# THE SOCIAL COSTS OF CARBON?

# NO, THE SOCIAL BENEFITS OF CARBON

Prepared for the American Coalition for Clean Coal Electricity

By

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# ABSTRACT

This report analyzes the impacts and benefits of carbon dioxide ($CO_2$) and then compares these to estimates of the social cost of carbon (SCC) that have been published by the U.S. federal government. $CO_2$ is the basis of life on Earth, it facilitates plant growth, and enhances agricultural productivity. It is the primary raw material utilized by plants to produce the organic matter out of which they construct their tissues, which subsequently become the ultimate source of food.

Of primary importance, the successful development and utilization of fossil fuels, which generate $CO_2$, facilitated successive industrial revolutions, created the modern world, and enabled the high quality of life currently taken for granted. There is a strong causal relationship between world GDP and $CO_2$ emissions over the past two centuries, and this relationship is forecast to continue for the foreseeable future. We compared these indirect $CO_2$ benefits to the SCC estimates. While the SCC estimates are of questionable validity, we nevertheless compared the $CO_2$ costs and benefits (on a normalized per ton basis) using the SCC estimates and assumptions. We found that the current benefits clearly outweigh any hypothesized costs by, literally, orders of magnitude: The benefit-cost (B-C) ratios range up to more than 200-to-1 (Figure AB-1). We utilized forecast data to estimate B-C ratios through 2040 and found that future benefits also greatly exceed hypothesized costs by orders of magnitude: In the range of 40-to-1 to 400-to-1. To place these findings in perspective, normally, B-C ratios in the range of 2-to-1 or 3-to-1 are considered favorable. Thus, our main conclusion is that the benefits of $CO_2$ overwhelmingly outweigh estimated $CO_2$ costs no matter which SCC estimates or assumptions are used. In fact, the SCC estimates are relatively so small as to be in the statistical noise of the estimated $CO_2$ benefits. These findings must be used to inform energy, environmental, and regulatory policies.

**Figure AB-1: 2010 $CO_2$ Benefit-Cost Ratios**
(Based on 2013 IWG Report)
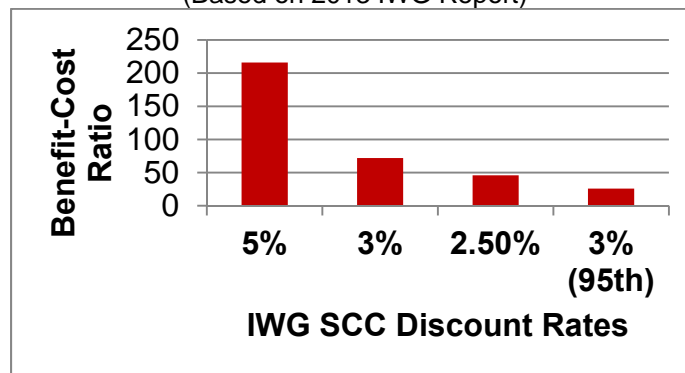


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

We also assessed the annual total monetary value of the direct $CO_2$ benefit for 45 crops over the period 1961-2011 and estimated that it cumulatively totaled $3.2 trillion – increasing from $19 billion in 1961 to over $140 billion in 2010. We forecast that over the period 2012 - 2050, these $CO_2$ benefits will total $9.8 trillion.

# EXECUTIVE SUMMARY

## IWG SCC Estimates

Federal agencies are required to assess the benefits and the costs of proposed regulations. In February 2010, a Federal Interagency Working Group (IWG) developed estimates of the social cost of carbon (SCC) of about $22/ton, and in May 2013 the IWG revised upward its SCC estimates to about $36/ton. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year, and is meant to be a comprehensive estimate of climate change damages. SCCs are being used by federal agencies to incorporate the social benefits of reducing $CO_2$ emissions into benefit-cost analyses of regulatory actions. However, in benefit-cost (B-C) analyses both the benefits and the costs of $CO_2$ must be considered, and, here we analyze and compare the benefits and the costs of $CO_2$.

## The Indirect Benefits of Carbon: Fossil Fuels

The successful development and utilization of fossil fuels facilitated successive industrial revolutions, created the modern world, created the world's advanced technological society, and enabled the high quality of life currently taken for granted. Over the past 250 years, global life expectancy more than doubled, population increased 8-fold, and incomes increased 11-fold. Concurrently, as shown in Figure EX-1, $CO_2$ emissions increased 2,800-fold, increasing from about 3 million tons to 8.4 billion tons.

**Figure EX-1: Global Progress — as Indicated by Trends in World Population, GDP Per Capita, Life Expectancy, and $CO_2$ Emissions From Fossil Fuels**
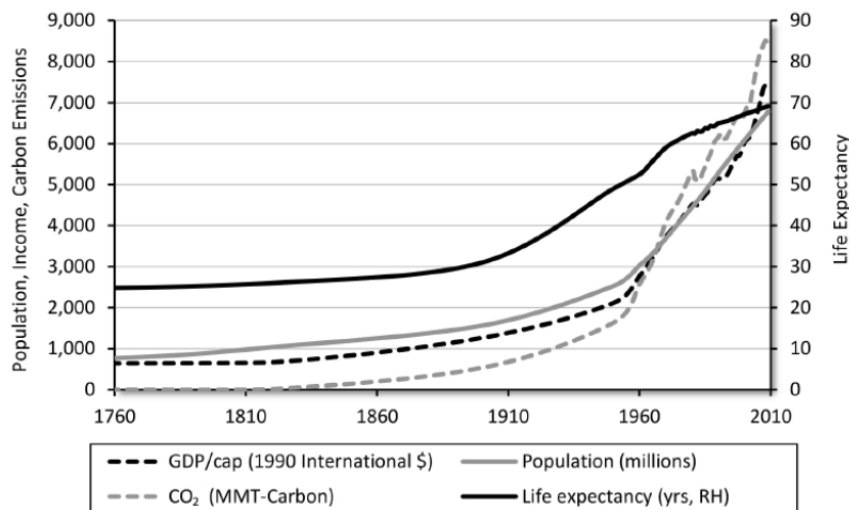


Source: Goklany, 2012.

**Continued Dominance of Fossil Fuels**

As shown in EX-2, population and economic growth will remain the key drivers behind increasing energy requirements.

**Figure EX-2:  Forecast of World Population, GDP, and Energy Growth 2030**
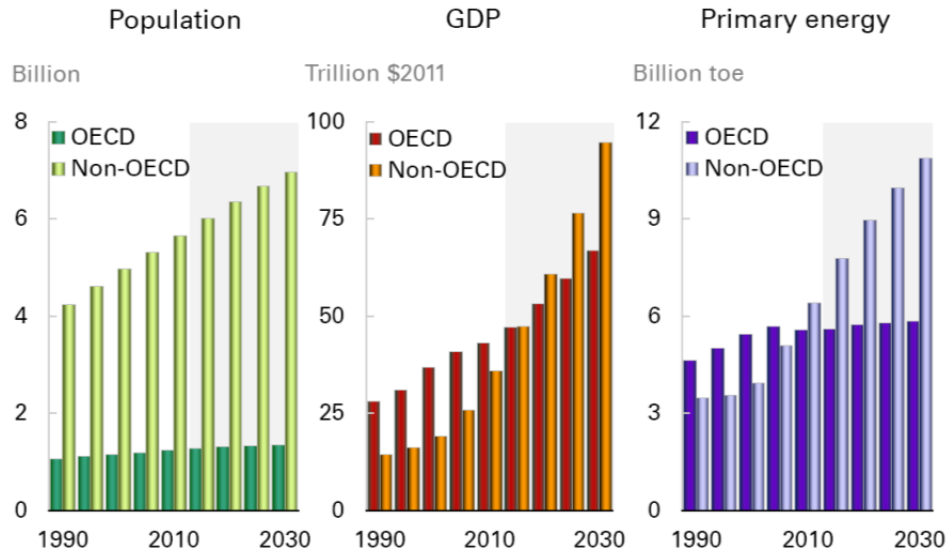


Source:  *BP Energy Outlook 2030.*

In the long term, the EIA reference case projects that fossil fuels will continue to provide 75 - 80 percent of the world's energy – Figure EX-3.

**Figure EX-3:  World Energy Consumption By Fuel Type (Quads)**
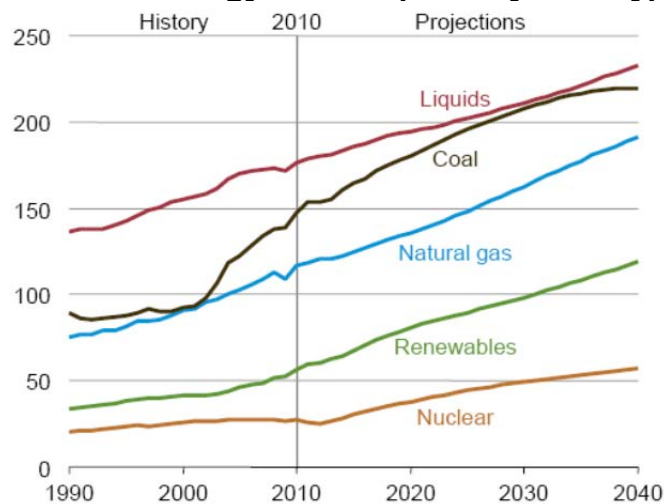


Source:  U.S. Energy Information Administration, *International Energy Outlook 2013*

Coal is the world's fastest growing energy source and over the past decade, in absolute terms, has increased nearly as much as all other fuels combined.  Since the start of the 21$^{st}$ century coal has dominated the global energy demand picture, alone accounting for 45 percent of primary energy demand growth.  Due to increasing use in

China and India, coal is forecast to exceed oil as the major fuel for the global economy by 2020. Further, when assessing the world's long term recoverable resources it is clear that coal — which can be gasified and liquefied — is the fossil fuel of the future, just as it has been in the past and present. Its recoverable resources are many times larger than natural gas or oil, or even of natural gas and oil combined – Figure EX-4.

**Figure EX-4: Fossil Energy Resources by Type**
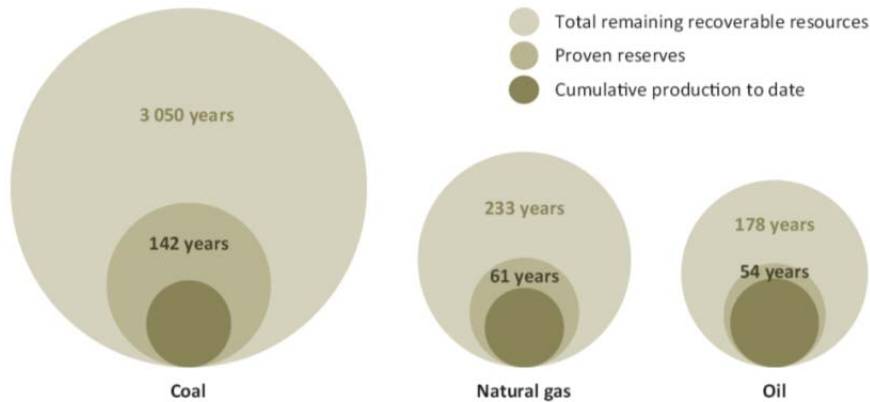


Source: International Energy Agency

### The Key Role of Electrification

Electrification is the world's most significant engineering achievement of the past century, and has been ranked as the world's second most significant innovation of the past 6,000 years, after the printing press. Electricity has created, shaped, and defined the modern world, economic growth and electricity usage are closely correlated, and electricity has facilitated virtually every technological achievement of the past 150 years. Electricity enables people to live longer and better and, as shown in Figure EX-5, the UN links electricity consumption to quality of life.

Further, electrification will be increasingly important in 21st century, and world electricity consumption is forecast to double within four decades as electricity supplies an increasing share of the world's total energy demand (Figure EX-6). However, an adequate, reliable, and affordable electricity supply is essential.

**Figure EX-5:  The UN Human Development Index and Per Capita Electricity Use**
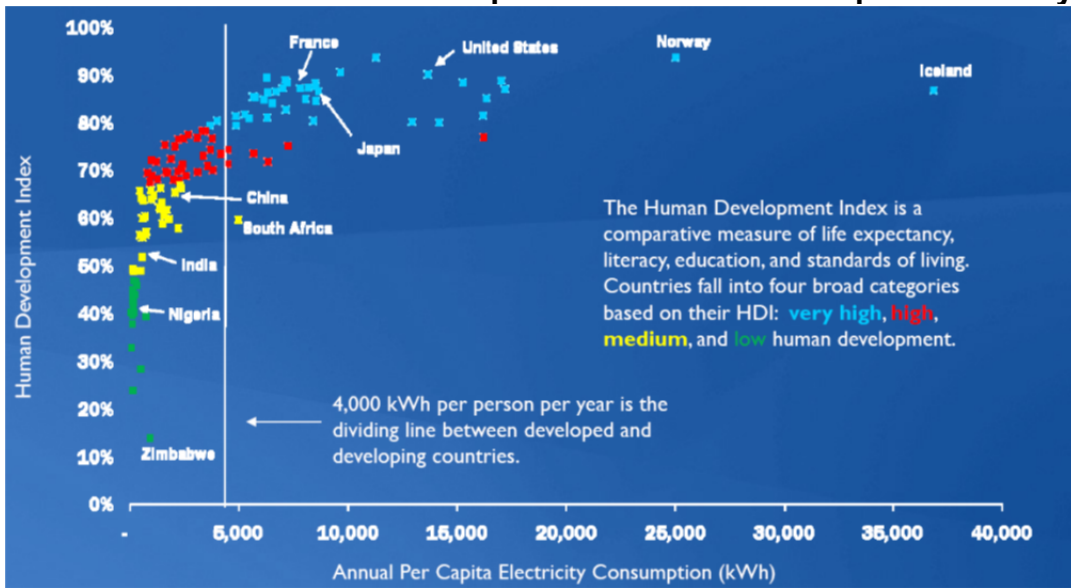


Source:  United Nations Development Program, *Human Development Report, 2012*.

**Figure EX-6:  Growth in World Total Electricity Generation and Total Delivered Energy Consumption** (Index, 1990 = 1)
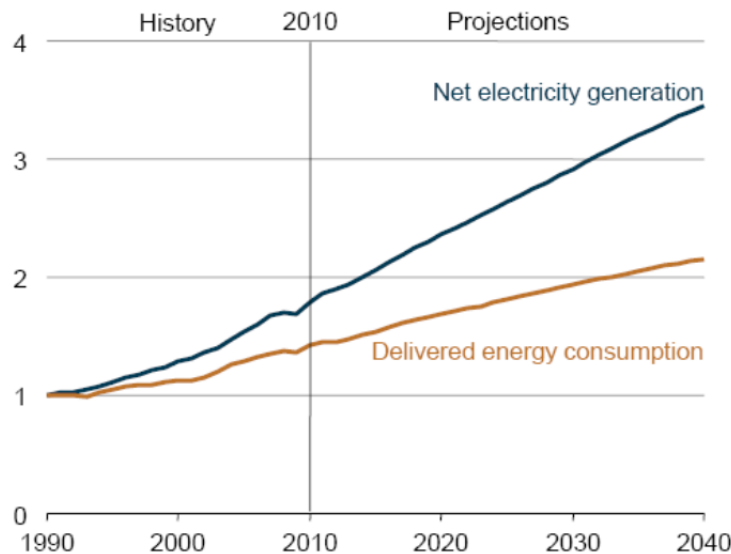


Source:  U.S. Energy Information Administration, *International Energy Outlook 2013.*

Coal is currently the world's predominant fuel used for electricity generation and is forecast to remain so for at least the next three decades – Figure EX-7.  Coal will provide a continually increasing share of world energy and, accordingly, a major new global build out of coal generation is under way driven by rapidly increasing demand in Asia.

**Figure EX-7: World Net Electricity Generation
by Energy Source, 2010-2040 (Trillion kWh)**
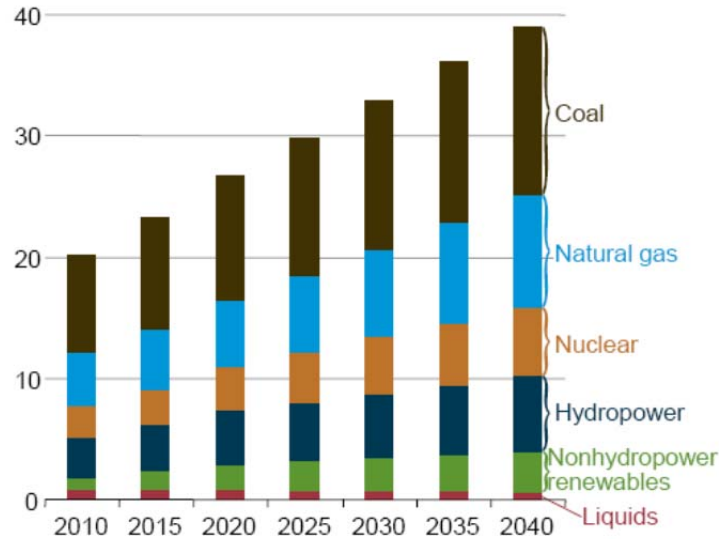


Source: U.S. Energy Information Administration, *International Energy Outlook 2013.*

### Energy, Poverty, and Health

Increased energy costs are highly regressive, since they hurt the poor, low income families, and seniors living on fixed incomes much more than the affluent. Expenditures for essentials such as energy consume larger shares of the budgets of low-income families than they do for those of more affluent families – Figure EX-8. For example, households earning $50,000 or less spend more on energy than on food, spend twice as much on energy than on healthcare, and spend more than twice as much on energy as on clothing. Further, being unable to afford energy bills can be harmful to one's health – Figure EX-9.

**Figure EX-8**



Source: American Association of Blacks in Energy.

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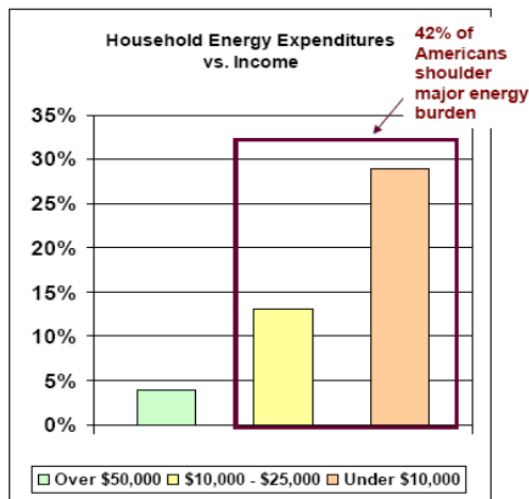
**Figure EX-9: Potential Health Impacts of
Increased Energy Costs on Low Income Persons**
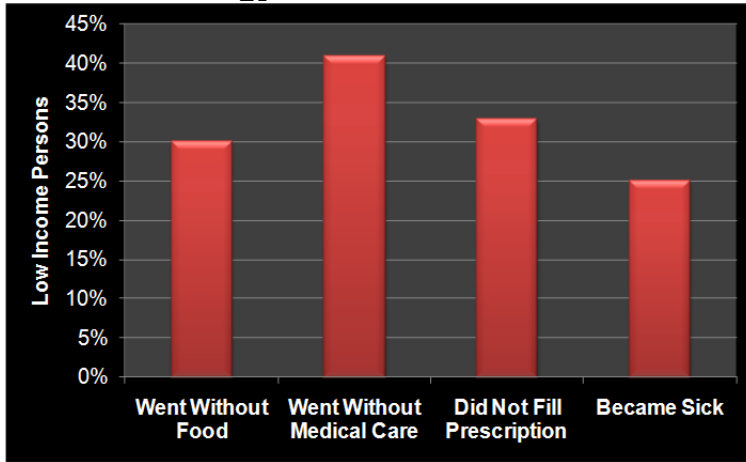


Source: National Energy Assistance Directors' Association.


## Energy, the Economy, and Jobs

There is a strong relationship between the economy and jobs, on the one hand, and the price of energy and electricity on the other. Economists who have analyzed the issue agree that the relationship is negative: Increases in energy and electricity prices harm the economy and decreases in energy and electricity prices benefit the economy. This relationship is important because coal is the low-cost option for generating electricity – Figure EX-10. As shown in Figure EX-11, there is a negative relationship between electricity prices and a state's use of coal to generate electricity: The higher percentage of coal used to generate electricity, the lower the electricity rate.

**Figure EX-10: Levelized Costs of Electricity by Generation Sources**
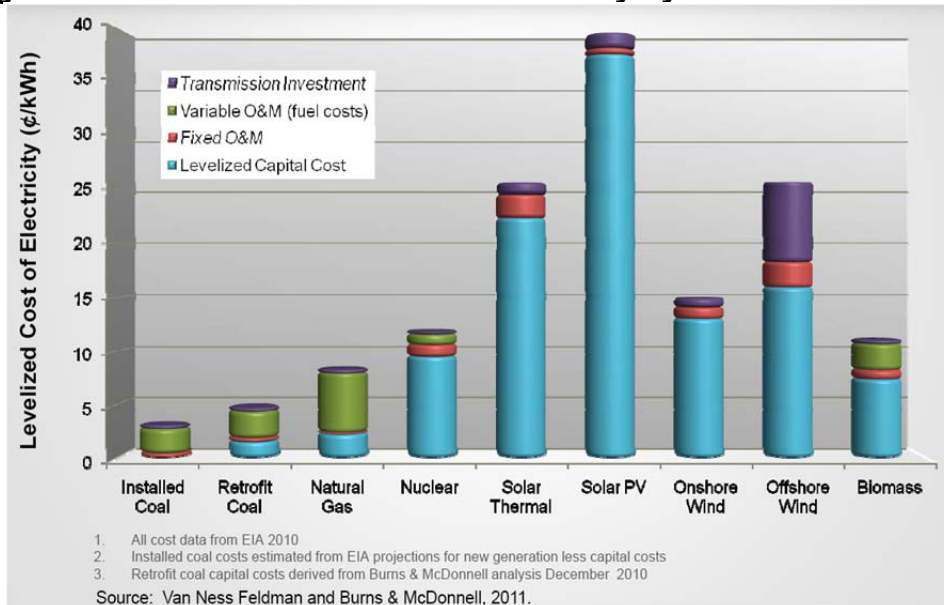


1. All cost data from EIA 2010
2. Installed coal costs estimated from EIA projections for new generation less capital costs
3. Retrofit coal capital costs derived from Burns & McDonnell analysis December 2010

Source: Van Ness Feldman and Burns & McDonnell, 2011.

The salient point is that the relationship between electricity prices and the economy is negative: Programs and policies that increase electricity prices – in a city, state, region, or nation — over what they would be otherwise will have adverse affects on the economy and jobs, and vice versa. We determined that a reasonable electricity elasticity estimate is -0.1, which implies that a 10 percent increase in electricity prices will result in a one percent decrease in GDP. Thus, for example, in a state such as Colorado where  GSP is currently about $275 billion, a 10 percent increase in the electricity price will (other things being equal) likely result in about a $2.8 billion decrease in Colorado GSP.

**Figure EX-11:  Relationship Between Coal Generation and State Electricity Prices**
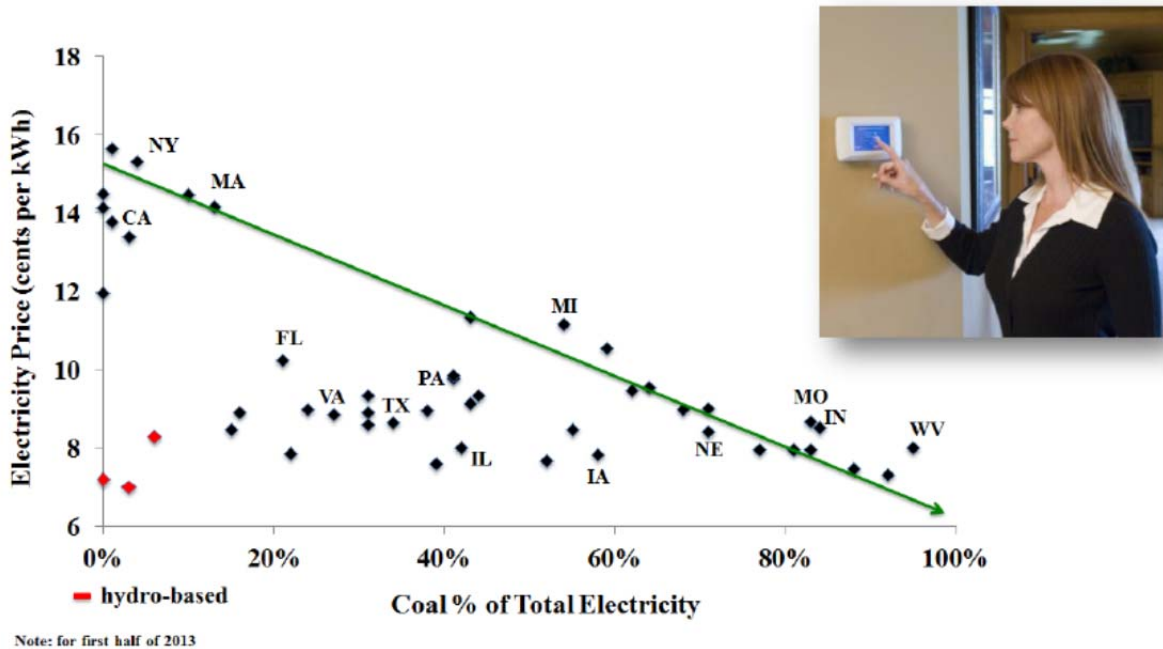


Source:  U.S. Energy Information Administration, *Electric Power Monthly*, August 2013.

## Direct CO$_2$ Benefits

CO$_2$ is the basis of life on Earth, it facilitates plant growth, and enhances agricultural productivity.  It is the primary raw material utilized by plants to produce the organic matter out of which they construct their tissues, which subsequently become the ultimate source of food for animals and humans.  Thus, the more CO$_2$ there is in the air, the better plants grow, as has been demonstrated in thousands of studies.

We assessed the annual total monetary value of the direct CO$_2$ benefit for 45 crops over the period 1961-2011 and estimated that it cumulatively totaled $3.2 trillion – increasing from $19 billion in 1961 to over $140 billion in 2010 – Figure EX-12.  We forecast that over the period 2012 - 2050, these CO$_2$ benefits will total $9.8 trillion.

**Figure EX-12: Total Annual Monetary Value of the Direct CO$_2$ Benefit on Crop Production, 1961-2011.**
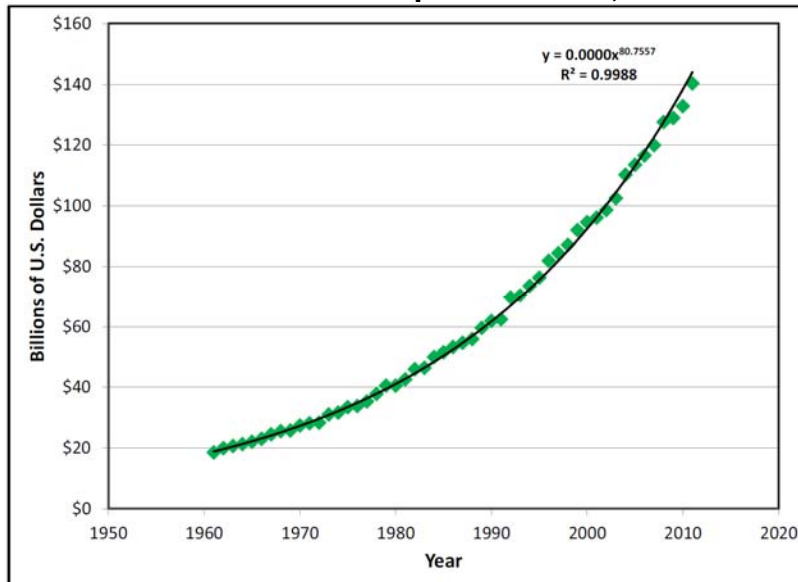


Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

## The Federal Interagency Working Group

The Federal IWG is comprised of 12 federal agencies. It published its first set of estimates of the Social Cost of Carbon in February 2010 and an updated, significantly increased set in May 2013. Integrated assessment models (IAMs) form the basis for the IWG SCC estimates, and the IWG ran simulations of three different IAMs with a range of parameter values, discount rates, and assumptions regarding GHG emissions to derive its SCC estimates. However, objective researchers have analyzed the IAMs and found that they are deeply flawed and useless as tools for policy analysis, that their use suggests a level of knowledge and precision that is illusory and can be highly misleading, and that they contain very serious weaknesses and must not be taken literally since they provide a very weak foundation for policy.

The IWG methodology requires that a large number of assumptions be made to complete the linkages between levels of human activity and the environmental consequences of that activity today and for generations to come. However, even small variations in the size of the assumed inputs can lead to very large and significant differences in the results produced by the IWG's methodology — differences in results that are so great as to render the IWG's policy recommendations invalid. The IWG process suffers from serious shortcomings, including: Lack of transparency to explain and justify the assumptions behind the estimates; questionable treatment of uncertainty and discounting of the future; assumption of perfect substitutability between manufactured capital and "natural" capital in the production of goods and services; and the way IAMs estimate monetary costs of non-market effects – which lead to skepticism about policies based on the results of the models. IAMs suffer from technical deficiencies that are widely recognized, there is a limited amount of research linking climate impacts to economic damages, and many of the impacts are speculative, at

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best.  We conclude that, to paraphrase Robert Pindyck, the IWG SCC estimates contain fatal flaws and that the IWG estimates are thus "close to useless" as tools for policy analysis.

