Energy Studies Review Vol. 17, No.1, 2010

ENERGY SUPPLY CONCERNS: A UNITED STATES PERSPECTIVE ON ELECTRIC POWER GENERATION

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ABSTRACT

This review discusses the outlook for electric power generation in the U.S. covering both traditional fossil fuel and renewable energy sources. Environmental policy, technology and economics combine with the advantages and disadvantages of each electric power source to drive the direction of the industry. Coal, while sensitive to carbon emissions regulations, will likely continue to play a large role; natural gas use will continue to be dependent on supply and price; nuclear power has the potential to grow, but requires new plant construction for the first time in 30 years; and despite projected growth in renewable energy sources (particularly for wind), changes in policy would be required to have renewable energy become a significant contributor to the electric power generation mix.

Subject Category:
Energy Technology and Policy

Suggested Keywords:
Electric power generation, renewable energy, carbon emissions, environmental policy.

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INTRODUCTION

Demand for energy in the United States grows daily as do concerns of energy prices, dependence on foreign oil, and greenhouse gas emissions. The media generally links these concerns with gasoline prices and automobile emissions inciting hopes wrapped up in fleets of hydrogen-powered fuel cell vehicles of the future. The reality is that, as the producer of one third of the greenhouse emissions in the U.S., the electric power industry will likely be the initial target for addressing these concerns. As a result, domestic electric power generation is at a crossroads. The last major shift in the mix of electrical power generation in the U.S. began 15 years ago as natural gas began its climb from 12% to 20% of U.S. electric power generation. Between record high natural gas prices, the rejuvenation of the nuclear power industry and increasing emphasis on reduction of greenhouse gases, the stage is set for a new mix between traditional and renewable electric power sources. The key is in understanding where the potential is for expansion and what road blocks are standing in the way.

1. ENERGY INFORMATION ADMINISTRATION FORECAST

The Annual Energy Outlook (AEO) provided by the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) contains a forecast for the U.S. electric power demand and generation as well as specific information regarding renewable energy utilization. Many assumptions must be made in the model regarding energy policy, technology advancements and world crude oil prices. The AEO reference cases make the assumption that current energy policies do not change through the period of evaluation and that real crude oil prices will recover in 2010, increasing through 2030 (EIA, 2009a). Note that the results of the AEO could be significantly different should new policies on greenhouse gas emissions be implemented or should world oil prices vary significantly from this projection. Recognizing the assumptions made, the AEO 2009 (EIA, 2009a) updated[1] reference case will serve as a benchmarking tool to understand the future of the electric power industry.

The AEO2009 forecasts a 1.0% annual growth rate through 2030 of electric power demand in the U.S. that will be met by an increase in most all current sources although at varying degrees (EIA, 2009a). Figure 1 shows historical data and projections for electric power by source while Figure 2 shows actual annual growth for each source from 2003 to 2007 and the model forecast annualized increase through 2030. This data shows that the model predicts that growth in coal, natural gas, nuclear power plants and hydropower will not keep pace with demand and that, while other renewables will grow faster than demand, fossil fuels will continue to play a dominate role.

Figures 3 and 4 show the 2007 mix and results of the growth in each sector in 2030 as a percentage of U.S. electric power generation. This information together shows that despite high growth rates in renewables in recent years, the impact on the electric power industry is small. Furthermore, the model predictions show that

[1] The updated AEO 2009 reference case reflects provisions of the American Recovery and Reinvestment Act and recent changes in the economic outlook.

without any significant changes to the current energy policy, the current growth rates in renewables will not be sustainable.

Figure 1. Projections of U.S. electric power by source (EIA, 2007, EIA 2009a)

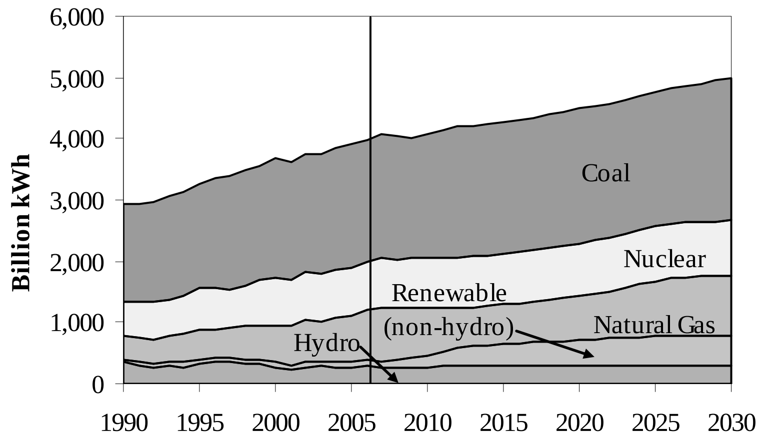


Figure 2. Historical and forecast annualized growth rates of U.S. electric power by source (EIA, 2007, EIA 2008, EIA 2009a)

