MORTALITY REDUCTIONS FROM USE OF LOW-COST COAL-FUELED POWER: AN ANALYTICAL FRAMEWORK

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December 2002

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EXECUTIVE SUMMARY[1]

It is now widely recognized that wealthier individuals are more likely to live safer, healthier, and longer lives. With more income, individuals tend to spend more on health care for themselves and their children, purchase more safety equipment, eat a more nutritious diet, and take other actions that decrease the likelihood of premature death by illness or accident. Consistent with this fact, individual reductions in disposable income tend to increase health and safety risks and the resulting deaths. Similarly, higher unemployment has been shown to have an adverse effect on safety, health, and longevity.

When regulations are enacted with the intent of reducing certain life-threatening risks, we expect to see benefits in the form of safer, healthier, and longer lives. But at the same time, the economic costs of these regulations – particularly the impacts on income and employment – tend to *worsen* individual health or safety and can shorten lifetimes. A key issue is whether net benefits or net losses in health and safety result from these opposing forces.

In this study, we develop a framework for analyzing the induced adult deaths that could arise from the higher costs of forgoing the use of low-cost coal-fueled power. These potential losses are the health, safety, and longevity gains that coal-fueled power now provides. We analyzed several energy and economic modeling studies that calculated the costs of significant reductions in coal-fueled power. We allocated these costs to different income groups, and then estimated the expected number of adult deaths that would be induced by this loss of income.

For this study, we have relied upon a variety of private and government studies estimating the household income and employment impacts of reduced coal utilization. Most of these studies focused on the Kyoto Protocol, which would be expected to result in large-scale switching from coal to natural gas. We extrapolated the findings of these studies to estimate the national income and employment effects of a hypothetical 100% displacement of coal. These extrapolations, and the related health effects estimates presented in this paper, do not presume any level of coal displacement of any particular policy initiative. Rather, the findings may be scaled on a linear basis to estimate the premature mortality implications of various policy initiatives given estimates of the potential coal displacement resulting from such policies.

Our findings include the following:

- Most of the energy studies we reviewed suggest that fully replacing coal-fueled power in the U.S. could reduce total household income substantially over a multiple year period. The peak year impact in 2010 could reduce total household income by $125 to $225 billion (in year 2000$). This replacement could also increase

[1] Note: The authors acknowledge the financial support of the Association of American Railroads (AAR), the Center for Energy and Economic Development (CEED), Edison Electric Institute (EEI), National Black Chamber of Commerce (NBCC), National Mining Association (NMA), and National Rural Electric Cooperative Association (NRECA). The opinions and views expressed herein are those of the authors, and do not necessarily reflect those of the sponsoring organizations.

unemployment by 2.2 to 4.5 million workers, an increase in the unemployment rate of about 1.4 to 2.9 percentage points. These impacts appear to be persistent, often taking 5-10 years or more before the economy adjusts to higher-cost alternatives.

- The analyses of the relationship between loss of disposable income and the resultant deaths indicate that a regulatory cost of $6.8 to $18.5 million induces one additional adult death. Where these costs are related primarily to electricity use, we estimate that a regulatory cost of about $8.9 million induces one additional adult death. Hence, a reduction in disposable income of about $125 to $225 billion in the year 2010 could be expected to induce 14 to 25 thousand deaths.

- Mortality impacts induced by the loss of disposable income are highly concentrated in lower income groups, and as such also disproportionately affect certain minority groups. Assuming costs are distributed proportional to electricity consumption, households with income under $15,000 (about 16.5% of all households) would incur about 43% of the deaths. In contrast, those households with income over $50,000 (about 40.9% of all households) would incur only about 9% of the deaths.

- The results of this analysis are logically applicable over a wide range of economic costs by proportionately scaling. If the reduction in disposable income is lessened by half, then the induced deaths would also be reduced by half.

These mortality estimates are conservative in that we have focused only on the year 2010 and only on adult deaths induced by economic costs of replacing low-cost coal-fueled power. We discuss – but do not quantify using models – two other major causes of mortality induced by the use of high-cost power:

- ***Income-induced deaths among children.*** The mortality estimates developed in this report are income-induced deaths among the *adult* population. There would also be mortality impacts among *children*, particularly those living in lower-income households.

- ***Unemployment-induced deaths.*** Increases in unemployment stemming from replacing coal-fueled power can have mortality consequences. Studies have examined the linkages between unemployment and health and mortality. These studies have concluded that increases in unemployment result in adverse effects such as cardiovascular mortality, stroke, violence, and suicide. The changes in mortality rates are seen to extend for several years following the changes in employment status.

There are indications that the mortality effects from these two other causes may collectively be similar in magnitude or even larger than the adult deaths resulting from loss of disposable income. However, the models and data to analyze these other causes are less developed, and there is the possibility of double-counting cost-induced mortalities with unemployment-induced mortalities. For these reasons, we have chosen at this time not to quantify potential additional deaths from these other causes. However, our extrapolations from other studies suggest substantial mortality impacts, possibly in excess of 100,000 lives. Such a high potential impact suggests that these causes are important areas for future research.

MORTALITY REDUCTIONS FROM USE OF LOW-COST COAL-FUELED POWER

INTRODUCTION

For decades, coal has been the dominant source of electricity in the United States. As it is abundant, geographically widespread, and inexpensive to mine, coal has been the energy source powering more than half of all electricity use since 1950.[2] Indeed, the availability of low-cost electricity has accelerated the electrification of our energy system, with an ever-growing share of our energy use comprised of electricity.[3]

Proposals are under consideration that could substantially curtail the use of coal as fuel for electricity generation in the United States. Proponents argue that by reducing coal use, there would be further reductions in pollutant emissions, and that this could in turn produce benefits that include improved human health and reductions in mortality.

If coal use were curtailed, a combination of other generation sources and conservation options would have to be deployed in order to maintain our nation's electricity generation capacity.[4] Most of the existing coal-fueled facilities would be replaced by combined cycle powerplants, fueled by more expensive natural gas. Higher fuel costs would result in higher costs for electricity, which would lead to less disposable income available for U.S. residents to meet other household needs.

Numerous studies have indicated that reductions in disposable income result in higher health and safety risks and increased deaths. In addition, regulatory proposals have the potential for increasing unemployment, and here too the literature documents linkages between higher unemployment and the attendant risks to health and life expectation. This set of circumstances creates a fundamental issue for evaluating proposed health and safety regulations that could significantly raise costs to the public. Simply put, are the potential benefits of the proposed action in terms of expected lives saved greater than the detrimental consequences of the proposed action in terms of expected lives lost?

Our analysis provides a framework and information to help examine this important tradeoff issue. Specifically, it provides a method of estimating the number of adult deaths that would be induced by the additional costs of replacing coal-fueled power. Such an estimate can be

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2 Over the 1950-2000 period, coal was the source of over 51 percent of all kilowatt-hours generated in the U.S., ranging from 44 to 57 percent in individual years. See EIA *AER 2000*, Table 8.2.

3 In 1960, 18.1 percent of total energy consumption was in the form of energy input to electric utilities. By 1999, while total energy consumption more than doubled, 34.9 percent of this larger amount went into the generation of electric power. Developed from EIA *SED 1999*, Tables 11, 14.

4 As with coal, these replacement alternatives may have various direct health and safety consequences associated with their operations and use.

viewed as the savings in lives due to the availability of low-cost power. One can then compare these impacts to the benefits estimated to result from reductions in coal-fueled emissions.

Additionally, we have examined the literature on the implications of lower income on child mortality and on the health and mortality impacts associated with potential unemployment increases. However, our efforts on these impacts are more qualitative in nature, as the analytic framework and data underpinnings are less well-established.

HIGHER INCOME PROMOTES SAFER AND HEALTHIER LIVES

In recent decades, government policy has increasingly focused on reducing the risks we face. We have enacted legislation aimed at improving the safety of our workplaces, the cars we drive, the water we drink, the air we breathe, the food we eat, the medicines we take, and much more. Many of the environmental laws we have enacted seek improvement not just as part of our environmental stewardship, but also for the reductions of risks to human health.[5] These actions and others have helped average Americans to live longer and healthier lives.[6]

Almost everyone would agree with the intent of such legislation – to promote a safe and healthy environment. However, any specific regulatory proposal may produce results contrary to this intent. It is important to investigate this possibility for proposals to further reduce emissions by reducing or eliminating use of low-cost coal-fueled power.

It is well documented that people in wealthier countries live longer, and that many impoverished countries suffer from shorter average life spans. Additionally, wealthier individuals within a country live longer on average than poorer individuals.[7] In the 1980s, the noted political scientist Aaron Wildavsky[8] clearly formulated the concept of "richer is safer" (or "wealthier is healthier"), which is echoed in the World Resources Institute's recognition that the "relationship between health and wealth holds true for individuals as well as countries."[9] Two decades of further research have upheld and extended this concept. According to Brenner (2002), the most widespread and strongest research finding in the field of medical population statistics is that the higher the social and economic status of the person (holding age and sex constant), the lower the probability of illness and mortality.

In essence, the link between wealth and health relies on two facts. First, when individuals incur the costs of regulatory actions – whether through higher prices or taxes, or through lower

5 For example, Section 101(b) of the Clean Air Act states a primary purpose of the Act as being "to protect and enhance the quality of the Nation's air resources so as to promote the public heath and welfare and the productive capacity of its population."

6 An American born in 1900 had an average life expectancy of 47.3 years; this average rose to 68.2 years for those born in 1950, and 76.5 years for those born in 1997. See CDC (2001), Table 12.

7 See Kitagawa and Hauser (1973), Sagan (1987), Wilkens *et al.* (1989).

8 See Wildavsky (1980, 1988).

9 See WRI (1998). WRI notes that "regardless of the overall level of a country's wealth, the rich are, as a whole, in better health than the poor."

wages, dividends, or stock prices – less of their income is available for other purposes. Second, individuals use additional disposable income in ways that on average reduce their health and safety risks and therefore reduce deaths. When regulatory costs reduce the disposable income available for other purposes, they can increase other health and safety risks to individuals. Let us consider these facts more carefully.

All expenditures, whether paid by government agencies or companies, are eventually paid by individuals. Ultimately, there is no one else to pay. It is the mechanism by which economic expenditures are passed on to individuals and the distribution of these expenditures that differs from case to case. If expenditures are initially borne by government, increased taxes must be used to pay the bill. Perhaps taxes aren't increased immediately, so expenditures are financed through increased borrowing. This simply increases the interest that must be paid on the federal debt by taxpayers in the future. If expenditures are initially borne by companies, some may increase their product prices, which eventually raises consumer prices. Other companies may, in the short term, cut their profit margins, creating smaller returns for shareholders or lower salaries (or salary raises) for employees. And some companies may be forced to go out of business, which has very significant economic impacts on employees who lose their jobs and shareholders who lose their investment.

There are many mechanisms that support the richer-is-safer and wealthier-is-healthier concepts. Some are directly due to individuals' actions and others are due to societal action. A few examples:

- When individuals have less disposable income, on average the following occur: nutrition is typically poorer, babies will have less prenatal health care, adults may forgo physical exams and preventative medical expenses (e.g. pap smears) and postpone safety purchases (e.g. home fire alarms), and individuals will not attend smoking clinics to stop smoking or spend as much to reduce stress (hire babysitters or pursue recreation).[10]

- A general increase in the standard of living influences societal structure.[11] Health and safety are improved via social mechanisms such as education. With more disposable income, students from poor families will more likely complete high school and attend college. Better education changes both one's knowledge about what is safe and healthy and one's practice to pursue them. For example, sanitary procedures are improved, homes are "child-proofed" to reduce accidents, and more people start wearing seat belts.

- A wealthier society leads to the development of a better and more diverse medical research establishment, to larger markets to stimulate creation of safer products, to an

[10] On the other hand, with more disposable income, some people may change their behavior in ways that increase their mortality risks (e.g. eat more fat-laden foods, or consume too much alcohol). However, the data are clear that the changes in behavior taken by most people with additional disposable income reduce their overall mortality risk. Hence, collectively, mortality is reduced as disposable income increases.

[11] See Wildavsky (1988).

infrastructure of health clubs and many opportunities for exercise, and to the societal resilience to rapidly and efficiently attack new unforeseen problems threatening our collective health and safety.

- A recent report by the World Health Organization found that for 167 countries in 1997, health expenditures were determined mainly by national income, and that each one percent rise in national income led to slightly more than a one percent rise in health spending.[12]

The fact that additional disposable income is used in ways that on average reduce the mortality risks of individuals applies to statistical averages and not necessarily to any specific individual whose behavior and risks contribute to those averages. For some individuals, additional income facilitates riskier and/or unhealthier activities. However, over broad populations the pattern is clear.

These relationships linking income to health, safety, and mortality are most evident for the poor. As the World Resources Institute has noted, of all factors that combine to degrade health, poverty stands out for its overwhelming role.[13] WRI notes that just being poor increases one's risk of ill health. Additionally, poverty contributes to disease and death through its second-order effects, such as living in less healthy environments. WRI also notes that this relationship between health and wealth holds true for both poorer countries and for poorer individuals within wealthier countries.

