Nuclear Energy of The Twenty-First Century

PUBPOL 481 – Science Policy Term Paper

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ABBREVIATIONS

AOE	The Annual Energy Outlook
DoE	The U.S. Department of Energy
EIA	The Energy Information Administration, an independent statistical agency of the U.S. Department of Energy.
OECD	Organization for Economic Co-operation and Development (OECD) promotes policies that will improve the economic and social well-being of people around the world. Today, there are 34 country member of the OECD.
PHEV	Plug-in Hybrid Electric Vehicles

Executive Summary

The U.S. faces an energy crisis. Our energy policies need to be reformed and innovated. As reported by the Energy Information Agency (EIA), the outlook of energy in the next twenty years is not encouraging: the U.S. is still a net importer of energy, coal is still the dominant source of energy, carbon footprints are still high, and crude oil prices continues to skyrocket.

The country faces an array of challenges with few innovations on the horizon. To reduce the emission of carbon, we are excitedly jumping into the drilling of shale gas and adopting a cap-and-trade program, which is essentially a stock market. Under this program, the government sets a limit on carbon emissions. Firms that meet their reduction goal may sell their emission allowance to firms that overspend their limits. We are reducing the use of Nuclear power, which is clean form of power, in electricity generation.

Considering all other long-term options, nuclear energy is the best viable option for safe and clean energy generation. Nuclear facilities are well prepared for any type of disaster due to a strict regulatory policy set for by the Nuclear Regulatory Commission. Despite this, there are concerns with nuclear material proliferation as well as spent fuel management. It is recommended that further research is put into closed nuclear fuel cycles by researching breeder reactors. Additionally it is encouraged that the United States' uses different forms of fuel for vehicles and batteries. It is also recommended that a collaborative infrastructe be created between industry and researching facilities in order to make information easier to access.

America's Energy Outlook

On December 16, 2010, the *Annual Energy Outlook 2011 (AOE2011)* issued a Reference Case focus on factors that shape the U.S. energy supply, demand, and price through 2035 [1]. The Reference Case served as the baseline for the government and industry projections of future energy policies. There are many optimistic future predictions in this Reference Case. For example, the *AOE2011 report* projected that the net import of petroleum will *decline* from 52 percent in 2009 to 42 percent in 2035; net natural gas import will decline from 11 percent in 2009 to 1 percent in 2035; share of energy consumption declines from 24 percent 2009 to 18 percent in 2035. The *AOE2011* reports shale gas will represent 45 percent of total natural gas production in 2035, compared to 14 percent in 2009; non-hydro renewable fuel is increasing as fuel source in electric generation as well.

Energy consumption by sector

Contrary to the above positive outlooks U.S. energy still faces many challenges. The U.S. production of natural gas, petroleum, and renewable sources have moderately increased, but our appetite for energy in all sectors--transportation, industrial, residential, and commercial-- are increasing much faster, as shown in Figure 1 Energy consumption by sector, 1980-2035, page 8. In the transportation sector, the energy consumption for light-duty vehicles has grown by 10 percent, and by 49% for the heavy trucks. The following figure shows that most energy consumption is in the area of transportation.

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[1] EIA, AEO211 Early Release Report, December 16, 2010, http://www.eia.gov/neic/press/press352.html

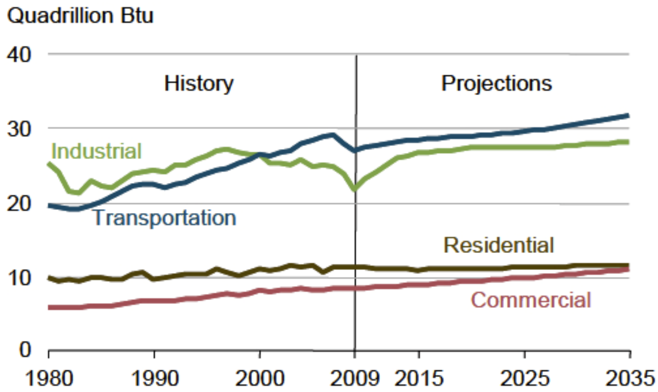

Figure 1 Energy consumption by sector, 1980-2035
(Source: U.S. Energy Information Administration, Annual Energy Outlook 2011)

Energy Prices

Crude oil costs are projected to increase from $125 per barrel in 2009 to about $200 per barrel in 2035; energy prices for natural gas, coal, and electricity are all going up [2].

