

The Political Economy of Clean Coal

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Doctor of Philosophy at George Mason University

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DEDICATION

This is dedicated to my loving wife Chau, whose unfailing support made all my dreams, including this one, come true.

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I would like to thank my committee members, Dr. Stephen Fuller and Dr. Bryan Caplan, for their timely and to-the-point comments which always kept me honest in my research.

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ABSTRACT

THE POLITICAL ECONOMY OF CLEAN COAL

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This dissertation investigates the nature of the political economy of Clean Coal. It begins by reviewing the literature of global warming and the current usage of coal in the United States and throughout the world. It examines the externality costs from burning coal, and reviews Clean Coal technologies. Based on the comparison of total costs of generating electricity between Clean Coal and conventional technologies, it concludes that Clean Coal technologies are more economically efficient. Based on marginal net benefit analysis, it proposes that the optimal approach to deploy Clean Coal technologies is to gradually replace existing facilities with ones equipped with Clean Coal technologies. It identifies two obstacles that prevent the large-scale deployment of Clean Coal technologies: the New Source Review program under the Clean Air Act and the regulation of greenhouse gases. It then uses a public choice framework to find that the rent-seeking activities of interest groups are the forces that created these obstacles. It concludes by making public choice compatible recommendations for policy reform that would one day make Clean Coal a reality.

Chapter 1: Global Warming and CO₂ – Setting the Scene

1. “King Coal” – Fuel for Economic Growth or Cancer to Society?

Humans have used coal for thousands of years (California Energy Commission 2002). Since the industrial revolution, coal has played a vital role in supplying the energy needed to fuel the economic growth of our society (Wrigley 1962). In recent years, however, coal has increasingly been vilified, portrayed by some not as the fuel that propels economic growth, but as a “cancer” to society. Consider, for example, articles with titles such as “Killing King Coal” (Martelle 2009) and “The Enemy of the Human Race” (Hansen 2009) have regularly appeared in pro-environment publications such as the Sierra magazine, and former Vice President and environmental activist Al Gore has urged young people to engage in “civil disobedience” against coal (Nichols 2008).

It has long been recognized that burning coal generates various pollutants, such as nitrogen oxides, sulfur dioxide, particulate matter, mercury, etc. However, the recent surge of vilification of coal is linked to one particular “pollutant” from coal – carbon dioxide (CO₂). The reason for this is that many believe that CO₂ has the potential to contribute to global warming. Related to this, the debate on Clean Coal has also been heating up: proponents think that it has a bright future, while others, such as Al Gore, decry and mock it as “nonexistent”. Indeed, even the term “Clean Coal” seems to be a source of confusion – some equate it with carbon capture and sequestration (CCS) while

others use it as an umbrella term that encompasses modern abatement technologies (I will give a clear definition of “Clean Coal” and discuss related issues in more detail in Chapter 4).

In this dissertation, I set out to understand the analytical history and political economy of Clean Coal. There are several concrete questions I ask at the end of this chapter. But for the moment, because global warming and CO₂ are at the center of the debate on Clean Coal, I shall take a brief detour to review the scientific literature of global warming and CO₂.

2. A Brief Detour – Global Warming and CO₂

The “Greenhouse Effect” was first hypothesized by the French mathematician and physicist Jean Baptiste Joseph Fourier in 1824, who discovered that certain gases have the property of trapping long-wave radiations. Later work by the Swedish physicist and chemist Svante August Arrhenius in 1896 formalized the theory that changes in the levels of atmospheric carbon dioxide could substantially alter the surface temperature through the greenhouse effect. In the 1930s the English engineer Guy Stewart Callendar expanded upon the works of Arrhenius and others and concluded that an increase in atmospheric CO₂, induced by human activity, could lead to global warming – this is what became to known as anthropogenic global warming (Ramanathan 1988). Because of this, CO₂ is considered to be a greenhouse gas (GHG).

A great deal of empirical work has been undertaken to measure atmospheric CO₂ concentration and global temperature variations. Atmospheric CO₂ concentration is

directly measurable; its increase has been verified. Measurements indicate that its mean annual concentration has increased steadily during the period from 1959 to 2004 – from 315.98 parts per million by volume (ppmv) of dry air to 377.38 ppmv (US NOAA 2009), a 19.4% increase. This result is reproduced in Figure 1.

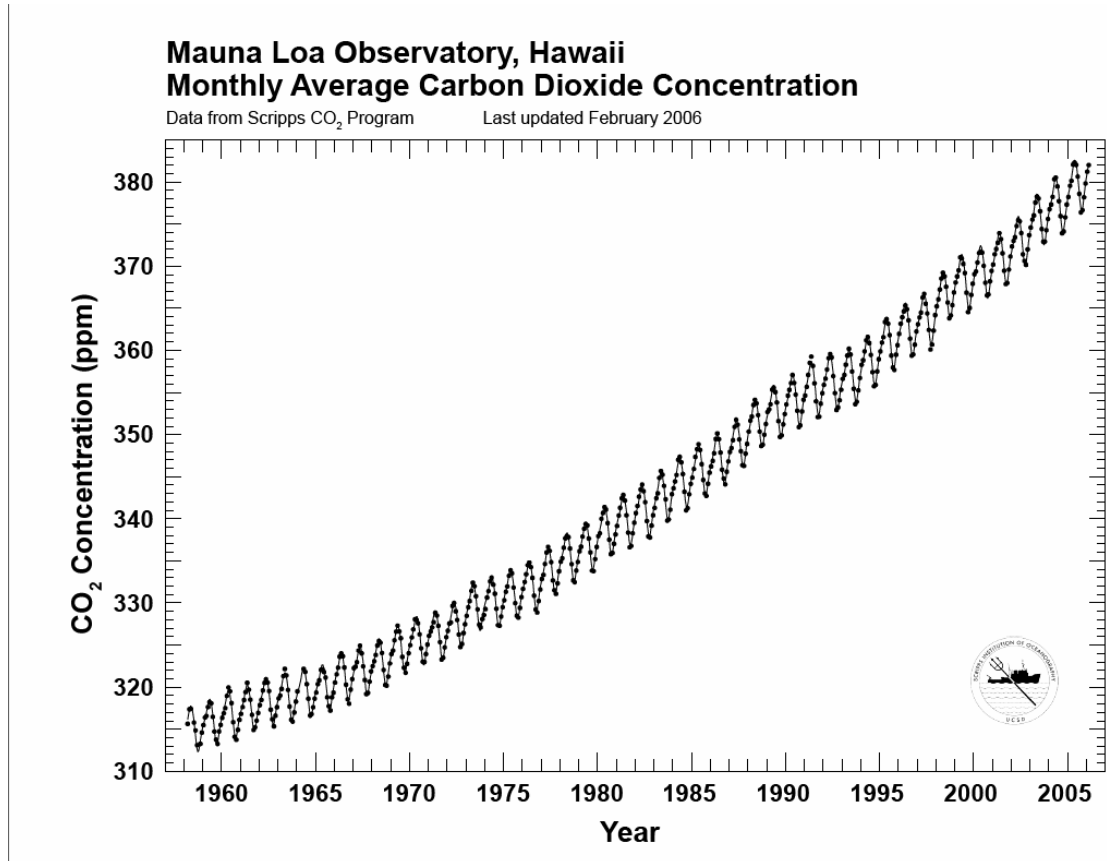


Figure 1: Monthly Average Carbon Dioxide Concentration
Data Source: US NOAA (2008)

Observation data of global earth surface temperature also show a warming trend: it increased by about 0.74 °C (1.33 °F) during the last 100 years (US NASA 2009). This result is reproduced in Figure 2 below. The National Academies (2006) also report that “... the late 20th century warmth in the Northern Hemisphere was unprecedented during

at least the last 1000 years.” and that “[t]his conclusion has subsequently been supported by an array of evidence that includes both additional large-scale surface temperature reconstructions and pronounced changes in a variety of local proxy indicators, such as melting on ice caps and the retreat of glaciers around the world.” But as we shall see shortly, recent development in the debate of global warming casts a serious doubt on the validity of such claims.

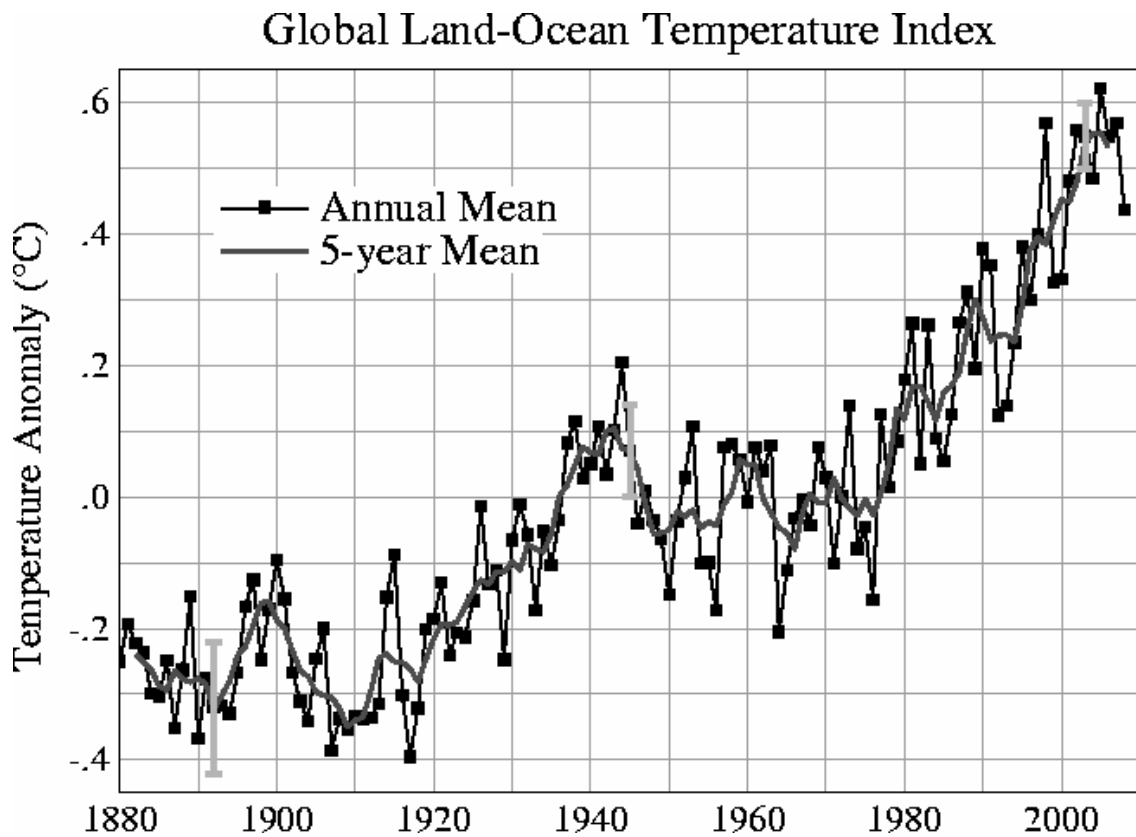


Figure 2: Global Land-Ocean Temperature Index
Data Source: US NASA (2009)

A majority though far from universal consensus in the scientific community is that global warming is real and it is anthropogenic (caused by human activities)¹. A

¹ A recent survey of a group of 3,146 earth scientists asked the following questions:

sizable yet growing minority of scientists challenge this position. For example, in a report to the Nongovernment International Panel on Climate Change, American atmospheric physicists S. Fred Singer (2008) and other scientists use results from latest climatologic research to demonstrate that most modern warming is due to natural causes and not human activities, and that the effects of human CO₂ emissions are benign. Other scientists also raise serious questions about the *extent*, *cause* and *effect* of global warming. The following is a partial list of these arguments:

1. The extent of global warming may not be as large as perceived (Soon and Baliunas, 2003)
2. A large portion of the recent warming trend may be part of longer climate cycle of the earth (Balling 2005)
3. Other effect, such as the El Niño phenomenon (ibid) and solar variability (Baliunas 2005) may have contributed to global warming.
4. Limitations in computer modeling makes climate change predications unreliable (Soon, et. al. 2001)

Some scientists also point out that the unusually large warming “spike” in 1998 may be caused by unprecedented El Niño activities (Michaels 2009). Indeed, more recent observation data suggest that there has been relative global “cooling” since 1998 (see Figure 3 below).

1) Have mean global temperatures risen compared to pre-1800s levels?

2) Has human activity been a significant factor in changing mean global temperatures?

About 90 percent of the scientists agreed with the first question and 82 percent the second. See Science Daily (Jan. 21, 2009) Scientists Agree Human-induced Global Warming Is Real, Survey Says (website: <http://www.sciencedaily.com/releases/2009/01/090119210532.htm>), the original survey was published in the journal *Eos, Transactions* by American Geophysical Union on Jan. 19, 2009

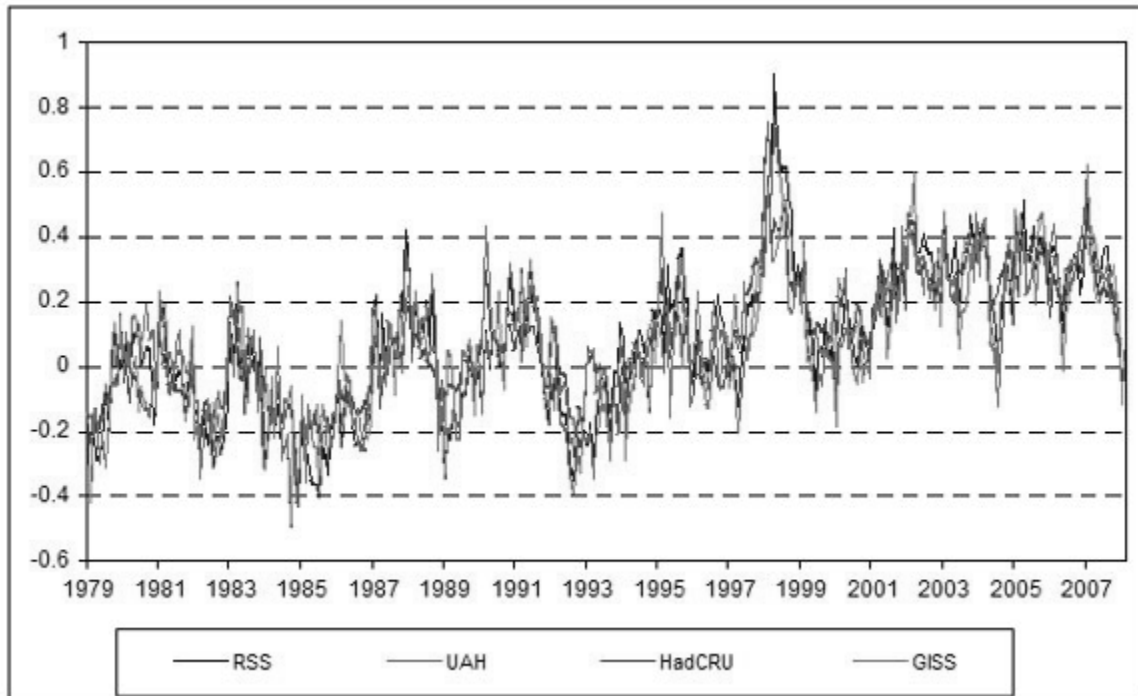


Figure 3: Global Surface and Lower Troposphere Monthly Mean Anomalies Relative to the 1979-1998 Mean Temperature.

Data from GISS, HadCRU, RSS, and UAH ranging from January 1979 to February 2008 (reproduced from Hausfather (2008))

As of this writing, the debate of global warming has taken another dramatic turn – now even the authenticity of the data supporting the anthropogenic global warming hypothesis has been called into question. In November, 2009, the leaked emails from one of the institutions at the center of studying climate change – the Climate Research Unit (CRU) of University of East Anglia (a second rate British university which nonetheless acts as a repository of atmospheric temperature data) suggest that leading researchers at this institution have manipulated the data to exaggerate the upward temperature trends (Hickman and Randerson 2009). In a more recently published correspondence with the person who is at the center of this controversy, the director of the CRU, Phil Jones, Jones admitted that a number of warming periods occurred in history, including the one that is

cited most often as the evidence of anthropogenic global warming – the period from 1975 to 2009, are “not significantly different from each other” (BBC News 2010). Jones also admitted that that has been a cooling trend from January 2002 to the present (February 2010), although he claims that this is not statistically significant. But the most revealing concession from Jones is the following statement: “There is still much that needs to be undertaken to reduce uncertainties [in the study of global warming]” (ibid).

I do not wish to delve further into the details of this debate, as that is beyond the scope of this dissertation and not the focus of my research. I conclude that there are still a lot of uncertainties regarding anthropogenic global warming – a point upon which even its most ardent believers agree.

Now let us turn to the economic aspects of global warming. The net economic effect of global warming is not universally negative. For example, within a certain range, global warming has positive economic effect on agriculture (Mendelsohn et. al. 1994). Even one of the staunchest advocates for global climate control Nicholas Stern concedes that at the lower end (increase of 2 or 3°C) climate change may have positive effects for countries in cold regions (Stern 2007). At the high end, the net economic effect of global warming may well be negative – intuitively, in the highly unlikely event that global warming is so severe as to make our planet inhospitable, certainly that outcome would be a net cost to society. Therefore the issue rests on the question: how severe will global warming be? Pooley (2008) asserts that “economists overwhelmingly agree that business as usual will lead to greatly increased societal costs as the impacts of climate change set in”. However, some economists also argue that even in the face of high degree of global

warming, human biophysical adaptations will be a factor mitigating against major impact (Davis 2005).

It is important to realize that even if anthropogenic global warming is real, if we were to enact some regulation to control it, we must take the economic cost and benefit of such regulation into consideration. For example, if the global warming is real, but its extent is not very great, its damages may be limited (in fact the net effect could be beneficial), then it makes no economic sense to implement measures that cost more than the damages to mitigate it. Similarly, if human activities that produce CO₂ and other GHG only play a limited role in causing global warming, which is mainly determined by longer climate cycles or influenced by solar variability, then restricting these activities may not reduce global warming very much, whereas the economic cost of reducing these activities may be enormous.

Yet global collective action on climate control is already a political reality – the European Union has already implemented an Emission Trading Scheme (ETS) in 2005 (European Commission 2008). In the U.S., a cap-and-trade program, Regional Greenhouse Gas Initiative (RGGI), supported by 10 northeastern states also went into effect in 2008 (RGGI 2009). Because coal-fired power plants are a major source of CO₂ emissions, climate regulations inevitably will affect – either facilitate or retard – the adoption of Clean Coal technologies. This is a topic that I shall return to in later chapters, but for now, I conclude this brief detour on global warming and CO₂ by remarking that despite the uncertainties about global warming and the role that CO₂ plays in causing it,

climate regulations are a political reality at the center of the political economy of Clean Coal.

3. Research Methodology and Agenda

Having briefly reviewed the literature on global warming and CO₂, I now return to the focus of my study: the political economy of Clean Coal.

There are two aspects of my study: first, the economic aspect of coal and Clean Coal technologies. For this, my methodology is grounded in economic efficiency analysis. For example, when I inquire about the nature of Clean Coal technologies, I am most interested in whether they are economically efficient – that is, whether the marginal social benefit of deploying Clean Coal technologies equals the marginal social cost; I am less interested in the engineering details.

The second aspect of my study is the political aspect of Clean Coal related activities by various players in this political “game”. For this, my methodology is grounded in public choice analysis. In particular, one of the premises in public choice is that individuals’ political activities – just as their economic activities – are motivated by self-interest; consequently, I am especially interested in examining the incentives and the constraints of the players in the political game; as such, I pay little attention to what people say (talk is cheap), but pay a great deal of attention to what they do.

A study of the political economy of Clean Coal is a major undertaking; one cannot hope to do it alone. There have been numerous studies on topics related to my inquiry, for example, cost estimates of coal-generated pollutants, economic analysis of

Clean Coal technologies, public choice studies of coal related environmental regulations, etc. I rely on this literature, especially peer-reviewed articles. I critically review and synthesize the relevant findings from this vast literature. Additionally, I also conduct my own studies, sometimes using the same methodologies used in other studies but applying them to different specific problems, sometimes conducting economic efficiency and econometric analyses of my own.

In my dissertation, I set out to answer the following questions:

Question #1: Is it realistic to expect coal use to be reduced significantly or eliminated altogether in the near future?

As I mentioned in the beginning paragraph of this chapter, there are individuals, particularly environmental activists, most noticeably Al Gore, who are trying to wipe out the coal industry in the United States. But is it realistic to expect coal to be “phased out” in the foreseeable future? Indeed, if coal is phased out entirely, the debate on Clean Coal becomes moot. Thus, this is the first question I must answer.

Question #2: How dirty is coal – in other words, what is the economic cost from coal-generated pollutants?

There are several cost estimates of a particular pollutant or pollutants from coal, but to my knowledge, there is no estimate of the economic cost of *all* the major coal-generated pollutants. I aim to estimate the damage cost of the sum total of all the major coal-generated pollutants. This estimate is crucial in evaluating the economic efficiency of Clean Coal technologies.

Question #3: What is the nature of the uncertainty regarding CO₂?

CO₂ is at the center of GHG regulations. However, as I pointed out earlier, there are still uncertainties about the *extent, cause* and *effect* of global warming, and there is uncertainty about the role CO₂ plays in causing it. But there is always uncertainty about any pollutant – cost estimates of pollutants can vary by orders of magnitude. Is the degree of uncertainty about CO₂ the same as or different from the degree of uncertainty about other pollutants? The answer to this question is very important in evaluating GHG regulations.

Question #4: Are “Clean Coal technologies” more economically efficient compared with conventional technologies?

Most comparisons of Clean Coal technologies with conventional technologies focus on the costs in producing electricity but ignore externality costs – costs from pollutants borne by people other than the owners and operators of coal-fired power plants. Because Clean Coal technologies have the potential to reduce emissions, I make the comparison based on full costs (inclusive of externality costs) in producing electricity. This is the most meaningful comparison, and by focusing on it I provide a new perspective in this line of research.

Question #5: If Clean Coal technologies are economically more efficient than conventional technologies, what is the optimal approach to large-scale deployment of Clean Coal technologies?

This question is contingent on the answer to the previous question. Given that the answer to the previous question turns out to be positive, then I sketch an optimal

approach to large-scale deployment of Clean Coal technologies based on economic efficiency analysis.

Question #6: If in reality, the level of utilization of Clean Coal technologies is suboptimal, what are the obstacles that prevented the optimal level from being achieved? This question is contingent on the findings of current utilization level of Clean Coal technologies and the answers to the previous two questions. Given that Clean Coal technologies turn out to be economically more efficient than conventional technologies, and that the utilization level of Clean Coal technologies turns out to be suboptimal, then I seek out and identify the political obstacles that are primarily responsible for such a suboptimal outcome. To this end, I deploy public choice analysis.

Finally, after answering all these questions, I outline public choice compatible policy reform recommendations designed to remove the political obstacles and to move toward a world with Clean Coal, a world in which coal can be used most efficiently to further the economic efficiency of society.

Chapter 2: Sitting on a Huge Pile of Coal

The U.S., like China and India, sits on a huge pile of coal ...

– John B. Heywood,
“*Growing Pains - Transitioning to a Sustainable Energy Economy*”
MIT World Lecture, November 1, 2006

1. Brief History of Coal

Coal is formed from plant remains from the Carboniferous Period (the word “Carboniferous” literally means “coal bearing” in Latin) of the late Paleozoic Era about 354 to 290 million years ago (Prothero & Dott 2003). It is composed mostly of carbon and hydrogen based organic compounds, but it also contains small quantities of other elements such as nitrogen, sulfur and mercury. The plants from whose remains coal is formed absorbed carbon dioxide (CO₂) from the atmosphere and transformed it into organic matters through photosynthesis. Thus, in essence, coal, like other fossil fuels such as petroleum and natural gas, is sequestered carbon from earlier geological times.

Humans have long recognized coal as an energy source. The Chinese may have used it as early as 3000 years ago (California Energy Commission 2002). When James Watt improved the steam engine in the 1770s, coal was used to heat up the water in the boiler to generate the steam; when Thomas Edison invented the electrical generator in the 1870s to provide electricity for another of his inventions, the light bulb, his choice of fuel was also coal. By some accounts, coal was “[t]he decisive technological change which

freed so many industries from dependence upon organic raw materials” (Wrigley 1962). The increasingly widespread use of coal was driven by both increased demand for energy and technological innovation in mining (Clark and Jacks 2007). We conclude that coal is the energy source that fueled the industrial revolution.

2. Estimates of Coal Reserves

Coal is the most abundant fossil fuel and readily usable energy source: according to the most recent U.S. Energy Information Administration report (USEIA 2008a), total recoverable reserves of coal around the world are estimated at 930 billion tons. To compare different fossil fuels, it is necessary to use a common unit. The “heat content” (energy content) is usually used for this purpose. The grade of coal can vary substantially, resulting in different heat contents; nevertheless, we can use an average value estimate the energy content of the total coal reserves in the world. According to the USEIA (2008b), the average heat content of coal used in electricity generation in the U.S. is 19.78 million Btu (British Thermal Unit) per ton, thus the world’s total coal reserves translate to a total heat content of 18,395 quadrillion Btu. In comparison, using the two aforementioned sources, the world’s total natural gas reserves are estimated at 6,186 trillion cubic feet, or 6,372 quadrillion Btu; the world’s total oil reserves are estimated at 1,332 billion barrels, or 8,258 quadrillion Btu. In other words, the energy content of the world’s coal reserves is about 25% greater than that of the world’s natural gas and oil reserves *combined*.

Anecdotally, the United States has 250 years of coal reserve. President George W. Bush once famously (and apparently mistakenly, by a factor of 1 million) said that we have “250 million years of coal?”² The Energy Information Agency (EIA) of the U.S. Department of Energy website also states that there is “enough coal to last approximately 225 years at today's level of use” (USEIA 2008c). However, such notion is not without dispute. A research by Molnia et. al. (1999) shows that such estimates may be grossly overestimated. Molnia et. al. used three definitions to distinguish between “original coal” (total coal deposits) vs. “recoverable resource” (technologically extractable coal) and “economically recoverable” coal:

Available coal \equiv original coal – areas already mined – land-use restrictions
– technologic considerations

Recoverable resource \equiv coal available for mining – mining loses –
washing losses

Economically recoverable coal \equiv recoverable resources – minable
resources too costly to extract

By their estimates, in some regions, the percentage of original coal that is available varies from 48% to 60%, while the percentage of original coal that is economically recoverable may be as little as 11%.

Molnia et. al.’s research highlights the uncertainties in fossil fuel reserve estimates and the many technological and economic constraints on these resources. But

² Source: President Discusses Strengthening Social Security in Washington, D.C., Official website of the White House (<http://georgewbush-whitehouse.archives.gov/news/releases/2005/06/20050608-3.html>, retrieved: 05/25/2009)

their research takes the technological and economic constraints as exogenous. As technologies advance, more coal will be extractable. Even more importantly, increased demand for a natural resource spurred by economic growth will exert an upward pressure on the price of that resource. This demand pressure makes resources that were previously too costly economically attainable. Indeed, economic conditions often play a more important role than technological advances in determining the use and availability of natural resources: historical evidence suggests that the expanded coal output in the Industrial Revolution was mainly a result of increased demand rather than technological innovations in mining (Clark and Jacks 2008). Furthermore, as Krautkremer (2005) argues, price increases because of increasing scarcity will also trigger a variety of responses such as substitutions with other resources, resource-saving technologies, methods for recovering resources and cost reduction of using lower-quality reserves, etc. All these responses will in turn ameliorate the scarcity. Because of these factors, we believe that Molnia et. al. have underestimated total coal reserves in the United States.

Molnia et. al.'s estimates also remind us of the gloomy prediction made by "The Club of Rome" that the world would run out of oil before 1992 (Meadows, Randers and Meadows, 1972[2004]). In reality, we are well into the 21st century, such resource depletion not only has not happened, it is nowhere nearly in sight.

From these researches we make the following conclusions: First, there is great uncertainty in estimates of available natural resources; history suggests that we have always tended to underestimate natural resource reserves in the past. Secondly, there are two aspects regarding the abundance of nonrenewable resources. On one hand, the

amounts of nonrenewable resources are finite; eventually they *will* run out. This is especially true in the case of fossil fuels as they are fossilized living organisms in earlier geological times³. It is conceivable that as technologies advance, we may be able to exploit inorganic minerals from the moon, other planets or even other celestial bodies. But so far scientific inquiries have not produced any evidence of extraterrestrial life forms, the possibility that we will find and utilize other sources of fossil fuels than from our own planet is exceedingly remote. On the other hand, the important issue is not *whether* these resources will run out, but *when* they will run out. In other words, we must put it within the timeframe of our researches. In the context of this dissertation, as I discussed in Chapter 1 and will discuss in later chapters, collective actions on global climate control and the debate on Clean Coal technologies are already taking place. Therefore, what is relevant is: Within this timeframe, will there be enough coal and will it play an important in our economic lives? The answer is a definite yes based on the evidence I have laid out in this section.

3. Coal Use in the United States and the World

Coal supplies a large share of the world's energy needs. According to BP (2008) and Renewable Energy Policy Network for the 21st Century (2008), as of 2007, coal accounts for 25% of worldwide energy consumption, or 5 times the amount supplied by non-biomass renewable sources (wind, solar and hydraulic power) (see Figure 4 below). In

³ If the conditions are right (such as when they are buried underground because of geological activities), living organisms today may one day become fossilized in the distant future; in this sense, fossil fuels are "renewable". But the timescale of such process, which takes millions of years, far exceeds that of human societies. We can ignore this factor in our discussions.

developing countries, coal is used even more heavily, for example, in 2005, Coal supplied 70 percent of China's total energy consumption requirements (USEIA 2006).

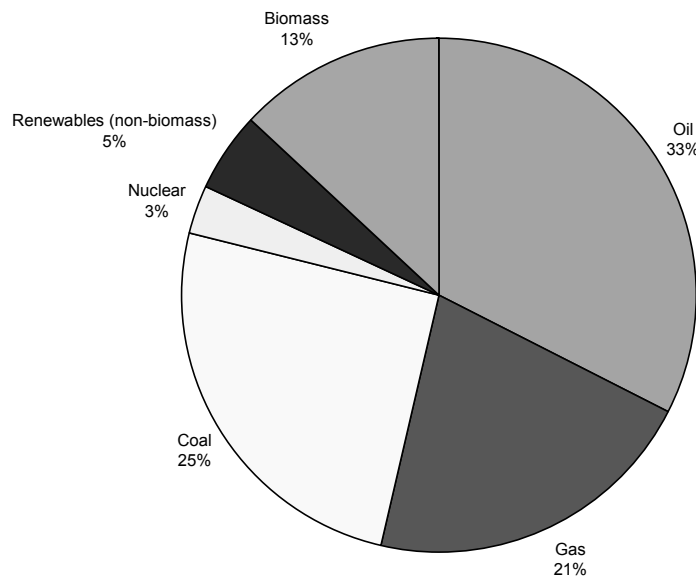


Figure 4: World Energy Consumption by Fuel Type, 2006
Data Source: Energy Policy Network for the 21st Century (2008) and BP (2008)

In terms of electricity generation, coal's share is even more pronounced. According to the US EIA (2009b), as of February 2009, about half (48.1%) of electricity in the United States is generated from coal (Figure 5). Indeed, in the United States, the vast majority of coal – about 94% – is used for electricity generation (USEPA, 2008a, p. ES-9). For this reason, in the context of my dissertation, the discussion about coal use is mostly about coal-fired power plants.

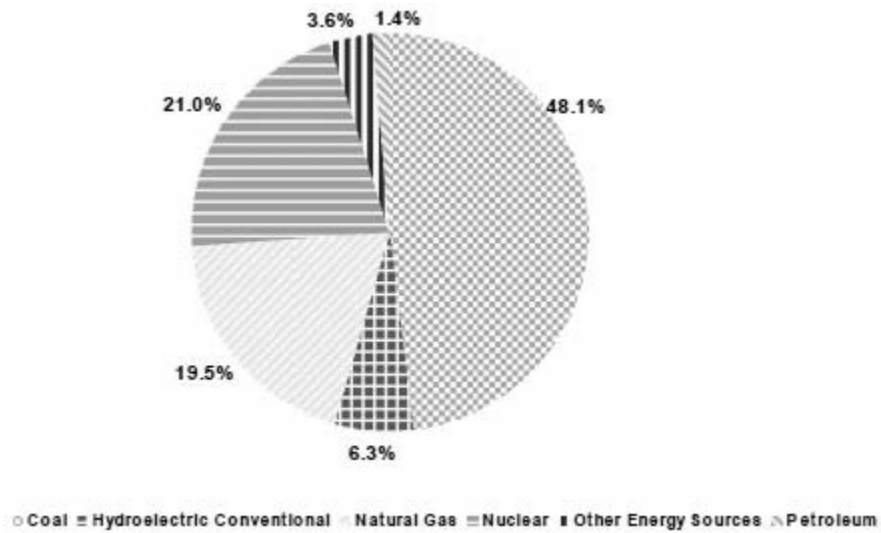


Figure 5: Net Generation Shares by Energy Source in the U.S., Year-to-Date through February, 2009
 Reproduced from USEIA (2009b)

Not only does coal already account for a large percentage of worldwide energy consumption, the rate at which its share increases is also projected to outpace all other energy sources (see Figure 6 below). The USEIA (2008a) estimates that coal consumption is projected to increase by 2.0 percent per year from 2005 to 2030 (by 35 quadrillion Btu from 2005 to 2015 and by another 44 quadrillion Btu from 2015 to 2030), and it will eventually account for 29 percent of total world energy consumption in 2030.