TRADEOFFS BETWEEN REGULATORY BENEFITS AND COSTS

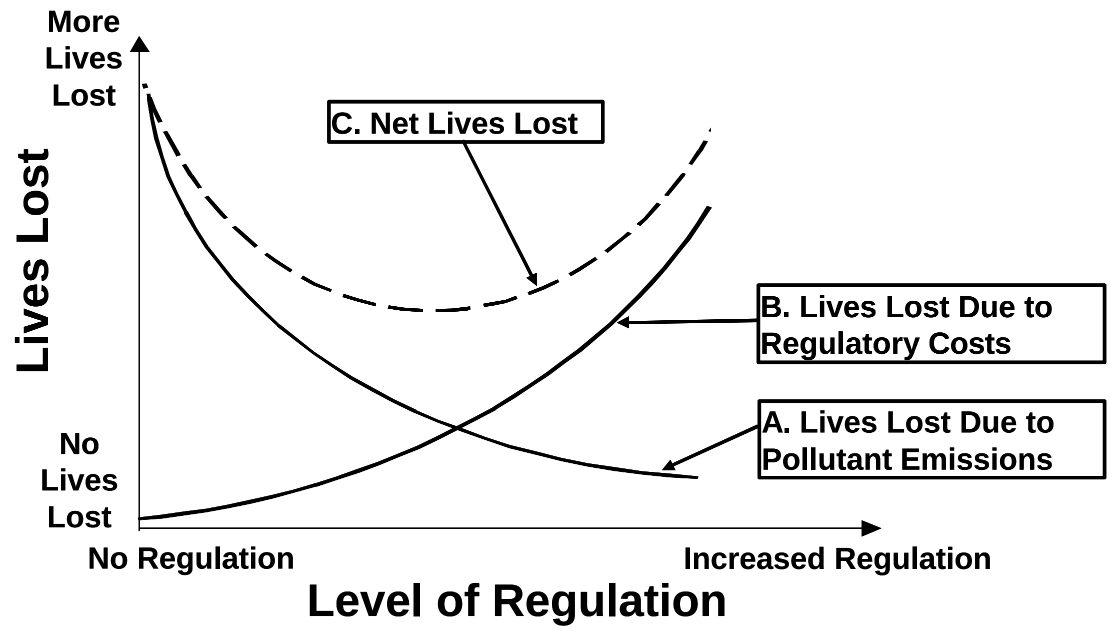
More stringent regulations require a more costly response to conform to them. This in turn reduces disposable income and results in the loss of human life. To illustrate this, consider a range of regulations for emissions from coal-fueled power plants from no regulation to more stringent regulation, as shown in Figure 1.

Figure 1 sketches the relationship between the level of regulation and potential lives lost due to both a pollutant and the regulatory costs. The curve labeled *"A. Lives lost due to pollutant emissions"* declines as higher levels of regulation reduce emissions and the associated health and mortality effects. The curve labeled *"B. Lives lost due to regulatory costs"* increases as higher levels of regulation entail increasingly higher costs of control. The sum of the two curves (i.e., adding the *y*-values at each point along the *x*-axis) is labeled *"C. Net lives lost"* and represents lives lost due to pollution *plus* lives lost due to the costs of regulation. As modest regulations are introduced, they are likely to have a net beneficial health effect – since initial reductions in emissions can often be made at a relatively low cost, the savings in lost lives due to emission reduction would likely be larger than the lives lost due to the cost of the regulation. However, the lives lost may eventually exceed the lives saved as further reductions in emissions entail increasingly higher costs. The main points of this illustration are that (1) if we are interested in

[12] See WHO (2001), p. 57.

[13] See WRI (1998).

Figure 1
General Relationship between Mortalities Induced by Pollutant Emissions and by Pollutant Regulations



reducing the number of overall lives lost, then there are inherent tradeoffs that must be considered, and (2) the minimum level of lives lost would very likely not be at either regulatory extreme.[14]

Similarly, should the increased regulation lead to greater unemployment, additional adverse health impacts can arise. Unemployment can increase both in the industries directly affected by the regulations as well as economy-wide effects from the reductions in disposable income. There are many studies in the literature relating increased unemployment with higher levels of illness, death, crime, and violence.[15] While far fewer people are directly affected by increased unemployment than by the reductions in disposable income, the magnitude of the effects on an individual unemployed worker and his or her family tends to be significant.

Because of these effects of costs upon health, safety, and mortality, the appropriateness of regulatory actions cannot be adequately framed as simply a debate of health and welfare versus costs and profits. Instead, we should consider the health and safety *improvements* due to the regulation relative to the health and safety *losses* due to the regulatory costs. The logical and moral comparison is one of "people saved versus people lost."

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[14] See also Breyer (1993), pp. 10-19. In his book, *Breaking the Viscious Circle*, Justice Breyer describes what he terms the problem of "the last ten percent" in regulating health risks, where most of the problem can often be addressed quickly and inexpensively, but the last few percent may be extremely difficult and costly, diverting funds from other worthwhile purposes.

[15] See, for example, Brenner (1984), Sorlie and Rogot (1990), and Merva and Fowles (1992).

Given these tradeoffs, what is the "right" level of regulatory stringency? In a framework such as that shown in Figure 1, a goal of minimizing loss of human life requires analysis of both the environmental benefits and the income-related loss of life.

Our focus here is on the income-related loss of life. We estimate the additional potential lives lost stemming from the costs of replacing low-cost coal-fueled power. We use literature from economics, risk analysis, and life sciences to develop these estimates. In so doing, we seek to illustrate these induced health effects of regulatory costs, and to offer the reader a better understanding of the issues to consider in interpreting these relationships. In this paper, we do not try to provide an estimate of the potential lives saved from emission reductions if coal-fueled power were precluded, but leave that to others.

We note that our analysis of the deaths induced by increased costs and unemployment represents only a portion of all of the potential impact pathways that could be examined. If coal use is restricted, there can also be additional health, safety, and mortality impacts resulting from the construction of replacement power facilities, development of natural gas supplies and pipelines, and environmental impacts of the alternative power sources. There may also be other mortality reductions, say from fewer accidents in coal mining and rail transportation. Ideally, the regulatory evaluation would identify all of the relevant pathways for the action and its alternatives.[16] Our limited analysis here is not intended to ignore the existence of these other pathways, but merely to focus on some that we believe are important and often overlooked.

ANALYZING ADULT MORTALITY INDUCED BY REGULATORY COSTS

This section describes an analytical framework for estimating the adult health and mortality benefits associated with the increased disposable income from having low-cost coal-fueled power. We first describe the steps involved in the causal chain. Then, for each step, we identify relevant data and studies used to implement the framework.

The basic idea to estimate cost-induced mortality effects is straightforward and logical. The methodology has four primary steps:

1. ***Identify the total economic costs associated with reducing coal use for power generation.*** This is based upon a review of several private and government energy and economic modeling analyses of policies that would result in sharply lower levels of coal consumption. Costs include the capital costs of conversion or premature replacement of any facilities and the increased fuel and operating costs associated with these actions. The macroeconomic models calculate the total national changes in disposable income for households. We scale up the results of these studies to approximate full coal elimination, so that the findings may later be interpolated to estimate the impacts of various levels of coal displacement.

2. ***Distribute the economic costs to households of different incomes.*** Our model examines the consequences of various methods of distributing the reduction in

[16] For a fuller discussion, see Keeney and von Winterfeldt (1986).

disposable income across different household income ranges. Three different allocation methods are examined, including apportionment based on increased electricity costs and the increased costs of all products and services that rely on electricity. The result is a specified reduction of disposable income to each household.

3. ***Estimate the relationship between reductions in disposable income and resulting health and mortality impacts.*** Models relating annual disposable income to annual risk of death for each of the income groups and different genders and races are developed.

4. ***Tabulate the health and mortality effects.*** Apply the mortality risk model to the loss in disposable income for the various income and demographic groups. Then, sum across all categories to estimate total effects.

Each of these steps is described in detail below.

1. What Are the Economic Impacts from Not Having Coal-Fueled Power?

If regulations were enacted to limit the use of coal for power generation, it would become necessary to develop alternatives to this low-cost power source that presently provides us with over half of our generation. These alternatives potentially include supply-side alternatives such as natural gas generation, renewable power sources, and nuclear energy, as well as energy conservation and other demand-side measures.

Most analyses of proposals that would reduce or replace coal use indicate that power costs would increase substantially, since the costs of operating an existing coal plant tend to be relatively low compared to alternatives of building and operating alternative power sources.[17] In general, the greater the cost difference between existing coal plants and alternative sources (both supply-side and demand side), the higher the impact on electric power costs, economic activity, and employment.

For this analysis, we have sought to build upon existing energy-economic analyses of reduced coal use. Since we are examining the effects of reduced coal use in general, rather than a specific policy or legislative proposal, we rely on general energy/economic models that have investigated the cost implications of numerous scenarios, focusing on those that mainly impact coal use. Ideally, candidate analyses should (1) encompass U.S. coal use, (2) evaluate one or more cases where coal use is substantially reduced, (3) incorporate economy-wide effects of these reductions, and (4) calculate the economic impacts in terms of household disposable income and overall employment.

[17] Typically, these analyses indicate that if coal use was to be restricted, most of the generation would be replaced by building and operating new natural gas combined cycle units. Natural gas deliveries to electricity generators often cost about triple that of coal deliveries. Thus, even with the greater efficiency of combined cycle units, the gas fuel costs per kWh are about double that of coal. Additional capital costs – associated with building the new gas units but not the existing coal units – could further widen this cost gap.

We identified the following six analyses that meet these criteria reasonably well and can serve as a representative sampling of the economic literature.[18] All six generally focus on or around the year 2010 as the time of full implementation. The analyses used are the following:

1. ***DRI (1998).*** Standard & Poor's DRI prepared an analysis of *The Impact of Meeting the Kyoto Protocol on Energy Markets and the Economy*. Using the Fall 1997 DRI Energy and Economic Base Case forecasts, the study evaluated the impacts of different levels of CO_2 reductions within the U.S., reflecting different assumptions on reductions that could be attained through Kyoto flexibility mechanisms, carbon sinks, and other greenhouse gases. For our purposes here, we used DRI's "Case 1," wherein 77% of U.S. CO_2 reductions must be achieved by either shifting the energy mix or curtailing fossil fuel usage. Given future growth in the Base Case, this resulted in coal use in the year 2010 declining 43.2 percent from the Base Case.

2. ***EIA SR 98-03 (1998).*** The Energy Information Administration prepared a report that focused on the impacts of the Kyoto Protocol on the U.S. energy markets and the economy. The analysis used EIA's NEMS model, an energy-economic model of the U.S. energy markets. EIA's analysis tested a variety of scenarios, differing primarily in the amount of GHG reductions attainable from international activities, carbon sinks, and other non-CO_2 GHGs. The scenario used here was named the "1990 Level Scenario" scenario. We selected this because it was among the more thoroughly documented scenarios, and because more stringent scenarios tended to show rapidly escalating costs without significant additional shifts from coal-fueled power.

3. ***EIA SR 2001-03 (2001).*** The Energy Information Administration prepared a report that focused on the impacts of reducing power sector NO_x, SO_2, CO_2, and mercury emissions. The analysis used EIA's NEMS model, an energy-economic model of the U.S. energy markets. The scenario used here was named the "Integrated NO_x, SO_2, CO_2 1990-7%, Hg" scenario. We selected this because the scenarios that did not require CO_2 reductions tended to show only modest changes in coal use. Additionally, scenarios that imposed renewable portfolio standards (RPS) were not used because those tended to include many costs unrelated to switching from coal use.

[18] Within the studies we've identified, care also needs to be exercised in picking representative scenarios. Even though most of the studies cover multiple energy uses and multiple economic sectors, the effects of the policies examined tend to be directed primarily toward energy use, both electricity generation and use as well as other sectors. It is also generally the case that when the policy being examined is a required reduction in CO_2 emission, reductions in electric utility coal use account for the primary share of the reductions, particularly at low to moderate levels of emission reductions. At higher required levels of reductions, fewer opportunities remain in the electricity sector, and additional reductions (and their associated costs) are drawn from other sectors and activities.

For our purposes here, we want to focus on impacts that are primarily related to changes in coal use, and so avoid using a scenario that is so stringent that most of the changes on the margin are the result of activities other than marginal coal reductions. At the same time, we need to have a scenario in which a substantial part of coal use is impacted, in order that we don't extrapolate too far off of a small change. This suggests identifying a scenario that is stringent in its impacts on coal use, but not necessarily so stringent that non-coal effects begin to dominate. By picking a moderately stringent scenario and then scaling it up to approximate a sector-wide impact, we hope to avoid the potential problems of using either extreme.

4. ***Rose and Yang (2002) - High Gas Price.*** The authors are with the Department of Energy, Environmental, and Mineral Economics at Pennsylvania State University. The purpose of the analysis was to project the likely impacts of the coal industry on state economies. Using the IMPLAN input-output model, projections were made for eight southern states for the year 2010, and then extended to the rest of the U.S. In the "high gas price case" scenario, the delivered price of gas to the electricity generation sector averaged about $5.00/MMBtu in 2010. For each gas price scenario, the authors measured coal impacts using varying assumptions for forward and backward linkages in the input-output model; the values used in our survey reflect the average impacts of their four combinations.

5. ***Rose and Yang (2002) - Low Gas Price.*** As part of the same study described above, Rose and Yang (2002) also evaluated a "low gas price" case wherein the delivered price of gas to the electricity generation sector averaged about $3.00 per MMBtu in 2010. For this gas price scenario as well, the authors measured coal impacts using varying assumptions for forward and backward linkages in the input-output model; the values used in our survey reflect the average impacts of their four combinations.

6. ***WEFA (1997).*** WEFA, Inc. developed an analysis of the national economic industry and energy sector impacts study of stabilizing carbon emissions at 1990 levels by the year 2010. The model assumed intra-country tradable permits, with carbon revenues recycled to consumers through annual lump-sum repayments.

The salient characteristics of these studies – particularly changes in coal consumption, reductions in household disposable income,[19] and employment impacts[20] – are summarized in Table 1. The detailed data for each study are presented in Appendix A.

