30	271.51	113.70	30.37	14.42	11.19	0.53
2004	1,953.97	788.56	618.60	264.50	112.48	29.35	14.36	14.15	0.58

Source: EIA's (Energy Information Administration) Annual Energy Review Database

Table 2. Historical CO_2 Emissions from Electric Power Sector Energy Consumption (Million Metric Tons CO_2)

Fuel	1950-59	1960-69	1970-79	1980-89	1990-99
Coal	2,950.03	5,239.66	8,343.89	13,090.14	16,542.71
Natural Gas	613.44	1,329.50	1,902.48	1,680.86	2,109.97
Petroleum	364.03	642.03	2,516.26	1,266.52	846.43

Source: EIA's Annual Energy Review Database

Table 3. Capacity Additions at U.S. Electric Industries, 1995-1999 and 2000-2004, by Fuel Type

Fuel Type	1995 to 1999		2000 to 2004	
	Capacity (MW)	*Number of units*	*Capacity(MW)*	*Number of units*
Coal	2,702	10	649	7
Gas	10,919	147	130,971	1,176
Petroleum	1,804	228	1,703	534

Source: Inventory of Electric Utility Power Plants and Electric Power Annual (various issues)

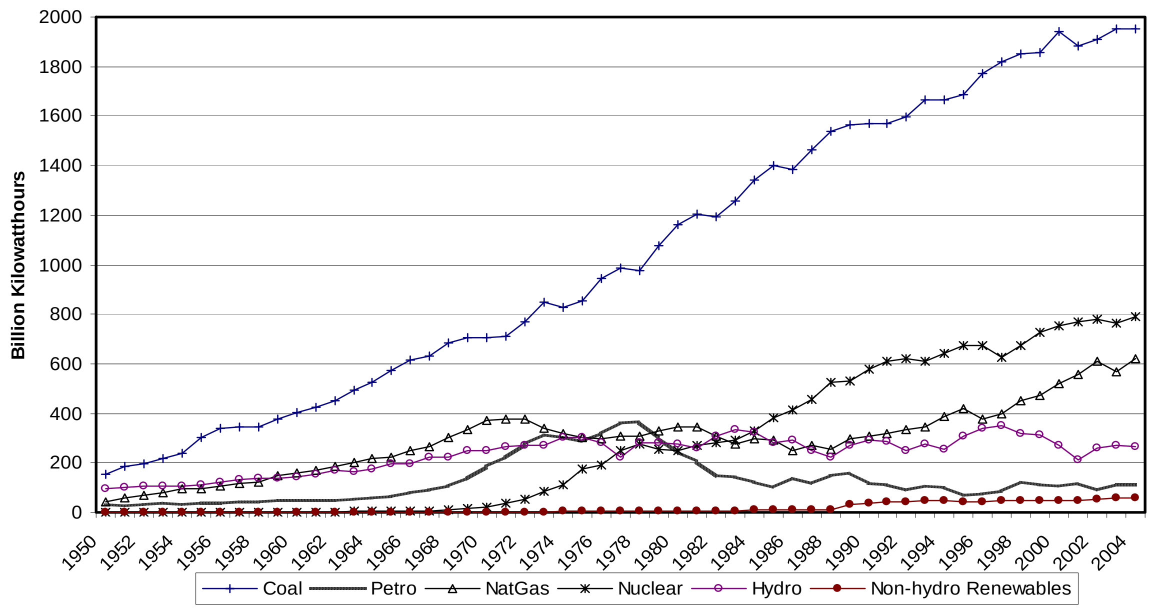


Figure 1. Electric Power Sector's Electricity Net Generation in Billion Kilowatt hours, 1950-2004.