Energy consumption by fuel type

The AEO2011 projects the total primary energy consumption will grow by 21 percent from 2009 to 2035. As Figure 2 Energy consumption by fuel, 1980-2035, page 9 shows that liquid fuels, including both fossil liquids and biofuels, will increase by14 percent, 36.6 quadrillion Btu, in 2009 to 41.8 quadrillion Btu in 2035. Natural gas consumption will grow by 16.7 percent, from 22.7 trillion cubic feet in 2009 to 26.5 trillion cubic feet in 2035. With the increase in shale gas, coal consumption will still increase, but decrease to a slower rate by 27.9%, from 19.7 quadrillion Btu in 2009 to 25.2 quadrillion Btu in 2035. Despite this coal remains the leading source of fuel for electricity generation in the U.S. Coal is the most

[2] EIA, Short-Term Energy Outlook, http://www.eia.doe.gov/steo/

intensive fossil fuel, which leads to the next energy policy criterion: environmental objective.

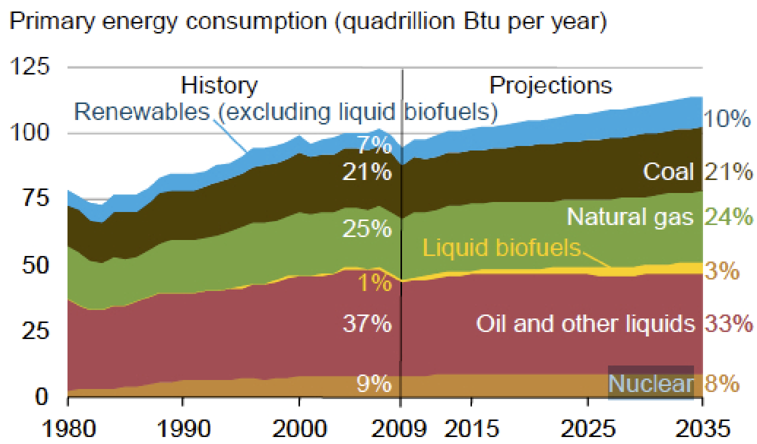

Figure 2 Energy consumption by fuel, 1980-2035

Energy-related carbon dioxide emission

Environmental objective is an important criterion when considering fuel sources. It is measured by the energy-related CO_2 emission into the environment. Energy-related CO_2 emissions reflect the mix of fossil fuels consumed because of their different carbon content. Given the high carbon content of coal and its current use in electricity generation as well as the growth of electricity demand in the U.S., the emissions are expected to increase. The *AEO2011* projected that energy-related carbon dioxide emissions will increase by 0.2 percent per year from 2005 to 2035. As a result the energy-related CO_2 emissions increase 6.31 percent of the total energy use.

America's energy outlook challenges

An increase in domestic production of shale gas will allow for a decrease of natural gas prices. Increasing the use of a natural gas source will also allows for a decrease usage of coal, which in turn leads to a small decrease of energy-related CO_2 emissions. However, the U.S. is still a net importer of energy to satisfy demands. Projection for crude oil prices increase almost 60%, from $125 per barrel in 2009 to $200 per barrel, Figure 3 World crude oil prices, 1980-2035. EIA projects that the retail price of regular-grade motor gasoline will increase by about 40 percent above the outlook of 2010 [3]. Rising crude oil prices are the primary reason for higher retail prices, but higher refining margins are also expected to be a contributing factor. Our demand for energy is growing; crude oil prices are increasing. Other alternative energy technologies, such as wind, solar, biomass, geo-thermal, and nuclear fusion power are feasible, but perhaps are unproved. Whereas the nuclear power is not only a viable technology, but it also has been proven to be safe, despite the current disaster at Fukushima, Japan. Nuclear energy is necessary in satisfying our demand for energy and plays down the role of fossil fuels.