We note that there have been other analyses of energy markets and emission reductions that suggest that coal use and its emissions can be sharply reduced at a very low cost, or even at a net saving to the economy.[21] These analyses often rely on a combination of assumptions that might include a slow underlying growth in electricity demand, rapidly improving cost and performance characteristics for renewable energy and conservation technologies, removal of structural barriers that have constrained the marketplace's ability to adopt these alternatives, and/or use of carbon taxes or allowance prices to mitigate other inefficiencies in our tax system. It is not our role here to be the arbiter of these analyses. However, if coal use for power generation could be replaced by lower-cost alternatives that would *increase* income and/or

[19] In these studies, "household disposable income" is variously referred to as "real disposable income" (DRI 1998, EIA *SR 2001-03*, WEFA 1997), "real disposable personal income" (EIA *SR 98-03*), or "annual household incomes" (Rose and Yang 2002), as indicated in the tables in Appendix A.

[20] In these studies, employment impacts are developed as part of the macroeconomic analysis, and the approach varies among the studies and models. In EIA *SR 98-03* and EIA *SR 2001-03*, for example, the employment impacts are calculated using the DRI Macroeconomic Model of the U.S Economy within EIA's National Energy Modeling System (NEMS). Employment impacts are typically net impacts, where job losses in some regions and sectors may be offset by job gains in others.

[21] See, for example, the "5-Lab Study" (IWG, 1997) and Tellus (2001).

Table 1
Summary of Analyses for Partial Coal Elimination

Source	Scenario	Change in 2010 Electricity Sector Coal Use	Change in 2010 Disposable Income (2000$	Year $	Change in 2010 Employment (millions)
DRI (1998)	Case 1: 77% of U.S. CO_2 reductions via shifting energy mix & curtailing fossil fuels.	-43.2%	($168)	1992	(1.60)
EIA SR 98-03 (1998)	Reference Case vs. 1990 Level Scenario	-72.1%	($139)	1992	(1.60)
EIA SR 2001-03 (2001)	Integrated NO_x, SO_2, CO_2 1990-7%, Hg (no RPS)	-52.8%	($106)	1996	(1.30)
Rose and Yang (2002)	High Price Gas Case (average of 4 scenarios)	-80.0%	($133)	1999	(3.60)
Rose and Yang (2002)	Low Price Gas Case (average of 4 scenarios)	-80.0%	($99)	1999	(2.70)
WEFA (1997)	Carbon Stabilization	-70.5%	($96)	1992	(1.80)

NOTE: Income and Employment impacts shown here reflect the partial reduction in coal use shown, and have not been adjusted to approximate a complete curtailment of coal use. Those adjustments are made in Table 2.

Full references for the Sources are in the Bibliography. Data for this summary table are presented in Appendix A.

decrease unemployment, then our methodology would subsequently indicate positive associated benefits for health and mortality.

The next step is to express the impacts of these various studies on a comparable basis. The primary adjustments involve scaling impacts to approximate a complete curtailment of coal use, restatement in year 2000 dollars, and conversion of percentage changes to absolute numbers:

- Because we are developing an analytical framework rather than analyzing any particular policy initiative, we adjusted the impacts of these studies to reflect a hypothetical 100 percent displacement of coal. By developing the framework this way, the findings may be scaled on a linear basis to estimate the premature mortality implications of various policy initiatives given estimates of the potential coal displacement resulting from such policies.

  In scaling impacts to approximate a complete curtailment of coal use, we first observe that the analyses and scenarios selected indicate a reduction of coal use in the year 2010 ranging between 43 and 80 percent from the respective reference case scenario.

Our approach to approximating the impacts of 100 percent curtailment was to scale the impacts linearly. For example, suppose a scenario indicated a 67 percent coal curtailment; then we would approximate the impacts of a 100 percent curtailment as 1.5 times that of the 67 percent value. This is likely a conservative assumption that understates the costs, since in the energy models the lower-cost switches from coal are generally made first, with the remaining switches becoming increasingly costly.

- Restatement in year 2000 dollars was made by adjusting the year $ of the specific study by the ratio of the respective GDP Implicit Price Deflators. These values are shown in Appendix B, Table B-1. For example, to restate values originally given in 1992$, we would multiply by 1.1654 (a 16.54% increase) to express this in year 2000 dollars.

- For the DRI (1998) analysis, most financial impacts were expressed as percentage changes from a reference case, rather than in absolute terms. The authors also reported that for the 2008-2012 period, real disposable income declined $1403 per household per year, a maximum of 2.6 percent below Base Case levels. Using Bureau of Census data, the number of households grew 12.84 percent over the 1990-2000 period. We applied that same 12.84 percent growth rate to the 106.4 million households in 2000 to estimate about 120 million households for 2010.[22]

Table 2 presents the impacts after these adjustments have been made. From Table 2 (and the details of the underlying studies in Appendix A), we can observe the following:

- With 100 percent coal replacement, the effects on disposable income in the peak year of 2010 are estimated to range between about $125 and $450 billion (in 2000$), with five of the six studies suggesting a narrower range of $125-$225 billion. (The sixth study – DRI (1998) – was estimated at $454 billion, at least double the other estimates.)

- With 100 percent coal replacement, unemployment around the year 2010 is estimated to range between 2.2 and 4.5 million workers above Reference Case levels.

- These effects, which occur over a multi-year period, are most pronounced around the peak year 2010 (in the 2008-2012 range), consistent with the modeling assumptions that targeted these years for initially meeting the required reductions. Recovery toward the Reference Case baselines ranges from several years to a decade or more. There are indications in some of the studies that the unemployment effects are of shorter duration than the loss of household income.

[22] See Census (2001a). Total households numbered 94,312 thousand in 1990 and 106,417 thousand in 2000. Continuing this 12.84 percent growth rate to the year 2010 would result in about 120 million households for 2010.

Table 2
Coal Impact Analyses, Adjusted to 100% Coal Replacement (2000$)

Source	Scenario	Change in 2010 Disposable income ($billions)	Change in 2010 Employment (millions)
DRI (1998)	Case 1: 77% of U.S. CO_2 reductions via shifting energy mix & curtailing fossil fuels.	($454)	(3.7)
EIA SR 98-03 (1998)	Reference Case vs. 1990 Level Scenario	($225)	(2.2)
EIA SR 2001-03 (2001)	Integrated NO_x, SO_2, CO_2 1990-7%, Hg (no RPS)	($215)	(2.5)
Rose and Yang (2002)	High Price Gas Case (average of 4 scenarios)	($170)	(4.5)
Rose and Yang (2002)	Low Price Gas Case (average of 4 scenarios)	($127)	(3.4)
WEFA (1997)	Carbon Stabilization	($159)	(2.6)

Source: Table 1, adjusted for 100% coal curtailment and GDP Implicit Price Deflator.

These are large impacts, much larger than the overall impacts of most other environmental and safety programs. For perspective, consider the cost implications on disposable income. Given a cost of $125-$225 billion in 2010 and an estimated population of about 120 million households, this equates roughly to $1,000 to $2,000 impact on annual income per household. Taking the unemployment impact estimates of 2.2 to 4.5 million workers, this would represent an increase in the unemployment rate of about 1.4 to 2.9 percentage points.[23]

[23] This estimate uses a Reference Case labor force of 156.5 million workers in 2010, as shown in EIA *SR 98-03*, p. 211.

2. How Are the Economic Impacts Distributed Across Income Groups?

For different regulations, the costs may be differentially borne among individuals in society. The allocation of these costs to individuals depends on the complex workings of our economy and the firms and institutions involved in the process.[24]

The question next arises as to how the economic costs might be distributed among the population. Why is this important to our analysis? It matters because lower-income segments of our society are more vulnerable to the income-related health and mortality effects of reductions in disposable income. For high-income individuals, higher electricity costs will be small relative to their overall income, and may result in little if any change in expenditures that enhance health and safety. Lower-income individuals, on the other hand, spend a much higher fraction of their income for energy, despite lower per-capita energy consumption. Higher electricity costs therefore would cut more deeply into the disposable income of lower-income individuals, displacing other health- and safety-related expenditures.

There are many ways in which we can estimate how the increased economic cost of replacing coal-fueled power would be distributed across income groups. Two cases will likely bound the reality. A third case distributes additional costs proportional to electricity use, which is consistent with the underlying circumstances.

1. ***Income-Proportional.*** This case assumes that increased costs are distributed proportional to income. For example, a household with $10,000 in income would incur only one-fifth of the additional costs of a $50,000 household.

   The data needed to implement this approach can be drawn from Census data or from EIA surveys on residential energy use (EIA *RECS 1997*). For consistency with the rest of this analysis, we use the household income data in the *Statistical Abstract of the U.S.*[25] Household data are presented for seven different income ranges, from under $10,000 to $75,000 and over. Generally, we took the midpoint of each income range as that range's average, using the methodology described in Keeney (1997).

2. ***Equal-per-Household.*** This case assumes that each household incurs an equal share of the additional national cost. Under this assumption, energy use and household income would have no effect on how the costs landed. As a result, low-income households would each absorb a much higher fraction of the overall cost.

   This approach is the simplest to implement. With Census (2002) data showing a total of 104.7 million households in 1999, an equal sharing of $1 billion in costs amounts to $9.55 per household over the same time period.

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[24] This point is described further in Keeney (1997), pp. 8-10.

[25] See Census (2002), Table 663: *Money Income of Households - Distribution by Income Level and Selected Characteristics: 1999.*

3. ***Electricity-Proportional.*** The third case uses electricity consumption as a basis for distributing national cost. This case produces estimates that fall between the two cases described above. It is intuitively appealing for the basic reason that a substantial portion of the overall costs relate directly to residential electricity consumption, and much of the remaining cost may also be reasonably allocated in this manner.

   To implement this case, we rely on data relating electricity consumption to household income, as developed by DOE's Energy Information Administration in its *Residential Energy Consumption Survey* (*RECS*). The *RECS* is a national statistical survey that collects energy-related data for occupied primary housing units. *RECS* was first conducted in 1978; the tenth, and most recent survey available, was conducted in 1997. In the 1997 *RECS*, data were collected from a sample of 5,900 housing units statistically selected to represent the 101.4 million units in the United States.

   The 1997 survey includes a wealth of data on energy use in residential housing units in the U.S. Of particular interest to this analysis are the data on the demographic characteristics of the household (# of households by income group) and the electricity consumption and expenditures data.[26] The relationship between residential income and electricity consumption, as developed in the 1997 *RECS* study, is graphed in Figure 2. As can be seen, electricity use tends to rise with income, but at a much slower rate. Consumption for the lowest income households averages a little over 7,000 kWh per year, and roughly doubles for the highest-income households. Fitting a regression line to the data (leaving off the highest-income data point[27]), we find that the annual electricity consumption for a household can be described by

$$kWh(x) = 7284 + (x * 0.0823) \qquad (1)$$

   where *x* represents the household income, in thousands of 1997 dollars.

   Residential use of electricity comprises over one-third of electric utility retail sales, accounting for 35 percent of sales in the year 2000.[28] Most of the remaining sales are

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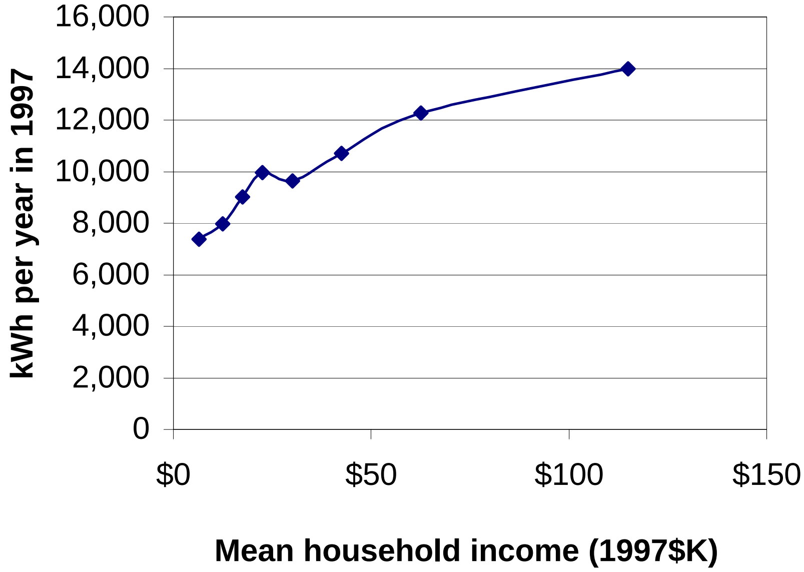
[26] See EIA *RECS 1997*, Table 2: Mean Annual Electricity Consumption by Household Income, 1997. http://www.eia.doe.gov/emeu/consumptionbriefs/recs/percentiles/el_income_tables.html.

[27] In developing the regression equation describing electricity use as a function of household income, we decided not to use the data point for the highest income (> $75,000) household range. This provided a better fit for the lower income ranges, where we are most concerned. Had we included the highest income data point in the regression, the modeled electricity use for the lower-income households would be larger, and the resulting mortality implications from cost changes would be higher. Any distortion created by applying this modified regression equation to the highest income range is small, and the resulting estimate in total mortality risks is conservative (i.e., less than the corresponding estimate of total mortality if the highest income data point was included in the regression).

It may be the case that the relationship between household income and electricity use is exponentially decreasing, as suggested by the highest-income data point in Figure 2. If so, then our dropping the highest-income data point is consistent with fitting our regression equation to the lower-income portions of the range.

[28] See EIA *AER 2000*, p. 241. In 2000, residential end-uses accounted for 1,192 out of 3,398 billion kWh of electric utility retail sales. Sales figures do not include 208 billion kWh from non-utility producers, primarily nonutility facility use of onsite net electricity generation.