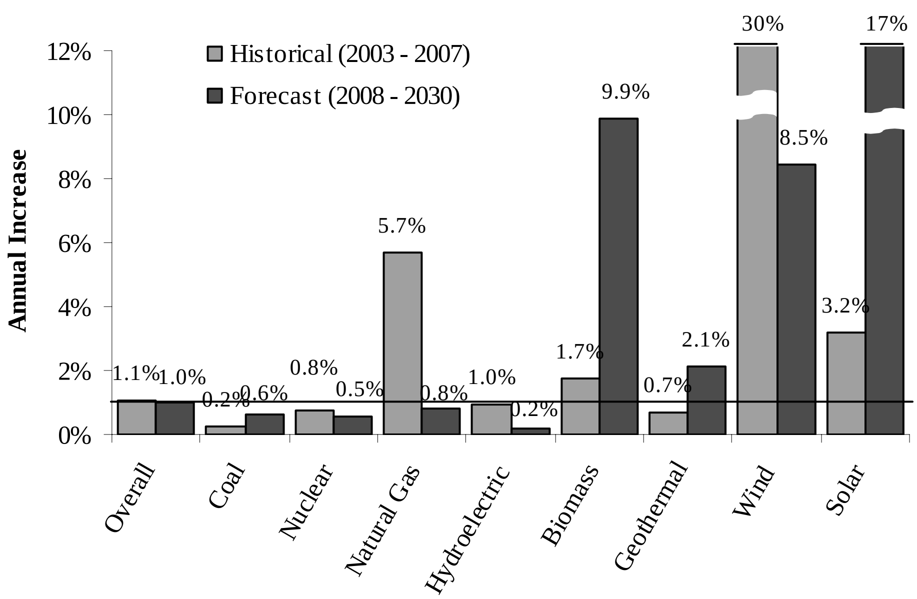


Figure 3. 2007 source mix for U.S. electric power (EIA, 2009a)

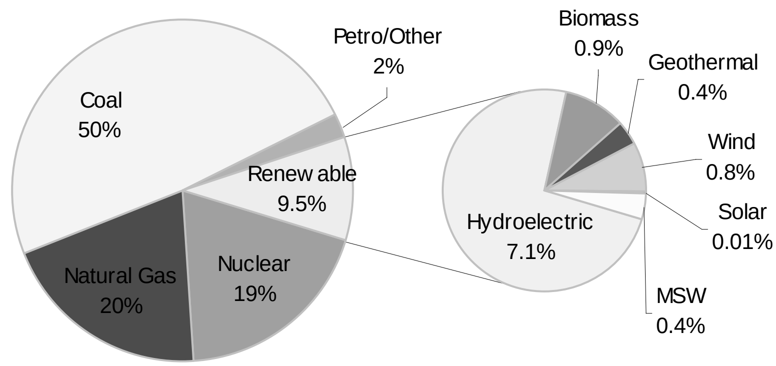
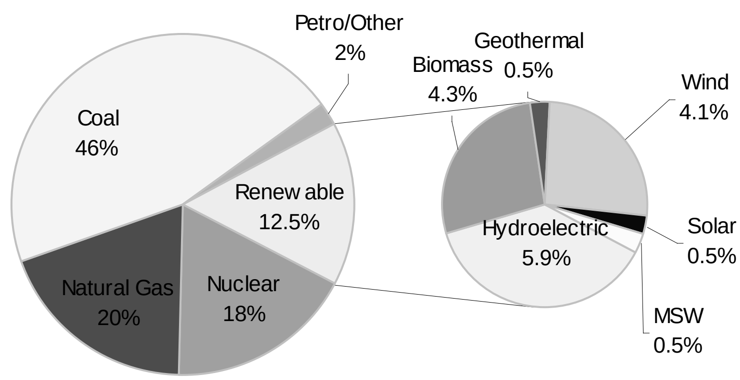


Figure 4. Forecast of 2030 source mix for U.S. electric power (EIA, 2009a)



Based on the AEO2009 updated reference case, this scenario, while resulting in a reduction of sulphur dioxide and nitrogen dioxide, shows an increase of CO_2 emissions from the electric power industry of 0.5% per year or 12% increase in total by the year 2030, almost on par with the increase in electric power demand (EIA, 2009a). This highlights once again that the assumptions of the model primarily around energy policy, greenhouse gases and world oil prices must be understood and the data combined with additional information regarding the various sources to understand the future of each of the types of U.S. electric power generation.