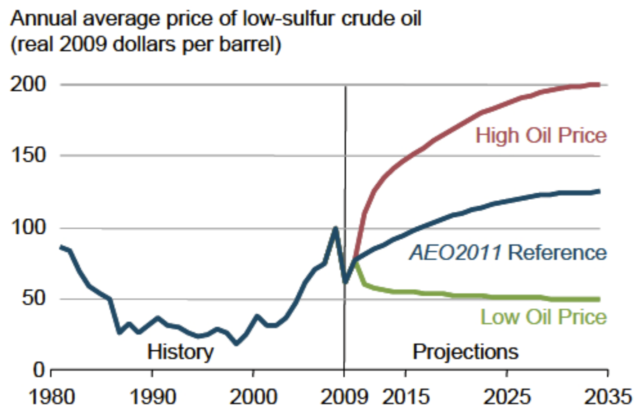

Figure 3 World crude oil prices, 1980-2035

[3] EIA, Short-term Energy Outlook, March 2011, http://www.eia.doe.gov/steo/#Electricity_Markets

There is an increase in non-hydro renewables and natural gas usage, but coal, the source of energy with highest carbon content, is still a dominant source of fuel. Ninety-three percent of coal consumption produces electricity. Figure 4 Net electric generation, 1990-2035 shows a shift in using renewables and natural gas fuel types for electric generation. *However the shift is not fast enough to satisfy the demand in electricity.*

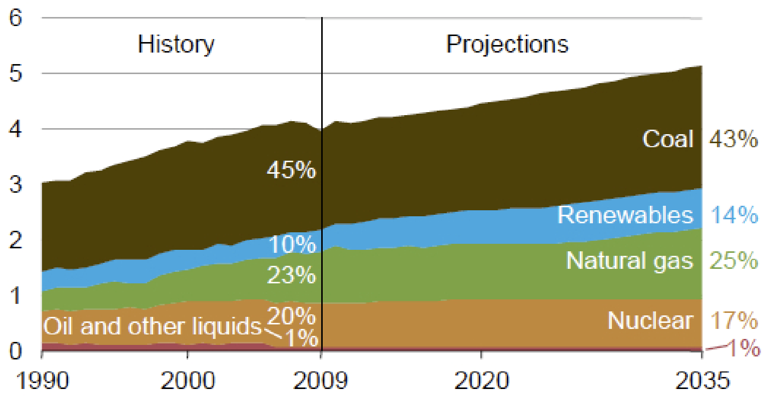

Figure 4 Net electric generation, 1990-2035

As for the environmental impacts, shale gas drilling comes at a high environmental cost, which will be discussed further in the next section. Coal is perhaps the "dirtiest" fuel source to the environment. The International Energy Outlook (IEO) published the emission of CO_2 by the fuel type as shown in the Figure 5 Energy-related CO_2 emission by fuel type, page 12. Though nuclear energy does not contribute to the green house effect, its risk to the public due to radioactivity is called into question. The Nuclear Regulatory Commission (NRC) requires that any and all radiation that is released be as low as reasonably achievable. Due to the rising demands for energy and crude oil prices, in addition to the requirements for the environmental protection, the 21st century should mark the nuclear renaissance as nuclear fission technology has been tested and has been proven to be safe and viable. The science policy should encourage further nuclear fusion together with other alternative energy source.