Figure 2
Relationship between Household Income and Electricity Use in 1997



Source: Developed from EIA *RECS 1997*, Table 2: *Mean Annual Electricity Consumption by Household Income, 1997*. Income medians for households under $10,000 and over $75,000 were approximated.

in the commercial and industrial sectors, in approximately equal proportions. We have no data that would allow us to distribute commercial and industrial electricity sales back to households according to income group (e.g., how is aluminum production – and the associated electricity requirement – distributed among income groups?). However, the type of pattern observed for residential electricity sales, where consumption increased slowly with higher incomes, does not seem to be an unreasonable assumption here.

As developed above, we now have three different cases for distributing costs across different income groups. The third case – proportional to electricity consumption – seems appropriate for analysis of policies aimed mainly at the electric power sector. The income-proportional and the equal-household approaches would seem to be reasonable lower and upper bounds on what might actually occur.

3. How Does Reduced Income Affect Health and Mortality?

Several quantitative studies have investigated the relationship between income and mortality rates. For example, a 1984 Congressional study examined the relationship between economic changes and indicators of social stress, and calculated that the drop in per capita income during the 1974-1975 recession brought about 60,000 deaths.[29] Evans *et al.* (1987) did regression analyses that "provide relatively strong evidence of a negative association between income and cardiovascular disease mortality risk." Feinstein (1993) undertook a comprehensive review of the literature of the relationship between socioeconomic status and health. He identifies several studies showing linkages such as those between higher education and lower mortality, higher household wealth and lower mortality, social class and heart disease mortality, and medical expenditures and mortality.[30]

It is important to consider the degree to which the relationship between reduced disposable income and increased mortality is causal, meaning – do wealthier people spend their money in ways that keep them healthier and safer, or do healthier and safer people tend to live longer and make more money? Researchers have analyzed this possibility, and have found that while reverse causality can exist, the causal effect of income is significant.[31] In addition, there may also be "feedback loops" between health and income, with the result that poorer health leads to less income, and this lower income in turn leads to even worse health. With both causality and reverse causality, there is a negative spiral with lower income leading to higher mortality at various stages of that spiral.

Several studies indicate that an exponential curve relating annual income and annual mortality risk is a very good model.[32] Figure 3 shows this model as an exponential curve, where at lower incomes the mortality risks are higher. The functional representation for this curve is

$$r(x) = ae^{-bx} + d \qquad (2)$$

where $r(x)$ is the annual mortality risk for an individual with income of x and a, b, and d are parameters (and e = 2.718218…, base value for the exponential function). In this equation, d is the lowest level of risk below which additional income can no longer reduce. The constant a is the amount of mortality risk that can be influenced by income, so that $a + d$ would represent the mortality risk at the very lowest income levels. The parameter b determines the rate of mortality decline as income increases, i.e., how quickly the risk curve approaches the lowest level of risk d.

This exponentially decreasing curve has three intuitively appealing properties: (1) the mortality risk decreases as income increases; (2) the mortality risk decreases at a decreasing rate (e.g., an income increase from $10,000 to $11,000 has a greater effect on the mortality risk drop

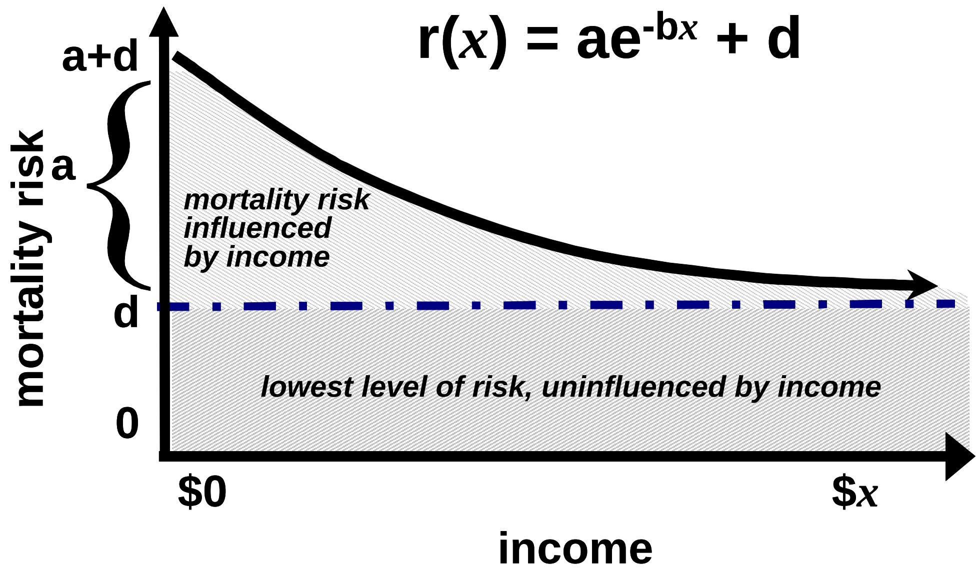
29 See Brenner (1984), pp. iv-v.

30 Many additional studies relevant to understanding and estimating the mortality induced by economic costs are referred to in Keeney (1997) and Hahn *et al.* (2000).

31 See Chapman and Hariharan (1994), Lutter *et al.* (1999), and Hahn *et al*. (2000). See also Pritchett and Summers (1996); in that study the authors estimated the pure income effect on health, isolated from reverse causation or incidental association. They found that the long-run income elasticity of infant and child mortality in developing countries lies between -0.2 and -0.4. Using these estimates, they calculated that over a half a million child deaths in the developing world in 1990 alone could be attributed to the poor economic performance in the 1980s.

32 For a more detailed discussion on this model for the annual mortality risk, see Keeney (1990).

Figure 3
Relationship between Annual Mortality Risk and Relative Income



Note:

r(x)	=	annual mortality risk for an individual with income *x*
d	=	lowest level of risk, uninfluenced by income
a	=	mortality risk influenced by income
b	=	determines the rate of mortality decline as income increases
e	=	2.718218…, base value for the exponential function

than an income increase from $40,000 to $41,000); and (3) the decrease in mortality risk essentially stops once an individual is at high income levels.

The annual mortality risk parameters *a, b,* and *d* are calculated from data in the National Longitudinal Mortality Study (NLMS) conducted by the National Institutes of Health (NIH) using information from 1979-1985.[33] The NLMS was developed by NIH to investigate social, demographic, and occupational differentials in mortality within a sample of the U.S. population. The data are based on a total sample size of over 500,000 individuals and reported in terms of family income adjusted to 1980 dollars. The data used for our analysis are only for the adult population (as described in Keeney, 1997); because of this restriction, the issue of potential child mortality is not addressed here, but is discussed in a later section of our analysis.

As longitudinal data are used to estimate the mortality risk parameters, data must naturally cover a period of time, in this case 1979-1985. In Keeney (1997), the stability over time of the amount of reduced disposable income that induced a fatality was investigated by using different data sets from 1960 to this longitudinal study. The results were very stable, which

[33] For more information on the NLMS, see NHLBI (1995) and Rogot *et al.* (1992).

suggests the National Longitudinal Mortality Study information is relevant for estimating current mortality risks of reduced disposable income.

Government publications on mortality rates typically disaggregate the statistics by gender and race. Indeed, observed differences in mortality rates by gender and race[34] have been the motivation behind numerous analytic investigations and public health initiatives. Several studies have found that even after controlling for income differences, gender and race have a significant influence on the mortality risk curves; i.e., the rate of cost-induced fatalities varies by gender and race.[35]

The NLMS sample includes data on gender and race in addition to income, employment status, and other factors. Using the NLMS data on race and gender allowed us to refine our estimates of income-related mortality risk by developing separate regressions for white males, black males, white females, and black females. The parameters for the mortality risk model *(2)* were determined by fitting a least-square regression to these data. The results of the least-square regression are presented in Appendix B, Table B-3.[36]

4. Estimating the Number of Regulatory Cost-Induced Adult Mortalities

Since the mortality risk model has been parameterized by race and gender, it is also necessary to estimate the distribution of household income for each. For this, we used the distribution of annual income from the *Statistical Abstract of the United States*.[37] Table 3 shows the total number of white, black, and other households in 1999 and the percentage of each within particular income ranges. The data for "Other Households," defined here as neither white nor black, were calculated as the total minus black and white households in the *Statistical Abstract* data, and amount to about 3.4 percent of total households.[38]

Next, the distribution of the individual costs across income groups was calculated assuming a "unit cost" of $1 billion (in 1999 dollars). Implications of different costs can then be

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34 For example, in CDC (2002) (p. 2), the age-adjusted death rate for men was 41 percent greater than that for women in 2000, and life expectancy for women exceeded that for men by 5.4 years. The age-adjusted death rate for the black population was 1.3 times greater than that for the white population in 2000, and life expectancy for the white population exceeded that for the black population by 5.7 years.

35 For example, see Baquet *et al.* (1991), Keeney (1997), Sorlie *et al.* (1995), and Smith *et al.* (1998).

36 Additionally, we adjusted the income data from 1980 to 1999 dollars using the change in the consumer price index (CPI) from 1980 to 1999. Bureau of Labor Statistics CPI values are from BLS (2002b), and are presented in Appendix B, Table B-2.

37 See Census (2002), Table 663: *Money Income of Households - Distribution by Income Level and Selected Characteristics: 1999.*

38 In most Census reports, the population is divided into five groups on the basis of race: White; Black; American Indian, Eskimo or Aleut; Asian or Pacific Islander; and Other races. See U.S. Census Bureau, *Current Population Survey (CPS) - Definitions and Explanations*, at http://www.census.gov/population/www/cps/cpsdef.html. Persons of Hispanic origin, accounting for nearly ten percent of the total households, may be of any race in the Census data.

Table 3
Distribution of Annual Income for Households in 1999

	Percentage of households with income in range			
Income Range (1999 $)	White Households	Black Households	Other Households	Total Households
Under $10,000	7.82%	18.43%	10.32%	9.22%
$10,000 - $14,999	6.96%	10.11%	6.24%	7.32%
$15,000 - $24,999	13.86%	16.41%	10.92%	14.06%
$25,000 - $34,999	12.63%	13.66%	10.63%	12.67%
$35,000 - $49,999	15.97%	14.68%	15.63%	15.80%
$50,000 - $74,999	19.08%	14.04%	17.61%	18.41%
$75,000 and over	23.68%	12.68%	28.60%	22.53%
Total, all incomes	100%	100%	100%	100%
Number of Households (1,000s)	87,671	12,849	3,598	104,705

Source: Developed from U.S. Census Bureau. January 2002. *Statistical Abstract of the United States: 2001,* Table 663: *Money Income of Households - Distribution by Income Level and Selected Characteristics: 1999.*

Note: The data for "Other Households," defined here as neither white nor black, were calculated from Table 663 as the total minus black and white households.

proportionately scaled from these results.[39] The cost to a household of specific income due to the $1 billion is shown in Table 4. These individual costs were calculated using the relative costs for the three cases discussed above. For the equal-per-household approach, the individual costs are simply one billion dollars divided by the 104.7 million households in 2000,[40] or $9.55 per household per $1 billion. For the income-proportional approach, the individual costs were derived using the approach described in Keeney (1997).[41] For the electricity-use-proportional

[39] The methodology of using a unit cost and scaling up proportionately allows us to apply the mortality estimates to varying levels of cost impacts. However, it is a conservative assumption in that it will tend to somewhat understate the impacts of higher costs to individuals. From the shape of the mortality risk curve, it can be seen that the slope steepens as income falls; each additional dollar of cost increases risk more than the previous dollar. For a low-income individual, the increased risk of $1000 less disposable income will be somewhat greater than 20 times the increased risk of $50 less. On the other hand, some of the costs estimated to occur in 2010 may be spread out over a multi-year period. This would effectively reduce the degree of conservatism. Indeed, if $1000 costs were spread over 20 years, the annual cost would be $50 per year. Both of these issues were examined in part in Keeney (1997, section 3.4), and the effects were found to be very small.

[40] See Census (2002), Table 54.

[41] See Keeney (1997), equations 3-5.

Table 4
Annual Cost per Household of a $1 Billion Regulation for Different Cost Allocations

	Relative regulatory costs per billion $		
Income range (1999$)	Costs proportional to income	Costs proportional to electricity use	Equal costs per household
Under $10,000	$0.87	$6.31	$9.55
$10,000 - $14,999	$2.18	$6.79	$9.55
$15,000 - $24,999	$3.48	$7.28	$9.55
$25,000 - $34,999	$5.22	$7.93	$9.55
$35,000 - $49,999	$7.40	$8.75	$9.55
$50,000 - $74,999	$10.88	$10.05	$9.55
$75,000 and over	$22.14	$14.26	$9.55

approach, we also used the approach in Keeney (1997), but used the regression equation *(1)* we developed earlier to relate electricity use to household income.

The expected deaths induced by an increased cost of $1 billion are presented in Appendix B, Table B-4. This table presents the results of calculations for each combination of black, white, and other; male and female; and allocations of costs. To calculate the expected deaths to persons in "other households," we used the distribution for other household income listed in Table 3 and the respective mortality risk parameters for white males and white females, as there were no separate data for those mortality risks. Since "white households" and "black households" accounted for 96.5% of the total households in Table 3, any change in the mortality risk parameters assumed for "other households" would not materially change the overall implications for cost-induced deaths.

For our calculations, we have made the simplifying assumption that each household has one male and one female adult of the corresponding race (i.e. white, black, or other). While this characterizes most of the households in the U.S., it will understate some and overstate others.[42] Since almost all adults live in some household and there were about 207.3 million adults living[43] in the U.S. in 1999, the assumption of two adults in each of the 104.7 million households would

[42] We note that the underlying data in NHLBI (1995) included data fields for adjusted family income, number of persons in household, and the individual's relation to the head of household. Future researchers may wish to use these data to construct a more comprehensive picture of individual mortality within household structures.