1.1 Key assumptions

One of the components in deciding the source mix is the capital cost of power plants. The AEO2009 assumes an approximately 30% increase in the capital cost of power plants with respect to the cost values used in AEO2008, which is approximately 50% more than that used in earlier estimates. In developing the AEO projections, NEMS utilizes a market-based approach to energy analysis. While forecasting the values for the future, it considers the competition among the energy sources and balances the demand and supply accordingly. The AEO2009 forecasts consider environmental legislation as of November 2008 and also add the projected impact of the "American Recovery and Reinvestment Act (ARRA)." The financial incentives identified in EPACT2005 are considered in AEO2009. With an increasing trend in investment in less GHG emission technologies, the cost of capital is increased by 3% point for the coal-fired power plants. Investment tax credit (ITC) and production tax credit (PTC) for renewable fuels are also considered in AEO2009. Because of high variability in the world oil prices, the model considers three cases with reference, low and high oil prices. In the reference case, it assumes that the world oil price will increase from \$61 per barrel (2007 dollars) to approximately \$117 in 2020 and \$130 in 2030 (EIA, 2009a). In the low price model, it assumes that world oil prices will decrease because of advanced technologies, more accessibility, and other factors. It is estimated to reach \$50 per barrel in 2030. In the high price model, it assumes that the oil price will increase to approximately \$200 per barrel in 2030. With respect to nuclear power plants, the reference case in AEO2009 assumes a 29% reduction in the capital cost. This paper focuses on the reference oil prices as base case scenario development.

2. FOSSIL FUEL POWER GENERATION

2.1 Coals

With plentiful domestic coal reserves and low operating costs, it is no surprise that coal has dominated the U.S. power generation industry through 2007, or that it will continue to do so, based on current energy and environmental policies as shown in the AEO2009. However, the top criticism of coal continues to be that of high carbon dioxide and other emissions which has resulted in significant political energy around "clean coal technologies." Since 2000, total sulphur dioxide and nitrogen oxides (NO_x) emissions from traditional power plants have been reduced by 6% and 2% per year, respectively (EIA, 2006). Much of this accomplishment has been achieved through scrubbers at power plants and use of lower sulphur coal.

The same accomplishment does not yet exist for carbon emissions as in the same period they rose just under 1% (EIA, 2006) highlighting that significant changes in technology and policy are necessary to tackle the reduction of CO_2. Efforts range from technologies to improve current power plant efficiency (which requires less fuel and results in lower emissions for the same power generation) to coal gasification facilities combined with carbon capture and sequestration (CCS), the capturing and permanent storage of CO_2 underground or in the ocean. While CCS technology is still in its infancy, coal gasification plants have recently begun operating both in the U.S. and internationally. The benefits for coal gasification include reduced sulphur and NO_x emissions and improved efficiency and adaptability to CCS technology in the future (DOE, 2007). Because of these benefits, the 2005 Energy Policy Act (EPACT2005) currently provides tax benefits for coal gasification projects, which, according to Sekar (2007), results in coal gasification and the traditional pulverized coal technology being competitive. While the continued domination of coal becomes uncertain with significant changes to government policy on carbon emission requirements, coal stands to have a place in the future of power generation regardless of environmental mandates through further development of clean coal technologies.

2.2 Natural Gas

Natural gas has experienced significant growth of 5.7% per year since 2003 (EIA, 2007a and EIA, 2009a) and has accounted for 95% of the new capacity additions since 2001 (EIA, 2006). This shift was not only economically favourable at the time but the lower carbon emissions of natural gas powered plants, which are roughly half that of coal (Meier, 2005), provided additional incentive for the industry to shift in that direction. However, natural gas prices have undergone significant increases as shown in Figure 5. Today this leaves natural gas as the source of power generation with the highest operating cost (Figure 6). As a result, capacity at coal and nuclear plants is generally maximized preferentially over natural gas plants, despite higher efficiency at the newer gas plants. While EIA reported in 2006 that the majority of planned capacity additions through 2010 were for natural gas plants at 60% (EIA, 2006), this percentage and the overall capacity increases are on a steady decline.