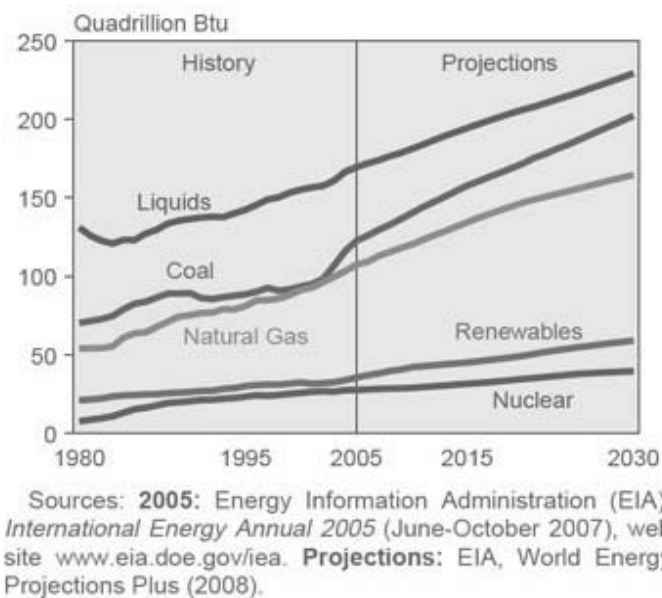


Figure 6: World Marketed Energy Use by Fuel Type, 1980-2030
 Reproduced from *Energy Outlook 2008*, USEIA (2008a)

Coal is also one of the cheapest energy sources: it can be produced – under current emission regulations – at a cost of between \$1 and \$2 per MMBtu⁴ compared to \$6 to \$12 per MMBtu for oil and natural gas (Massachusetts Institute of Technology 2007). Clearly, coal is an abundant and affordable natural resource. Renewable energies such as wind and solar will not be able to completely replace coal (or other fossil fuels) in the foreseeable future. To meet the world’s demand on energy and economic growth, we simply cannot ignore coal, unless we are prepared to allow the world’s economy to retreat to medieval times.

4. Consequences of Fossil Fuel Price Increases

⁴ 1 MMBtu = 1,000,000 Btu

An important inquiry relevant to my research is: What will happen to coal use if substantial price increases are imposed on fossil fuels?

To answer this question, first we must determine the demand and supply price elasticities for different fossil fuels. For my purpose, I will focus my attention on long-run elasticities, as the time horizon of the problem I investigate spans at least several decades.

First we consider demand price elasticities. The first thing we notice in this literature is the wide range of estimates. For example, Pindyck (1979) finds that in the industrial sector in OECD countries the demand elasticities for oil range between -0.22 and -1.17, and between -0.41 and -2.34 for natural gas. Thus, there is a high degree of uncertainties in these estimates. Figure 7 below summarized the results of demand price elasticity estimates that have appeared in literature:

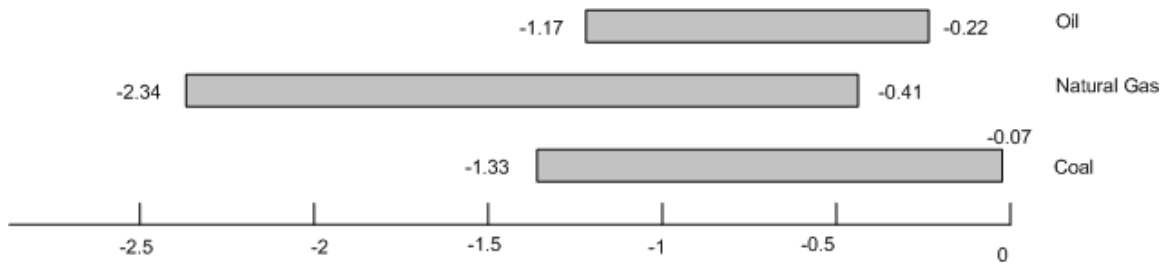


Figure 7: Summary of Estimates of Demand Price Elasticities for Fossil Fuels
Data Sources: various sources, see text.

Some of these uncertainties stem from *research methodology*. Energy prices can change as a result of changes from the demand side and supply side simultaneously. A credible study on energy demand elasticities must overcome the problem of identification

(separating demand responses from supply responses) and employ a model that incorporates both supply and demand side factors. Two recent studies illustrate this: employing a supply and demand model, Krichene (2002) finds the long-run world demand price elasticities of crude oil and natural gas to be -0.005 and -1.1 respectively (for the period from 1973 to 1999), whereas Liu (2004), using a demand-side-only model, finds the long-run demand price elasticities of natural gas in the industrial section to be -0.243 for OECD countries⁵. Some of the difference can be attributed to the scope of their studies (one on the world market while the other on OECD countries), but the large discrepancy highlights the fact that estimates of energy demand elasticities are highly sensitive to model specification. Even for models that consider demand and supply side factors, how the models are constructed will influence the estimates.

Some of the uncertainties are not because of research methodology but rather due to the complexities intrinsic to energy use, which may vary from region to region, from one country to another, and is subject to market distortions introduced by political institutions. For instance, Berstein and Griffin (2005) find the price elasticities for residential natural gas in the U.S. vary from -0.163 to -1.826 in different states⁶, and Stevens et. al. (1979) find that the price elasticities for coal vary from -1.33 to -0.07 in different regions in the U.S.

Supply price elasticities also exhibit similar uncertainties, for example, Krichene (2002) shows that there was profound change (from 1.10 to 0.10) in long-run crude oil

⁵ Liu's study used a "one-step GMM estimation method" which in essence suppresses any supply side factors. Consequently, Liu also estimated the price elasticities for "Gas Oil" and "Hard Coal" to be positive (although these are not statistically significant), which he acknowledges these to be "unexpected".

⁶ I have only included estimates that are significant at the 5% level.

supply price elasticity after the establishment of the OPEC quotas. Furthermore, when considering the impact of price hikes imposed on fossil fuels, we must consider the substitution effects (cross-price elasticities) between different fossil fuels, and between fossil fuels and other energies. Estimates of these cross-price elasticities also exhibit a high degree of uncertainty (e.g. see Reddy 1985). We must also consider the impact of the increase in fossil fuel prices on economic growth – if the price hike is very large, since fossil fuels account for such a large portion of global energy use, overall demand will decrease. Finally, with large price increases, we cannot treat demand or supply elasticities as uniform along the entire demand and supply curves, but must consider their values at different points. In short, to fully understand the impact of a substantial price increase in fossil fuels, we must construct a general equilibrium model that incorporates all these elements.

Fortunately, a research by Rout et. al. (2008) uses just such a general equilibrium model. In their research, Rout et. al. use a linear programming (and iterative) computer simulation model that takes into consideration such factors as extraction of fuels, demand price elasticities in different sectors, inter-regional trading, etc. to study a 60-70% price hike on fossil fuels. Although we should not regard this study as anything like a “final say” in this research, their results give us a glimpse into the impact of a substantial fossil price hike.

In their research, Rout et. al. consider several different scenarios: price hikes on one, two or all three fossil fuels (crude oil, natural gas, coal), and with or without a 550 ppmv CO₂ stabilization policy. Of interest to us is scenario R1, the reference scenario (no

price hikes on any fossil fuels, and no CO₂ stabilization), R3 (price hikes on all fossil fuels, no CO₂ stabilization) and S3 (price hikes on all fossil fuels, with CO₂ stabilization).

These results are reproduced in Figure 8 below:

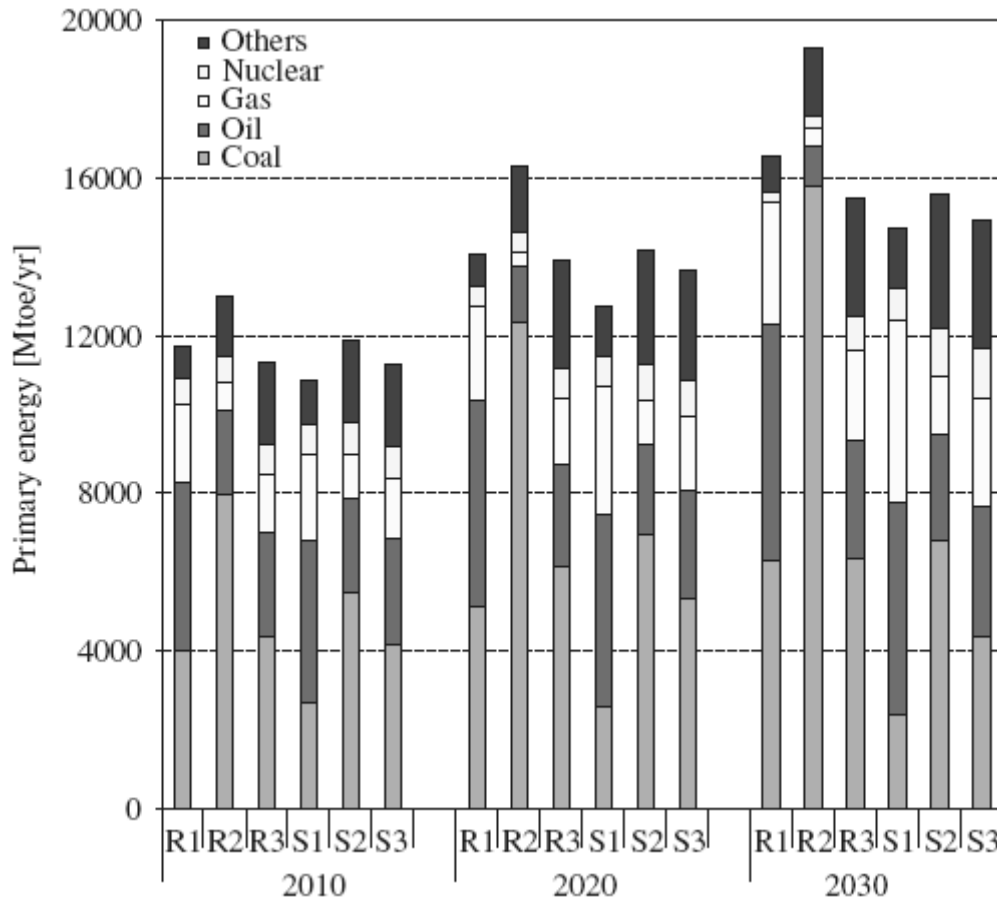


Figure 8: Global primary energy supply
(Reproduced from Rout, et. al. (2008))

From the results from Rout. et. al., we can see that in either scenario R3 or S3, in 2030, consumption of coal in absolute quantity will *increase* relative to the reference scenario R1 in 2010. These results thus answer our question: even with substantial price increases on fossil fuels, the portion of global energy supply that comes from coal will

remain significant (in the 20-25% range). This reconfirms the relevance and necessity of my inquiry on the political economy of Clean Coal.

5. Summary

Coal is the most abundant and cheapest fossil fuel. It already contributes a large share to meet the world's energy demand. In the U.S., the vast majority of coal (more than 90%) is used for electricity generation and it accounts for nearly half of the electricity generation. In the timeframe relevant to my inquiry on the political economy of Clean Coal – the coming decades or century – coal will remain plentiful and continue to play an important role in our economic lives. Even in the face of substantial price hikes (60-70%) on fossil fuels, coal will continue to account for a major portion (about 20-25%) of global energy use.

Chapter 3: Dirtiest fuels of all – externalities of burning coal

Coal is the dirtiest of the fossil fuels.

– Phil Barnhart , Oregon State Representative⁷

1. Introduction

Extracting and burning coal both generate externalities – effects, harmful or otherwise, that are not borne by the people who extract or burn the coal. The recaptured gaseous, liquid or solid wastes from burning coal may also generate externalities if not handled properly.

As of 2007, surface mines produce nearly 70% of U.S. coal (USEIA 2009a). Indeed the trend is that the percentage of coal from surface mines has been increasing for the last half century and is continuing to do so (ibid). Surface mining removes large areas of topsoil or entire mountaintops. This disrupts the hydrology (Bonta, et. al. 1997) and degrades the soil quality in surrounding regions (Mummey et. al. 2002), and it also impairs the landscape and causes displeasure to viewers. These are examples of externalities. However, for the purpose of my dissertation, I shall not focus on externalities from mining for the reasons stated below.

⁷ Source: The Creswell Chronicle, “Energy efficiency is key component of state’s economic recovery” by Helen Hollyer, January 21, 2009, website:
http://www.thecreswellchronicle.com/news/story.cfm?story_no=6197

First, the choice of mining method is determined by the geology and topography of the coal seam (TEEIC undated⁸) as well as the economics of extraction. In the United States, in areas such as the Powder River Basin in Wyoming, there is a vast amount of coal seam close to the surface that is both physically accessible and economically recoverable. In addition, the total cost per ton of material handled is normally much lower in a surface mine than in an underground mine (Nicholas 1992). These factors indicate that surface mineable coal is not only the most physically accessible; it is also the most economically recoverable. Because of these factors, as long as surface mineable coal is abundant, it will be a favored method of production. Indeed, in 2007, the Powder River Basin alone produced about 42% of total U.S. coal (USEIA 2009a).

Secondly, as I demonstrate in Chapter 2, coal will play a significant role in the energy future of the United States and the world, accounting for about 25% of global energy supply in the foreseeable future. Combining this fact with the previously point, we conclude that surface mining of coal is likely to remain a major production method in the foreseeable future.

Lastly, the Surface Mining Control and Reclamation Act of 1977 (USOSM 2008)⁹ and its amendment in 1990 mandate various taxes on coal mined with different methods, with the highest tax imposed on surface mined coal. These regulations, imperfect as they may be, to a certain extent internalize the externalities from coal mining¹⁰.

⁸ The TEEIC (Tribal Energy and Environmental Information Clearinghouse) is funded by the U.S. Department of the Interior, website: <http://teeic.anl.gov>.

⁹ OSM (Office of Surface Mining Reclamation and Enforcement) is a bureau within the United States Department of the Interior, website: <http://www.osmre.gov>.

¹⁰ I do not imply that these regulations are perfect solutions for an externality problem. In fact, inquiry into them can be a public choice research project in itself. The keyword here is “to a certain extent”.

Emissions from burning coal are a different story. As I shall discuss in the next chapter, modern abatement technologies exist to reduce or eliminate these emissions, so it would be interesting to investigate whether it is technologically feasible and economically efficient to employ these abatement methods. For these reasons I shall focus on externalities from burning coal in my research.

Presently in the United States, about 94% of coal used is for electricity generation (USEPA, 2008, p. ES-9). Therefore, when we discuss coal use, our primary focus is coal-fired power plants. It is this use of coal that I focus on in this chapter and throughout this dissertation.

I also highlight one more fact. The end products (that is, in addition to energy) from burning coal are gaseous and particulate emissions and solid and liquid wastes. I discuss the gaseous and particulate emissions in great detail in this chapter, but I shall point out that the solid and liquid wastes, which in essence are captured pollutants, also generate externalities if they are not stored properly. The infamous December 2008 Kingston Fossil Plant sludge spill¹¹ is one example. The TVA (Tennessee Valley Authority)'s own estimates of the clean-up costs range from \$525 million to \$824 million (TVA 2009), which is comparable to the damages from some of the coal generated pollutants *per year* in the United States (see next section). Clearly, the proper handling and storage of wastes are an integral part of internalizing coal generated externalities, a point I shall return to later in my dissertation.

¹¹ <http://www.cnn.com/2008/US/12/26/tennessee.sludge/>

2. Emissions from coal-fired power plants

When coal is burnt, the organic and inorganic materials in it bind with oxygen to generate heat. But heat is not the only end product of this process. When the materials in coal bind with oxygen, they form other compounds. The main ingredient of coal – carbon – binds with oxygen to form carbon monoxide (CO) and carbon dioxide (CO₂). Other elements, such as hydrogen, sulfur and nitrogen also bind with oxygen to form water (H₂O), sulfur dioxide (SO₂) and nitrogen oxides (NO_x), a mixture of nitrogen-oxygen based compounds. These gases also lead to the formation of secondary compounds, such as ozone (O₃). The emitted materials are not limited to gases but also include particulate matter (PM). Particulate matter refers to a mixture of solid particles and liquid droplets found in the air, it can be further distinguished in two categories: “Inhalable coarse particles” or particles larger than 2.5 micrometers and smaller than 10 micrometers in diameter (PM₁₀), and “Fine particles” or particles of 2.5 micrometers in diameter and smaller (PM_{2.5}) (USEPA 2009a). These particles contain harmful material themselves, such as heavy metal elements and arsenic; they can also become carriers for other substances. Left untreated, these materials will cause health and environmental hazards.

Table 1 lists the major harmful substances emitted from coal-fired power plants:

Table 1: Major Harmful Materials from Coal Emission

Pollutant		Health and environmental hazard
Gaseous Materials	Nitrogen dioxide	Main ingredient in the formation of ground-level ozone; nitrate particles, acid aerosols and NO ₂ trigger serious respiratory problems, contributes to formation of acid rain.
	Sulfur dioxide	Causes respiratory illness and aggravates existing heart and lung diseases, contributes to the formation of acid rain
	Ozone	Causes airway irritation, coughing, and pain in the respiratory system, even permanent lung damage.
	Carbon monoxide	Causes harmful health effects by reducing oxygen delivery to the body's organs and tissues.
	Carbon dioxide	Can cause adverse health effects such as acidosis, can cause suffocation at high concentration. Most abundant greenhouse gas in the atmosphere.
Toxic Elements	Mercury	Damages the brain, nervous systems and kidneys, developing fetus, sperm and male reproductive organs, causes spontaneous abortions and stillbirths.
	Lead	Harms the nervous system, kidney function, immune system, reproductive, cardiovascular and developmental systems.
	Chromium	Causes respiratory problems, ulcer in the stomach and small intestine, damages the male reproductive system. Certain forms are carcinogenic.
	Cadmium	Causes flu like symptoms, respiratory tract, kidney and liver failures, and loss of bone density.
	Arsenic	Causes skin changes, circulatory and peripheral nervous disorders, large oral doses can result in death.
Particulate Matters (PM)		Causes respiratory symptoms, lung disease, asthma, bronchitis, irregular heartbeat, reduces visibility, changing nutrient balance in water and soil.

Data Sources: USEPA (2009a, 2009b) USATSDR (2009)

Table 2 below shows a list of the major harmful materials emitted from coal-fired power plants in terms of annual amount and percentage of total annual emissions from all anthropogenic sources.

Table 2: Major Pollutants Emitted by Coal-fired Power Plants

Pollutant	Total amount of emissions from coal	% of emissions from all anthropogenic sources	Note
Nitrogen Oxides	5,153 thou. short tons	20.7%	as of 2000 [1]
Sulfur Dioxide	12,243 thou. short tons	67.3%	as of 2000 [1]
Carbon Monoxide	359 thou. short tons	0.3%	as of 2000 [1]
Carbon Dioxide	2065.3 teragrams	35.5%	as of 2006 [2]
Mercury	72.8 tons	46.1%	as of 1994-5 [3]
Lead	73 short tons	1.7%	as of 2000 [1]
Chromium	87.43 tons	---	projected for 2010 [4]
Cadmium	3.82 tons	---	projected for 2010 [4]
Arsenic	70.61 tons	---	projected for 2010 [4]
PM2.5	147 thou. short tons	6.5% *	as of 2000 [1]
PM10	361 thou. short tons	12.2% *	as of 2000 [1]

Data Sources: [1] USEPA (2003a)*, [2] USEPA (2008), [3] USEPA (2000), [4] USEPA (1998a). All measurements are per annum in the U.S.

If the users of coal – in the context of this dissertation, the owners and operators of coal-fired power plants – do not bear the cost of these hazards, their private cost will be less than the full social cost, leading to over-consumption of coal. This is a classic example of externality. But how much cost do these pollutants impose on society? I answer this question in the next section.

3. Flow pollutants and stock pollutants

A distinction needs to be made among the pollutants listed in Table 1 and Table 2. A stock pollutant is a pollutant for which the environment has little or no absorptive

* PM10 emissions are from Table A-6 in USEPA 2003, total emissions from fuel combustion, industrial processes and transportation. Total PM2.5 emissions include emissions from fuel combustion, industrial processes and transportation from Table A-8 in USEPA 2003, excluding natural and miscellaneous sources; this is consistent with the reporting method for PM10. Miscellaneous and natural sources of PM10 emissions are reported in Table A-7 in USEPA 2003, which are also excluded here.

capacity (Maatta 2006) – in other words, a pollutant that stays in the environment for a long time. A flow pollutant, in contrast, does not accumulate in the environment. Some pollutants are strictly flow pollutants, such as light and noise, for there can be no “accumulation” of them. For pollutants with a very short environmental half-life (or environmental half-time – the time necessary for one-half of the pollutant to be removed from the environment), we can approximate them as flow pollutants. Other pollutants have a very long environmental half-life and should be treated as stock pollutants. When considering the externality stock pollutants cause, we must consider the effects of the flow within a given period *and* the effect of the current stock.

Among the pollutants listed in Table 1 and Table 2, some have relatively short environmental half-life. The environmental half-life of SO₂ is on the order of 3 days (Hocking 2006). NO_x, a mixture of nitrogen-oxygen compounds, is rapidly oxidized into nitrogen dioxide (NO₂), which has a half-life of about 50 days (ibid). PM also has a short environmental half-life on the order of hours (Kruizea, et. al. 2003).

Other pollutants, such as heavy metals and arsenic, are toxic elements. Strictly speaking, the only way for them to diminish in the environment is through radioactive decay. For the most stable isotopes of these elements, the radioactive decay half-life can be extremely long (²⁰Hg, an isotope of mercury, and ⁷⁵As, an isotope of Arsenic, are both radioactively stable¹² – that is, they do not exhibit any radioactive decay). For these toxic elements, what is important is how long they will remain in the food chain and drinking water. These can also be a very long times – for example, the environmental half-life for

¹² ²⁰Hg: <http://www.periodictable.com/Elements/080/data.html>, ⁷⁵As: <http://www.periodictable.com/Elements/033/data.html>

mercury in fish can be as long as 10 years (Pallera and Litterel 2007), and for cadmium, 10-30 years (Di Giulio and Hinton 2008). Therefore, for practical purposes, toxic elements should be treated as stock pollutants.

4. Costs of Externalities from Coal-fired Power Plants

From Table 1 and Table 2 in the previous section, we can get a *qualitative* impression of what the major pollutants are in terms of plentitude and the severity of health and environmental hazards that they cause. These pollutants are: mercury, arsenic, chromium, NO_x, SO₂, particulate matter (PM2.5 and PM10) and CO₂. In this section I shall conduct a *quantitative* analysis on the externality cost caused by each pollutant. It is also worth noting that NO_x, SO₂ and lead are among EPA's six "criteria pollutants" (USEPA 2009b). In my dissertation, however, I shall refer to all non-CO₂ pollutants as *criteria pollutants*, for reasons that will become clear at the end of this chapter.

My research methodology is as follows: when first hand estimates are available in the literature (usually peer-reviewed articles), I cite these estimates with my own critique. Whenever possible, I cross check with other researches to validate these estimates. When first hand estimates are not available, I perform my own estimates using the same methods found in other researches. I break down these costs by pollutants below.

4.1. Mercury

Trasande et. al. (2005) estimate the cost due to lost productivity from methyl mercury pollution generated by coal-fired power plants to be \$1.3 billion (range, \$0.1-6.5 billion) each year in the U.S. The formula that Trasande et. al. use is shown below:

$$\text{Costs} = \text{disease rate} \times \text{EAF} \times \text{population size} \times \text{cost per case}$$

where EAF is the “environmentally attributable fraction” in their model, which they explained to be “the percentage of a particular disease category that would be eliminated if environmental risk factors were reduced to their lowest feasible concentrations”. With this method, they calculate the total cost of anthropogenic mercury emissions. As to the cost of American power plant emissions, they linearly scale it by the percentage of emissions.

There are reasons to believe that Trasande et. al.’s results are underestimated. First, they focus on decreased lifetime earnings due to loss of intelligence caused by *in utero* methyl mercury exposure, and omit the cost of cardiovascular and other impacts, or the costs of mercury exposure to children in their early life, which can still cause significant damage to their development. Secondly, they do not consider other societal cost such as health care beyond decreased lifetime earnings. Nevertheless, their estimates give us a credible range of the economic cost of this externality.

4.2. NO_x, SO₂ and PM

Muller and Mendelsohn (2007) measure the damages due to emissions of air pollution in the U.S. Their estimates are (gross annual damages, \$billion/year) listed in the second column in Table 3. Combining these results with the percentage of emissions from Table

2, I calculate the costs contributed by coal (\$billion/year). These results are listed in the third column in Table 3.

Table 3: Gross Annual Damages of NO_x, SO₂ and PM

Pollutant	Gross Annual Damages (\$billion/year) Source: Muller and Mendelsohn (2007)	Percentage contributed by coal (from Table 2)	Gross Annual Damages from Coal (\$billion/year)
NO_x	6.2	20.7%	1.3
SO₂	19.5	67.3%	13.1
PM2.5	17.4	6.5%	1.1
PM10	9.1	12.2%	1.1

Muller and Mendelsohn’s analysis focuses on air pollution only. They consider seven categories of damages: mortality, morbidity, agriculture, timber, visibility, materials and recreation. From the text and the references they use, it is evident that they also consider the effects of acid rain. For gaseous pollutants, such as NO_x and SO₂, they are likely to capture the full effects of damages. For particulate matter, since Muller and Mendelsohn do not specifically consider the composition (what toxic elements it contains) and the fact that PM can become carriers of other pollutants, it is possible that they may have underestimated its effect. This is supplemented by my estimates of toxic elements in the next section.

4.3. Arsenic, Chromium and Cadmium

The first-hand estimates of arsenic, chromium and cadmium pollutions in the United States are unavailable to the best of my knowledge. However, in a study on air pollution cost estimates for Europe, Spadaro and Rabl (2002) give estimates for arsenic, cadmium and chromium (among other pollutants) in terms of costs per kilogram of pollutants (ibid, p90, Table 6). As we can see in Table 2, the amount of cadmium from coal is quite small compared with other pollutants, nonetheless, since Spadaro and Rabl's results already include cadmium, I shall also include it in my estimates.

My estimation method is to apply Spadaro and Rabl's per-kilogram estimates to the U.S. with appropriate conversions. The conversions I make in this computation are as follows: First, Spadaro and Rabl's studies are based on a population density of 80 persons/km². The United States' population density as of 2000 is 28.6 persons/ km². (U.S. Census Bureau 2009, USCIA 2009)¹³. Thus, I multiply their results with a "population scaling factor", which we designate as p . The value of p is shown below:

$$p = 28.6 / 80 = 0.36$$

Second, we also need to consider currency conversion as the estimates in this study are denominated in euros. We note that Spadaro and Rabl's paper was published in the first issue of International Journal of Risk Assessment and Management in 2002, therefore, I use the exchange rate as of end of 2001. This exchange rate is 0.8913 euro for a dollar¹⁴, which we designate as e :

¹³ According to U.S. Census Bureau (2009), the total population in 2000 is 281,421,906; according U.S. CIA, the total area of the United States is 9,826,675 km². Dividing the former number by the latter, we obtain a population density of 28.6 persons/ km².

¹⁴ According to <http://finance.yahoo.com/currency-investing>, cross-checked with multiple sources.

$$e = 0.8913$$

Then I use the total emission amounts (which I designate as w , which I also convert to kilograms) in Table 2 and the costs per kilogram (which we designate as c) from Spadaro and Rabl (2002) to compute the total externality costs caused by these pollutants. Thus, the formula I use is:

$$\text{Total cost of pollutant} = c \times w \times p \times e$$

The results are summarized in Table 4 below:

Table 4: Total costs of Arsenic, Chromium and Cadmium

Pollutant	Total Annual Emissions (w) (from Table 2) (kilograms)	Cost per kilogram (from Spadaro and Rabl 2002) (in euro)	Total Costs (c × w × p × e) (in 2001 dollar)
Arsenic	70,610	171	3,874,260
Chromium	87,430	140	3,927,488
Cadmium	3,820	20.9	25,617
Total			7,827,366

Data Source: Spadaro and Rabl (2002)

I shall briefly discuss the limitations of my estimation method. First, I assume linearity in damage costs with regards to population density. This may be inaccurate because the distribution of population will certainly have a big impact on the costs of damages. It is worth pointing out, however, that linearity is used routinely in this literature. For example, in the mercury case, Trasande et. al. (2005) use a linear factor to estimate the proportional cost attributed to coal. Therefore my method is consistent with this line of research. The second potential limitation in my estimation is that, because of differences in expected lifetime earnings of Europeans and Americans, applying Spadaro

and Rabl's study to U.S. populations may introduce some distortions. These limitations notwithstanding, because no one – to the best of my knowledge – has attempted to estimate the damage costs from these pollutants in the U.S., my results are the most accurate.

As a cross-reference, I also check the literature on arsenic pollution in the U.S. The 2001 EPA arsenic rule is under a lot of criticism because most studies find its benefits do not justify the costs. For instance, Burnett and Hahn (2001) estimate that the benefits of EPA's arsenic rule ranges from \$10 million to \$200 million per year (which do not justify the costs of implementing EPA's rule, \$210 million per year). Since both EPA and Burnett and Han's studies are based on the total (*stock*) amount of arsenic in drinking water, whereas my estimate in Table 4 is for the annual *flow* of arsenic, therefore, my estimate of \$3.9 million per year has the correct order of magnitude.

4.4. Lead

Landrigan et. al. (2002) conduct a research that estimates of the annual costs of lead poisoning in American children. Their methodology is identical to what Trasande et. al. (2005) use to estimate the costs of mercury pollution – the environmentally attributable fraction (EAF) model, with which they arrive at the estimate of \$43.4 billion per year for lead poisoning.

Because Landrigan et. al.'s research focuses on pediatric illness, their results are likely to be underestimated as lead can also cause illnesses in adults (see Table 1). However, lead poisoning is much more harmful to children than adults because it can

affect children's developing nerves and brains (USNIH 2009), Landrigan et. al.'s results should in theory capture the majority of human health related costs.

In Table 2, we can see that the 73 short tons of lead generated from coal represent 1.7% of anthropogenic lead pollutions. Multiplying this number with Landrigan et. al.'s results, we arrive at the estimate of \$738 million per year for the damage costs of coal-generated lead.

4.5. Discussions and Summary of Damage Costs from Coal-generated Criteria

Pollutants

Before we summarize the damage costs from coal-generated criteria pollutants, I shall have a brief discussion on various issues in this line of research:

1. Uncertainty in the estimates

The first thing we note is that there is a significant degree of uncertainty in all these estimates. For instance, Trasande et. al. (2005)'s estimate of mercury pollution cost ranges from \$0.1-6.5 billion, that is a range of more than one order of magnitude. This kind of uncertainty is due to our imperfect understanding of the full effect of health and environmental harm a certain pollutant causes and the difficulty in measuring the amount of emission from all sources. This is what I call "technical uncertainty" which I shall discuss in more detail later in this chapter.

2. Completeness of the estimates

Referring back to Table 1, there are pollutants such as CO for which I have not obtained estimates, and certainly there are yet other pollutants not even listed in Table 1.

However, the estimates I have obtained are for the most abundant and harmful pollutants. These estimates capture a major portion of the externality costs originated from coal-fired power plants (besides CO₂, which I shall discuss in a separate section below).

3. Interactions among pollutants and overlapping of estimates

Muller and Mendelsohn (2007) discuss the interactions among various gaseous materials and particulate matter and their estimates include the effect of such interactions (they specifically state that they "...value the emissions of each pollutant, which includes the effect on other pollutants after atmospheric chemistry processes, not the concentrations". There is some discussion of SO₂ being a global cooling agent (Schwartz 1994), but since the cost estimates I have obtained for criteria pollutants do not reflect the effects of global warming, these are ignored in this section. To the best of my knowledge, there is also very little interaction among toxic elements. But there is one area where there is some overlap – in the cost estimates of PM. Muller and Mendelsohn (2007)'s results calculate the health (mortality and morbidity) effects, but they do not specifically mention the range of health issues they investigate. Since PM can also become carriers of toxic elements, it is possible that there is some overlapping in the cost estimates of PM and the cost estimates of toxic elements. However, it is plausible that Muller and Mendelsohn (2007) only include the first-order health effects of PM (lung disease, asthma, etc., see Table 1) as the focus of their study is air pollution, whereas the cost estimates of toxic elements generally focus on long-term health effects such as damage to the nervous and cardiovascular systems, such overlapping is likely to be insignificant.

