The Economics of Nuclear Power: Is Nuclear the Socially Optimal Technology?

INTRODUCTION/PURPOSE

Electricity has become a basic necessity of life in the United States, and the demand for electricity is only expected to continue to grow with time. As generating firms search for least-cost methods of producing this electricity, the government continually evaluates the external costs to society associated with these methods and shapes energy policy accordingly.

The makeup of the nation's electricity supply changes with changes in a number of factors similarly to any other economic good. These factors include technology, prices of inputs and future expectations. There are important determinants of these factors that will be relevant here; specifically public opinion and government intervention. Due to the lack of significant changes in these factors, the technologies used in electricity generation have remained largely unchanged since the 1970's. This relative stability was recently broken.

The Bush Administration has implemented policies meant to result in drastic changes in the makeup of the nation's electricity supply.[1] The most drastic change is the intent to add more nuclear capacity, despite the fact that no new commercial nuclear plants have been built in the United States since the early 1970's. Due to increasing demand for electricity and the potential external costs nuclear generation might incur, it is of interest whether or not this decision was made in an optimal way.

This idea causes a primary point of contention to arise; namely, how is "optimal" decision-making defined? Mainstream public economic theory suggests that the optimal technology to be used is the one which incurs the lowest social cost. Since most technological decisions are made in private markets, the government may intervene and use a variety of tools in order to manipulate the price mechanism in such a way that the socially optimal outcome will necessarily prevail. The first purpose of this study is to evaluate the decision-making process of the Bush Administration that led to the advocacy of nuclear power with respect to social cost.

Under the federal system of government, states have the autonomy to create laws as they wish as long as those laws are within the parameters of federal law. This system extends to electricity policy and states have created various regulations that can steer state energy policy in ways that are not necessarily in line with that of the federal government. One example of this can be seen in California. The California government has been able to shape its statewide electricity market in a way that has resulted very different technological mix from the national market by implementing more stringent environmental standards. Although the majority of electricity generation nationwide comes from coal, California implemented emissions standards that effectively barred the use of coal-fired plants in the state. Instead, California relies on natural gas plants for the majority of its electricity generation.

Demand for natural gas is growing at an alarming rate due to rapid increases in population in California and in other states, thus the finite supply of this resource is dwindling. This has resulted in major changes in the price. Since 2001, the wholesale price of natural gas has doubled.[2] In its 2005 Energy Policy Report, the California Energy Commission notes that "California must also address its long-term electricity needs by aggressively bringing new generation on line."[3] The Report further notes that California must add 24,000MW by 2016 to meet projected peak energy demand. [4] With demand for electricity growing, the price of natural gas increasing and the absence of coal as an option for California, the second purpose of this study will be to determine whether the strategy of increased nuclear power advocated by the Bush Administration would be a prudent strategy to adopt in California.

METHODOLOGY

Due to the complicated nature of the subject at hand, this study has been divided into eight sections. The first four sections serve as a primer for any discussion of electricity decision-making. The next two sections outline the direction of energy policy and how those decisions are being made. The next section evaluates the decision-making process being used for electricity planning.

The first four sections of this study give the reader the necessary technological, theoretical and institutional knowledge that will be crucial to understanding this market. Section I is an introduction to the generation technologies that are currently available. After this introduction the reader should come to understand the difficulties faced by policymakers when determining energy policy. Section II is a review of public economics. It may be assumed that policymakers are interested in maximizing social welfare when determining energy policy. Public economics is a field that proposes various models of determining policy in a way that maximizes social welfare. This section also establishes the two most significant externalities involved in this market; emissions and accident risk. Section III determines a standard of "social efficiency" against which electricity policy will be evaluated in this study. This is done by establishing the standard of least social cost as a cost accounting methodology that will lead to the socially optimal technological selection. It is important to note that environment created by the regulatory scheme must be one in which all significant externalities are fully internalized in order for this to be true. Finally, section IV describes the current technological and regulatory makeup of the electricity market in the United States and California. With this solid foundation in hand, one may turn to electricity planning.

The next two sections review recent changes in policy planning and how those decisions were made. Section V outlines the changes in policy advocated by Bush Administration's Energy

Policy Act of 2005 and the Advanced Energy Initiative. Section VI determines that decisions regarding these policies are made by reviewing reports commissioned by the federal government such as “The Economic Future of Nuclear Power” done by the University of Chicago. After becoming familiarized with recent policy changes and how those decisions were made, all of the relevant information needed for an analysis of the social efficiency of the decision-making process done in such a study.

Section VII evaluates the cost accounting methodology used in the University of Chicago report with respect to social efficiency. While the method appears to be socially efficient, upon further investigation one finds that the current regulatory scheme fails to fully internalize the risk externality. It is important to remember that socially efficient decision making is only sufficient for optimal technological selection, not necessary. Thus it is important to attempt to find a way to estimate these costs to use in a socially efficient analysis. One finds that this cannot be done in a way that maintains academic integrity due to the problem of determining a social discount rate.

Section VIII discusses the conclusions of this study. Through the evaluation of the decision-making methodology used at the federal level with respect to social efficiency, one finds that the current regulatory scheme does not necessarily lead to the socially optimal technological selection. One way to remedy this problem would be to make the nuclear industry strictly liable for damages in case of an accident. Since the levelized cost equivalent with the risk externality internalized is beyond the scope of this study, one cannot be sure as to which technology is truly the socially optimal one. That being determined, and considering the catastrophic effects of such an accident, it would be prudent for lawmakers at the federal level and California to first consider adding these potential social costs to their estimates for nuclear capacity. For the time being, California lawmakers may consider the possibility of meeting some short-term capacity needs and renewable standards with renewable technologies.

I. INTRODUCTION TO ELECTRICITY TECHNOLOGIES

In order to understand the difficulties that firms and policymakers face when choosing among generation technologies, one must have a general understanding of the technologies that are currently available. There are three categories of resources used to generate electricity: fossil fuel, renewable and nuclear. Each of the technologies within these categories has strengths and weaknesses that need to be taken into account.

Fossil fuels are hydrocarbon-containing natural resources which can be combusted to power a turbine to generate electricity. Fossil fuel deposits are found all over the world and are made from plants and animals that lived up to 300 million years ago. From an economic standpoint, reliance on fossil fuels is a dangerous game in that fossil fuels are a finite resource. This causes the market to be subject to pressure during times of political unrest (like wars in the Middle East) and because of the rapid industrialization of countries like India and China. Another problem with the use of fossil fuels is that their combustion results in significant emissions of greenhouse gasses which have been linked to global warming, as well as other pollutants including particulates and mercury. Resources used for the production of electricity in the United States that fall into this category are coal, natural gas and petroleum.