**Indirect Benefits of $CO_2$ and Fossil Fuels**

Seminal research has concluded:

- "Ours is a high energy civilization based largely on combustion of fossil fuels."
- "The theoretical and empirical evidence indicates that energy use and output are tightly coupled, with energy availability playing a key role in enabling growth."

The relationship between world GDP and $CO_2$ emissions over the past century is illustrated in Figure EX-13, which shows a strong relationship between world GDP and the $CO_2$ emissions from fossil fuels.  It is clear that, at present, fossil fuels – from which $CO_2$ is an essential byproduct – are creating, annually, $60 - $70 trillion in world GDP.

**Figure EX-13:  Relationship Between World GDP and $CO_2$ Emissions**
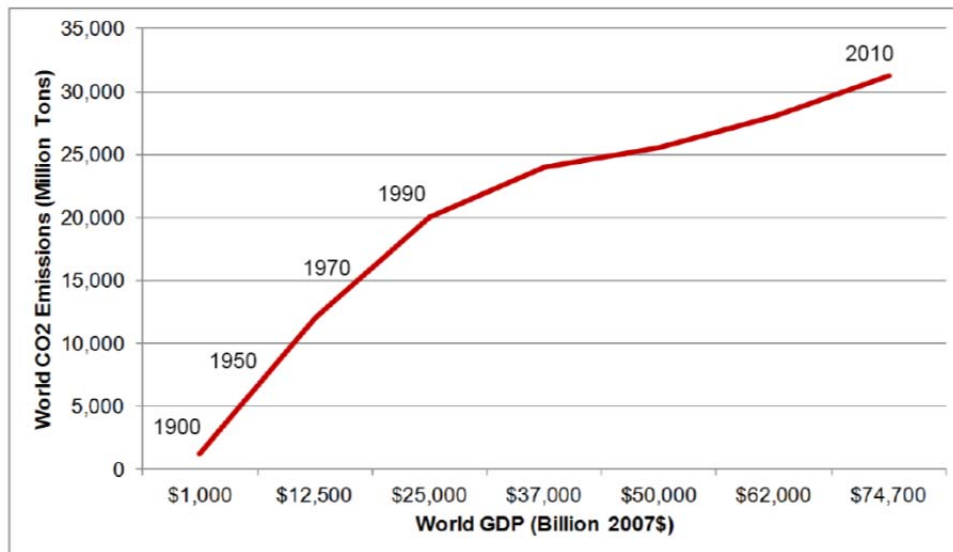


Source:  U.S. Energy Information Administration, International Energy Agency, U.S. Bureau of Economic Analysis, and Management Information Services, Inc.

How do these indirect $CO_2$ benefits compare to the IWG SCC estimates?  While the SCC estimates are of questionable validity, Figures EX 14 and EX-15 compare the $CO_2$ costs and benefits (on a per ton basis) based on both the IWG 2013 and 2010 SCC estimates.  It is seen that the benefits clearly outweigh any hypothesized costs by, literally, orders of magnitude:  Anywhere from 50-to-1 to 500-to-1.  Normally, B-C ratios in the range of 2-to-1 or 3-to-1 are considered very favorable.  In other words, the benefits of $CO_2$ overwhelmingly outweigh the estimated $CO_2$ costs no matter which

government report or discount rates are used.  In fact, any of the SCC estimates are relatively so small as to be in the statistical noise of the estimated $CO_2$ benefits.

**Figure EX-14:  2010 $CO_2$ Benefit-Cost Ratios**
(Based on 2013 IWG Report)
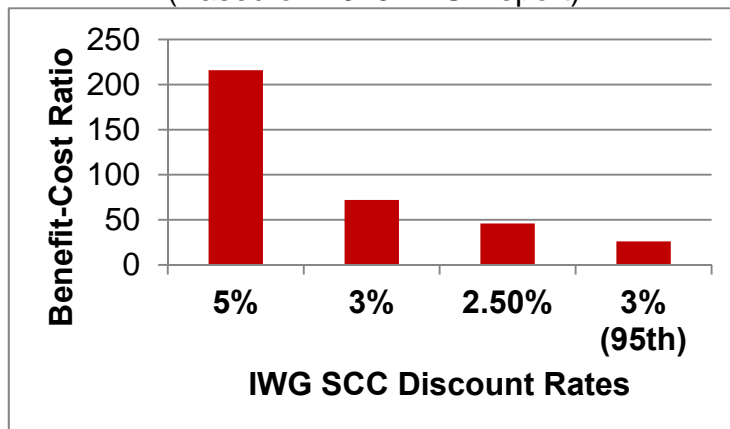


Source:  U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

**Figure EX-15:  2010 $CO_2$ Benefit-Cost Ratios**
(Based on 2010 IWG Report)
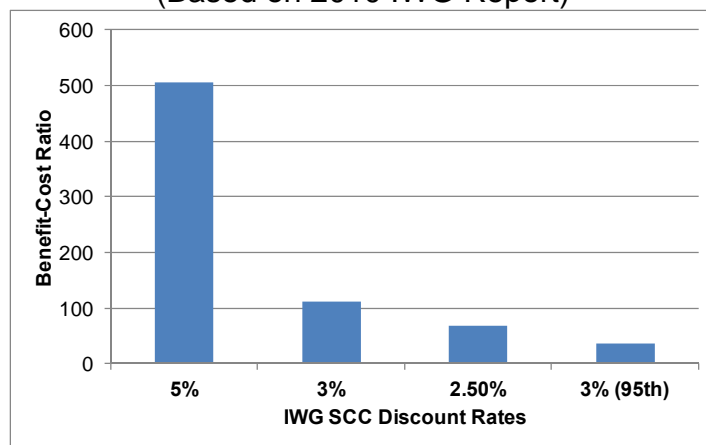


Source:  U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

Since much of the relevant SCC debate concerns future emissions, future potential costs, and future policies, we analyzed forecast $CO_2$ benefits compared to available SCC forecasts.  Figure EX-16 shows the forecast relationship between world GDP and $CO_2$ emissions in the EIA reference case through 2040.  Once again, future economic growth – as measured by world GDP – requires fossil fuels which, in turn, generate $CO_2$ emissions.  Thus, according to EIA data and forecasts, fossil fuels, which generate $CO_2$ emissions, are essential for world economic growth, and significant $CO_2$ emissions reductions will be associated with significant reductions in economic growth.

**Figure EX-16:  Forecast Relationship Between World GDP and CO$_2$ Emissions**
(EIA Reference Case)
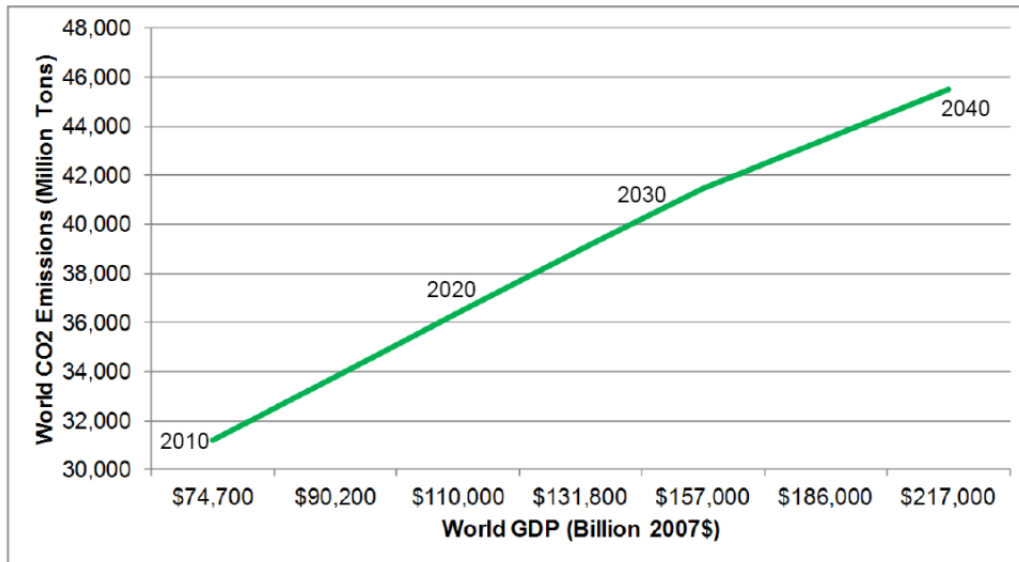


Source:  U.S. Energy Information Administration, International Energy Agency, U.S. Bureau of Economic Analysis, and Management Information Services, Inc.

We utilized the information shown in Figure EX-16 with the forecast IWG SCC estimates to develop estimated future CO$_2$ B-C ratios — Figure EX 17.  This figure indicates that the CO$_2$ B-C ratios remain extremely high through 2040, ranging from about 50-to-1 to 250-to-1.

**Figure EX-17:  Forecast Reference Case CO$_2$ Benefit-Cost Ratios**
(Based on 2013 IWG Report)
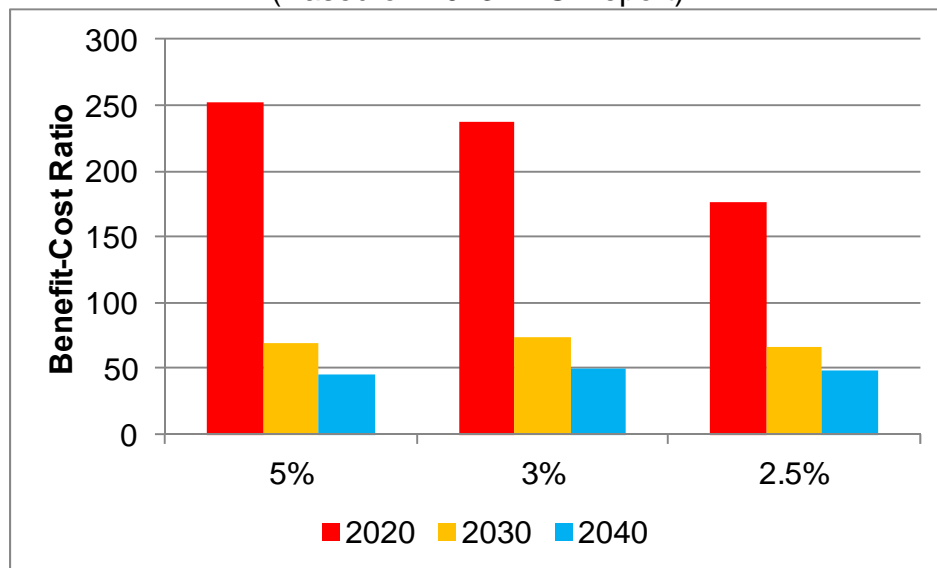


Source:  U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

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The reference case estimates are shown for the three 2010 IWG report discount rates in Figure EX-18. This figure indicates that, using the 2010 SCC estimates, the $CO_2$ B-C ratios are even higher through 2040 under each of the three discount rates, ranging from about 80-to-1 to about 500-to-1.

**Figure EX-18: 2010 and Forecast Reference Case CO$_2$ Benefit-Cost Ratios**
(Based on 2010 IWG Report)
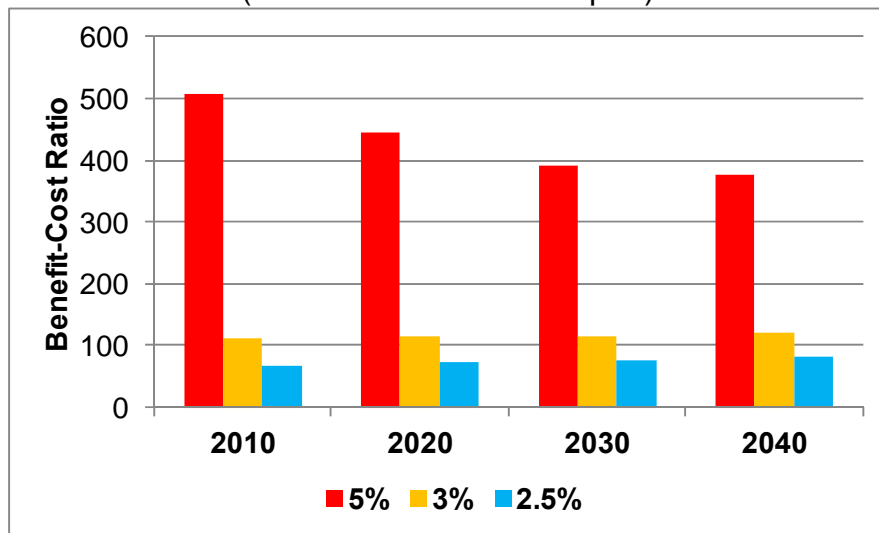


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

Figures V-17 and V-18 may be somewhat misleading because they indicate, basically, the average $CO_2$ B-C ratio for each year. To compare marginal $CO_2$ benefits to marginal costs we computed the marginal $CO_2$-related change in world GDP, 2010-2011, and compared this with the 2010 SCC estimates from the 2013 and 2010 IWG reports — Figure EX-19. These "marginal" B-C ratios are even larger than the average ratios, and the marginal B-C ratios range from about 170-to-1 to about 1,260-to-1.

**Figure EX-19: 2010-2011 Reference Case Marginal CO$_2$ Benefit-Cost Ratios**
(Based on 2010 and 2013 IWG Reports)
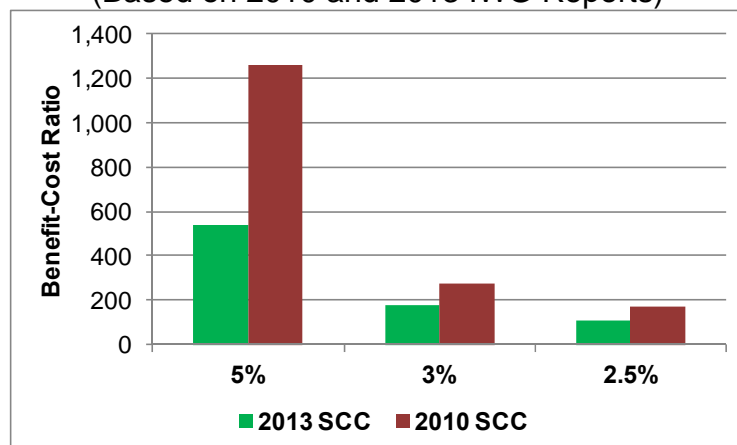


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

Not all of the world's energy is derived from fossil fuels: In 2010 about 81 percent of world energy was comprised of fossil fuels, while forecasts indicate that in 2040 somewhere between 75 percent and 80 percent of world energy will be comprised of fossil fuels. To determine how taking this into consideration may affect the B-C estimates, we developed a scenario where the portion of world energy comprised of fossil fuels decreased gradually from 80 percent in 2010 to 75 percent in 2040. The results of this simulation are shown in Figure EX-20, based on the SCC estimates from the IWG 2013 report, and in Figure EX-21, based on the SCC estimates from the IWG 2010 report. These figures indicate that, while the scaling of $CO_2$ benefit estimates somewhat decreases the B-C ratios, the ratios remain very high, ranging from about 40-to-1 to about 280-to-1.

**Figure EX-20: 2010 and Forecast 2040 Reference Case Scaled $CO_2$ B-C Ratios**
(Based on 2013 IWG Report)
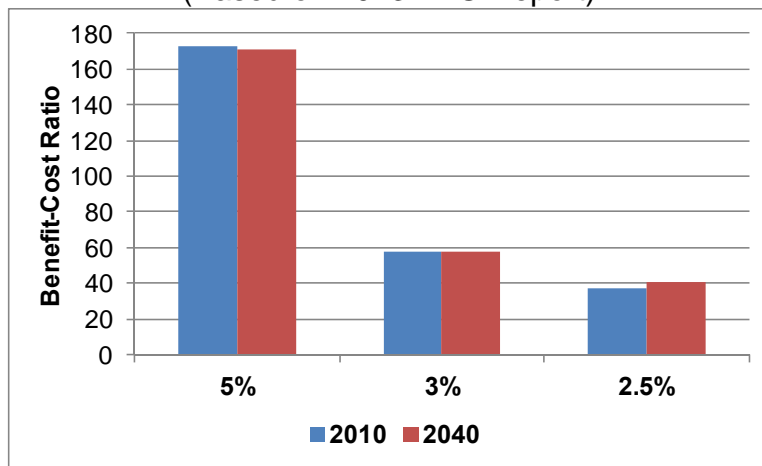


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

**Figure EX-21: 2010 and Forecast 2040 Reference Case Scaled $CO_2$ B-C Ratios**
(Based on 2010 IWG Report)
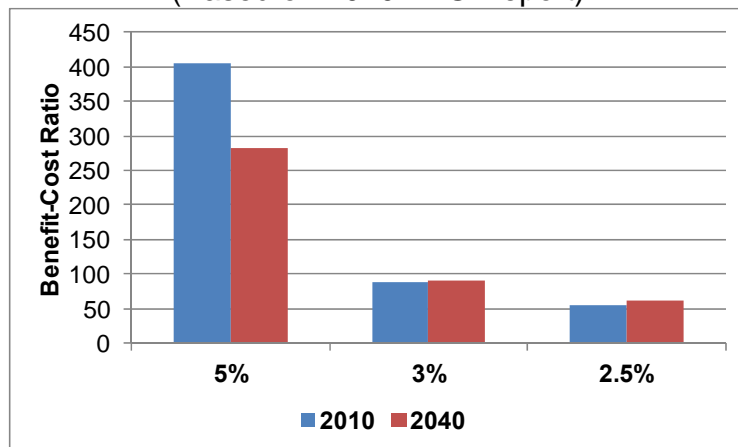


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

**Caveats and Implications**

How viable are these estimates? We feel that the benefit estimates are, if anything, more understandable, believable, and robust than the cost estimates.

The SSC estimates are questionable because they are based on highly speculative assumptions, forecasts, IAM simulations, damage functions, discount rates, etc. Independent assessments concluded that these estimates suffer from uncertainty, speculation, and lack of information about critical variables, that they "raise serious questions of science, economics, and ethics," and that they are "close to useless" as tools for policy analysis."

The benefit estimates developed here are simple, straightforward, logical, understandable, and based on two centuries of historical fact. The $CO_2$ benefits are almost entirely indirect: They derive from the fossil fuels which produce $CO_2$. There is extensive literature verifying the critical role of fossil fuels in creating current technology, wealth, and high standards of living: It is a truism; a statement of fact. Further, this relationship will remain well into the foreseeable future.

The benefit estimates derived here are extremely large compared even to the questionable IWG SCC estimates, and thus the B-C ratios are very high. The benefit estimates can be modified: They can be scaled, adjusted, forecast, expressed as average or marginal values, be converted to different base year dollars, estimated for past, current, or future years, etc. Nevertheless, they will remain orders of magnitude larger than any reasonable SCC estimates and, therefore, the B-C ratios will remain very high. Under Executive Order 12866, agencies are required to assess both the costs and the benefits of a proposed regulation and it states that "agencies should proceed only on the basis of a reasoned determination that the benefits justify the costs." The implications of our research for such assessments are obvious.

**The Technology Imperative**

In conclusion, prodigious amounts of fossil fuels will be required to sustain future economic growth, especially in the non-OECD nations. In terms of recoverable reserves coal will be the fossil fuel of the future – just as it has been the fossil fuel of the present and of the past. Advanced supercritical technology is currently available and is the best commercial technology to keep electricity affordable and achieve desired environmental goals. Thus, if the world is serious about maintaining and increasing economic growth, reducing energy poverty, lessening persons' energy burdens, and increasing standards of living in the non-OECD nations while at the same time limiting $CO_2$ emissions, advanced technologies and meaningful carbon capture and sequestration (CCS) polices are required.

# I.    INTRODUCTION:  THE ISSUE

Under Executive Order 12866, Federal agencies are required "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs."[1]  In February 2010, a Federal Interagency Working Group (IWG) consisting of 12 agencies developed estimates of the social cost of carbon of about $22/ton, and in May 2013 the IWG revised upward its SCC estimates to about $36/ton.[2]  The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year, and is meant to be a comprehensive estimate of climate change damages.[3]

The purpose of the SCC estimates is to allow agencies to incorporate the social benefits of reducing $CO_2$ emissions into benefit-cost analyses of regulatory actions,[4] and EPA and other federal agencies use the SCC to estimate the climate benefits of rulemakings.  The new, higher SCC estimates were used for the first time in a June 2013 rule on efficiency standards for microwave ovens.[5]  These SCC estimates, prepared will little publicity, debate, or public input, have potentially ominous implications for fossil fuels in general and for the coal industry in particular.  EPA states that "The U.S. government has committed to updating the current estimates as the science and economic understanding of climate change and its impacts on society improves over time."[6]  Given recent history, it is highly likely that in forthcoming updates the SCC values will increase, and there are literally trillions of dollars at stake.

There are at least two major deficiencies in the use of SCC in benefit-cost analysis and proposed rulemaking.  First, as discussed in Chapters IV and V, the methodology used by the IWG in developing the SCC estimates is not rigorous and is flexible enough to produce almost any estimates desired by the IWG.  The IWG used three integrated assessment models (IAMs) to estimate the SCC:  The FUND, DICE, and PAGE models.[7]  These models are supposed to combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. However, there is a limited amount of research linking climate impacts to economic damages, and much of this is speculative, at best.  Even

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[1]"Regulatory Planning and Review, Executive Order 12866 of September 30, 1993," *Federal Register*, Vol. 58, No. 190, Monday, October 4, 1993.

[2]Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Support Document:  Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," May 2013; Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010.

[3]Ibid.

[4]Ibid.

[5]U.S. Department of Energy, "Energy Conservation Program:  Energy Conservation Standards for Standby Mode and Off Mode for Microwave Ovens," 10 CFR Parts 429 and 430.

[6]U.S. Environmental Protection Agency, "The Social Cost of Carbon:  Estimating the Benefits of Reducing Greenhouse Gas Emissions," www.epa.gov/climatechange.

[7]Interagency Working Group, 2010 and 2013, op. cit.

the IWG admits that the exercise is subject to "simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships."[8] Further, each model uses a different approach to translate global warming into damages, and transforming the stream of economic damages over time into a single value requires "judgments" about how to discount them. As objective analysts have concluded, the SCC estimates developed and utilized by the IWG have little or no validity and are "close to useless."[9]

Second, and more serious, no attempt is made to estimate, or even acknowledge the existence of carbon benefits or positive externalities of carbon. Since the development of rigorous benefit-cost (B-C) analysis by the U.S. Army Corps of Engineers and the Bureau of Reclamation in the 1950s, such analysis has sought to assess both the costs and the benefits of a proposed initiative, program, or regulation to determine if the benefits exceed the costs.[10] It is thus a self-evident truism that a valid B-C analysis must include both costs and benefits and, indeed, as noted, under Executive Order 12866, agencies are required "to assess both the costs and the benefits of the intended regulation."[11] It is thus inexcusable that the IWG process hypothesizes almost every conceivable carbon "cost" – including costs to agriculture, forestry, water resources, forced migration, human health and disease, coastal cities, ecosystems, wetlands, etc. – but fails to analyze potential carbon benefits, either direct or indirect.[12] This is especially true because OMB has recently emphasized that careful consideration of both costs <u>and</u> benefits is important in determining whether a regulation will improve social welfare and to assess whether it is worth implementing at all.[13]

There are two types of carbon benefits that must be identified, analyzed, and, to the degree possible, quantified: Direct benefits and indirect benefits. The major direct carbon benefit is to increase agricultural productivity. As discussed in Chapter III, in addition to increasing the quantity of food available for human consumption, the rising atmospheric $CO_2$ concentration is also increasing the quality of the foods.

Much more important, as discussed in Chapters II and V, the indirect benefits of carbon include the immense benefits to the economy and society of affordable, reliable energy produced by carbon-based fuels. These fuels have literally created modern technological society worldwide, raised the standard of living of everyone on the planet, increased life spans by decades, and over the past 20 years alone have elevated over a

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[8]Ibid.

[9]Robert S. Pindyck, "Climate Change Policy: What Do The Models Tell Us?" National Bureau of Economic Research, Working Paper 19244, July 2013.

[10]See, for example, John S. Dryzek, *The Politics of the Earth: Environmental Discourses*, UK: Oxford University Press, 2013, pp. 84-88.

[11]"Regulatory Planning and Review, Executive Order 12866 of September 30, 1993," op. cit.

[12]This should, theoretically, invalidate the IWG methodology and disqualify the use of the SCC estimates in any Federal rulemaking or cost-benefit analysis. However, as was the case with the recent microwave regulation, this is not the case.

[13]U.S. Office of Management and Budget, "2013 Draft Report to Congress on the Benefits and Costs of Federal Regulations and Agency Compliance With the Unfunded Mandates Reform Act," www.whitehouse.gov/sites/default/files/omb/inforeg/2013_cb/ draft_2013_cost_benefit_report.pdf.

billion persons out of poverty. They are simply invaluable and irreplaceable, and will remain so for the foreseeable future.

This report is organized as follows:

- Chapter II discusses the indirect social benefits of carbon: The energy produced by fossil fuels – including coal.
- Chapter III analyzes direct carbon benefits resulting from increased agricultural productivity and plant growth.
- Chapter IV reviews and critiques the IWG reports used to develop the SCC estimates.
- Chapter V assesses carbon benefits compared to carbon costs and finds that the benefits exceed the costs by orders of magnitude.
- Chapter VI discusses caveats and implications.

## II. THE INDIRECT SOCIAL BENEFITS OF CARBON:  FOSSIL FUELS

### II.A.  Three Industrial Revolutions

The successful development and utilization of fossil fuels facilitated successive industrial revolutions, created the modern world, created our advanced technological society, and enabled the high quality of life currently taken for granted.  While this may appear to be a self-obvious truism, the centrality of fossil fuels to everything in society can be appreciated from the recent work of Robert Gordon.[14]  He raises basic questions about the process of economic growth and questions the assumption that economic growth is a continuous process that will persist indefinitely.  Gordon notes that there was virtually no growth before 1750, and thus there is no guarantee that growth will continue indefinitely.  Rather, his research suggests that the rapid progress made over the past 250 years could well turn out to be a unique episode in human history.

Of central importance to our work, Gordon's analysis of past economic growth is anchored by the three industrial revolutions:

- The first (IR #1) centered in 1750-1830 resulted from the inventions of the steam engine and cotton gin through the early railroads and steamships, although much of the impact of railroads on the American economy came later between 1850 and 1900.
- The second industrial revolution (IR #2), 1870-1900, created the inventions that made the biggest difference in the standard of living — electric light, the internal combustion engine, municipal waterworks and subsidiary and complementary inventions, including elevators, electric machinery and consumer appliances; motor vehicles, and airplane; to highways, suburbs, and supermarkets; sewers, television, air conditioning, and the interstate highway system.
- The third revolution (IR #3) is associated with the invention of the web and Internet around 1995.[15]

Gordon's analysis links periods of slow and rapid growth to the timing of the three IR's that is, IR #1 (steam, railroads) from 1750 to 1830; IR #2 (electricity, internal combustion engine, running water, indoor toilets, communications, entertainment, chemicals, petroleum) from 1870 to 1900; and IR #3 (computers, the web, mobile phones) from 1960 to present.  As noted, he finds that IR #2 was more important than the others and was largely responsible for 80 years of relatively rapid productivity growth between 1890 and 1972.  Once the spin-off inventions from IR #2 (airplanes, air conditioning, interstate highways) had matured, productivity growth during 1972-96 was

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[14]Robert J. Gordon, "Is U.S. Economic Growth Over?  Faltering Innovation Confronts the Six Headwinds," NBER Working Paper No. 18315, August 2012; © 2012 by Robert J. Gordon.

[15]However, he notes that electronic mainframe computers began to replace routine and repetitive clerical work as early as 1960. His treatment of IR #3 includes examples of the many electronic labor-saving inventions and convenience services that already were widely available before 1995.

much slower than before.  In contrast, IR #3 created only a short-lived growth revival between 1996 and 2004.  Many of the original and spin-off inventions of IR #2 could happen only once – urbanization, transportation speed, the freedom of females from the drudgery of carrying tons of water per year, and the role of central heating and air conditioning in achieving a year-round constant temperature.[16]

A useful organizing principle to understand the pace of growth since 1750 is the sequence of three industrial revolutions.[17]  The first (IR #1) with its main inventions between 1750 and 1830 created steam engines, cotton spinning, and railroads.  The second (IR #2) was the most important, with its three central inventions of electricity, the internal combustion engine, and running water with indoor plumbing, in the relatively short interval of 1870 to 1900.  Both the first two revolutions required about 100 years for their full effects to percolate through the economy.  During the two decades 1950-70 the benefits of the IR #2 were still transforming the economy, including air conditioning, home appliances, and the interstate highway system.  After 1970 productivity growth slowed markedly, most plausibly because the main ideas of IR #2 had by and large been implemented by then.