[43] Census (2002) listed the adult population 18 and older as 209.1 million in 2000 and the total percentage increase in population from 1999 to 2000 as 0.89%. From this, we calculated 207.3 million adults in 1999.

likely not substantially alter the results in Appendix B, Table B-4. In addition, as income-induced deaths on children are not calculated, the total deaths in that table calculated just for adults should not overestimate the deaths induced by higher costs.

Table 5 tabulates the expected deaths induced by a $1 billion increase in cost, for each of the three different allocations of the costs shown in Appendix B, Table B-4. Dividing the $1 billion "unit cost" by the expected number of deaths gives the regulatory cost that will induce one death. In Table 5, we restated these expected deaths and costs per death in year 2000 dollars, so as to be consistent with the cost estimates from the energy and macroeconomic models.[44]

Table 5
Estimated Deaths Induced per $1 Billion (in 2000$) in Regulatory Costs

	Relative cost allocation		
Group	Proportional to income	Proportional to electricity use	Equal per household
White males	31.99	59.00	75.12
White females	10.58	24.24	32.40
Black males	6.39	16.09	21.88
Black females	3.39	9.66	13.41
Other males	1.21	2.34	3.01
Other females	0.40	0.99	1.34
Combined	53.95	112.32	147.17
B. Cost inducing one death, in millions of 2000 dollars:			
Combined	$18.54	$8.90	$6.79

Source: Developed from data in Appendix B, Table B-4, with adjustments to year 2000 $ made using CPI index in Appendix B, Table B-2.

Note: Totals for each group reflect number of households and income distribution as well as underlying income-mortality risk curves.

[44] Cost estimates were adjusted using the CPI, All Urban Consumers (CPI-U), U.S. city average. See Appendix Table B-2 for all values. The year 2000 CPI Index average of 172.2 was 3.4 percent above 1999's CPI average of 166.6.This ratio was divided into the number of expected deaths per $1 billion of 1999 dollars in order to reflect the 3.4% fewer nominal dollars. With this adjustment, the deaths per billion 2000$ are fewer than the deaths per billion 1999$, since there are similarly fewer real (inflation-adjusted) dollars. Similarly, the cost to induce one death in year 2000 dollars is nominally larger than the cost as expressed in 1999$.

When the additional costs are proportional to electricity use, we estimate that each additional $8.90 million (2000$) induces an adult death. The range is from $6.79 million for an equal-cost allocation to $18.54 million for the proportional-to-income allocation.

From the first step of this framework, our review of the literature suggested that replacement of U.S. coal-fueled power could impact household income by about $125-$225 billion in 2010. With one death for each $8.90 million in regulatory costs (assuming costs are distributed proportional to electricity use), this amount would induce about 14,000 to 25,000 additional deaths per year. Under the equal-per-household allocation ($6.79 million per death), mortality impacts would range from about 18,000 to 33,000 additional deaths per year. At the low end, under the income-proportional allocation ($18.54 million per death), induced deaths would range from about 7,000 to 12,000 additional deaths per year. At the upper end of the studies reviewed – $454 billion estimated from the DRI (1998) analysis – the estimated induced deaths under an electricity-proportional assumption would be 51,000 lives in the year 2010.

These induced deaths fall disproportionately on lower-income households, as can be seen in Table 6.[45] For example, assuming that costs are distributed proportional to electricity consumption, households with income less than $15,000 (about 16.5 percent of all households) would incur about 43 percent of the deaths. In contrast, those households with income over $50,000 (about 40.9 percent of all households) would incur only about 8 percent of the deaths. Even though the lower-income households use less electricity, their consumption is relatively inelastic with respect to household income. Further, mortality sensitivity to reduced income is much greater for these lower-income households, resulting in their incurring more of the deaths.

Since the income-induced deaths are disproportionately focused on the lower income groups, they also disproportionately fall upon minorities. Each year the Census Bureau reports on poverty in the U.S.[46] In the year 2000, the overall poverty rate dropped to 11.3 percent, a total of about 31.1 million people. The poverty rate was higher for blacks at 22.1 percent; for Hispanics it was 21.2 percent.[47]

The results developed in this analysis are proportionately scalable, in that lesser impacts on coal-fueled generation and on disposable income can be estimated to have linearly proportional mortality impacts.[48] If the reduction in disposable income is lessened by half, for example, then the induced deaths would also be reduced by half.

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45 Percentage of households is estimated from Census (2002), Table 663: *Money Income of Households—Distribution by Income Level and Selected Characteristics: 1999*, as shown in Table 3 here. Percentage of deaths is estimated from Appendix B, Table B-4 (Case C: Assuming costs are allocated proportional to electricity use).

46 See Census (2001c). Note that the definition of poverty is not a single constant income number, but varies by the size of the family and the number of related children under 18 years.

47 The question as to whether female-householder families are disproportionately more vulnerable is a little more complicated. According to Census data, a higher-than-average 24.7 percent of female-householder families are below the poverty line (Census, 2001c). However, the mortality risk for females is less income-sensitive than for males.

48 Specifically, the costs of 100% coal replacement were scaled up linearly from lower levels, and the mortality impacts were scaled up linearly from a $1 billion “unit cost.” These costs and impacts can therefore be scaled

(continued on next page)

Table 6
Incidence of Death by Household Income Range

	Households		Deaths	
Income range (1999$)	Percent in Income Range	Cumulative Percent	Percent in Income Range	Cumulative Percent
Under $10,000	9.2%	9.2%	27.2%	27.2%
$10,000 - $14,999	7.3%	16.5%	15.9%	43.1%
$15,000 - $24,999	14.1%	30.6%	23.1%	66.2%
$25,000 - $34,999	12.7%	43.3%	14.5%	80.7%
$35,000 - $49,999	15.8%	59.1%	11.6%	92.3%
$50,000 - $74,999	18.4%	77.5%	6.7%	99.1%
$75,000 and over	22.5%	100.0%	0.9%	100.0%
	100.0%		100.0%	

Sources: Percentage of households is estimated from Census (2002), Table 663: *Money Income of Households—Distribution by Income Level and Selected Characteristics: 1999*, as shown in Table 3 of this report. Percentage of deaths is estimated from Appendix B, Table B-4 (Case C: Assuming costs are allocated proportional to electricity use).

ANALYZING CHILD MORTALITY INDUCED BY REGULATORY COSTS

As noted, the mortality estimates in the previous section were for the adult population, and were based on data that exclude children. This was done because there are fewer data about the relationship of childhood mortality and income, and not because of a view that it is unimportant.

Lower household income affects children's health, safety, and mortality in many ways, both short-term and long-term. Many of the deaths will be infants and young children. Others will take the form of children dying prematurely in adulthood; they will not likely be in their childhood family units, and the data in the National Longitudinal Mortality Study do not enable a tracking of family income across time and family units.

While we have not developed estimates of income-induced childhood mortality, other researchers have investigated some of these linkages. Examples from the literature that document

(continued from preceding page)

down linearly, at least to the levels of coal replacement observed in the energy-economic studies. As previously discussed in the text, both assumptions are conservative, particularly if most or all coal-fueled capacity is being replaced.

the implications of income on childhood mortality in across different countries include the following:

- Filmer and Pritchett (1997) used cross-national data to examine the impact of both non-health factors (economic, educational, cultural) and public spending on health in determining child mortality (under 5 years old) and infant mortality (under 1 year old). They found that 95 percent of cross-national variation in mortality can be "explained" by a country's income per capita, the distribution of income, extent of female education, level of ethnic fragmentation, and predominant religion. Further, they found that 84 percent of mortality differences can be "explained" by income alone, defined here as per-capita differences in GDP.[49]

- The World Bank annually publishes its *World Development Indicators*. Mortality rates are presented by country for various age groupings. The data are further subtotaled by low, middle, and high income countries, and the 1999 data show a striking difference in mortality risks across income levels:[50]

Income level	**Infants < 1 year**	**Children < 5 years**
Low Income	77 per 1000	116 per 1000
Middle Income	31 per 1000	39 per 1000
High Income	6 per 1000	6 per 1000

- Pritchett and Summers (1996) developed a worldwide country comparison using time-series data on infant and child mortality, life expectancy, and per capita income. They note the sharp improvements in health performance as income rises, particularly when income levels are low. For 1990, they found the following relationships among income and health worldwide:

Income Quartile	**1990 Per Capita Income**	**1990 Infant Mortality per 1,000**	**1990 Life Expectancy (years)**
Poorest 25%	$650	114	50
Second Quartile	$1,727	66	61
Third Quartile	$3,795	34	69
Richest 25%	$11,422	9	76

  Pritchett and Summers conclude that raising per capita incomes would be an important component of any country's health strategy. They estimate that if income were 1 percent higher in the developing countries, then as many as 33,000 infant and 53,000 child deaths would be averted annually. They also estimate that over half a

49 See Filmer and Pritchett (1997), especially pages, 7, 39.

50 See World Bank (2001a), Table 2.19, *Mortality*, at http://www.worldbank.org/data/wdi2001/pdfs/tab2_19.pdf.

million child deaths in the developing world in 1990 alone can be attributed to the poor economic performance in the 1980s.[51]

- Shortly after the September 11, 2001 terrorist attacks, the World Bank released a preliminary economic study on the expected rise in poverty and the associated increase in child mortality (World Bank 2001b). As a result of the attacks, the World Bank anticipated a delay in the economic recovery by the wealthier countries, and that this in turn would lower economic growth among the developing countries by 0.5 to 0.75 percentage points in 2002. As a result, some 10 million more people would likely be living below the poverty line of $1 per day. Using the elasticity estimates developed in Pritchett and Summers (1996), the percentage increase in child deaths was calculated. From this, the Bank estimated that an additional 20,000 to 40,000 children under the age of five could die from the economic consequences of the worsening poverty.

- The World Resources Institute has studied the links between health and wealth, noting that "by and large, the wealthier a country becomes, or the higher its average per capita income, the healthier its population becomes."[52] WRI notes that similar to population-wide relationships, child mortality rates also decline with rising income. WRI makes particular note of the clear linkages between households with more education and better health, and that the wealthier tend to be better educated and thus more informed about the disease process and prevention.

Research in Canada has examined the relationship between childhood mortality rates and neighborhood income.[53] Health Canada, through its Canadian Perinatal Surveillance System, collects and evaluates data on infant births and deaths. Given Canada's comparable level of economic development, societal structures, and geographic proximity, these data can provide useful insights for researchers interested in exploring the U.S. situation.

- Health Canada reports that in 1991, the overall infant mortality rate (those who die before their first birthday) in urban Canada was 5.8 per thousand live births. Pronounced differences in infant mortality rates were seen among income groups in urban Canada. Canadians in the high-income group (the highest income quintile) had an infant mortality rate of 4.5 per 1,000, compared with a rate of 7.5 per 1,000 among Canadians in the low-income group (the lowest income quintile). The rate difference between the highest and lowest income groups was 2.9 per 1,000 live births.[54]

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51 See Pritchett and Summers (1996), esp. pp. 841-845.

52 See WRI (1998).

53 In these Canadian studies, "neighborhood income" is a ranking based upon the percentage of a Census tract's population with income below the Statistics Canada low-income cut-offs.

54 See Health Canada (1998). Rate differences in mortality reflect independent rounding. Original source of data is Wilkins, R., *Mortality by neighbourhood income in urban Canada, 1986-1991*. Presentation to the Canadian Society for Epidemiology and Biostatistics (CSEB), St. John's, Newfoundland, August 16-19, 1995.

- Wilkins *et al*. (2000) extended the analysis of Canada's infant mortality through the year 1996. They noted the continuing overall decline in Canada's infant mortality, and that these gains had been greatest in the poorest urban neighborhoods.

Income Quintile	1991 Infant Mortality per 1,000	1996 Infant Mortality per 1,000
Lowest	7.5	6.5
Lower Middle	6.7	5.2
Middle	5.0	5.1
Upper Middle	5.1	4.7
Highest	4.5	3.9

In 1996, the infant mortality rate in Canada's poorest neighborhoods was two-thirds higher than that of the richest neighborhoods. Additionally, while most children in Canada were seen to be in very good health, the children of parents with a low level of education were more likely to have poorer perceived health and were less likely to enjoy unbroken good health.

From these studies, it appears that there may also be significant child mortality impacts stemming from lower income. Accordingly, the mortality estimates developed in the preceding section may be conservative in that we have focused only on adult deaths. However, the analysis of these child mortality impacts is more complex and more uncertain, so we have chosen at this time not to quantify potential additional deaths. However, the potential magnitude of these impacts suggests this area as an important one for future research.

ANALYZING MORTALITY IMPACTS OF INCREASED UNEMPLOYMENT

As discussed earlier, replacement of coal-fueled power in the U.S. could lead to substantial increases in unemployment in addition to losses in household disposable income. But while the estimated numbers are large – 2.2 to 4.5 million workers – they are still a small fraction of a future labor force of more than 150 million workers.[55] But for these workers, unemployment is a far more stressful and economically painful event than is a more moderate reduction in disposable income.

A widespread observation in the field of medical population statistics is that socioeconomic status is a principal factor in predicting illness and mortality differentials: the lower the economic and social status of an individual or family, the greater the likelihood of illness, disability and death (Brenner, 2002). For many people, maintaining their working position is fundamental to self-esteem, public esteem, and achieving what is thought to be important in life. Being unemployed poses risks to health and life expectation, not only through

[55] From EIA *SR 98-03*, the Reference Case labor force in the year 2010 was projected at 156.5 million workers.

lower income and a declining social and economic position, but also through weakening the linkages between the individual and that person's work colleagues, friends, family, and society in general.