Coal-fired power plants are known as the “dirtiest” source of electricity and have severe environmental impacts. The technology requires the use of a great deal of water and emits high levels of pollutants. Coal is, however, is the most plentiful and the most cheap of the fossil fuels. In fact, the wholesale price of coal to actually declining.[5] Due to rapid increases in the price of natural gas, the use of coal-fired plants is predicted to rise significantly by 2030.[6]

Natural gas is a gaseous fossil fuel that consists primarily of methane. This gas is produced during the anaerobic decay of non-fossil organic material. Many economists, notably Alan Greenspan, feel that the United States is soon to be subject to a natural gas crisis. The supply of natural gas in the United States has effectively leveled off while the demand continues to grow, causing prices to skyrocket. Most in the industry concede that it is only a matter of time before this source is no longer cost effective for the production of electricity.

Petroleum has been called the “lifeblood” of America’s economy. This highly versatile fuel is used in the transportation, heating and electricity sectors. The price of petroleum has made its use in the electricity sector highly inefficient for some time. The Energy Information Administration has predicted that no new petroleum plants will be built between now and 2030, thus the possibility of new petroleum plants will be discarded in this study.[7]

Fossil Fuels - Pounds per Billion Btu of Energy Input and Price (see Appendix I)

Pollutant	**Natural Gas**	**Petroleum**	**Coal**
Carbon Dioxide	17,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0	.007	.016
PRICE	$7.39/MBTU	$7.57/MBTU	$1.04/MBTU

Looking at the comparison above it is easy to see the dilemma faced by policymakers when choosing among fossil fuels. The fuels that produce electricity at the lowest pecuniary costs emit the most pollutants and vice versa.

Renewable energy sources are defined as those which capture their energy from existing flows of energy. These are ongoing natural processes such as sunshine, wind, flowing water, biological processes and geothermal heat flows. Further complicating the choices for policymakers, these sources of electricity emit zero or negligible levels of pollutants but have extremely high pecuniary costs.

The most plentiful renewable resource is solar energy. Putting this into perspective, each day the earth receives over 15,000 times the energy production of all kinds by humans from the sun.[8] The solar technology relevant to this study is photovoltaics, which convert sunlight directly into electricity. A typical photovoltaic system consists of solar panels and an inverter. The solar panels collect photons from sunlight and convert them directly into DC power. The inverter then converts the DC power into AC power that is connected to the structure and can power the building like any other source of electricity. Photovoltaics create no pollutants and have no fuel costs, but are very expensive to build.

Wind can be harnessed by installing large fan blades at the top of a tall tower to capture the energy and use it to turn a turbine. There are five locations in California that have major wind farms containing hundreds of these turbines. These five locations create 95% of California's wind power.[9] The generation process has no fuel costs and no harmful emissions. Wind power can be controversial in that arguments have been made that the technology is extremely noisy and that the fan blades kill a large number of birds and bats.

Wind and solar installations are both intermittent sources of power, sources that are not consistent throughout the day or time of year. One important characteristic of the electricity market is that supply must always equal demand; storage technology is not advanced enough to be used on a wide scale. This decreases the benefits of any intermittent source because its generation is not reliable.

Hydroelectric power captures energy from moving or falling water. In most cases hydroelectricity is created when water from a dam in a river is used to turn a hydraulic turbine.

One of the best features of hydroelectric power is that during times of low-demand, more water can be stored to be used during high-demand times. Again, this source of energy does not create any harmful emissions and has no fuel cost. There are, however, some arguments against this technology. Some environmentalists claim that large hydroelectric dams disrupt the local ecosystem. In California dams have been shown to have considerable negative effects on the salmon population. Most usable sites have been utilized for large hydro in California, and new hydro plants face environmental concerns. Thus the ability to meet any significant increase in demand with hydroelectricity in the state is slight.

Biomass electricity is generated through the combustion of organic material to drive a turbine. The organic material comes in a number of different forms. Energy crops are grown specifically to be combusted and are most commonly hybrid willow or switchgrass. Several types of residue can also be used including agricultural residue (wheat straw, corn stover) and forestry residues (logging residues, rough rotten salvageable dead wood, excess small pole trees) to turn a turbine and generate electricity. California's biomass industry is the largest in the country. One problem with biomass is that the fuel is not readily available and is labor-intensive, thus it is very expensive.

Geothermal power is created by utilizing heat deep within the earth. This heat either creates steam or hot water that is used to turn a turbine. Most efficient geothermal sites in California have already been utilized. Also, because the heat at a particular site can eventually run out, this technology is not strictly renewable and should therefore not be crucial to long-term energy plans.

One important consideration for the evaluation of any renewable source of electricity is the amount of land use required. Photovoltaic and wind installations require huge tracts of land on which to place the infrastructure. In California land is extremely expensive and can be the factor that makes a technology cost-ineffective. This has led to the promotion at the federal and state level of residential photovoltaics. A residential system typically places the solar panels on the roof of a house. A grid-connected residential system uses photovoltaics to power the entire house and can use electricity from a utility when the electricity generated by the system is not enough. This can solve the problems associated with intermittent technologies in that during times of low production other sources can be used.

The final category to be discussed is nuclear power. Nuclear energy is produced when a fissile material, such as uranium, is concentrated such that the natural rate of radioactive decay is accelerated in a controlled chain reaction and creates heat. This heat is used to boil water, produce steam, and drive a steam turbine. Nuclear power plants emit no greenhouse gasses and have a fuel that some arguably call “sustainable” because the amount of uranium used is so small compared to total reserves. The negative aspects of nuclear power include the risk of a nuclear accident and the creation of nuclear waste. The predominant “mature” reactor design operating in the United States today is referred to as Generation II. Advanced reactors, or Generation III, have a standardized design and therefore cut a number of the costs associated with licensing, capital costs and construction time. They also have safety mechanisms that are said to nearly eliminate the potential for human error. These reactors have been operating in Japan for some time. Optimistic estimates for the availability of some Generation IV reactors are around 2020, while others set it at 2045 if at all.[10] Thus for the purposes of this study any potential new reactor being considered will be assumed to be a Generation III reactor.

II. PUBLIC ECONOMICS

After being introduced to each of the available technologies, even when given the negative and positive aspects of each, it is still extremely difficult to choose which one to use. A profit-maximizing firm will want to choose the technology which produces electricity at the lowest pecuniary cost, but a citizen may want a technology used that will emit the lowest possible level of harmful substances. Whose preferences should be weighted more heavily? When should the government intervene in this market? When it does, how should a policymaker make these difficult decisions? Luckily, there is an entire field of economics dealing with exactly this subject called public economics.

Contrary to the simpler market-based conclusions of economics, public economics suggests that the competitive market equilibrium is not always the most efficient outcome for society. This condition is known as a market failure. A market failure can result from one of two disparities: one between private and social costs, or one between private and social benefits. The primary reason for government intervention in the market according to public economics is to correct such market failures.

A market failure due to a disparity between private and social costs will cause distortions in cost accounting. Private cost is defined as the total cost to a firm of producing a given good. Included are all fixed and variable costs incurred by the firm directly as a result of production. Social cost is defined as the private cost plus any additional costs not included in the private cost that are incurred by society as a whole as a result of the production of a given good. When the social cost is higher than the private cost, by definition there is a negative production externality present in this market. The purpose of government intervention is to correct for these distortions by eliminating the disparity between social and private costs and benefits to induce the private market to arrive at the socially optimal outcome.