AEO2009 predicts an average annual increase of 0.8% for natural gas power generation, slightly below the annual increase in demand of 1.0% (EIA, 2009). In the near term, it predicts a decline trending with its forecast of crude oil prices as shown in Figure 7. While not the only factor, AEO's forecast predicts natural gas power generation as being sensitive to the crude oil price assumptions in the model. It is clear that world crude oil prices will have some impact on the future of natural gas as a source and the overall mix of electric power generation in the U.S.

Figure 5. Historical and projected plant purchase price of fuel in 2006 and 2007 dollars (EIA, 2008b and EIA 2009a)

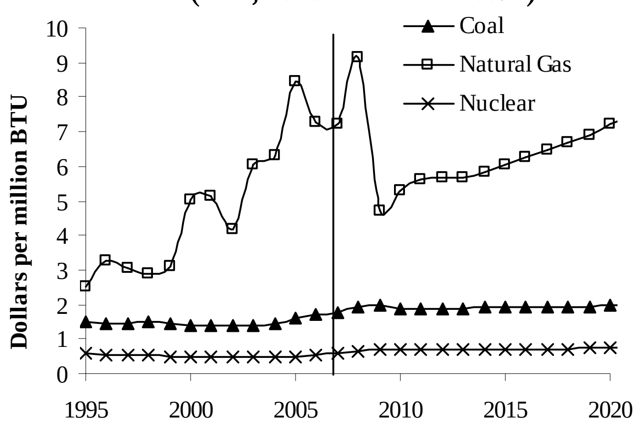


Figure 6. 2005 average operating costs by plant type (NEI, 2007)

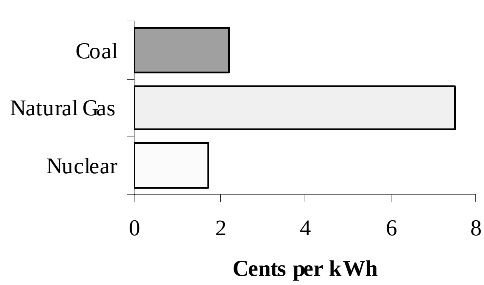
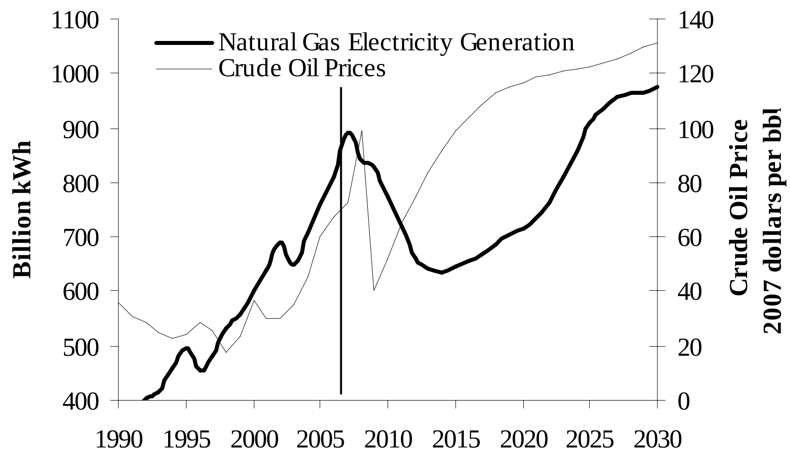


Figure 7. Forecast U.S. natural gas electric power generation and crude oil prices (EIA, 2009a, EIA 2009b, EIA 2007)



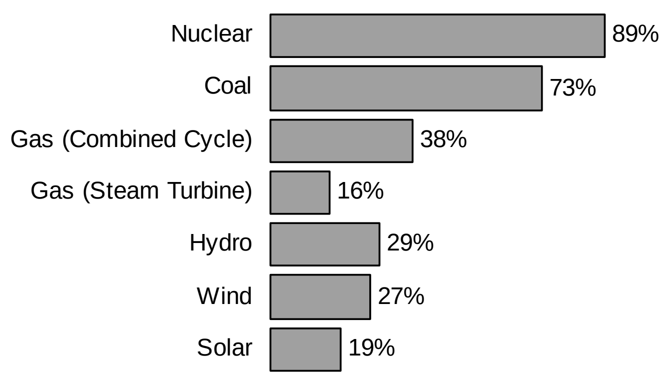
2.3 Nuclear

Nuclear energy, currently providing 19% of the U.S. electric power generation, has held the second place position behind coal for more than 20 years (EIA, 2008). Rising natural gas prices and concern with carbon emissions, together with the legislative support of EPACT2005, have provided a brighter future for the nuclear industry. There are still a variety of factors, however, that will continue to determine what size piece of the pie nuclear power will have in the future of U.S. electric power generation.