Workers who have lost their jobs face a variety of stresses. The loss of income is usually no more than partially replaced by unemployment compensation and other payments. The unemployed workers also face a possible loss of health coverage and other job-related benefits, a loss of self-esteem, and the risks of downward social mobility and falling into poverty.

Joblessness may also subject family relationships to considerable strain. The financial and psychological pressures can produce greater stress for the entire household, not just those out of work. Further, workers who remain employed face stresses of their own stemming from the threat of unemployment and the additional pressures likely in the workplace.[56]

These financial setbacks and other pressures can have both shorter-term and longer-term outcomes. Shorter-term effects can include health impacts such as heart attacks and stroke, as well as societal impacts such as property crimes, violence, and suicide. Longer-term impacts occur over many more years, and can stem from the financial implications of lower income on health and safety expenditures, and from the longer-term effects of stress on our physical and emotional health.

Several studies have sought to clarify and/or quantify the linkages between unemployment and resulting effects such as serious illness, premature death, violence, crime, and suicide. A review of some of these provides some insight into the potential magnitude of the mortality impacts of increased unemployment resulting from replacement of coal-fueled power:

- ***Brenner (1984).*** An earlier Congressional committee study (Brenner, 1984) researched at length the possible pathological effects of unemployment and other forms of national economic distress. The focus was on the 1974-1975 recession, marked by a sharp 14.3 percent increase in unemployment, a 200 percent increase in business failures, and a decrease of 3.0 percent in real per capita income.[57] Principal findings were that real per capita income growth is strongly associated with decline in mortality, and that recession is related to increased pathology in the areas of mental and physical illness and criminal aggression. The unemployment rate was found to be the most reliable indicator of recession-related injury.

  Brenner's analysis estimated that in addition to the 60,000 deaths brought about by the drop in per capita income, the rise in unemployment (14.3%) during 1973-1974 was linked to the following mortality impacts:

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[56] For a fuller discussion of the stresses, see Brenner (1984) and Merva and Fowles (1992).

[57] See Brenner (1984), pp. iv, v, 3. The analysis used data covering the years from 1950 to 1980.

Pathological Indicator	Increase in Incidence (# people)	% change related to a 14.3% unemployment rise
Total Mortality	45,936	up 2.3%
Cardiovascular Mortality	28,510	up 2.8%
Cirrhosis Mortality	430	up 1.4%
Suicide	270	up 1.0%

The mortality impacts as estimated by Brenner (1984) appear substantial. The 14.3 percent rise in unemployment, while not translated by the author into a specific number of jobs, would appear to be on the order of a million or fewer workers.[58] If we were to extend these impacts to our estimates of employment impacts resulting from replacement of coal-fueled power in the U.S. (as was seen in Table 2, these impacts ranged from 2.2 to 4.5 million workers), this would suggest mortality impacts in excess of 100,000 people.

- ***Brenner (2002).*** In a three-year study commissioned by the European Union, Brenner (2002) examined data over a 30-year period, investigating whether changes in the employment rate influenced mortality patterns in European countries and the United States. The multiple regression model incorporated terms designed to measure different lag effects in the mortality data, and also to control for the effects of economic growth apart from the unemployment changes. Brenner found that increased employment provided important benefits to population health. These decreased mortality benefits were seen in some countries to be nearly contemporaneous, although the mortality reduction could extend over a decade. Brenner found that increased employment rates towards a "full employment" economy are fundamental sources of decreased mortality in European Union countries and the United States. Conversely, increased rates of unemployment are related to heightened mortality rates and thus decreased life expectancy in these countries. While growth in per capita wealth was seen to be the principal long-term factor in the trend in mortality decline, higher unemployment rates also exerted an independent and damaging effect on the national health.

- ***Merva and Fowles (1992).*** Merva and Fowles (1992) undertook an in-depth statistical analysis of the relationship between economic stressor variables (such as a change in unemployment) and associated stress outcomes (such as the incidence of

[58] Using time-series data from BLS (2002a), the average 1972 unemployment rate was 5.6%, comprising 4.8 million workers. A 14.3% increase would be less than one percentage point in the rate, or about one million workers out of a labor force that was then about 100 million workers (Census (2002), Table 567). As another indication, seasonally adjusted monthly unemployment data from BLS for 1972-1974 shows the number of unemployed workers ranging from 4.0 to 5.1 million; a 14% increase here would be under one million workers. (BLS unemployment data at ftp://ftp.bls.gov/pub/special.requests/lf/UNEMPL.MON.)

fatal heart attacks). The analysis used data for a 15-year period covering 30 major metropolitan areas[59] in the U.S. with a combined 1990 population of nearly 80 million people. Their analysis found significant relationships between unemployment, poverty, and inequality and the incidence of heart attacks, strokes, suicides, accidents, and criminal activity. They estimated that a one percentage point increase in the unemployment rate would have the following outcomes, among others:[60]

Social Stress Outcome	**Incidence per 100,000 people in 1990**	**change per 100,000 people per 1.0% unemployment**
Major Heart Disease Mortality	387.8	up 21.7
Stroke Mortality	55.8	up 1.7
Homicide Mortality	13.2	up 0.9
Violent Crime	1,158.4	up 39.3
Property Crime	5,941.7	up 140.5

Using the Merva and Fowles (1992) estimates, we see that here too, the impacts could be large. An increase of 2.2 to 4.5 million unemployed workers would represent an increase of about 1.4 to 2.9 percentage points in the unemployment rate.[61] Looking just at the mortality from major heart disease (their biggest impact category), this unemployment increase could increase mortality about 30 to 60 people per 100,000. If applied to a projected population of about 300 million people in 2010,[62] this too could exceed 100,000 additional deaths.[63]

- ***Sorlie and Rogot (1990).*** Using the National Longitudinal Mortality Study, Sorlie and Rogot (1990) analyzed data on persons aged 25-64 with respect to employment status. Employed persons aged 25-64 years were found to have standardized mortality ratios from 61% to 74% of the average, depending upon their sex and race. Unemployed men had standardized mortality ratios slightly above 100, but these values were 1.6 and 2.2 times higher than those for employed white men and black men, respectively.

59 Standard Metropolitan Statistical Area, or SMSA.

60 See Merva and Fowles (1992), Table 1.

61 From EIA *SR 98-03,* the Reference Case labor force in the year 2010 was projected at 156.5 million workers.

62 From EIA *SR 98-03,* p. 211, the Reference Case population in the year 2010 is 298.9 million people.

63 Another way of extrapolating from the Merva and Fowles (1992) estimate is to begin with their estimates that nearly 40,000 additional people died during the two-year period due to heart disease, stroke, and homicides (p.2). This increase related to an average unemployment rate increase of 1.5% and a covered population of about 80 million people. This mortality level, applied to a 1.4 - 2.9 percentage point increase in the unemployment rate and a 2010 population of about 300 million people, would suggest roughly 100,000 additional deaths.

> From these values, we can estimate an approximate number of increased deaths associated with additional unemployment. Using average mortality data from CDC (2001), we infer that the Sorlie and Roget (1990) analysis found death rates for employed persons aged 25-64 to be about 600 people per 100,000, while unemployed persons were roughly 1,100 people per 100,000. The difference – roughly 500 people per 100,000 – represents the increase in mortality risk to the unemployed. If we apply this increment to an increase of 2.2 to 4.5 million unemployed workers, we would expect to see about 11,000 to 22,000 additional deaths among the additional unemployed. This number is substantially below the estimates inferred from the Brenner (1984) and Merva and Fowles (1992) studies described above. However, this estimate concerns only the more limited subset of unemployed persons, whereas the other estimates concerned population-wide impacts of unemployment.

While both the Brenner (1984) and Merva and Fowles (1992) studies suggested large potential impacts – on the order of 100,000 deaths or more – there are several cautions in order. With the income-related impacts, we are generally examining the effects of reduced spending over a large population over a long time period. In contrast, unemployment surges are typically of shorter duration and affecting fewer people. While the unemployed are more intensely affected than others who suffer smaller losses of disposable income, some health effects may lag in time (e.g., less health care spending) while others may be more immediate (e.g., suicide, stroke). Brenner (2002) found that in virtually all countries examined, the actual relationship between employment rates and decreased mortality extended over at least a ten-year period, although many countries showed effects at shorter intervals as well.

Additionally, changes in the workforce composition and in unemployment relief programs make it difficult to extend the effects of one recessionary event into another. Further, the extrapolations developed in the examples above may extend beyond the useful range of the underlying analyses.

As a last point of caution, there could be double counting between unemployment impacts and disposable income impacts. While the additional unemployed represent only a small portion of the total labor force, their loss in disposable income is large. Collectively, their share of the total decline in disposable income could be significant. Care needs to be exercised to ensure that impacts on the unemployed are not also being counted as part of the income impact analysis. Alternatively, it should be recognized that the increased mortality risks due to loss of a job and due to the reduction of income, although caused by the same event, may influence mortality risks independently due to different mechanisms.

Accordingly, the data analysis needed to isolate unemployment impacts apart from the broader impacts on disposable income is very complex. For these reasons, we chose at this time not to estimate additional mortality impacts due to increased unemployment. There are strong indications that such effects exist, and may be similar in magnitude or even larger than the impacts resulting from loss of disposable income. However, we see further work as being necessary before supportable quantitative estimates can be drawn.

GLOSSARY OF TERMS

CO_2	carbon dioxide
CPI	Consumer Price Index
DOE	U.S Department of Energy
EIA	Energy Information Administration, the independent statistical and analytical agency within the U.S Department of Energy (DOE)
GDP	Gross Domestic Product
Heat rate	amount of energy used in producing a unit of electricity, typically expressed in Btu/kWh
Hg	mercury
kWh	kilowatt-hour
MMBtu	million British thermal units
MWh	megawatt-hour
NEMS	National Energy Modeling System, developed and maintained by the DOE Energy Information Administration
NIH	National Institutes of Health
NLMS	National Longitudinal Mortality Study
NO_x	nitrogen oxides
RPS	Renewable Portfolio Standard
SMSA	Standard Metropolitan Statistical Area
SO_2	sulfur dioxide

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APPENDIX A:
SUMMARY OF ECONOMIC ANALYSES OF LOWER COAL USE

1. DRI (1998)

Standard & Poor's DRI. July 1998. *The Impact of Meeting the Kyoto Protocol on Energy Markets and the Economy.* (Case 1: 77% of U.S. CO_2 reductions achieved by shifting energy mix or curtailing fossil fuel usage)

2. EIA *SR 98-03*

U.S. Department of Energy, Energy Information Administration. October 1998. *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity.* Washington DC: DOE/EIA Report No. SR/OIAF/98-03. (Reference Case vs. 1990 Level Scenario)

3. EIA *SR 2001-03*

U.S. Department of Energy, Energy Information Administration. July 2001. *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide, Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio Standard.* Washington DC: DOE/EIA Report No. SR/OIAF/2001-03. (Integrated NO_x, SO_2, CO_2 1990-7%, Hg (no RPS))

4. Rose and Yang (2002)

Rose, Adam, and Bo Yang. 2002. *The Economic Impact of Coal Utilization in the Continental United States.* University Park, PA: The Pennsylvania State University Department of Energy, Environmental, and Mineral Economics. (High Price Gas Case (average of 4 scenarios))

5. Rose and Yang (2002)

Rose, Adam, and Bo Yang. 2002. *The Economic Impact of Coal Utilization in the Continental United States.* University Park, PA: The Pennsylvania State University Department of Energy, Environmental, and Mineral Economics. (Low Price Gas Case (average of 4 scenarios))

6. WEFA (1997)

WEFA, Inc. 1997. *Global Warming: The Economic Cost of Early Action.* Eddystone, PA: WEFA, Inc. (Carbon Stabilization)

Summary data from coal impact studies

Source 1: DRI (1998)

Citation: DRI. July 1998. *The Impact of Meeting the Kyoto Protocol on Energy Markets and the Economy*. Prepared by Standard & Poor's DRI.

Case/Scenario: Case 1: 77% of U.S. CO2 reductions achieved by shifting energy mix or curtailing fossil fuel usage.

Variable	units of measure	2005	2010	2015	2020	Notes
Coal consumed for electricity						
- Reference Case	quad Btu					
- Scenario	quad Btu		-43.2%		-47.0%	p. 11
Electricity sector coal price						
- Reference Case	1997 $/MMBtu					
- Scenario	1997 $/MMBtu		407%		468%	p. 13. Increase includes carbon price.
Electricity sector gas price						
- Reference Case	1997 $/MMBtu					
- Scenario	1997 $/MMBtu		111%		91%	p. 13. Increase includes carbon price.
Carbon price						
- Reference Case	1997 $/metric ton		N/A		N/A	
- Scenario	1997 $/metric ton		$ 180			
Electricity price						
- Reference Case	1997 ¢/kWh					
- Scenario	1997 ¢/kWh					
Electricity total sales						
- Reference Case	billion kWh					
- Scenario	billion kWh					
GDP						
- Reference Case	1992$ billions					
- Scenario	1992$ billions		-1.6%			p. 21
Real disposable income						
- Reference Case	1992$ billions					
- Scenario	1992$ billions		-$168.36			p. 14, 21. -$1403 per household
Employment						
- Reference Case	million workers					
- Scenario	million workers		(1.6)			p. 21
Population						
- Reference Case	millions					
- Scenario	millions					

Other Notes: Disposable income drop averaging $1403/household over 2008-2012 period converted into billion dollars using projection of 120.0 million households in 2010, based on historic data in Census (2001).