A. Production Externalities

Production externalities are benefits or costs that occur when production by one firm make another party better or worse off, yet the firm does not bear the benefits or costs of doing so.[11] When this occurs, there is an extra benefit or cost being imposed on society that is not being considered in the decision-making process of the private entity. Any extra costs (or benefits, which for these purposes will be included as a negative cost) being imposed on society in these situations is referred to as an external cost. In short, the difference between social cost and private cost is external cost. When the government intervenes in a market the goal is to internalize the external cost by adding the external cost to the private cost through policy in order to induce the socially efficient outcome.

The public sector corrects for the presence of externalities in a market in one of two ways; by affecting quantity or by affecting price.[12] The government affects quantity through direct regulation. The way in which the public sector corrects for the majority of externalities is by simply mandating a given level of the externality. A maximum/minimum level of the externality is generally determined by government agencies in such cases, and the public sector uses its regulatory powers in order to mandate that level. Continuing with the rubber plant example above, the government may mandate a maximum level of smell that the plant can emit in order to be permitted to operate. The plant owners will be willing to buy the necessary equipment to reduce the smell to the allowable level until the point that the costs of doing so outweigh the benefits. In this way, the costs of the basic level of the externality have been internalized.

Once this basic level of an externality has been limited, there may still be some external effects on society. In order to internalize remaining effects the government may intervene by using the price mechanism by making the relative costs to a firm reflect the presence of the externality. This is done most often by using corrective taxation and subsidies. The most commonly accepted method of taxation in public economics is one that was advocated by Arthur Pigou, the author of externality theory. This system taxes or subsidizes a producer by exactly the amount of external damage or benefit. While it is extremely difficult to place a monetary value on non-market external damages and benefits, governments have devised various ways of doing so.

B. Social Costing

Social costing describes methods for estimating and accounting for the externalities of economic activities.[13] Ideally, these estimates could be used to determine the optimal regulations and Pigouvian taxes. Although the merits of various theories of social costing have been argued by economists for decades, one particular methodology has been widely accepted and applied by governments around the world: the Extern-E methodology launched by the United States and the European Commission. The study uses software called EcoSense to assign monetary values to externalities. The social cost estimates in the study consider the "impact pathways" of various technologies quantify effects from primary and secondary pollution, morbidity and mortality, agricultural crops, amenity (noise, visual impact) and global warming. Applications of the Extern-E methodology by government agencies have been observed in investment decisions and technology assessment.[14] While the methodology used by Extern-E can be disputed, its major relevance to this study is that the use of social costing is becoming increasingly important to energy policy decisions worldwide.

This study will focus on the two most significant negative externalities of electricity generation; emissions and the threat of an accident.

C. Emissions

From an economic perspective, the government generally uses a “command and control” approach to emission. This approach is equivalent to the regulation method, by which government agencies set a maximum quantity of emissions that a plant is allowed to discharge. It has been argued by several scholars that a “cap and trade” system of tradable permits would lead to greater economic efficiency and innovation.[15] While some California regional air quality districts have implemented such strategies within their jurisdictions, this type of analysis is outside the scope of this study. The command and control approach here simply reflects the additional cost to the firm that owns the generator in terms of equipment that must be purchased to reduce emissions to the maximum allowable level.

As described earlier, there are still technologies that emit pollutants that are still cost effective once the minimum emissions standards have been met. In order to account for the social cost that is still being incurred, the government taxes the emission. While under a theoretical model an actual tax would be imposed, say, per some unit of carbon dioxide emission, most states use what is called an externality “adder.” The adder acts just like a tax, the government requires that utilities use the adder in any cost calculations done when choosing among various technologies to account for costs to society. In California adders have been mandated for emissions of nitrogen oxide, sulfur dioxide, particulate matter, reactive organic gasses and carbon.[16]

It has therefore been established that the government’s approach to emissions control internalizes the bulk of the external cost through regulation and the rest through externality adders. Under this system, when a firm is choosing among various generation technologies any cost calculation undertaken will have internalized the costs to society and the firm will choose the socially optimal technology.[17]

D. Risk of an Accident

The second externality that is created by electricity generation is the risk of an accident. Again, due to this social cost imposed on society the government has intervened in the market in order to obtain a more efficient outcome than the private outcome. The two ways in which the government eliminates the externality of the risk of an accident is through safety regulations and by mandating liability insurance.

Safety regulations at power plants are generally found in the form of mandatory equipment purchases and operational procedures. Unlike emission mandates, safety regulations can only be said to eliminate *most* of the risk externality. This is because the source of the risk goes beyond equipment and procedure. Some small amount of risk comes from unpredictable factors such as human error and terror attacks. In order to ensure that all externalities are accounted for, there needs to be a way for a firm to pay for this extra risk.

Liability insurance is the typical way in which firms correct for any additional accident risk to society. If the insurance is based on a condition of strict liability, in which the firm is fully responsible for any injury incurred even if there was no negligence, economic theory holds that the risk has been fully internalized. [18]

E. Positive Production Externalities

It is important to note here that there are positive production externalities associated with the production of electricity by some methods as well. For example, when a low-emission technology is chosen over a high-emission technology, there is an external benefit accrued to society of cleaner air. In order to correct for this type of externality the government can subsidize this industry to make the cost of production lower.

III. Socially Efficient Decision-Making

A. Least Social Cost

The preceding review of public economics allows one to determine a standard against which one may evaluate any of cost accounting for an electricity technology. The economic justification of government intervention in this market to create policies that will ensure the internalization of externalities so that any cost comparisons done by firms when selecting technology will also reflect costs to society. For the purposes of this study the methods used in decision-making will be considered "socially efficient" if the major externalities have been internalized. Socially efficient decision-making should be the goal of policymakers because once externalities have been internalized a least-cost analysis *must* yield the technology with the lowest social costs which is the optimal outcome for society as a whole.

B. Notes on Internalization

It is also useful here to decide what standards will be used to determine whether an externality has been internalized. It will be assumed here that because government agencies hire economists who have specialized knowledge of public preferences and the impacts of externalities that the direct health, safety and environmental regulations currently being enforced are set to achieve socially optimal maximum levels of externalities. For this same reason it can be inferred that the values of "adders" and subsidies also internalize externalities.