Nuclear power's benefits compared to traditional fossil-fuel power plants are numerous. Nuclear power produces no greenhouse gas emissions. Uranium fuel is plentiful and readily available in the U.S. and over half of the Uranium in the world is located in Canada and Australia (NEI, 2007). Uranium fuel costs are low and relatively stable compared to other fossil fuels, resulting in nuclear power's position as lowest operating costs per kWh of non-renewable energy sources as shown in Figure 6. Nuclear power has the highest capacity factor of all electric power technologies at 90%, meaning that 90% of the capacity is utilized each year for power generation. Figure 8 shows the capacity factors for nuclear and other electric power sources. The low capacity factor for natural gas is related to economic sparing of capacity due to high operating costs previously mentioned.

While fuel and production costs are low, capital costs associated with building a plant are significant. A new plant has not been built in the U.S. since 1977 and the AEO projections are sensitive to this unknown factor (EIA, 2007a). Duke Energy, who has expressed serious interest in a new plant, estimates $4 to $6 billion to put two reactors totalling 2,000 MW in service (S&P, 2006). Historically, the most significant hurdle that the nuclear industry has faced regarding new plant construction has been regulatory concerns. EPACT 2005, in addition to providing direct credits for new plant capacity, has provisions to reduce the risk level of building a new plant by addressing delays due to regulatory issues and litigation (S&P, 2006). While the legislation addresses the government hurdles, the support of the public is still of concern with regards to new nuclear power plants and nuclear waste disposal which could affect the continuation of the industry in general. Public opinion has improved over time as well with the NEI reporting that 68% in favor and 29% in opposition of nuclear energy compared to 50% in favor and 46% opposition from the mid '80s (2006b). This improvement in public opinion is likely due to the time elapsed since such nuclear plant disasters as Three Mile Island and Chernobyl and not due to the public's concern over carbon emissions since the same poll showed that less than half of the respondents knew that nuclear power plants help to reduce greenhouse gases. These results are certainly an improvement in public opinion on nuclear power, but there is still significant and vocal dissent to overcome.

Figure 8. 2005 capacity factors for U.S. electric power generation by source (NEI, 2006a)



Since 1990, the growth rate of nuclear power has been approximately 2% per year or 36% overall growth despite no new capacity being added (EIA, 2007a). This has been achieved through significant improvement of the capacity factor and through capacity uprates often requiring capital outlay and always requiring Nuclear Regulatory Commission approval. While there are still applications for uprates planned or under review (amounting to roughly 5% of the current capacity), the opportunities available for expansion within the existing plants is diminishing (NEI, 2007). Even if new plants or reactors are built, it will be years before one comes online and with each reactor only increasing the capacity of nuclear power by 1%, it is not likely that nuclear power can keep pace with the overall anticipated growth of electric power demand and maintain its 19% share in the electric power market. The AEO2009 shows that based on current policies, economics will support 10.6 GWe of new nuclear power plant capacity through 2030. However, this increase only results in 0.5% annual increase in nuclear power resulting in nuclear power slipping to 18% of total generation by 2030 (EIA, 2009a).

3. RENEWABLE ENERGY SOURCES

3.1 Hydroelectric power

At 7% of the US electric power generation, hydropower is the number one renewable energy source in the U.S. and one of the oldest as well. Like all renewable energy sources, hydroelectric power's primary benefit is that it results in near-zero emissions. However, hydropower generation can be impacted significantly by a drought and thus is often used to supplement more traditional fossil-fuel power generation plants. Hydroelectric power is constrained in its location (waterways) and thus is dependent on infrastructure and transmission lines matching the location to support any new facility. Criticism of hydroelectric power includes adverse effects such as fish injury or death, impacts on fish migration and downstream water quality effects such as low dissolved gases. Research to address these issues is currently underway such as new turbine technology designed to minimize damage to water life. Additionally, critics will argue that hydropower results in unnecessary damming of waterways. In defense of this statement, Environmental and Energy Study Institute reports that only 3% of dams are primarily for hydroelectricity, with most dams serving the purpose of recreation and flood control (2006).

Information regarding the opportunity for additional hydropower generation capacity is limited. A resource study conducted by DOE indicates that there is approximately 35% additional capacity available for hydropower in U.S. waterways, but anticipates little increase in the use of hydropower due to environmental concerns, regulatory barriers and economics (2008). AEO2009 predicts only a 0.2% increase in hydropower well below the 1.0% increase in overall power generation (EIA, 2009a). As previously stated, AEO reference cases assume no changes to current energy or environmental policies. Additional constraints on carbon emissions could increase the acceptable cost and bring some of the hydropower facilities into fruition. While changes in environmental policy could raise hydropower slightly, it is unlikely that the U.S. will ever see a large portion of its power generation provided by water.