Importantly, the computer and Internet revolution (IR #3) began around 1960 and reached its climax in the dot.com era of the late 1990s, but its main impact on productivity has withered away over the past decade.  Many of the inventions that replaced tedious and repetitive clerical labor by computers happened a long time ago, in the 1970s and 1980s.[18]

Gordon developed a graph that links together decades of research by economic historians to provide data on real output per capita through the ages.[19]  Figure II-1 displays the record back to the year 1300 and traces the "frontier" of per-capita real GDP for the leading industrial nation – the U.K. or the U.S.  The blue line represents the U.K. through 1906 (approximately the year when the U.S. caught up) and the red line the U.S. from then through 2007.  British economic historians estimate that the U. K. grew at about 0.2 percent per year for the four centuries through 1700.  The graph shows striking the lack of progress; there was almost no economic growth for four centuries and probably for the previous millennium.

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[16]Gordon, op. cit.
[17]Ibid.
[18]As Gordon notes, "Invention since 2000 has centered on entertainment and communication devices that are smaller, smarter, and more capable, but do not fundamentally change labor productivity or the standard of living in the way that electric light, motor cars, or indoor plumbing changed it."
[19]Gordon, op. cit.

**Figure II-1**
**Growth in Real Per Capita GDP, 1300 - 2100**
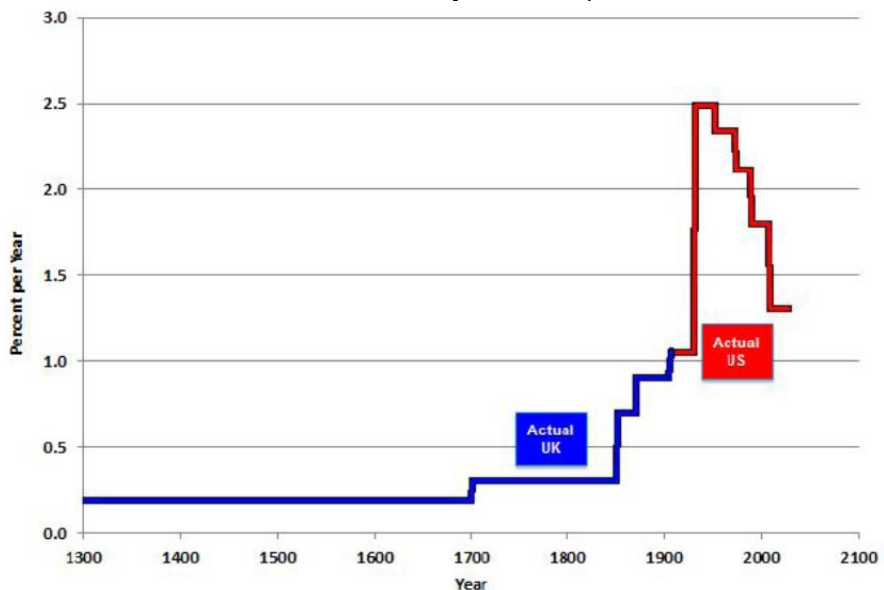


Source:  Robert J. Gordon, National Bureau of Economic Research, 2012.


Gordon's research, as summarized in this figure, is of potentially profound importance for several reasons.  First, it forcefully and poignantly illustrates the critical importance of the industrial revolutions that began in the late 1700s in dramatically improving economic growth rates, productivity, and persons' standards of living and well-being.  Second, and much more controversially, it indicates that the trends of the period of 1800 to about 1975 may have been one-time anomalies and that prospects for continued productivity and economic growth may be much less favorable than most analysts anticipate.


## II.B.  The Unique, Essential Historical Role of Fossil Fuels

The third implication of Gordon's work, which he does not seem to fully appreciate, is the absolutely essential role in all of the IRs played by fossil fuels – especially coal.[20]   Simply stated, without the availability of adequate supplies of accessible, reliable, and affordable fossil fuels none of the industrial and economic progress of the past two centuries would have been possible.  This is an indisputable, critical fact that seems to have been insufficiently appreciated in the debate over the social cost of carbon – see the discussion in section II.C.

For example, coal was the essential driving force behind most of the revolutionary technologies Gordon identifies:  Steam engines, cotton spinning, railroads, electric light, municipal waterworks and subsidiary and complementary inventions,

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[20]See, for example, Robert U. Ayres and Benjamin Warr, *The Economic Growth Engine:  How Energy and Work Drive Material Prosperity*, Northampton, MA:  Edward Elgar. 2009.

including elevators, electric machinery and consumer appliances; suburbs and supermarkets; sewers, television, air conditioning, indoor plumbing, etc. Further, coal provides the reliable and inexpensive electricity that powers computers, the web and Internet, social media, mobile devices, high tech manufacturing, and numerous other more recent applications.

It is constructive to compare the growth in per capita GDP shown in Figure II-1 with the increased use of fossil fuels over roughly the same period. Figure II-2 shows the enormous increase in world energy consumption that has taken place over the last 200 years. This rise in energy consumption is almost entirely from increased fossil fuel use.[21]

Figure II-3 shows the rapid increase in world per capita annual primary energy consumption by fuel over the past two centuries. Once again, it is seen that almost all of the entire increase (90 percent) in per capita primary energy consumption resulted from increased fossil fuel utilization – the increased use of hydro offset the decreased use of wood.[22] Figure II-4 shows the growth of world population, per capita energy consumption, and total energy use over the past two centuries, compared to 2010 levels. Figures II-3 and II-4 illustrate that, over the period 1850-2010:

- World population increased 5.5-fold.
- Total world energy consumption increased nearly 50-fold.
- World per capita energy consumption increased nearly 9-fold.
- Nearly all of the world's increase in energy consumption was comprised of fossil fuels.

**Figure II-2**
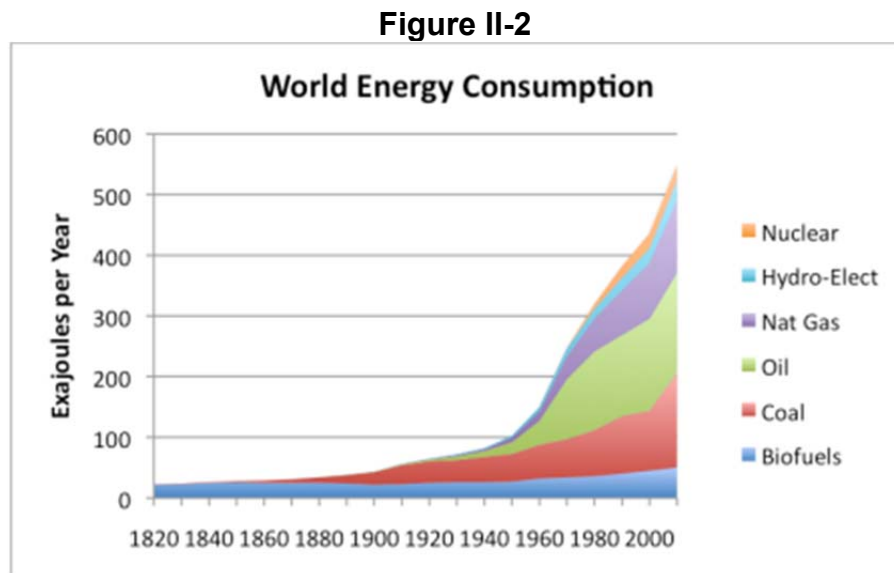


Source: Gail Tverberg," World Energy Consumption Since 1820"

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[21]Gail Tverberg," World Energy Consumption Since 1820," www.ourfiniteworld.com, March 12, 2012.
[22]J. David Hughes, "The Energy Sustainability Dilemma: Powering the Future in a Finite World," presented at Cornell University, Ithaca, New York, May 2, 2012.

**Figure II-3**
**World Per Capita Annual Primary Energy Consumption by Fuel 1850-2010**
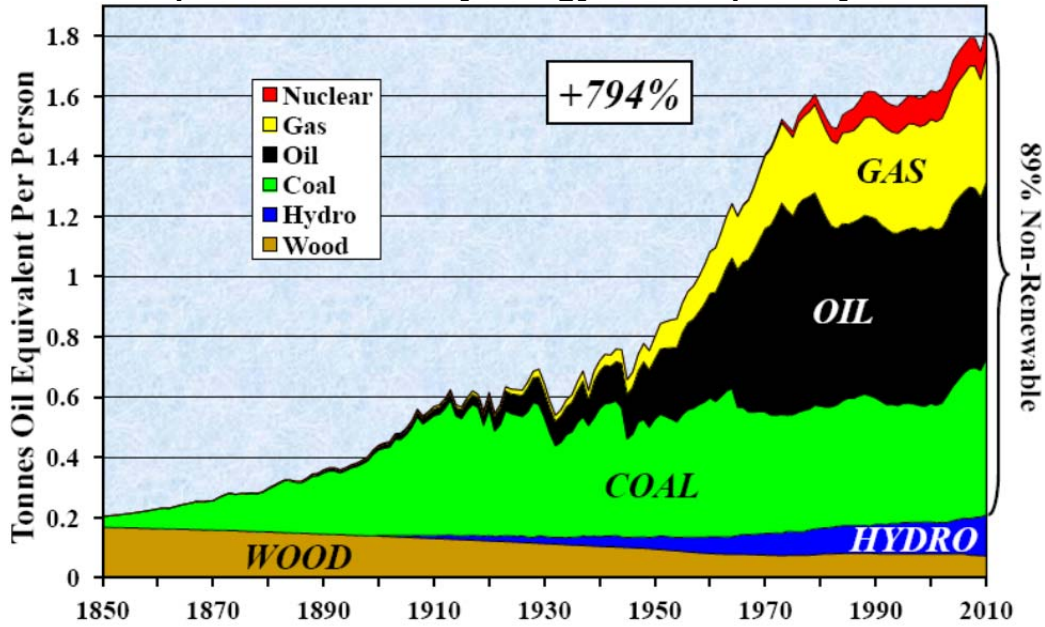


Source: Hughes, "The Energy Sustainability Dilemma: Powering the Future in a Finite World,"

**Figure II-4**
**World Population, Per Capita and Total Energy**
**Consumption, 1850-2010, as a Percentage of 2010 Levels**
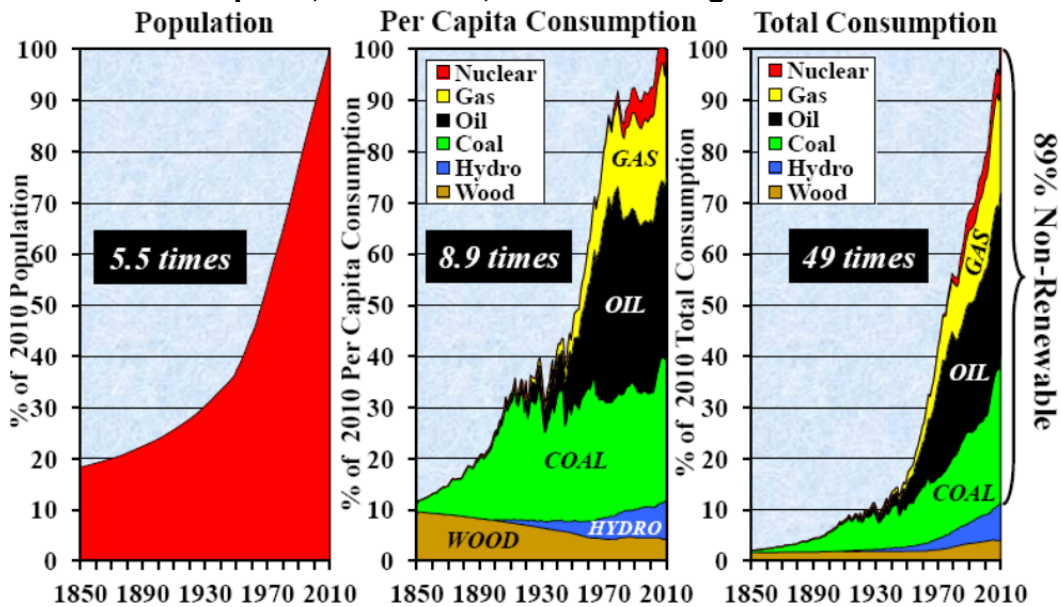


Source: Hughes, "The Energy Sustainability Dilemma: Powering the Future in a Finite World,"

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Comparison of Figure II-1 with Figures II-2 through II-4 forcefully illustrates a central fact: World economic and technological progress over the past two centuries would simply have been impossible without the massive, successful use of vast quantities of fossil fuels.

Thus, "For most of its existence, mankind's well-being was dictated by disease, the elements and other natural factors, and the occasional conflict. Virtually everything required — food, fuel, clothing, medicine, transport, mechanical power — was the direct or indirect product of living nature."[23] Subsequently, mankind developed technologies to augment or displace these resources, food supplies and nutrition improved, and population, living standards, and human well-being advanced.[24] The IRs discussed above accelerated these trends: Growth became the norm, population increased rapidly, and productivity and living standards improved dramatically. Technologies dependent on cheap, abundant, reliable fossil fuels such as coal enabled these improving trends. Nothing can be made, transported, or used without energy, and fossil fuels provide 80 percent of mankind's energy and 60 percent of its food and clothing.[25]

Key to these developments was that these technologies accelerated the generation of ideas that facilitated even better technologies through, among other things, greater accumulation of human capital (via greater populations, time-expanding illumination, and time-saving machinery) and more rapid exchange of ideas and knowledge (via greater and faster trade and communications). From 1750 to 2009, global life expectancy more than doubled, from 26 years to 69 years; global population increased 8-fold, from 760 million to 6.8 billion; and incomes increased 11-fold, from $640 to $7,300.[26] Living standards advanced rapidly over the past two centuries and, concurrently, as shown in Figure II-5, carbon dioxide emissions increased 2,800-fold, from about 3 million metric tons to 8.4 billion metric tons.

Figure II-6 illustrates that in the U.S. from 1900 to 2009 population quadrupled, U.S. life expectancy increased from 47 years to 78 years, and incomes (denoted "affluence") grew 7.5-fold while carbon dioxide emissions increased 8.5-fold. Thanks largely to the extensive utilization of fossil fuels, "Americans currently have more creature comforts, they work fewer hours in their lifetimes, their work is physically less demanding, they devote more time to acquiring a better education, they have more options to select a livelihood and live a more fulfilling life, they have greater economic and social freedom, and they have more leisure time and greater ability to enjoy it."[27]

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[23]Indur M. Goklany, "Humanity Unbound How Fossil Fuels Saved Humanity from Nature and Nature from Humanity," *Policy Analysis*, No. 715, December 20, 2012, pp. 1-33.
[24]Ibid.
[25]Thus, "Absent fossil fuels, global cropland would have to increase by 150 percent to meet current food demand, but conversion of habitat to cropland is already the greatest threat to biodiversity. By lowering humanity's reliance on living nature, fossil fuels not only saved humanity from nature's whims, but nature from humanity's demands." See Ibid.
[26]Ibid.
[27]Ibid.

And these trends are evident not just in the United States but, for the most part, elsewhere as well.[28]

**Figure II-5**
**Global Progress, 1760–2009 — as Indicated by Trends in World Population, GDP Per Capita, Life Expectancy, and $CO_2$ Emissions From Fossil Fuels**
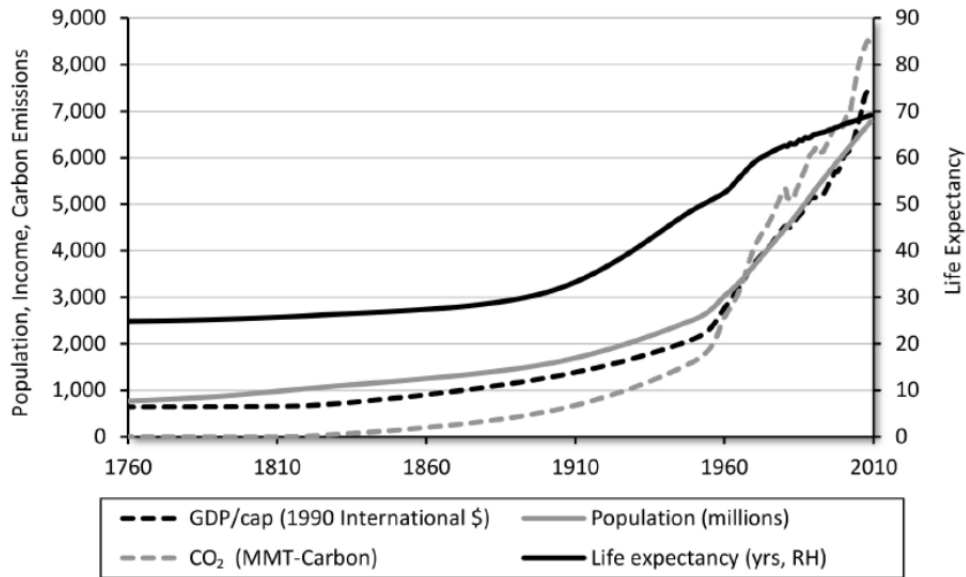


Source: Goklany, 2012.

**Figure II-6**
**U.S. Carbon Dioxide Emissions, Population, GDP per Capita, and Life Expectancy at Birth, 1900–2009**
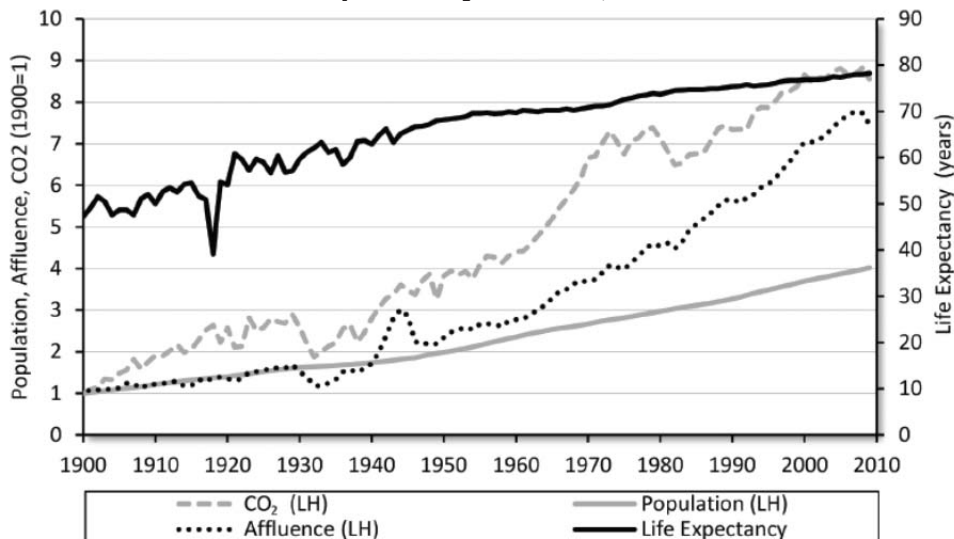


Source: Goklany, 2012.

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[28]Indur M. Goklany, *The Improving State of the World: Why We're Living Longer, Healthier, More Comfortable Lives on a Cleaner Planet*, Washington, D.C.: Cato Institute, 2007; © 2007 the Cato Institute.

Figure II-7 shows fossil fuel prices over the past five decades. It illustrates that oil has been, by far, the most expensive and price-volatile, followed by natural gas. Coal has been the least expensive and least price-volatile.

**Figure II-7**
**Historical Fossil Fuel Prices**
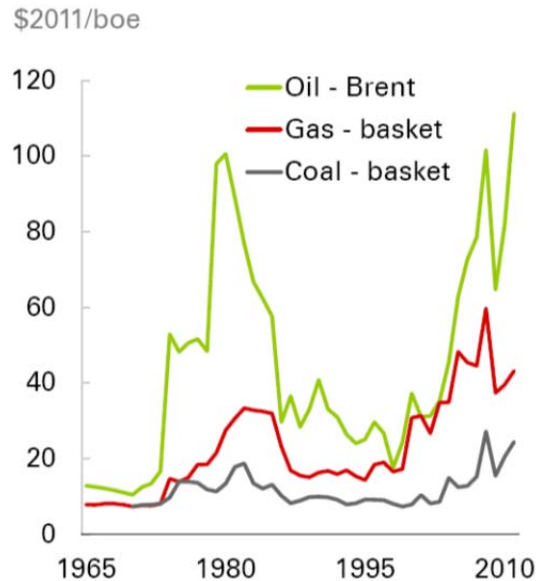


Source: *BP Energy Outlook 2030*

## II.C. The Unique, Essential Future Role of Fossil Fuels

Robert Gordon combined the historical U.K./U.S. growth record with a hypothetical, rather pessimistic forecast and overlaid on the historical record a smoothly curved line showing growth steadily increasing to the mid-20th century and then declining back to where it started, 0.2 percent per year by the end of the 21st century. He then are translated these growth rates into the corresponding levels of per-capita income in 2005 dollars, which for the U.S. in 2007 was $44,800 – Figure II-8. The implied level for the U.K. in 1300 was about $1,150 in current prices, and it took five centuries for that level to triple to $3,450 in 1800 and more than a century almost to double to $6,350 in 1906, the transition year from the U. K. to the U.S. data. Even with the steady slowdown in the growth rate after 1988, the forecast level implied by the green line in Figure II-8 for the year 2100 is $87,000, almost double the actual level achieved in 2007.[29]

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[29]Gordon, op. cit.

**Figure II-8**
**Actual and Hypothetical Levels of GDP Per Capita, 1300 - 2100**
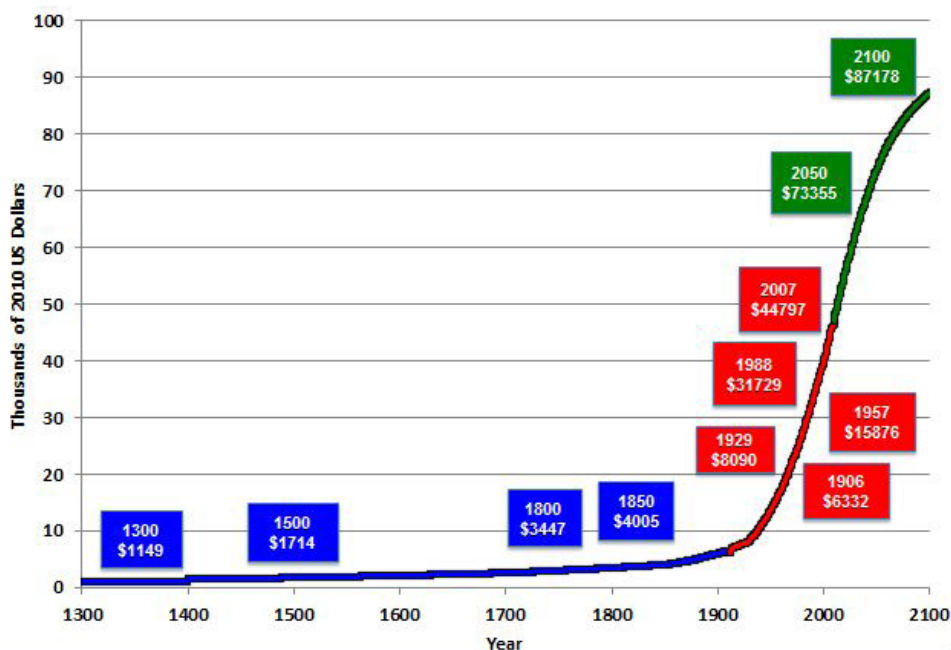


Source: Robert J. Gordon, National Bureau of Economic Research, 2012.

Notably, even with Gordon's pessimistic assumption that the economic growth rate will decrease to 0.2 percent annually by 2100, the green forecast line in Figure II-8 rises rapidly. Further, under any reasonable assumptions, even modest forecast economic growth will require a very significant increase in energy supplies over the coming century. World economic growth over the past two centuries was powered almost exclusively with fossil fuels. What energy sources are forecast to power future world economic growth? That is, the question is: *What energy sources are required to enable the world to continue to (even modestly) increase income, wealth, productivity, and standards of living?*

According to all major forecasts available, fossil fuels will remain the principal sources of energy worldwide for the foreseeable future and will continue to supply 75 - 80 percent of world energy. Demand for oil, natural gas, and coal will increase substantially in both absolute and percentage terms over the next several decades. Assuring continued world economic growth, increased per capita income, and rising living standards requires this greatly increased use of fossil fuels.

The International Energy Agency (IEA) finds that fossil fuels will continue to meet the vast majority of the world's energy needs over the next two decades. These fuels, which represented 81 percent of the primary fuel mix in 2010, remain the dominant source of energy through 2035 in all of the IEA scenarios.[30]

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[30]International Energy Agency, *World Energy Outlook*, Paris, November 2012; © OECD/IEA 2012.

Indeed, greater utilization of fossil fuels may be required than is currently forecast. For example, the IEA notes that, even with the anticipated increase in economic growth and fossil fuel utilization, in 2030 nearly one billion people will be without electricity and 2.6 billion people will still be without clean cooking facilities.[31]

As shown in Figure II-9, population and income growth are the key drivers behind growing demand for energy. By 2030 world population is forecast to reach 8.3 billion, and thus an additional 1.3 billion people will require access to energy. World income in 2030 is expected to be about double the 2011 level in real terms, and low and medium income economies outside the OECD account for over 90 percent of population growth to 2030. Due to their rapid industrialization, urbanization and motorization, they also contribute 70 percent of the global GDP growth and over 90 percent of the global energy demand growth.[32]

**Figure II-9**
**Forecast of World Population, GDP, and Energy Growth Through 2030**
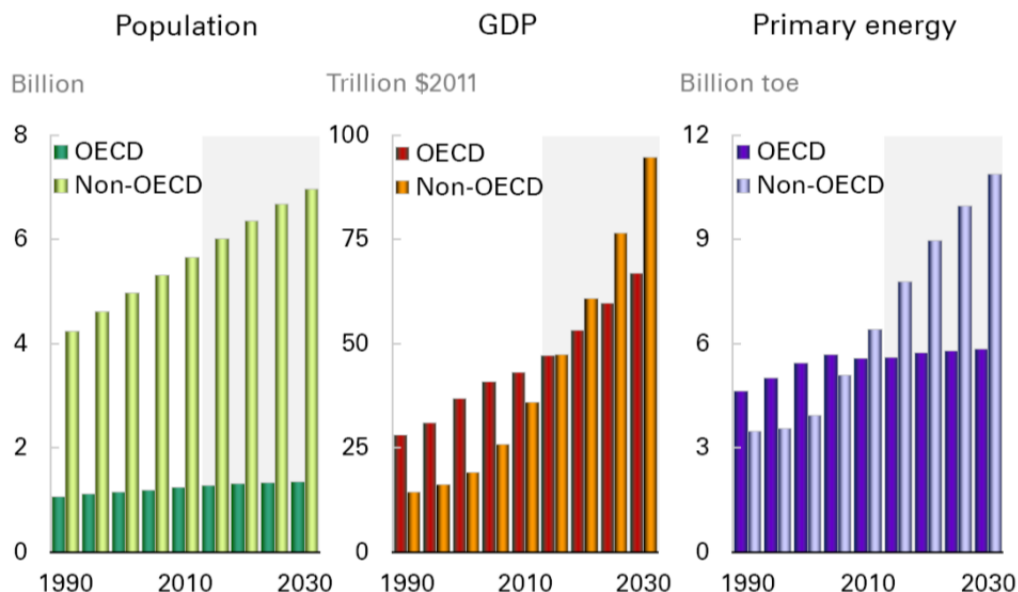


Source: *BP Energy Outlook 2030*

Similarly, fossil fuels continue to supply most of the world's energy throughout BP's *IEO 2013* Reference case projection.[33] In 2030, liquid fuels, natural gas, and coal still supply more than three-fourths of total world energy consumption – Figure II-10. World primary energy consumption is forecast to increase by about 40 percent by 2030 and by nearly 60 percent by 2040 – from 524 quads[34] in 2010, to 729 quads in 2030, and to 820 quads in 2040; from about 12 billion tons of oil equivalent (btoe) in 2010, to

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[31]Ibid.
[32]*BP Energy Outlook 2030*, BP p.l.c., January 2013; © BP 2013.
[33]Ibid.
[34]A quad is a unit of energy equal to $10^{15}$ (quadrillion) BTUs.

about 17 btoe in 2030, and about 19 btoe in 2040.[35]   This figure also illustrates that, over the next two decades:

- Almost all of the increased energy demand will come from the non-OECD nations.
- Most of the increased demand will be for power generation.
- Fossil fuels will continue to be the world's dominant energy source.
- Non-hydro renewables will continue to supply a very small portion of the world's energy requirements.