IV. THE CURRENT STATE OF THE ELECTRICITY MARKET

A. Where does electricity come from now?

Before any discussion of the application of public economics to the electricity planning, one must understand the current makeup of United States electricity supply. In the most recent release of Electric Power Annual by the Energy Information Administration the United States generated a total of 3,970,555,000 MWh of electricity.[19] Of this, 70.9% is generated using fossil fuels. This statistic breaks down to 49.8% coal, 17.9% natural gas, 3% petroleum, .4% other gasses. Of the remainder of US electricity production, 19.9% comes from nuclear, 6.5% comes from hydroelectric, 2.3% comes from other renewables (such as wind and solar), and .2% comes from other sources.[20]

In 2005, California had a total of 225,788,000 MWh of "in-state" electricity generation. This breaks down into 20.1%% coal, 15.3% large hydro, 42.6% natural gas, 16% nuclear and 13.7% renewables. Specific renewable technologies as a percentage of in-state electricity generation comes to 2.7% biomass, 6.35% geothermal, 2.35% small hydro, 0.3% solar and 2% was wind.[21] One extremely important component of California's electricity supply about one-fifth of it comes from out-of-state coal plants that are owned by California utilities. As noted earlier, the difference in the makeup of California's electricity generation capacity and the United States' as a whole can be attributed to differences in energy policy.

Now that the makeup of electricity supply has been outlined, it is necessary to understand which entities influence the market. A thorough discussion of the entities involved in this market and the way in which they influence it is necessary in order to understand whether this market is efficient from a public economics standpoint.

B. Who's Who in the Electricity Market?

The electricity market is an extremely complex system of private and public entities. Electricity facilities are owned either independently or by a utility. Independent generators sell electricity to utilities at wholesale rates. Utilities can be owned either privately or publicly, and sell electricity to consumers at a retail rate. Publicly owned utilities have a great deal of accountability, and most are governed by an elected board. Privately owned utilities, on the other hand, function much like a typical profit-seeking firm.

Federal and state governments influence which types of electricity generation technologies are used through the creation of environmental standards, mandates and subsidies. The federal and state government has utilized these tools to different degrees in order to steer energy policy. In the area of environmental standards, policymakers have been able to affect electricity sources by setting maximum levels of pollutants. The federal policy most relevant to this study is the Federal Clean Air Act, which sets maximum allowances of air pollutants from electricity facilities.[22] California has chosen to set additional, more stringent emissions standards which account for the significant difference in sources of electricity from the Unites States as a whole. These standards come primarily from the state's Air Resources Board.

Only California has set strict mandates for any type of electricity generation. The federal government has come close to setting similar standards in the past, but it has not actually been done. Most notably California has a Renewable Portfolio Standard, under which electricity providers have to provide 20% of California's electricity from renewable resources by 2010. As of this writing in 2006 only 13.7% of the current electricity supply comes from renewables, thus it is safe to expect a surge in renewable technology use over the next few years.

Subsidies are used by governments quite extensively in the energy market. Some even argue that these subsidies create price distortions which lead to inefficient outcomes in this market. At the federal level, most subsidies come via contributions to research and development of favored technologies or via production tax credits. The effect of subsidies on cost analyses of various technologies will be demonstrated later on. Taxes are not generally used in this market, as the shadow cost to society is used to manipulate relative costs through the use of adders determined by the California Public Utilities Commission.

Final decisions regarding what types of power plants will be built are directly determined by state agencies. In California an independent generator or utility must submit a proposal to the California Energy Commission, which distributes licenses to build plants as long as the region needs the additional capacity and the technology will meet all relevant laws, ordinances, regulations and standards.[23] The California Energy Commission also conducts extensive studies involving the projected supply and demand for electricity and makes policy recommendations to the legislature to set new standards, etc.

V. ELECTRICITY PLANNING

A. Electricity Planning by the Bush Administration

On August 8, 2005 President Bush signed the Energy Policy Act of 2005. This legislation was the first comprehensive energy bill in over a decade and was designed to address the nation's growing energy problems. A significant part of this bill would decide the direction of electricity policy in the United States for decades. This bill gave subsidies to wind and solar generation and authorized $200 million annually for clean coal initiatives. More importantly this bill included huge incentives for the use of nuclear power. Some of these incentives included liability caps for the nuclear industry, production tax credits and cost-overrun support. The effects of this bill on costs will be discussed later.

On January 31, 2006 President Bush announced the Advanced Energy Initiative. The initiative lays out a number of energy sources that the federal government is pursuing, and proposes various spending accordingly. A number of these are electricity sources. The initiative will spend money toward "clean" electricity generation as follows:

Chart 1[24]

Technology	**Spending**
Clean Coal	
Future Gen	$335 million
Traditional Renewables	
Solar (Solar America Initiative)	$148 million
Wind	$44 million
Nuclear	
Global Nuclear Energy Partnership (GNEP)	$250 million
(R&D) to support Generation IV nuclear energy	$32 mil
Yucca Mountain	$544.5 million
Nuclear Power 2010 (NP 2010) initiative	$54 million

For the purposes of this study, one may use the Advanced Energy Initiative to perceive a general sense of what technologies the federal government is supporting for use in long-term electricity planning. The high level of spending toward clean coal technology reflects the Administration's desire to take advantage of the large amount of coal reserves in the United States. After all, one-quarter of the world's coal is found within the United States, and the energy content of that coal exceeds that of all of the world's known oil reserves.[25] The federal government's pursuit of "clean coal" has led to four potential technologies to reduce various pollutants, but there is no guarantee that they will be ready for implementation in the near future.

This leaves the two most supported technologies by the Bush Administration to be solar and nuclear. While solar has been used to varying (but small) degrees since the 1970's, a push toward the use of nuclear power is a dramatic shift in energy policy since this period.

B. A Brief History of Commercial Nuclear Power

Although there are currently 103 commercial reactors in use today, no new nuclear plant has been commissioned in the United States since 1978. Prior to 1979, the primary reason was the extremely long construction period required for the plants due to delays in the licensing process.[26] After 1979 preferences for nuclear power dropped significantly due to the near-meltdown at Three Mile Island.

Again, California has additional requirements regarding the construction of new nuclear plants. During the national debates of the late 1970's on nuclear power, concerns in California revolved around nuclear waste disposal. In 1976 the Legislature enacted laws requiring that an operational federal waste disposal site is available before any new nuclear plants could be built. This moratorium is still in effect today.

In 1982 Congress passed the Nuclear Waste Policy Act, charging the Department of Energy with the task of finding a suitable site, building and operating a spent fuel repository. The department proposed Yucca Mountain in 1987, and President Bush signed House Joint Resolution 87 allowing the construction of the repository in 2002. The total cost of the site is estimated to be between $50-100 billion dollars. So where is the renewed interest in nuclear power coming from?

C. How Were These Planning Decisions Made?

Any economist attempting to analyze the electricity market with an intention to use this analysis for long term planning knows that this is a daunting task. Least-cost analysis methods are used when choosing among technologies, but even with externalities accounted for by government intervention the costs are difficult to calculate. Much of the analysis relies on forecasts that have very high levels of uncertainty; including world fuel prices, construction times, advances in technology and ever-changing environmental and safety regulations. Any unexpected changes in these factors can easily change whether or not building a plant will be cost-effective. One such example of changing environmental regulations involves coal plants. Equipment needed to meet environmental standards imposed on coal plants in California were so high that they almost equaled the initial capital costs of the plants. Needless to say the plants were no longer cost effective and were shut down by the firms that built them, incurring net losses. Regardless of this inevitable uncertainty, decisions must be made regarding investment in power plants therefore public and private entities spend a great deal of money hiring professional economists to get the best estimates possible.