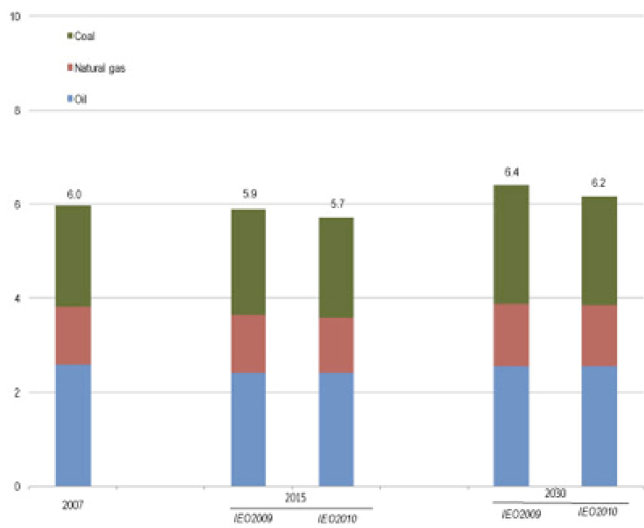

Figure 5 Energy-related CO2 emission by fuel type

Challenges

Challenges with Energy Sources

Shale Gas

During the 1980s and 1990s, Mitchell Energy and Development Corporation made deep shale gas production commercially viable in Barnett Shale in North-Central Texas [4]. Hydraulic fracturing is a technique that is a combination of horizontal drilling and fracking—pumping water at high pressure deep beneath the ground to crack the rock and release natural gas. In 1980's when George Mitchell experimented this advanced technique at the Barnett Shale, Texas. In 2007, the technique was used to drill wells at the Marcellus, Pennsylvania. It was estimated that the recoverable amount of gas at the Marcellus at 1.4 trillion cubic meter. With this success, *Marcellus alone would provide the energy equivalent to 86 billion barrels of oi*l [5]. The development of shale gas has become a "game changer" for the natural gas market; the EIA called shale gas a "global phenomenon". Today the importance of U.S. shale gas resources is reflected in AOE2011 energy projection. Given a total natural gas resource base of 2,543 trillion cubic feet (Tcf), shale gas resources estimated at 862Tcf, and by 2035 shale gas production accounts for 46 percent of U.S. natural gas production [3].

[4] EIA, April 5, 2011, *World Shale Gas Resources: An Initial Assessment of 15 Regions Outside of the United States,* http://www.eia.gov/analysis/studies/worldshalegas/
[5] Time Magazine, Bryan Wash, April 11, 2011, *The Gas Dilemma*, page 44

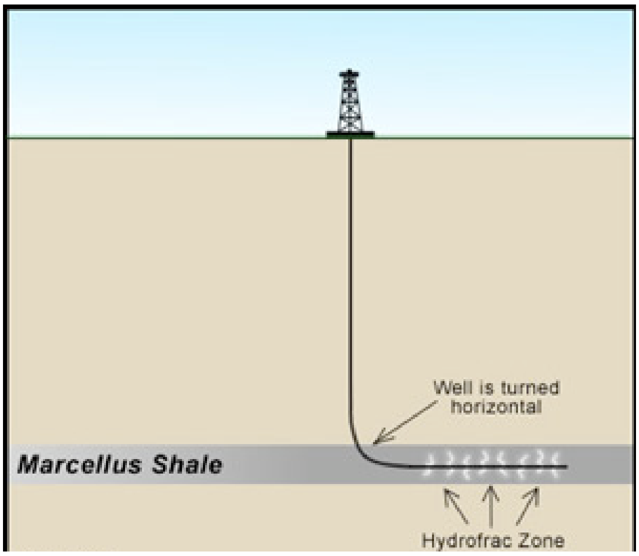

Figure 6 Hydraulic fracturing - combination of horizontal drilling and fracking
(Source: New York state, Department of Environmental Conservation)

There was an accident related to wells where there were fractures on cement casing near the well surface; the accident happened in Dimock , Pennsylvania[6]. Improper well casing allowed fracking fluids and methane gas to contaminate the water. No report was found on how shale gas affected the environment, and whether or not it emitted CO_2 into the environment. Further research by the EIA/DoE and EPA is required to find the effects of shale gas on the environment.

Long-Range Energy Sources

Solar power, geothermal power, and controlled thermonuclear fusion are long-range energy sources as they are characterized by extremely enormous sources. Solar power lasts as long as the sun continues to shine; geothermal power

[6] Time Magazine, Bryan Wash, April 11, 2011, *The Gas Dilemma,* page 46

is an untapped energy from the heat of the earth; controlled thermonuclear fusion, in theory, releases an infinite fuel supply [7].