**Figure II-10**
**Growth in Primary Energy Demand**



Source:  *BP Energy Outlook 2030.*
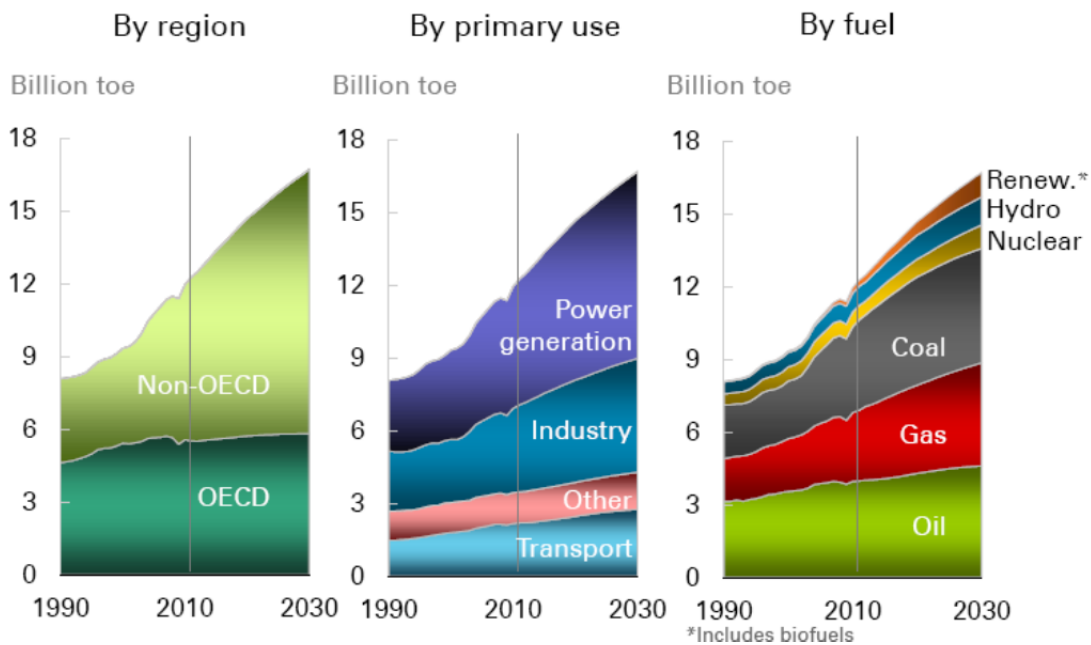
World primary energy consumption is forecast to increase by 1.6 percent annually, from 2011 to 2030, adding 36 percent to global consumption by 2030. However, the growth rate declines, it is:

- 2.5 percent annually, 2000 – 2010,
- 2.1 percent annually, 2010 – 2020, and
- 1.3 percent annually, 2020 — 2030.

Almost all (93 percent) of the energy consumption growth is in non-OECD countries.  Non-OECD energy consumption in 2030 is 61 percent above the 2011 level, with growth averaging 2.5 percent annually (or 1.5 percent annually per capita),

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[35]Ibid.

accounting for 65 percent of world consumption — compared to 53 percent in 2011. OECD energy consumption in 2030 is only six percent higher than in 2011 (0.3 percent annual average growth rate), and will decline in per capita terms to -0.2 percent annually, 2011-2030.[36]

Most of the world's energy growth will be in the power sector:  Energy used for power generation increases by 49 percent, 2.1 percent annually, 2011 - 2030, and accounts for 57 percent of global primary energy growth.  Primary energy used directly in industry grows by 31 percent (1.4 percent annually), accounting for 25 percent of the growth of primary energy consumption.   World primary energy production growth matches consumption, growing by 1.6 percent annually from 2011 to 2030.

Figure II-11 shows the forecast of world primary energy shares over the coming decades.  It illustrates that:

- Oil continues to decline as the world's major energy source, decreasing from nearly 50 percent of world energy in the 1960s to less than 30 percent by 2030.
- Coal overtakes oil as the world's major energy source.
- Natural gas continues to gradually increase its share of the world energy market.
- The share of hydro remains about constant.
- Nuclear power declines slightly in relative importance.
- Non-hydro renewables (including biomass) increase to about five percent of total world energy by 2030.

**Figure II-11**
**Shares of World Primary Energy**
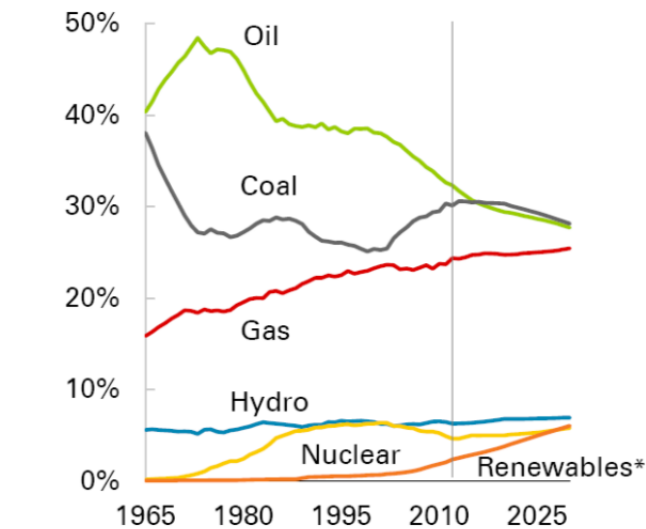


*Includes biofuels
Source:  *BP Energy Outlook 2030*

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[36]Ibid.

As shown in Figure II-12, global energy intensity — measured as energy demand per dollar of GDP — in 2030 is 31 percent lower than in 2011, declining at 1.9 percent annually compared to a decline rate of 1.0 percent annually for 2000-10. The rate of decline accelerates post 2020, averaging 2.2 percent annually for 2020-30, in large part the result of China moving onto a less energy-intensive development path. However, energy intensity declines in all regions.

**Figure II-12**
**Energy and GDP Intensity**
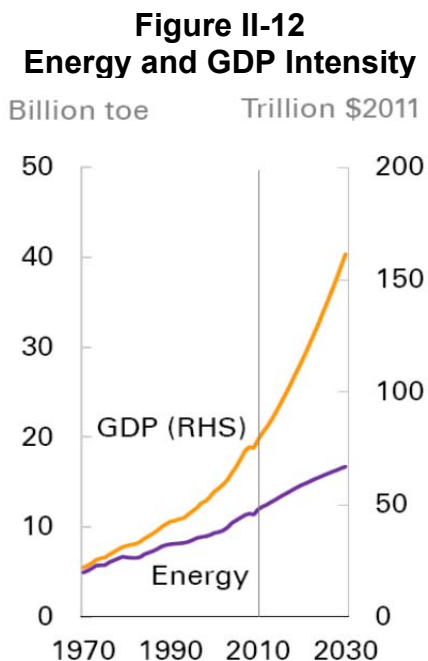


Source: *BP Energy Outlook 2030*

In the two years that followed the economic crisis of 2008, global energy demand grew at a faster rate than the global economy. This disrupted the broad trend of delinking global energy intensity over the last several decades.[37] However, preliminary data indicate a 0.6 percent improvement in energy intensity in 2011, indicating that the long-run trend may have been restored. Nevertheless, the main conclusions to be derived from these forecasts are that economic growth will continue to require prodigious amounts of energy and that investment, competition, and innovation are the key to meeting this need.

The latest U.S. Energy Information Administration (EIA) forecast projects that the world's real GDP[38] will increase at an average of 3.6 percent per year from 2010 to 2040. The most rapid rates of growth are projected for the emerging, non-OECD

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[37]This discontinuity can be attributed to a number of factors: The financial crisis delayed investment in more efficient buildings, vehicles and appliances; emerging economies, where energy intensity is higher, were less affected by the global crisis; energy intensive infrastructure projects were funded by economic stimulus programs; etc. International Energy Agency, op. cit.

[38]Expressed in purchasing power parity (PPP) terms.

regions, where combined GDP increases by 4.7 percent per year. In the OECD regions, GDP grows at a much slower rate of 2.1 percent per year over the projection, owing to more mature economies and slow or declining population growth trends. The strong growth in non-OECD GDP drives the fast-paced, large growth in future energy consumption projected for these nations.[39]

This growth in GDP will be driven by a world energy consumption increase of 56 percent between 2010 and 2040.[40] EIA forecasts that total world energy use will increase from 524 quads in 2010 to 630 quads in 2020, and to 820 quads in 2040 — Figure II-13. More than 85 percent of the increase in global energy demand from 2010 to 2040 occurs among the developing nations outside the OECD, driven by strong economic growth and expanding populations. In contrast, OECD member countries are, for the most part, already more mature energy consumers, with slower anticipated economic growth and little or no anticipated population growth. Energy use in non-OECD countries increases by 90 percent; in OECD countries, the increase is 17 percent.[41]

**Figure II-13**
**World Total Energy Consumption, 1990-2040**
**(Quadrillion Btu)**
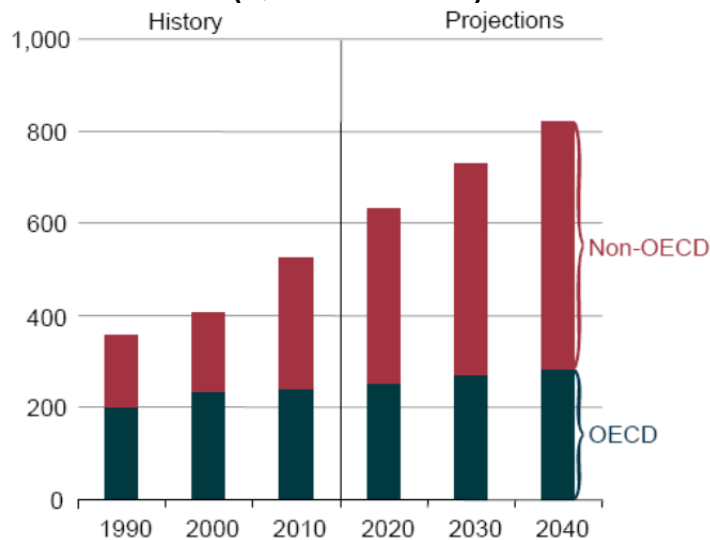


Source: U.S. Energy Information Administration, *International Energy Outlook 2013*

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[39]U.S. Energy Information Administration, *International Energy Outlook 2013, With Projections to 2040*, July 2013.
[40]Ibid.
[41]The *IEO 2013* Reference case does not incorporate prospective legislation or policies that might affect energy markets.

In the long term, the EIA reference case projects increased world consumption of marketed energy from all fuel sources through 2040 (Figure II-14).  EIA forecasts that fossil fuels will continue to supply most of the energy used worldwide.  Although liquid fuels — mostly petroleum-based — remain the largest source of energy, the liquids share of world marketed energy consumption falls from 34 percent in 2010 to 28 percent in 2040, as projected high world oil prices lead many energy users to switch away from liquid fuels when feasible.

**Figure II-14**
**World Energy Consumption By Fuel Type,**
**1990‒2040 (Quadrillion Btu)**
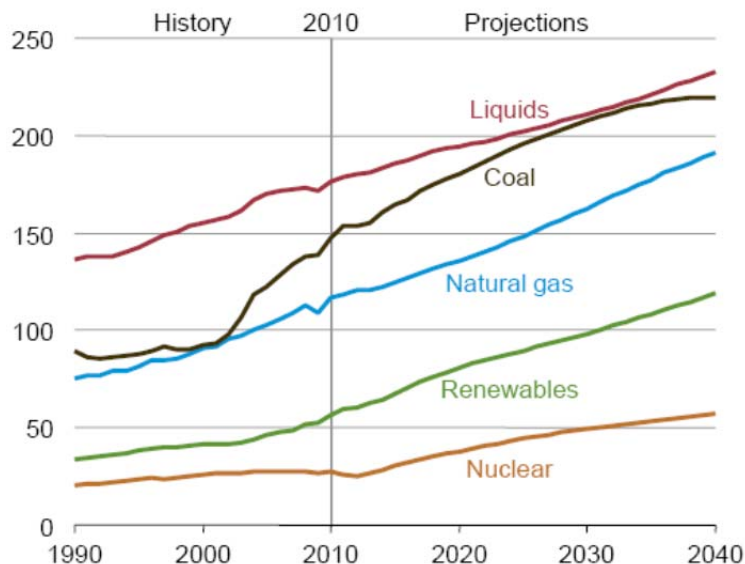


U.S. Energy Information Administration, *International Energy Outlook 2013*

## II.D.  World Fossil Fuel Reserves, Resources, and Consumption

Given the huge increase in demand for fossil fuels in the coming decades, the question arises of whether there are likely to be sufficient supplies available at reasonable prices.  The short answer to this question is "yes."

IEA, taking into account energy price assumptions and expectations for advances in technology and extraction methods, found that the world's endowment of energy resources is sufficient to satisfy projected energy demand to 2035 and well beyond.[42]  It found that fossil fuel resources remain plentiful (Table II-1) and that coal, in particular, is extremely abundant.  Proven reserves of coal, essentially an inventory of what is currently economic to produce, are much greater than those of oil and gas combined, on an energy basis.  They are sufficient to supply around 132 years of

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[42]International Energy Agency, *World Energy Outlook 2012*, op. cit.

production at 2011 levels.[43]  Ultimately recoverable resources, the measure of long-term fossil fuel production potential used by the IEA, are, especially for coal, much larger than proven reserves.   IEA concluded that, "As market conditions change and technology advances, some of these resources are set to move into the proven category, providing further reassurance that the resource base will not constrain production for many decades to come."[44]

**Table II-1**
**World Fossil Fuel Reserves and Resources**[a]

|  | Coal* (billion tonnes) | | Natural gas (tcm) | | Oil (billion barrels) | |
|---|---|---|---|---|---|---|
|  | Proven reserves | Recoverable resources | Proven reserves | Recoverable resources | Proven reserves | Recoverable resources |
| OECD | 427 | 10 657 | 28 | 193 | 244 | 2 345 |
| Non-OECD | 576 | 10 551 | 205 | 597 | 1 450 | 3 526 |
| World | 1 004 | 21 208 | 232 | 790 | 1 694 | 5 871 |
| *Share of non-OECD* | 57% | 50% | 88% | 76% | 86% | 60% |
| R/P ratio (years) | 132 | 2 780 | 71 | 241 | 55 | 189 |

\* For coal, the data are for 2010.
[a]tcm:  Trillion cubic meters.

Source:  International Energy Agency.

In fact, when assessing the world's long term recoverable resources it is clear that coal – which can be gasified and liquefied — is the fossil fuel of the future, just as it has been in the past and present.  Its recoverable resources are many times larger than natural gas or oil, or even of natural gas and oil combined.  Specifically, as shown in Figures II-15 and II-16, in terms of R/P ratios,[45] coal recoverable reserves are:

- Larger than those of natural gas by a factor of 12,
- Larger than those of oil by a factor of 15, and
- Larger than those of natural gas and oil combined by a factor of 7.

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[43]German Federal Institute for Geosciences and Natural Resources, *Energy Resources 2011, Reserves, Resources, Availability*, Hanover, Germany, 2011.
[44]Further, "The costs of supply will undoubtedly be higher than in the past, as existing sources are depleted and companies are forced to turn to more difficult sources to replace lost capacity.  Investors in energy projects are exposed to a wide array of risks, including geological, technical, regulatory, fiscal, market and geopolitical risks.  As a result, harnessing the necessary investment, technology and skilled workforce is expected to be an ongoing challenge. At certain times, sectors and places, investment will undoubtedly fall short of what is needed (though there will also be occasions when the reverse occurs)." International Energy Agency, *World Energy Outlook 2012*, op. cit.
[45]The Reserves-to-production ratio (R/P) is the remaining amount of a non-renewable resource, expressed in time.  The reserve portion (numerator) of the ratio is the amount of a resource known to exist in an area and to be economically recoverable (proved reserves).   The production portion (denominator) of the ratio is the amount of resource used in one year at the current rate.

**Figure II-15**
**World Recoverable Fossil Fuel Resources**
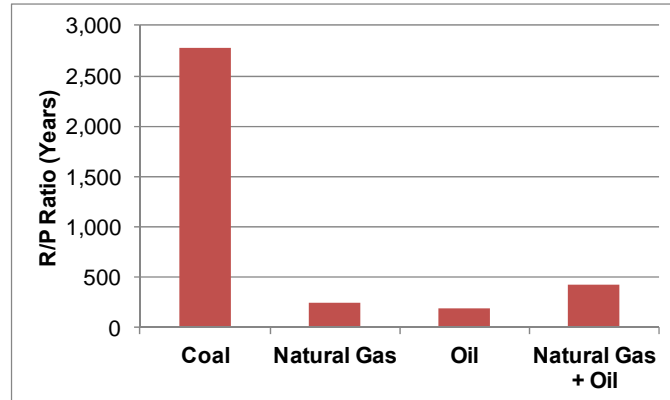


Source: International Energy Agency

**Figure II-16**
**Fossil Energy Resources by Type**
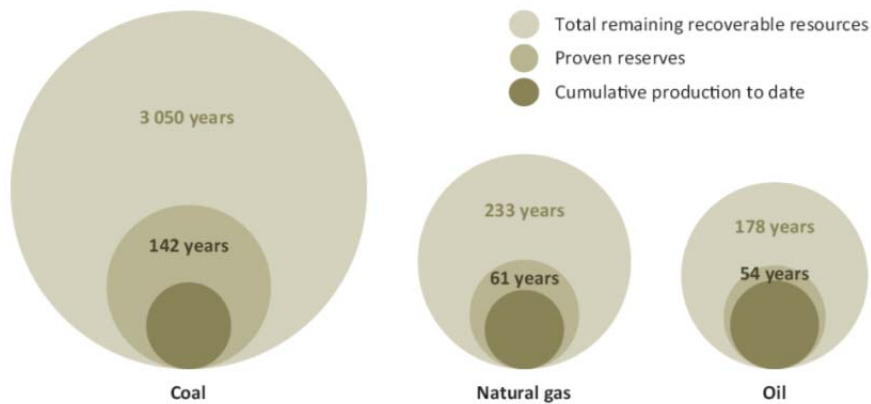


Source: International Energy Agency

Thus, while it is little recognized, coal is the primary world energy source of the past, present, and future:

- Coal was the world's dominant energy source in the 19th century and, as noted, powered the first industrial revolution that ended millennia of human poverty and economic stasis.
- Coal was the world's major energy source in the 20th century. More energy was obtained from coal than from oil and, contrary to common perception, the 20th century was really the "coal century," not the "oil century."
- Coal is the world's most rapidly growing energy source in the 21st century. Coal use grew twice as fast as any other energy source

over past decade and is poised to be the world's most rapidly growing energy source in the second decade of the 21$^{st}$ century.[46]

- Coal's dominance is forecast to continue and coal will shortly again become the world's largest primary energy source, exceeding oil for the first time since about 1960.[47]
- Coal is essential to meet the world's rising energy demand, for it comprises 75 percent of the world's recoverable fossil fuel resources.

## II.E.  The Key Role of Electrification

### II.E.1.  The Engineering Achievement

Electrification is perhaps the world's most significant engineering achievement of the past century.  For example:

- Electricity created modern cities:  Climate control, lighting, elevators, subways, etc.
- Air conditioning led to technological changes and huge geographic population shifts – see the discussion below.
- Electricity made the assembly line and mass production possible
- Refrigeration and sanitation technologies made the modern food industries possible, and vastly enhanced human health and safety
- Electricity revolutionized transportation:  Vehicles, airlines, mass transit, telecommuting, etc.
- Electricity revolutionized medicine, greatly improved human health, and increased life spans.
- Electricity revolutionized agriculture and facilitated reduction of the required agricultural labor force by 95 percent.
- Electricity created the "global village:"  Telephone, radio, TV, FAX, cell phones, computers, Internet, IT, satellites, email, social media, etc.

Electricity has created, shaped and defined the modern world and, "For the U.S., access to electricity brought about a sea change to the quality of life, ranging from surviving childhood to drinking cleaner water to learning to read.[48]  Economic growth and electricity usage are closely correlated, and electricity has facilitated virtually every technological achievement of the past 100 years, transforming industry, commerce, agriculture, transportation, medicine, communications, etc.  The U.S. National Academy of Engineering assessed how engineering shaped the 20$^{st}$ century and changed the

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[46]"Coal 4-Year Low Lures Utilities Ignoring Climate:  Energy Markets," Bloomberg, October 12, 2013.
[47]*BP Energy Outlook 2030*
[48]Jude Clemente, "The Statistical Connection Between Electricity and Human Development," *Power* Magazine, September 1, 2010.

world, analyzed the 20th century's greatest engineering achievements, and ranked the top 20.[49]  As shown in Table II-2, NAE ranked electrification as the "most significant engineering achievement of the 20th Century."

Similarly, in November 2013 the *Atlantic* magazine assembled a panel of scientists, engineers, entrepreneurs, and technologists to assess the 50 innovations "that have done the most to shape the nature of modern life since the widespread use of the wheel."[50]  Electricity was ranked the second most significant, after the printing press.

**Table II-2**
**Greatest Engineering Achievements of the 20th Century**

| | |
|---|---|
| 1. Electrification | 11. Highways |
| 2. Automobile | 12. Spacecraft |
| 3. Airplane | 13. Internet |
| 4. Water Supply and Distribution | 14. Imaging |
| 5. Electronics | 15. Household Appliances |
| 6. Radio and Television | 16. Health Technologies |
| 7. Agricultural Mechanization | 17. Petroleum and Petrochemical Technologies |
| 8. Computers | 18. Laser and Fiber Optics |
| 9. Telephone | 19. Nuclear Technologies |
| 10. Air Conditioning and Refrigeration | 20. High-performance Materials |

Source:  National Academy of Engineering.

To take just one example of these electricity-dependent technologies, it is little appreciated how air conditioning – climate control – has profoundly affected and improved modern life.[51]  For example, in the U.S.:

- Many of the central changes in society since World War II would not have been possible were air conditioning not available for homes and workplaces.
- Florida, Southern California, Texas, Arizona, Georgia, and New Mexico all experienced above-average growth during the latter half of the 20th century – which would have been impossible without air conditioning, and AC was crucial for the explosive postwar growth of Sunbelt cities like Houston, Phoenix, Las Vegas, and Miami.

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[49]U.S. National Academy of Engineering, "Greatest Engineering Achievements of the 20th Century," 2000; © 2014 National Academy of Engineering.
[50]James Fallows, "The 50 Greatest Breakthroughs Since the Wheel," *Atlantic*, November 2013, pp. 56-68; © 2014 The Atlantic Monthly Group.
[51]One reason for choosing this example is that there is currently a "war against air conditioning" being waged because it is alleged that AC contributes to global warming and other assorted evils; see, for example, Stan Cox, *Losing Our Cool:  Uncomfortable Truths About Our Air-Conditioned World*, The New Press, 2012; and Doug Mataconis, "The War Against Air Conditioning," July 6, 2010, www. outsidethebeltway.com/the-war-against-air-conditioning.

- The advent of AC helped launch the massive Southern and Western population growth that has transformed the U.S. electoral map in the last half century:  The Sunbelt's share of the nation's population increased from 28 percent in 1950 to 40 percent in 2000.
- Computers generate a lot of heat, and the development of the entire IT industry could not have occurred without cooling technologies first pioneered by air conditioning.
- As discussed in section II.G.1, climate control improves health and saves lives.  For example, more than 700 people died in the 1995 Chicago heat wave, and an estimated 30,000 Europeans succumbed to heat-related illnesses during the heat wave that struck the continent in 2003.
- AC launched new forms of architecture and altered the ways Americans live, work, and play:  From suburban tract houses to glass skyscrapers, indoor entertainment centers, high-tech manufacturers' clean rooms, and pressurized modules for space exploration, many of modern structures and products would not exist without the invention of climate control.
- AC changed peoples' relationship with nature itself by creating indoor artificial climates, shifting seasonal patterns of work and play, and making U.S. geographical differences environmentally insignificant.
- As the technology of climate control developed, so also did the invention of more sophisticated products that required increasingly precise temperature, humidity, and filtration controls — consumer products such as computer chips and CDs must be manufactured in "clean rooms," which provide dust-free environments.
- Willis Carrier originally developed climate control to facilitate ink drying in the printing industry in New York City in the early 1900s and, ironically, by facilitating developments in computers and IT air conditioning helped create the 21st century Age of Information.
- Historian Raymond Arsenault found that air conditioning made factory work tolerable in the South, reduced infant mortality, eliminated malaria, and allowed developers to build skyscrapers and apartment blocks.  Air conditioning industrialized and urbanized the South, lifting it out of its post-Civil War depression.[52]
- Gail Cooper found that "Air conditioning became an instrument of American modernity — it was a tool marking an American middle class identity as well as a symbol representing a particular and highly specified standard of living.[53]

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[52]Raymond Arsenault, "The End of the Long Hot Summer: The Air Conditioner and Southern Culture," *The Journal of Southern History*, Vol. 50, No. 4. (Nov., 1984), pp. 597-628.
[53]Gail Cooper, *Air-Conditioning America: Engineers and the Controlled Environment 1900-1960,* Baltimore:  Johns Hopkins University Press, 1998.  Cooper notes that AC for cars became a status

- Political economist Richard Nathan stated that "The civil rights revolution and air conditioning are the two biggest factors that have changed U.S. demography and a lot of our politics in the last 30 years."[54]

Further, electrification will be increasingly important in 21st century, and examples of electricity's potential this century include addressing:

- Energy challenges, energy efficiency, and energy conservation,
- Environmental, sustainability, and climate issues,
- Economic development,
- Transportation issues,
- Improving people's standard of living,
- Health, medicine, and bio-tech,
- Continuing developments in communications, IT, etc.,
- The productivity challenge, electricity use, and productivity growth, and
- Others: Emerging electro-technologies, new industries, nanotechnology, robotics, superconductivity, 3-D printing, space exploration, etc.

### II.E.2. Electrification and Human Development

Energy alone is not sufficient for creating the conditions for economic growth, but it is absolutely necessary. It is impossible to operate a factory, run a store, grow crops, or deliver goods to consumers without using some form of energy. Access to electricity is particularly crucial to human development as electricity is, in practice, indispensable for certain basic activities, such as lighting, refrigeration, and the running of household appliances, and cannot easily be replaced by other forms of energy. Individuals' access to electricity is one of the most clear and un-distorted indication of a country's energy poverty status.[55] Thus, electricity access is increasingly at the forefront of governments' preoccupations, especially in the poorest countries.

As a representative of modern energy, the level of electricity consumption can be regarded as indicative of a country's development level, and studies have confirmed the causality between electricity consumption and human development. For example, it was found that long-run causality exists between electricity consumption and five basic human development indicators: Per-capita GDP, consumption expenditure, urbanization rate, life expectancy at birth, and the adult literacy rate. In addition, it was

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symbol, so much so that some people without it supposedly drove around with their windows up in 100 degree heat to give an impression otherwise.

[54]Dr. Richard Nathan is the Distinguished Professor of Political Science and Public Policy at the State University of New York at Albany and the former Director of the Rockefeller Institute of Government; he was quoted in the *New York Times*, August 29, 1998.

[55]International Energy Agency, *World Energy Outlook 2011*, Paris, 2012.

found that the higher the income of a country, the greater is its electricity consumption and the higher is its level of human development and, further, that as income increases, the contribution of electricity consumption to GDP and consumption expenditure increases.[56]  In addition, researchers have found that:

- Electricity consumption is significantly correlated with GDP as well as HDI for 120 countries, and the countries with high consumption levels of per capita electricity rank high with respect to the UN Human Development Index.[57]
- Per-capita energy and electricity consumption are highly correlated with economic development and other indicators of modern lifestyle, inferring that the more energy that is consumed, especially in the form of electricity, the better life is.[58]
- Electricity consumption is essential for people to improve their well-being in less-developed countries, especially in populous nations such as China and India.[59]

These benefits are so extensive that it is unequivocal the world requires more electricity, not less.[60]

Since 1993, the United Nations Development Program has used a summary composite index, the Human Development Index (HDI), to measure, on a scale of 0 to 1, a nation's average achievements in three basic dimensions of human development: health, knowledge, and standard of living: (1) Health is measured by life expectancy at birth; (2) Knowledge is measured by a combination of the adult literacy rate and the combined primary, secondary, and tertiary gross enrollment ratio; and (3) Standard of Living is measured by GDP per capita.[61]  UN member states are listed and ranked each year according to these measures.

The IEA reports more than 1.5 billion people in the world have no electric power, and another 2 billion have extremely limited access.  In essence, 3.5 billion people — almost 12 times the population of the U.S. — have either no electricity or only a constrained supply.  Indeed, the disparity in access to electricity around the world is

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[56]See, for example, Shuwen Niu, Yanqin Jia, Wendie Wang, Renfei He, Lili Hu, and Yan Liu, "Electricity Consumption and Human Development Level:  A Comparative Analysis Based on Panel Data For 50 Countries," *International Journal of Electrical Power & Energy Systems*, Volume 53, December 2013, pp. 338–347.  These authors recommended that, to improve human development, electricity should be incorporated into the basic public services construction to enhance the availability of electricity for low-income residents.

[57]M. Kanagawa and T Nakata, "Assessment of Access to Electricity and the Socioeconomic Impacts in Rural Areas of Developing Countries," *Energy Policy*, Vol. 36, No. 6 (2008), pp. 2,016-2,029.

[58]K.H. Ghali and M.I.T El-Sakka, "Energy Use and Output Growth in Canada:  A Multivariate Cointegration Analysis," *Energy Economics*, Vol. 26 (2004) pp. 225-238.