4. Valuation of human life and intelligence

Since some of the pollutants cause death and/or loss of intelligence to the victims, all these studies have to address the issue of how to value human life and (loss of) intelligence in term of dollar value. Two different approaches are adopted in these studies. The first approach is using expected lifetime earnings. Trasande et. al. (2005) use this approach: they use Max et. al. (2002)'s expected lifetime earnings results and a 3% discount rate to calculate its present value to arrive at a present value of expected lifetime earnings of \$1,032,002 for a boy born in 2000 and \$763,468 for a girl. They then use this as a basis to calculate lost earnings due to loss of productivity resulting from loss of IQ. Landrigan et. al. (2002) use a very similar approach, except that their baseline lifetime earnings numbers are from a different source (U.S. Bureau of Labor Statistics). The present value of lifetime expected earnings numbers they use are \$881,027 for a 5-year-old boy, and \$519,631 for a 5-year-old girl. I believe the expected lifetime earnings approach will underestimate the damage cost because it does not take into account the externalities (positive and negative) of human life, and I believe that a productive person will generate, on net, a positive externality to society.

The second approach is using willingness to pay to avoid mortality risks. This is in fact the "standard" approach used by USEPA, which comes up with a value of a statistical life (VSL) of \$6.2 million based on a number of labor market and contingent valuation studies. Because it measures people's willingness to pay to avoid a significant probability increase in mortality risk, there is an ingredient of subjectivity in this method. Indeed, critics point out that the EPA's analytical methods are "ad hoc at best" (Krupnick and Morgenstern 2002) and much of the literature suggests that the EPA's estimate for

the VSL is too high. They also point out that the people's dread for their own death may lead them to significantly inflate the VSL (ibid). I shall not devote much more time to this subject, except to say that it is likely that this approach tends to overestimate damage costs. On top of that, Muller and Mendelsohn (2007) simply use EPA's reported VSL of \$6.2 million and apply it to victims of *all ages*, which will further skew the results toward the high end. Nor surprisingly, the largest cost estimate, that of SO₂, is from their study. Spadaro and Rabl (2002) use the same approach, except that they use a most modest value of 3.1 MEuro (\$3.4 million) as the VSL.

Despite the difference in methodology and potential bias in these studies, I choose not to "normalize" these results because there is no clear consensus on which approach is decidedly superior. I believe in doing so my synthesis of these results also reflects the reality of diverse analytical approaches used in this literature. The under- and over-estimates may also cancel each other out to some extent, which will improve the accuracy of *total* damage cost estimate. Had I chosen one method and "normalized" all results base on that method, the bias may be in one direction.

5. Monetary values in the estimates and currency conversion

I do not convert the currencies used in these researches to a baseline year currency, except in the case of Arsenic, Chromium and Cadmium, which I explicitly convert from the Euro to dollar. Since all of these studies were conducted between 2002 and 2006, a period with little inflation, and because of the intrinsic technical uncertainties in these studies, I believe converting to a baseline year currency has very little effect.

These “caveat emptors” notwithstanding, the results I have obtained reflect the best and most up-to-date of our knowledge about the magnitude of damage costs caused by coal-generated criteria pollutants. These results are summarized in Table 5 below.

Table 5: Gross Annual Damages from Coal-generated Pollutants

Pollutant	Gross Annual Damages (\$million/year)
Nitrogen Oxides	1300.00
Sulfur Dioxide	13100.00
Mercury	1300.00
Lead	738.00
Chromium	3.92
Cadmium	0.03
Arsenic	3.87
PM2.5	1100.00
PM10	1100.00
Total	18645.82

5. Externality Costs – Stock vs. Flow

The estimated costs caused by each pollutant in Table 5 represent the costs per year, which is to say, they are the estimated annual costs of the flow pollutants. As discussed in the previous section, for toxic elements, there are also stocks of them in the environment, which will continue to cause harm and impose a cost to society. When analyzing the externality costs, we must take both stock and flow externalities into account, although there may be little we can do about the stock of accumulative negative externalities.

The diagram in Figure 9 below illustrates this point. The marginal abatement cost (MAC) curve represents the marginal abatement cost. It is downward sloping because as

pollutants are being removed from the environment, it becomes more costly to remove each additional unit. The first marginal damage cost curve (MDC1) represents the marginal damage cost caused by flow pollutants. If we only analyze flow pollutants, we will come to the (incorrect) conclusion that the optimal amount of pollution is at the intersection of the MAC and MDC1 curve, q . However, because there are stock pollutants in the environment, we must take the effects of both stock and flow pollutants into consideration. The second marginal damage cost curve (MDC2) represents the marginal damage cost of the externality caused by both the stock and flow pollutants. Because MDC2 represents the sum total of the marginal costs of stock and flow pollutants, it always lies above the MDC1 curve. The optimal amount of pollution, then, is at the intersection of the MAC and MDC2 curve, q^* , which always lies to the left of (i.e. less than) q .

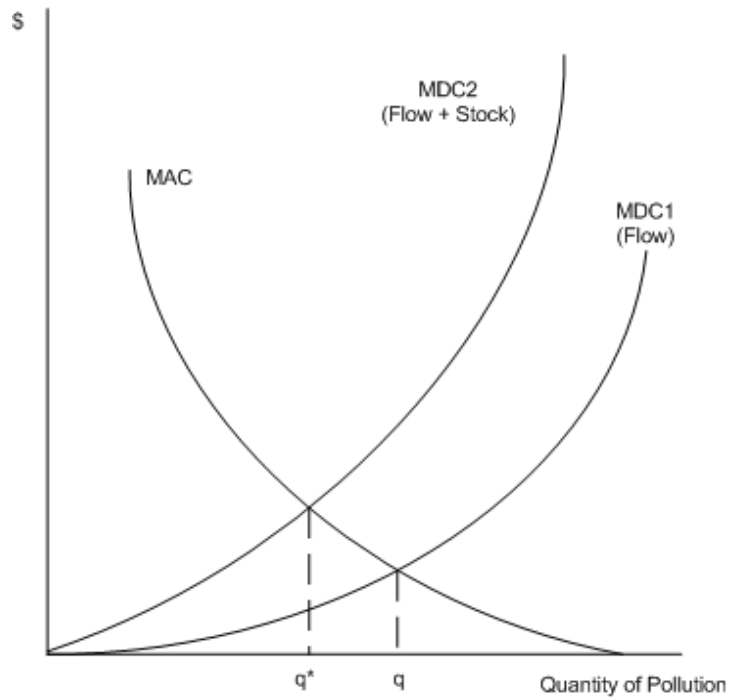


Figure 9: Stock and Flow Externalities

So far we have not done any estimates on abatement cost – that has to wait until next chapter. What we conclude now is that the optimal amount of pollution (q^*) will be less than the result based on flow externality and abatement cost alone (q). This means that the optimal pollution control policy would be more stringent than a pure flow externality analysis recommends.

6. Carbon Dioxide

In a sense CO_2 is very different from other pollutants: it is not toxic in itself. Indeed, we exhale CO_2 with every breath. CO_2 is also an ingredient in photosynthesis – the process by which plants convert light, water and CO_2 into carbohydrates and oxygen. An atmosphere devoid of CO_2 is sterile. At low levels, an increase in atmospheric CO_2

concentration stimulates plant growth and is therefore beneficial (Amthor 1995). Only at above 10,000 ppm – a level significantly higher than the current atmospheric CO₂ concentration (~ 380 ppm) – does it start to pose some health risks (Rice 2003). Therefore, when we discuss the harmful effects of CO₂, we are not concerned with the direct health hazard it causes, but with its potential to cause global warming (see Chapter 1).

From an economic perspective, the externality cost caused by CO₂ also has a distinct characteristic. This is illustrated in Figure 10 below.

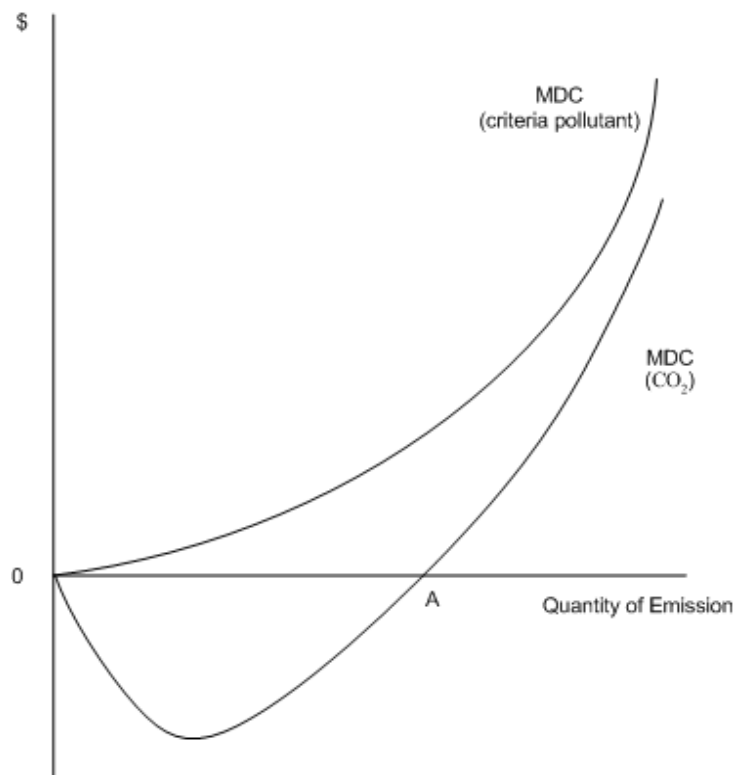


Figure 10: Externality Comparison between Criteria Pollutants and Carbon Dioxide

Figure 10 illustrates the stylized marginal damage cost (MDC) curves of a criteria pollutant (top) and of CO₂ (bottom). The MDC of the criteria pollutant stays above the

horizontal axis across the entire range of quantity of emission, which is to say, it causes harm at any quantity. The MDC curve of CO₂ is quite different: initially it dips below the horizontal axis, which means that at low levels it in fact generates a *benefit*. Only at some given quantity of emission (point A) does CO₂ cause a positive damage cost.

Regarding the cost of CO₂, different sources give widely varied estimates. The much-publicized and much-criticized “Stern Review” (Stern 2006) estimates that “if we don’t act ... the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever”, and “if a wider range of risks and impacts is taken into account”, the cost could “rise to 20% of (global) GDP or more (now and forever)”. This would be an enormous cost to society of apocalyptic proportions. Other studies generally produce more moderate and realistic results. Tol (2005) conducts survey of 28 published studies that contain 103 estimates. He uses four different ways to combine these results to plot the probability density function of the cost damage estimates:

1. “simple average” which gives equal weight to each *estimate* (not each study, as some studies contain more than one estimate)
2. “author weights” which gives equal weight to each *study*
3. “quality weights” which considers five criteria including whether the study is peer-reviewed, whether it estimates the marginal damage costs rather than average costs and the age of the study
4. “peer-reviewed only” which only includes peer-reviewed articles.

These results are reproduced in Figure 11 and Figure 12 below.

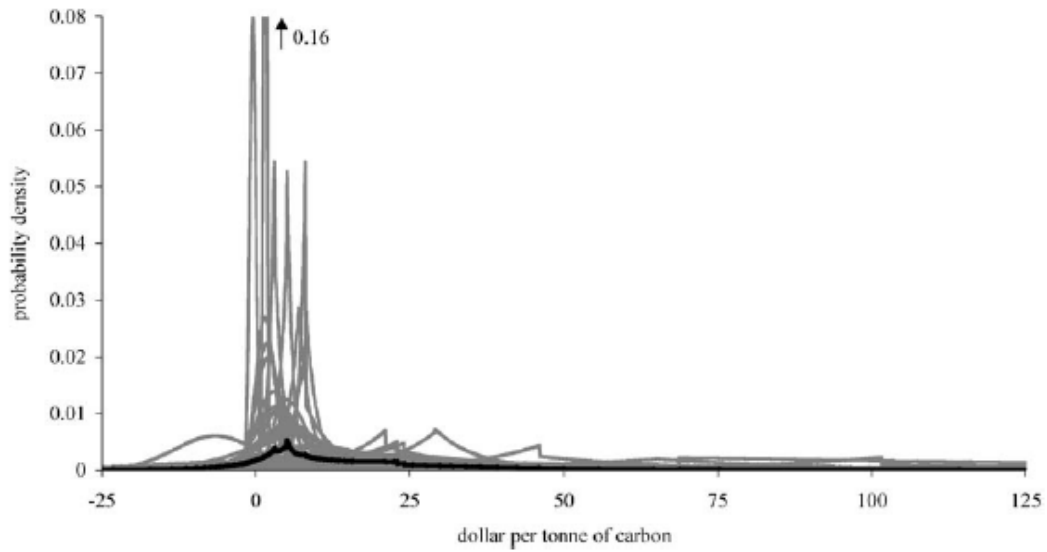


Figure 11: The probability density functions of the 103 estimates of the marginal costs of carbon dioxide emissions (gray) and the composite probability density function (black).
(Reproduced from Tol (2005))

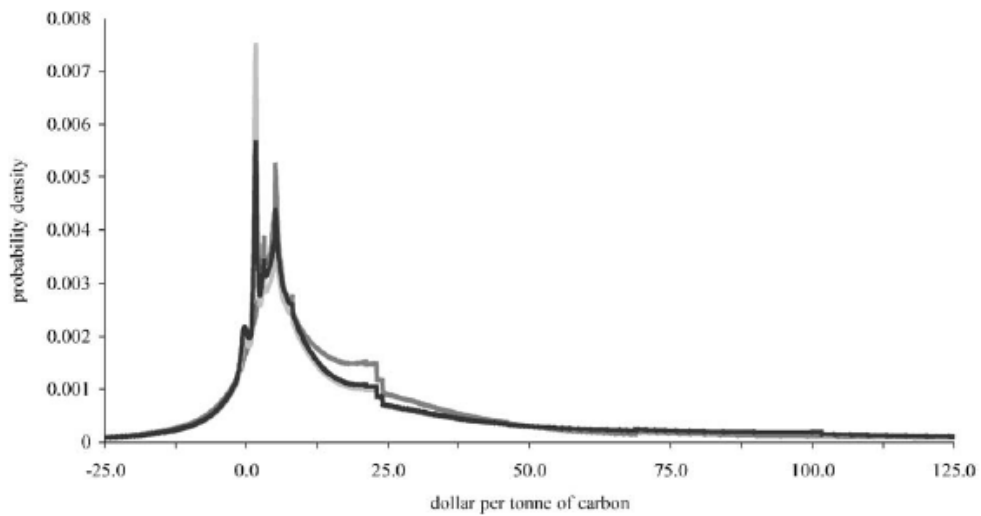


Figure 12: The composite probability density function of the marginal costs of carbon dioxide using author weights (light gray), quality weights (black), and quality weights including peer-reviewed studies only (dark gray).
(Reproduced from Tol (2005))

For all studies (Figure 11), the CO₂ damage cost estimates have a mean of \$93/tC (tonne of carbon), a median of \$14/tC and a mode of only \$1.5/tC; for peer-reviewed studies only (Figure 12), the mean is \$50/tC, the median is \$14/tC and the mode is \$5/tC (for brevity, I shall skip the “author weights” and “quality weights” results).

From the results compiled by Tol, we draw the following conclusions:

1. There is an enormous degree of uncertainty in CO₂ damage cost estimates. The range of estimates is very large: one study even has an estimate of \$1666.7/tC, or about 118 times larger than the median. The standard deviations are also very large: it is \$203/tC for all results, or about 2.2 times the arithmetic mean. Considering that the estimates are strongly right-skewed (most estimates are in the lower part of the range), the uncertainty is even more pronounced, as can be seen in Figure 11.
2. Interestingly, but not surprisingly, some estimates are negative (benefits), as can be seen in Figure 11 and Figure 12. This means the uncertainty is not merely about the *magnitude* of CO₂ damage cost, but also its *nature* (whether it is “good” or “bad”).
3. Another interesting thing is that peer-reviewed studies have a lower mean and smaller standard deviation. This is evidenced by comparing Figure 11 and Figure 12. This leads the author to observe that “a substantial part of the larger cost estimates are in the so-called gray literature” and remark that “[i]t seems as if the most pessimistic estimates of climate change impacts do not withstand a quality test”.

After surveying this literature and analyzing the results, Tol comments that “the marginal costs of carbon dioxide emissions are unlikely to exceed \$50/tC, and probably [are] much smaller”.

It is interesting to compare the compiled results from Tol (2005) with those from the “Stern Review”: In 2006, total global CO₂ emission was 29.0 billion tonnes (USEIA 2009b). If we multiply it by the mean of \$93/tC from all studies surveyed in Tol (2005), which is equivalent to \$25.3/tCO₂¹⁵, we arrive at an estimate of total annual CO₂ damage cost of \$734 billion. According to The World Bank Work Group, in 2006 total global GDP was \$48.9 trillion (in 2009 dollars)¹⁶, thus the total annual CO₂ damage cost in 2006 represents 0.0015% of global GDP, far less than the 5% or even 20% global GDP estimated by Stern (2006). Of course, we must keep in mind that the \$93/tC from Tol (2005) is the marginal value, which will not remain constant at all CO₂ levels, and that CO₂ is a stock pollutant – its residence time in the atmosphere is as long as decades to centuries (Schwartz 1994) – and will continue to cause damages, whereas our computation only includes the damage from one year’s emissions and will undoubtedly underestimate the full damage cost. Nonetheless, Stern’s result is more than 3000 times higher than our first-order result and quite far outside the range of estimates in economic literature surveyed in Tol (2005). We can then safely, using Tol’s term, categorize the “Stern Review” as being the extreme end of the “gray literature”.

¹⁵ 1 tonne of carbon is equivalent to 3.67 tonne of CO₂, therefore $\$90 / 3.67 = \$25.3/\text{tCO}_2$.

¹⁶ The World Bank Group maintains a website (<http://ddp-ext.worldbank.org/ext/DDPQQ/report.do?method=showReport>) that allows users to run live queries. I did not find any achieved report for 2006 global GDP, but the live query generated a number of 48863326912303 in “current US \$”. The query was run on September 8, 2009.

7. Two Types of Uncertainties

We have seen in this chapter that there are many sources of uncertainties with regards to the effects of coal-generated externalities. But we must distinguish between two very different types of uncertainties.

The first type is the uncertainty in estimating the magnitude and cost of a pollutant. This type of uncertainty stems from the complex and dynamic nature of environmental and economic issues, accuracies and completeness of reporting, measurement methodologies and so on. For this type of uncertainty, in theory at least, as we continue to deepen our understanding of the underlying scientific and economic issues and perfect our measurement and reporting techniques, we will be able to obtain more and more accurate results. I call this type of uncertainty “technical uncertainty”.

The second type of uncertainty is the uncertainty in our understanding of the effects of a pollutant. If our understanding of the role that a substance plays in affecting the natural environment and human health is unclear or immature, then even if we have the best techniques to measure the quantity of this material and trace its flow throughout the environment, our estimate of its economic effect will not be fundamentally sound. I call this type of uncertainty “theoretical uncertainty”, which is similar to the “model uncertainty” in economic literature (Rowley and Smith 2009, p.70), that is, we do not know or are not sure what model best describes the real world. If a substance exhibits a considerable degree of theoretical uncertainty, it is imperative that we have the correct understanding of its nature before taking costly actions changing its level.

Technical uncertainty will always be present as it is impossible to get the “perfect” measurement of the effects of a pollutant. But the degree of theoretical uncertainty varies substantially from one pollutant to another. For example, although ozone in the stratosphere (“ozone layer”) filters out harmful ultraviolet rays from the sun and is therefore beneficial to human health, ground level ozone, which is a derivative from nitrogen oxides emitted from coal-fire power plants, causes various health hazards, as shown in Table 1. Since the net transport of ozone between the stratosphere and the troposphere (the layer of atmosphere closest to the Earth) is downward (Collins, et. al. 2002)¹⁷, ground-level ozone does not contribute to the ozone layer, thus its net effect is unequivocally harmful. There is even less ambiguity regarding the harmful health and environmental effects of other pollutants, such as nitrogen oxides, sulfur dioxide, arsenic and heavy metals. Therefore, the theoretical uncertainty of these criteria pollutants is virtually eliminated.

The situation is quite different in the case of CO₂. As I discussed in Chapter 1, there are still ongoing debates about the effects of global warming, and the role CO₂ plays in causing it. Regional effects, the difficulty in capturing human adaptation in impact analysis further complicate the issue (Tol 2005). Additionally, models are often highly sensitive to the choice of time preference and require assumptions about the relative importance of impacts in different sectors and regions, which all involve (subjective) value judgments (ibid). Consequently, the uncertainty about CO₂’s effects to human societies is of the “theoretical” type. Furthermore, as I illustrated in Figure 10,

¹⁷ Although this is beyond my area of studies, intuitively, ozone (O₃) is a much heavier gas than atmosphere, which probably partially explains the predominantly downward movement.

CO₂ is actually beneficial at low levels, a characteristic distinct from other pollutants, and indeed as we can see in Figure 11 and Figure 12, some studies estimate that there is a net benefit in increased atmospheric CO₂ concentration levels. If we cannot pinpoint the level at which the marginal benefit of CO₂ turns into a marginal cost (point A in Figure 10), then we may mistake a benefit for cost. Therefore, greater caution needs to be taken when dealing with externalities with theoretical uncertainty. It may require a different strategy dealing with them than what is used to deal with externalities without theoretical uncertainty, a point that I shall return to later in this dissertation.

8. Corrections for Coal-generated Externalities

As discussed in this chapter, burning coal generates externalities, most of which are harmful. If there are some institutional constraints – whether tax, subsidy, direct regulation, or a combination of these – imposed upon the owners of coal-fired power plants to internalize these externalities, what are the measures they can employ to correct these externalities?

The most primitive measure is dilution – to disperse pollutants into the environment. There is an old saying “the solution to pollution is dilution”. Primitive as it is, dilution actually has its scientific and economic grounding. Dilution has the following effects:

1. The ecosystem has a certain level of assimilative capacity (Perman, et. al., 2003, pp.168-9). At low concentration, the ecosystem is able to assimilate pollutants.

When there are few power plants and they are dispersed geographically, dilution

is an effective solution to mitigating or even elimination pollution. However, when the concentration of pollutants exceeds the assimilative capacity of the ecosystem, dilution is not an appropriate approach.

2. Detection instruments have sensitivity thresholds. Dilution makes the pollutants harder to detect. In the case where multiple pollution sources are involved, the instruments may be able to detect the total level of pollution, but it may be harder to trace back to each source.

For the owners of coal-fired power plants, dilution is almost certainly less costly than abatement (which involves capturing and safely storing the pollutants). For the victims, dilution has the following effects:

1. It lowers the harmful effects to each victim.
2. It converts a private externality to a public externality (Baumol and Oates, 1988), or at least a "more private" externality to a "more public" one, and disperses the pollutants to a wider area so that the number of victims will increase.
3. By including more victims, it raises the transaction cost for collective action for the victims.

Thus, there is a powerful incentive for the polluters to use dilution rather than abatement as a pollution control measure. The most common way to dilute is to build taller smokestacks to disperse the emissions above the inversion layer (a layer in the atmosphere in which the usual temperature gradient – warm air below cold air – is reversed such that pollutants below it are trapped locally) (Jensen and Bourgeron 2001).

There is evidence that taller smokestacks can improve local air quality without reducing total emissions (Bellas and Lange, 2008).

Unfortunately, as the number of polluters increase, dilution will lose its effectiveness because the amount of pollution will eventually exceed the assimilative capacity of the environment. Further, even though the pollution from each polluter gets diluted, the total amount of pollution will still add up in the environment. The sum total of disutilities faced by the victims (measured by willingness to avoid) and the cost of dilution may exceed the total cost of abatement, resulting in a suboptimal outcome. I believe this “many polluters, many victims, dispersed pollution” scenario accurately depicts reality, evidences include:

1. There are many sources of emissions. There are 616 coal-fired power plants in the U.S. alone (USEIA 2008) and one is built in every week to 10 days in China¹⁸.
2. The pollutants are dispersed widely. Satellite images have shown that plume from Chinese core-fired power plants can propagate over the Pacific Ocean and reach the west coast of the United States (USNASA 2008).

This “many polluters, many victims” situation significantly raises the transaction cost between polluters and victims, which makes Coasian bargain (Coase 1960) to reach Pareto efficient outcome unrealistic. Furthermore, when the effects of some of the pollutants, such as acid rain from SO₂ and global warming from CO₂ (insofar as we believe that is one of the major causes for global warming) are global in scale, the

¹⁸ New York Times, June 11, 2006, *Pollution From Chinese Coal Casts a Global Shadow*, By Keith Bradsher and David Barboza

victims' choices, such as "moving away from the nuisance", is also no longer be feasible. Under these conditions, as Baumol and Oates (1988, Chapter 3) illustrate, the proper device is a Pigouvian tax equal to marginal social damage levied on the generator of the externality with no supplementary incentive for victims. The case for coal is a bit more complicated than the textbook example because taxes and regulations are already imposed on coal and coal-fired power plants, and in the U.S. there is a SO₂ permit-trading program in effect. In addition, in this chapter I only look at the damage cost side of the problem. To determine whether it is efficient to use modern abatement technologies for coal-fired power plants, we must look at the abatement cost side of the issue, which I shall discuss in the next chapter. The discussion here points out that in the world we inhabit today, dilution alone is an inadequate measure to control pollution and will lead to economically inefficient outcomes. Modern abatement technologies, and policy instruments that provide proper incentive for polluters to adopt these technologies, should be considered as meaningful pollution control measures. These will be the focus of following chapters.

9. Summary and Conclusion

Coal, more specifically coal-fired power plants generate a range of pollutants that cause health and environmental hazards. These health and environmental hazards become externalities when the operators of coal-fired power plants do not have to bear their full cost. In this chapter I give damage cost estimates to all major coal-generated criteria pollutants by critically reviewing and synthesizing this literature, and performing my own

estimates. I also discuss the difference between stock and flow pollutants. The case of CO₂ is very different than other pollutants as it is beneficial at lower levels. I critically review a survey of the damage cost estimates of CO₂. In doing so, I also make a distinction between two types of uncertainties – technical uncertainty and theoretical uncertainty. I conclude that technical uncertainty exists for all pollutants, but for CO₂, a high degree of theoretical uncertainty also exists. This requires greater caution when dealing with the abatement of CO₂. Finally, I discuss why the primitive method of dilution is no longer effective in a world with “many polluters, many victims”, and conclude that the combination of a Pigouvian tax and modern abatement technologies (which I shall discuss in the next chapter) provide the most appropriate corrective measure.

Chapter 4: Clean Coal Technologies

Clean coal is like healthy cigarettes. It does not exist.

– Al Gore, Former Vice President of the United States¹⁹

I believe the future of clean coal is very bright.

– Joe Lucas, Spokesman for American Coalition for Clean Coal Electricity²⁰

1. Introduction: What is Clean Coal?

“Clean Coal” is a confusing term; it means different things to different people, as the opening quotations suggest. To some people, it means 100% carbon capture and sequestration (CCS) in coal-fired power plants. This is the stance that many environmental activists take. At present, no commercial coal-fired power plants utilize CCS technologies; this is what Al Gore means when he says Clean Coal “does not exist”.

To others, however, “Clean Coal” is just an umbrella term that encompasses modern abatement technologies – not merely CCS, but including abatement for SO₂, NO_x, PM and all kinds of pollutants from coal-fired power plants described in Chapter 3. This was in fact the most common usage of the term “Clean Coal Technologies” in

¹⁹ *Taking On King Coal* by Bryan Walsh, Time magazine, Nov. 05, 2008, website: <http://www.time.com/time/magazine/article/0,9171,1856987-1,00.html>

²⁰ *McCain, Obama tout coal, But investor skepticism evident in scant interest in Colorado firms* by Gargi Chakrabarty, Rocky Mountain News, October 31, 2008, website: <http://www.rockymountainnews.com/news/2008/oct/31/mccain-obama-tout-coal>

engineering communities and publications before CO₂ became a hot topic (for example, see McMullan, et. al. 1997).

In this dissertation I adopt the latter convention used in engineering literature, that is, I use “Clean Coal” or “Clean Coal Technologies” to refer to modern technologies that reduce emissions of any pollutant, not just CO₂. I do so for two reasons: First, this was the convention before the current debate about CO₂ and CCS. Continuing with this convention puts my research in the proper historical context. Secondly, as I summarize in Chapter 3, there are many types of pollutants emitted from coal-fired power plants, there is no particular reason why the abatement of CO₂ should take higher priority than the abatement of other pollutants. In fact, as I discuss in Chapter 3, there is still a considerable degree of theoretical uncertainty about the damage cost of CO₂ and this theoretical uncertainty is virtually nonexistent in criteria pollutants. Therefore, abatement of criteria pollutants should take higher priority. Equating “Clean Coal” with CCS would imply that the abatement of CO₂ is of paramount importance, which does not reconcile with facts from scientific and economic literature.

But what is a “modern” technology? This modifier suggests a level of subjectivity. On the spectrum of abatement (and dilution) technologies, there are very primitive ones and ones that reflect the state-of-the-art engineering achievement of our time. At one end of this spectrum, we have building taller smokestacks and dispersing the pollutants. I do not consider this to be a “Clean Coal Technology”. At the other end, we have IGCC (Integrated Gasification Combined Cycle), a process that converts coal into syngas (synthesis gas) that consists mainly of carbon monoxide (CO) and hydrogen. This

technology has the potential of virtually eliminating all criteria pollutants from coal. I consider IGCC to be a Clean Coal Technology.

In between them, there are some gray areas. For example, the vast majority – all except 2 (USEIA 2009a) – of coal-fired power plants built in the last half century use a technology called pulverized coal (PC) combustion or one of its variants (more on this in the next section). There are technologies, such as chemical cleaning, scrubbers and electrostatic precipitators to reduce emissions from PC combustion plants. Indeed, these technologies have helped to produce a 38% reduction in total SO_x emissions, and 25% reduction in total NO_x emissions from coal-fired power plants in the last 30 years (MIT 2007, p23). However, as I demonstrate Chapter 3, even with these technologies, coal-fired power plants still generate large amounts of pollutants which impose negative external cost on society. Because of the nature of PC combustion, further emission reduction becomes prohibitively expensive and economically unviable. For these reasons, I do not consider PC combustion technologies to be “Clean Coal Technologies”.

IGCC is a totally different mechanism – it gasifies coal to produce syngas, which is then burned to generate heat. This means most solid material is “left behind” during the gasification process, making them easier to capture. Also, the generated syngas is kept at a high pressure which makes the removal of pollutants more technically and economically effective than cleaning up large volumes of low pressure flue gas (MIT 2007, p 141). Because of these factors, I consider IGCC, with or without CCS, to be a “Clean Coal Technology”.

2. Current Technologies Used in Coal-fired Power Plants in the United States

There are mainly two major types of coal-fired power plants: pulverized coal (PC) combustion and IGCC. “Pulverization” is a process to grind coal to very fine particles, which are then injected through the burners into the furnace with combustion air and burned there. Depending on the pressure and temperature at which the pulverized coal is burned, PC combustion can be further divided into subcritical (~ 550°C, ~3200 psi), supercritical (~ 565°C, ~3530 psi) and ultra-supercritical (>565°C, and at pressures in the 4000-6000 psi range). A variation of PC is fluid-bed combustion, in which the pulverized coal is burned in a “bed” of upward-blowing jets of air, typically a circulating fluid bed (CFB).

IGCC is essentially a combination of two processes, the second of which also contains two electricity-generating cycles (hence the words “integrated” and “combined cycle”). In the first step, coal is gasified to produce syngas. The syngas is further cleaned, and then burned in a gas turbine to drive a generator. Because the syngas is burned at a much higher temperature (>1000°C) than PC combustion units, the turbine exhaust is also at a very high temperature and goes into a heat recovery generator to produce steam to drive a steam turbine. Because of the two electricity generating cycles, generating efficiency is very high in IGCC plants – IGCC plants can achieve a generating efficiency of 38.4%, higher than the current average efficiency of 34% in PC plants, although supercritical and ultra-supercritical PC plants can also achieve similar efficiencies (Beer 2007). Higher efficiency means that for a given unit of electricity, less coal is burned; this also helps reduce emissions.

At the end of 2008, there are 601 coal-fired power plants with 1458 generating units in the United States, 1415 of these units are in operating or standby (backup) status, with a total capacity of 333241 megawatts. Of these, the vast majority is of the PC design type; only 3 units at 2 plants (1 unit at the Wabash River Station in Vigo County, Indiana and 2 units at the Polk Station in Tampa, Florida) are IGCC units. These 3 units represent a mere 0.2% of the total number of generating units, and their 518 megawatts generating capacity represents only about 0.16% of the total generating capacity of all operating and standby power plants (USEIA 2009a). Table 6 below shows the descriptive statistics of all coal-fired power plants in the U.S.