D. Levelized Cost of Electricity (LCOE)

Levelized costing is the most common cost accounting method used by public and private entities when comparing different generation methods for electricity. This method annualizes any up-front costs associated with each technology and allows for more accurate cost-benefit analyses. By considering life-cycle fuel costs, this method also accounts for forecasted increases in the cost of fuel. The method can incorporate a number of the uncertainties mentioned above and is economically a very sound method of cost accounting. As this study determined earlier, a least-cost method of choosing among technologies can lead to the socially optimal choice as long as externalities are being accounted for. By accounting for uncertainty levelized costing in a least-cost analysis with government intervention to account for externalities creates an ideal environment for socially optimal technology selection.

E. "The Economic Future of Nuclear Power"

In response to the increasing price of natural gas and the pollution concerns over coal, the federal government has recently explored many options for the necessary additional generation capacity. In 2004, a University of Chicago study initiated by the Department of Energy was released entitled “The Economic Future of Nuclear Power.” The 300-plus page report is an exhaustive study of previous work and original research resulting in a clear economic methodology under which the authors compare nuclear power with existing technologies in the United States; namely coal and natural gas.

Much to the credit of the authors, the study did conceive an LCOE methodology that quantified many of the infinite number of factors which go into any cost comparison of various technologies. To account for some uncertainties the authors also included a number of probable policy scenarios and technological advances that would have an impact on the costs. The methodology can be said to account for externalities in that it estimates the costs for a new plant that will meet current and even more stringent emissions standards. The study also estimates the costs of nuclear power including nuclear decommissioning and waste disposal.

The study initially finds the LCOE of coal to be 33-41$/MWh, natural gas to be 35-45 $/MWh and nuclear to be 53-71 $/MWh. The study also finds that “even if clean coal research were to reduce the carbon sequestration costs associated with coal plants by 50 percent, an LOCE of $65 per MWh could still emerge. Improved capture and sequestration technology for gas plants could leave the gas LCOE in the range of the mid-$50s per MWh. Reasonable scenarios for new nuclear power would yield LCOEs competitive with such coal and gas costs.[27] (pg 208) The study then goes on to analyze various scenarios that could affect the LCOE of coal, natural-gas or nuclear. Two of those scenarios; a federal loan guarantee and a production of 1.8 cents/KWh have become reality due to provisions of the Energy Policy Act of 2005[28]. The federal loan guarantee can be up to “80% of the project’s cost.” The Chicago study makes predictions based on 25% and 50% guarantees, thus the higher of these estimates will be used. Given a 50% loan guarantee, the LCOE of nuclear power drops the range to $49-$65/MWh.

Furthermore, the study predicts that a $18/MWh tax credit would decrease costs an additional $15/MWh. The combination of these two policies makes the final range $34-$50/MWh. The final results are shown below:

Levelized Costs Under Various Scenarios

Technology	**LCOE $/MWh (**basic)	**LCOE $/MWh** (loans, tax credit)	**LCOE $/MWh (**more stringent regulations & loans, tax credit)
Coal	33 to 41	33 to 41	83 to 91
Natural Gas	35 to 45	35 to 45	58 to 68
Nuclear	53 to 71	34 to 50	34 to 50

Since this study and others like it have been commissioned by the federal government and used in congressional hearings, it is clear to see why Congress took the steps of granting loan guarantees and tax breaks to the nuclear industry. One can also see the reason for the huge recent policy shift in favor of nuclear energy.

F. LCOE in California

The California Energy Commission (CEC) also hires economists to conduct thorough analyses of various technologies that are used for energy policy planning. These estimates are done with respect to California's more stringent environmental standards and externality adders, and therefore reflect the extra costs associated with the internalization of various externalities. The CEC also uses a levelized cost method when comparing various technologies.

CEC levelized costs[29]

Technology	**$/MWh**
Coal	N/A
Natural Gas	45.8
Nuclear	N/A

As one can see, the cost associated with a natural gas plant is fairly consistent with the Chicago study estimate of a natural gas plant under more stringent emissions standards. In short, it may be assumed that the government has hired economists to quantify the costs associated with various technologies and have come to a conclusion. It can be taken as given that these numbers are under a high level of scrutiny and are accurate to the best of the ability of these economists.

It is obvious to any economist that a levelized cost methodology for comparing various technologies is an extremely prudent way to make investment decisions as a private firm. By choosing the method with the least cost in over the life of the investment within the parameters of environmental regulations and government subsidies, a firm will undoubtedly maximize profit. But is this the right methodology to be used by policymakers in Congress? The purpose of this analysis then is to answer the question, “Is a least-cost method using levelized costs a socially efficient method of cost accounting to be used in decisions about energy technology?”

VI. EVALUATION OF COST ACCOUNTING OF ELECTRICITY TECHNOLOGIES

A. Is the LCOE method of cost accounting socially efficient?

It has been established that the use of a least-cost analysis of levelized costs will lead to the socially optimal technology selection when externalities have been accounted for. The question then becomes, “to what degree does the Chicago LCOE methodology internalize externalities?”

First it is useful to look at the various components that make up the levelized cost in the Chicago study:

$$\mathbf{EGC = I/(E\sum (1+r)^{-t}) + M/E + F}$$

Where:

EGC = Average lifetime levelized electricity generation cost per kWh
I = Total Capital expenditures discounted to year 1

M = Yearly operation and maintenance expenditures
F = Fuel Cost
E = Yearly electricity generation
r = Discount rate
n = Plant life

According to the methodology developed earlier, one can determine the social efficiency of this method of cost accounting according to the degree to which externalities are accounted for. The positive externality associated with nuclear power is the increase in clean air when it is chosen over a technology that emits pollutants. This externality has been internalized through government subsidies in the 2005 Energy Policy Act. One document notes that the $18/MWh production tax credit is meant to place nuclear power on equal footing with other sources of emission-free power.[30] These subsidies are included in the second analysis done in the study when loan guarantees and tax credits are included that lower the cost.

The negative externality associated with nuclear power is the risk of an accident. Public economics holds that this externality can be eliminated through safety standards and liability insurance. Nuclear safety is overseen by the Nuclear Regulatory Commission. This body sets the standards for equipment and procedures aforementioned. While not explicitly mentioned in the study, these regulatory compliance costs are accounted for through the capital (**I**) and operational (**M**) costs above. It has been assumed in this study that direct regulations are set by experts with specialized knowledge in this field and thus will be assumed to be set at some socially optimal level.

As expected, safety regulations do not eliminate all of the risk of an accident. With these regulations in place, the estimated probability of core damage for an Advanced Boiling Water Reactor (Generation III) has been found to be: [31]

$$\textbf{Core Damage Frequency (ABWR)} = \mathbf{1.6x10^{-7}}$$

This small risk of an accident at a nuclear plant can be internalized by the purchase of liability insurance. Nuclear generators are required by law to purchase insurance. Again, since this is already a mandate, it is safe to assume that the insurance premium is included in the Chicago study as a component of operational costs (**M**).