[59]A. Mazur, "Does Increasing Energy or Electricity Consumption Improve Quality of Life in Industrial Nations?" *Energy Policy*, Vol. 39, No. 5 (2011), pp. 2,568-2,572.

[60]Clemente, op. cit.

[61]See United Nations Development Program, "International Human Development Indicators," http://hdr.undp.org/en/statistics.

staggering. The average consumer in Germany, for example, uses 6,670 kWh of power each year; the average Indian uses just 444 kWh. In Europe, virtually no household lacks access to electricity. By contrast, in India, over 400 million people have no electricity, 600 million cook with wood or dung, and over 900 million have no refrigeration.[62]

The consequences of these differences in electricity access are stark. In Germany, a newborn can expect to live until age 79, in India, only until age 64. In Germany, primary completion and literacy rates are about 100 percent, in India, they hover around 70 percent. In Germany, the GDP per capita is $34,401, in India it is $2,753. Consequently, Germany's HDI is 0.947 and India's is 0.612.

Statistical analyses find that there is sufficient evidence to conclude that those countries that use at least 2,000 kWh per capita a year (High Electricity Consumers) have a significantly higher HDI than those countries that do not (Low Electricity Consumers).[63] Electricity is essential, and access to electric power is central to human development. There is simply no better indicator of a country's level of development than its per capita use of electricity. Electricity enables people to live longer and better and, as shown in Figure II-17, the UN links electricity consumption to quality of life.

**Figure II-17**
**The UN Human Development Index and Per Capita Electricity Use**
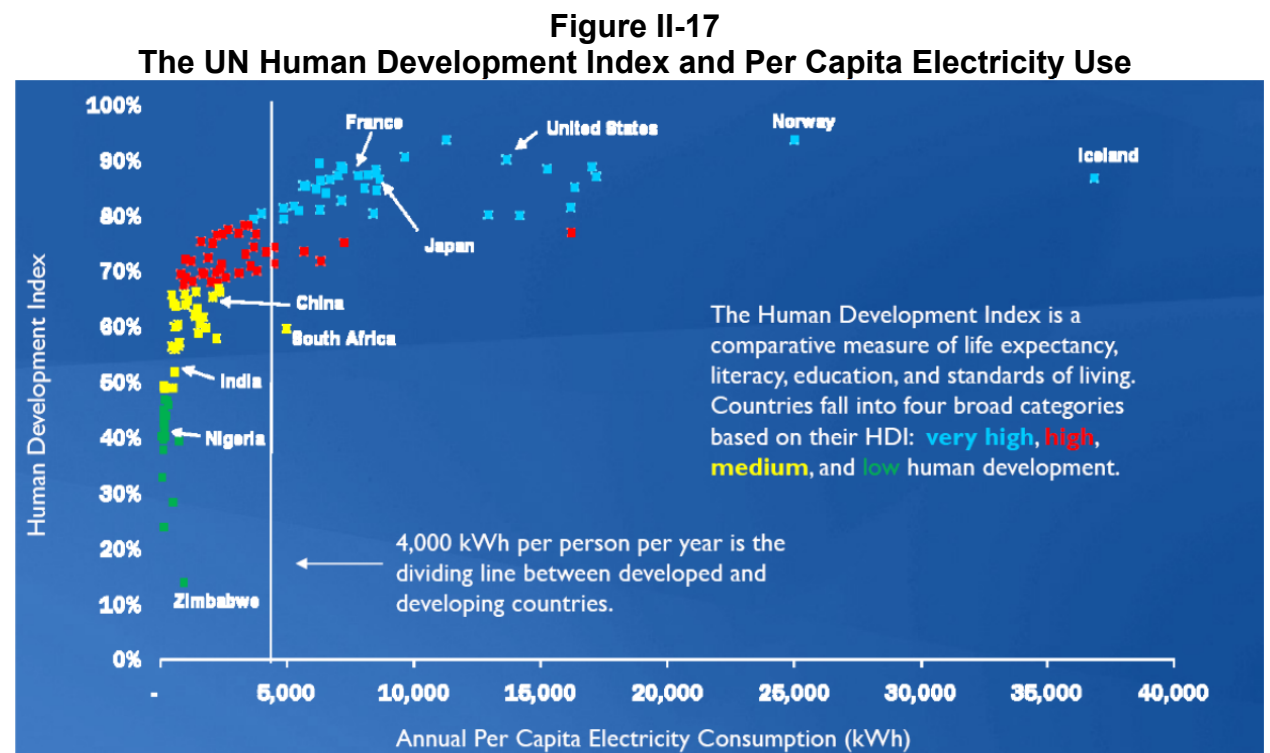


Source: United Nations Development Program, *Human Development Report, 2012*.

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[62]International Energy Agency, op. cit.
[63]Clemente, op. cit.

Electricity fuels and sustains prosperity and, as shown in Figure II-18, wealth expands with greater electricity use.

**Figure II-18**
**Per Capita Income and Per Capita Electricity Consumption**
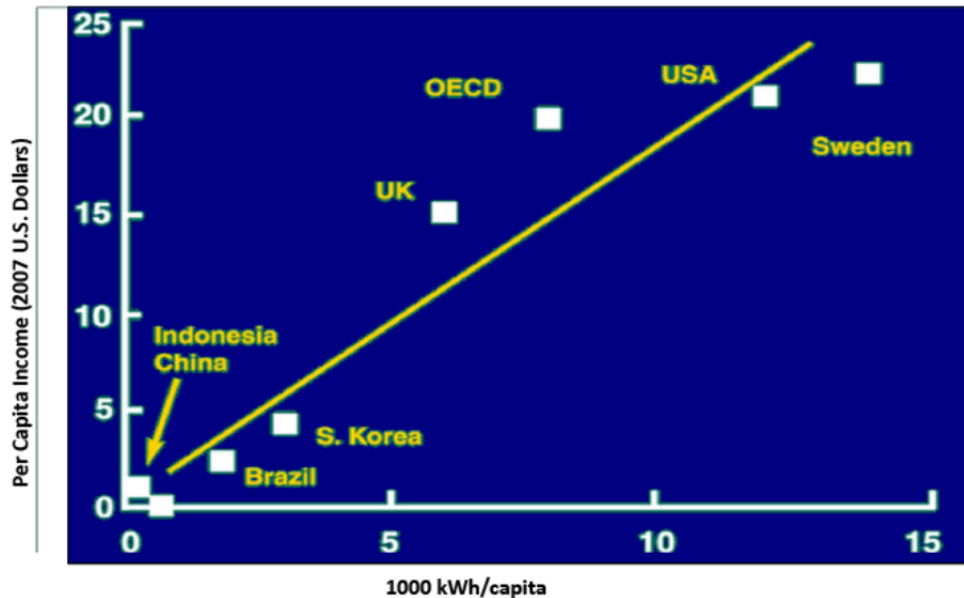


Source:  World Resources Institute, *IEEE Spectrum*.

Electricity facilitates increased health and well-being and, as shown in Figure II-19, longevity expands with greater electricity use.

The current drive in some parts of the world (including parts of the U.S.) to increase the price of electricity in order to decrease consumption stands at great odds with experience and poses grave risks.  Price increases and higher rates take electricity out of the reach of large segments of society and have adverse consequences and undesirable socioeconomic impacts.  Indeed, the UN's eight Millennium Development Goals center not only on electricity availability, but on affordably priced power.[64]  For the foreseeable future, mainstream generation technologies, typically based on fossil fuels, will continue to be the least expensive sources of electricity in virtually every country in the world.

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[64]United Nations, "Millennium Development Goals Beyond 2015," www.un.org/millenniumgoals.

**Figure II-19**
**Average Life Spans and Per Capita Electricity Consumption**

### II.E.3.  The Increasing Importance of Electricity

EIA forecasts that world net electricity generation will nearly double in the *IEO 2013* Reference case, from 20.2 trillion kWh in 2010 to 39.0 trillion kWh in 2040.[65]  As shown in Figure II-20, this near doubling between 2010 and 2040 represents a nearly 7-fold increase in electricity consumption since 1980.

**Figure II-20**
**World Electricity Consumption**
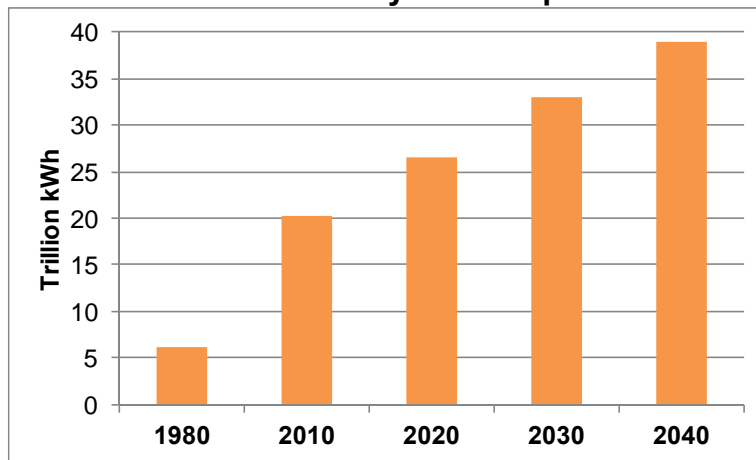
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[65]U.S. Energy Information Administration, *International Energy Outlook 2013*, op. cit.

Electricity supplies an increasing share of the world's total energy demand and, as shown in Figure II-21, is growing rapidly. EIA forecasts that world electricity delivered to end users will increase by 2.2 percent per year from 2010 to 2040, as compared with average growth of 1.4 percent per year for all delivered energy sources.[66] In general, projected growth in OECD countries, where electricity markets are well established and consumption patterns are mature, is slower than in non-OECD countries, where at present many people do not have access to electricity. The electrification of historically off-grid areas plays a strong role in determining relative growth.[67]

Non-OECD nations consumed 49 percent of the world's total electricity supply in 2010, and their share of world consumption is expected to increase over the projection period. In 2040, non-OECD nations are forecast to account for 64 percent of world electricity use. Total net electricity generation in non-OECD countries increases by an average of 3.1 percent per year in the Reference case, led by annual increases averaging 3.6 percent in non-OECD Asia (including China and India) from 2010 to 2040. In contrast, total net generation in the OECD nations grows by an average of only 1.1 percent per year from 2010 to 2040.

**Figure II-21**
**Growth in World Total Electricity Generation and**
**Total Delivered Energy Consumption, 1990-2040**
(Index, 1990 = 1)
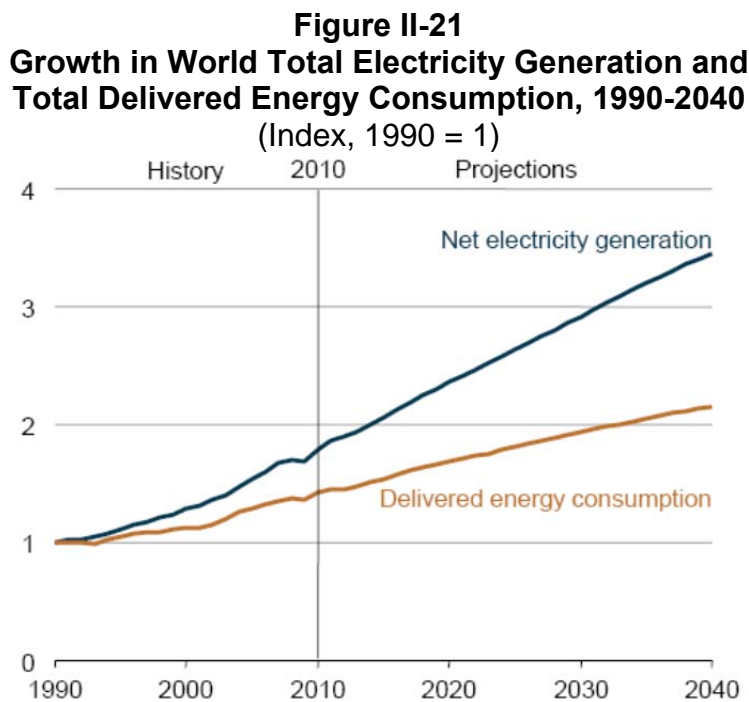


Source: U.S. Energy Information Administration, *International Energy Outlook 2013.*

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[66]Ibid.

[67]IEA estimates that 19 percent of the world's population, or about 1.3 billion people [*219*], did not have access to electricity in 2010. Moreover, almost 57 percent of the population in Africa currently remains without access to electric power. International Energy Agency, *World Energy Outlook 2012* (Paris, France: November 2012), p. 532.

The worldwide mix of primary fuels used to generate electricity has changed significantly over the past four decades, but coal continues to be the fuel most widely used in electricity generation.  Although coal-fired generation increases by a slower annual average of 1.8 percent over the EIA projection period, it remains the largest source of generation through 2040 and grows by the largest absolute amount over the period.[68]

A continually increasing share of the world's energy will be in the form of electricity.  In 2040, fossil fuels will account for over 60 of the world's electricity generation, with coal accounting for well over half of fossil fuel electricity production – Figure II-22.

Over the past two decades, the global share of power generation from non-fossil sources has decreased from 37 percent in 1990 to 33 percent in 2010; whereas in contrast, the share of coal-fired power generation has increased from 37 percent to 42 percent.[69]  Fossil fuels, and especially coal, will thus continue to fuel global electricity generation for the foreseeable future.

Coal is currently the predominant fuel used for electricity generation worldwide and is forecast to remain so for at least the next three decades.  In 2010, coal-fired generation accounted for 40 percent of overall worldwide electricity generation.  Coal-fired electricity generation grows in the EIA Reference case at a 1.8 percent annual rate from 2010 to 2040, and in 2040, total world electricity generation from coal is forecast to be 73 percent higher than the 2010 level.  China and India alone account for 89 percent of the projected growth in coal-fired generation.[70]

Coal will provide a continually increasing share of world energy and, accordingly, a major new global build-out of coal generation is under way – driven by rapidly increasing demand in Asia (Figure II-23).

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[68]U.S. Energy Information Administration, *International Energy Outlook 2013*, op. cit.
[69]International Energy Agency, *Resources to Reserves:  Oil, Gas, and Coal Technologies for the Energy Markets of the Future*, Paris, 2013; © OECD/IEA 2013.
[70]Ibid.

**Figure II-22**
**World Net Electricity Generation by Energy Source, 2010-2040 (Trillion kWh)**
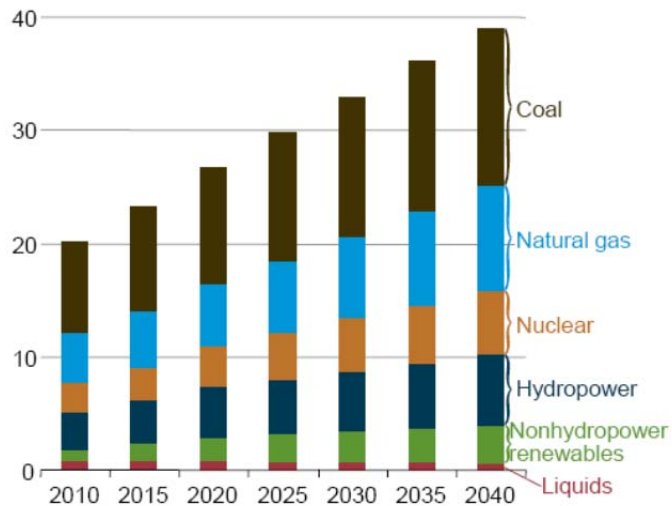


Source: U.S. Energy Information Administration, *International Energy Outlook 2013.*

**Figure II-23**
**Worldwide Coal Build-out**



- Global coal-fueled generation expected to grow 90% by 2035
- 340 MTPA coal growth just in new plants starting up in 2010
- 2010 rate equates to ~1 billion tonnes of new demand every three years
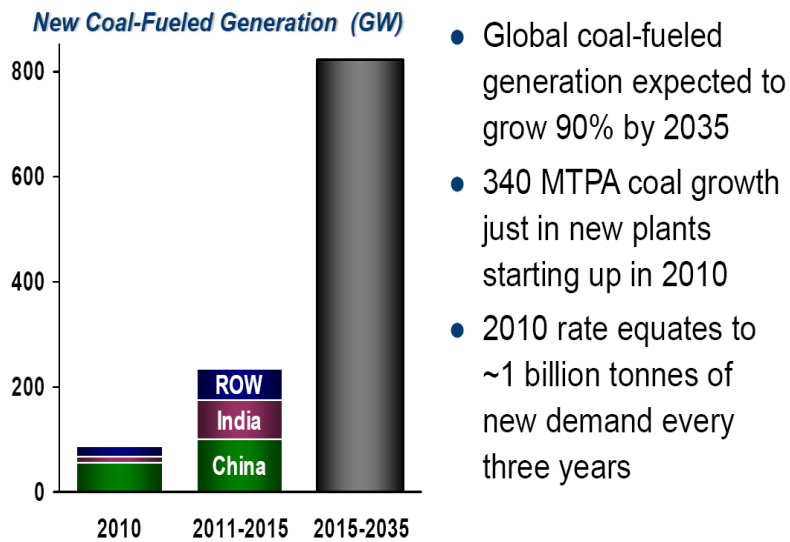
Source: Platts Worldwide Power Plant Database and EIA.

Figure II-24 shows that U.S. generating capacity and electricity sales are forecast to continue to increase significantly through 2040.

**Figure II-24**
**Electricity Sales and Power Sector**
**Generating Capacity, 1949-2040**
(indexes, 1949 = 1.0)
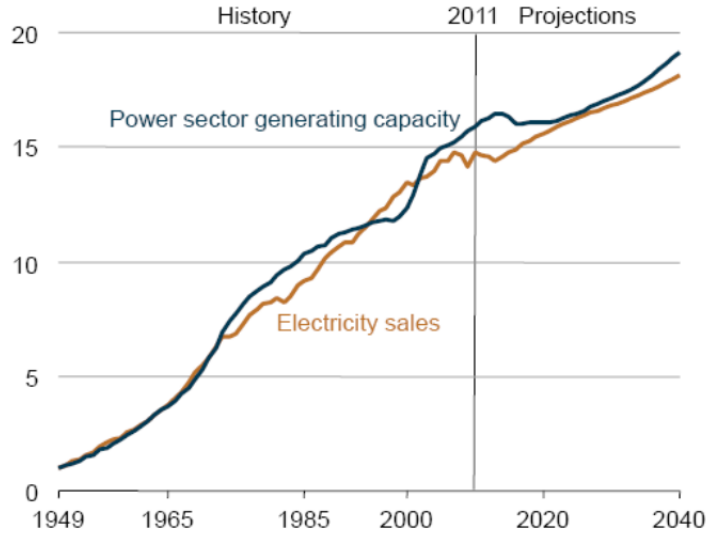


Source: U.S. Energy Information Administration, 2013


Similarly, electricity is of increasing in importance in the U.S. economy. As shown in Figure II-25, EIA forecasts that between 2010 and 2040 total U.S. energy consumption will increase by about nine percent, whereas electricity consumption will increase nearly twice as fast – more than 15 percent.

Thus, the long term trend of the U.S. economy becoming more electricity-intensive will continue for at least the next three decades. As shown in Figure II-26, whereas in 2000 electricity comprised less than 39 percent of U.S. energy consumption, by 2040 it is forecast to comprise more than 42 percent of U.S. energy consumption.

**Figure II-25**
**Increase in U.S. Energy Consumption, 2010 - 2040**



Source: U.S. Energy Information Administration, 2013

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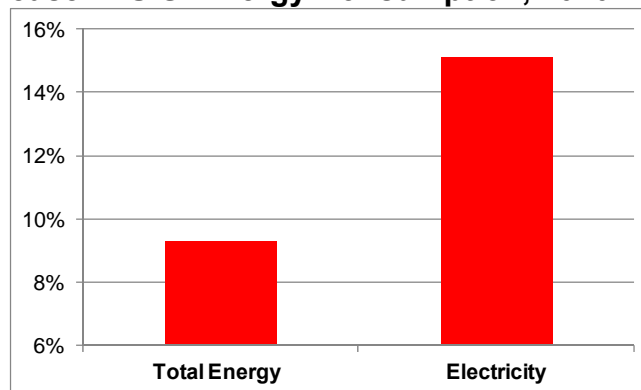
**Figure II-26**
**Electricity as a Percent of Total U.S. Energy Consumption**
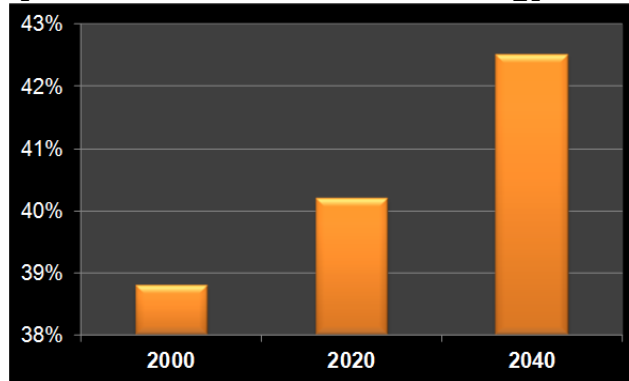
Coal will remain a mainstay of U.S. electricity production:  As shown in Figure II-27, coal will continue to produce more than 40 percent of U.S. electricity through at least 2040.

**Figure II-27**
**Coal Share of U.S. Electricity Production, 2020 - 2040**
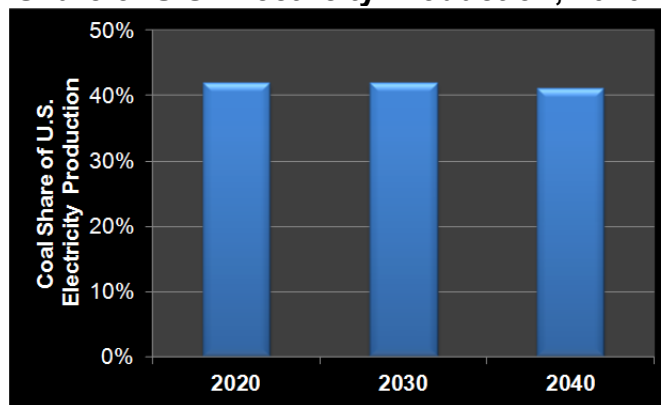
The bottom line here is that coal is forecast to remain a major source of future electricity supplies both worldwide and in the U.S.  As such, it cannot be removed without great replacement cost or reduced electricity consumption, which could be economically damaging, and this must be understood when assessing SCC policies and implications.

## II.F.  The Regressive Burden of Energy Costs

### II.F.1.  The Energy Burden Defined

The "energy burden" is defined as the percentage of gross annual household income that is used to pay annual residential energy bills, and it includes electricity, gasoline, heating, and cooking fuel.[71]  It is a widely used and accepted term and is officially defined in the *Code of Federal Regulations* and in numerous federal and state documents.[72]  Energy burden is an important statistic widely used by policy-makers in assessing the need for energy assistance and can be defined broadly as the burden placed on household incomes by the cost of energy, or more simply, the ratio of energy expenditures to household income.[73]

The energy burden concept is used to compare energy expenditures among households and groups of households, and it is often used in the Low Income Home Energy Assistance Program (LIHEAP) and similar programs to estimate required payments.  For example, consider the case where one household has an energy bill of $1,000 and an income of $10,000 and a second household has an energy bill of $1,200 and an income of $24,000.  While the first household has a lower energy bill ($1,000 for the first household compared to $1,200 for the second), the first household has a much higher energy burden (10 percent of income for the first household compared to five percent of income for the second).

The energy burdens of low-income households are much higher than those of higher-income families, and energy burden is a function of income and energy expenditures.  Since residential energy expenditures increase more slowly than income, lower income households have higher energy burdens.  High burden households are those with the lowest incomes and highest energy expenditures.

As shown in Figure II-28:

- Families earning more than $50,000 per year spent only four percent of their income to pay energy-related expenses.
- Families earning between $10,000 and $25,000 per year (29 percent of the U.S. population) spent 13 percent of income on energy.

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[71]The individual household energy burden is calculated for each household and then averaged within income/origin categories.  See the discussion in Applied Public Policy Research Institute for Study and Evaluation, *LIHEAP Energy Burden Evaluation Study*, report prepared for the Office of Community Services, U.S. Department of Health and Human Services, July 2005.

[72]The CFR defines the residential energy burden as residential expenditures divided by the annual income of that household.  See 10 CFR 440.3 - Definitions. - *Code of Federal Regulations* - Title 10: Energy - PART 440.

[73]U.S. Department of Energy, *Buildings Data Energy Book*, 2.9.2., "Energy Burden Definitions," March 2011.

- Those earning less than $10,000 per year (13 percent of population) spent 29 percent of income on energy costs.

Thus, for 42 percent of households – mostly senior citizens, single parents, and minorities – increased energy costs force hard decisions about what bills to pay: Housing, food, education, health care, and other necessities.  Cost increases for any basic necessity are regressive in nature, since expenditures for essentials such as energy consume larger shares of the budgets of low-income families than they do for those of higher-income families.  Whereas higher-income families may be able to trade off luxury goods in order to afford the higher cost of consuming a necessity such as energy, low-income families will always be forced to trade off other necessities to afford the higher-cost good.

When families with income constraints are faced with rising costs of essential energy, they are increasingly forced to choose between paying for that energy use and other necessities (also often energy-sensitive) such as food, housing, or health care.  Because all of these expenditures are necessities, families who must make such choices face sharply diminished standards of living.  For example, of the 8.7 million American households earning less $10,000 per year in 2008, 60 percent of the average after-tax income was used to meet those households' energy needs.  Among the highest earners, the 56 million households making more than $50,000 per year, only 10 percent of the average after-tax income was spent on those households' energy needs.  The national average for energy costs as a percentage of household income is about 12 percent.

**Figure II-28**
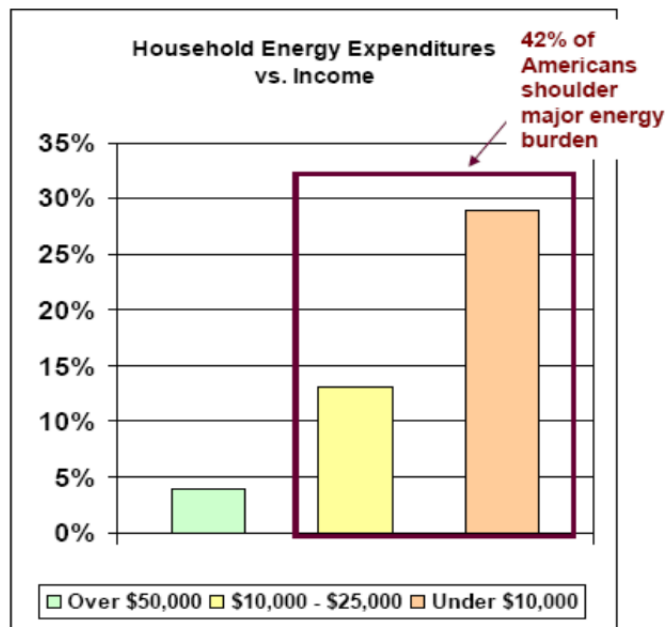


Source:  American Association of Blacks in Energy.

## II.F.2.  The Regressive Nature of Energy Costs

Table II-3 shows that households in the lowest-income classes spend the largest shares of their disposable income to meet their energy needs.  For example, for the 8.7 million American households earning less $10,000 per year in 2010, nearly 70 percent of their average after-tax income was used to meet those households' energy needs. Among the highest earners, the 56 million households making more than $50,000 per year, only eight percent of the average after-tax income was spent on energy needs. The national average for energy costs as a percentage of household income is about 10.4 percent.[74]

**Table II-3**
**Estimated U.S. Household Energy Expenditures as a Percentage of Income, 2010**

| Pre-tax income | <$10K | $10K-$30K | $30K-$50K | >$50K | Average |
|---|---|---|---|---|---|
| Percent of Households | 7.1% | 23.1% | 19.4% | 50.3% | |
| Residential Energy | $1,559 | $1,729 | $1,997 | $2,501 | $2,157 |
| Transportation Fuel | $1,837 | $2,280 | $3,221 | $4,316 | $3,456 |
| Total Energy | $3,395 | $4,009 | $5,218 | $6,817 | $5,613 |
| Average After-Tax Income | $4,903 | $18,138 | $33,436 | $84,337 | $53,904 |
| Energy Percent% of After-Tax Income | 69.3% | 22.1% | 15.6% | 8.1% | 10.4% |

Sources:  U.S. Bureau of the Census, *Current Population Survey*; U.S. DOE, *Residential Energy Consumption Survey*; U.S. DOE/EIA, *Annual Energy Review* and *Short-Term Energy Outlook*; U.S. DOE/EIA, *Household Vehicle Energy Use: Latest and Trends*; U.S. Congressional Budget Office, *Effective Federal Tax Rates Under Current Law, 2001-2014* and *Effective Federal Tax Rates, 1979-2006*.