Table 6: Descriptive Statistics of All Coal-fired Power Plants in the United States

Total number of coal-fired power plants	601
Total number of generating units	1458
Operating and standby units	
Number of units	1415
Total Capacity (mW)	333241.1
Mean Age	41.1
IGCC units	
Number of units	3
Total Capacity (mW)	518.3
Mean Age	12.6
Out of service units	
Number of units	41
Total Capacity (mW)	3031.8
Mean Age	52.4

Data Source: USEIA (2009c)²¹

²¹ USEIA 2009a divides these power plants in 5 categories in terms of operating status: operating (OP), standby/backup (SB), out of service, but will be returned to service in the next calendar year (OA) and out of service and not expected to be returned in the next calendar year (OS), and retired (RE). No plants of status RE is listed, and only 2 of status OA are listed. Table 1 includes plants of status OP and SB in the “Operating and standby” category, but only includes plants of status OS in the “Out of service” category.

Figure 13 below shows these plants grouped by their initial year of operation in 5-year intervals (except the first group, which has a 6-year interval of 1924-1930 because there is only 1 plant with an initial year of operation of 1924; and the last group which has a 3-year interval because no data is available yet for 2009 and 2010).

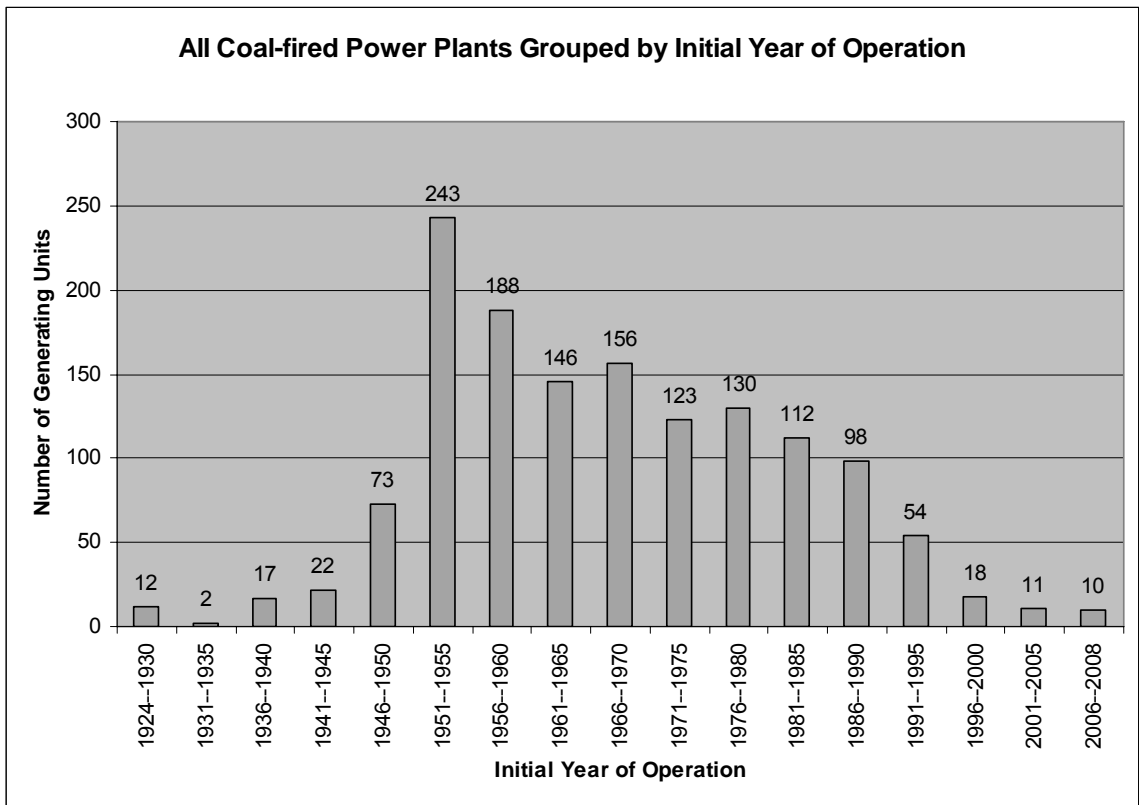


Figure 13: All Coal-fired Power Plants in the United States Grouped by Initial Year of Operation

Data Source: USEIA (2009c)

The most interesting thing we note in Figure 13 is that, since the typical lifespan of a coal-fired power plant is 40-50 years (Pouris 1987, Kahrl and Roland-Holst 2006, Holdren 2007), 557 or 39% of these units are already operating beyond their “life expectancy”, and in the next 20 years, that number will almost exactly double, to 1112. What causes these plants to operate beyond their typical “life expectancy”? This is a

puzzle that be unraveled later in my dissertation, but for now, the important point we take from the descriptive statistics is that in the coming couple of decades, a large percentage of coal-fired power plants will need to be replaced. So the question we want to ask is: what should we replace them with?

3. The Case for IGCC without Considering CCS

MIT (2007, Chapter 3) gives a list of “levelized COE (cost of electricity)” (meaning fully accounted for capital, operation, maintenance and fuel costs) for each plant type. These numbers are reproduced in Table 7 below.

Table 7: Levelized Cost of Electricity for Each Plant Type

Plant Type	Cost of Electricity (c/kw-h)
Subcritical PC	4.84
Supercritical PC	4.78
Ultra-supercritical PC	4.69
Subcritical CFB	4.68
IGCC	5.13

Data Source: MIT (2007)

From Table 7 we see that power plants of the PC design can produce electricity more cheaply than IGCC plants. However, these numbers do not include externality costs – costs caused by pollutants emitted from these plants. To compare their “true costs”, we must take externality costs into account.

As I show in the previous section, the current fleet of coal-fired power plants in the U.S. is predominantly of the PC design (including CFB). For simplicity, I shall take

the average of the COEs for these plant types from Table 7 to represent that of existing coal-fired power plants – this number is 4.75 c/kw-h. From MIT (2007), we also obtain the emission numbers for PC and IGCC plants. Combining these with the externality costs I obtain in Chapter 3, we can then calculate the FCOE (Full Cost of Electricity, inclusive of externality costs) for PC and IGCC power plants (see Appendix). These numbers are listed in Table 8 below:

Table 8: Full Cost of Electricity Comparison of Existing Plants and IGCC Plants

Plant Type	Cost of Electricity (c/kw-h)	Externality Cost (c/kw-h)	Full Cost of Electricity (c/kw-h)
Existing Plants	4.75	0.90	5.65
IGCC	5.13	0.23	5.36

Data Sources: MIT (2007), USEIA (2009b), Chapter 3 of current dissertation

From Table 8, we see that once externality costs are considered, the full cost of electricity (FCOE) for IGCC plants is actually lower than existing coal-fired power plants. Actually, the externality costs in Table 8 only includes the damage costs of NO_x, SO₂, Mercury and PM, since IGCC plants generate less emissions than PC plants in almost every category, if other pollutants were included, the cost discrepancy would be even larger.

In order to avoid over-reliance on one study, I conduct a second comparison (see Appendix A) based on different sources (Phillips 2005, MPCA 2006 and USEIA 2009b), these results are listed in Table 9 below.

Table 9: Full Cost of Electricity Comparison of SCPC and IGCC Plants

Plant Type	Cost of Electricity (c/kw-h)	Externality Cost (c/kw-h)	Full Cost of Electricity (c/kw-h)
SCPC	4.58	0.90	5.48
IGCC	5.08	0.32	5.40

Data Sources: Phillips (2005), MPCA (2005), USEIA (2009b), Chapter 3 of current dissertation

Note that the COE numbers (second column) in Table 9 are lower than those in Table 7. This is because Phillips (2005) lists “30-year levelized cost of electricity” whereas MIT (2007) lists fully levelized costs. The difference can be explained by differences in amortization methodology. After taking this into account, the numbers from Table 8 and Table 9 are consistent. In addition, in this second compilation of data, I use SCPC (supercritical PC) plants as a representative of existing plants as an approximation, which in fact under-represent the externality costs of existing coal-fired power plants (because some use technologies more primitive than SCPC and produce more emissions). That is the reason why the difference in FCOE is smaller in Table 9 than in Table 8 (for more discussions on these calculations, see Appendix).

The second case listed in Table 9 also confirms my conclusion that when externality costs are taken into account, the FCOE of IGCC plants is lower than the FCOE of existing coal-fired power plants.

The above analyses are not marginal analyses, and there is a large degree of simplification – even within each category (PC, CFB or IGCC), there are wide variations of designs, and the generating efficiency and emission from plants depend on the grade of

coal. In general, plants with the highest emission rates are older (Source Watch 2009a). If we start replacing the aging generating units with IGCC units one by one, then the marginal (per-unit) benefit of replacement (measured by the net difference between FCOEs of the old unit and the new IGCC unit) will be higher for the initial units. For newer plants, especially ones with the CFB and IGCC design, which already have higher generating efficiency and lower emissions, the marginal benefit of replacement (MBR) may possibly be negative, thus it crosses the horizontal axis at some point. The MBR curve is shown in Figure 14 below.

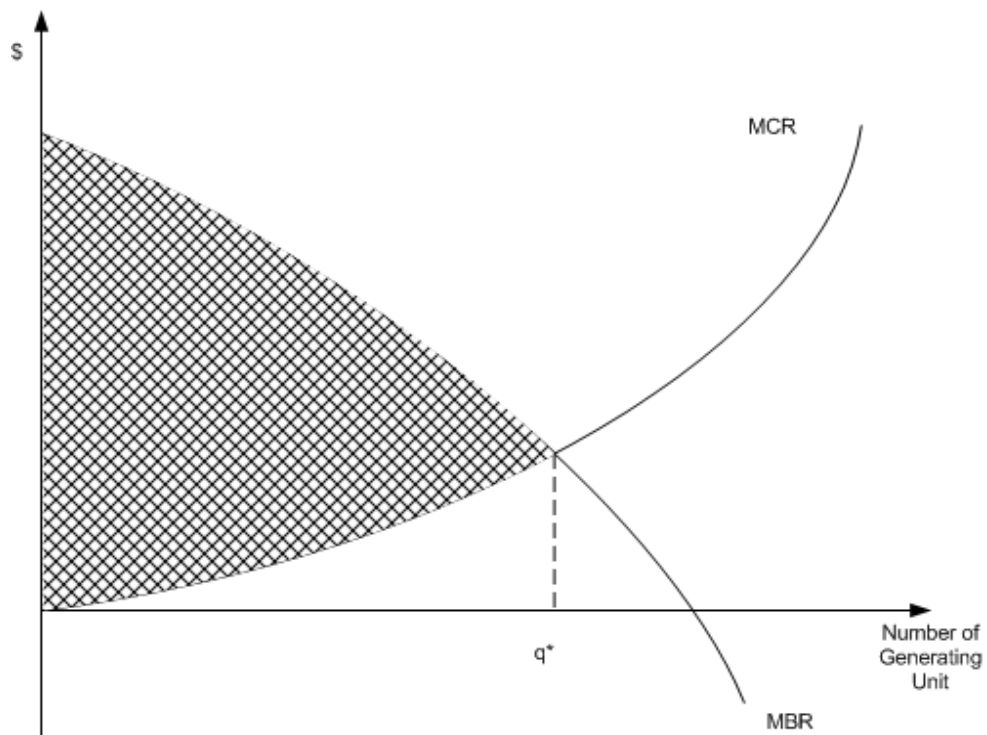


Figure 14: Marginal Benefit of Replacement (MBR) and Marginal Cost of Replacement (MCR) for Replacing Existing Coal-fired Power Plants with IGCC Generating Units in One Period

In Figure 14, I also show the marginal cost of replacement (MCR) curve for these units. Note that since the MBR curve measures the *net* difference between the FCOE of the existing unit and the FCOE of the new unit, the MCR curve does not include the FCOE of the new IGCC units; it only includes cost *in addition to* the FCOE. Thus, the MCR curve starts at 0. As more and more units are being replaced and as labor and capital become scarcer, the cost of replacement goes up. The intersection of the MBR and MCR curves, q^* , is the optimal number of generating units being replaced. The shaded area between the MBR, MCR and the vertical axis is the welfare surplus of replacement.

The situation depicted in Figure 14 is for replacing all generating units at once. If, instead, we use a “staggered” replacement approach, that is, replacing one unit or a few units in one time period (for example, one year). This will ease the pressure on labor and capital scarcity, thus the MCR curve will have a smaller slope. Meanwhile, as time goes on, existing plants will deteriorate even more, magnifying the benefit of replacement, thus the MBR curve will not drop as steeply compared with the one-period situation depicted in Figure 14. The net result of these effects is that the optimal number of generating units being replace, q^* , will shift to the right; that is, more units should be replaced in the “staggered” scenario. This situation is depicted in Figure 15 below.

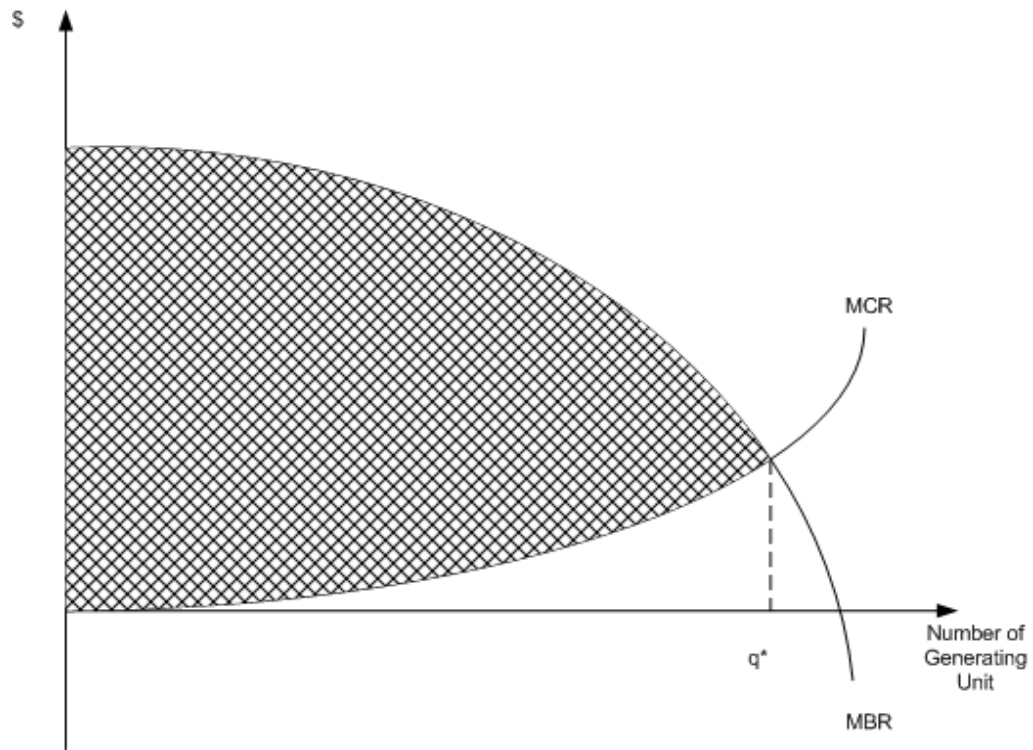


Figure 15: Marginal Benefit of Replacement (MBR) and Marginal Cost of Replacement (MCR) for Replacing Existing Coal-fired Power Plants with IGCC Generating Units, Staggered Scenario

Because in the “staggered” replacement scenario depicted in Figure 15 the MBR and MCR curves are both less steep than their counterparts in Figure 14, and q^* shifts to the right, the total welfare surplus of the replacement – the shaded area in Figure 15 – will be larger than its counterpart in Figure 14. This means, the “staggered” replacement approach is more economically efficient than a one-time replacement approach.

The analyses in Figure 14 and Figure 15 are, of course, stylized. A more detailed marginal analysis based on empirical data is certainly necessary to pinpoint the location of q^* and estimate the size of welfare surplus. But based on the FCOE cost comparisons I have effected, and the fact that a very large portion of existing coal-fired power plants are

beyond their normal “life expectancy” (see previous section), the evidences are compelling that the “staggered refreshing” of coal-fired power plants is the optimal path. There are other advantages of IGCC: Compared with PC plants, IGCC plants generate 40-50% less solid waste (Johnson et. al. 2007). The solid waste IGCC plants generate is also very different in nature: the two major solid byproducts are slag (a fused mixture of metal oxides and sulfides and elemental metals) and sulfur. Slag can be used to make concrete, bricks and as a road base material (Bijen 1996, Chen et. al. 2009), sulfur can also be processed into commercially viable products (Chen et. al. 2009). In comparison, the waste from air-blown combustion (PC and CFB) plants is in sludge or slurry (watery mixture) form, which is more leachable (Ratafia-Browen et. al. 2002) and when leaked to the environment can cause environmental and health hazards. Also, because coal is gasified, IGCC plants are less dependent on the grade of coal, and indeed, it can even be used to gasify biomass (Chmielniak and Sciazko 2003).

I do not suggest that IGCC is a perfect technology. Because it is a relatively new technology, one of the challenges facing IGCC plants is that their operating availability level (defined as the amount of time that a power plant is able to produce power in a given period divided by the total amount of time in that period) is usually lower than comparable PC based plants (Watson 2005). However, in recent years the availability level of IGCC plants has seen major improvements. For example, the Wabash River station has achieved availability level in the 80% range (Conoco Phillips 2005). Many of the problems facing IGCC plants were design and materials related which were corrected and are unlikely to reappear as the technology matures (MIT 2007).

Nor do I suggest that IGCC should be used exclusively for coal based power generation in the future. Oxygen-blown (instead of air-blown) PC combustion, or Oxy-fuel PC combustion, is a technology that has potential to generate lower emissions, especially NO_x because an oxidant gas – usually 95% oxygen with very little nitrogen – is used to burn the pulverized coal (MIT 2007). Air blown partial gasification of coal (Xiao et. al. 2007), a hybrid of air-blown and gasification technologies, is also showing some promise. However, oxy-fuel PC combustion is still in early development and there is no commercial experience with it yet (MIT 2007), and partial gasification technologies are also in the experimental stage. IGCC, in comparison, though also at an early stage of development, is already used commercially in the U.S. and throughout the world, albeit only in a handful of plants.

What we conclude from this section is that, when the FCOE is considered, IGCC becomes superior to existing PC-based technologies for coal-fired power generation. The optimal path for replacing current aging coal-fired power plants is a “staggered refreshing” approach. Yet, as I describe in the previous section, the percentage of coal-fired power plants that use IGCC is miniscule (0.2% in terms of generating units and 0.16 in terms of capacity), and there have not been one built in the last decade. Although more IGCC plants are being proposed – indeed, 21 of 83 or 25% of proposed plants use IGCC (National Energy Technology Laboratory 2009), many also have been or are being cancelled (Source Watch 2009b). What has led to this outcome? That is a question I shall answer in the next chapter when I investigate the political economy of Clean Coal, but for now, I shall once again turn my attention to CO₂ and global warming.

4. CO₂ and Global Warming – Risk or Uncertainty?

I use the word “uncertainty” throughout this dissertation; at this point it is necessary to give it a more precise definition.

In his seminal paper, Frank Knight (1921) makes a distinction between risk and uncertainty. In Knight’s interpretation, risk refers to situations where the decision-maker can assign mathematical probabilities to the randomness that he is faced with, whereas uncertainty refers to situations when this randomness cannot be expressed in terms of specific mathematical probabilities.

Global warming may lead to catastrophic outcome to human society. Is this situation a risk or an uncertainty in the Knightian sense? As I discussed in Chapter 1, there are still uncertainties (there I use the word “uncertainty” in its more broad sense) about the *extent*, *cause* and *effect* of global warming. It is not possible with our current repository of knowledge to assign a probability to the catastrophic outcome (or to say if indeed it will happen).

In Chapter 3, I show the probability density functions of marginal cost estimates of CO₂, reproduced from Tol (2005) (see Figure 11 and Figure 12 in Chapter 3). But these are composite probability densities compiled from publications, each with a different estimation methodology. It would be wrong to equate these probability density curves with the true objective probability. It is, of course, our goal that as our understanding of CO₂ and global warming deepens, such probability curves will more accurately reflect the underlying objective probability. But with our current knowledge

about CO₂ and global warming, we cannot yet assign a mathematical probability to each outcome with confidence.

The situation with CO₂ and global warming, then, is an uncertainty and not a risk in the Knightian sense. If it were a risk, then we would be able compare the cost of CO₂ abatement with the expected utility loss from its effects, with adjustment for risk-averseness for catastrophic events and formulate a strategy – in other words, we would adopt a strategy of maximizing expected utility. But because it is a Knightian uncertainty, it is then sensible to adopt a different strategy: For example, we will want to learn more about the nature of CO₂ and global warming before deploying costly abatement technologies. We will also want to take actions on issues with smaller degree of uncertainty, such as the abatement of criteria pollutants because, as I discuss in Chapter 3, criteria pollutants have “technical uncertainty” but virtually no “theoretical uncertainty”.

5. Carbon Capture, Transportation and Sequestration

It is generally agreed that when equipped with CO₂ capture, IGCC plants can produce electricity more cheaply than other types of plants also equipped with CO₂ capture. Table 10 shows the levelized cost of electricity from different types of plants when equipped with CO₂ capture.

Table 10: Levelized Cost of Electricity for Each Plant Type When Equipped With CO₂ Capture

Plant Type	COE with CO₂ capture (c/kw-h)
Subcritical PC	8.16
Supercritical PC	7.69
Ultra-supercritical PC	7.34
Subcritical CFB	7.79
Oxy-fuel Supercritical PC	6.98
IGCC	6.52

Data Source: MIT (2007)

MIT (2007) also compares their own results with other studies that compare the cost of electricity of IGCC and PC plants when equipped with CO₂ capture. These studies all reach the same conclusions. These results are listed in Table 11 below.

Table 11: Relative Cost of Electricity Comparison of PC and IGCC Plants When Equipped With CO₂ Capture From Various Studies²²

	MIT	GTC	AEP	GE
PC	1.60	1.69	1.84	1.58
IGCC	1.35	1.39	1.52	1.33

Data Sources: MIT (2007), Lowe (2005), AEP (2005), Childress (2005)

However, carbon capture is only part of the story. Transportation and storage (sequestration) are the other two vital components of CCS (carbon capture and sequestration). To date, there is no commercial power plant (of any energy source, not just coal) that uses integrated CCS anywhere in the world²³, although there are a few “pilot” plants with integrated CCS technologies, FutureGen (FutureGen 2008a) being one of them. Ocean injection and geosequestration (storage in deep saline formations) are two

²² GTC is Lowe (2005), AEP is AEP (2005), GE is Childress (2005), see References

²³ For example, see “Laura Miller’s clean coal plant seeks stimulus funding” by Elizabeth Souder, published on September 25, 2009 in the Dallas Morning News, website:

<http://energyandenvironmentblog.dallasnews.com/archives/2009/09/laura-millers-clean-coal-plant.html>

possible options for storage of enormous quantities of CO₂ (Herzog 2001). However, there are still questions remaining to be answered regarding the environmental and safety aspects of these options. For ocean injection, there are concerns that perturbations in the pH (acidity) level may have adverse consequences for deep-sea ecosystems and for global biogeochemical cycles (Seibel and Walsh 2001). For geosequestration, safety is a concern because leaked CO₂ can cause suffocation at high concentrations (Herzog 2001). Although there are a handful of non-integrated CO₂ geosequestration projects in the world, the technology is still at its infancy. There is also a degree of uncertainty regarding the geo-storage capacity for CO₂ (Bradshaw 2007). Carbon transportation through pipelines is a more mature technology – it has been commercially used to transport CO₂ for enhanced oil recovery (Parfomak and Folger 2007). However, because of the geographic distribution of coal-fired power plants (see Figure 16 below), a vast network of pipelines will need to be built. For these reason, the study by MIT (2007) concedes that the “estimate of CCS cost (including transportation and storage) is uncertain”.

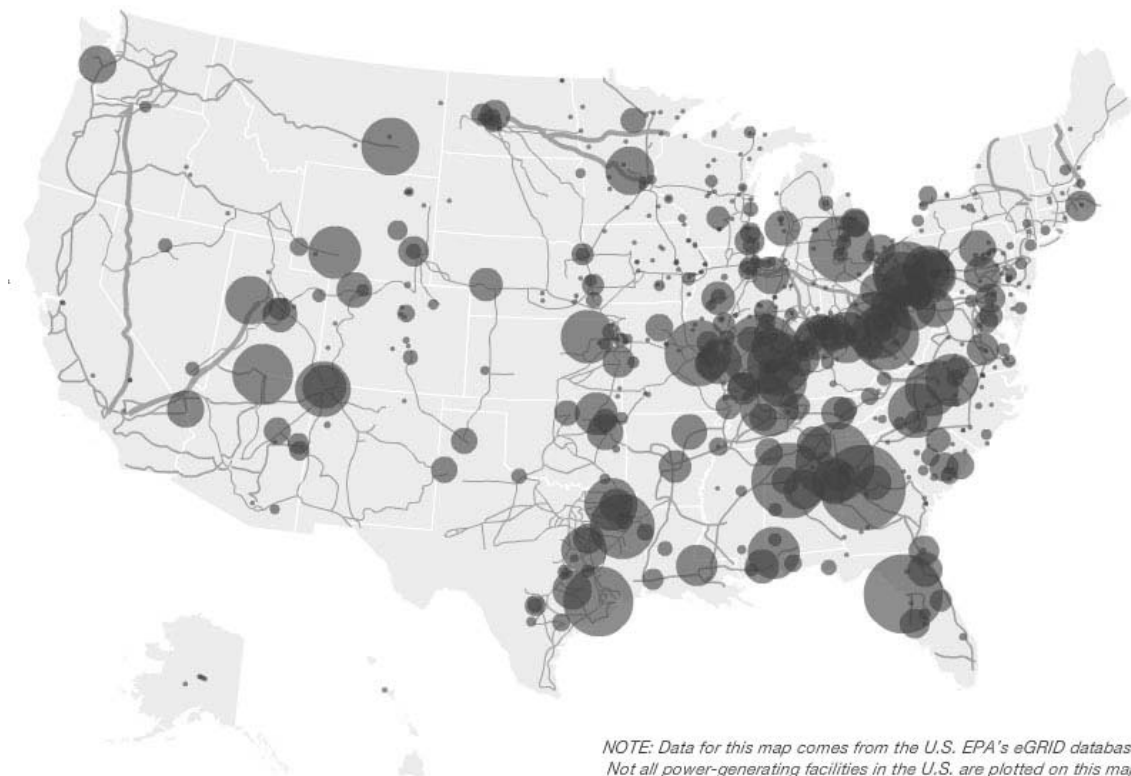


Figure 16: Geographic Distribution of Coal-fire Power Plants in the United States²⁴

These facts reinforce my discussion in the previous section about the Knightian uncertainty nature of CO₂. Because IGCC is already a superior technology compared with conventional technologies when the FCOE (including externality costs of criteria pollutants but excluding costs of CO₂) is taken into account, and IGCC plants can be refitted with CCS cheaply than other types of power plants, IGCC emerges as an even stronger candidate for the technology to be used in future coal-fired power plants. It can be used as an efficient technology to produce electricity *and* an insurance policy against the uncertainty about global warming and CO₂. And because of the uncertainty in the

²⁴ This was captured from the interactive site on the National Public Radio's website (<http://www.npr.org/templates/story/story.php?storyId=110997398>) on 09/26/2009, the data for the map came from the U.S. EPA's eGRID database, size of circles indicate power plant capacity.

transportation and storage of CO₂, the case for “staggered refreshing” of current fleet of coal-fired power plants with IGCC-based plants becomes even more compelling – the optimal path should be to start replacing aging plants with IGCC (or comparable technology) based plants (but initially without CO₂ capture). Then, as we gain more knowledge about the effects of global warming and CO₂, and as CO₂ transportation and storage technologies mature, we can equip them with devices for CO₂ capture if necessary.

6. FutureGen – The Future of Coal or a Misguided Experiment?

The FutureGen project is a joint project by the U.S. Department of Energy and several private companies, including U.S. companies such as Peabody Energy and Peabody, and foreign companies such as China Huaneng Group and Anglo American Services of the U.K (FutureGen 2008b) to demonstrate how IGCC-based coal-fired power plants can be used to generate electricity with near-zero emissions. It was announced in 2003 by President George W. Bush and is touted as “a first-of-its-kind coal-fueled, near-zero emissions power plant” (USDOE 2009a). However, the FutureGen project has seen a faltering start since its inception. Due to rising costs, several partner companies started dropping out of the alliance²⁵ and in January 2009, the DOE decided to drop support for the project²⁶.

²⁵ Reuters: UPDATE 2-AEP, Southern pull out of FutureGen project, Jun 25, 2009, website: <http://www.reuters.com/article/bondsNews/idUSN2529464020090625>

²⁶ Reuters: U.S. drops support for clean coal plant: lawmaker, Jan 29, 2008, website: <http://uk.reuters.com/article/environmentNews/idUKN2962235220080129?sp=true>

With the inauguration of the Obama Administration, the FutureGen project has regained some life. On the DOE website, Dr. Steven Chu, the new Secretary of Energy, claims that “The FutureGen project holds great promise as a flagship facility to demonstrate carbon capture and storage at commercial scale” (USDOE 2009a). Despite the rosy outlook, however, the DOE and the FutureGen Alliance are still debating whether to continue with this project and “will make a decision either to move forward or to discontinue the project early in 2010” (USDOE 2009b).

Aside from the politics behind FutureGen (which I shall discuss in the next chapter), what can we say about its economics after the analyses I have done in this chapter? As I have shown, the optimal path to upgrade the current fleet of coal-fired power plants is a two-step “staggered refreshing” approach (converting older plants to IGCC based plants first, and equip them with CCS later). Because there are already a few commercial IGCC plants in existence, the FutureGen project should follow the two-step approach and demonstrate how an IGCC plant without CCS can be converted to one equipped with CCS. In addition, although IGCC plants can be refitted with CO₂ capture more cheaply than PC type plants, the refitting is not costless and will require some changes to the plants (MIT 2007, Chapter 3). Therefore, FutureGen should be used as a platform to research how to lower the cost of equipping IGCC plants with CO₂ capture, or to even experiment with new design paradigms that will make CO₂ capture a “plug-and-play” add-on to IGCC plants. Because of the Knightian uncertainty with CO₂, such an approach would allow us to formulate a strategy to deal with an uncertain future. The current FutureGen project takes the “harmful effects” of CO₂ as a foregone conclusion

and makes CCS its foremost priority (and in doing so fails to control cost and reaches an economic dead end); this completely ignores the Knightian uncertainty with CO₂. In this respect, the FutureGen is a misguided (and costly) experiment.

7. Conclusion

Modern clean coal technologies, especially IGCC, can be used to reduce criteria pollutants emissions. When the externality cost of criteria pollutant emissions is taken into consideration, IGCC plants can generate electricity more cheaply than coal-fired power plants based on PC designs. A high percentage of current fleet of coal-fired power plants is operating beyond their normal life expectancy. The economically optimal path is to replace aging plants with IGCC plants in a “staggered” fashion – that is, to replace a few in a given time period. When CO₂ capture is taken account, the superiority of this “staggered refreshing” approach seems reinforced because IGCC plants can be refitted for CO₂ capture more cheaply than PC-type plants. Based on a Knightian (Knight 1921) framework of risk and uncertainty, CO₂ and global warming are an uncertainty, and not a risk, and because of the uncertainty about the cost of CO₂ transportation and storage, the optimal path should be to replace aging coal-fired power plants with IGCC plants (or plants with comparable technologies) but without CO₂ capture first, then in the future refit them with CO₂ capture (if necessary) as we deepen our understanding of CO₂ and global warming. The FutureGen project does not follow this optimal path and appears to be a misguided experiment.

Chapter 5: Obstacles to the Large-scale Deployment of Clean Coal Technologies

1. Introduction

In Chapter 4, I investigated Clean Coal technologies and concluded that modern Clean Coal technologies such as IGCC are available and maturing. Coal-fired power plants equipped with these technologies are able to produce electricity at lower full cost (inclusive of externality cost) than plants with older design, mostly of the pulverized coal type. I also pointed out that the optimal approach to deploy Clean Coal technology is a “staggered refreshing” approach, that is, to replace older plants that are near or at the end of their lifecycle with plants equipped with these new technologies.

But this optimal path is not being adopted. We observe that there are currently very few IGCC coal-fired power plants in the U.S. (Chapter 4, Table 6), while at the same time a large percentage of coal-fired power plants are operating beyond their typical life expectancy (Chapter 4, Figure 13). How can we explain this reality of a sub-optimal outcome?