By all outward appearances it would seem that socially efficient decision-making is occurring at the federal level. The University of Chicago study used to advocate for the use of nuclear power in Congress seems to account for all significant positive and negative externalities. Since socially efficient decision-making necessarily leads to the socially optimal technological choice, this would imply that nuclear really is the socially optimal source. However upon further research one finds that there is one key requirement of socially efficient decision-making that is not being met.

B. Determining the cost of an accident

The key here is to remember that in order to internalize this externality, the insurance would have to cover all costs associated with such an accident. This is the point at which the nuclear option requires additional scrutiny. The problem with determining whether or not the insurance coverage meets this requirement is determining what the costs associated with an accident actually are. In order to determine the cost of an accident one must first explore the consequences of a nuclear accident. For the sake of strict scrutiny in cost accounting it is prudent to assume that a worst-case scenario would result from an incidence of core damage.

The most recent publicly available, comprehensive study on the impact of such an accident was done by Sandia Labs (the research arm of the US Department of Energy) in 1982. Since costs tend to be site-specific, the Consequences of Reactor Accident or CRAC-2 report estimated the deaths, injuries and property damage that would result from a severe nuclear accident at each of the 103 nuclear power plants in the United States. It has been found that citizens fear new nuclear plants more than existing plants, thus it is safe to assume that any new plants will have to be cited on or around existing nuclear sites. Since the worst-case scenario is being used, one can assume that land has not appreciated nor has population risen in these areas since the study was conducted (although this is highly unlikely). Of the three reactors located in California, the Unit 2 reactor at Diablo Canyon has the latest expiry date, 2025.[32] CRAC-2 estimates that in 1982 population and dollars there are the following consequences associated with an accident at this reactor. These numbers have also been adjusted to 2004 levels for relevant analysis (see Appendix II).

Consequences of Reactor Accident

Diablo Canyon Unit 2 San Luis Obispo, CA	**Peak Early Fatalities**	**Peak Early Injuries**	**Peak Cancer Deaths**	**Property Damage**
1982 dollars/ 1982 population	10,000	12,000	12,000	$158 Billion
2004 dollars/ 2004 population	12,500	15,000	15,000	$312 billion

Translating consequences into monetary value

Valuation of property in monetary terms is an easy task because physical goods have an observable market price. More problematic is trying to ascertain the value of harm and/or death to a human being in the event of such an accident. Economists have approached this problem from a number of angles. One method, probably the more common approach in the American legal system, is to value harm as a cost equal to the present value of expected gross earnings that are lost. Under this methodology a person who is killed in an accident would have his or her medical bills paid in addition to the present value of the person's expected earnings for the rest of his life. This amount is occasionally supplemented with additional funds to compensate for the suffering of the family of the victim.[33]

It is easy to see the major flaws in this method. One scholar notes the fact that under this system the death of a retired worker would be worth nothing besides the suffering of others, implying that human life has no inherent value.[34] A more realistic method of valuing the loss of life or limb is a version of derived demand in which market prices for non-market goods are determined in related markets. The "value of a statistical life" (VSL) involves deriving this value from the additional salary an individual would need to be paid to take a job with a risk of death, weighted by the probability of death. This method tends to largely understate the value of a human life. This is because people tend to have limited information on the actual risks of these situations and because a great deal of self-selection occurs among those who will take a job with a risk of death.

A third method used to value a human injury and death that is particularly relevant to this discussion is to use the "cost per life saved" that can be economically derived from various government programs already in place. This methodology makes the most sense for the purposes of this study because it is assumed that regulatory agencies have specialized knowledge of risks and preferences. Extensive studies have been conducted to find these numbers with respect to major programs in the United States. Harvard economist Kip Viscusi is known as the authority in this area and has been the source of a number of excellent studies comparing these values.[35] The most relevant estimation found for the purposes of this study is one done by Bernard Cohen at the University of Pittsburgh that uses the same methodology and estimates the cost per life saved derived from NRC safety programs is approximately $2.5 billion in 1987 dollars.[36] Normalize this figure to 2004 dollars and one derives a cost per life estimate of approximately $4.1 billion.

Now that a credible estimate of the value of life by administrators in this field has been determined, one would be interested in a similar valuation of illness or injury. Granted the difficulty with which one comes to value a life, it is easy to imagine the difficulty of estimating these numbers. Numerous scholars have found that this task is virtually impossible.[37] Therefore, this study will rationally assume these values to be some positive numbers that are less than the value of human life.

This information can now be applied in order to estimate the cost of an accident. The following methodology is an economically ideal way used to quantify the cost of the risk of an accident described above in 2004 dollars:

$$\mathbf{A = (E*V) + (C*V) + (D) + (I*W)}$$

Where:

A = Cost of accident risk
E = Number of early deaths
V = Value of human life
C = Number of cancer deaths
D = Dollars property damage
I = Number of injured individuals
W = Value of wellbeing

Using the estimates previously found in this study, the cost of an accident is approximately equal to $**69.1 trillion + $15,000W,** where W is some positive number less than $2.5 billion (See Appendix III).

Now that the cost of an accident has been estimated, one can determine whether or not the liability insurance mandated for nuclear generators is sufficient to internalize the externality. As stated earlier, negative externality of the risk of an accident may be fully internalized if the firm is insured for strict liabilities for damages. So what kind of liability insurance do nuclear generators have?

C. Nuclear liability insurance

The Price-Anderson Nuclear Industries Indemnity Act, commonly called the Price-Anderson Act, covers all commercial nuclear power plants built before 2026. Under this act the owners of a nuclear plant must obtain the maximum amount of coverage against a nuclear accident available in the market, which as of 2005 is $300 million. The Price-Anderson fund, which is financed by the reactor companies themselves, is then used to make up the difference. Each reactor company is obliged to contribute up to $95.8 million in the event of an accident. If there were an accident today and each company were obliged to pay the full amount, the maximum amount of money in the Price Anderson Fund would amount to $9.5 billion. The $95.8 million mark is a cap on the liability of any company, thus there is an effective cap on the liability for the industry as a whole for any accident at $9.5 billion.

It is interesting to discuss here that in a socially efficient insurance scheme the price of insurance is said to be “actuarially fair.” An actually fair insurance premium is equal to the present value of risk. The average annual premium paid for a single-unit reactor site is $400,000.[38]

It is obvious from the previous calculations that generators are not fully insured for the cost of an accident. While the cap on liability is $9.5billion, this study has found the estimated cost of an accident to be $69.1trillion. To put this disparity in perspective, even if the costs estimated here of an accident were overestimated 7,000 times the “actual” cost the insurance coverage would still be insufficient (See Appendix IV). This study shows that the current level of insurance coverage fails to fully internalize the externality of risk.[39] Therefore the decision-making process being used to advocate for the use of nuclear power is socially inefficient and therefore does not *necessarily* lead to the socially optimal technological selection.