3.2 Wind power

Wind energy, while growing 30% per year since 2003, makes up only 0.8% of the U.S. electric power generation (EIA, 2008b and EIA, 2009a). As a renewable, the lack of carbon emissions and green house gases is the primary benefit of wind power along with preservation of fossil fuels. Wind energy, like all renewables, has low operating costs, but faces the challenge of high capital costs relative to the traditional fossil-fuel power generation facilities. In addition to competing with other energy technologies, wind energy must compete with other uses for the land that may be of higher value. Wind energy must be used when it is produced and since availability of wind power is intermittent, it is primarily used as a supplement to traditional energy sources. Even then, the peak wind power production will likely not meet timing of the peak demand, thus requiring natural gas power plants, for example, to be built to provide a back-up power source. Transfer line capacity and proximity to high energy demand is another roadblock that wind power faces as the best sites for wind farms are generally in remote locations. Like hydropower, wind energy has environmental challenges of its own. Bird injuries and deaths as well as visual and noise impacts of the wind farms are of concern.

Opportunities for growth of wind power are primarily restricted by the costs (monetary and environmental) less so that the availability of resources. The DOE quotes that 6% of the land in the U.S. is identified as a good source for wind energy and could provide as much as one and a half times the total current energy usage in the U.S. (2005). Despite this, the AEO2009 shows an increase of wind power by 8.5% per year to 4.1% of the U.S. electric power demand for 2030 (EIA, 2009a). Since it is likely that government incentives for renewable energy sources will be greater than in the reference case and that the cost of this relatively new technology could outpace the experience factors in the NEMS model, it is highly possible that wind power has a larger future. In fact, Kydes (2007) shows an alternate case to AEO2002 with a requirement that 20% of power comes from non-renewable energy sources where wind energy has the largest shift versus the reference case, growing at more than 20% annually through 2020. However, with the restrictions and limitations that wind power faces, it is questionable if the recent growth rate of 30% per year is sustainable.

3.3 Other Renewables

For the purpose of electric power generation, biomass energy encompasses both the burning of wood waste and biomass trash and the collection of methane gas off of landfills. Both result in lower carbon emissions than fossil fuel processes – collection of methane gas does so because methane itself is a greenhouse gas and to a lesser degree, burning of biomass does because the carbon cycle is shorter than with fossil fuels. Based on the AEO2009, biomass is expected to increase 9.9% annually from 0.9% to 4.3% of the U.S. electric power industry based on availability of biomass and economics versus alternative sources of power generation (EIA, 2009a).

Geothermal, at 0.4% of U.S. electric power is similar to hydropower in that it is geographically constrained. AEO2009 forecasts geothermal power generation to increase its share of U.S. power generation to 0.5% by 2030 (EIA, 2009a).

Solar power, while familiar as a renewable energy source, makes up a minor part of U.S. electric power generation at less than a tenth of a percent with little expectation of growth above 1% in the near future (EIA, 2008). The high capital cost of solar power primarily due to the cost of materials is a significant barrier to expansion of this source of power generation. The cost of both thermal solar panels and photovoltaic cells and modules struggle to come down even with improvements in technology and economies of scale because of the continued increase in the costs of materials (EIA, 2007b).

One of the policies, carbon cap-and-trade (EIA, 2007; Cap and Trade 101, 2008), if implemented may have significant impact on the economics of the renewable energy sources. Though the policy is designed to promote energy efficiency and reduce greenhouse gas emissions, compliance with this policy will increase the cost of fossil fuels and may favor the market for the renewable energy sources. Energy Policy Act (EPAct) of 2005 requires that at least 7.5% of the total electricity (if feasible and practical) consumed by the Federal Government come from renewable energy (EPACT 2005). Similar policies, if implemented, will increase the use of renewable energy use in the United States. The U.S. Department of Energy (DOE) examined the feasibility of 20% Wind Energy by 2030 and published the report in 2008 (20% Wind Energy by 2030, 2008). It outlined the costs and challenges associated with achieving this goal. With increasing price of the fossil fuels, this goal may become a reality and thus increase the share of wind energy.