In the United States, the Clean Air Act (CAA) is the legislation that regulates air pollutants. Properly designed and enforced air pollution legislations are supposed, through either direct regulation, taxes, or cap-and-trade mechanisms, force polluters to internalize the externality costs of pollutions. The reality is of course far from perfect: the

CAA and related legislations are enacted by politicians and enforced by bureaucrats. These politicians and bureaucrats have their own interests which may not always be consistent with economically efficient outcome and may introduce inefficiencies to such legislation. I shall investigate the motives and behavior of politicians and bureaucrats in the next chapter; in this chapter, I shall first focus my attention on the following questions: What are the obstacles that have prevented or will prevent Clean Coal technologies from being deployed at a large scale? The analysis in this chapter is grounded in economic efficiency, and the focus is the obstacles that prevent the economic efficient outcome from being achieved. Once I have identified these obstacles, I can then turn my attention to the next puzzle (which I shall investigate in the next chapter): What is the institutional framework and who are the individuals that are responsible for the creation of these obstacles? Only when the questions presented in this chapter and the next are answered, can a clear picture of the political economy of Clean Coal emerge.

2. New Source Review (NSR) Program under the Clean Air Act

In the United States, the Clean Air Act²⁷ is the statutory law that is the basis for all air pollution regulations. Regulations governing coal-fired power plant emissions all fall under the regulatory authority of the CAA. A detailed analytical history and a comprehensive economic evaluation of the CAA are not only beyond the scope of this dissertation, but would also detract from the focus of my study: the political economy of

²⁷ see: <http://epw.senate.gov/text/envlaws/cleanair.pdf>

Clean Coal. Therefore, I shall focus on the part of the CAA that is most relevant to Clean Coal.

The 1977 Clean Air Act Amendment established the New Source Review (NSR) program, which requires that “new major sources or major sources making a major modification” “do not significantly worsen air quality” (USEPA 2009a). The initial justification for the NSR is that applying the new standards to all existing source of pollution would be ruinously expensive (Hayward, 2003) and would inevitably have met strong resistance from industries. As a result, Congress put the vague language of excluding from the regulation facilities that go through “routine maintenance” instead of “substantial modification”, the precise definitions of either phrases never clearly defined. To further complicate matter, there is also the distinction of “Attainment Areas” (areas that have good air quality and air pollution levels that are lower than the national air quality standard) and “Nonattainment Areas” (areas that need to improve air quality because air pollution levels exceed the national air quality standard). A facility owner who wishes to make modifications to his facility may need to apply for one of the following permits (USEPA 2009b):

1. PSD (Prevention of Significant Deterioration) permits which are required for new major sources or a major source making major modification in an attainment area
2. NNSR (Nonattainment New Source Review) permits which are required for new major sources or major sources making a major modification in an nonattainment area

3. Minor source permits which are required for minor pollution sources, the standard of which can vary from state to state as it is customized by each permit agency as part of the SIP (State Implementation Plan) program.

From an economic perspective, the NSR creates a perverse incentive for facility owners to prolong the life of existing facilities since they do not have to meet the more stringent standards imposed on new sources. In the extreme, instead of tearing down a plant and building a new one (an event that would trigger NSR and require the installation of pollution-control equipment), a plant owner can rebuild a plant piece-by-piece, gradually changing the plant, but without ever triggering NSR and without ever installing pollution-control equipment (Hsu 2006).

Several empirical studies confirm the existence of such perverse incentives. Maloney and Brady (1988) use data on electricity generators nation-wide to examine capital turnover in electric utility generating capacity and find significant slowdown in capital turnover after the implementation of the new-source standards, and conclude that NSR actually increased the level of air pollution from the industry. List et. al. (2004) examine more than 2500 plant-level modifications and more than 2200 closures of electric utilities and find that NSR retards modification rates, while having virtually no effect on the closure of existing dirty plants. Thus, they also conclude that the NSR “has led to *more*, rather than less, pollution” (emphasis original).

Cruenspecht and Stavins (2002) argue that because NSR discourages companies from maintaining their existing facilities, wastes resources and retards environmental progress, it should be replaced with more effective and efficient environmental policies.

The solution proposed by Cruenspecht and Stavins is to cap total pollution emissions and use an allowance trading system so that if the owner of facilities increases emission at one plant (through either “major” or “minor” modification), he can offset it by reduction at another plant (in a more cost-effective manner), or by purchasing more permits from other plant owners. This way, the market mechanism will ensure that the emission goals are achieved at the least cost. John and Paddock (2003) go even further to suggest that an emissions cap-and-trade system is the “surprising consensus” among economists.

The fact that NSR excludes existing sources from the more stringent regulations imposed on new sources constitutes a “grandfathering” clause (Nash and Revesz 2007). Even if we concede that grandfathering has its justification under certain circumstances such as when installing and upgrading pollution control equipment in existing plants are both logistically difficult and expensive, there is no justification to expand it, as the EPA regulations do. Existing plant owners can modify these plants piece-by-piece, bypassing the more stringent rules imposed on new plants, but new entrants still have to comply with the more stringent rules. It is little wonder that industries have always preferred such direct regulations, as Buchanan and Tullock (1975) demonstrate in their seminal paper. Thus, the true nature of grandfathering is a transfer payment to those with grandfathered plants from those who lack them (Hsu 2006). The indefinite extension of grandfathering under the current NSR rules is a major loophole that not only creates the disincentive, but also perpetuates it. A sensible approach is to offer a reasonable amortization period to preexisting plants to allow them to comply with current environmental standards (Nash and Revesz 2007).

The cost of the NSR program does not just stop here. Because of the vague language of the Clean Air Act regarding “routine maintenance” and “substantial modification”, NSR has always been a hotbed for litigations. In 1999 alone, the EPA sued owners of 46 plants for NSR violation (Keohane, et. al. 2009). When determining what constitutes RMRR (routine maintenance, repair and replacement) exclusions, Courts have also been inconsistent in determining these lawsuits, sometimes looking to industry practice for guidance, sometimes basing such decisions on EPA’s practices and policies (Hsu 2006). But one thing the courts agree is that applying the NSR rules “entails a fact-intensive, case-by-case determination” (ibid). Such bureaucratic review and litigation inevitably increases the enforcement and compliance costs of NSR, not to mention further delaying capital turnover.

If bureaucratic review and litigation represents the direct costs of enforcement and compliance, the hidden costs of regulatory uncertainty may be even greater. As Douglass North (1991) points out, one major benefit of political institutions is to create order and reduce uncertainty in exchange. Conversely, regulatory uncertainty often leads to foregone production (North, 1993). The *ad-hoc* nature of the NSR process introduces just this kind of uncertainty, which is further complicated by the litigations and the courts’ inconsistent rulings. Now not only do plant owners have to invest time and effort to see how they can cloak expansion of plant capacity under the guise of “routine maintenance”, they also have to invest time and effort to strategize how their applications get through the lengthy bureaucratic review process and how to avoid getting themselves involved in

litigations – all these activities can only take away their time and effort from truly welfare enhancing technological innovations.

Finally, the NSR itself is a source of political contention. For instance, in 2002 and 2003, the Bush Administration sought to extend the grandfathering of old plants by reducing the number of modifications that are subject to NSR rules, and by granting a “safe harbor” for plant modifications of grandfathered plants that cost less than twenty percent of the replacement cost of the unit (Nash and Revesz 2007). These rules, especially the “safe harbor” rule, would make it even easier for owners of grandfathered plants to replace such an aging plant piece-by-piece (as long as each piece is less than 20% of the cost of replacing the entire plant) while bypassing NSR. In 2006, the State of New York, joined by several other states and cities as well as environmental groups, challenged such rule at the United States Court of Appeals for the District of Columbia Circuit in a case known as *New York v. EPA*²⁸. On March 17, the D.C. Circuit Court ruled to invalidate the twenty percent safe harbor rule. The EPA subsequently filed *writs of certiorari* (petition for rehearing) at the Supreme Court, which was eventually denied on April 30, 2007²⁹. This is, of course, just one of the many cases that illustrate how NSR has become a source of political contention. The manipulations of the rules by the administration and the subsequent litigations all entail political costs. Additionally, because the regulation is subject to manipulation by the executive branch, it is in the interest of coal-fired power plant owners to seek political favor to modify the regulation

²⁸ 443 F.3d 880 (D.C.Cir.2006), *cert. denied*, 127 S. Ct. 2127 (2007), see:

<http://files.findlaw.com/news.findlaw.com/wp/docs/epa/nyepa31706opn.pdf>

²⁹ see: http://supreme.lp.findlaw.com/supreme_court/orders/2006/043007pzor.html

in their favor. This diversion of effort from economic innovation to rent-seeking will inevitably lead to reduced social welfare.

Thus, the first obstacle to the large-scale deployment of Clean Coal technologies that we identify is the NSR program under the CAA. The NSR program creates perverse incentives, retards innovation, incurs high political cost and creates regulatory uncertainty, thus it reflects a political failure. To deploy Clean Coal technologies at a large scale, the NSR program needs to be reformed – and the consensus among economists is to replace it with a cap-and-trade program for criteria pollutants.

3. Regulation of Greenhouse Gases (GHG)

The CAA and its various amendments charge the EPA with regulating “any air pollutant (section 302(g) of the CAA). The exact language of section 302(g) of the CAA is quite important to the discussion here, so I display it here in its entirety:

The term “air pollutant” means any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air. Such term includes any precursors to the formation of any air pollutant, to the extent the Administrator has identified such precursor or precursors for the particular purpose for which the term “air pollutant” is used.

So if the EPA were to establish authority on regulating a chemical agent that is emitted into or enters the ambient air, it must prove that such chemical agent is in fact a pollutant, or a precursor to the formation of any air pollutant. As early as 1998, the EPA (1998) published a memorandum (known as the "Cannon Memo" for it was written by the then-EPA general counsel Jonathan Cannon to the then-EPA administrator Carol Browner) on its regulatory authority on CO₂. The Cannon Memo uses the language in section 302(g) of the CAA to conclude that CO₂ is in fact an air pollutant under the regulation of CAA.

The justification in the Cannon Memo is worth considering here so I also show it below:

This broad definition states that "air pollutant" includes any physical, chemical, biological, or radioactive substance or matter that is emitted onto [sic] or otherwise enters the ambient air SO₂, NO_x, CO₂, and mercury from electric power generation are each a "physical [and] chemical... substance which is emitted into . . . the ambient air," and hence, each is an air pollutant within the meaning of the Clean Air Act.

But the logic in the Cannon Memo is flawed. It clearly establishes CO₂ as a *substance* emitted into the ambient air, but to prove that it is a *pollutant*, it is incumbent on the EPA to find it is harmful to public welfare. By lumping CO₂ together with SO₂, NO_x and mercury, the Cannon Memo hastily draws the conclusion that it is an air pollutant. The next paragraph of the Cannon Memo then goes on to discuss that the EPA does regulate pollutants that are naturally present in the air, etc., but it takes as a foregone

conclusion that CO₂ is an air pollutant. The Cannon Memo concludes by stating that “the Administrator has made no determination to date to exercise that authority under the specific criteria provide under any provision of the Act”. Thus the Cannon Memo, with its ambivalent language, defines CO₂ as a pollutant but declines to actually regulate it.

At this point it is worth considering the implication of the Cannon Memo. As I demonstrated in Chapter 3, CO₂, at high concentration, will indeed cause harmful effects to human health. But the concentration of CO₂ in the atmosphere is nowhere near that level. When discussing the harmful effects of atmospheric CO₂, the only effect is its hypothesized potential to cause global warming. But as I discussed in Chapter 1 and Chapter 3, there exists a considerable degree of “theoretical certainty” about the *extent*, *cause* and *effect* of global warming, and especially the role CO₂ plays in causing it. This situation is vastly different from other pollutants, such as SO₂, NO_x and mercury (also see Chapter 3), as there is very little theoretical uncertainty about their harmful effects and consequently little doubt whether they fall into the jurisdiction of the CAA (whether these regulations are economically efficient is a different matter). It is, then, incumbent on the EPA to prove that the CO₂ is a pollutant before it can establish its authority on regulating it. By sidestepping this question, the Cannon Memo left the door open for the subsequent debates and lawsuits over whether the EPA should regulate CO₂.

Sure enough, not long after the publication of the Cannon Memo, in 1999, the International Center for Technology Assessment (ICTA) submitted a petition to compel the EPA to regulate GHG (International Center for Technology Assessment, undated). In 2003, the EPA published a Notice of Denial of this petition (USEPA 2003). The EPA’s

position in this Notice of Denial is actually a reversal of its position articulated in the Cannon Memo: this time, it declined to regulate GHG emissions because they were beyond their statutory authority under the CAA so in effect the EPA denied that CO₂ is an air pollutant this time (see Sugar 2007). But by this time, the train of regulating GHG (and especially CO₂) had already been set in motion. In the same year, the ICTA, Sierra Club, several other environmental groups, 14 U.S. states and territories including Massachusetts and California, and 3 cities jointly sued the EPA in what is known as “*Massachusetts et. al. v. EPA*”³⁰. Although the contention in “*Massachusetts et. al. v. EPA*” is whether the EPA has authority to regulate GHG from motor vehicles, once the precedence is established on regulation of GHG, it will be only a matter of time before such regulations extend to other sources of GHG and CO₂ emissions such as coal-fired power plants. Thus this case is worth considering here in detail.

The questions presented in “*Massachusetts et. al. v. EPA*” are:

1. Whether the EPA Administrator properly exercised his discretion not to issue carbon dioxide emission standards for new motor vehicles under section 202(a)(1) (of the CAA)
2. Whether the EPA Administrator has authority to regulate carbon dioxide and other air pollutants for climate change purposes under section 202(a)(1) (of the CAA)

And there is the implicit question whether the petitioner has standing (a legal term meaning whether the complainant has suffered an injury in fact or fairly traceable to the challenged action). The EPA challenged the petitioner’s standing in this case.

³⁰ 127 S. Ct. 1438 (2007), website: <http://www.supremecourtus.gov/opinions/06pdf/05-1120.pdf>

On September 13, 2005, The U.S. Court of Appeals for the District of Columbia Circuit upheld the decision of EPA³¹. In its ruling, the Appellate Court stressed the uncertainty in our “current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gasses”, citing data from the National Research Council, and that this uncertainty “is compounded by the possibility for error inherent in the assumptions necessary to predict future climate change” – a finding consistent with what I discussed in Chapter 1 and Chapter 3. The Appellant Court then went on to rule that the language in section 202(a)(1) of the CAA gives the EPA “policy judgments” as to whether to regulate an air pollutant or not.

It is interesting to read Circuit Judge Sentelle’s dissenting opinion (dissenting in part and concurring in the judgment), in which he stresses that the plaintiffs lacked “particularized injury”, thus did not have standing, and concluded that the case should be dismissed outright. In my opinion, Judge Sentelle’s opinion is correct. This is not to say we know for certain that GHG do not cause harmful effects – they may or may not and that is why more research is needed to eliminate the theoretical uncertainty; but from a legal standpoint, the plaintiffs in “*Massachusetts et. al. v. EPA*” had not *demonstrated* that they had suffered injury. The burden of proof should not be speculative and rests on the plaintiffs.

The case was appealed to the U.S. Supreme Court. On April 7, 2007, The United States Supreme Court decided narrowly (with a vote of 5-4) to reverse the appellate court’s decision. The Supreme Court decided that although “[t]hat climate-change risks

³¹ see: <http://pacer.cadc.uscourts.gov/docs/common/opinions/200507/03-1361a.pdf>

are “widely shared” does not minimize Massachusetts’ interest in the outcome of this litigation’, thus the plaintiff’s injury is concrete and particularized. The Supreme Court ruled that “[u]nder the clear terms of the Clean Air Act, EPA can avoid taking further action only if it determines that greenhouse gases do *not* contribute to climate change or if it provides some reasonable explanation as to why it cannot or will not exercise its discretion to determine whether they do” (emphasis added), and found EPA’s denial to regulate GHG to be “arbitrary, capricious, . . . or otherwise not in accordance with law.”³² Thus, in the Supreme Court’s ruling the burden of proof is entirely reversed: the EPA ought to regulate any substance unless it can explain why such substance does not cause harm. The Supreme Court’s ruling in *Massachusetts et. al. v. EPA* disregards the Knightian uncertainty in our understanding of global warming and GHG (see Chapter 4), is logically flawed and on dubious legal ground with respect to the plaintiff’s standing in this case.

The Supreme Court’s decision on *Massachusetts et. al. v. EPA* is a watershed moment in the history of air pollution regulation because it paves the way for the EPA to regulate GHG under the CAA. This will have a profound and lasting impact on our economic lives for decades to come. The sheer amount of GHG – 7,182,600,000 tons of CO₂ equivalent (USEIA 2009) compared with 13,273,080 tons of SO₂ for the year 2005 (USEPA 2009c)³³, a difference of more than 500 times – and the innumerable sources of GHG emissions suggest that the regulation of GHG will most certainly overwhelm the regulatory system. As I argued in the previous section, one of the major obstacles to the

³² see: <http://www.supremecourt.us/opinions/06pdf/05-1120.pdf>

³³ The year 2005 is used here because USEPA 2009c reports 2005 SO₂ emission numbers

large-scale deployment of Clean Coal technologies is the NSR under the CAA, which needs urgent reform. The expansion of the EPA's regulatory authority over GHG will likely lead to the delay of NSR reform or the expansion of the EPA itself, or both. Thus, the regulation of GHG is another obstacle to the large-scale deployment of Clean Coal technologies.

The far-reaching nature of *Massachusetts et. al. v. EPA* extends beyond just the regulation of GHG. It also sets a precedence for future lawsuits, including tort cases. To understand this, we note that although *Massachusetts et. al. v. EPA* itself is not a tort case but an administrative case, the history of the Clean Air Act is intertwined with tort cases from the beginning. The Clean Air Amendments of 1970 authorize "citizen suits" to allow any citizen to bring lawsuits against any polluters or the EPA for failing to perform "nondiscretionary" duties (Melnick 1983). Traditionally, for a tort case to succeed under classic common law, there had to be a breach of duty owed to the plaintiff by the defendant, harm suffered by the plaintiff, and proximate cause (Tulloch 1997). The common law system, eroded as it is, has been utilized by rent-seekers to specifically target the deep pockets (ibid.). The rule on *Massachusetts et. al. v. EPA* effectively lowers the bar on the definition of "harm" and will predictably encourage future tort suits against GHG emitter and further "fire the engines" of the rent-seekers (ibid). Indeed, several tort cases have already been filed, including *Comer v. Murphy Oil USA, et al*³⁴, filed by residents along the Mississippi Gulf against GHG emitting corporations for property damage caused by Hurricane Katrina, and in establishing standing the Fifth

³⁴ No. 07-60756 (5th Cir. Oct. 16, 2009), see: <http://www.ca5.uscourts.gov/opinions/pub/07/07-60756-CV0.wpd.pdf>

Circuit Court of Appeals cited the Supreme Court's embrace of the causal link (of GHG emissions to damage) in *Massachusetts et. al. v. EPA* (Hester and Armstrong 2009) despite the fact that the causal link from GHG to the occurrences of hurricanes is never scientifically proven. It is still too early to be certain, but it appears that the ominous cloud of GHG emission related lawsuits is growing ever darker.

Finally, although the EPA has not implemented any GHG emission enforcement yet, rumors have already been swirling that the EPA will use its old trick of grandfathering again with GHG (especially CO₂) regulations³⁵. These are only rumors. But based on the EPA's history of using the grandfathering scheme in the case of the NSR (Hsu 2006), it would not be surprising if this turned out to be true. If so, then old, aging plants will continue to be grandfathered and to be exempted from newer regulations, whereas new plants will be subject to the more stringent new standards and undergo lengthy bureaucratic review. The combination of NSR with GHG regulation would thus compound the problems and further delay the large-scale deployment of Clean Coal technologies.

4. Summary and Conclusion

In this chapter I identify two obstacles to the large-scale deployment of Clean Coal technologies: the EPA's New Source Review (NSR) program and the regulation of greenhouse gases (GHG). The first obstacle, NSR, has been in place for years and is a primary reason why Clean Coal technologies have not been widely deployed. The

³⁵ for example, see: <http://www.ohioenvironmentallawblog.com/2009/08/articles/climate-change/rumors-swirl-that-epa-may-apply-new-source-review-to-sources-of-greenhouse-gases/>

consensus among economists is that it needs reform and should be replaced with a cap-and-trade program for criteria pollutants.

The second obstacle, the regulation of GHG, is just under way, but looms large over the horizon. The sheer amount of GHG emissions and number of emission sources imply that the regulation of GHG will overwhelm the regulatory system and delay the reform of NSR, or even push it off the table completely. Because there is still a considerable degree of theoretical uncertainty regarding the effects of GHG (Chapter 4), the regulation of GHG should only be considered when the more real and urgent issues of criteria pollutant emissions are resolved. In Chapter 4, I point out that the optimal path to the large-scale deployment of Clean Coal technologies is a “staggered refreshing” approach, that is, to replace older plants which are near or at the end of their lifecycle with plants equipped with new Clean Coal technologies. In addition, coal-fired power plants equipped with IGCC or comparable technologies have the potential of being modified for carbon capture and sequestration at lower costs. Therefore, the optimal path is to reform the NSR, to address the problems with criteria pollutants, while at the same time still further researching the effects of GHG. Then, within a decade or two, we shall have power plants equipped with state-of-the-art Clean Coal technologies and a deeper understanding of the effects of GHG. These technologies and the deepened understanding of global warming and GHG will enable us to solve the problem with GHG emissions in an efficient manner – that is, if we actually find GHG emissions to be a problem.

This optimal approach is based on the criteria of economic efficiency. In reality, we cannot ignore the political aspect of our society. In this chapter I have highlighted that the

obstacles to the large-scale deploy of Clean Coal technologies are the results of political failures. In the next chapter, I shall investigate what caused these political failures and who are the players responsible for such political failures.

Chapter 6: The Political Economy of Clean Coal

We measure men, not by what they say they believe, not by what they say they feel, not by what they say they are going to do, but by what they do. That is the test.

– Lyman Abbott, *The Test of Character*

1. Introduction – Following the Money

In Chapter 5 I identify two obstacles to the large-scale deployment of Clean Coal technologies: the New Source Review (NSR) program under the Clean Air Act, and the impending regulation of greenhouse gases (GHG) emissions. The next questions that we pose are: What, and who, created these obstacles in the first place? And, more importantly, how do we remove these obstacles through institutional reform and achieve the goal of large-scale deployment of Clean Coal technologies?

I start with a concrete example, and with this example I reveal the players and institutional framework that have led us to the present situation. In June, 2008, the Senate voted on whether to invoke cloture (i.e. end debate) on the Boxer substitute to S.3036, the Lieberman-Warner Climate Security Act, a bill that would establish a GHG cap-and-trade program and other measures to reduce U.S. GHG emissions (U.S. Senate 2008). Had the motion passed, the Senate would have moved to a post-cloture debate on the bill, followed by a vote on the substitute itself. The motion did not pass – it received only 48

votes, with 36 voting against, falling short of the 60 votes required to invoke cloture. But it can be viewed as the Senators' position on the GHG cap-and-trade program.

We shall ask then: how do Senators make their decisions on their voting in this motion? What are the factors that affect their decision making?

The Center for Responsive Politics (2009a, 2009b, 2009c, 2009d) lists campaign contribution data for election cycles. Since the above-mentioned voting took place in June 2008, and since Senate elections are held every two years (although, since the term of a Senator is six years, not every Senator faces reelection in each election cycle), I include the campaign contributions for the election cycle at the time and the most recent cycle prior to the voting, namely, the 2008 and 2006 election cycles, in my analysis. Because of the nature of the GHG cap-and-trade program (that it concerns the environment and affects the energy, especially fossil fuel, industry), two groups of contributors, environment groups and the energy and natural resources sector, are of particular interest. These contribution data are listed in Table 12 below under the headings of "2008 Environment" (which lists campaign contributions from environmental groups for the 2008 election cycle) and so on.

Table 12 also lists each Senator's voting position, party affiliation and home state. Also listed in Table 12 is whether a Senator is from a major coal producing state (under the heading "Major Coal State"). The coal producing state information is obtained from the USDOE website (USDOE 2003), which lists the following states as "major coal producing states": Arizona, Alabama, Colorado, Illinois, Indiana, Kentucky, Montana,

New Mexico, North Dakota, Ohio, Pennsylvania, Texas, Utah, Virginia, West Virginia, and Wyoming.

Table 12: Senator Voting Records on the Boxer substitute to the Lieberman-Warner Climate Security Act

Senator	Vote	Party	State	Major Coal State	2008 Environ. (\$)	2006 Environ. (\$)	2008 Energy (\$)	2006 Energy (\$)
Akaka	Y	D	HI	N	0	10	1000	26300
Alexander	N	R	TN	N	500	0	223450	28600
Allard	N	R	CO	Y	0	0	0	12878
Barrasso	N	R	WY	Y	0	0	351700	0
Baucus	Y	D	MT	Y	18950	0	414778	150098
Bayh	Y	D	IN	Y	0	0	2750	95550
Bennett	N	R	UT	Y	0	0	16000	32750
Bingaman	Y	D	NM	Y	0	16001	28000	401667
Bond	N	R	MO	N	0	0	61300	-1071
Boxer	Y	D	CA	N	56900	5200	63450	1400
Brown	N	D	OH	Y	0	0	31700	0
Brownback	N	R	KS	N	0	0	119465	4700
Bunning	N	R	KY	Y	0	0	14500	7750
Burr	N	R	NC	N	2300	0	71850	65400
Cantwell	Y	D	WA	N	0	0	24600	101575
Cardin	Y	D	MD	N	0	0	10000	0
Carper	Y	D	DE	N	0	0	10930	96195
Casey	Y	D	PA	Y	0	0	20600	0
Chambliss	N	R	GA	N	0	0	540405	47350
Coburn	N	R	OK	N	0	0	2800	12350
Cochran	N	R	MS	N	2300	0	127800	15200
Collins	Y	R	ME	N	17400	0	183600	3000
Corker	N	R	TN	N	0	0	111882	0
Crapo	N	R	ID	N	0	0	15980	17844
Dodd	Y	D	CT	N	5250	2100	140400	23400
Dole	Y	R	NC	N	0	0	365168	16550
Domenici	N	R	NM	Y	0	0	278750	193250
Dorgan	N	D	ND	Y	0	0	151750	18925
Durbin	Y	D	IL	Y	20660	0	149700	18250
Ensign	N	R	NV	N	0	0	0	135839
Enzi	N	R	WY	Y	0	0	186150	15000
Feingold	Y	D	WI	N	900	900	15275	11000
Feinstein	Y	D	CA	N	0	32600	29500	107775
Grassley	N	R	IA	N	0	0	69150	42980
Hagel	N	R	NE	N	0	0	46060	15800

Table 12 (continued)

Senator	Vote	Party	State	Major Coal State	2008 Environ. (\$)	2006 Environ. (\$)	2008 Energy (\$)	2006 Energy (\$)
Harkin	Y	D	IA	N	13065	250	115752	9450
Hatch	N	R	UT	Y	0	0	14500	223550
Hutchison	N	R	TX	Y	2300	2933	138850	438519
Inhofe	N	R	OK	N	0	0	726404	135200
Inouye	Y	D	HI	N	0	0	17500	1000
Isakson	N	R	GA	N	0	0	37150	7090
Johnson	N	D	SD	N	5800	0	199580	41821
Kerry	Y	D	MA	N	18920	0	44700	2580
Klobuchar	Y	D	MN	N	0	0	31500	0
Kohl	Y	D	WI	N	0	0	0	1300
Kyl	N	R	AZ	Y	0	0	8500	387764
Landrieu	N	D	LA	N	0	250	516493	124910
Lautenberg	Y	D	NJ	N	18403	0	111300	38250
Leahy	Y	D	VT	N	6200	250	3750	3000
Levin	Y	D	MI	N	23095	0	119204	9200
Lieberman	Y	I	CT	N	0	36700	-250	444248
Lincoln	Y	D	AR	N	0	0	113100	10750
Lugar	N	R	IN	Y	0	6700	3425	115395
Martinez	Y	R	FL	N	0	0	31700	49095
McCaskill	Y	D	MO	N	900	0	26700	0
McConnell	N	R	KY	Y	0	0	794350	208300
Menendez	Y	D	NJ	N	750	29900	54200	194950
Mikulski	Y	D	MD	N	1000	0	19500	14500
Murray	Y	D	WA	N	1250	7300	84050	12450
Nelson	Y	D	FL	N	4150	58255	0	137630
Nelson	Y	D	NE	N	0	1500	17000	222249
Pryor	Y	D	AR	N	0	0	197985	54102
Reed	Y	D	RI	N	4560	0	23750	1200
Reid	Y	D	NV	N	6850	0	102450	10500
Roberts	N	R	KS	N	0	0	281671	30250
Rockefeller	Y	D	WV	Y	44700	0	263050	20150
Salazar	Y	D	CO	Y	0	1700	171688	35059
Sanders	Y	I	VT	N	0	0	1000	0
Schumer	Y	D	NY	N	0	0	0	0
Sessions	N	R	AL	Y	2000	0	285021	8950
Shelby	N	R	AL	Y	2300	0	6000	1000
Smith	Y	R	OR	N	4600	0	353729	94200
Snowe	Y	R	ME	N	0	9400	-1000	79750

Table 12 (continued)

Senator	Vote	Party	State	Major Coal State	2008 Environ. (\$)	2006 Environ. (\$)	2008 Energy (\$)	2006 Energy (\$)
Stabenow	Y	D	MI	N	0	25310	8250	82703
Sununu	Y	R	NH	N	0	0	200400	19500
Tester	Y	D	MT	Y	0	0	3000	0
Thune	N	R	SD	N	0	0	65721	11495
Vitter	N	R	LA	N	3800	0	112950	166033
Voinovich	N	R	OH	Y	0	0	281757	74989
Warner	Y	R	VA	Y	0	0	12500	4000
Webb	Y	D	VA	Y	0	0	46500	0
Whitehouse	Y	D	RI	N	0	0	6500	0
Wicker	N	R	MS	N	2300	0	309950	0
Wyden	Y	D	OR	N	0	0	30925	1000

Data Sources: U.S. Senate (2008), Center for Responsive Politics (2009a, 2009b, 2009c, 2009d), USDOE (2003)

In order to analyze this dataset, I ran two logit regressions using the voting outcome as the dependent variable (1 = voted yes, 0 = voted no). I combined the campaign contribution amounts from environmental groups for the 2006 and 2008 election cycles into one variable, “*environment*” (in unit of \$1,000). Likewise, I combined campaign contributions from the energy and natural resources sector for the two election cycles into one variable, “*energy*” (in unit of \$1,000). A third independent variable, “*from_coal*”, is a dummy variable indicating whether the Senator is from a major coal producing state or not. For the first regression, I used these three independent variables. For the second regression, I added another independent variable – a party affiliation indicator, “*democrat*”, a dummy variable indicating whether the Senator is Democrat or not. These results are shown in Table 13 below.

Table 13: Multivariate Logit Regression Results of Senator Voting Data

Independent Variable	Regression 1	Regression 2
Intercept	0.802 (0.412)*	-0.600 (0.587)
Environment Contributions (<i>environment</i>) (\$1,000)	0.268 (0.093)***	0.229 (0.113)**
Energy and Natural Resource Contributions (<i>energy</i>) (\$1,000)	-0.0059 (0.0022)***	-0.0046 (0.0025)*
From Major Coal Producing State (<i>from_coal</i>)	-1.02 (0.597)*	-1.48 (0.826)*
Democrat (<i>democrat</i>)		3.37 (0.777)***
Log Likelihood Function	-39.55	-26.08
Pseudo R²	0.3105	0.5453
Number of Observations	84	84

***: statistically significant at the 99% level

**: statistically significant at the 95% level

*: statistically significant at the 90% level

From the first regression, we see that campaign contributions exert a statistically significant impact on the Senators' voting: if a Senator receives contributions from environmental groups, he or she is more likely to vote for the motion, *ceteris paribus*. Similarly, if a Senator receives contributions from the energy and natural resource sector, he or she is more likely to vote *against* the motion. Both coefficients are statistically significant at the 99% level. The smaller magnitude of the coefficient on “*energy*” may be explained by the fact that “energy and natural resources” is a very broad category. Within this umbrella, fossil fuel intensive industries are likely to be opposed to GHG cap-and-trade legislations whereas “renewable” energy industries are likely to be for them, so

there are some canceling effects within this category. To probe this more deeply, a more detailed dataset is necessary.

The coefficient on “*from_coal*” (whether the Senator is from a major coal producing state) also has the expected sign (a Senator from a major coal producing state is more likely to vote *against* the motion), although its statistical significance is somewhat lower (significant at the 90% level). This can be explained by multicollinearity between “*from_coal*” and the other two independent variables, especially between “*from_coal*” and energy – campaign contributions from energy and natural resource industries are likely higher in major coal producing states. Nevertheless, all these coefficients are statistically significant (especially the campaign contribution variables) and have the expected sign. Based on these results, we conclude that money matters – a Senator’s decision is influenced by the amount of campaign contributions he or she receives from interest groups. Geography also matters – whether a Senator is from a major coal producing state is also a determinant on his or her voting decisions.