The portion of U.S. household incomes expended on energy costs has increased significantly over the past decade, especially for lower-income groups — as illustrated in Figure II-29.  Energy costs as a percentage of after-tax income increased nearly 75 percent between 2001 and 2010, from a national average of 6.0 percent to 10.4 percent.  However, this figure indicates that the increases for different income groups varied widely:

- For households earning less than $10,000 per year, the percent of after-tax income consumed by energy costs increased from 36 percent to 69 percent.
- For households earning between $10,000 and $30,000 per year, the percent of after-tax income consumed by energy costs increased from 14 percent to 22 percent.

[74]Estimates derived from U.S. Bureau of Labor Statistics, *Consumer Expenditure Survey*; U.S. Bureau of the Census, *Current Population Survey*; U.S. Department of Energy, *Residential Energy Consumption Survey*; U.S. Energy Information Administration, *Annual Energy Review*, *Short Term Energy Outlook*, and *Household Vehicle Energy Use:  Latest and Trends*; U.S. Congressional Budget Office, *Effective Federal Tax Rates Under Current Law, 2001-2014* and *Effective Federal Tax Rates, 1979-2006*.  See the discussion in "Energy Cost Impacts on American Families, 2001-2012," American Coalition for Clean Coal Electricity, February 2012, www.americaspower.org.

- For households earning between $30,000 and $50,000 per year, the percent of after-tax income consumed by energy costs increased from 10 percent to 16 percent.
- For households earning more than $50,000 per year, the percent of after-tax income consumed by energy costs increased from five percent to eight percent.

Thus, in 2010 the poorest households were paying, in percentage terms, nearly nine times as much for energy as the most affluent households. Even households earning between $10,000 and $30,000 per year were paying in percentage terms, nearly three times as much for energy as the most affluent households.

**Figure II-29**
**Energy Costs as a Percentage of Annual After-Tax Income, 2001-2010**
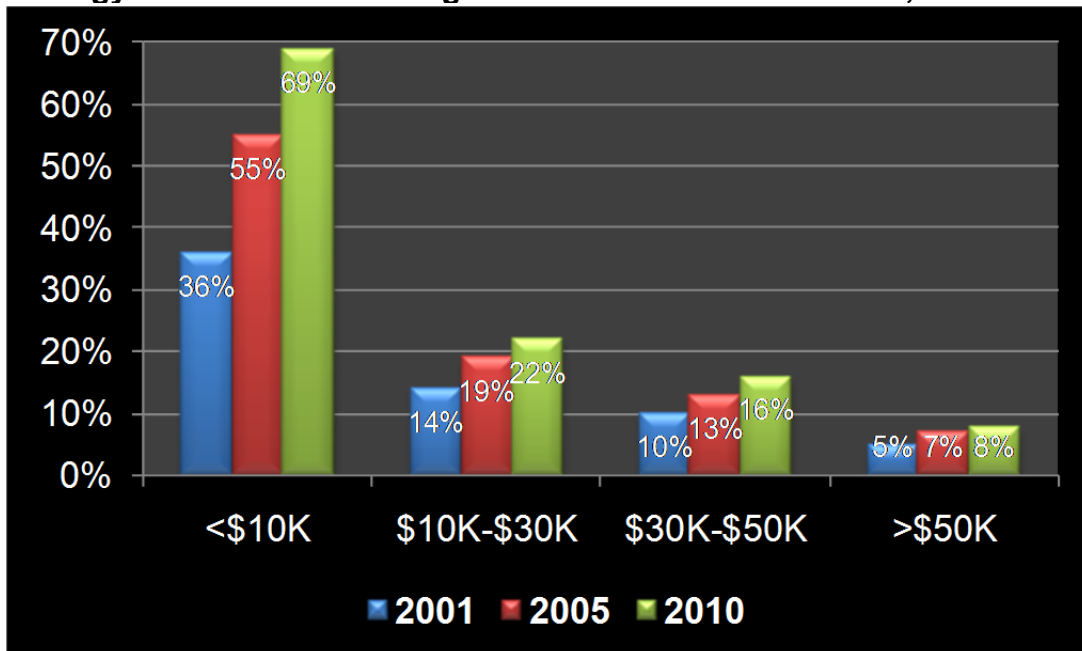


Source: 2010 BLS Consumer Expenditure Survey.

Thus, energy costs as a percentage of annual after-tax income have increased significantly for household incomes under $50,000:

- Nearly 50 percent of U.S. households earn less than $50,000 per year, and they spend 16 percent or more of their income on energy.
- Nearly 40 million U.S. households earning less than $30,000 per year spend 20 percent or more of their income on energy.

Table II-4 shows the average annual household expenditures for U.S. households earning $50,000 or less. Note that these households:

- Spend more on energy than on food,
- Spend twice as much on energy than on healthcare,
- Spend more than twice as much on energy as on clothing,
- Spend more on energy than on anything else, except housing,
- Spend more than 1/4 of their income on housing – nearly 40% on housing if utilities are included, and
- Have little discretionary income, and thus increased energy costs will displace spending on health, food, clothing, housing, and other necessities.

**Table II-4**
**Average Annual Household Expenditures, 2009**

| Pre-tax annual income (average) | $50,000 or Less | % of Total Expenditures |
|---|---|---|
| After-tax income (average) | $36,218 | -- |
| Clothing | $1,340 | 3.7% |
| Energy – residential & transportation | $5,396 | 14.9% |
| Healthcare | $2,861 | 7.9% |
| Food | $5,287 | 14.6% |
| Housing (ex. utilities) | $10,395 | 28.7% |
| Transportation (ex. fuel) | $5,179 | 14.3% |
| Entertainment | $1,920 | 5.3% |
| Insurance and pensions | $1,956 | 5.4% |
| Education and reading | $507 | 1.4% |
| Tobacco and alcohol | $761 | 2.1% |
| All other | $616 | 1.7% |
| Total expenditures | $36,218 | 100% |

Source:  U.S. Bureau of Labor Statistics, *Consumer Expenditure Survey 2009*, October 2010.

## II.F.3.  Impacts and Effects

High and Increasing energy prices have a detrimental effect on the lives of those with limited incomes, and they suffer from home energy arrearages and shut-offs, cutbacks on necessities and other items, risks to health and safety, and housing instability.[75]  For example, in recent years, 15 – 20 million U.S households have been in arrears on their home energy bills, and more than 15 percent of all households were at least 30 days delinquent.[76]  Unpaid utility bills harm both energy suppliers and low-income families.  For example, in 2008, suppliers were experiencing a loss of nearly $5 billion in unpaid household bills, costs that they pass on to other consumers.[77]  Families

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[75]Joy Moses, *Generating Heat Around the Goal of Making Home Energy Affordable to Low Income Americans:  Current Challenges and Proposed Solutions*, Center for American Progress, Washington, D.C., December 2008.
[76]National Energy Assistance Directors' Association, "NEADA Press Release: Consumers Continue to Fall Behind on Utility Bills, Arrearages Approach $5 billion, Up 14.8% From Last Year," May 2008.
[77]Ibid.

unable to pay their bills face utility shut-offs that deprive them of the basics of living such as heating, cooling, lights, refrigeration, and the ability to cook food. As discussed below, a survey conducted by the Energy Programs Consortium (EPC) found that eight percent of low-income respondents (defined as those living at 150 percent of the federal poverty level) experienced a utility shut-off during the past year due to rising home energy and gasoline costs.[78]

In addition to experiencing threats of disruption to their energy services, low-income families are often forced to limit the amount of money they spend on necessities and other important items in order to help manage their energy costs. Of particular concern are reduced purchases of food. According to the EPC survey, 70 percent of those living at or below 150 percent of poverty reported that they were buying less food in response to increases in home energy and gasoline costs. Further, families that are slightly above this poverty marker (151 percent to 250 percent of poverty) and families across all other income levels also reported spending less on food — although they were affected to a lesser degree than the lowest-income families. Thirty-one percent of the poorest families indicated that they purchased less medicine due to high energy costs.[79] They changed plans for education (19 percent), fell behind on credit card bills (18 percent), and reduced their contributions to savings (58 percent) — Table II-5.[80] Thus, Americans of all income levels suffer financially from high energy costs, but those at the bottom of the economic spectrum are under the greatest strain – and those families at or below 150 percent of poverty are the most affected by increased energy prices.[81]

**Table II-5**
**Actions Taken by U.S. Households as a Result of High Energy Prices**

| Actions taken | All respondents | ≤150% of poverty | 151%-250% of poverty |
|---|---|---|---|
| Reduced purchases of food | 43% | 70% | 51% |
| Reduced purchases of medicine | 18% | 31% | 23% |
| Changed plans for education or children's education | 11% | 19% | 18% |
| Behind on credit card bills | 11% | 18% | 15% |
| Reduced amount of money put into savings | 55% | 58% | 58% |

Source: 2008 Energy Costs Survey (NEADA).

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[78]Energy Programs Consortium and National Energy Assistance Directors' Association, "2008 Energy Costs Survey," June 2008.

[79]Ibid.

[80]Ibid. For a more detailed discussion of the actions taken and their implications, see Appendix I.

[81]The energy burdens in the third world are much higher and the implications of high energy prices more severe; see, for example, Gautam N. Yadama, *Fires, Fuel and the Fate of 3 Billion: The State of the Energy Impoverished*, Oxford University Press, 2013.

## II.G.  The Health and Safety Benefits of Affordable, Reliable Energy

### II.G.1.  Health Risks

A major impact of carbon restrictions will be to significantly increase U.S. electricity costs and rates.   This will make electricity more expensive and less affordable, especially to those with limited incomes, and being unable to afford energy bills can be harmful to one's health – as illustrated in Figure II-30.  Many people are forced to purchase less medicine when their utility bills increase.  Other health hazards can occur if inside temperatures are too low or too high as a result of shut-offs or efforts to lower bills by reducing the use of heating and cooling equipment.  Surveys have found that nearly one-third of households with incomes at or below 150 percent of poverty kept their homes at a temperature that was unsafe or unhealthy at some point during the year.  Similarly, so also did 24 percent of those between 151 percent and 250 percent of poverty.[82]

Temperature extremes can be damaging to vulnerable populations, including the elderly, the disabled, and small children.  These groups are particularly susceptible to hypothermia (cold stress or low body temperatures) and hyperthermia (heat stress or high body temperatures), conditions that can cause illness or death.[83]  Young children are particularly at risk from extreme temperatures because their small size makes it difficult for them to maintain body heat.[84]  Small children in households that are struggling to afford energy costs are more likely to be in poor health, have a history of hospitalizations, be at risk for developmental problems, and be food insecure.  Compared with families receiving energy assistance, families who are eligible for such benefits but not receiving them are more likely to have underweight babies and 32 percent more likely to have their children admitted to the hospital.[85]

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[82]Energy Programs Consortium and National Energy Assistance Directors' Association, "2008 Energy Costs Survey," June 2008.

[83]U.S. Department of Health and Human Services, "Tips for Health and Safety," available at www.acf. hhs.gov/programs/ocs/liheap/consumer_info/health.html.

[84]Children's Sentinel Nutrition Assessment Program and Citizens Energy Corporation, "Fuel for Our Future: Impacts of Energy Insecurity on Children's Health, Nutrition, and Learning," September 2007.

[85]Ibid.

**Figure II-30**
**Potential Health Impacts of Increased**
**Energy Costs on Low Income Persons**
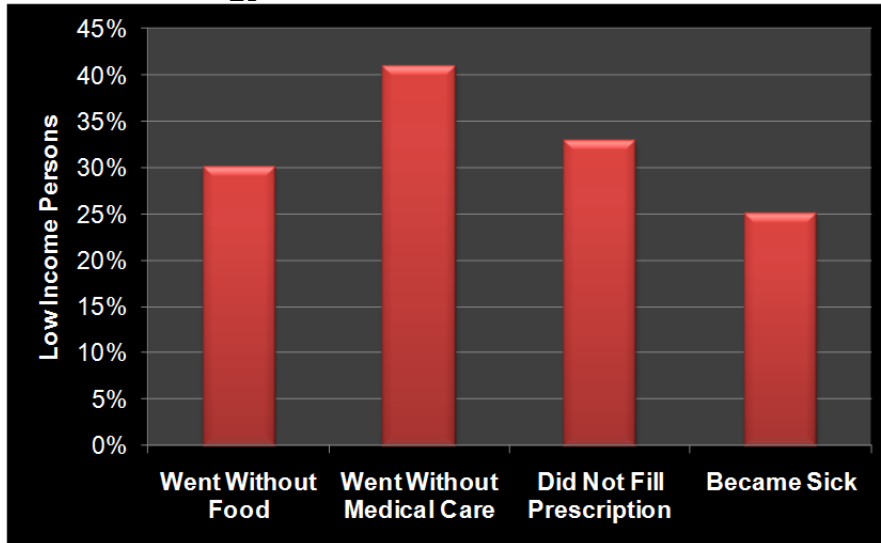


Source: National Energy Assistance Directors' Association.

High energy burdens among older, low-and moderate-income households, expose them to the risks of going without adequate heating or cooling, frequently resulting in adverse health and safety outcomes, including premature death – Figure II-30. Unaffordable home energy undermines state and national priorities for seniors to age in place and avoid institutional care.[86] Households at the lowest income level are often on a fixed income from Social Security, disability, or retirement. When energy prices escalate, their incomes do not keep pace, and they have little flexibility in their budgets to address increases in energy costs.[87]

Further, the job losses and price increases resulting from the increased energy costs will reduce incomes as firms, households, and governments spend more of their budgets on electricity and less on other items, such as home goods and services. The loss of disposable income also reduces the amount families can spend on critical health care, especially among the poorest and least healthy.[88]

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[86]"Home Energy Costs: The New Threat to Independent Living for the Nation's Low-Income Elderly," *Journal of Poverty Law and Policy*, January-February 2008.
[87]Ibid.
[88]Randall Lutter and John F. Morrall. "Health-Health Analysis: A New Way to Evaluate Health and Safety Regulation", *Journal of Risk and Uncertainty*, 8(1), 43-66 (1994); Ralph L. Keeney, "Mortality Risks Induced by Economic Expenditures", *Risk Analysis* 10(1), 147-159 (1990); Krister Hjalte et al. (2003). "Health Analysis – an Alternative Method For Economic Appraisal of Health Policy and Safety Regulation: Some Empirical Swedish Estimates," *Accident Analysis & Prevention* 35 (1), 37-46; W. Kip Viscusi "Risk-Risk Analysis," *Journal of Risk and Uncertainty* 8 (1), 5-17 (1994); see also Viscusi and Richard J. Zeckhauser, "The Fatality and Injury Costs of Expenditures", *Journal of Risk and Uncertainty* 8(1), 19-41 (1994).

More generally, a substantial body of literature has developed examining the potential impacts of energy and environmental regulations on GDP, energy prices, income, and employment. It has been estimated, for example, that initiatives requiring expanded use of high cost energy alternatives would increase the cost of electricity to the point that per-capita income and employment rates would decrease in a quantitatively predictable manner.[89] Assuming these estimates to be approximately correct, and given the epidemiological findings on socioeconomic status and health, it follows that policies such as carbon restrictions that increase the costs of energy and electricity would bring about a net increase in population mortality. Thus, a major impact of restricting the use of coal and other fossil fuels will be to increase U.S. mortality rates.[90]

Brenner's research found that changes in the economic status of individuals produce subsequent changes in the health and life spans of those individuals and that decreased real income per capita and increased unemployment have consequences that lead to increased mortality in U.S. and European populations. Econometric analyses of time-series data were used to measure the relationship between changes in the economy and changes in health outcomes, and studies have found that declines in real income per capita and increases in unemployment led to elevated mortality rates over a subsequent period of six years.[91] For example, a 1984 study by the Joint Economic Committee of the U.S. Congress found that a one-percentage-point increase in the unemployment rate (e.g., from five percent to six percent) would lead to a two percent increase in the age-adjusted mortality rate.[92] The growth of real income per capita also showed a significant correlation to decreases in mortality rates (except for suicide and homicide), mental hospitalization, and property crimes.[93] The European Commission has supported similar research showing comparable results throughout the European Union.[94]

Upward trends in real income per capita represented the most important factor in decreased U.S. mortality rates over the past half-century, for being unable to afford energy bills can be harmful to one's health. As indicated above, some people purchase less medicine when their utility bills are too high. Other health hazards can occur if inside temperatures are too low or too high as a result of shut-offs or efforts to lower bills by reducing the use of heating and cooling equipment. Thirty-one percent of households with incomes at or below 150 percent of poverty kept their homes at a

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[89]Harvey Brenner, "Health Benefits of Low-Cost Energy: An Econometric Study," *Environmental Management*, November 2005, pp 28 – 33; © 2005 Air and Water Management Association.
[90]Ibid.
[91]Ibid.
[92]Harvey Brenner, *Estimating the Effects of Economic Change on National Health and Social Well-Being*; Joint Economic Committee, U.S. Congress: Washington, DC, 1984.
[93]Ibid.
[94]See Harvey Brenner, *Estimating the Social Cost of Unemployment and Employment Policies in the European Union and the United States*; European Commission Dir.-Gen. for Employment, Industrial Relations, and Social Affairs: Luxembourg, 2000; Harvey Brenner, *Unemployment and Public Health in Countries of the European Union*; European Commission Dir.-Gen. for Employment, Industrial Relations, and Social Affairs: Luxembourg, 2003.

temperature that they thought was unsafe or unhealthy at some point during the year. Similarly, so also did 24 percent of those between 151 percent and 250 percent of poverty.[95]

Further, there are substantial health benefits of temperature control in warmer climates, and studies have analyzed the effect of temperature on mortality and morbidity and documented the effectiveness of air conditioners (ACs) as a mitigation strategy. For example, a recent study investigated the association between temperature and hospital admissions in California from 1999 to 2005 and also determined whether AC ownership and usage, assessed at the zip-code level, mitigated this association.[96]  It found that ownership and usage of ACs significantly reduced the effects of temperature on adverse health outcomes, after controlling for potential confounding by family income and other socioeconomic factors. These results demonstrate important effects of temperature on public health and the potential for mitigation.  That is, the research found significant associations between heat and several disease-specific hospital admissions in California, and concluded that the use of central AC significantly reduces the risk from higher temperatures.  Thus, higher electricity costs that limit or prohibit the use of AC can be hazardous to one's health.

EPA has acknowledged that "People's wealth and health status, as measured by mortality, morbidity, and other metrics, are positively correlated.  Hence, those who bear a regulation's compliance costs may also suffer a decline in their health status, and if the costs are large enough, these increased risks might be greater than the direct risk-reduction benefits of the regulation."[97]  In addition to EPA, the Office of Management and Budget, the Food and Drug Administration, and the Occupational Safety and Health Administration use similar methodology to assess the degree to which their regulations induce premature death amongst those who bear the costs of federal mandates.[98]  Further, OMB Circular A-4, which provides the procedures for federal regulatory impact analysis and benefit-cost analysis, states "the benefits of a regulation that reduces emissions of air pollution might be quantified in terms of the number of premature deaths avoided each year; the number of prevented nonfatal illnesses and hospitalizations."[99]

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[95]Ibid.
[96]This study used temperature data during the warm season in California to estimate the impact on several disease-specific categories of hospitalizations. To limit exposure misclassification, the authors limited the study to buffer areas with individuals living in zip codes within 25 kilometers of a temperature monitor.  They quantified the likely reduction in health impacts based on both ownership and use of ACs using individual-level data for each buffer, and examined the potential confounding effect that local measures of family income may have on their effect estimates.  See Bart Ostro, Stephen Rauch, Rochelle Green, Brian Malig, and Rupa Basu, "The Effects of Temperature and Use of Air Conditioning on Hospitalizations," *American Journal of Epidemiology*, October 2010.
[97]U.S.EPA, "On the relevance of risk-risk analysis to policy evaluation," August 16, 1995.
[98]Ibid.
[99]U.S. Office of Management and Budget, "Regulatory Impact Analysis: A Primer," Circular A-4, 1993.

## II.G.2.  Safety Risks

High energy prices also compromise the safety of low-income households.  For example, the inability to pay utility bills often leads to the use of risky alternatives.  In a survey of energy assistance recipients, 21 percent of respondents indicated that at some point in the previous year they were unable to use a main heating source because they could not pay their utility bill.[100]  Twelve percent indicated that a utility company had shut off their main heating sources of natural gas or electricity during the previous year due to nonpayment.[101]

When households are cut off from their main heating source such as natural gas or fuel oil, or are trying to save money by reducing use of a main heating source, they most commonly turn to heating alternatives such as electric space heaters, which can be risky.   According to the National Fire Protection Agency, these devices are associated with a significant risk of fire, injury, and death.   In 2005, space heaters accounted for 32 percent of home heating fires, totaling 19,904 fires and 73 percent of home heating fire deaths, which killed 489 people.[102]   Researchers at the Johns Hopkins School of Medicine also noted this problem in a 2005 study in which they found that power terminations were associated with a significant subset of fires involving children — 15 percent of fires that brought patients to their hospital were rooted in utility shut-offs.[103]

## II.G.3.  Housing Instability

Families and individuals who cannot afford their energy bills are at risk of housing instability.  They may have to move to locations with lower utility costs, or shut-offs can make homes uninhabitable, forcing household members into homelessness or alternative forms of shelter.  Often, unaffordable housing compounds this problem as families experiencing difficulty paying mortgages or rent fall further behind due to energy bills that represent a higher-than-normal percentage of their income.  This factor was particularly relevant during the recent subprime mortgage crisis, which resulted in excessively high mortgage payments for some families.

The connections between unmanageable home energy costs and homelessness have been well documented.  For example, a Colorado study found that 16 percent of homeless people in the state cited their inability to pay utility bills as one of the causes of their homelessness.[104]   A nationwide survey of individuals receiving energy

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[100]National Energy Assistance Directors' Association, "2009 National Energy Assistance Survey," April 2009.
[101]Ibid.
[102]National Fire Protection Association, "U.S. Home Heating Equipment Fires Fact Sheet," 2007.
[103]Johns Hopkins School of Medicine, "Burn Injuries and Deaths of Children Associated with Power Shut-offs," April 2005.
[104]The Colorado Statewide Homeless Count, "Colorado Statewide Homeless Count, Summer 2006: Final Report," February 2007.

assistance produced further evidence of this phenomenon. Twenty-five percent reported that within the previous five years, they had failed to make a full rent or mortgage payment due to their energy bills.[105] Difficulties with paying utilities resulted in other negative outcomes such as evictions (two percent of respondents), moving in with friends or family members (four percent of respondents), and moving into a shelter or homelessness (two percent).[106]

Housing instability disrupts lives, especially if individuals are forced to move between several different locations before regaining permanent housing. Household members may find themselves at a greater distance from work and/or school and face increased transportation costs and challenges. They can also be disconnected from familiar communities, neighbors, family members, and friends. For children, the outcomes can be devastating, with homelessness being associated with increased risk of physical illness, hunger, emotional and behavioral problems, developmental delays, negative educational outcomes, and exposure to violence.[107]

## II.G.4. Energy-Related Health Risks to the Elderly

Between 2010 and 2050, the U.S. will experience rapid growth in its older population, and in 2050 the number of Americans aged 65 and older is forecast to be 88.5 million — more than double its population of 40.2 million in 2010.[108] The baby boomers are largely responsible for this increase in the older population, as they began crossing into this category in 2011.[109] The aging of the population will have wide-ranging implications for the country,[110] and senior citizens are particularly vulnerable to energy price increases due to their relatively low incomes. The average basic Social Security retirement benefit is currently about $15,200.[111] The median gross income of senior households over 65 years is currently about $31,400, and seniors have the highest per capita residential energy consumption among all age categories.[112] For many senior households, as with other households earning less than $50,000 annually, energy price increases can force difficult choices among energy, food, and other basic necessities of life, choices that would be made more difficult by higher energy costs resulting from restrictions on fossil fuels.

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[105]National Energy Assistance Directors' Association, "2005 National Energy Assistance Survey," September 2005.
[106]Ibid.
[107]The National Center on Family Homelessness, "The Characteristics and Needs of Families Experiencing Homelessness," 2011.
[108]See U.S. Census Bureau, *The Next Four Decades: The Older Population in the United States: 2010 to 2050*, May 2010. Here, the "older population" refers to those aged 65 and older.
[109]The baby boomer generation consists of people born between 1946 and 1964.
[110]Projecting the size and structure, in terms of age, sex, race, and Hispanic origin, of the older population is important to public and private interests, both socially and economically. The projected growth of the older population in the United States will present challenges to policy makers and programs, such as Social Security and Medicare, and it will also affect families, businesses, and health care providers.
[111]U.S. Social Security Administration, "Monthly Statistical Snapshot," August 2013, September 2013.
[112]U.S. Census Bureau, "American Community Survey – 2010 American Community Survey 1-Year Estimates," 2012.

Older consumers with the lowest incomes will experience the greatest cost burdens: 35 percent of older households have total household incomes of less than $20,000, and they will experience the greatest energy burden. Although consumption data show that low-income older consumers tend to use less heating fuel than higher-income groups, higher winter heating costs are likely to be a greater burden on this group than on higher-income older consumers who have greater financial resources available to meet the increased costs. As shown in Figure II-31, large percentages of the elderly have high energy burdens, and nearly 34 percent of the elderly and more than 36 percent of the frail elderly have high energy burdens.

**Figure II-31**
**Energy Burdens of the Elderly**
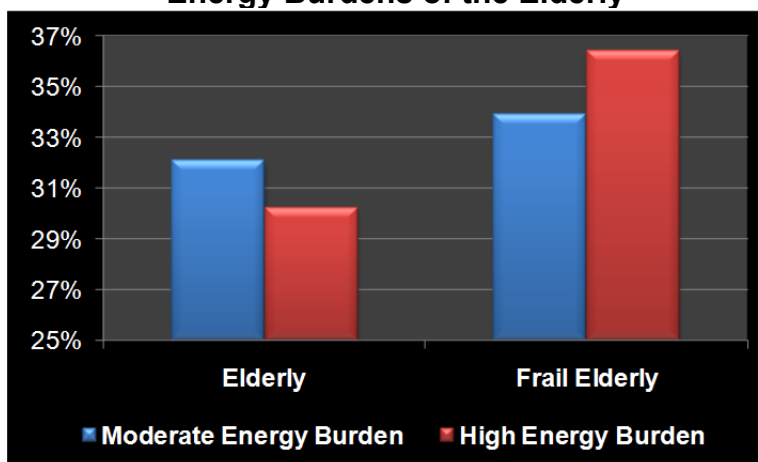


Source: Division of Energy Assistance, U.S. Department of Health and Human Services.

Low income senior citizens dependent primarily on retirement income have especially high energy burdens: About 45 percent of such individuals have high energy burdens, as compared to about 36 percent of all low income persons.[113] Thus, the greatest burdens of increased energy costs will fall on households of elderly Social Security recipients – 20 percent of all households — who depend mainly on fixed incomes, with limited opportunity to increase earnings from employment. These households have an average Social Security income of about $15,000.

Elderly individuals with low average annual incomes are more vulnerable to increasing energy costs even if their energy consumption levels are below those for households with similar annual incomes. Unlike young working families with the potential to increase incomes by taking on part-time work or increasing overtime, fixed income seniors are largely limited to cost-of-living increases that often do not keep pace

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[113]APPRISE, "LIHEAP Energy Burden Evaluation Study Final Report," Prepared for Division of Energy Assistance, Office of Community Services, Administration for Children and Families, U.S. Department of Health and Human Services, PSC Order No. 03Y00471301D, July 2005.

with rising energy prices. Maintaining affordable energy costs is critical to the well-being of millions of the nation's elderly citizens.

For many senior households energy price increases represent a serious financial burden — for example, the elderly relying on SSI spend nearly 20 percent of their incomes on utility bills. The diversion of increased shares of family incomes to energy costs implied by higher electricity bills will reduce available funds for other necessities, such as housing and healthcare, and diminish quality of life and the ability to save and invest for future needs.

The low-income elderly are particularly susceptible to weather-related illness, and a high energy burden can represent a life-threatening challenge. Given their susceptibility to temperature-related illnesses, elderly households tend to require more energy to keep their homes at a reasonable comfort level. However, despite this requirement, low-income elderly households spend 16 percent less on residential energy than all households. Higher utility bills would place many elderly households at serious risk by forcing them to heat and cool their homes at levels that are inadequate for maintenance of health. Finally, senior homeowners may be forced to sell their homes because they cannot afford their energy bills.

Elderly Americans' limited budgets are stretched even further by higher health care expenditures. Medical spending for those between the ages of 55 and 64 is almost twice the amount spent by those between the ages of 35 and 44, and the health care expenditures of those 65 and older are even larger. Health care costs have contributed to the rise in bankruptcy filings among the elderly. More serious, being unable to afford home energy can be harmful to the health of household members, and many persons are forced to purchase less medicine and health care when their utility bills are too high. A 2009 survey of low-income seniors[114] found that due to energy costs:

- 41 percent were forced to defer or forgo medical or dental care.
- 33 percent were unable to afford their prescriptions.
- 22 percent were unable to pay their energy bills due to medical expenses.
- Nearly 30 percent became ill because their home was too cold or too hot.
- 33 percent went without food for at least one day.