4. SENSITIVITY ANALYSIS

A summary of sensitivity analysis performed in AEO2009 is shown in Figures 9, 10, and 11. As can be seen in Figure 9, with lower plant costs, the generation capacity of coal, nuclear, and renewable energy based plants is increased while the capacity of natural gas based or other plants decrease or remain at the same level. With an extension in the production tax credit (PTC), the generation capacity of wind based power plants increases significantly (Figure 10). The last sensitivity analysis is performed with respect to public concern related to green house gas (GHG) emissions. In the case of "No GHG concern", the capacity of coal based plants increases because of lower costs associated with coal. On the other hand, with GHG emission reduction policy (LW110), the generation capacity of renewable and nuclear energy based plants increase while natural gas and coal based plants decrease. It is also interesting to note that with the LW110 policy, the total generation capacity decreases, which can be attributed to less energy usage to minimize GHG emissions.

Figure 9. Electricity generation by fuel in four cases, 2007 and 2030 (billion kWh) (EIA, 2009b)

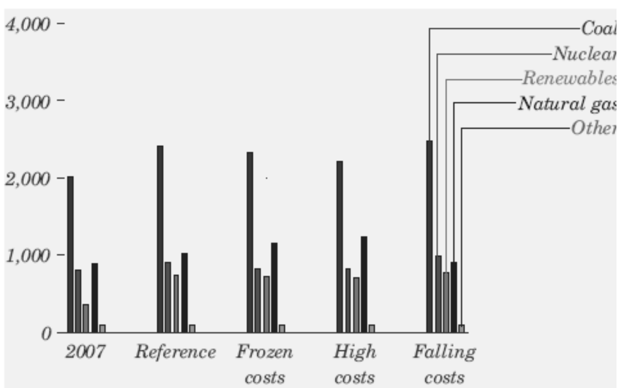


Figure 10. Installed renewable generation capacity in two cases, 2007-2030 (gigawatts) (EIA, 2009b)

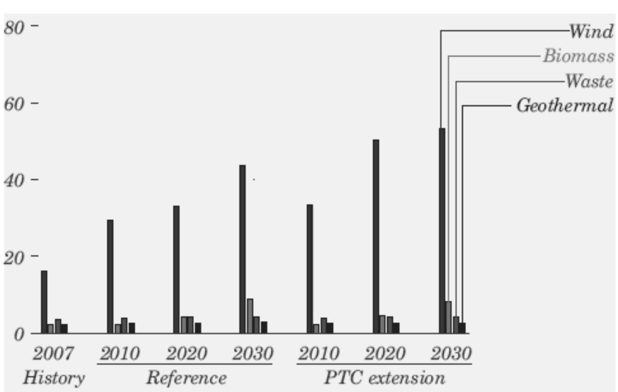
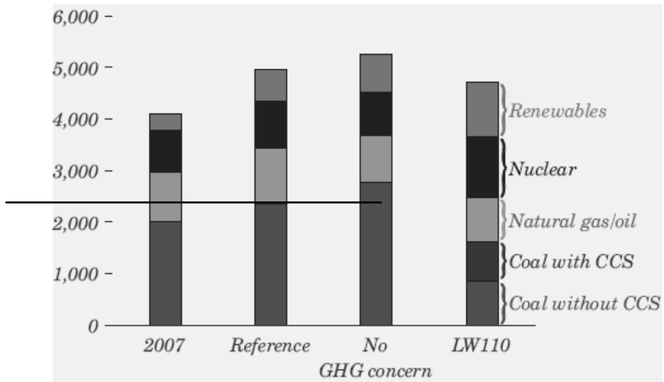
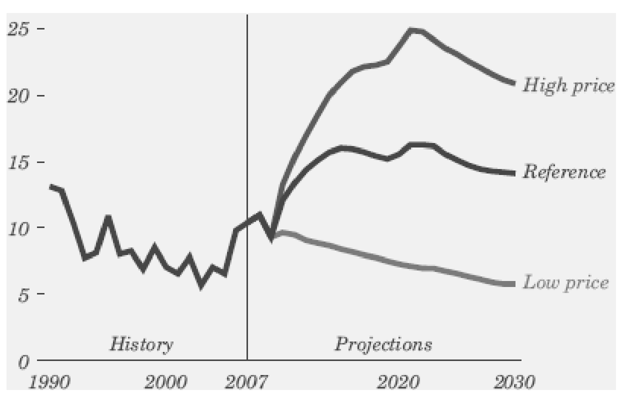


Figure 11. U.S. electricity generation by source in three cases, 2007 and 2030 (billion kilowatthours) (EIA, 2009b)



Since coal, nuclear and several renewable plants are capital intensive, the plant type mix can change in the reference cost, low cost and high cost scenarios for the ratio of crude oil price to natural gas price (Figure 12). The new natural gas fired plants are projected to have lower fuel prices which will affect the relative economical preference for other plants. It is expected that the proportion of natural gas based plants will increase in the low cost scenario and decrease in the high cost scenario. The mix of other plant types will follow the same ratio as that in the reference case.