I run a second regression, adding another dummy variable, “*democrat*”, to indicate each Senator’s party affiliation. In this regression, we see that a Senator’s party affiliation also has a statistically significant impact on his or her voting (a Democrat is more likely to vote for the motion). It also increases the explaining power of the model (Pseudo R^2 increases). By incorporating this independent variable, the magnitude and statistical significance of the other coefficients decrease. This may also be explained by multicollinearity amongst these independent variables – a Republican Senator from a major coal producing state is likely to receive more contributions from the energy

industry, whereas a Democrat Senator from a West Coast state where environmental groups are most active (and which happen to be non-coal producing states) is likely to receive more contributions from environmental groups, and so on. Indeed the software I use to run the regression, Stata, shows correlations among these variables. In addition, there may be logrolling coalitions along party lines – in other words, party affiliation is correlated to other factors not described in this model. To fully analyze the impact of these factors, a more sophisticated model will be required and the nuances of the institutional structures must be taken into account. Nevertheless, from the analysis here, if we view the “party affiliation” dummy variable as a control variable for all these other factors, we see that the coefficients on “*environment*”, “*energy*” and “*from_coal*” are still statistically significant. Based on these findings, we cannot reject the hypothesis that “campaign contributions and geography influence Senator’s voting pattern”.

Of course, the hypothesis that legislators are self-interested utility maximizers is not new to the public choice literature (for example, see Tollison 2003). What I highlight here is that in climate legislations, this model is still applicable. This also sets the stage for my further research in this chapter. I model legislators and members of interest groups (environmental groups and industrial groups alike) as self-interested utility maximizers.

2. Legislative Market Place and the Players

As I demonstrate in the preceding section, legislators are influenced by money (usually in the form of, but not limited to, campaign contributions). There is then a legislative market place, in which the legislators act like brokers, and interest groups of different persuasion

compete against each other, trying to pass legislations that would benefit them or block legislations that would harm them. Because large, encompassing groups such as consumer groups generally lack the incentive to organize effectively (Olson 1961), legislation that passes is not necessarily economically efficient. Furthermore, the rent-seeking costs of competing interest groups are significant (see numbers I provided in the previous section) and constitute wasted resources. In equilibrium there will be significant deadweight losses.

Institutional structures also matter. In the U.S., there are two chambers in the legislature – the House of Representatives and the Senate. In both chambers, committees are gate-keepers in areas of jurisdiction, are repositories of policy expertise and policy incubators, and possess agenda control power (Weingast and Marshall 1988). The president, though not part of the legislature, possesses *ex-post* veto power, which acts as an *ex-ante* threat that ensures the administration’s preferences are reflected in legislations and also enhance the durability of legislations (Crain & Tollison 1979). Evidences in the political economy of Clean Coal support this model (for example, see the section on legislators below).

These models form the core of the framework with which I analyze the political economy of Clean Coal. With this framework in place, we now take a closer look at the different players.

2.1. The Public (Voters)

First, we analyze the public – after all, in democratic societies, legislators are elected by the voters. What does the public believe, especially when it comes to issues related to Clean Coal? And what are the factors that affect the public’s opinions?

The first issue of note is that the public’s belief in issues related to Clean Coal and climate change fluctuates over time, sometime widely. An October 2009 survey conducted by the Pew Research Center for the People and the Press (2009) finds 57% of the respondents think there is solid evidence that the world is getting warmer, down 20 points from just three years ago (Cappiello 2009). A Gallup poll (Saad 2009) also shows that the public’s perception of the seriousness of global warming fluctuates over a span of more than a decade. The Gallup poll result is reproduced in Figure 17 below.

Thinking about what is said in the news, in your view is the seriousness of global warming -- [generally exaggerated, generally correct, or is it generally underestimated]?

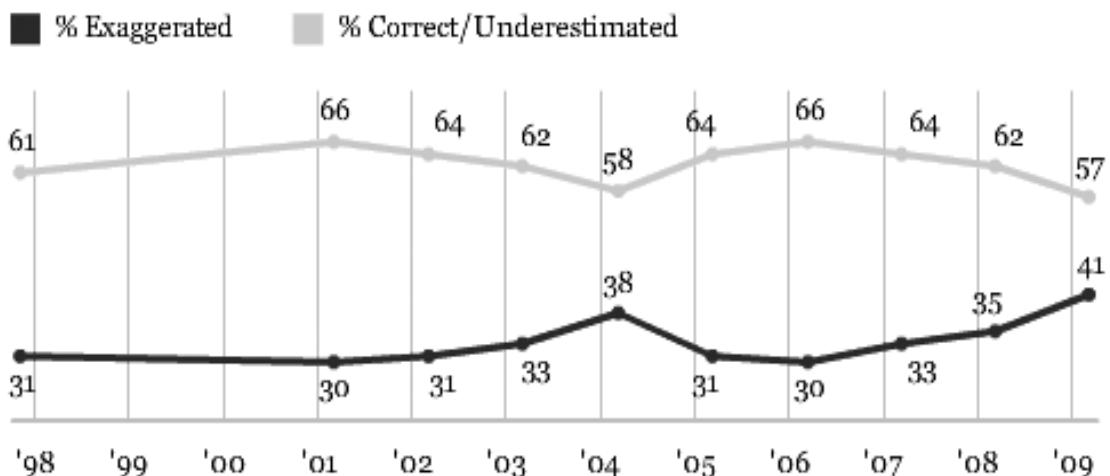


Figure 17: Global Warming Survey Results, 1998 – 2009
Data Source: Gallop Organization, reproduced from Saad (2009)

What is the cause of such fluctuations in the public's belief? If the public is well informed and there have been changes in information, that would explain such fluctuations. Another possibility is that other factors may have changed the public's perception of the issues. In Figure 18 below, I reproduce the Dow Jones Industrial Average Index for the period covered in Figure 17.



Figure 18: Dow Jones Industrial Average Index from 1998 to 2009
Data Source: Reproduced from Yahoo! Finance (2010a)

Looking at Figure 17, we can see that the peaks of the public's doubt about the seriousness of global warming occurred in 2004 and 2009 (and the latter may not even have reached its true peak yet). Comparing with Figure 18, we notice that these two points in time also happen to occur after a large drop (> 25%) in the Dow Jones Industrial Average Index in the previous year. We may interpret this as: in an economic downturn, the public is more aware of the cost that climate policies impose on them, and

consequently has a more incentive to pay attention to the issues and be opposed to these costly policies. Of course, the data are only suggestive, to further investigate this, we need to look at other evidences.

One of such evidences is our observation that the public's response to a particular question varies, sometimes significantly, depending on how the question is framed. For example, Nisbet and Myers (2007) give an example that illustrates how changes can be observed in people's responses to the same question, presented in slightly different forms, A and B (emphasis added):

- A. To help prevent the greenhouse effect, would you favor or oppose taxing oil, coal, and natural gas to provide economic incentives for shifting away from the use of fossil fuels?
- B. To help prevent global warming, would you favor or oppose taxing oil, coal, and natural gas **that would raise the costs of these fuels**, thus providing an incentive to shift away from the use of fossil fuels?

The three surveys asking form A of the question find 58% of respondents in favor while 30.3% opposing such tax, but the three surveys asking form B of the question find 50.3% of respondents in favor the tax while 42% opposing it³⁶. This suggests that when the economic impact of the policies is clearly articulated and presented to the respondent, he or she is likely to incorporate that information in the decision making. In other words,

³⁶ It must be mentioned that these six surveys were conducted at different times between 1989 and 1994, so some changes in people's attitude must be allowed when interpreting these results. See Nisbet and Myers (2007).

the public responds to economic incentives, or, in economic terminology, the public is rational.

But here we encounter another issue: it is usually not costless to obtain and assimilate information. Clean Coal, climate change, global warming, cap-and-trade programs ... these are all very scientifically and economically challenging concepts that require a person to spend a great deal of time to understand. In politics, the private cost of political action, which includes information cost as well as the cost of carrying out the action (such as voting), is non-trivial. On the other hand, the expected benefit (in the extremely unlikely event that one's vote affects the outcome) is infinitesimal. Thus, it is rational for the voter to remain ignorant – this is what is known in public choice literature as “rational ignorance”, first proposed by Downs (1957).

Indeed, in surveys on global warming related issues, we observe that the public exhibits such rational ignorance. The same survey conducted by the Pew Research Center for the People and the Press (2009) mentioned above finds the majority of respondents (55%) had heard nothing at all about the cap and trade programs being discussed in Congress, and the percentage of respondents who had heard little or nothing at all about such programs is a staggering 85%. From these survey data we see that the evidence that the public is rationally ignorant on global warming related issues is overwhelming.

The public also holds systematically biased beliefs about environmental problems. In his book, Caplan (2007, p161) uses an example in toxicology to describe this problem: the layperson tends to “view chemicals as either safe or dangerous and they appear to equate even small exposure to toxic ... chemicals with almost certain harm” whereas

toxicologists are far more likely to emphasize dosage. Thus, the public's belief in the dosage of pesticides deviates systematically from that of the experts (Kraus et. al. 1992). This example resonates well with most environmental issues: global warming, environmental catastrophes are potentially very "dangerous" outcomes, and the public is likely to over-exaggerate the probability and severity of such events. Indeed, Baron (2006) argues that when it comes to environmental policies, people's intuitions often lead them to favor sub-optimal policies due to systematic biases caused by common heuristics, which include "naturalism" (tolerating bad outcomes from natural causes but not from human causes, even when the costs are the same), "undoing" (undoing damage done rather than spending those resources on doing something else more beneficial), and "parochialism" (the tendency to favor a group that people see as including themselves over helping strangers). Baron further provides experimental evidence that when it comes to global warming people prefer undoing, are parochial, and show some degree of naturalism. All these factors create systematically biased beliefs in the layperson about global warming and cause them to demand inefficient amount of climate regulation (Humphrey 2009).

Caplan (2007, p 115) also gives some explanation as to why people may hold systematically biased beliefs and why they have "preferences over beliefs", one of these being social pressure for conformity: espousing unpopular vies often transforms a person into an unpopular person and imposes a private cost for that person in terms of lost popularity. When one's friends are trying to be "green", believing or acting otherwise may harm that person's popularity, thus that person may "go along to get along".

The example from Nisbet and Myers (2007) of how the public may respond to the same question depending on how it is represented also suggests that the public is susceptible to what is known in psychology as the “framing effect” – presenting the same option in different formats can alter people’s decisions. This, together with the public’s rational ignorance, makes the public especially vulnerable to the manipulation of interest groups. It is no wonder, then, that in the tug-of-war about Clean Coal by different interest groups we observe both camps (industrial groups and environmental groups) using catchy phrases to influence the public’s perception.

In summary, survey literature provides evidence that the public is largely ignorant of the issues related to climate change and Clean Coal, and its perception fluctuates, sometimes significantly, over time. The public’s rational ignorance and rational irrationality make it vulnerable to interest groups’ manipulations. These attributes of the public are important determinants of how the political game of Clean Coal is played.

2.2. Interest Groups

There are two major types of interest groups in the political game of Clean Coal: industrial groups and environmental groups. I shall use separate sub-sections to discuss these two types of interest groups.

2.2.1. Industrial Interest Groups

The first is industrial groups – lobbying arms of coal producers and utility companies and their trade associations. In the United States, the bulk of coal production comes from a

few large companies. According to the USEIA (2008d), the top three producers (Peabody Energy Corp., Rio Tinto Energy America and Arch Coal Inc.) account for nearly 40% of total U.S. coal production, and the top five companies account for more than 50%. On the other hand, everyone in modern society is ultimately a consumer of coal – anyone who uses grid electricity is a consumer of coal-fired power plants, including green zealots who charge their hybrid vehicles. If the major coal producers were to seek regulatory favor in order to obtain above-market profits (rent seeking), the cost would be borne by all citizens. In the Olsonian framework (Olson 1965), this is a situation of concentrated benefits and diffuse cost and there is a clear incentive for these companies to organize for collective action. Indeed, these companies are very active in lobbying. According to the Center for Responsive Politics (2009e, 2009f, 2009g), in 2008, Peabody Energy spent \$8,404,000 in lobbying, Rio Tinto and Arch Coal also spent \$695,000 and \$970,000 each. It is interesting to note that although Rio Tinto is the behemoth among these three companies – \$81.2 billion in market cap, compared with \$12.1 billion for Peabody Energy and \$4 billion for Arch Coal (as of January 24, 2010, Yahoo! Finance (2010b, 2010c, 2010d)), its lobbying spending is less than the other two companies. This can be explained by the fact that both Peabody and Arch Coal are almost exclusively coal producers whereas Rio Tinto is a diversified mining company, producing aluminum, copper, diamonds and other minerals (Rio Tinto 2010). In other words, the other two companies have even more concentrated benefits or losses (especially in the case of Peabody, which is the largest coal producers in the U.S. and accounts for 17.1% of all U.S. coal productions (USEIA 2008b)) riding on the outcome of climate legislations, so

they have even stronger incentive to organize. Industry wide associations are also big spenders, for example, the National Mining Association spent \$4,564,285 in the same period (Center for Responsive Politics 2009h), and the American Coalition for Clean Coal Electricity (an alliance formed by major power, mining and transportation companies), \$9,945,276 (Center for Responsive Politics 2009i).

Some of the inefficient policies can be traced to industrial interest groups' lobbying effort. Ackerman and Hassler (1981) illustrate one such example: under the 1970 Clean Air Act, the EPA required all coal plants to meet an emission standard for sulfur dioxide (SO₂). This regulation had disparate regional effects: most of the coal in the eastern United States has high sulfur content than western coal. Coal-burning utilities can meet the federal standard without installing costly scrubbers by using western coal, even after taking into account factors such as transportation cost and the low heat content of western coals. Eastern coal companies realized this and campaigned for a "universal scrubbing" requirement to be inserted into the 1977 Clean Air Act amendments – and this eventually gave rise to the new-source performance standards (NSPS) that forced facilities to attain a percentage reduction in emissions, regardless of the existing emission level of these facilities. With the establishment of the NSPS, western coal's advantages suddenly disappeared, and coal-burning utilities had to switch back to eastern coal. In addition, eastern coal producers and eastern-based United Mine Workers successfully pushed for additional provisions to encourage the use of "local" coal in the eastern United States, which became part of Section 125 of the Clean Air Act. Thus, the NSPS program and Section 125 of Clean Air Act are a form of regional protectionism (Adler 1996),

reflecting a distribution of economic rents to those who sought for them – in this case, eastern coal producers and unions in the eastern United States. Furthermore, the 1977 amendments also established the New Source Review (NSR) program, imposing scrubber requirements on all new coal plants but grandfathering existing, older coal-fired plants, resulting in increased SO₂ emission in some regions (ibid). Helland and Matsuno (2003) also provide evidence that existing firms use environmental regulations as entry barriers for new firms.

2.2.2. Environmental Groups

The other type of interest group is the environmental group. It is relatively straightforward to understand the incentive for industrial groups – owners of companies are profit-maximizers, their incentive is well understood. It is less obvious why environmental groups fight tirelessly for ever-tighter environmental regulations. Some environmental groups, such as the Sierra Club and Environmental Defense have also been very litigious and involved in some high profile environmental lawsuits: both these groups are the plaintiffs in *Massachusetts v. EPA* which establishes the EPA's authority to regulate GHG (discussed in Chapter 5). Environmental groups also boast very high number of memberships – The Sierra Club (2010) boasts 1.3 million members, and the National Wildlife Federation (2010) even claims more than 4 million members. It is doubtful that benefits from environmental activism are appropriable to all these members. It is important to understand the incentive for environmentalists and environmental

groups' mechanism for collective actions, thus I shall take a brief detour to probe this question.

2.2.2.1. A Brief Detour – Incentive for Environmentalists

The first, and obvious, answer is that environmentalists placed very high existence value on the environment (Krutilla 1967). If so, to them, tighter environmental regulations will “produce” more “environmental goods”, and since they are the claimants of such goods, they, like profit-seeking industrialists, also have an incentive to organize.

But the key to understanding the incentive for environmentalists and their mechanism for collective actions is to recognize that there are two types of environmentalists: one type we may call “leaders”, who are the leaders or persons holding key positions at various environmental groups and coalitions. The other type we may call “participants” who are the ordinary members of environmental groups who do not hold key positions. I shall illustrate with facts below that the incentive structures for these two types of environmentalists are quite different.

For “leaders”, opportunities for personal gains from their involvement in environmental activism are not only possible, but are ubiquitous, and the magnitude of personal gains can be very impressive. For example, former Vice President of the United States Al Gore made a movie (“An Inconvenient Truth”) about global warming; his involvement in environmental activism directly promotes the movie and brings himself money income. The fame that he gains through such activism also gives him opportunities to charge \$100,000 for a multimedia global warming lecture (West 2007),

not to mention that the Nobel Prize that he won also comes with a handsome cash award. Al Gore is a staunch proponent for subsidies to sustainable businesses, but a closer look reveals that he is also a partner of a firm that is a would-be recipient of such subsidies (Richtel 2007). Clearly, for leaders in environmental organizations, personal gains in money income and fame are an important motivation for their activities.

For participants, first, we observe that there is a strong expressive component in their behavior. The Expressive Voting theory from Brennan and Lomasky (1993) states that because the probability of one person's vote affecting the outcome in elections with a reasonably large electorate is effectively zero, it is "safe" (in the sense that it bears no consequence on the outcome) for people to vote for "feel good" policies. Participation in activism is similar in this regard – in fact, when one participates in protests and demonstrations, one does not even get to cast a vote. Realistically, one person's contribution matters little to the outcome. Thus, we infer that there is an expressive component in the behavior of participants in social activism. This is supported by our observation that in recent years, social activism – including, but not necessarily limited to, environmental activism – has taken a "festal" aspect. Indeed, there is an extensive literature in this research area, phrases such as "protestival", "carnivalized politics" and "carnavalesque ritual" are used to describe such phenomena (for example, see St. John (2008)). As long as one wants to express oneself, why not have a jolly time while doing it? Furthermore, such "festal" aspect of social activism also means that participation in social activism has the characteristic of a club good that displays positive returns to "participatory crowding" – which is what Iannaccone (1992) uses to describe religious

groups but which he also suggests can be used to address “social clubs”. Finally, we also note that there is some semblance in modern social activism and especially environmental groups and religious groups (for example, see Lowry 1998).

In addition, environmental organizations also use “selective incentives” (Olson 1961) as a means to overcome collective action problems: they often organize outings to members, offer member-only tours led by experts to exotic location (and one organization, The Nature Conservancy, which is the second largest private landowner in the U.S. (Daily and Ellison 2002), has even built resorts on its properties for member exclusive access) and even provide annuity programs. Thus, existence value, the expressive behavior of participants, the club good nature of participation are the forces that bind ordinary participants to environmental groups, with collective incentives offered by environmental organizations providing an additional binding force. Leaders, who have a different incentive structure and opportunities to appropriate personal gains, can then direct the collective action to further their agenda.

2.2.2.2. A Model of Booglegger and Baptist Coalitions

But who, and through what channels, benefits from environmental activism? I will use the time-tested method of “following the money” in public choice to investigate this. First, we notice that the Environmental Defense is member of the “25x25” initiative – an alliance that promotes “to get 25 percent of [America’s] energy from renewable resources like wind, solar, and biofuels by the year 2025” (25x25 2009). The Sierra Club, though currently not listed as a member of the 25x25 alliance, has worked closely with 25x25 to

lobby President Obama to combat climate change (25x25 2008). We also note that the 25x25 alliance also includes industry groups such as American Soybean Association, National Corn Growers Association and American Wind Energy Association.

Next, we note that studies show that the U.S. government's "alternative energy" policies often take on a distributional characteristic. For example, Rubin et. al. (2008) conduct an empirical study based on commodity prices and conclude that the U.S. government's biofuel policies "have allowed large income transfers to crop growers and landowners". Some argue that such policies are in fact inefficient: Runge and Senauer (2007) demonstrate that when energy and fertilizer usages are taken into account, corn-based ethanol releases only about 12 to 26 percent less GHG, but can increase emission of nitrogen oxide, which contributes to air pollution, and prevalent use of corn and soybean for biofuel production also has the unintended consequence of shooting up food prices and may "starve the poor". Runge and Senauer also argue that the benefits of biofuels are greater when plants other than corn or soybeans are used (ibid). Yet it is the corn and soybean growers' associations that we find in alliance with the environmental groups, who are at the forefront of lobbying and litigations. And as I demonstrate empirically in the opening section of this chapter, lobbying contributions from environmental groups have a significant impact on legislator's voting pattern.

How do we explain such facts? The public choice scholar Bruce Yandle (1983) uses the "Bootleggers and Baptists" analogy to describe the situation that apparently opposing interests are found in a coalition to demand for regulation. In this model, the Baptists take the moral high road and lobby for the regulation that requires Sunday

closing of stores that sell alcoholic beverages; the bootleggers who sell alcohol illegally everyday of the week benefit from such regulations so they too support the same regulation. Thus the two seemingly different groups collude and lobby for the same regulation. Yandle (2001) further argues that such “bootlegger coalitions” are indeed emerging in the political economy of global warming. The example I give above also fits this model – environmental groups such as the Sierra Club and Environmental Defense take on the role of “Baptists” whereas the would-be beneficiaries from the U.S. government’s policies such as American Soybean Association and National Corn Growers Association take on the role of “Bootleggers”, and we find these two groups in the same coalition.

A couple of numerical examples illustrate this more clearly. The Energy Foundation is a charity that is a staunch alternative energy proponent and provides large sums of funds to other environmental groups, among which are Natural Resources Defense Council, Environmental Defense Fund, etc. – all of which are plaintiffs in *Massachusetts v. EPA* (see Chapter 5). Indeed, 10 of the 13 organizational plaintiffs in *Massachusetts v. EPA* received funds from The Energy Foundation. The amounts these organizations received are listed below (Activist Watch 2010):

Table 14. Plaintiffs in *Massachusetts v. EPA* that received money from The Energy Foundation

Recipients of Funds from The Energy Foundation	Total Amount	Time Frame
Natural Resources Defense Council	\$14,733,574.00	1991 – 2005
Union of Concerned Scientists	\$6,754,100.00	1992 – 2005
Environmental Defense	\$5,497,340.00	1993 – 2003
Sierra Club	\$1,677,630.00	1992 – 2003
National Environmental Trust	\$1,307,600.00	1998 – 2001
U.S. Public Interest Research Group	\$625,000.00	1995 – 2001
Environmental Advocates	\$161,000.00	1995 – 2001
Friends of the Earth	\$160,000.00	1998 – 1999
International Center for Technology Assessment	\$20,000.00	1999 – 1999
Greenpeace	\$15,000.00	1992 – 1992

So who are the people of the Energy Foundation? On its Board of Directors we find Rose McKinney-James (Energy Foundation 2010), president and managing partner of Energy Works Consulting, LLC, a Las Vegas based renewable energy consulting company (The Forbes Magazine 2010). A pro-renewable energy policy would clearly benefit McKinney-James and her consulting firm. In fact, McKinney-James was picked by President Obama as part of his transition team reviewing the operations of the Federal Energy Regulatory Commission (Tetreault 2008). Is it then a surprise to anyone that McKinney-James and The Energy Foundation support tighter regulation of GHG, which is precisely what *Massachusetts v. EPA* is about?

Another example: From 2005 to 2009, David Gelbaum, Chairman of the Board at Entech Solar (Entech Solar, Inc. 2010), donated \$47.7 million to the Sierra Club. From Entech Solar's 10-Q report on November 9, 2009 (Entech Solar, Inc. 2009), it is clear from the auditors' comments that government subsidies are vital not only for the company's profitability, but for its viability:

We believe that the growth of the market for our solar energy products and services depends in large part on the availability and size of government-generated economic incentives. At present, the cost of producing solar energy generally exceeds the price of electricity in the U.S. from traditional sources. As a result, to encourage the adoption of solar technologies, the U.S. government and numerous state governments have provided subsidies in the form of cost reductions, tax write-offs and other incentives to end users, distributors, systems integrators and manufacturers of solar power products. Reduction, elimination and/or periodic interruption of these government subsidies and economic incentives because of policy changes, fiscal tightening or other reasons may result in the diminished competitiveness of solar energy, and materially and adversely affect the growth of these markets and our revenues.

Thus, the funds Gelbaum donates to the Sierra Club flow to the legislators. The Sierra Club is, needless to say, very active in lobbying. It contributed \$379,696 to federal candidates and \$1.3 million in total for the 2008 election cycle (Center for Responsive Politics 2009j). In addition, the Sierra Club also lobbies under the disguise of other coalitions, such as the Blue Green Alliance (2010) that spent \$720,000 in hiring “climate lobbyists” and is one of the biggest money spenders in lobbying for the Waxman-Markey Climate Bill, which includes a \$5 billion subsidy to solar and wind industry (Johnson 2009).

Other examples of such coalitions are aplenty; to name just a few:

- The Energy Action Coalition (2009) includes environmental groups such as The Sierra Club and Greenpeace and alternative energy associations such as Utah Clean Energy; the latter is sponsored by trade associations such as Interwest Energy Alliance, an association for renewable energy companies.
- The Blue Green Alliance includes environmental groups such as The Sierra Club and unions such as United Steelworkers and Utility Workers Union of America.
- In his own blog (Pope 2009), Sierra Club's Executive Director Carl Pope admits he and Chevron's CEO, Dave O'Reilly "might jointly lobby in the Senate" against "coal companies and their utility allies".

I do not imply that alternative energies are economically inefficient in themselves.

In fact, I think alternative energies should, and will, play an important role in our energy future. The point I make is that the development of alternative energies must be guided by sound economics. Government policies that are distributional in nature and/or that are funded by political pressures, will distort the market process and lead to inefficient allocation of resources. The rent seeking activities of the "bootlegger coalitions" introduce just this kind of market distortions.

2.2.3. Politicians (Legislators)

As I demonstrate in the opening section of this chapter, legislators' voting decisions are influenced by money, usually in the form of campaign contributions, and geography. In

this section I provide another detail of the institutional context in which members of the congress organize.

On January 18, 2007, House Speaker Nancy Pelosi announced plans to create a “Select Committee on Energy Independence and Global Warming” (U.S. Office of the Speaker 2007). If the committee were to be granted authority to draft legislations, it would conflict with the jurisdiction of the Energy and Commerce Committee. Because of this, the plan met with objections from the Energy and Commerce Committee chairman John Dingell at the time. A compromise was reached such that the Select committee would conduct hearings on energy independence and climate change issues but would not have authority to draft legislation. It is interesting, however, to note that the chairman of this “Select Committee”, Ed Markey, also happens to be the chairman of the Subcommittee on Energy and Environment (U.S. House of Representatives 2009) of the Committee on Energy and Commerce, which *does* have authority to draft energy and environment related legislations. It is highly unlikely that Congressman Markey has some magic to separate information that he obtains and processes for one committee from the information that he obtains and processes for another, it is then most logical to conclude that the Select Committee is not isolated from affecting legislative outcomes.

Cragg and Kahn (2009) use a “Carbon Dioxide Factor”, measured in pounds of carbon dioxide emissions per megawatt-hour, to analyze the behavior of legislators. They hypothesize that low-carbon states such as California, would bear less of the incidence of GHG emission regulations than high-carbon Midwestern states. Thus, congressmen from

low-carbon states face fewer objections from their constituents; in other words, these congressmen are “high demanders” of GHG emission regulations.

Niskanen (1971) demonstrates with convincing evidence that committee members tend to be high-demand members of the legislature. We use Cragg and Kahn’s “Carbon Dioxide Factor” to test Niskanen’s model. Table 15 below lists the members of the 111th Congress Select Committee on Energy Independence and Global Warming. The last column lists the “Carbon Dioxide Factor” from Cragg and Kahn (2009):

Table 15: Members of the 111th Congress Select Committee on Energy Independence and Global Warming and Carbon Dioxide Factors

Member	Party	State	CO₂ factor
Ed Markey (chair)	D	MA	1213
Earl Blumenauer	D	OR	456
Jay Inslee	D	WA	360
John Larson	D	CT	754
Stephanie Herseth Sandlin	D	SD	1215
Emanuel Cleaver	D	MO	1877
John Hall	D	NY	891
John Salazar	D	CO	1978
Jackie Speier	D	CA	697
James Sensenbrenner	R	WI	1711
John Shadegg	R	AZ	1219
Candice Miller	R	MI	1399
John Sullivan	R	OK	1717
Marsha Blackburn	R	TN	1255
Shelley Capito	R	WV	1988

From Table 15, we see that of these 15 members, 9 have carbon dioxide factors below the median of 1299, and 10 have carbon dioxide factors below the mean of 1401

off all states. In other words, about two-thirds of the committee members are “high demanders” of GHG emission regulations. The data fit Niskanen’s model.

Empirical evidence supports the model of self-interested legislators and explains the existence of inefficient policies. For example, Pashigian (1985) studies the voting patterns on the 1977 CAA amendments. He finds that representatives from older industrialized regions systematically supported tighter standards for competing regions that were beginning to attract new industrial plants. My own analysis in the opening section of this chapter also demonstrates that legislators’ voting patterns are influenced by campaign contributions and geographic locations. The EPA’s regulatory actions are also traced back to influence from lobbyists. Mixon (1995) studies the EPA’s citations for carbonaceous emissions which cause urban temperature rises³⁷ for SMSAs (Standard Metropolitan Statistical Area). Using data reported by the EPA on 40 SMSAs between 1988-1990, Mixon finds that lobbyists per capita significantly reduces the magnitude of fines and the probability that the EPA would issue such citations.

From this evidence, we conclude that one of the cornerstones of the public choice discipline – that politicians are self-interested utility maximizers, is again proven to be true in air pollution and climate control legislations.

3. Putting It All Together: The Political Economy of Clean Coal

Having identified the players in the political economy of Clean Coal, a picture of how this game is played emerges. Because of the complexity of the issues related to global

³⁷ Note: “carbonaceous emissions” are carbon based compounds, usually in particulate form; this is to be distinguished from CO₂, a gaseous substance.

warming and Clean Coal, the public is rationally ignorant or rationally irrational. Politicians' behavior is motivated by self interest; therefore they act as brokers, handing out political favors to the highest bidders – such as those who make campaign contributions. Interest groups, including industrial groups and environmental groups, with more concentrated benefits or losses from legislations, have stronger incentive to organize than the public. They try to influence legislators to pass regulations in their favor through campaign contributions and lobbying. In addition, environment groups and alternative energy companies and trade associations – potential beneficiaries of policies favoring alternative energies – form “bootlegger coalitions” and lobby for policies in their favor. In this coalition, environmental groups take the prominent role of “Baptists” and are at the forefront of lobbying, litigations and publicity campaigns, whereas alternative energy companies take the role of “bootleggers” and work in coalition with, and often sponsor, environmental groups.

One thing that also stands out in this political game of Clean Coal is that interest groups on both sides of the battle (for and against tighter environmental, and especially GHG, regulations) appear to have realized the rational ignorance or rational irrationality of the public and have tried to use catchy slogans and one-liners to seize the attention and sway the opinion of the public. In 2008, American Coalition for Clean Coal Electricity (then known as Americans for Balanced Energy Choices) launched a \$35 million advertisement campaign to promote “Clean Coal” (Mufson, 2008), which uses phrases such as “[coal is] an American resource that will help us with vital energy security”. In the same year, Al Gore and his Reality Coalition led a \$45 million counter advertisement

campaign to mock Clean Coal as a “myth” and liken it to “healthy cigarettes”. Because the public’s rational ignorance and rational irrationality stem from a lack of incentive to obtain information, by using catchy slogans interest groups are able to reduce the information cost and transmit to the public sometimes misleading information that is advantageous to themselves. The Sierra Club has been systematically attacking coal while promoting alternative energy at the same time. In 2009, every issue of the Sierra Magazine contains one or more articles vilifying coal, with titles such as “The Dirt on Coal”, “Killing King Coal” and “The Enemy of the Human Race”. Through these and other publicity campaigns, environmentalists are manipulating the mind of the public – the voters.

In previous sections, I also trace the money flow among the various players in the political economy of Clean Coal: industrial groups and environmental groups alike make campaign contributions to legislators. Anti-coal industrial interest groups (mostly alternative energy companies and trade associations) form “bootlegger and Baptist” coalitions with environmental groups and sometimes directly provide funds for the latter. Legislators pass legislations that are distributional in nature to appropriate money for industrial groups. The money, of course, does not come from legislators’ own pockets but from the taxpayers (the public); legislators can do so because they have the state’s coercive power at their disposal. The following figure illustrates the interactions of these players and the flow of money diagrammatically.