For the elderly, the impact of higher energy costs on food expenditures is an especially serious problem. Nearly 18 percent of low-income elderly (with incomes below 130 percent of the poverty line) who live with others are food insecure, as are more than 12 percent of low-income seniors who live alone. And although 65 percent of individuals who are eligible for food stamps receive benefits, the participation rate among the elderly is much lower at only 30 to 40 percent.[115]

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[114]Jackie Berger, 2009 National Energy Assistance Survey, prepared for NEADA by APPRISE, June 15, 2010.
[115]Hawthorne, op. cit.

Other health hazards can occur if inside temperatures are too low or too high as a result of shut-offs or household member efforts to lower bills by reducing their use of heating and cooling sources.  Thirty-one percent of households with incomes at or below 150 percent of poverty kept their homes at a temperature that they thought was unsafe or unhealthy at some point during the past year.  Similarly, so also did 24 percent of those between 151 percent to 250 percent of the poverty level.[116]

These temperature extremes can be dangerous to the elderly, who are particularly susceptible to hypothermia (cold stress or low body temperatures) and hyperthermia (heat stress or high body temperatures), conditions that can cause illness or death.[117]  Of the approximately 600 people who die from hypothermia each year, half are typically 65 or older,[118] and this group accounts for 44 percent of those who die from weather-related heat exposure.[119]  Senior citizens are at increased risk for these conditions because they do not adjust well to sudden changes in temperature and are more likely to have medical conditions or take medications that impair the body's response to hot and cold temperatures.[120]  Thus, increased utility costs have serious implications for the health of many senior citizens.

## II.G.5.  2009 Energy Cost Survey

In 2009, the National Energy Assistance Directors Association, representing state LIHEAP directors, conducted a survey to update the information about LIHEAP-recipient households that was collected in the 2003, 2005, and 2008 surveys – more detail on these surveys is contained in Appendix I.  LIHEAP is administered by the U.S. Department of Health and Human Services (HHS).  Its purpose is "to assist low-income households, particularly those with the lowest incomes, that pay a high proportion of household income for home energy, primarily in meeting their immediate home energy needs."[121]  The statutory intent of LIHEAP is to reduce home heating and cooling costs for low-income households.[122]  During the period of study, low-income households across the country faced an increasingly difficult economic climate and continued to deal with high energy costs.  The study confirmed that LIHEAP recipient households are likely to be vulnerable to temperature extremes:

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[116]Energy Programs Consortium and National Energy Assistance Directors' Association, "2008 Energy Costs Survey," June 2008.

[117]U.S. Department of Health and Human Services, "Tips for Health and Safety," available at www.acf.hhs.gov/programs/ocs/liheap/consumer_info/health.html.

[118]National Institutes of Health, "Staying Warm in the Winter Can be a Matter of Life and Death for Older People," *NIH News* (January 2005).

[119]Centers for Disease Control, "Heat-Related Illnesses, Deaths, and Risk Factors—Cincinnati and Dayton, Ohio, 1999, and United States, 1979-1997," *MMWR Weekly* (June 2, 2000).

[120]National Institutes of Health, "Staying Warm"; Centers for Disease Control, "Extreme Heat Fact Sheet" (August 2004).

[121]See "Low Income Home Energy Assistance Program. Report to Congress for Fiscal Year 2001." U.S. Department of Health and Human Services, Administration for Children and Families, Office of Community Services, Division of Energy Assistance.

[122]Ibid.

- 39 percent had a senior in the household aged 60 or older.
- 44 percent had a disabled household member.
- 45 percent had a child 18 or younger.
- 92 percent had at least one vulnerable household member.

The study also provided information on challenges that these households faced:

- 36 percent were unemployed at some point during the previous year.
- 82 percent had a serious medical condition.
- 25 percent used medical equipment that requires electricity.

LIHEAP recipients reported that they face high energy costs:

- 37 percent reported that their energy bills were more than $2,000 in the past year.
- Pre-LIHEAP energy burden averaged 16 percent and post-LIHEAP energy burden averaged 11 percent for these households, compared to seven percent for all households in the U.S. and four percent for non low-income households in the U.S.
- 35 percent said that their energy bills were higher than they had been in the previous year and 40 percent said that they were more difficult to pay than in the previous year.
- 60 percent of those who said that it was more difficult to pay their energy bills reported that the main reason was their financial situation.

Households reported that they took several actions to make ends meet:

- 36 percent closed off part of their home.
- 26 percent kept their home at a temperature that was unsafe or unhealthy.
- 20 percent left their home for part of the day.
- 33 percent used their kitchen stove or oven to provide heat.

Many LIHEAP recipients were unable to pay their energy bills:

- 49 percent skipped paying or paid less than their entire home energy bill.
- 35 percent received a notice or threat to disconnect or discontinue their electricity or home heating fuel.
- 12 percent had their electric or natural gas service shut off in the past year due to nonpayment.
- 27 percent were unable to use their main source of heat in the past year because their fuel was shut off, they could not pay for fuel

delivery, or their heating system was broken and they could not afford to fix it.

- 17 percent were unable to use their air conditioner in the past year because their electricity was shut off or their air conditioner was broken and they could not afford to fix it.

Many LIHEAP recipients had problems paying for housing over the past five years, due at least partly to their energy bills:

- 31 percent did not make their full mortgage or rent payment.
- Five percent were evicted from their home or apartment.
- Four percent had a foreclosure on their mortgage.
- 12 percent moved in with friends or family.
- Three percent moved into a shelter or were homeless.

Many of the LIHEAP recipients faced significant medical and health problems in the past five years, partly as a result of high energy costs. All of these problems increased significantly since the 2003 survey:

- 30 percent went without food for at least one day.
- 41 percent went without medical or dental care.
- 33 percent did not fill a prescription or took less than the full dose of a prescribed medication.
- 25 percent had someone in the home become sick because the home was too cold.

## II.H  Energy Costs and the Economy

Virtually all economists agree that there is a negative relationship between energy price changes and economic activity, but there are significant differences of opinion on the economic mechanisms through which price impacts are felt – see the discussion in Appendix II. Beginning with the oil supply shocks of the 1970's, analyses that have addressed the impact of energy price shocks on economic activity have produced, and continue to produce, a steady stream of reports and studies on the topic.

A number of studies have analyzed the long run impacts of changes in energy and electricity prices on the economy and jobs. For example:[123]

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[123]See also the discussion in Section II.H.2 and Appendices II and III.

- In 2012 and 2013, Bildirici and Kayikci in several studies found causal relationships between electricity consumption and economic growth in the Commonwealth of Independent States countries and in transition countries in Europe.[124]

- In 2010, Lee and Lee analyzed the demand for energy and electricity in OECD countries and found a statistically valid relationship between electricity consumption and economic growth.[125]

- In 2010, Baumeister, Peersman, and Van Robays examined the economic consequences of oil shocks across a set of industrialized countries over time and found that energy costs and GDP are negatively correlated.[126]

- In 2010, Brown and Hunnington employ a welfare-analytic approach to quantify the security externalities associated with increased oil use, which derive from the expected economic losses associated with potential disruptions in world oil supply.[127]

- In 2009, Blumel, Espinoza, and Domper used Chilean data to estimate the long run impact of increased electricity and energy prices on the nation's economy.[128]

- In 2008, in a study of the potential economic effects of peak oil, Kerschner and Hubacek reported significant correlations between energy and GDP – although they noted that sectoral impacts are more significant.[129]

- In 2008, Sparrow analyzed the impacts of coal utilization in Indiana, and estimated that electricity costs significantly affect economic growth in the state.[130]

In this section we:

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[124]Melike Bildirici, Frazil Kayikci, "Economic Growth and Electricity Consumption in Former Soviet Republics" IDEAS, Federal Reserve Bank of St. Louis, 2012; Melike Bildirici, Frazil Kayikci, "Economic Growth and Electricity Consumption in Former Soviet Republics," *Energy Economics*, Volume 34, Issue 3 (May 2012), pp. 747–753; "Economic Growth And Electricity Consumption In Emerging Countries Of Europa: An ARDL Analysis," *Economic Research - Ekonomska Istrazivanja*, Vol. 25, No. 3 (2013), pp 538-559.

[125]Chien-Chaing Lee and Jun-De Lee, "A Panel Data Analysis of the Demand for Total Energy and Electricity in OECD Countries," *The Energy Journal*, Vol. 31, No 1 (2010), pp. 1-23.

[126]Christiane Baumeister, Gert Peersman and Ine Van Robays, "The Economic Consequences of Oil Shocks: Differences Across Countries and Time," Ghent University, Belgium, 2010.

[127]Stephen P.A. Brown and Hillard G. Huntington, "Estimating U.S. Oil Security Premiums," Resources for the Future, Washington, D.C., June 2010.

[128]Gonzalo Blumel, Ricardo A. Espinoza, and G. M. de la Luz Domper, "Does Energy Cost Affect Long Run Economic Growth? Time Series Evidence Using Chilean Data," Instituto Libertad y Desarrollo Facultad de Ingenier´ıa, Universidad de los Andes, March 22, 2009.

[129]Christian Kerschnera and Klaus Hubacek, "Assessing the Suitability of Input-Output Analysis For Enhancing Our Understanding of Potential Economic Effects of Peak-Oil," Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK, 2008.

[130]F.T. Sparrow, Measuring the Contribution of Coal to Indiana's Economy," CCTR Briefing: Coal, Steel and the Industrial Economy, Hammond, Indiana, December 12, 2008.

- Review two comprehensive studies that provide guidance on methodology and data
- Summarize a large number of studies that quantified the elasticity of economic variables with respect to changes in energy and electricity prices

## II.H.1.  Estimating the Impact of Energy Prices on the Economy and Jobs

### Penn State Study

This study forecast the likely impacts of coal utilization for electricity generation on the economies of the 48 contiguous states in 2015.[131]  The authors first estimated the overall economic benefits associated with the availability of coal as a relatively low-cost fuel resource, including the increased economic output, earnings, and employment associated with projected coal utilization for electricity generation in 2015.  They also estimated the net economic impacts of displacing 33 percent and 66 percent of projected coal generation by alternative energy resources, taking into account the positive economic effects associated with alternative investments in oil, natural gas, nuclear, and renewable energy supplies.

The authors noted that, with a broad base and high level of technological advancement, the U.S. economy exhibits a great deal of interdependence.  Each business enterprise relies on many others for inputs into its production process and provides inputs to them in return.  This means that the coal and coal-based electric utility industries' contributions to the nation's economy extend beyond their own production to include demand arising from a succession of "upstream" inputs from their suppliers and "downstream" deliveries to their customers.  The economic value of these many rounds of derived demands and commodity allocations is some multiple of the value of direct production itself.

Thus, the coal and coal-based electric utility industries generate "multiplier" effects throughout the U.S. economy.  The first round of demand impacts is obvious — the direct inputs to electricity generation, including coal and primary factors (labor and capital).  Subsequent rounds, or indirect demands for goods and services used by the providers of these inputs, however, thread their way through the economy in subtle ways, eventually stimulating every other sector in some way.  Similarly, they generate income that is transformed into consumer spending on still more products.  All of this economic activity also generates local, state, and federal tax revenues, which, when spent by all three levels of government, creates still more multiplier effects.

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[131]Adam Rose and Dan Wei, *The Economic Impacts of Coal Utilization and Displacement in the Continental United States, 2015,* report prepared for the Center for Energy and Economic Development, Inc., Alexandria, Virginia, the Pennsylvania State University, July 2006.

A method of capturing the locational attractiveness of a good or service is not to claim the entirety of output of its direct and indirect users, but only an amount relating to the price advantage of the input over its competitors. In this study, the authors calculated a "price differential" between coal and alternative fuels in electricity production, and then estimated how much economic activity is attributable to this cost saving. For this purpose, they used an economy-wide elasticity of output with respect to energy prices that measures the percentage change in economic activity with respect to a 1.0 percent change in price. They analyzed a variety of sources of information to arrive at a value of 0.10, meaning that the availability of coal-fueled electricity at a price 10 percent lower than that of its nearest competitor is responsible for increasing total state or regional economic activity by 1.0 percent.

To assess the importance of coal to state and regional economies in 2015, the authors first estimated the level of coal-based electricity generation in each state in 2015 based on projections by EIA and EPA.[132] They evaluated coal-related impacts according to various assumptions embodied in their scenarios.[133]

Their set of scenarios estimated the positive impact on national and regional economic output, household income, and jobs attributable to the projected levels of coal-fueled electricity in 2015. These scenarios estimated the "existence" value of coal as the key fuel input into electricity generation in the U.S. The economic impacts of coal estimated in the study included two components: 1) the backward linkage, or demand-side multiplier, effects for coal-fueled electricity generation, and 2) the effects of the favorable price differential attributable to the relatively cheaper cost of coal-based electricity.

The authors first used IMPLAN input-output tables to estimate the direct and indirect (multiplier) economic output, household income, and jobs created by coal-fueled electricity generation in each state.[134] They then evaluated the impacts of the favorable price differential attributable to coal-based electricity. Essentially, they measured the economic activity attributable to relatively cheaper coal in contrast to what would take place if a state were dependent on more expensive alternatives, which they assumed would be a combination of oil, natural gas, renewable, and nuclear electricity. They conducted two calculations: 1) an upper-range ("high") price scenario, and 2) a lower-range ("low") price scenario. These two scenarios had the same backward linkages effects, but different price differential effects based on their different energy price assumptions. As noted, they estimated the impact of higher electricity prices on state economies using a price elasticity estimate of 0.10.

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[132]They also assumed that the technological structure of the economy, embodied in individual state input-output tables, would remain unchanged over the projection period to 2015.
[133]These are detailed in Appendix B of their report.
[134]They estimated only the minimum backward linkage effects for the "multiplier" effects. Their method excluded all forward linkages (all the production that uses coal-fueled electricity directly or indirectly) and focuses only on the factor inputs of coal-based electricity generation, such as fuel and electric generating equipment.

Finally, they assigned equal weight to each of the two price scenarios to obtain the average "existence" impacts of coal-fueled electricity generation in 2015. They then derived results for each state and region in 2015 that showed that coal, as the low-cost electricity generation option, has significant economic and job benefits and that displacing coal in the generation mix would have severe economic consequences. For example, the study estimated the average impacts of displacing 33 percent of coal-based generation in 2015 at:

- $166 billion (2005$) reduction in gross economic output
- $64 billion reduction of annual household incomes
- 1.2 million job losses

### National Coal Council Study

This study for the NCC estimated the economic impacts from coal Btu energy conversion, which affect all segments of the energy industry, including natural gas, crude oil, petroleum, and electricity.[135] An aggregate energy supply and demand framework was utilized, which distilled the effects down to a few key parameters, such as:

- The price elasticity of aggregate energy demand
- The elasticity of gross domestic product to energy price changes
- The output multipliers associated with energy output and plant construction

This study used estimates derived from the economic literature, and the scenarios discussed were aggregated into one key variable: The quantity of Btus delivered to energy consumers. This involved making assumptions about the size of Btu conversion plants and the thermal efficiencies of the conversion processes. Another key assumption involved timing. The actual adoption of these technologies in the marketplace depends upon how energy prices and energy conversion plant costs evolve over time.[136] A key premise of the study is that the additional energy production from coal conversion will lower equilibrium energy prices, and the extent of the price reduction from additional energy production from coal depends upon the slope of the demand curve as illustrated in Figure II-32.

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[135]Tim Considine, *Coal: America's Energy Future*, Volume II, "Appendix: Economic Benefits of Coal Conversion Investments," prepared for the National Coal Council, March 2006.
[136]The author avoided making assumptions about such specific factors and instead used a smooth extrapolation technique that attempts to model a process of steady and accelerating adoption of Btu energy conversion technologies over to the year 2025.

**Figure II-32**
**Impacts of Coal Conversion on Energy Supply and Prices**
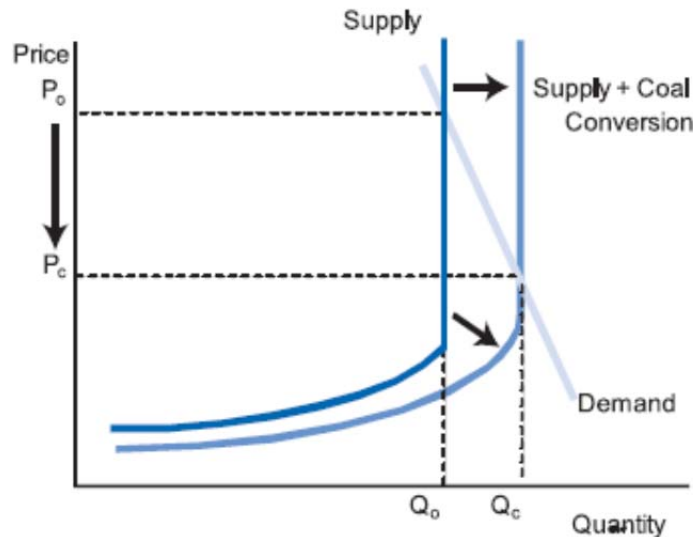


Source: Economic Analysis Conducted at Penn State University, 2006

Demand and supply relationships are characterized using elasticities. An own-price elasticity of demand is defined as the percentage change in quantity for a given percentage change in price, and its solution for the percentage change in price is as follows:

$$\varepsilon = \frac{\%\Delta Q}{\%\Delta P} \rightarrow \%\Delta P = \frac{\%\Delta Q}{\varepsilon}$$

The above equation provided a simple model for estimating the impacts of coal energy conversion on aggregate energy prices, and the author estimated the annual changes in quantities, which are the incremental supplies of energy products from coal conversion plants.

To compute the percentage change in quantity, the study used the long-term forecast of aggregate primary energy consumption produced by EIA. Own-price elasticities (the elasticity of demand with respect to the good's own price)[137] were utilized. This study adopted an intermediate value of -0.3, based on the peer-reviewed literature, which can be interpreted as an intermediate-run elasticity.

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[137]"Own" price elasticity of demand is a measure of the percentage change in the quantity demanded caused by a percentage change in price. Because the demand function is an inverse relationship between price and quantity, the coefficient of price elasticity will always be negative. This measure of elasticity is referred to as the own-price elasticity of demand for a good, i.e., the elasticity of demand with respect to the good's own price, in order to distinguish it from the elasticity of demand for that good with respect to the change in the price of some other good.

The study found that the resulting energy price reductions (from the EIA reference case) from coal conversion would be significant, ranging from .04 percent in 2010 to more than 33 percent in 2025. This implies lower prices for electricity, natural gas, petroleum products, and many other energy products.

The study noted that a smaller own-price elasticity of demand in absolute terms or a steeper demand schedule in Figure II-32 would imply even sharper reductions in energy prices from coal energy conversion. Similarly, a larger absolute value for the own-price elasticity would imply a smaller impact on energy prices. The study's elasticity estimate of -0.3 can thus be viewed as a reasonable compromise between these two extremes.

The study noted that these energy price reductions act like a tax cut for the economy, reducing the outflows of funds from energy consumers to foreign energy producers. In addition, the supply-side push from additional domestic energy production will directly increase the nation's economic output. Finally, the plant construction will stimulate the economy at local, regional, and national levels. The study found these combined effects to be significant: Total real 2004 dollar GDP gains by the year 2025 exceed $600 billion, and the discounted present value of these gains, assuming a real discount of three percent, exceeds $3 trillion.[138]

The author noted that, even though electricity costs vary from state to state, coal generated electricity is among the lowest-cost power produced in the U.S. – see the discussion below. The consumer cost-savings realized from using coal to generate electricity increase the disposable incomes of working families and, this income, when used to buy other goods and services, creates additional economic benefits.

## II.H.2. Elasticity Estimates in the Literature

Numerous studies have developed estimates of the elasticity of GDP with respect to energy and electricity prices.[139] Examples of these are summarized in Table II-6 and are discussed in more detail in Appendix III.

The meaning and interpretation of these elasticities are discussed below.

As indicated in Table II-6, three decades of rigorous research support elasticity estimates factors of about:

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[138]The study cautioned that these estimates should be considered only order of magnitude estimates given the wide range of uncertainty surrounding the coal energy conversion technology. In addition, such large-scale coal utilization could increase equilibrium prices for basic materials and services used to produce Btus from coal. To estimate these impacts, a general equilibrium model of energy markets and the economy would be needed.

[139]An elasticity of -0.1 implies that a 10 percent increase in the electricity price will result in a one percent decrease in GDP or – in the case of a state – Gross State Product (GSP). Thus, for example, in a state such as Arizona where GSP is currently about $270 billion, a 10 percent increase in the electricity price will (other things being equal) likely result in about a $3 billion decrease in Arizona GSP.

- -0.17 for oil,
- -0.13 for electricity,
- -0.14 for energy, and
- -0.15 for every energy-related study (all of the above).

The meaning and interpretation of these elasticities are discussed in Section II.H.3.

**Table II-6**
**Summary of Energy- and Electricity-GDP Elasticity Estimates**

| Year Analysis Published | Author | Elasticity Estimate |
|---|---|---|
| | | |
| 2010 | Lee and Lee (energy and electricity) | -0.01 and -0.19 |
| 2010 | Brown and Huntington (oil) | -0.01 to -0.08 |
| 2010 | Baumeister, Peersman, and Robays (oil) | -0.35 |
| 2009 | Blumel, Espinoza, and Domper (energy and electricity) | -0.085 to -0.16 |
| 2008 | Kerschner and Hubacek (oil) | -0.03 to -0.17 |
| 2008 | Sparrow (electricity) | -0.3 |
| 2007 | Maeda (energy) | -0.03 to -0.075 |
| 2007 | Citigroup (energy) | -0.3 to -0.37 |
| 2007 | Lescaroux (oil) | -0.1 to -0.6 |
| 2006 | Rose and Wei (electricity) | -0.1 |
| 2006 | Oxford Economic Forecasting (energy) | -0.03 to -0.07 |
| 2006 | Considine (electricity) | -0.3 |
| 2006 | Global Insight (energy) | -0.04 |
| 2004 | IEA (oil) | -0.08 to -0.13 |
| 2002 | Rose and Young (electricity) | -0.14 |
| 2002 | Klein and Kenny (electricity) | -0.06 to -0.13 |
| 2001 | Rose and Ranjan (electricity) | -0.14 |
| 2001 | Rose and Ranjan (energy) | -0.05 to -0.25 |
| 1999 | Brown and Yucel (oil) | -0.05 |
| 1996 | Hewson and Stamberg (electricity) | -0.14 |
| 1996 | Rotemberg and Woodford (energy) | -0.25 |
| 1996 | Gardner and Joutz (energy) | -0.072 |
| 1996 | Hooker (energy) | -0.07 to -0.29 |
| 1995 | Lee and Ratti (oil) | -0.14 |
| 1995 | Hewson and Stamberg (electricity) | -0.5 and -0.7 |
| 1982 | Anderson (electricity) | -0.14 |
| 1981 | Rasche and Tatom (energy) | -0.05 to -0.11 |

Source: Management Information Services, Inc.

## II.H.3.  The Impact of Electricity Price Increases on the Economy and Jobs

We summarized above some of the major studies that estimated the relationship between the economy and jobs, on the one hand, and the price of energy and electricity on the other, and Appendix III cites over 60 references to studies published over the past three decades.  These references pertain to studies published in peer-reviewed international professional and scientific journals, reports prepared by researchers at major universities and research institutes (such as the UK University of Leeds, the Colorado School of Mines, Citigroup Energy, Inc., Duke University, Pennsylvania State University, the National Science Foundation, the OECD, the Federal Reserve Bank, Statistics Norway, etc.), and papers presented at major international scientific conferences.

The sources cited include analyses of the economic and jobs effects of oil price increases, energy price increases, and electricity price increases in both developed and developing countries throughout the world.  This breadth of coverage strengthens the analysis and findings.

The research discussed here finds that virtually all economists who have analyzed the issue agree that there is a negative relationship between energy price changes and economic activity, but there are significant differences of opinion on the economic mechanisms through which price impacts are felt.  Estimates of the impacts of oil shocks and other energy price perturbations have produced different results, with smaller time-series econometric models producing energy price change-output elasticities of -2.5 percent to -11 percent, while large disaggregated macro models estimate much smaller impacts – in the range of -0.2 percent to -1.0 percent.

Nevertheless, the salient point is that the relationship between energy prices and the economy is negative:  Increases in energy and electricity prices harm the economy and decreases in energy and electricity prices benefit the economy.  This relationship is important because coal is currently the low-cost option for generating electricity and is forecast to remain so – as discussed below.  The mix of electric generating capacity – existing and new — among the various fossil, nuclear, and renewable sources will significantly affect electricity prices.  Estimates of the levelized cost of electricity (LCOE) of existing and, especially, new electricity generating technologies vary by orders of magnitude – see Figure II-33.  Nevertheless, it seems clear that coal is the least expensive, followed by natural gas.  New builds of nuclear and renewables are the most expensive and, among renewables, geothermal and biomass are the least expensive, followed by onshore wind, offshore wind, solar thermal, and PV.[140]  As shown in Figure II-34, there is a negative relationship between electricity prices and a state's use of coal to generate electricity:  The higher percentage of coal used to generate electricity, the lower the electricity rate.[141]

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[140]No new builds of large hydro are assumed here.
[141]This figure compares estimated current and retrofit power plant costs.

**Figure II-33**
**Levelized Costs of Electricity by Generation Sources**



1. All cost data from EIA 2010
2. Installed coal costs estimated from EIA projections for new generation less capital costs
3. Retrofit coal capital costs derived from Burns & McDonnell analysis December 2010

Source: Van Ness Feldman and Burns & McDonnell, 2011.
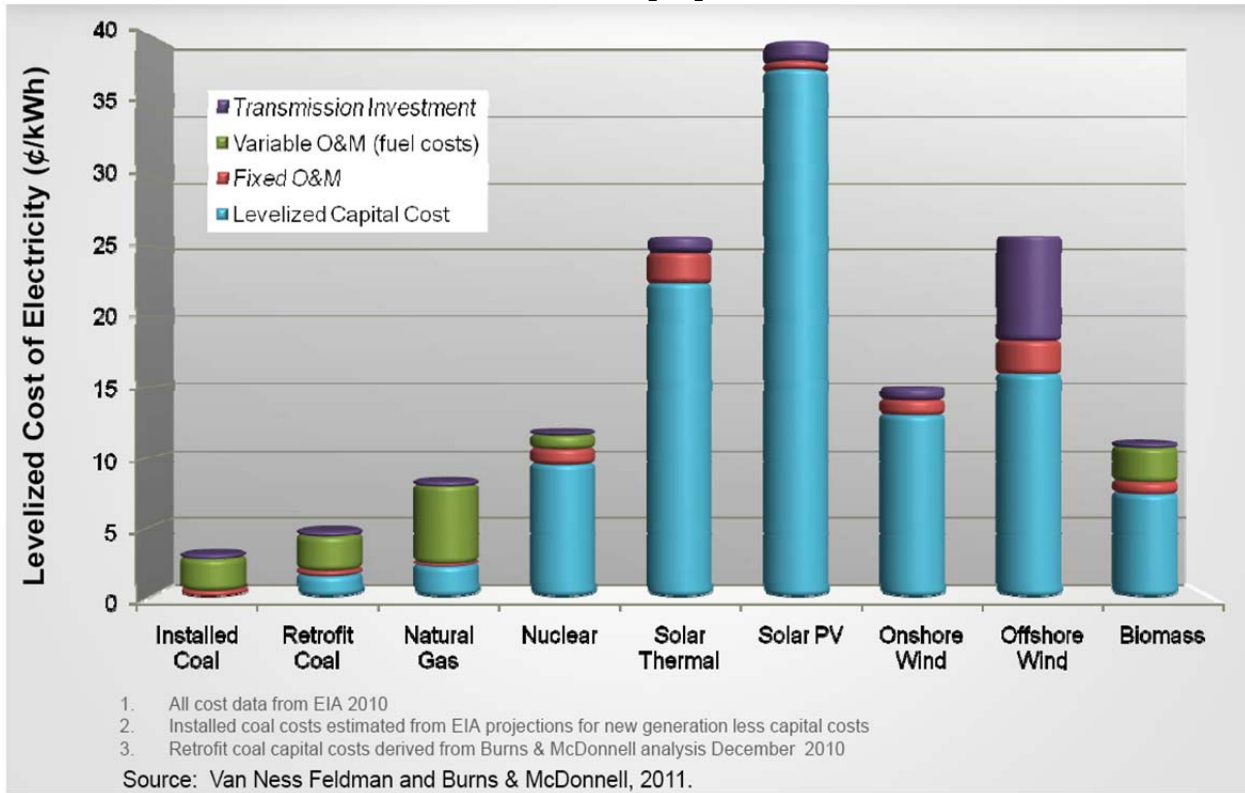
**Figure II-34**
**Relationship Between Coal Generation and Electricity Prices by State**
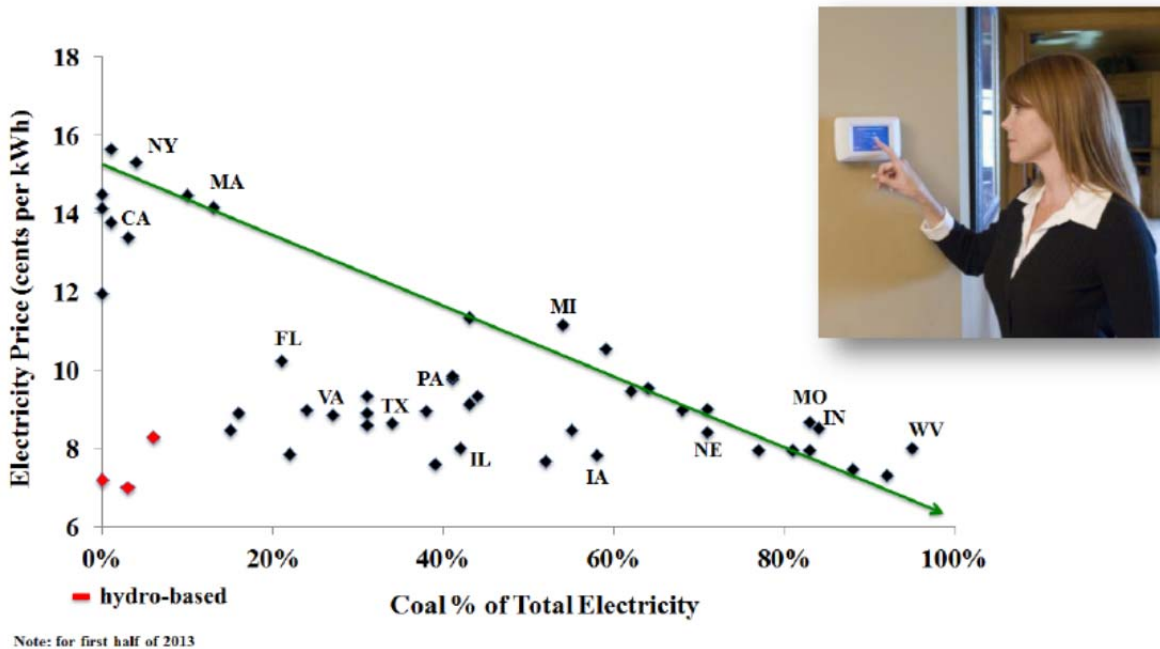


Note: for first half of 2013

Source: U.S. Energy Information Administration, *Electric Power Monthly*, August 2013.