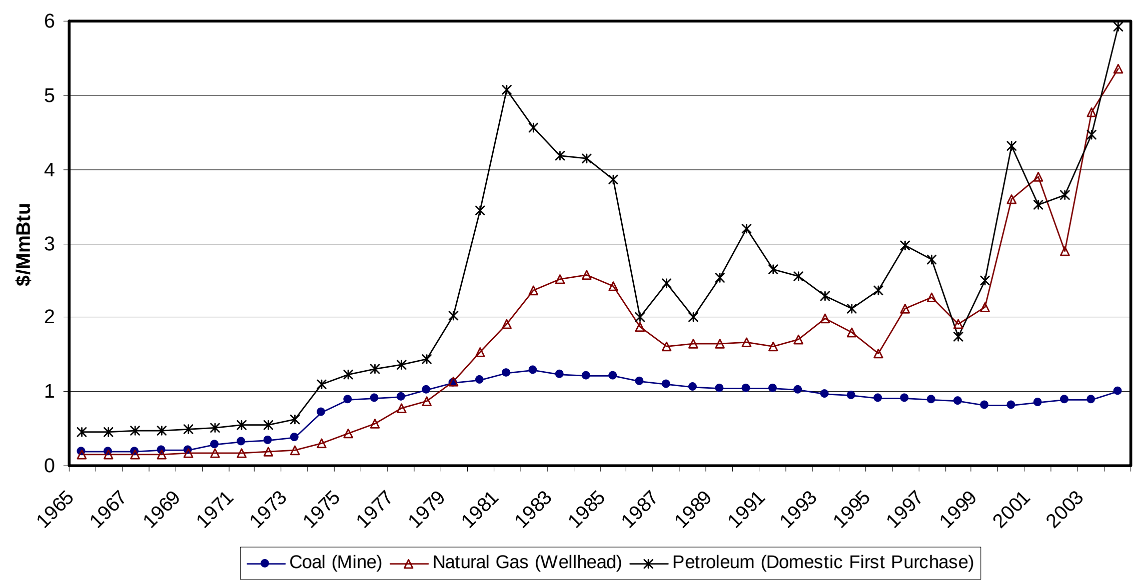


Figure 2. Annual Average Fossil Fuel Prices in $/Million Btu, 1965-2004.

Sources: EIA's Annual Energy Review Database

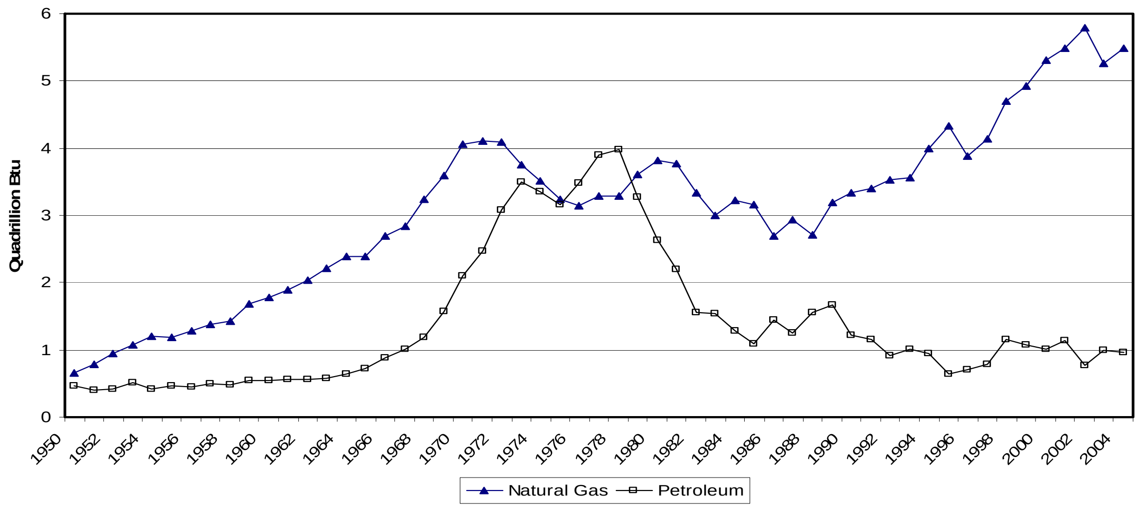


Figure 3. Annual consumption of Natural Gas and Petroleum Fuel Oil by Electric Power Sector in Quadrillion Btu, 1950-2004.