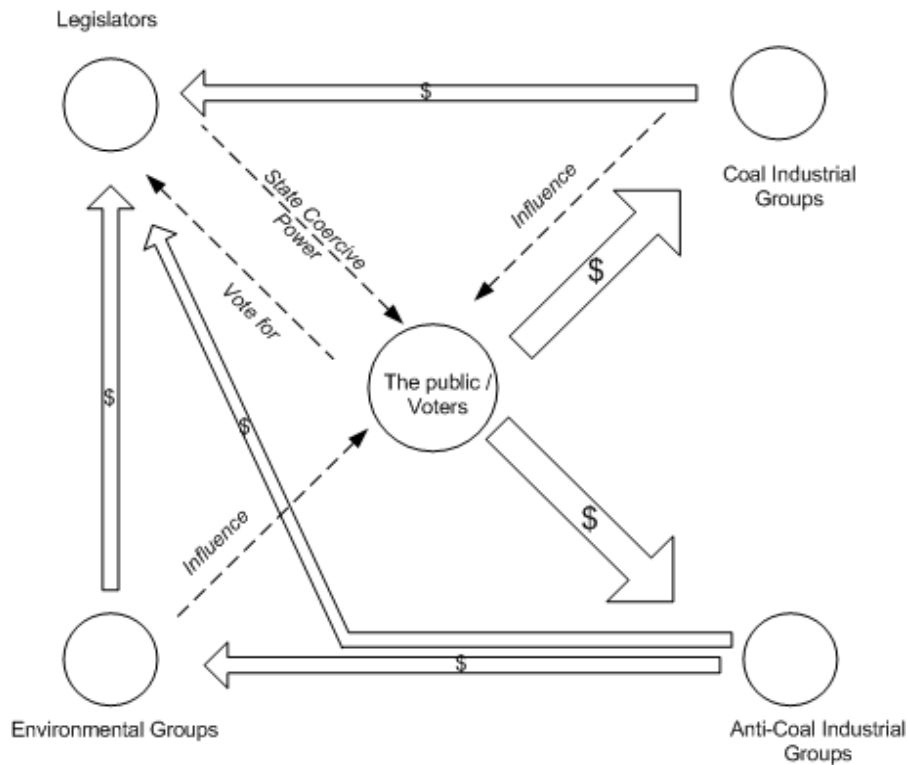


Figure 19: Interactions and Money Flow among Players in the Political Economy of Clean Coal

In Figure 19, the hollowed arrows denote the flow of money whereas dashed lines with an arrowhead denote the actions taken by the players. Note that the “money flow” may not literally mean a cash distribution – sometimes this is the case, such as subsidies to alternative energy companies; but sometimes this implies a distribution of economic rents such as the new-source performance standards (NSPS) under the Clean Air Act that has the nature of distributing economic rents to eastern coal producers (Adler 1996). Also, I divide industrial groups into “Coal Industrial Groups” and “Anti-Coal Industrial Groups”. This is of course a simplification: even within the coal industry there are distributions between different groups (ibid). These simplifications notwithstanding, this diagram sums up my own findings in this chapter accurately.

4. Conclusion

In Chapter 5 I identify two major obstacles to the large-scale deployment of Clean Coal technologies. In this chapter, I provide evidence that the creation of both these obstacles as well as other inefficient policies can be traced back to interest groups' rent-seeking activities. Interest groups do so through lobbying expenditure and campaign contributions to legislators, who are motivated by self-interest. In addition, I provide evidence that environmental groups and industrial groups (mostly alternative energy industrial groups) form "Bootlegger and Baptist" coalitions and engage in rent-seeking activities aimed to appropriate gains to themselves through distributional policies.

As I illustrate in Chapter 2, coal is an abundant and cheap energy source and will continue to play an important role in our economy. The important question is: how do we – that is, if it is possible at all – remove these obstacles and move toward a world in which Clean Coal technologies are efficiently deployed?

Chapter 7: Conclusions

1. Summary of Findings

In Chapter 1, I posed six questions that are central to understanding the political economy of Clean Coal. In this chapter, I summarize the findings from my research by providing answers to these questions.

Question #1: Is it realistic to expect coal use to be reduced significantly or eliminated altogether in the near future?

Answer: Coal is an abundant and affordable energy source that currently accounts for about 50% of electricity in the U.S. and 25% of global energy supply. It will continue to account for a major portion (around 25%) of global energy supply in the foreseeable future even if a significant price hike is imposed on fossil fuels (see Chapter 2). Therefore, the answer to the first question is an emphatic “**No**”.

This inevitability is one that environmental activists choose to ignore. When a “green” advocate charges his electrical vehicle from the power grid, he is consuming electricity generated from coal-fired power plants. It is absolutely certain that the focus must be on how to use coal efficiently. Should green activists succeed in wiping out the coal industry, the U.S. and world economy would have to revert to power mechanisms

reflective of medieval Europe. It is this conclusion that makes my subsequent inquiries relevant and necessary.

Question #2: How dirty is coal – in other words, what is the economic cost from coal-generated pollutants?

Answer: When coal is burned, it generates various types of pollutants – nitrogen oxides (NO_x), sulfur dioxide (SO₂), particulate matters (PM), arsenic, mercury, other heavy metals and carbon dioxide (CO₂). The economic costs of criteria pollutants amount to about \$18.6 billion a year in the United States (Table 5). There is a significant degree of uncertainty in the estimate of damage cost from CO₂. Using the mean of CO₂ damage of \$93/tC from more than 100 studies (Tol 2005), the annual cost of CO₂ is estimated to be \$734 million (see Chapter 3).

Question #3: What is the nature of the uncertainty regarding CO₂?

Answer: Technical uncertainty exists for both criteria pollutants and CO₂, but theoretical uncertainty of criteria pollutants is largely absent (their effects on human health and the environment are well understood). Theoretical uncertainty remains significant for CO₂. More research needs to be done to eliminate or reduce this uncertainty before costly abatement measures are adopted (see Chapter 3).

Question #4: Are “Clean Coal technologies” more economically efficient compared with conventional technologies?

Answer: Coal-fired power plants equipped with Clean Coal technologies (especially IGCC technologies) are capable of generating electricity at lower total cost (inclusive of externality cost) than conventional coal-fired plants. Another advantage of

IGCC coal-fired power plants is that they can be adapted for carbon capture and sequestration (CCS) at lower cost than conventional plants (see Chapter 4). Therefore, the answer to this question is an emphatic “*Yes*”.

Question #5: If Clean Coal technologies are economically more efficient than conventional technologies, what is the optimal approach to large-scale deployment of Clean Coal technologies?

Answer: The optimal approach to deploying Clean Coal technologies is a “staggered refreshing” approach – that is, to replace existing plants gradually with plants equipped with Clean Coal technologies (especially IGCC technologies). This optimal approach is further reinforced when we consider the fact that IGCC power plants can be adapted for CCS more cheaply than conventional coal-fired power plants, therefore they can be utilized as an insurance against the uncertainty about CO₂ (see Chapter 4).

Question #6: If in reality, the level of utilization of Clean Coal technologies is suboptimal, what are the obstacles that prevented the optimal level from being achieved?

Answer: There are two major obstacles that have prevented or will prevent Clean Coal technologies to be deployed at a large scale: one is the New Source Review (NSR) program under the Clean Air Act; the other is the regulation of GHG (see Chapter 5).

My empirical analysis indicates that legislators’ voting pattern in climate control related legislations is influenced by lobbying contributions from interest groups and the legislators’ geographic location. Because of the public’s rational ignorance and rational irrationality and the self-interest of the legislators, interest groups are able to use money to influence legislators and push for policies that are distributional in nature and

economically inefficient. Thus, a model of legislators as self-interest maximizers selling favor to the highest bidding interest groups accurately depicts the political economy of Clean Coal. With this framework, the establishment of the NSR and similar programs is traced back to the lobbying efforts by coal industry interest groups as a form to distribute economic rents and as entry barrier for new firms.

The Supreme Court's ruling *Massachusetts v. EPA*, a lawsuit brought forth by several states and environmental organizations to demand that the EPA regulate GHG, is based on shaky legal grounds. In particular, the plaintiffs in *Massachusetts v. EPA* did not truly establish their legal standing and the EPA has not proven that GHG are air pollutants before it established authority to regulate it, a violation of the original language of the Clean Air Act. Empirical data help identify the existence of “bootlegger and Baptist” coalitions between environmental groups and alternative energy companies. The lobbying for climate control legislations is traced to the rent seeking of such “bootlegger and Baptist” coalitions (see Chapter 6).

2. Public Choice Compatible Recommendations for Policy Reform

In this section I outline a policy reform proposal regarding how to remove these obstacles to large-scale deployment of Clean Coal technologies.

My first recommendation for reform is to repeal the New Source Review program and replace it with a comprehensive cap-and-trade program for criteria pollutants. This is indeed a consensus among economists (see, for example, Cruenspecht and Stavins 2002 and Nash and Revesz 2007). The repeal of the NSR will remove the impediment to

capital turnover at coal-fired power plants and the barrier for new entrants. A comprehensive cap-and-trade program for criteria pollutants will provide the correct incentive for coal-fired power plant owners to use the most efficient Clean Coal technologies.

The second recommendation is to postpone the regulation of greenhouse gases (GHG) until it is reasonably certain that anthropogenic global warming is harmful to human society and it is economically efficient to reduce GHG emissions using available technologies. Because of the significant degree of theoretical uncertainty in our understanding of global warming and CO₂, our best strategy is to deploy technologies that allow us to use coal efficiently while deepening our understanding of these issues. Clean Coal technologies (especially IGCC) fit this strategy because IGCC power plants can be adapted for carbon capture and sequestration more cheaply than conventional power plants. Therefore, Clean Coal technologies ought to be used as an insurance policy against the uncertainty about CO₂ and global warming. If GHG regulation is postponed and the NSR is repealed, state-of-the-art Clean Coal technologies will be deployed at a large scale in a few decades. Should GHG emission reduction be necessary in the future, these state-of-the-art facilities can then be modified to facilitate carbon capture and sequestration.

We also must not underestimate the power of economic growth – as the economy grows, so does the “software of economic development” (knowledge, structural flexibility, entrepreneurship and institution) that shifts the aggregate production functions upwards (Kasper 2007). If we use coal wisely and efficiently as an energy source to

stimulate economic growth, we will find new ways to solve problems such as GHG emission reduction. Some economists such as Mendelsohn (2008) also suggest that emergency plans that would reproduce the effect of volcanoes to introduce particles into the upper atmosphere to cool the planet could be developed as a hedge against catastrophic results from global warming. Clean Coal technologies must be used in conjunction with this type of emergency plans as a safeguard against any potential catastrophic outcome of global warming.

These two policy reform recommendations are based on the criteria of economic efficiency. From a public choice perspective, how realistic is it to expect these reforms to be carried out?

Public choice tells us that in politics, all actors are self-interested utility maximizers. Efficient policies often cannot be implemented because of rent seeking of different political actors. In this section I analyze the feasibility of Clean Coal from a public choice perspective. In particular, I identify three impulses behind the movement toward large-scale deployment of Clean Coal technologies – the economic impulse, the intellectual impulse and the political impulse, and discuss whether they are strong enough to make Clean Coal a reality.

The economic impulse for Clean Coal comes from the economics of coal and the efficiency of Clean Coal technologies. Coal is more abundant than all other fossil fuels combined and it is by far the cheapest. Most serious researches all agree that renewable energies are insufficient to meet the energy demand of our society in the foreseeable future (for example, see Rout et. al. 2008). Unlike petroleum, coal is more widely

distributed globally. The United States, Russia, China and Australia all have vast reserves (USEIA 2010). This means that coal is free of the politically induced supply side distortions facing petroleum. As petroleum reserves continue to be depleted, and especially if there is another “oil shock” such as what happened in the 1970s, coal’s price advantage will be even more pronounced. These facts determine that coal will continue to play a vital role in the economic growth of our society. As long as coal is being used, innovative entrepreneurs will find ways to use it more efficiently and more profitably. Clean Coal technologies are the strongest candidate for such purpose. This entrepreneurial ingenuity and profit-seeking desire will drive new players to seek entry into the market and demolish entry barriers such as the NSR. The economic impulse for Clean Coal is clearly present and strong.

The intellectual impulse for Clean Coal comes from researchers, including scientists and engineers who develop new technologies to use coal, and economists who evaluate the efficiency of these technologies, and public policy and public choice scholars who analyze the policies that govern the use of coal. Public choice tells us that we must also treat researchers as self-interested utility maximizers. The recent story about some “climate scientists” manipulating global warming data in order to push their agenda (Moore 2009) is just one such example. Efficiency analyses of Clean Coal technologies, estimates of coal-generated pollutants, and public choice analyses of coal related regulations are fruitful lines of research. In this dissertation, I also start a new direction of research by comparing the efficiency of coal technologies based on their full cost of generating electricity. Researchers, motivated by getting more publications and

citations and obtaining tenured positions, will continue to pursue these lines of research. Some researchers are also motivated by truth-seeking and securing their legacy, and they can only secure their legacy if they can “get it right”. Therefore, the academia is a fertile ground for good ideas. It is not surprising that in the past decades visionaries such as Milton Friedman and James Buchanan came from the academia.

But researchers cannot operate in their ivory tower and hope that efficient policies will be magically adopted one day. Too often good policy recommendations are ignored or defeated in the political process. James Buchanan’s constitutional reform proposal to require balanced budget and Milton Friedman’s advocacy for monetary stability are such examples. The intellectual impulse alone is insufficient to change the world; only when it is combined with the economic and political impulses can it make a meaningful impact.

The political impulse for Clean Coal is a more complicated matter. This impulse has several components of varying strengths. First, coal is currently portrayed as dirty and Clean Coal technologies are mocked as a “myth” by environmental activists such as Al Gore. Environmentalists and their alternative energy allies do this in order to enact policies in their favor. This threatens the profitability of coal companies. In recent years, coal companies have fought back, pouring millions of dollars in campaigns to promote Clean Coal (see Chapter 6). Because money is an important determinant in legislators’ voting decision, the political force to promote Clean Coal is present. However, it is counter-balanced by money from environmental groups and their allies.

In addition to the money spent in publicity campaign, companies invested in Clean Coal technologies have also conducted their own researches on the effectiveness of

Clean Coal technologies (for example, see Conoco Phillips 2005). However, most of their researches are narrowly technical. As the economic impulse grows stronger, more research will be demanded on Clean Coal, global warming and public policies related to these issues. It is likely that these companies will start funneling money to research programs in these areas. In fact, in recent years, some electric utility companies have funded the research of climatologists such as the prominent global warming skeptic Patrick Michaels³⁸. There is a strong likelihood that the intellectual impulse for Clean Coal will be reinforced by this political force.

There is another political force that moves policies (including energy policies) toward the efficient. When the negative economic impact of policies becomes obvious, the public will become more aware of the nature of these policies and will demand better ones. For instance, if a government artificially and excessively inflates energy price through climate regulations and other inefficient policies, the public will become discontent and will demand a change to such policies. This is what Caplan (2010) describes as “negative feedback” to stress how bad growth can lead to good ideas (policies) because undesirable outcomes inspire the public to search for wiser approaches. In recent years, countries such as China, Russia and India have seen tremendous economic growth and substantial improvements in their standards of living. This is partly because of the prevalent use of coal that fueled the economies in these countries. If the obstacles to the efficient use of coal continue to retard economic growth and improvement of living standards in the United States, the American public will

³⁸ ABC News Reporting Cited As Evidence In Congressional Hearing On Global Warming (URL: <http://abcnews.go.com/Technology/print?id=2242565>)

eventually feel their impact and demand a policy reform to remove these obstacles. Thus, the world's growing energy demand, the abundance of coal, and the public's "negative feedback" mechanism work together to form a strong force to push for the efficient use of coal.

Politics in the United States is more decentralized compared with other democracies. Geography is also a determinant in legislators' voting decisions (see Chapter 6). Elections, especially presidential elections, are often determined in a few "battleground states". Of the 16 major coal producing states, 5 are battleground states (Colorado, New Mexico, Ohio, Pennsylvania and Virginia). With elections being increasingly contested in recent years, 2 more states (Illinois and Indiana) are also becoming battleground states. Politicians are opportunists. A politician or politicians may emerge from these states to seize the opportunity to promote coal in order to get into office. However, this component of the political impulse is relatively weak because only about half of major coal producing states are battleground states.

The current administration is preoccupied with health care reform, global climate treaties and takeovers of failing financial institutions and automobile companies. It remains to be seen whether President Obama can keep his promise to "develop and deploy Clean Coal Technology"³⁹. If he fails to deliver, this will create an opportunity for political entrepreneurs to draw on the public's insatiable appetite for cheap energy to run for office. Clean Coal technologies being the most efficient way to use coal, such politicians will act (perhaps unintentionally) to promote Clean Coal.

³⁹ http://my.barackobama.com/page/content/newenergy_more

So there is a political impulse to promote Clean Coal, but its components are of varying strengths. It is also counter-balanced by other forces such as the rent seeking from environmental groups and their “bootlegger and Baptist” coalitions. Self-interested politicians can also renege on their promises. Public choice is sometimes described as the “most dismal of all dismal sciences” (Rowley 1997) because it impassionately (and correctly) treats all political actors as self-interested individuals. These actors’ self-interests do not always (in fact they rarely do) align with economic efficiency. But the economic impulse and the intellectual impulse for Clean Coal are strong. And in a democracy, the public’s “negative feedback” is a powerful mechanism against truly ruinous policies. For these reasons, I remain cautiously optimistic that large-scale deployment of Clean Coal technologies will be reality one day.

We also need a statesman who can elevate himself or herself above the pettiness of distributional politics and unflinchingly push for economic growth and the large-scale deployment of Clean Coal technologies. Rowley and Smith (2009) give the example of Sir Robert Peel who sacrificed his own political future to repeal the rent-protecting-in-nature *Corn Laws* in 19th century United Kingdom. It is somewhat paradoxical for a student of public choice, a discipline based on the premise that politicians are self-interest maximizers, to make such a recommendation. But to some extent, the existence of statesmen and self-interest can be reconciled. For example, they may face diminishing marginal utility of money if they have already accumulated a certain amount of wealth; other components in their utility function, such as reputation, truth-seeking and securing their legacy become important. There are also the “exceptions” such as Sir Robert Peel

and Winston Churchill who sacrifice their own political future to carry out welfare-enhancing reforms.

Those who survive the political process and succeed in carrying out welfare-enhancing reforms represent a miniscule proportion of those who set out to achieve unpopular objectives⁴⁰. There is no doubt that such statesmen emerge only very rarely, which leads Rowley and Smith to lament that “[t]here are no statesmen currently on the political horizon” (ibid). But it has happened in history. The economic and intellectual impulses for Clean Coal are strong. They create opportunities for politicians and provide the conditions for a statesman to emerge. We need a statesman who has the wisdom to see that economic growth is the only way to get more for everyone and the courage and sacrifice to go down such a road. Therefore, I remain hopeful, but very cautiously optimistic, that such a statesman will emerge in our generation.

Finally, because researchers have an important role to play in the political economy of Clean Coal, I have an advice for them. Caplan (2007) tells us that in democracy, voters usually get the policies they want. On the other hand, the public is rationally ignorant and rational irrational (which, according to Caplan, often leads to inefficient policies). How do we get out of this conundrum? Caplan (2010) makes three recommendations for economists to persuade the public to abandon their systematically biased beliefs and adopt economically efficient policies. Actually, Caplan’s recommendations can be further distilled into two essential points:

1. Simplify the message(s).

⁴⁰ Rowley, C. K. (2010) The Statesman (<http://charlesrowley.wordpress.com/2010/01/15/the-statesman/>)

2. Make it fun.

Thus, the recommendation I make for researchers is that they ought to take their messages about the importance of coal and the advantages of Clean Coal technologies to the public, and make such messages easy to understand and fun. The public has little incentive to spend the time to digest the information; therefore it is imperative that researchers reduce their messages to a few easy-to-understand and catchy sentences that can be understood in an instant. This is precisely the strategy various interest groups have utilized. By adopting this strategy, researchers can then “beat the enemies at their own game”. Further, because the public tends to pay more attention to the issues when the economic impact of the policies is clearly presented to them, researchers must “frame” their messages in a concise yet powerful way to get the public’s attention. It is not an easy task, but it is worth trying. With the advent of the internet and “blogspace”, hopefully it will be easier for researchers to get their messages across.

Appendix: Calculation of Full Costs of Electricity for IGCC and PC plants

1. Calculation based on MIT (2007) and USEIA (2009d)

I have obtained the externality costs of NO_x, SO₂, Mercury and PM (see Table 5), these are reproduced in the second column in Table 16 below (the cost of PM is the sum of PM2.5 and PM10).

According to USEIA (2009d), in 2006, total electricity generation from coal-fired power plants was 1,991 million mw-h. Dividing the numbers in the second column by this total yearly total electricity production number (and after unit conversion), we obtain the externality cost per unit of electricity, listed in the third column in Table 16 below.

Table 16: Externality Costs of Existing Coal-fired Power Plants

Pollutant	Annual Externality Cost (\$)	Externality Cost Per Unit Of Electricity (c/kw-h)
NO _x	1300	0.07
SO ₂	13100	0.66
Mercury	1300	0.07
PM	2200	0.11
Total	17900	0.90

From MIT (2007), Appendix 3.D, we have the following numbers emission numbers:

PC plants:

- NO_x: 0.09 – 0.13 lb/million Btu
- SO₂: 0.21 to 0.23 lb/million Btu
- Mercury: 85-95% removal
- PM: 0.015 lb/million Btu

IGCC plants:

- NO_x: 0.01 – 0.06 lb/million Btu
- SO₂: 0.02 – 0.03 lb /million Btu
- Mercury: 95% removal from Syngas
- PM: 0.004 to 0.01 lb/million Btu⁴¹

Taking the mean from all these emission ranges, then dividing the emission number from IGCC plants by the corresponding number from PC plants, we obtain emission from IGCC plants as a *percentage* of PC plants; these are listed in the second column in Table 17 below. Multiplying these percentage numbers with the numbers from the third column in Table 16, we obtain the projected externality cost per unit of electricity for IGCC plants, listed in the third column in Table 17 below.

⁴¹ MIT (2007) actually listed 0.4 – 0.01 lb/million Btu (page 141). I found this unfathomably large – this would imply that there is a 40 times variance in PM emissions. Through out the whole publication, all the ranges start from a lower number and end with a higher number, except this one place. This is why I suspect that this is a typo and it should be 0.004 to 0.01. Moreover, in the same paragraph it also mentioned that “particular emission in the stack gas are below 0.001 lb PM/million Btu”, lending further evidence to my suspicion. In any case, As can be seen in Table A.1, the cost of PM actually accounts for a very small portion of the total externality cost (my calculations produced a 0.01 c/kw-h difference between PC and IGCC plants), this correction would not alter the result in Table A.2 substantially.

Table 17: Projected Externality Costs of IGCC Plants based on MIT (2007) and USEIA (2009d)

Pollutant	Percentage of PC plant emission	Externality Cost Per Unit Of Electricity (c/kw-h)
NO_x	31.8%	0.02
SO₂	11.4%	0.08
Mercury	50.0%	0.03
PM	93.3%	0.10
Total		0.23

The numbers in the last column and the last row from Table 16 and Table 17 are the “Externality Cost” numbers used in Table 8.

2. Calculation based on Phillips (2005) and MPCA (2006)

Phillips (2005) lists the “30-year levelized cost of electricity” for 2 designs of IGCC and 2 designs of SCPC (super critical PC) plants. The averages of these two designs are 50.8 \$/mw-h (for IGCC) and 45.9 \$/mw-h (for SCPC) respectively. After conversion to c/kw-h, these numbers are listed in the second column in Table 9.

MPCA (2006) is a testimony/study done by the Minnesota Pollution Control Agency, which lists the emissions of various pollutants from ‘EPA “generic” subbituminous IGCC’ plants and ‘EPA “generic” subbituminous supercritical’, which are two types of plants (IGCC and SCPC) used in Philips (2005). These emission numbers are listed in the second and third columns in Table 18 below, which are then used to compute the percentage of IGCC plant emissions in terms of SCPC plant emissions (fourth column). These percentage numbers are then multiplied by the externality cost of existing plants (Table 16) to obtain externality costs for IGCC plants (last column).

Table 18: Projected Externality Costs of IGCC Plants based on Phillips (2005), MPCA (2006) and USEIA (2009d)

Pollutant	Emission from IGCC Plants (lb/mw-h)	Emission from SCPC Plants (lb/mw-h)	Percentage of IGCC plant emission in terms of SCPC plant emission	Externality Cost Per Unit Of Electricity for IGCC plants (c/kw-h)
NO_x	0.326	0.500	65.20%	0.046
SO₂	0.090	0.540	16.67%	0.110
Mercury	3.420	3.780	90.48%	0.063
PM	0.090	0.100	90.00%	0.099
Total				0.32

One thing to note is that both the cost of electricity and emission data are for SCPC plants. As discussed in Chapter 4, the current fleet of coal-fired power plants is a mixture of various PC design, CFB and a few IGCC plants. Since SCPC is a more advanced design than subcritical PC design, which a large percentage of existing coal-fired power plants use, this second calculation is actually biased toward favoring existing plants – i.e. it *underestimates* the emission reduction of a conversion to IGCC plants, thus *narrowing* the difference in externality costs between SCPC plants and IGCC plants. A more thorough study would divide current coal-fired power plants by design types, and compute the potential emission reduction (of converting to IGCC) for each design type. However, since this second study is used as a cross-check for the first study based on MIT (2007) and USEIA (2009d), I think this is a reasonable approximation.

REFERENCES

REFERENCES

- 25x'25 (2008) 25x'25 e-News, December 5, 2008, URL:
http://www.25x25.org/storage/25x25/documents/newsletters/e-newsletter_12-05-08_final.pdf, retrieved: 11/1/2009
- 25x'25 (2009) Factsheet Over 825 Key Groups Support 25x'25, URL:
<http://www.25x25.org/storage/25x25/documents/CoreDocuments/organizationendorsements3.19.09.pdf>, retrieved: 03/19/2009
- Ackerman, B., Hassler, W. T. (1981) *Clean Coal/Dirty Air: or How the Clean Air Act Became a Multibillion-Dollar Bail-Out for High-Sulfur Coal Producers*, Yale University Press, Binghamton, N.Y.
- Activist Watching (2010): *Energy Foundation*, URL:
<http://activistcash.com/foundation.cfm?did=88>, retrieved: 01/24/2010
- Adler, J. H. (1996) *Rent Seeking Behind the Green Curtain*, Regulation, No.4, pp 26-34
- AEP, American Electric Power (2005) Ohio Public Utilities Commission Filing for Meigs IGCC Power Plant, O. PUC, 2005.
- Amthor, J. S. (1995) *Terrestrial higher-plant response to increasing atmospheric [CO₂] in relation to the global carbon cycle*, Global Change Biology, Volume 1 Issue 4, pp. 243 - 274
- Baliunas, S. (2005) *Possible Effects of Solar Variability on the Earth's Ecosystems* in Michaels, P. J. (eds) 2005, pp. 210-240
- Balling, R. C. Jr. (2005) *Observational Surface Temperature Records Versus Model Predictions*, in Michaels, P. J. (eds) 2005, pp. 50-71
- Baron, J. (2006) *Thinking about Global Warming Climatic Change 77*: 137-150 (2006), p. 138.
- Baumol, W. J. and Oates, W. E. (1988) *The theory of environmental policy*, Cambridge University Press, Cambridge, 2nd Edition

BBC News (2010) *Q&A: Professor Phil Jones*, February 13, 2010, URL: <http://news.bbc.co.uk/2/hi/science/nature/8511670.stm>, retrieved: 2/16/2010

Beer, J. M. (2007) *High efficiency electric power generation: The environmental role*, Progress in Energy and Combustion Science 33(2), pp. 107-134

Bellas, A. S., and Lange, I. (2008) *Did State Regulation of Power Plants Cause an Increase in Pollution Exportation?* U.S. Environmental Protection Agency Papers, *Economics Letters* 98 (2008) 213–219

Bijen, J. (1996) *Benefits of Slag and Fly Ash*, Construction and Building Materials, 10(5), pp. 309-314

Blue Green Alliance (2010) About Us, URL: http://www.bluegreenalliance.org/about_us/organizations, retrieved: 1/24/2010

Bonta, J.V., Amerman, C. R., Harlukowicz, T. J. and Dick, W. A. (1997) *Impact of Coal Surface Mining on Three Ohio Watersheds - Surface Water Hydrology*, Journal of the American Water Resources Association, Volume 33 Issue 4, Pages 907 – 917

BP (2008) Statistical Review of World Energy June 2008, URL: http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/downloads/pdf/statistical_review_of_world_energy_full_review_2008.pdf (retrieved: 1/22/2009)

Bradshaw, J., Bachu, S., Bonijoly, D., Burruss, R., Holloway, S., Christensen, N.P., Mathiassen, O.M. (2007) *CO₂ storage capacity estimation: Issues and development of standards*. International Journal of Greenhouse Gas Control, v. 1, no. 1, p. 62-68.

Brennan, G., Lomasky, L. (1997) *Democracy and Decision*, Cambridge, Cambridge University Press

Buchanan, J. M., Tullock, G. (1975) *Polluters' Profits and Political Response: Direct Controls versus Taxes*, The American Economic Review, Vol. 65, No. 1 (Mar., 1975), pp. 139-147

Burnett, J. K., Hahn, R. W. (2001) *EPA's Arsenic Rule: The Benefits of the Standard Do Not Justify the Costs*, AEI-Brookings Joint Center for Regulatory Studies, Regulatory Analysis 01-02, January 2001

California Energy Commission, 2002, The Energy Story, Chapter 8, URL: <http://www.energyquest.ca.gov/story/index.html>

Caplan, B. (2007) *The Myth of the Rational Voter: Why Democracies Choose Bad Policies*, Princeton University Press, Princeton, NJ.

Caplan, B. (2010) *Persuasion, slack, and traps: how can economists change the world?* Public Choice, 142(1-2), 1-8

Cappiello, D. (2009) Poll: US Belief in Global Warming Is Cooling, URL: <http://abcnews.go.com/US/wireStory?id=8889500>, retrieved: 11/01/2009

Center for Responsive Politics (2009a) *Energy/Natural Resources: Money to Congress (2006 election cycle)*, URL: <http://www.opensecrets.org/industries/summary.php?ind=E&cycle=2006&recipdetail=S&sortorder=N&mem=Y>, retrieved: 10/01/2009

Center for Responsive Politics (2009b) *Energy/Natural Resources: Money to Congress (2008 election cycle)*, URL: <http://www.opensecrets.org/industries/summary.php?ind=E&recipdetail=S&sortorder=N&cycle=2008>, retrieved: 10/01/2009

Center for Responsive Politics (2009c) *Environment: Money to Congress (2006 election cycle)*, URL: <http://www.opensecrets.org/industries/summary.php?ind=Q11&cycle=2006&recipdetail=S&sortorder=N&mem=Y>, retrieved: 10/01/2009

Center for Responsive Politics (2009d) *Environment: Money to Congress (2008 election cycle)*, URL: <http://www.opensecrets.org/industries/summary.php?ind=Q11&recipdetail=S&sortorder=N&cycle=2008>, retrieved: 10/01/2009

Center for Responsive Politics (2009e) *Lobbying Summary: Peabody Energy*, URL: <http://www.opensecrets.org/lobby/clientsum.php?year=2008&lname=Peabody+Energy&id=>, retrieved: 10/01/2009

Center for Responsive Politics (2009f) *Lobbying Summary: Rio Tinto Group*, URL: <http://www.opensecrets.org/lobby/clientsum.php?year=2008&lname=Rio+Tinto+Group&id=>, retrieved: 10/01/2009

Center for Responsive Politics (2009g) *Lobbying Summary: Arch Coal*, URL: <http://www.opensecrets.org/lobby/clientsum.php?year=2008&lname=Arch+Coal&id=>, retrieved: 10/01/2009

Center for Responsive Politics (2009h) *Lobbying Summary: National Mining Assn*, URL: <http://www.opensecrets.org/lobby/firmsum.php?year=2008&lname=National+Mining+Assn&id=>, retrieved: 10/01/2009

- Center for Responsive Politics (2009i) *Lobbying Summary: American Cltn for Clean Coal Electricity*, URL: <http://www.opensecrets.org/lobby/clientsum.php?year=2008&lname=American+Cltn+for+Clean+Coal+Electricity&id=>, retrieved: 10/01/2009
- Center for Responsive Politics (2009j) *Lobbying Summary: Seirra Club*, URL: <http://www.opensecrets.org/pacs/lookup2.php?strID=C00135368&cycle=2008>, retrieved: 10/01/2009
- Chen, L, Chau, M. M., Sheng, Chou, S. J., Stucki, J. W. (2009) *Producing Fired Bricks Using Coal Slag from a Gasification Plant in Indiana*, 2009 World of Coal Ash (WOCA) Conference, May 4-7, 2009 in Lexington, KY, USA
- Childress, J. (2005) Coal Gasification & IGCC/Polygen Performance & Prospects for the U.S., in (2005) Platts IGCC Symposium. 2005: Pittsburgh, PA.
- Chmielniak, T., Sciazko, M. (2003) *Co-gasification of biomass and coal for methanol synthesis*, Applied Energy, 74 (3-4), pp. 393-403
- Clark, G. and Jacks, D. (2008) *Coal and the Industrial Revolution, 1700-1869*, Working Paper, UC Davis., URL: http://gpih.ucdavis.edu/files/Clark_Jacks.pdf, retrieved: 05/25/2009
- Coase, R.H. (1960) *The Problem of Social Cost*, Journal of Law and Economics, October 1960, pp. 1-44.
- Collins, W. J., Derwent, R. G., Garnier, B., Johnson, C. E., Sanderson, M. G., Stevenson, D. S. (2002) *Effect of stratosphere-troposphere exchange on the future tropospheric ozone trend*, Journal of Geophysical Research, Vol. 108, No. D12
- Conoco Phillips (2005) *E-Gas Technology for Coal Gasification*, [presentation for] Indiana Utility Regulatory Commission, URL: http://www.narucpartnerships.org/Documents/Terre_Haute_Wabash_Coal_Gasification_Plant.pdf, retrieved: 09/26//2009
- Cruenspecht, H. K., Stavins, R. N. (2002) *New Source Review Under the Clean Air Act*, Resources, Spring 2002, Issue 147, pp. 19-23
- Cragg, M. I., Kahn, M. E. (2009) Carbon Geography: The Political Economy of Congressional Support for Legislation Intended to Mitigate Greenhouse Gas Production, NBER Working Paper No. 14963, URL: <http://mek1966.googlepages.com/w14963.pdf>, retrieved: 1/3/2010

Crain and Tollison (1979) *The executive branch in the interest-group theory of government* *Journal of Legal Studies* 8, pp. 555-67; also in Rowley ed. Volume III, 3-15.