Solar Energy

The sun is the Earth's natural power source. Conversion of solar power, with only 10 percent of efficiency would provide 10 TW of power, nearly twice the world's consumption rate of fossil energy and the equivalent of 20,000 1-GW_e nuclear fission plants [8]. Sunlight arrives on Earth as radiation distributed across the color spectrum from infrared to ultraviolet. The energy of this radiation must be *captured* as excited electron hole pairs in a semiconductor. The excited electron is tapped off for *conversion* to electrical power. Mimicking the natural photosynthetic process, the power drives chemical reactions to produce fuels that link to the existing energy network. These fuels *store* energy from day-to-night throughout each day. Solar energy exploits the functional steps of *capture, conversion, and storage*. Solar energy applications include electricity, heat, and fuel generation; however, none are currently competitive with fossil fuels due to cost, reliability and performance of solar panels. Due to the intermittent nature of sunlight, solar energy is not a stand-alone solution since solar panel installations need a different energy source as a back-up system, whether it is fossil fuels or nuclear energy. However, such a solution will be costly. In 2005, the Department of Energy, *Basic Research Needs for Solar Energy Utilizatio,* recognized the enormous untapped potential of the Sun, but it also specified the challenges in all three steps-- capture,

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[7] Duderstadt, James J. (1979) *Nuclear Power Technology on Trial*, The University of Michigan Press

[8] Department of Energy (DoE) (2005) *Basic Research Needs for Solar Energy Utilization*

conversion, and storage, of the process to make the technology viable, before a small fraction of the sun energy can be utilized.

Geothermal Energy

Geothermal energy is another enormous and renewable energy source. The heat from the Earth can be for accessed via drilling. The energy source does not emit any carbon dioxide and is domestic. Geothermal resources range from shallow ground to hot water miles below the Earth's surface or even further down to extremely hot molten rock called magma. Geothermal heat on the shallow ground or upper 10 feet of the earth surface can be tapped to heat or cool buildings. The United States' most geothermal reservoir of hot water is located in the western most states: Alaska, and Hawaii. Wells are drilled into the underground reservoirs to generate electricity. Drilling of molten rock magma at 3-5 miles depth currently does not have any applications though and there is no existing technology to recover the heat directly from magma. Although geothermal sources contribute to the generation of electricity, it is not a major contribution.

Nuclear Fusion

Nuclear fusion involves fusing small atoms when two light nuclei collide to form a heavier nucleus. Similar to nuclear fission, the reaction releases a significant energy. Unlike nuclear fission, there is no potential melt down, there are no radioactive by-products and fuel is virtually unlimited. The solar system is the largest fusion energy source. Holdren (1978)[9] suggested that fusion options are not cheap, and "none is likely to be widely available before the year 2010". It is 2011

[9] Holdren , John P. (1978) *Fusion Energy in Context: Its Fitness for the Long Term*, Science 200:168

and there isn't a nuclear fusion reactor ready to be deployed. There are other non-electric applications of fusion such as hydrogen production and space propulsion.

Concluding remarks for fuel source challenges

Shale gas is hailed to be a "global phenomenon", but it is expensive and it does present some threat to the environment. There is not enough research and testing to ensure that it releases less CO_2 than other viable options.

After reviewing the alternative long-range alternative sources of energy, the energy crisis that we are facing is underscored, and recognized as enormous and complex problems. The problems require not only federal energy reform, but perhaps also call for innovations and collaboration efforts with private sectors. Gasoline prices and crude oil prices are skyrocketing. Nuclear fusion, solar, wind, and geothermal energy provides possibilities and promises for alternative energy sources with little or no CO_2 emissions. Nuclear fusion and geothermal energy not only generate electricity, but also have different applications such as producing hydrogen or for space propulsion. Despite these optimistic views, we are in the second decade of the 21st century and there still isn't enough research to develop these technologies to be commercially viable.

Challenges with energy for transportation

About 27 percent of total energy consumption is for transportation, of which 81 percent (gasoline, diesel, biofuel ethanol, and biodiesel energy) is used for cars, motorcycles, light trucks.