D. Accident cost and LCOE

It is important to understand that simply because the externality has not been completely eliminated does not mean that nuclear power is not the least-social-cost technology. In order to incorporate these findings on the cost of an accident into a least-cost comparison, one would first have to determine the "cost" of the externality itself: accident risk. This can be done by calculating the expected cost of an accident using the following equation:

$$\mathbf{R = P(A)}$$

where,

R = Expected Cost of accident
P = Probability of accident
A = Cost of accident

If the numbers found thus far in this study are applied to this equation the cost of an accident is approximately **$11,049,920 + $.0024W,** where W is some positive number less than $2.5 billion (See Appendix V).

E. Levelizing an externality and the social discount rate

Now that the externality of accident risk has been quantified, economics would suggest that the final step would be to incorporate this cost into a levelized cost estimate in order to compare the technologies. Arguably this would enable one to compare a true "social" LCOE of nuclear power to other technologies which presumably already have accounted for all externalities and thus already have LCOEs that reflect social cost. Should the social costs derived in such an analysis cause nuclear power to no longer be cost competitive with other technologies, nuclear power would not be a socially optimal source of additional capacity.

Unlike the common use of a discount rate being used to calculate the present value of a private investment, there is a great deal of debate as to whether a sort of "social discount rate" should be applied to a public investment (here being risk). During the early 20th century when the debate first began, many economists were paternalistic in their arguments. One scholar argued that it was "ethically indefensible" for a decision-maker to discount the future in such cases.[40] However as the concept of derived demand began to emerge scholars had some way of gauging public preferences toward the future and estimates began to emerge. Still, a general consensus exists among economists for a number of reasons that the decision-maker should use some number that reflects more patient than the citizen, mainly because citizens tend to be short-sighted in their preferences. It is generally argued that the conventional "derived" method of determining the social discount rate tends to incredibly overestimate this number because of a tendency to ignore intergenerational equity. It is also argued that policymakers, who are to some extent accountable of citizens with these preferences, tend to overestimate this number as well.[41] These higher rates tend to favor projects with benefits that are largely "front-end loaded" as where lower rates tend to favor projects with the highest total benefits.[42]

It would be inefficient to refrain from making decisions on investments with potential risks simply because of a lack of consensus on a social discount rate. After all, is has been determined here that there is still a possibility that nuclear power is the most socially cost-effective technology. In 2004 Mark A. Moore et al. set out to find such a social discount rate in a study entitled "Just Give Me a Number! Practical Values for the Social Discount Rate." The authors carefully study individual behavior to determine a shadow price of capital in addition to the traditional measure of a consumer's willingness to trade present for future consumption. The result is a very reasonable factor tree that gives estimates of the social discount rate for different projects. For the purposes of this study the relevant social discount rates are found to be:[43]

Years 0-50: 3.5%   Years 51-100: 2.5%

These numbers are consistent with those used by the Environmental Protection Agency and a number of other governmental organizations, thus they will be used here. Since the plant life of an ABWR is 60 years, the following value is generated:

$$\mathbf{D = \frac{(R)}{(1+s_1)^{50}} + \frac{(R)}{(1+s_2)^{t-50}}}$$

where,

D = Socially Discounted Value of Accident
R = Expected Cost of accident
t = Years of Plant Operation
$\mathbf{s_1}$ = Social Discount Rate Years 1-50
$\mathbf{s_2}$ = Social Discount Rate Years 51-100

Using the above equation one finds that the socially discounted value of an accident is found to be: **D = $10,610,705.31 + $.0023046043W** (see appendix VI). This would mean that at least $10,610,705.31 should be added to the present cost of the plant.

It is important to note here that this number is extremely sensitive to the value of the social discount rate. For example, let us assume that generators considered the social cost of accident risk in their cost calculations, but used the discount rate applied to insurance (as in the Chicago study) of 10%. At this rate the discounted value adds a minimum of only $5,201,515 to the cost of risk, only half of the above estimate. While it is fairly easy to tell that given the commonly accepted social discount rates a cost difference of over $10 would most probably change the optimal technology selection. Incorporation of this number into a $/MWh calculation to literally compare costs of production would require highly specialized technological and industrial knowledge and is beyond the scope of this study. However, there is a derived method of evaluating the social efficiency of nuclear power by evaluating the social discount rate that would be needed to keep nuclear power competitive.

Recall that in the best-case scenario the difference between the highest nuclear power cost ($50/KWh) and the lowest alternative technology's cost is $8. Since this is the marginal saving from using nuclear power, the marginal cost of risk cannot exceed this amount or else nuclear will not be the least-social cost technology. We would then have to solve for **S**, the necessary social discount rate.

$$\mathbf{8 = \frac{(\$11{,}049{,}920 + \$.0024W)}{(1+S)^{60}}}$$

Solving this equation (not including the unknown injury value), one finds that the social discount rate must be .265 or 27%. Compared to the ideal derived social discount rate of 2-4%, this kind of social discount rate is unthinkable. As noted earlier, large social discount rates tend to be used to favor "front-end-loaded" projects rather than ones with largest total benefits. If injury costs were included, this rate would only be larger. Allowing the construction of new nuclear plants would only be cost-effective under the parameters given in this study if the cost associated with risk is discounted at an unreasonably heavy rate.

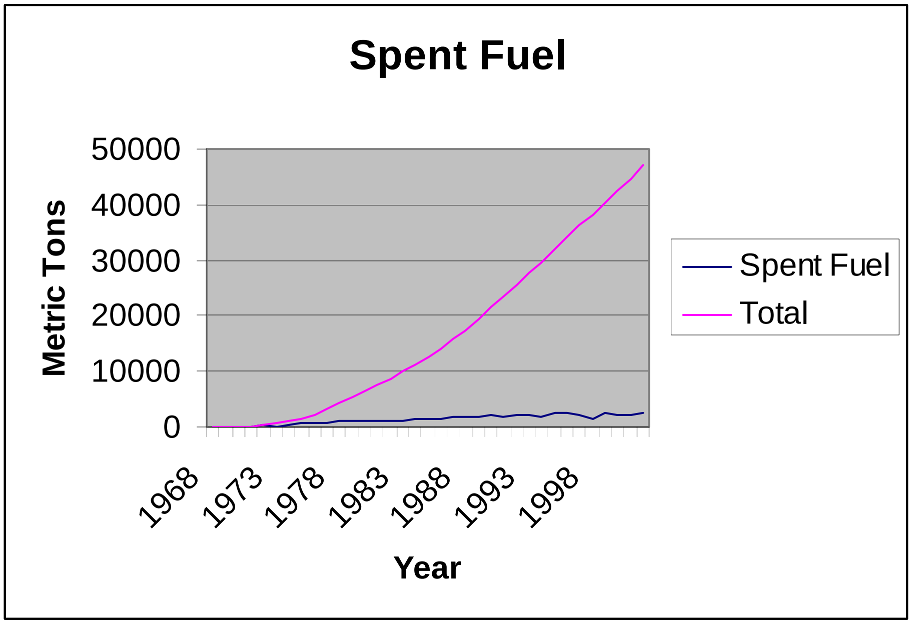
C. Other factors that may alter social cost

It has been established that the social cost associated with the risk of death from nuclear accidents are very significant. There are also potentially large social costs associated with injury from such an accident, although the pervasive numbers on value of wellbeing keep one from determining an actual value. Aside from these factors, it is important to consider other factors that may raise the social cost of nuclear power even further.