Source: EIA's Annual Energy Review Database

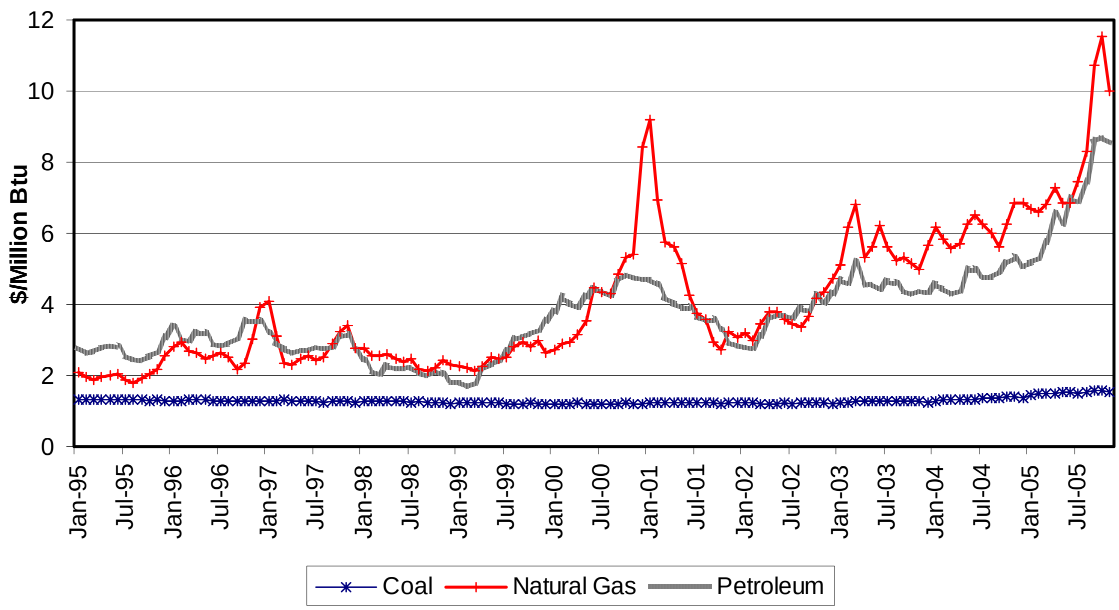
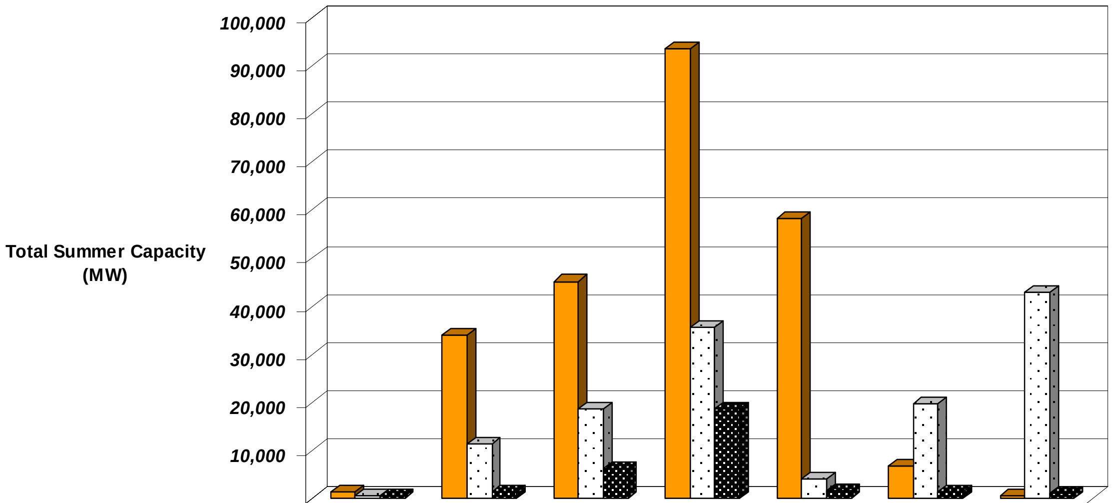


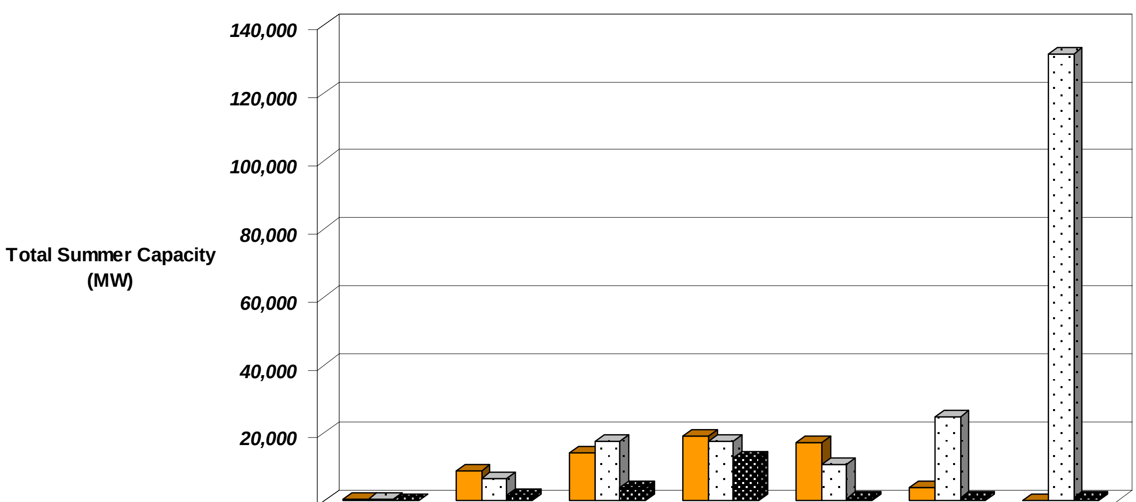
Figure 4. Average Monthly Fossil Fuel Prices at Electric Utilities in $/Million Btu, Jan/1995-Nov/2005.

Source: Electric Power Monthly (various issues)



	1940's	1950's	1960's	1970's	1980's	1990's	2000-2004
Coal	1,412	34,075	45,145	93,550	58,159	6,726	526
Natural Gas	559	11,390	18,570	35,640	4,053	19,822	42,956
Petroleum	550	1,405	6,159	18,653	1,572	1,361	1,251

Figure 5. U.S. Electric Utility's Existing Generating Capacity in 2004 by Unit Vintage and Fuel Type



	1940's	1950's	1960's	1970's	1980's	1990's	2000-2004
Coal	686	8,756	14,122	19,068	17,167	3,959	156
Natural Gas	607	6,697	17,384	17,678	10,637	24,703	131,526
Petroleum	94	1,648	4,038	12,527	718	929	766

Figure 6. U.S. Electric Non-utility's Existing Generating Capacity in 2004 by Unit Vintage and Fuel Type

Source: EIA's Existing Electric Generating Units in the United States (2004)