Figure 12. Ratio of crude oil price to natural gas price in three cases, 1990-2030 (EIA, 2009a)

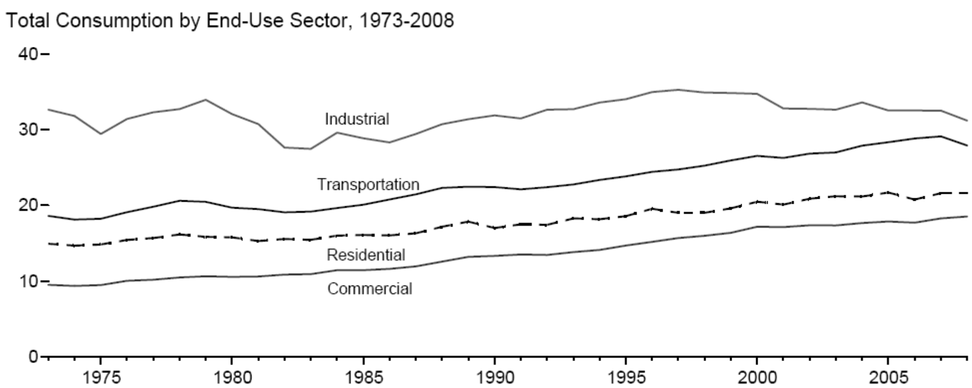


5. ENERGY CONSERVATION

Based on Executive Order 13423, DOE is required to reduce the energy intensity by at least 30% by the end of fiscal year 2015, relative to the Department's use in 2003 (TEAM 2007). DOE has launched several other programs such as "Save Energy Now (SEN)" to promote energy conservation in industrial facilities. SEN is a national initiative by the Industrial Technology Program (ITP) of the U.S. Department of Energy to reduce industrial energy intensity by 25% in 10 years

(SEN, 2009). As seen in Figure 13, industrial energy consumption is the highest among the four sectors and reduction of 25% will lead to significant reduction in the overall energy usage. This may also be reflected in the energy prices and help in minimizing greenhouse gas emissions. Since its inception in 2006, the program has saved an average of $2 million for participating U.S. Manufacturers or approximately 8% of their energy cost. Several other energy efficiency initiatives are underway and have resulted in significant savings for U.S. manufacturers. It may be noted that programs similar to TEAM and SEN focus on the end users and thus indirectly affect the mix of energy sources for the production of electricity. Global warming has been one of the biggest drivers for energy efficiency as steps to minimize energy usage is the most effective measure to reduce the CO_2 emissions. Energy conservation measures minimize the pressures to focus on renewable sources but at the same time reduce the need for fossil fuels as a result of reduced electricity requirements.

Figure 13. Energy Consumption by Sector (Quadrillion Btu) (EIA, 2009c)



CONCLUSIONS

The future of the U.S. electric power industry depends not on one technology, but on all technologies combined as each brings strengths and sensitivities to the table. The unknowns around world energy demand, availability of cost effective technology and uncertain government policies regarding greenhouse gases requires that all technologies be maintained and improved to meet the growing and changing needs of U.S. energy demand. The analysis is summarized as follows:

- Coal – This abundant and dominating fossil fuel has the highest carbon footprint for power production and thus the most sensitive to environmental policies. It also has significant potential for improvement through blossoming clean coal technologies.
- Natural Gas – As the lowest carbon-emitter of the fossil fuels, natural gas will continue to be welcome in a carbon-sensitive atmosphere. At the same time, it has the highest sensitivity to world oil prices resulting in significant swings in the economics of operating gas powered plants.
- Nuclear – While U.S. energy policy has provided a rejuvenation of the nuclear industry, concerns regarding government regulations and public opinion must be continually addressed to ensure successful continuation of this industry.

Regardless of the success of the new energy policies, it is doubtful that the building of new plants can occur quickly enough for nuclear power to even maintain its share of the U.S. electric power industry.

- Hydroelectric – Limited geographic locations for hydropower result in all likelihood the stagnation of hydropower for the foreseeable future.
- Wind – While resource studies claim that there is more than enough land area to support significant growth of wind power, extensive expansion is not supported by the economics related to this intermittent and often remote power source. That being said, of the renewables, models predict wind power as one of the most upwardly sensitive sources to a more stringent energy and global warming policy.

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