Cruenspecht, H. K., Stavins, R. N. (2002) *New Source Review Under the Clean Air Act*, Resources, Spring 2002, Issue 147, pp. 19-23

Daily, G., Ellison, K. (2002) *The New Economy of Nature*, Island Press, Washington D.C.

Davis, R. E. (2005) *Climate Change and Human Health*, in Michaels, P. J. (eds) 2005, pp.183-209

Di Giulio, R. T., Hinton, D. E. (eds) (2008) *The Toxicology of Fishes* (1st edition), CRC Press, Boca Raton, FL

Downs, A. (1957) *An Economic Theory of Democracy*. New York: Harper, 1957.

Energy Action Coalition, The (2009) *Power Shift 2009*, URL: <http://www.energyactioncoalition.org/about/history>, retrieved: 1/24/2010

Energy Foundation (2010) *Board of Directors*, URL: http://www.ef.org/contact_board.cfm, retrieved: 1/24/2010

Entech Solar, Inc. (2009) *ENTECH SOLAR, INC. - FORM 10-Q - November 9, 2009*, URL: http://www.faq.s.org/sec-filings/091109/ENTECH-SOLAR-INC_10-Q/, retrieved: 1/24/2010

Entech Solar, Inc. (2010) Board, URL: <http://www.entechsolar.com/board.php>, retrieved: 1/24/2010

European Commission (2008). *Emission Trading Scheme (EU ETS)*. Retrieved October 2, 2008, from Europa, Web site: http://ec.europa.eu/environment/climat/emission/index_en.htm

Forbes Magazine, The (2010) *Rose E. McKinney-James, J.D.*, URL: <http://people.forbes.com/profile/rose-e-mckinney-james-j-d-/29324>, retrieved: 1/24/2010

FutureGen (2008a) *Clean energy starts here. FutureGen*, Last updated November 2008, retrieved: 02/18/2009, URL: <http://www.futuregenalliance.org>

FutureGen (2008b) Alliance Members, URL: <http://www.futuregenalliance.org/alliance/members.stm>, Last Updated: November 2008, retrieved: 09/26/2009

Hansen, J. (2009) *The Enemy of the Human Race*, Sierra, Vol. 94, Issue 3, May/June 2009

Hausfather, Z. (2008) Global Temperature Records, *The Yale Forum on Climate Change*, URL: <http://www.yaleclimatemediaforum.org/2008/04/common-climate-misconceptions-global-temperature-records/>, retrieved: 05/14/2009

Hayward, S. F. (2003) *Making Sense of "New Source Review"*, AEI (American Enterprise Institute for Public Policy Research) Outlook Series, July 2003, URL: <http://www.aei.org/outlook/18961>, retrieved: 11/20/2009

Helland, E., Matsuno, M. (2003) *Pollution Abatement as a Barrier to Entry*, Journal of Regulatory Economics, 24:2 243-259

Herzog, H. J. (2001) *What Future for Carbon Capture and Sequestration?* Environmental Science & Technology, 35(7), pp. 148A-153A

Hester, T. D., Armstrong, M. J. (2009) A Flood of Climate Change Tort Cases, Power News, December 1, 2009, URL: http://www.powermag.com/issues/departments/legal_and_regulatory/A-Flood-of-Climate-Change-Tort-Cases_2300.html, retrieved: 12/10/2009

Hickman, L, Randerson, J. (2009) *Climate sceptics claim leaked emails are evidence of collusion among scientists*, Guardian, November 20, 2009, URL: <http://www.guardian.co.uk/environment/2009/nov/20/climate-sceptics-hackers-leaked-emails>, retrieved: 2/16/2010

Hocking, M. B. B. (2006) *The Handbook of Chemical Technology and Pollution Control* (3rd Edition), Academic Press, San Diego, CA

Holdren, J. P. (2007) *Linking Climate Policy with Development Strategy in Brazil, China, and India*, Final Report to The William and Flora Hewlett Foundation From The Woods Hole Research Center, Woods Hole Research Center, November 15, 2007

Hsu, S. L. (2006) *What's Old Is New: The Problem with New Source Review*, Regulation, Spring 2006, CATO Institute

Humphrey, M. (2009) *Rational Irrationality and the 'Paradox' of Climate Change*, BC Journal of International Affairs, V12, Spring 2009

Iannaccone, L. R. (1992) *Sacrifice and Stigma: Reducing Free-riding in Cults, Communes, and Other Collectives* The Journal of Political Economy, Vol. 100, No. 2, pp. 271-291

International Center for Technology Assessment (undated) *Chronology of the Global Warming Case Against the EPA*, URL: <http://www.icta.org/doc/GHG%20Case%20Chronology.pdf>, retrieved: 11/20/2009

- Jensen, M. E. and Bourgeron P. S. (2001) *A Guidebook for Integrated Ecological Assessments*, Springer, New York, NY
- John, D., Paddock, L (2003) *Clean Air and the Politics of Coal*, Issues in Science and Technology, Winter 2003, URL: <http://www.issues.org/20.2/john.html>, retrieved: 11/20/2009
- Johnson, B. (2009) Cleaning Up The Polluter Influence On Waxman-Markly, Think Progress, May 22, 2009, URL: <http://wonkroom.thinkprogress.org/2009/05/22/cleaning-waxman-pollution/>, retrieved: 1/24/2010
- Johnson, N., Yang, C., Ogden, J. (2007) H2 Production via Coal Gasification, Advanced Energy Pathways (AEP) Project, Public Interest Energy Research (PIER) Program, California Energy Commission, URL: <http://steps.ucdavis.edu/People/cyang/aep/techology-assessments/AEP%20Tech%20Assessment%20-%20H2%20from%20Coal.doc>, retrieved: 9/26/2009
- Kahrl, F., Roland-Holst, D. (2006) *China's Carbon Challenge: Insights from the Electric Power Sector*, Research Paper No. 110106, Center for Energy, Resources, and Economic Sustainability, University of California, URL: http://are.berkeley.edu/~dwrh/CERES_Web/Docs/CCC_110106.pdf, retrieved: 09/26/2009
- Kasper , W. (2007) *The Political Economy of Global Warming, Rent Seeking and Freedom*, International Policy Press a division of International Policy Network
- Keohane, N. O., Mansur, E. T., Voynov, A. (2009) *Averting Regulatory Enforcement: Evidence from New Source Review*, Journal of Economics & Management Strategy, Volume 18, Number 1, Spring 2009, pp. 75–104
- Knight, F. H. (1921/2009) *Risk, Uncertainty and Profit*, (eds. McClure, J.), Signalman Publishing, Kissimmee, FL
- Kraus, N., Malmfors, T., Slovic, P. (1992) *Intuitive Toxicology: Expert and Lay Judgments of Chemical Risks*, Risk Analysis, 12(2) pp. 215-232
- Krautkremer, J. A. (2005) Economics of Natural Resource Scarcity: The State of the Debate, Resource for the Future, Washington, D.C., URL: <http://www.rff.org/Documents/RFF-DP-05-14.pdf> (retrieved: 1/27/2009)
- Krichene, N. (2002) *World crude oil and natural gas: a demand and supply model*, Energy Economics 24 (2002) 557–576

Kruizea, H., Hänninenb, O., Breugelmansa, O., Lebreta, E., Jantunenb, M. *Description and demonstration of the EXPOLIS simulation model: Two examples of modeling population exposure to particulate matter*, Journal of Exposure Analysis and Environmental Epidemiology (2003) 13, 87–99

Krupnick, A., Morgenstern, R. (2002) *The Future of Benefit-Cost Analyses of the Clean Air Act*, Annual Review of Public Health, Vol. 23, pp. 427–48

Krutilla, J. V. 1967. *Conservation Reconsidered*. American Economic Review 57 (4): 777-786

Landrigan, P. J., Schechter, C. B., Lipton, J. M., Fahs, M. C., Schwarts, J. (2002) *Environmental Pollutants and Disease in American Children: Estimates of Morbidity, Mortality, and Costs for Lead Poisoning, Asthma, Cancer, and Developmental Disabilities*, Environmental Health Perspectives, Vol. 110, No. 7, pp. 721-728

List, John A.; Millimet, Daniel L.; and McHone, Warren (2004) *The Unintended Disincentive in the Clean Air Act*, Advances in Economic Analysis & Policy: Vol. 4 : Iss. 2, Article 2.

Lowe, E. (2005) GE's Gasification Development, in Gasification Technologies Council. 2005: San Francisco, CA.

Lowry, R. C. (1998) *Religion and the demand for membership in environmental citizen groups*, Public Choice, Volume 94, Numbers 3-4

Maatta, K (2006) *Environmental Taxes: An Introductory Analysis*, Edward Elgar, Northhampton, MA

Martelle, S. (2009) *Killing King Coal*, Sierra Vol. 94, Issue 2, Mar/Apr 2009

Max W, Rice DP, Sung H-Y, Michel M. (2002) *Valuing Human Life: Estimating the Present Value of Lifetime Earnings*, 2000. San Francisco:Institute for Health & Aging.

McMullan, J. T. Williams, B. C., Sloan, E. P. (1997) *Clean coal technologies* Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, Volume 211, Number 1, pp. 95-107

Meadows, D.H., Randers, J., Meadows, D. L. 1972 [2004] *Limits to Growth: The 30-year Update*, Chelsea Green, White River Junction, VT 2004

Mendelsohn, R. (2008) *Is the Stern Review an Economic Analysis?* Review of Environmental Economics and Policy 2 (1): 45-60

- Mendelsohn, R., W. D. Nordhaus and D. Shaw. (1994) *The impact of global warming on agriculture: a Ricardian analysis*. *American Economic Review* 84(4) (September) 753-71.
- Michaels, P. J. (2005) *Shattered Consensus*, Rowman & Littlefield, Lanham, Maryland
- Michaels, P. J., Balling, R. C. Jr. (2009) *Climate of Extremes: Global Warming Science They Don't Want You to Know*, Cato Institute, Washington D. C.
- MIT, Massachusetts Institute of Technology (2007) *The Future of Coal*, An Interdisciplinary MIT Study, retrieved: 2/25/2009, URL: <http://web.mit.edu/coal/>
- Mixon, F. G. (1995), *Public choice and the EPA: empirical evidence on carbon emission violations*, *Public Choice*, 83, 127–37.
- Molnia, C. L, Osmonson, L.M., Wilde, E.M., Biewick, R.H., Rohrbacher, T.J., Carter, M.D. (1999) *Coal availability and recoverability studies in the Powder River Basin, Wyoming and Montana*, U.S. Geological Survey Professional Paper
- Moore, M. (2009) *Lord Lawson calls for public inquiry into UEA global warming data 'manipulation'*, *Telegraph*, November 23, 2009, URL: <http://www.telegraph.co.uk/earth/environment/globalwarming/6634282/Lord-Lawson-calls-for-public-inquiry-into-UEA-global-warming-data-manipulation.html>, retrieved: 1/15/2010
- MPCA (Minnesota Pollution Control Agency) (2006) *Comparison of Nitrogen Oxides, Sulfur Dioxide, Particulate Matter, Mercury and Carbon Dioxide Emissions for IGCC and Other Electricity Generation*, URL: http://legalectric.org/f/2007/05/ago_docs-1696085-v1-excelsior_energy_final_emission_comparison_anne_jackson-overland.pdf, retrieved: 10/04/2009
- Mufson, S. (2008) *Coal Industry Plugs Into the Campaign*, *The Washington Post*, January 18, 2008, URL: <http://www.washingtonpost.com/wp-dyn/content/article/2008/01/17/AR2008011702837.html>, retrieved: 10/1/2009
- Muller, N. Z., Mendelsohn, R. (2007) *Measuring the damages of air pollution in the United States*, *Journal of Environmental Economics and Management* Volume 54, Issue 1, pp. 1-14
- Mummey, D. L., Stahl, P. D. and Buyer, J. S. (2002) *Applied Soil Ecology*, Volume 21, Issue 3, October-November 2002, Pages 251-259
- Maloney, M. T., Brady, G. L. (1988), *Capital turnover and marketable pollution rights*, *Journal of Law and Economics*, 31, 203–26.

- Melnick, R. S. (1983) *Regulation and the courts: the case of the Clean Air Act*, Brookings Institution Press, Washington, D.C.
- Nash, J. R., Revesz, R. L. (2007) *Grandfathering and Environmental Regulation: The Law and Economics of New Source Review*, Northwestern University Law Review, Vol. 101, No. 4, pp. 1677-1733
- National Energy Technology Laboratory (2009) *Tracking New Coal-Fired Power Plants*, URL: <http://www.netl.doe.gov/coal/refshelf/ncp.pdf>, retrieved: 09/26/2009
- National Wildlife Federation (2010) About the National Wildlife Federation, URL: <http://www.nwf.org/About.aspx>, retrieved: 1/24/2010
- Nicholas, D. E. (1992) *Chapter 23.1 Section Variables* in Hartman, H. L. (eds) *SME mining engineering handbook*, Volume 1, 2nd edition, Society for Mining Metallurgy & Exploration, 1992
- Nichols, M. (2008) *Gore urges civil disobedience to stop coal plants*, Reuters, September 24, 2008, URL: <http://www.reuters.com/article/idUSTRE48N7AA20080924>, retrieved: 2/16/2010
- Nisbet, M. C. and Myers, T. *Twenty Years of Public Opinion about Global Warming* Public Opinion Quarterly 2007 71(3):444-470
- Niskanen, W. A. (1971) *Bureaucracy and representative government*, Aldine Transaction, Piscataway, N.J.
- North, D. C. (1991) *Institutions*, Journal of Economic Perspectives, Vol 5, No. 1, pp. 97-112
- North, D. C. (1993) *Institutions, Transaction Costs and Productivity in the Long Run*, Economics Working Paper Archive (EconWPA), URL: <http://129.3.20.41/eps/eh/papers/9309/9309004.pdf>, retrieved: 11/20/2009
- Olson, M. (1965). *The Logic of Collective Action*. Harvard University Press.
- Pallera, M.H., Littrell, J. W. (2007) *Long-term changes in mercury concentrations in fish from the middle Savannah River*, Science of The Total Environment, Volume 382, Issues 2-3, 1 September 2007, Pages 375-382
- Parfomak, P. W., Folger, P. (2007) *Carbon Dioxide (CO₂) Pipelines for Carbon Sequestration: Emerging Policy Issues*, CRS Report for Congress, April 19, 2007

Pashigian, B. P. (1984), *The effects of environmental regulation on optimal plant size and factor shares*, *Journal of Law and Economics*, 27, 1–28.

Pashigian, B. P. (1985), *Environmental regulation: whose interests are being protected?*, *Economic Inquiry*, 23, 551–84.

Perman, R., Ma, Y., McGilvray, J. and Common, M. (2003) *Natural Resource and Environmental Economics*, Pearson Addison Wesley, New York, NY. (3rd Edition)

Pew Research Center for the People and the Press (2009) *Fewer Americans See Solid Evidence of Global Warming*, URL: <http://people-press.org/report/556/global-warming>, retrieved: 10/01/2010

Phillips, J. (2005) *Coal Gasification 101*, Electric Power Research Institute, URL: <http://www.netl.doe.gov/technologies/coalpower/gasification/pubs/bizmark-2006/01Phillips.pdf>, retrieved: 09/26/2009

Pindyck, R.S., (1979) *The Structure of World Energy Demand*. MIT Press, Cambridge, MA.

Pope, C. (2009) *Debating Chevron*, June 11, 2009, URL: <http://sierraclub.typepad.com/carlpope/2009/06/debating-chevron.html>, retrieved: 1/24/2010

Pooley, E. (2009) *How Much Would You Pay to Save the Planet? The American Press and the Economics of Climate Change*, Joan Shorenstein Center on the Press, Politics and Public Policy Discussion Paper Series

Pouris, A. (1987) *On the Economics of Nuclear and Coal – Fired Electricity Generation*, *South African Journal of Economics* 55(4): 267 - 276.

Prothero, D. R., Dott, H. D (2003) *Evolution of the Earth*, 7th Edition, McGraw-Hill, New York, NY

Ramanathan, V. (1988) *The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment*, *Science* 15 April 1988: Vol. 240. no. 4850, pp. 293 – 299
RGGI (2009) *About RGGI*, URL: <http://www.rggi.org/about>, retrieved: 03/29/2009

Ratafia-Brown, J. A., Manfredo, L. M., Hoffmann, J. W., Ramezan, M, Stiegel, G., J. (2002) *An Environmental Assessment of IGCC Power Systems*, Presented at the Nineteenth Annual Pittsburgh Coal Conference

Reddy, N. (1985) *Market boundaries between coal, oil, and natural gas*, *Review of Industrial Organization*, Volume 2, Number 3 / September, 1985

Renewable Energy Policy Network for the 21st Century (2008) Renewables 2007 Global Status Report, URL: http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf (retrieved: 1/15/2009)

Rice, S. A. (2003) *Health Effects of Acute and Prolonged CO₂ Exposure in Normal and Sensitive Populations*, Second Annual Conference of Carbon Sequestration, May 5-8, 2003, URL: <http://www.netl.doe.gov/publications/proceedings/03/carbon-seq/PDFs/173.pdf>, retrieved: 9/1/2009

Richtel, M. (2007) Investment Firm Names Gore as a Partner, The New York Times, November 13, 2007, URL: http://www.nytimes.com/2007/11/13/technology/13gore.html?_r=2, retrieved: 11/1/2010

Rio Tinto (2010) *What we produce: Minerals and metals for the world*, URL: http://www.riotinto.com/index_whatweproduce.asp, retrieved: 1/24/2010

Rout, U. K., Akimoto, K., Sano, F., Oda, J., Homma, T., Tomoda, T. (2008) *Impact assessment of the increase in fossil fuel prices on the global energy system, with and without CO₂ concentration stabilization*, Energy Policy 36 (2008) 3477– 3484

Rowley, C.K. (1997) *Introduction: The relevance of public choice for constitutional political economy*, Public Choice v90: p1-10

Rowley, C.K., Smith, N. (2009) *Economic Contractions in the United States: A Failure of Government*, The Locke Institute, Fairfax VA

Rubin O.D., Carriquiry, M. Hayes, D.J. (2008): Implied Objectives of U.S. Biofuel subsidies, Working Paper, URL: <http://ageconsearch.umn.edu/bitstream/6333/2/wp080459.pdf>, retrieved: 1/3/2010

Runge, F., Senauer, B. (2007) *How Biofuels Could Starve the Poor*, Foreign Affairs, V. 86, pp.41-53

Saad, L. (2009) *Increased Number Think Global Warming Is “Exaggerated”*, URL: <http://www.gallup.com/poll/116590/increased-number-think-global-warming-exaggerated.aspx>, retrieved: 11/01/2009

Seibel, B. A., Walsh, P. J. (2001) *Potential Impacts of CO₂ Injection on Deep-Sea Biota*, Science 294(5541), pp. 319 – 320

Schwartz, S. E. (1994) *Atmospheric Heating and Cooling from Fossil-Fuel Combustion*, CDIAC (Carbon Dioxide Information Analysis Center) Communications, Fall 1994, Issue No. 20

Sierra Club, The (2010) Sierra Club Home Page: Explore, Enjoy and Protect the Planet, URL: <http://www.sierraclub.org/>, retrieved: 1/24/2010

Singer, S. F. (2008) (eds.) *Nature, Not Human Activity, Rules the Climate, Summary for Policymakers of the Report of the Nongovernmental International Panel on Climate Change*, The Heartland Institute, February, 2008.

Soon, W., Baliunas, S. (2003) *Proxy climatic and environmental changes of the past 1000 years*, *Climate Research*, Vol. 23: 89–110, January 2003

Soon, W., Baliunas, S., Idso, S. B., Kondratyev, K. Y., Posmentier, E. S. (2001), *Modeling climatic effects of anthropogenic carbon dioxide emissions: unknowns and uncertainties*, *Climate Research*, Vol. 18: 259–275, November 2001

Source Watch (2009a) Existing U.S. Coal Plants, URL: http://www.sourcewatch.org/index.php?title=Existing_U.S._Coal_Plants, updated: September 5, 2009, retrieved: 09/26/2009

Source Watch (2009b) Coal plants cancelled in 2007, URL: http://www.sourcewatch.org/index.php?title=Coal_plants_cancelled_in_2007, updated: September 5, 2009, retrieved: 09/26/2009

Spadaro, J. V., Rabl, A. (2002) *Air pollution damage estimates: the cost per kilogram of pollutant*, *Int. J. Risk Assessment and Management*, Vol. 3, No. 1, pp. 75-98

St. John, G (2008) *Protestival: Global Days of Action and Carnivalized Politics in the Present*, *Social Movement Studies*, Vol. 7, No. 2, 167–190

Stern, N. (2007) *The Economics of Climate Change: The Stern Review* (Cambridge Univ. Press, Cambridge, UK, 2007).

Stevens, T. H., Blake, M. J., Williams, L. G. (1979) *Demand for Coal: The Problem of Aggregation*, *Western Journal of Agricultural Economics*, 1979, vol. 04, issue 01

Sugar, M. (2007) *Massachusetts v. Environmental Protection Agency*, *Harvard Environmental Law Review*, Vol 21, pp. 531-544

TEEIC (Tribal Energy and Environmental Information Clearinghouse) (undated) *Coal Mining Technologies*, URL: <http://teeic.anl.gov/er/coal/restech/tech/index.cfm>, retrieved: 8/12/2009

Tetreault, S. (2008) *Las Vegas woman selected for Obama's transition team*, Las Vegas Review Journal, November 18, 2008, URL: <http://www.lvrj.com/news/34633879.html>, retrieved: 1/24/2010

Tol, R. S. J. (2005) *The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties*, Energy Policy Volume 33, Issue 16, pp. 2064–2074

Tollison, R.D. (2003) *Legislators* in Rowley and Schneider (eds) Volume II, pp. 353-356. Rowley, C.K. and Schneider, F. (eds) (2003) *The Encyclopedia of Public Choice*, Volumes I and II, Kluwer Academic Publishers, Volumes I and II.

Trasande, L., Landrigan, P. J., Schechter, C. (2005) *Public Health and Economic Consequences of Methyl Mercury Toxicity to the Developing Brain*, Environmental Health Perspectives, Vol. 113, No. 5, pp. 590-596

Tullock, G. (1997) *The case against the common law* in Tullock, G. (2005). *Law and Economics*. (Ed. Rowley, C. K.). Vol. 9 in *The Selected Works of Gordon Tullock*, Liberty Fund, Indianapolis, IN.

TVA (Tennessee Valley Authority) (2009) *TVA Reports First Quarter Net Loss, Expenses For Ash Spill Recovery*, February 12, 2009, URL: http://www.tva.gov/news/releases/janmar09/1st_quarter.htm, retrieved: 8/12/2009
USATSDR (2009) *Agency for Toxic Substances and Disease Registry*, Last updated: February 2, 2009, retrieved: 02/08/2009, URL: <http://www.atsdr.cdc.gov>

US Census Bureau (2009) *State & County QuickFacts > USA*, URL: <http://quickfacts.census.gov/qfd/states/00000.html>, retrieved: 9/1/2009

USCIA (2009) *The World Factbook*, URL: <https://www.cia.gov/library/publications/the-world-factbook/geos/us.html>, retrieved: 9/1/2009

USDOE (2009a) *FutureGen Clean Coal Project*, URL: <http://www.fossil.energy.gov/programs/powersystems/futuregen/>, updated on: July 14, 2009, retrieved: 09/26/2009

USDOE (2009b) *Secretary Chu Announces Agreement on FutureGen Project in Mattoon, IL*, USDOE press release June 12, 2009, URL: <http://www.energy.gov/news2009/print2009/7454.htm>, retrieved: 09/26/2009

USEIA (2008a) *International Energy Outlook 2008*, URL: <http://www.eia.doe.gov/oiaf/ieo/index.html> (retrieved 1/2/2009)

USEIA (2008b) Average Heat Content of Fossil-Fuel Receipts, Electric Power Monthly with data for September 2008, Released: December 12, 2008, URL: <http://www.eia.doe.gov/cneaf/electricity/epm/tablec1.html>

USEIA (2008c) Energy Kid's Page, Coal – A Fossil Fuel, URL: <http://www.eia.doe.gov/kids/energyfacts/sources/non-renewable/coal.html> , last revised: July 2008, retrieved: 05/25/2009

USEIA (2008d) *Frequently Asked Questions – Electricity*, Last updated: April 16, 2008, retrieved: 02/10/2009, URL: http://tonto.eia.doe.gov/ask/electricity_faqs.asp

USEIA (2009a) *Energy Information Sheet Index > Coal Production*, URL: <http://www.eia.doe.gov/neic/infosheets/coalproduction.html>, retrieved: 8/12/2009

USEIA (2009b) *International Energy Outlook 2009*, URL: <http://www.eia.doe.gov/oiaf/ieo/highlights.html>, retrieved: 9/1/2009

USEIA (2009c) *Electricity > U.S. Data > Electric Power Plants > Existing Generating Capacity by Fuel Type (2008 Preliminary)*, URL: <http://www.eia.doe.gov/cneaf/electricity/page/capacity/existingunitsbs2008.xls>, retrieved: 09/26/2009

USEIA (2009d) *Electric Power Annual, Electric Power Industry 2007: Year in Review*, URL: http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html, retrieved: 09/26/2009

USEIA (2009e) Emissions of Greenhouse Gases in the United States 2008, URL: <ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/ggrpt/057308.pdf>, retrieved: 11/20/2009

USEIA (2010) *Coal Reserves Current and Back Issues*, Data for 2008, Report Released: February 17, 2010. URL: <http://www.eia.doe.gov/cneaf/coal/reserves/reserves.html>, retrieved: 3/19/2010

USEPA (1998a) *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units -- Final Report to Congress*, Volume 1, February 1998

USEPA (1998b) Memorandum, Subject: EPA's Authority to Regulate Pollutants Emitted by Electric Power Generation Sources, Apr. 10, 1998, URL: <http://www.law.umaryland.edu/faculty/bpercival/casebook/documents/epaco2memo1.pdf>, retrieved: 11/20/2009

USEPA (2000) *Fact Sheet, EPA to Regulate Mercury and Other Air Toxics Emissions from Coal- and Oil-Fired Power Plants*, December 14, 2000, URL: http://www.epa.gov/ttn/oarpg/t3/fact_sheets/fs_util.pdf

USEPA (2003a) *National Air Quality and Emissions Trends Report 2003*, Appendix A. retrieved: 02/08/2009, URL: <http://www.epa.gov/air/airtrends/aqtrnd03/>

USEPA (2003b) *Control of Emissions From New Highway Vehicles and Engines*, Federal Register, Vol. 68, No. 173, Monday, September 8, 2003, URL: <http://edocket.access.gpo.gov/2003/pdf/03-22769.pdf>, retrieved: 11/20/2009

USEPA (2008) U.S. Greenhouse Gas Inventory Reports: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006 (April 2007), URL: <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

USEPA (2009a) *Particulate Matter*, Last updated: January 15, 2009, retrieved: 02/08/2009, URL: <http://www.epa.gov/particles/>

USEPA (2009b) *Six Common Air Pollutants*, URL: <http://www.epa.gov/air/urbanair/>, last updated: Monday, June 29th, 2009, retrieved: 8/16/2009.

USEPA (2009d) *New Source Review (NSR)*, URL: <http://www.epa.gov/NSR/>, Updated: November 2, 2009, retrieved: 11/20/2009

USEPA (2009d) *New Source Review (NSR), Basic Information*, URL: <http://www.epa.gov/NSR/info.html>, Updated: May 28, 2009, retrieved: 11/20/2009

USEPA (2009e) *Air Emission Sources: Sulfur Dioxide*, URL: <http://www.epa.gov/air/emissions/so2.htm>, Updated: November 4, 2009, retrieved: 11/20/2009

USNASA (2008) *Satellite Measures Pollution From East Asia to North America, March, 17, 2008*, Retrieved: 02/10/2009, URL: http://www.nasa.gov/topics/earth/features/pollution_measure.html

US NASA (2009) GISS Surface Temperature Analysis, Last modified: 2009-02-09, retrieved: 02/21/2009, URL: <http://data.giss.nasa.gov/gistemp/graphs>

US NOAA Mauna Loa Observatory (2008) Scripps Carbon Dioxide (CO₂) Measurements, Page created on November 3, 2008, retrieved: 02/21/2009, URL: <http://www.mlo.noaa.gov/programs/coop/scripps/co2/co2.html>

USNIH (2009) *Medical Encyclopedia: Lead poisoning*, URL: <http://www.nlm.nih.gov/MEDLINEPLUS/ency/article/002473.htm>, update date: 3/14/2009, retrieved: 8/19/2009

USOSM (Office of Surface Mining Reclamation and Enforcement) *Surface Mining Law*, URL: <http://www.osmre.gov/topic/SMCRA/SMCRA.shtm>, last updated Last Updated 00/00/2008⁴², retrieved: 8/16/2009

U.S. House of Representatives (2009) *Subcommittee on Energy and Environment*, URL: <http://www.speaker.gov/newsroom/pressreleases?id=0038>, retrieved: 10/1/2009

U.S. Office of the Speaker (2007) Pelosi Announces the Creation of Select Committee on Energy Independence and Global Warming, Press Release January 18, 2007, URL: <http://www.speaker.gov/newsroom/pressreleases?id=0038>, retrieved: 10/1/2009

U.S. Senate (2008) *U.S. Senate Roll Call Votes 110th Congress - 2nd Session*, URL: http://www.senate.gov/legislative/LIS/roll_call_lists/roll_call_vote_cfm.cfm?congress=110&session=2&vote=00145

Watson, J. (2005) *Advanced Cleaner Coal Technologies for Power Generation: Can they deliver?* Paper for the 2005 BIEE Academic Conference: European Energy – Synergies and Conflicts

Weingast, B. R. and Marshall, W.J. (1988) *The Industrial Organization of Congress* JPE 1988, pp. 132-63 and in Rowley (ed) Volume II, pp. 443-474.

West, P. (2007) *Al Gore, 'The Goracle'*, Baltimore Sun, March 21, 2007, URL: <http://www.nhne.org/news/NewsArticlesArchive/tabid/400/articleType/ArticleView/articleId/2789/language/en-US/Al-Gore-The-Goracle.aspx>, retrieved: 11/1/2009

Wrigley, E.A. 1962. 'The Supply of Raw Materials in the Industrial Revolution,' *Economic History Review* 15(1), 1-16.

Xiao, R., Zhang, M., Jin, B., Xiaong, Y., Zhou, H., Duan, Y. Zhong, Z., Chen, X., Shen, L., Huang, Y. (2007) *Air blown partial gasification of coal in a pilot plant pressurized spout-fluid bed reactor*, Fuel, 86 (10-11)

Yandle, B. (1983) Bootleggers and Baptists: The Education of a Regulatory Economist, *Regulation Journal* 7:14-24

Yandle, B. (2001) Bootleggers, Baptists, and Global Warming, *Hoover Digest* 2001 No. 1

Yahoo! Finance (2010a) *Dow Jones Industrial Average*, URL: <http://finance.yahoo.com/echarts?s=DJI#chart3:symbol=DJI;range=19980102,2010123>

⁴² That is what the web page stated, Last Updated 00/00/2008.

1;indicator=volume;charttype=line;crosshair=on;ohlcvvalues=0;logscale=on;source=undefined, retrieved: 1/15/2010

Yahoo! Finance (2010b) *Rio Tinto plc (RTP)*, URL: <http://finance.yahoo.com/q?s=RTP>, retrieved: 1/24/2010

Yahoo! Finance (2010b) *Peabody Energy Corp. (BTU)*, URL: <http://finance.yahoo.com/q?s=BTU>, retrieved: 1/24/2010

Yahoo! Finance (2010c) *Arch Coal Inc. (ACI)*, URL: <http://finance.yahoo.com/q?s=ACI>, retrieved: 1/24/2010

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