Summary data from coal impact studies

Source 2: EIA *SR 98-03*

Citation: U.S. Department of Energy, Energy Information Administration. October 1998. *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*. Washington DC: DOE/EIA Report No. SR/OIAF/98-03.

Case/Scenario: Reference Case vs. 1990 Level Scenario

Variable	units of measure	2005	2010	2015	2020	Notes
Coal consumed for electricity						
- Reference Case	quad Btu	20.75	21.35		22.48	pp. 164-165
- Scenario	quad Btu	16.11	5.95		1.41	pp. 164-166
Electricity sector coal price						
- Reference Case	1996 $/MMBtu	$ 1.17	$ 1.11		$ 1.00	pp. 168-169
- Scenario	1996 $/MMBtu	$ 3.39	$ 7.53		$ 6.04	pp. 168-169. includes carbon price
Electricity sector gas price						
- Reference Case	1996 $/MMBtu	$ 2.62	$ 2.82		$ 3.20	
- Scenario	1996 $/MMBtu	$ 3.99	$ 7.28		$ 7.21	includes carbon price
Carbon price						
- Reference Case	1996 $/metric ton		N/A		N/A	
- Scenario	1996 $/metric ton		$ 254		$ 200	
Electricity price						
- Reference Case	1996 ¢/kWh	6.0	5.9		5.6	pp. 184-185
- Scenario	1996 ¢/kWh	7.7	10.0		8.7	pp. 184-185. includes carbon price
Electricity total sales						
- Reference Case	billion kWh	3,630	3,865		4,240	pp. 184-185
- Scenario	billion kWh	3,435	3,344		3,750	pp. 184-185
GDP						
- Reference Case	1992$ billions	8,525	9,482		10,865	pp. 210-211
- Scenario	1992$ billions	8,464	9,429		10,799	pp. 210-211
Real disposable personal income						
- Reference Case	1992$ billions	6,206	6,891		8,192	pp. 210-211
- Scenario	1992$ billions	6,225	6,752		8,188	pp. 210-211
Employment						
- Reference Case	million workers	149.7	156.5		162.2	pp. 210-211
- Scenario	million workers	149.6	154.9		161.9	pp. 210-211
Population						
- Reference Case	millions	287.1	298.9		323.5	pp. 210-211
- Scenario	millions	287.1	298.9		323.5	pp. 210-211
Other Notes:						

Summary data from coal impact studies

Source 3: EIA *SR 2001-03*

Citation: U.S. Department of Energy, Energy Information Administration. July 2001. *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide, Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio Standard.* Washington DC: DOE/EIA Report No. SR/OIAF/2001-03.

Case/Scenario: Integrated NO_x, SO_2, CO_2 1990-7%, Hg (no RPS)

Variable	units of measure	2005	2010	2015	2020	Notes
Coal consumed for electricity						
- Reference Case	quad Btu	21.68	22.93		23.70	p. 241
- Scenario	quad Btu	20.43	10.83		9.97	p. 241
Electricity sector coal price						
- Reference Case	1999 $/MMBtu	$ 1.14	$ 1.06		$ 0.98	p. 243
- Scenario	1999 $/MMBtu	$ 1.08	$ 0.93		$ 0.85	p. 243
Electricity sector gas price						
- Reference Case	1999 $/MMBtu	$ 3.44	$ 3.26		$ 3.71	p. 243
- Scenario	1999 $/MMBtu	$ 3.40	$ 4.41		$ 4.49	p. 243
Carbon price						
- Reference Case	1999 $/metric ton		N/A		N/A	
- Scenario	1999 $/metric ton		$ 120		$ 90	
Electricity price						
- Reference Case	1999 ¢/kWh	6.4	6.1		6.2	p. 245
- Scenario	1999 ¢/kWh	6.7	8.4		8.6	p. 245
Electricity total sales						
- Reference Case	billion kWh	3,794	4,147		4,788	p. 245
- Scenario	billion kWh	3,738	3,851		4,257	p. 245
GDP						
- Reference Case	1996$ billions		12,667		16,515	p. 67
- Scenario	1996$ billions		12,555		16,493	p. 67
Real disposable income						
- Reference Case	1996$ billions		8,928		11,842	p. 67
- Scenario	1996$ billions		8,822		11,789	p. 67
Employment						
- Reference Case	million workers		149.7		165.1	p. 67. Non-agricultural employment
- Scenario	million workers		148.4		165.2	p. 67. Non-agricultural employment
Population						
- Reference Case	millions					
- Scenario	millions					
Other Notes:						

Summary data from coal impact studies

Source 4: Rose and Yang (2002): High Gas Price

Citation: Rose, Adam, and Bo Yang. 2002. *The Economic Impact of Coal Utilization in the Continental United States* . University Park, PA: The Pennsylvania State University Department of Energy, Environmental, and Mineral Economics.

Case/Scenario: High Price Gas Case (average of 4 scenarios)

Variable	units of measure	2005	2010	2015	2020	Notes
Coal consumed for electricity						
- Reference Case	quad Btu					
- Scenario	quad Btu		-80%			p. 1
Electricity sector coal price						
- Reference Case	1999 $/MMBtu					
- Scenario	1999 $/MMBtu					
Electricity sector gas price						
- Reference Case	1999 $/MMBtu					
- Scenario	1999 $/MMBtu					
Carbon price						
- Reference Case	1999 $/metric ton					
- Scenario	1999 $/metric ton					
Electricity price						
- Reference Case	1999 ¢/kWh					
- Scenario	1999 ¢/kWh					
Electricity total sales						
- Reference Case	billion kWh					
- Scenario	billion kWh					
GDP						
- Reference Case	1999$ billions		--			
- Scenario	1999$ billions		(411)			p. 3
Annual Household Incomes						
- Reference Case	1999$ billions		--			
- Scenario	1999$ billions		(133)			p. 3
Employment						
- Reference Case	million workers		--			
- Scenario	million workers		(3.6)			p. 3
Population						
- Reference Case	millions					
- Scenario	millions					
Other Notes:						

Summary data from coal impact studies

Source 5: Rose and Yang (2002): Low Gas Price

Citation: Rose, Adam, and Bo Yang. 2002. *The Economic Impact of Coal Utilization in the Continental United States*. University Park, PA: The Pennsylvania State University Department of Energy, Environmental, and Mineral Economics.

Case/Scenario: Low Price Gas Case (average of 4 scenarios)

Variable	units of measure	2005	2010	2015	2020	Notes
Coal consumed for electricity						
- Reference Case	quad Btu					
- Scenario	quad Btu		-80%			supplemental documentation
Electricity sector coal price						
- Reference Case	1999 $/MMBtu					
- Scenario	1999 $/MMBtu					
Electricity sector gas price						
- Reference Case	1999 $/MMBtu					
- Scenario	1999 $/MMBtu					
Carbon price						
- Reference Case	1999 $/metric ton					
- Scenario	1999 $/metric ton					
Electricity price						
- Reference Case	1999 ¢/kWh					
- Scenario	1999 ¢/kWh					
Electricity total sales						
- Reference Case	billion kWh					
- Scenario	billion kWh					
GDP						
- Reference Case	1999$ billions		--			
- Scenario	1999$ billions		(324)			supplemental documentation
Annual Household Incomes						
- Reference Case	1999$ billions		--			
- Scenario	1999$ billions		(99)			supplemental documentation
Employment						
- Reference Case	million workers		--			
- Scenario	million workers		(2.7)			supplemental documentation
Population						
- Reference Case	millions					
- Scenario	millions					

Other Notes:

Summary data from coal impact studies

Source 6: WEFA (1997)

Citation: WEFA, Inc. 1997. *Global Warming: The Economic Cost of Early Action* . Eddystone, PA: WEFA, Inc.

Case/Scenario: Carbon Stabilization

Variable	units of measure	2005	2010	2015	2020	Notes
Coal consumed for electricity						
- Reference Case	quad Btu	19.29	20.12	21.28	23.09	p. 61
- Scenario	quad Btu	13.43	8.69	6.28	4.03	p. 63
Electricity sector coal price						
- Reference Case	1996 $/MMBtu	$ 1.25	$ 1.19	$ 1.12	$ 1.11	p. 62
- Scenario	1996 $/MMBtu	$ 3.63	$ 6.09	$ 7.32	$ 8.59	p. 64. Includes carbon price.
Electricity sector gas price						
- Reference Case	1996 $/MMBtu	$ 2.44	$ 2.52	$ 2.59	$ 2.66	p. 62
- Scenario	1996 $/MMBtu	$ 3.94	$ 5.55	$ 6.38	$ 7.30	p. 64. Includes carbon price.
Carbon price						
- Reference Case	1996 $/metric ton	N/A	N/A	N/A	N/A	
- Scenario	1996 $/metric ton	$ 100	$ 200	$ 250	$ 300	p. 4
Electricity price						
- Reference Case	1996 ¢/kWh	6.40	6.19	6.04	5.89	p. 62
- Scenario	1996 ¢/kWh	8.42	9.90	10.20	10.56	p. 64. Includes carbon price.
Electricity total sales						
- Reference Case	billion kWh	12,200	13,239	14,366	15,629	p. 61
- Scenario	billion kWh	11,373	11,462	11,946	12,551	p. 63
GDP						
- Reference Case	1992$ billions	8,403	9,314	10,359	11,478	p. 27
- Scenario	1992$ billions	8,287	9,087	10,159	11,282	p. 28
Real disposable income						
- Reference Case	1992$ billions	6,226	6,942	7,790	8,671	p. 27
- Scenario	1992$ billions	6,152	6,846	7,736	8,605	p. 28
Employment						
- Reference Case	million workers	134.7	142.5	149.8	155.8	p. 27
- Scenario	million workers	133.8	140.7	148.5	155.4	p. 28
Population						
- Reference Case	millions					
- Scenario	millions					
Other Notes:						

APPENDIX B:
SUPPLEMENTARY TABLES

Table B-1
GDP Implicit Price Deflators

Current-Dollar and "Real" Gross Domestic Product

	BEA Data		Adjustment to 2000$	
YEAR	GDP in billions of current dollars	GDP in billions of chained 1996 dollars	GDP in billions of chained 2000 dollars	GDP adjustment factor for 2000 dollars
1970	1,039.7	3,578.0	3,829.7	3.6835
1971	1,128.6	3,697.7	3,957.8	3.5068
1972	1,240.4	3,898.4	4,172.6	3.3640
1973	1,385.5	4,123.4	4,413.5	3.1855
1974	1,501.0	4,099.0	4,387.4	2.9230
1975	1,635.2	4,084.4	4,371.7	2.6735
1976	1,823.9	4,311.7	4,615.0	2.5303
1977	2,031.4	4,511.8	4,829.2	2.3773
1978	2,295.9	4,760.6	5,095.5	2.2194
1979	2,566.4	4,912.1	5,257.7	2.0487
1980	2,795.6	4,900.9	5,245.7	1.8764
1981	3,131.3	5,021.0	5,374.2	1.7163
1982	3,259.2	4,919.3	5,265.4	1.6155
1983	3,534.9	5,132.3	5,493.4	1.5540
1984	3,932.7	5,505.2	5,892.5	1.4983
1985	4,213.0	5,717.1	6,119.3	1.4525
1986	4,452.9	5,912.4	6,328.3	1.4212
1987	4,742.5	6,113.3	6,543.4	1.3797
1988	5,108.3	6,368.4	6,816.4	1.3344
1989	5,489.1	6,591.8	7,055.5	1.2854
1990	5,803.2	6,707.9	7,179.8	1.2372
1991	5,986.2	6,676.4	7,146.1	1.1938
1992	6,318.9	6,880.0	7,364.0	1.1654
1993	6,642.3	7,062.6	7,559.4	1.1381
1994	7,054.3	7,347.7	7,864.6	1.1149
1995	7,400.5	7,543.8	8,074.5	1.0911
1996	7,813.2	7,813.2	8,362.9	1.0703
1997	8,318.4	8,159.5	8,733.5	1.0499
1998	8,781.5	8,508.9	9,107.5	1.0371
1999	9,268.6	8,856.5	9,479.5	1.0228
2000	9,872.9	9,224.0	9,872.9	1.0000

Source: U.S. Dept. of Commerce, Bureau of Economic Analysis.
National Accounts Data: Current-dollar and "real" GDP, 1929-2000. http://www.bea.doc.gov/bea/dn/gdplev.xls

Table B-2
Consumer Price Index, 1970-2001

YEAR	AVG.	% CHANGE (DEC-DEC)
1970	38.8	5.6
1971	40.5	3.3
1972	41.8	3.4
1973	44.4	8.7
1974	49.3	12.3
1975	53.8	6.9
1976	56.9	4.9
1977	60.6	6.7
1978	65.2	9.0
1979	72.6	13.3
1980	82.4	12.5
1981	90.9	8.9
1982	96.5	3.8
1983	99.6	3.8
1984	103.9	3.9
1985	107.6	3.8
1986	109.6	1.1
1987	113.6	4.4
1988	118.3	4.4
1989	124.0	4.6
1990	130.7	6.1
1991	136.2	3.1
1992	140.3	2.9
1993	144.5	2.7
1994	148.2	2.7
1995	152.4	2.5
1996	156.9	3.3
1997	160.5	1.7
1998	163.0	1.6
1999	166.6	2.7
2000	172.2	3.4
2001	177.1	1.6

Source: Bureau of Labor Statistics, U.S. Department of Labor. *Consumer Price Index - All Urban Consumers (CPI-U), U.S. City Average*. ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt.