One major claim by nuclear proponents is that Generation III plants eliminate the human error that caused the accidents at Chernobyl and Three Mile Island by having automated safety mechanisms controlled by computers. One Nuclear Energy Institute (NEI) annual report notes that one necessary future activity should be data collection on the failure of digital instrumentation and control systems. A recent report entitled “Digital Instrumentation and Control Failure Events Derivation and Analysis for Advanced Boiling Water Reactor” comes to the following conclusion: “Conflicts among plant status, computer status, and human cognitive status are successfully identified. The operator might not easily recognize the abnormal condition, because the computer status seems to progress normally.”[44] This suggests that the accident probability listed earlier may actually be higher, increasing the social cost of nuclear power.

An additional dimension to the social cost of nuclear power is individuals’ perception of the risks associated with nuclear power. In one study authors found that individuals dread a nuclear accident more than they dread AIDS.[45] Psychological effects on people concerned with the accident risks associated with increased use of nuclear power, especially post-9-11, may become a significant negative externality.

As aforementioned, the Chicago study did internalize the social cost of nuclear waste disposal by including the cost of Yucca Mountain and other disposal costs. However there has been some speculation that the spent fuel already waiting to be stored in this facility will have already nearly reached capacity (70,000 metric tons) by the time it becomes operational (legal battles continue to hold up construction and operation for many years). If this is the case, the social cost of nuclear power will need to include the costs of citing yet another nuclear waste storage facility.



VII. CONCLUSIONS AND POLICY IMPLICATIONS FOR CALIFORNIA

This study began with a review electricity generation technologies, markets and influential entities. Then the relevant public economic theory was discussed. Next it was useful to consider current capacity planning and how those decisions are made. One finds that from a public economic standpoint the least-cost analysis of LCOE estimates with the government correction of externalities will necessarily lead to the socially optimal technological selection. However, in the case of nuclear power the lack of full accident liability coverage creates some uncertainty as to which technology actually has the lowest costs under this standard. While some estimate of the effect on cost was feasible, it is difficult to find the levelized cost due to the lack of consensus on social discount rates in the academic community.

The findings of this study show that policymakers should be extremely cautious when considering nuclear power. While the pecuniary costs can be very appealing, this study shows that the inclusion of social costs can have a significant impact on the outcome. Studies like the ExternE project reflect the growing importance of social cost in public sector decision-making. As noted during the discussion of this market, it is not the government that builds power plants but private firms. The government only manipulates costs through policy. One possible strategy that would resolve the inconsistencies presented in this study would be the requirement of the nuclear industry to be fully liable for accidents. The extra cost would either spur the implementation of safer methods or economically cause the selection of different technology altogether. Either way this would make society better off.

There is still the problem of California's need to add 24,000MW of additional peak capacity by 2016. Given that this is peak capacity and not base load capacity, it may be of interest to explore the prospects of solar photovoltaics. As aforementioned, this technology is an ideal peak technology. An additional incentive to explore this and other renewable technologies comes from the fact that only 13.7% of the Renewable Portfolio Standard has been met. This number needs to reach 20% by 2010. As was true of the government in general, the California Government may consider the requirement of full liability insurance. A second option that California has already implemented to control for pollution externalities is the externality adder. The government could require that any firm choosing between technologies use a sort of "risk adder" in cost calculations. Unlike the insurance requirement, which would undoubtedly cost firms a great deal of money, this may just induce firms into making better planning decisions. An important lesson to take from this study is that while a great deal of policy has attempted to deal with the pollution externalities of fossil fuel technologies, policies dealing with the risk externality of nuclear power appear to be somewhat inefficient. While nuclear power might now or be a viable option to meet electricity needs, it is important for government entities to ensure that externalities are being sufficiently internalized to be sure that socially efficient decisions are being made.

Appendices

Appendix I

1) \$7.62 per thousand cubic feet of natural gas
   \$7.62 = 1.035 MBTU

   $\frac{\$7.62}{1.035}$ = MBTU

   \$7.39/MBTU

2) \$43.91 per barrel oil
   \$43.91 = 5.8 MBTU

   $\frac{\$43.91}{5.8}$ = MBTU

   \$7.57/MBTU

3) \$1.04/MBTU

Appendix II

Population San Luis Obispo 1982: 35,200
Population San Luis Obispo 2004: 44,213
44,213/35,200= 1.25

Peak Early Fatalities	Peak Early Injuries	Peak Cancer Deaths
10,000	12,000	12,000
10,000*1.25 =12,500	12,000*1.25 =15,000	12,000*1.25 =15,000

Appendix III

A = (E*V) + (C*V) + (D) + (I*W)

where:

A = Cost of accident
E = Number of early deaths = 12,500
V = Value of human life = 2,500,000,000
C = Number of cancer deaths = 15,000

D	= Dollars property damage	= 312,000,000,000
I	= Number of injured individuals	=15,000
W	= Value of wellbeing	=**W**

A = (12,500*2,500,000,000**) + (**15,000*2,500,000,000**) + (**312,000,000,000**) + (**15,000***W)**

therefore,

A = **69,062,000,000,000 + 15,000W**

Appendix IV

$$= \frac{69,062,000,000,000 + 15,000W}{7,000} = 9,866,000,000$$

Appendix V

R = P * [(E*V) + (C*V) + (D) + (I*W)]

where:

R	= Cost of accident risk	
P	= Probability of accident	= $1.6*10^{-7}$
E	= Number of early deaths	= 12,500
V	= Value of human life	= 2,500,000,000
C	= Number of cancer deaths	= 15,000
D	= Dollars property damage	= 312,000,000,000
I	= Number of injured individuals	=15,000
W	= Value of wellbeing	=**W**

R = ($1.6*10^{-7}$**)* [(**12,500*2,500,000,000**) + (**15,000*2,500,000,000**) + (**312,000,000,000**) + (**15,000***W)]**

therefore,

R = 11,049,920 + .0024W

Appendix VI

$$D = \frac{(R)}{(1+s_1)^{50}} + \frac{(R)}{(1+s_2)^{t-50}}$$

where,

D	**=** Socially Discounted Value of Accident	
R	**=** Expected Cost of accident	**11,049,920 + .0024W**
t	= Years of Plant Operation	**60**
s_1	= Social Discount Rate Years 1-50	.035
s_2	= Social Discount Rate Years 51-100	.025

$$D = (11{,}049{,}920 + .0024W)/(1+.035)^{50} + (11{,}049{,}920 + .0024W))/(1+.025)^{60-50}$$

therefore,

D = $10,610,705.31 + $..0023046043W

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