As the crude oil prices increase together with the concerns for energy, environmental, and economic security, the Plug-in hybrid electric vehicles (PHEVs) gained more attention. In order to stop our energy dependence, more research on prolonging battery life, or batteries using a different fuel source, is required. Additionally vehicles that operate on different type of fuels rather than fossil fuels will have to be researched and developed. Nuclear fission should be used more in producing electricity to slowly remove our dependence on petroleum.

Challenges with nuclear energy

Nuclear power is the technology that is on trial since its inception and it continues to face challenges from the public.

Safety of Nuclear Power Plant Operations

Nuclear power is subject to the strictest regulation than any other technologies. Such regulations are exercised at every step of the licensing process from plant survey, to design, to construction and operations of the plant. For example, after the September 11th, 2001, nuclear power plants designs were assessed whether or not the facilities would withstand an airplane crashes into it. On March 11, 2011, when an earth quake of magnitude 9.0 hit the east coast of Honshu and the subsequent tsunami caused significant damage to the Fukushima Daiichi nuclear plant, U.S. plants were again called into question. All nuclear power plants in the United States were assessed whether or not their plants would sustain an earth quake of the same intensity which would be followed by a tsunami, and whether or not the plant is on a subduction zone. Since it is unlikely that tsunamis will occur in the Midwest of U.S., for example, some plants are assessed instead of all. Defense-in-depth is a requirement set forth from the Nuclear Regulation Commission (NRC) intended to protect the public safety; public hearings or protests often cause delays in the building, testing, and obtaining of licensing for operations of a plant. *Strict requirements and delays in building and operations will drive the building cost up resulting in the utility companies passing the cost to the consumers.*

Secure Nuclear materials

Many obstacles that nuclear power faces stemmed from the fear that nuclear materials are making their way into the hands of terrorists or countries that may abuse enrichment technologies to produce nuclear materials. Some of the fears are justified, some are manipulated for political reasons, but often these fears prevent the advances of the nuclear technology. For example, the breeder reactors produce and utilize large quantity of plutonium fuels. This could be framed to provoke the fear of nuclear weapons. *Hence it slows down the pace of research and development.* Other similar examples are small modular reactors (SMRs) are being presented that its small size can be compromised for smuggling.

Nuclear spent fuel management

Yucca Mountain was the place for permanent storage of nuclear spent fuels. However, President Obama made clear that it is not an option for waste nuclear materials, and resulting in stop funding. Without a permanent solution for nuclear spent fuel the opponents to the nuclear power have more reason to oppose to the technology. Reprocessing of the nuclear spent fuel to “recycling” the fuel should be encouraged, and more research of efficiency of fuel cycles should be invested.

Energy Policy Recommendations

Increase public awareness of the energy crisis

The public is well aware of the energy crisis that the U.S. is experiencing through the increasing of gasoline prices. However more effort must be placed on dissemination of knowledge and matter-of-fact information through educational institutions and media to the public. Internet and social networks should be used to allow for the flow of factual information to reach the public.

Nuclear energy has been proven and well tested, but the public fear of radiation, of "the end of the world" accidents is vivid; some of such fears are justified, but most are emotional. Easy access to information and more education, including middle school age children would help in acceptance of the technology.

Addressing security and non-proliferation by Research on advanced, proliferation-resistance nuclear fuel

Since proliferation of nuclear materials is always a concern and in the absence of a permanent "waste" management, the nuclear science policy calls for research focus on increasing efficiency of nuclear fuel cycles, reducing the long –term hazard of spent fuel by separate uranium, plutonium in the spent fuel, or research on breeder reactors using plutonium in the spent fuel. Research programs may also focus on disarming nuclear weapons making nuclear weapons a lot less desirable.

Reducing dependency on fossil oil

Transportation consumes 27 percent of net fossil oil, largest among all sectors – industrial, commercial, and residential usage. To reduce the dependency on fossil oil, research programs should focus on new fuel types for vehicles, such as hydrogen. Research may also focus on new nuclear batteries that extend the life of the batteries.

Create a collaborative infrastructure, between research and industry, for technology transfer

A collaborative infrastructure between the research and industry environments will help the transferring of technology into industry and make manufacturers more efficient. Research does not have to be carried out in silos, also sharing information allows to expand the knowledge base