Table B-3
Parameters Calculated for the Annual Mortality Risk Model

Parameter	White Males	Black Males	White Females	Black Females
a	0.009262	0.012195	0.003902	0.007009
b	0.036824	0.044259	0.057920	0.057100
d	0.004223	0.006145	0.002770	0.003429

[a] The parameters in the annual mortality risk model are calculated in thousands of 1999 dollars.

$$r(\boldsymbol{x}) = ae^{-b\boldsymbol{x}} + d$$

where: $r(\boldsymbol{x})$ = annual mortality risk for income $\boldsymbol{x}$
$\boldsymbol{x}$ = income in thousands of \$US

Table B-4
Expected Deaths Induced by a $1 Billion Regulatory Cost (in 1999 $)

A: Assuming costs are allocated equally among all households

	number of expected deaths per $1 billion						
	White		Black		Other		Total
Income range (1999$)	Male	Female	Male	Female	Male	Female	Deaths
Under $10,000	18.58	11.08	9.79	6.80	1.01	0.60	47.86
$10,000 - $14,999	12.54	6.39	3.85	2.43	0.46	0.23	25.91
$15,000 - $24,999	18.96	8.24	4.49	2.57	0.61	0.27	35.14
$25,000 - $34,999	11.95	4.21	2.40	1.21	0.41	0.15	20.32
$35,000 - $49,999	9.54	2.58	1.48	0.64	0.38	0.10	14.72
$50,000 - $74,999	5.46	0.97	0.59	0.19	0.21	0.04	7.45
$75,000 plus	0.63	0.03	0.03	0.00	0.03	0.00	0.72
All incomes [a]	77.65	33.49	22.62	13.86	3.11	1.39	152.12

B: Assuming costs are allocated proportional to household income

	number of expected deaths per $1 billion						
	White		Black		Other		Total
Income range (1999$)	Male	Female	Male	Female	Male	Female	Deaths
Under $10,000	1.69	1.01	0.89	0.62	0.09	0.05	4.36
$10,000 - $14,999	2.86	1.46	0.88	0.55	0.11	0.05	5.90
$15,000 - $24,999	6.91	3.00	1.64	0.94	0.22	0.10	12.81
$25,000 - $34,999	6.54	2.30	1.31	0.66	0.23	0.08	11.12
$35,000 - $49,999	7.39	2.00	1.15	0.49	0.30	0.08	11.41
$50,000 - $74,999	6.22	1.10	0.67	0.22	0.24	0.04	8.49
$75,000 plus	1.45	0.07	0.07	0.01	0.07	0.00	1.67
All incomes [a]	33.06	10.94	6.60	3.50	1.25	0.41	55.76

C: Assuming costs are allocated proportional to electricity use

	number of expected deaths per $1 billion						
	White		Black		Other		Total
Income range (1999$)	Male	Female	Male	Female	Male	Female	Deaths
Under $10,000	12.27	7.32	6.46	4.49	0.66	0.40	31.60
$10,000 - $14,999	8.92	4.54	2.74	1.73	0.33	0.17	18.43
$15,000 - $24,999	14.46	6.28	3.42	1.96	0.47	0.20	26.79
$25,000 - $34,999	9.93	3.49	1.99	1.00	0.34	0.12	16.88
$35,000 - $49,999	8.73	2.36	1.36	0.58	0.35	0.09	13.48
$50,000 - $74,999	5.74	1.02	0.62	0.20	0.22	0.04	7.84
$75,000 plus	0.94	0.04	0.05	0.01	0.05	0.00	1.08
All incomes [a]	60.98	25.06	16.63	9.98	2.42	1.02	116.09

[a] Totals for columns may not sum due to independent rounding.

NOTE: A detailed discussion of the relative contributors to total induced fatalities of the different mortality risk curves and different income distributions for gender and race to the resulting morality is found in Keeney (1997).

APPENDIX C:
ABOUT THE AUTHORS

DANIEL E. KLEIN

EDUCATION

1975	M.B.A., Graduate School of Business, Stanford University
1973	S.B., Urban Studies, Massachusetts Institute of Technology

EXPERIENCE

Daniel E. Klein, President of Twenty-First Strategies, has over 25 years of consulting experience in energy, environmental, and economic analysis. For many years a Senior Vice President and Director of ICF Resources Incorporated, he founded Twenty-First Strategies in 1995 to offer energy and environmental consulting services to energy companies, government agencies, associations and NGOs, and others.

Over the course of his consulting career, Mr. Klein has conducted hundreds of projects related to energy and environmental concerns, electric utility fuel use, coal supply, transportation, and antitrust issues. His work in recent years has focused primarily on climate change issues and related issues, both on policy from the government side as well as strategies for the private sector.

SELECTED PUBLICATIONS AND PRESENTATIONS

Suitability of Methane Sources for Emissions Trading, presented at the Center for Clean Air Policy's Greenhouse Gas Emissions Trading Braintrust, Airlie VA, February 2000. Publication forthcoming.

Carbon Sequestration: An Option for Mitigating Global Climate Change (co-authored with Robert L. Kane, DOE), published as Chapter 6 in Environmental Challenges and Greenhouse Gas Control for Fossil Fuel Utilization in the 21st Century, edited by M. Mercedes Marato-Valer, Chunshan Song, and Yee Soong, New York: Kluwer Academic/Plenum Publishers, 2002.

Carbon Sequestration: An Option for Mitigating Global Climate Change (co-authored with Robert L. Kane, DOE), published in *Chemical Engineering Progress*, June 2001, pp. 44–52.

Opportunities for Advancements in Chemical Processes in Carbon Sequestration and Climate Change Mitigation (co-authored with Robert L. Kane, DOE), presented at the American Chemical Society 221st Annual Meeting, San Diego California, April 4, 2001.

Environmental Benefits of Fossil Energy Technologies and Importance for Future Carbon Mitigation Costs (co-authored with Robert L. Kane, DOE), presented at Combustion Canada '99: Combustion and Global Climate Change, Canada's Challenges and Solutions, Calgary, Alberta, Canada, May 26-28, 1999.

Climate Challenge Program: Lessons Learned and Prospects for the Future (co-authored with Daniel R. Cleverdon, Cadmus Group Inc.), presented at Combustion Canada '99: Combustion and Global Climate Change, Canada's Challenges and Solutions, Calgary, Alberta, Canada, May 26-28, 1999.

Coal Mine Methane: Opportunities for Low-Cost Zero-GHG Power (co-authored with Paul Teske, MCNIC Oil & Gas Co.), presented at Combustion Canada '99: Combustion and Global Climate Change, Canada's Challenges and Solutions, Calgary, Alberta, Canada, May 26-28, 1999.

Buyer vs. Seller Liability in International Emissions Trading, presented at the CCAP International Emissions Trading Dialog Group, Toronto, Ontario, Canada, March 4, 1999.

Fossil Energy-Related Greenhouse Gas Control Strategies and Associated Environmental Benefits (co-authored with Robert L. Kane, DOE), presented at the Electric Utilities Environmental Conference: Science, Regulations & Impacts of SO_2, CO_2, O_3, NO_x & Mercury, Tucson AZ, January 11-13,1999.

Global Climate Change: The Road to Kyoto, (co-authored with C.V. Mathai, Arizona Public Service Co., and Nikhil Desai), published in *EM Magazine*, a publication of the Air & Waste Management Association, November 1997.

Managing the Climate Change Risks in a Restructuring Electric Utility Industry (co-authored with Robert L. Kane, DOE), presented at the International Climate Change Conference & Technologies Exhibition, Baltimore MD, June 12-13, 1997.

Interactions Between Greenhouse Gas Policies and Acid Rain Control Strategies (co-authored with Robert L. Kane and Larry Mansueti, DOE), presented at the Air & Waste Management Association's Acid Rain and Electric Utilities II Conference, Scottsdale, AZ, January 21-22, 1997.

Climate Challenge Program Report (co-authored with Princeton Economic Research, Inc.), U.S. Dept. of Energy Publication DOE/FE-0355, December 1996. http://www.eren.doe.gov/climatechallenge/progressreport/titlpg.htm.

Climate Change, Voluntary Programs, and Risk Management in a Restructuring Industry (co-authored with Robert L. Kane, DOE), presented at the International Association for Energy Economics 11th Annual North American Conference, Boston, Massachusetts, October 28, 1996.

Meeting the Climate Change Challenge: Climate-Related Activities of the U.S. Department of Energy's Office of Fossil Energy (co-authored with Robert L. Kane, DOE, and Steven Reich, ICF), presented at the 18th IAEE International Conference, Washington DC, July 5-8, 1995.

Trends in Greenhouse Gas Emissions in the U.S. and Potential Future Outlook (co-authored with Robert L. Kane, DOE, and Steven Winkelman, ICF), presented at the 88th Annual Meeting and Exhibition of the Air & Waste Management Association, San Antonio, Texas, June 18-23, 1995.

Climate Change and New Opportunities for Coal Combustion Byproducts (co-authored with Samuel S. Tyson, ACAA), presented at the 11th International Symposium on Use & Management of Coal Combustion Byproducts, Orlando, Florida, January 15-19, 1995.

Full Consideration of Externalities (co-authored with David Kathan, ICF), presented to the NARUC - DOE Fifth National Integrated Resource Planning Conference, May 1994.

The Dynamic Energy & GReenhouse Emission Evaluation System (DEGREES) (co-authored with Ira H. Shavel, et. al.), presented to the 15th Annual North American Conference, International Association for Energy Economics, Seattle, Washington, October 1993.

Impacts of Including Externalities in National Electric Utility Planning (co-authored with David Kathan, ICF), presented to the 15th Annual North American Conference, International Association for Energy Economics, Seattle, Washington, October 1993.

Assessment of Greenhouse Gas Emissions Policies of the Electric Utility Industry: Costs, Impacts, and Opportunities, submitted to the Edison Electric Institute, January 1992.

Lower Sulfur Coals as a Means of Reducing Sulfur Dioxide Emissions, presented to the First International Conference on Acid Rain: Regulatory Aspects and Engineering Solutions, published in *Power Magazine*, Washington, D.C., March 1984.

Analysis of Cost-Effective, Phased-In Reductions of Sulfur Dioxide Emissions, submitted to the Alliance for Clean Energy, February 1984.

Forecasting Employment Impacts of Acid Rain Control Programs, presented to Resources for the Future Symposium, Washington, D.C., December 1983.

DR. RALPH L. KEENEY

EDUCATION

1969 Ph.D., Operations Research, Massachusetts Institute of Technology
1968 E.E., Electrical Engineering, Massachusetts Institute of Technology
1967 S.M., Electrical Engineering, Massachusetts Institute of Technology
1966 B.S., Engineering, University of California, Los Angeles

EXPERIENCE

Dr. Keeney is a Research Professor at Duke University's Fuqua School of Business. From 1983-2002, Dr. Keeney was Professor of Industrial and Systems Engineering and a Professor of Management in the Marshall School of Business at the University of Southern California, and also a researcher in the Center for Telecommunications Management. Before joining USC in 1983, he was on the faculties of Civil Engineering and Management at MIT, worked as a research scholar at the International Institute for Applied Systems Analysis near Vienna, Austria, and built the Decision and Risk Group at a major consulting firm.

Dr. Keeney's areas of expertise are decision analysis, risk analysis, and management decision-making. He is an authority on decision making with multiple objectives. During the past thirty years, Dr. Keeney has contributed substantially toward the development of decision analysis and risk analysis. His experience includes corporate management problems, risk analyses, energy policy, large-scale siting studies (e.g., airports, power plants), and environmental studies.

Dr. Keeney has been a consultant for several organizations including Fair Isaac, Seagate Technology, American Express, British Columbia Hydro, Pacific Gas and Electric, Westinghouse, Kaiser Permanente, Proctor and Gamble, Hewlett-Packard, GTE, Hunton & Williams, the Electric Power Research Institute, Arkansas Power and Light, International Institute of Management (Berlin), Ministry of Public Works (Mexico), U.S. Department of Commerce, U.S. Department of Energy, Environmental Protection Agency, and the Office of Naval Research.

PROFESSIONAL AFFILIATIONS

National Academy of Engineering

Institute for Operations Research and The Management Sciences (INFORMS)

Society for Risk Analysis

HONORS

2001 Awarded Best Annual Publication on Decision-Making by the Decision Analysis Society for Smart Choices, co-authored with John S. Hammond and Howard Raiffa.

1999 Awarded Annual Book Prize of the CPR Institute for Dispute Resolution for Smart Choices, co-authored with John S. Hammond and Howard Raiffa.

1998 Awarded Gold Medal of the International Society for Multiple Criteria Decision Making

1995 Selected as a Fellow of The Society for Risk Analysis

1995 Awarded Honorary Membership in Omega Rho, the International Operations Research and Management Science Honor Society

1995 Elected a member of The National Academy of Engineering.

1994 Decision Analysis Publication Award awarded by The Decision Analysis Group of The Operations Research Society of America for best publication on decision analysis in 1992 for the book Value-Focused Thinking.

1993 Philip McCord Morse Lectureship of The Operations Research Society awarded to an individual who exemplifies the spirit of Dr. Morse and is an outstanding spokesman of the operations research profession.

1991 Hermes Award from the Faculty of Administrative Sciences of Laval University for exceptional contributions to multiattribute utility theory.

1989 Ramsey Medal awarded by the Decision Analysis Group of the Operations Research Society for distinguished contributions to decision analysis.

1988 Applications Award from the Decision Analysis Group of the Operations Research Society for the best application of decision analysis for the presentation "*Evaluation of Alternative Sites for the Disposal of Nuclear Waste*" with M.L. Merkhofer.

1976 Lanchester Prize of the Operations Research Society for the best publication in Operation Research for the book Decisions With Multiple Objectives, co-authored with H. Raiffa.

SELECTED PUBLICATIONS

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