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Thus, a large body of rigorous research conducted over the past three decades indicates that energy and electricity prices have significant economic and job impacts. All of these studies indicated that there is a negative correlation between energy and electricity prices and economic variables. That is, electricity price increases will harm the economy and jobs, whereas electricity price decreases will stimulate economic and job growth. Basically, energy price increases act like a tax increase on the economy, increasing the outflows of funds and reducing the incomes of energy consumers and ratepayers. In addition, the supply-side impacts from rate increases will depress business development and economic output. On the other hand, the consumer cost-savings realized from lower rates increase the disposable incomes of ratepayers and, this income, when used to buy other goods and services, creates additional economic benefits.

Energy costs have Keynesian economic effects similar to those of taxes:[142]

- Increased energy and utility costs act as a "hidden tax" that have deflationary, economically constrictive impacts; e.g., they decrease sales, GDP, jobs, etc.
- Conversely, decreased energy and utility costs have the effect of a "tax cut" & have economically stimulating effects by putting more money in the hands of consumers and businesses, thus increasing sales, creating jobs, etc.
- Like tax increases and decreases, changes in energy costs have both direct and indirect effects on the economy.

Programs and policies that increase electricity prices – in a city, state, region, or nation — over what they would be otherwise will have adverse effects on the economy and jobs. First, businesses currently located in the jurisdiction with the electricity price increase will face increased competitive disadvantages. Second, some businesses currently in the jurisdiction will leave. Third, new businesses will be discouraged from locating in the jurisdiction. Fourth, electric customers will have less money to spend on other things.

Review of the literature revealed a number of studies that estimated the energy price/GDP elasticities – Table II-6 and Appendix III. On the basis of this review and an analysis of studies conducted to estimate the impact on GDP of changes in energy prices, we determined that a reasonable electricity elasticity estimate is -0.1, which implies that a 10 percent increase in electricity prices will result in a one percent decrease in GDP. The reported elasticity estimates ranged between -0.85 and -0.01, and most were in the range of about -0.1. This elasticity estimate has been used in rigorous, scholarly studies of these issues, and it is the estimate we use in our research. As noted in the preceding section, a reasonable average estimate of this elasticity is about -0.13. In our work, we use a conservative value of -0.1 and, thus, if anything, we understate the impact of electricity price changes on the economy and jobs.

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[142]See Roger H. Bezdek, "Energy Costs: The Unseen Tax? A Case Study of Arizona," presented at the National Taxpayers Conference, Chandler, Arizona, October 2013.

An elasticity of -0.1 implies that a 10 percent increase in the electricity price will result in a one percent decrease in GDP or – in the case of a state – Gross State Product (GSP). Thus, for example, in a state such as Colorado where GSP is currently about $275 billion,[143] a 10 percent increase in the electricity price will (other things being equal) likely result in about a $2.75 billion decrease in Colorado GSP.

We do not imply here that this an exact estimate or that it implies a misleading level of precision. However, the overwhelming weight of scientific evidence shows that the relationship between electricity prices and the economy is negative; e.g., electricity price increases will harm the economy. And, as indicated, the metric of that relationship is not precise. While the elasticity used in our research, -0.1, is supported in the published literature and has been used by other researchers in related studies, the elasticity could be somewhat higher or lower – both in general and in specific jurisdictions. Thus, for example, in Colorado, the elasticity could range from -0.08 to -1.13. This would correspond to the estimates in the literature and would also support the -0.1 estimate used in the MISI research. Nevertheless, either of these alternative elasticity estimates would give only slightly different results. For example, if the elasticity is -0.08, then a 10 percent increase in electricity prices in Colorado would result in a decline of state GSP of about $2.2 billion. If the elasticity is -0.13, then a 10 percent increase in electricity prices in Colorado would result in a decline of state GSP of about $3.5 billion.[144]

Thus, while the direction of the relationship between electricity prices and GSP is clear, the precise quantification of this relationship is less than exact. That is why in discussing our research results we are careful to give ranges of estimates, to qualify the findings, and to avoid imputing a misleading level of precision to the estimates.[145]

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[143]U.S. Department of Commerce, Bureau of Economic Analysis, "GDP by State," 2013.

[144]See "Answering Testimony and Exhibits of Roger H. Bezdek on Behalf of the Colorado Mining Association in the Matter of Commission Consideration of Public Service Company of Colorado Plan in Compliance With House Bill 10-1365, 'Clean Air-Clean Jobs Act,'" before the Public Utilities Commission of the State of Colorado, Docket No. 10m-245e, September 17, 2010; Roger H. Bezdek, "Economic and Energy Impacts of Fuel Switching in Colorado," Presented at the 2010 North American Regional Science Association Meeting, Denver, Colorado, November 2010.

[145]This approach has withstood the intense scrutiny of contentious PUC Hearings in Colorado; see Ibid.

## III.  DIRECT CARBON BENEFITS[146]

Advances in technology and scientific expertise since the Industrial Revolution have led to vast improvements in agricultural yield and production values.  More efficient machinery and improved plant cultivars, for example, paved the way for higher crop yields and increased global food production.  And with the ever-increasing population of the planet, the increase in food production was a welcome societal benefit.  But what remained largely unknown to society at that time was the birth of an ancillary aid to agriculture that would confer great benefits upon future inhabitants of the globe throughout the decades and centuries to come.  The source of that aid is atmospheric carbon dioxide ($CO_2$).  Ironically, however, the modern rise of the air's $CO_2$ content is currently viewed by many as a source of concern, not a benefit.

Driven primarily by gaseous emissions produced from the burning of fossil fuels such as coal, natural gas and oil, the air's $CO_2$ content has risen steadily from a mean concentration of about 280 parts per million (ppm) at the onset of the Industrial Revolution in 1800 to a current value of approximately 400 ppm; and if current fuel consumption trends continue, the planet's atmospheric $CO_2$ concentration could reach upwards of 700 ppm by the end of this century.[147]  One of the more publicized potential consequences of this rise in the air's $CO_2$ content is the possibility of significant $CO_2$-induced global warming, which according to proponents of this hypothesis, constitutes the greatest environmental threat ever to be faced by the biosphere.  Predicting many adverse consequences for human health, ecosystems, and the world economy, its supporters contend that augmented atmospheric $CO_2$ concentrations will alter important energy transfer processes in the Earth-ocean-atmosphere system, leading to warmer global temperatures, devastating heat waves, melting of substantial portions of the polar ice caps, rising sea levels, crop-decimating droughts, and, potentially, a variety of other climate- and extreme-weather-related problems.

Against this backdrop of projected negative externalities, economists and policy makers have sought to estimate the monetary damages of rising atmospheric $CO_2$ – as discussed in Chapter IV.  These estimates, termed the social cost of carbon (SCC), have been used in evaluating the $CO_2$ impact of government rulemakings and are also used as justification for fostering rules and regulations aimed at reducing $CO_2$ emissions.  As discussed in Chapter I, the IWG produced a technical document "to allow agencies to incorporate the social benefits of reducing carbon dioxide ($CO_2$) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions".[148]

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[146]This chapter is based on the report by Craig Idso, "The Positive Externalities of Carbon Dioxide," Center for the Study of Carbon Dioxide and Global Change, 2013; © 2013, www.co2science.org, which was commissioned as a part of the current study.

[147]In May 2013, the Mauna Loa Observatory reported that atmospheric $CO_2$ had reached 400 ppm, although the Observatory later reported that the concentration in November 2013 was 395 ppm.  See co2now.org.

[148]Interagency Working Group on Social Cost of Carbon, 2013, op. cit.

However, largely absent from most SCC analyses is the incorporation of many important direct $CO_2$-induced benefits, such as improvements in human health and increases in crop production.[149] With respect to human health, studies have shown that the net effect of an increase in temperature is a reduction in sickness and death rate.[150] A warmer climate, therefore, is less expensive in terms of health care costs than a colder one. With respect to crop production, literally thousands of laboratory and field studies have documented growth-enhancing, water-conserving, and stress-alleviating benefits of atmospheric $CO_2$ enrichment on plants.[151] For a 300-ppm increase in the air's $CO_2$ content, such benefits typically enhance herbaceous plant biomass by around 30 to 35 percent, which represents an important positive externality entirely absent from current state-of-the-art SCC calculations.

Here we address this discrepancy by providing a quantitative estimate of the direct monetary benefits of atmospheric $CO_2$ enrichment on both historic and future crop production.[152] The incorporation of these estimates into future SCC studies will help to ensure a more realistic assessment of the total net economic impact of rising $CO_2$ concentrations due to both negative and positive externalities.

### III.A. How Increasing Atmospheric $CO_2$ Is a Biospheric Benefit

At a fundamental level, carbon dioxide is the basis of nearly all life on Earth. It is the primary raw material or "food" utilized by the vast majority of plants to produce the organic matter out of which they construct their tissues, which subsequently become the ultimate source of food for nearly all animals and humans. Consequently, the more $CO_2$ there is in the air, the better plants grow, as has been demonstrated in literally thousands of laboratory and field experiments.[153] And the better plants grow, the more food there is available to sustain the entire biosphere.

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[149]Few of the SCC analyses attempt to incorporate $CO_2$ benefits, and those that do fail to explain how these benefits are estimated; see the discussion in Chapter IV.

[150]See, for example, Christidis, N., Donaldson, G.C. and Stott, P.A., "Causes For the Recent Changes in Cold- and Heat-Related Mortality in England and Wales." *Climatic Change* 102: 539-553, 2013; Egondi, et al., "Time-Series Analysis of Weather and Mortality Patterns in Nairobi's Informal Settlements." *Global Health Action* 5: 23-31, 2012; Wichmann et al., "Apparent Temperature and Cause-Specific Mortality in Copenhagen, Denmark: A Case-Crossover Analysis." *International Journal Of Environmental Research And Public Health* 8: 3712-3727, 2011; Wanitschek, et al., "Warm Winter is Associated With Low Incidence of ST Elevation Myocardial Infarctions and Less Frequent Acute Coronary Angiographies in an Alpine Country. *Herz* 38: 163-170, 2013; Wu, et al. "Temperature-Mortality Relationship in Four Subtropical Chinese Cities: a Time-Series Study Using a Distributed Lag Non-Linear Model." *Science Of The Total Environment* 449: 355-362, 2013. Comprehensive discussion of the health benefits of increased $CO_2$ was outside the scope of the current analysis.

[151]C.D. Idso and Singer, S.F., *Climate Change Reconsidered: 2009 Report of the Nongovernmental International Panel on Climate Change (NIPCC)*. The Heartland Institute, Chicago, Illinois, USA, 2009; C.D. Idso and Idso, S.B., *The Many Benefits of Atmospheric $CO_2$ Enrichment*. Vales Lake Publishing, LLC, Pueblo West, Colorado, USA, 2011.

[152]Determining the net monetary effect of rising atmospheric $CO_2$ is beyond the scope of this analysis; see Section III.E.

[153]Idso and Singer, Ibid.

The idea that an increase in the air's $CO_2$ content may be of benefit to the biosphere can be traced back over 200 years. As early as 1804, for example, de Saussure showed that peas exposed to high $CO_2$ concentrations grew better than control plants in ambient air; and work conducted in the early 1900s significantly increased the number of species in which this growth-enhancing effect of atmospheric $CO_2$ enrichment was observed to occur.[154] In fact, by the time a group of scientists convened at Duke University in 1977 for a workshop on Anticipated Plant Responses to Global Carbon Dioxide Enrichment, an annotated bibliography of 590 scientific studies dealing with $CO_2$ effects on vegetation had been prepared.[155] This body of research demonstrated that increased levels of atmospheric $CO_2$ generally produce increases in plant photosynthesis, decreases in plant water loss by transpiration, increases in leaf area, and increases in plant branch and fruit numbers, to name but a few of the most commonly reported benefits. And five years later, at the International Conference on Rising Atmospheric Carbon Dioxide and Plant Productivity, it was concluded that a doubling of the air's $CO_2$ concentration would likely lead to a 50 percent increase in photosynthesis in $C_3$ plants, a doubling of water use efficiency in both $C_3$ and $C_4$ plants, significant increases in biological nitrogen fixation in almost all biological systems, and an increase in the ability of plants to adapt to a variety of environmental stresses.[156]

Numerous studies conducted on hundreds of different plant species testify to the very real and measurable growth-enhancing, water-saving, and stress-alleviating advantages that elevated atmospheric $CO_2$ concentrations have for Earth's plants.[157] In commenting on these and many other $CO_2$-related benefits, Wittwer wrote that "the 'green revolution' has coincided with the period of recorded rapid increase in concentration of atmospheric carbon dioxide, and it seems likely that some credit for the improved [crop] yields should be laid at the door of the $CO_2$ buildup."[158] Similarly, Allen et al. concluded that yields of soybeans may have been rising since at least 1800 "due to global carbon dioxide increases,"[159] while more recently, Cunniff et al. hypothesized that the rise in atmospheric $CO_2$ following deglaciation of the most recent planetary ice age, was the trigger that launched the global agricultural enterprise.[160]

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[154]E. Demoussy, "Sur, La Vegetation Dans Des Atmospheres Riches En Acide Carbonique." *Comptes Rendus Academy of Science Paris* 136: 325-328; 138: 291-293; 139: 883-885, 1902-1904; M.B. Cummings, and Jones, C.H., "*The Aerial Fertilization of Plants With Carbon Dioxide.*" Vermont Agricultural Station Bulletin No. 211, 1918.

[155]Strain, B.R., *Report of the Workshop on Anticipated Plant Responses to Global Carbon Dioxide Enrichment.* Department of Botany, Duke University, Durham, NC, 1978.

[156]E.R. Lemon, (Ed.), $CO_2$ *and Plants: The Response of Plants to Rising Levels of Atmospheric Carbon Dioxide.* Westview Press, Boulder, CO, 1983. $C_3$ plants are those in which photosynthesis takes place throughout the leaf; $C_4$ plants are those in which photosynthesis takes place in inner cells.

[157]Idso and Singer, op.cit.; Idso and Idso, op.cit.

[158]S.H. Wittwer, "Carbon Dioxide and Crop Productivity." *New Scientist* 95: 233-234, 1982.

[159]Allen et al. "Response of Vegetation to Rising Carbon Dioxide: Photosynthesis, Biomass, and Seed Yield of Soybean," *Global Biogeochemical Cycles* 1: 1-14, 1987.

[160]Cunniff et al., "Response of Wild $C_4$ Crop Progenitors to Subambient $CO_2$ Highlights a Possible Role In the Origin of Agriculture." *Global Change Biology* 14: 576-587, 2008.

In a test of this hypothesis, Cunniff et al. designed "a controlled environment experiment using five modern-day representatives of wild $C_4$ crop progenitors, all 'founder crops' from a variety of independent centers," which were grown individually in growth chambers maintained at atmospheric $CO_2$ concentrations of 180, 280 and 380 ppm, characteristic of glacial, post-glacial and modern times, respectively. The results revealed that the 100-ppm increase in $CO_2$ from glacial to postglacial levels (180 to 280 ppm) "caused a significant gain in vegetative biomass of up to 40 percent," together with "a reduction in the transpiration rate via decreases in stomatal conductance of ∼35 percent," which led to "a 70 percent increase in water use efficiency, and a much greater productivity potential in water-limited conditions."[161]

In discussing their results, the five researchers concluded that "these key physiological changes could have greatly enhanced the productivity of wild crop progenitors after deglaciation ... improving the productivity and survival of these wild $C_4$ crop progenitors in early agricultural systems."[162] And in this regard, they note that "the lowered water requirements of $C_4$ crop progenitors under increased $CO_2$ would have been particularly beneficial in the arid climatic regions where these plants were domesticated."[163] For comparative purposes, they also included one $C_3$ species in their study – *Hordeum spontaneum* K. Koch – and they report that it "showed a near-doubling in biomass compared with [the] 40 percent increase in the $C_4$ species under growth treatments equivalent to the postglacial $CO_2$ rise."[164] In light of these and other similar findings,[165] it can be appreciated that the civilizations of the past, which could not have existed without agriculture, were largely made possible by the increase in the air's $CO_2$ content that accompanied deglaciation, and that the peoples of the Earth today are likewise indebted to this phenomenon, as well as the additional 110 ppm of $CO_2$ the atmosphere has subsequently acquired. And as the $CO_2$ concentration of the air continues to rise in the future, this positive externality of enhanced crop production will benefit society in the years, decades, and centuries to come.

## III.B. Data Sets Utilized

In order to estimate the monetary benefit of rising atmospheric $CO_2$ concentrations on historic crop production, a number of different data sets were required. From the United Nations' Food and Agriculture Organization (FAO), annual global crop yield and production data were obtained, as well as the monetary value associated with that production.[166]

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[161]Ibid.

[162]Ibid.

[163]Ibid.

[164]Ibid.

[165]H.S. Mayeux et al., "Yield of Wheat Across a Subambient Carbon Dioxide Gradient." *Global Change Biology* 3: 269-278, 1997.

[166]FAO (Food And Agriculture Organization), FAO Statistics Database. FAO, Rome, Italy, 2012. These data sources are published in the FAO's statistical database FAOSTAT, which is available online at http://faostat.fao.org/site/567/default.aspx#ancor.

For the world as a whole, the FAO's statistical database (FAOSTAT) contains data on these agricultural parameters for over 160 different crops that have been grown and used since 1961. No data are available prior to that time, so the temporal scope of this analysis was limited to the 50-year time window of 1961-2011. In addition, because more than half of the crops in the database each account for less than 0.1 percent of the world's total food production, it was deemed both prudent and adequate to further constrain this analysis to focus on only those crops that accounted for the top 95 percent of global food production. This was accomplished by taking the average 1961-2011 production contribution of the most important crop, adding to that the contribution of the second most important crop, and continuing in like manner until 95 percent of the world's total food production was reached. The results of these procedures produced the list of 45 crops shown in Table III-1.

**Table III-1**
**The Forty-Five Crops That Supplied 95 Percent of**
**Total World Food Production Over the Period 1961-2011**

| Crop | % of Total Production | Crop | % of Total Production |
|---|---|---|---|
| Sugar cane | 20.492 | Rye | 0.556 |
| Wheat | 10.072 | Plantains | 0.528 |
| Maize | 9.971 | Yams | 0.523 |
| Rice, paddy | 9.715 | Groundnuts, with shell | 0.518 |
| Potatoes | 6.154 | Rapeseed | 0.494 |
| Sugar beet | 5.335 | Cucumbers and gherkins | 0.492 |
| Cassava | 3.040 | Mangoes, mangosteens, guavas | 0.406 |
| Barley | 2.989 | Sunflower seed | 0.398 |
| Vegetables fresh nes | 2.901 | Eggplants (aubergines) | 0.340 |
| Sweet potatoes | 2.638 | Beans, dry | 0.331 |
| Soybeans | 2.349 | Fruit Fresh Nes | 0.321 |
| Tomatoes | 1.571 | Carrots and turnips | 0.320 |
| Grapes | 1.260 | Other melons (inc.cantaloupes) | 0.302 |
| Sorghum | 1.255 | Chillies and peppers, green | 0.274 |
| Bananas | 1.052 | Tangerines, mandarins, clem. | 0.264 |
| Watermelons | 0.950 | Lettuce and chicory | 0.262 |
| Oranges | 0.935 | Pumpkins, squash and gourds | 0.248 |
| Cabbages and other brassicas | 0.903 | Pears | 0.243 |
| Apples | 0.886 | Olives | 0.241 |
| Coconuts | 0.843 | Pineapples | 0.230 |
| Oats | 0.810 | Fruit, tropical fresh nes | 0.230 |
| Onions, dry | 0.731 | Peas, dry | 0.228 |
| Millet | 0.593 | | |
| **Sum of All Crops = 95.2%** | | | |

Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

Other data needed to conduct the analysis included annual global atmospheric $CO_2$ values since 1961 and plant-specific $CO_2$ growth response factors. The annual global $CO_2$ data were obtained from the most recent United Nations Intergovernmental Panel on Climate Change report, *Annex II: Climate System Scenario Tables - Final Draft Underlying Scientific-Technical Assessment* (IPCC, 2013). The plant-specific $CO_2$ growth response factors – which represent the percent growth enhancement expected

for each crop listed in Table III-1 in response to a known rise in atmospheric $CO_2$ – were acquired from the online Plant Growth Database of $CO_2$ Science.[167]

The $CO_2$ Science Plant Growth Database lists the results of thousands of $CO_2$ enrichment experiments conducted on hundreds of different crops growing under varying environmental conditions over the past few decades.[168]  This database was used to estimate the mean crop growth response to a 300-ppm increase in atmospheric $CO_2$ concentration for each crop listed in Table III-1.  For some crops, however, there were no $CO_2$ enrichment data contained in the database, and in those cases the mean responses of similar plants, or groups of plants, were utilized.  Also, there were some instances where the plant category in the FAO database represented more than one plant in the *CO$_2$ Science* Plant Growth Database.  For example, the designation *Oranges* represents a single FAO crop category in the FAO database, yet there were two different types of oranges listed in the *CO$_2$ Science* database (*Citrus aurantium, and Citrus reticulata x C. paradisi x C. reticulata*).  Thus, in order to produce a single number to represent the $CO_2$-induced growth response for the *Oranges* category, a weighted average from the growth responses of both orange species listed in the *CO$_2$ Science* database was calculated.  This procedure was repeated in other such circumstances; and the final results for all crops are listed in Table III-2, which provides the average biomass response by FAO plant category for a 300-ppm increase in the air's $CO_2$ concentration for all 45 crops listed in Table III-1, which values are based upon data downloaded from the *CO$_2$ Science* Plant Growth Database on 1 October 2013.

## III.C.  Historical Monetary Benefit Estimates and Results

The first step in determining the monetary benefit of historical atmospheric $CO_2$ enrichment on historic crop production begins by calculating what portion of each crop's annual yield over the period 1961-2011 was due to each year's increase in atmospheric $CO_2$ concentration above the baseline value of 280 ppm that existed at the beginning of the Industrial Revolution.

Illustrating this process for wheat, in 1961 the global yield of wheat from the FAOSTAT database was 10,889 hectograms per hectare (Hg/Ha), the atmospheric $CO_2$ concentration was 317.4 ppm, representing an increase of 37.4 ppm above the 280-ppm baseline, while the $CO_2$ growth response factor for wheat as listed in Table III-2 is 34.9% for a 300-ppm increase in $CO_2$.  To determine the impact of the 37.4 ppm rise in atmospheric $CO_2$ on 1961 wheat yields, the wheat-specific $CO_2$ growth response factor of 34.9% per 300 ppm $CO_2$ increase (mathematically written as 34.9%/300 ppm) is multiplied by the 37.4 ppm increase in $CO_2$ that has occurred since the Industrial Revolution.  The resultant value of 4.35% indicates the degree by which the 1961 yield was enhanced above the baseline yield value corresponding to an atmospheric $CO_2$

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[167]Center for the Study of Carbon Dioxide and Global Change, *CO$_2$ Science Plant Growth Database*, Http://Www.Co2science.Org/Data/Plant_Growth/Plantgrowth.Php, 2013.
[168]http://www.co2science.org/data/plant_growth/plantgrowth.php.

concentration of 280 ppm.  The 1961 yield is then divided by this relative increase (1.0435) to determine the baseline yield in Hg/Ha (10,889/1.0435 = 10,435).  The resultant baseline yield amount of 10,435 Hg/Ha is subtracted from the 1961 yield total of 10,889 Hg/Ha, revealing that 454 Hg/Ha of the 1961 yield was due to the 37.4 ppm rise in $CO_2$ since the start of the Industrial Revolution.  Similar calculations are then made for each of the remaining years in the 50-year period, as well as for each of the 44 remaining crops accounting for 95% of global food production.

**Table III-2**
**Mean Percentage Yield Increases Produced by a 300-ppm**
**Increase in Atmospheric $CO_2$ Concentration For All Crops**
**Accounting For 95 Percent of Total Food Production**

| Crop | % Biomass Change | Crop | % Biomass Change |
|---|---|---|---|
| Sugar cane | 34.0% | Rye | 38.0% |
| Wheat | 34.9% | Plantains | 44.8% |
| Maize | 24.1% | Yams | 47.0% |
| Rice, paddy | 36.1% | Groundnuts, with shell | 47.0% |
| Potatoes | 31.3% | Rapeseed | 46.9% |
| Sugar beet | 65.7% | Cucumbers and gherkins | 44.8% |
| Cassava | 13.8% | Mangoes, mangosteens, guavas | 36.0% |
| Barley | 35.4% | Sunflower seed | 36.5% |
| Vegetables fresh nes | 41.1% | Eggplants (aubergines) | 41.0% |
| Sweet potatoes | 33.7% | Beans, dry | 61.7% |
| Soybeans | 45.5% | Fruit Fresh Nes | 72.3% |
| Tomatoes | 35.9% | Carrots and turnips | 77.8% |
| Grapes | 68.2% | Other melons (inc.cantaloupes) | 4.7% |
| Sorghum | 19.9% | Chillies and peppers, green | 41.1% |
| Bananas | 44.8% | Tangerines, mandarins, clem. | 29.5% |
| Watermelons | 41.5% | Lettuce and chicory | 18.5% |
| Oranges | 54.9% | Pumpkins, squash and gourds | 41.5% |
| Cabbages and other brassicas | 39.3% | Pears | 44.8% |
| Apples | 44.8% | Olives | 35.2% |
| Coconuts | 44.8% | Pineapples | 5.0% |
| Oats | 34.8% | Fruit, tropical fresh nes | 72.3% |
| Onions, dry | 20.0% | Peas, dry | 29.2% |
| Millet | 44.3% | | |

Source:  Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

The next step is to determine what *percentage* of the total annual yield of each crop in each year was due to $CO_2$.  This was accomplished by simply taking the results calculated in the previous step and dividing them by the corresponding total annual yields.  For example, using the calculations for wheat from above, the 454 Hg/Ha yield due to $CO_2$ in 1961 was divided by the total 10,889 Hg/Ha wheat yield for that year, revealing that 4.17% of the total wheat yield in 1961 was due to the historical rise in atmospheric $CO_2$.  Again, such percentage calculations were completed for all crops for each year in the 50-year period 1961-2011.

Knowing the annual percentage influences of $CO_2$ on all crop yields (production per Ha), the next step is to determine how that influence is manifested in total crop production value. This was accomplished by multiplying the $CO_2$-induced yield percentage increases by the corresponding annual production of each crop, and by then multiplying these data by the gross production value (in constant 2004-2006 U.S. dollars) of each crop per metric ton, the data for which were obtained from the FAOSTAT database. The end result of these calculations becomes an estimate of the annual monetary benefit of atmospheric $CO_2$ enrichment (above the baseline of 280 ppm) on crop production since 1961. These monetary values are presented for each of the 45 crops under examination in Table III-3.

## Table III-3
## The Total Monetary Benefit of Earth's Rising Atmospheric $CO_2$ Concentration
## on Each of the 45 Crops Listed in Table III-1 For the 1961-2011
(Values in Constant 2004-2006 U.S. Dollars)

| Crop | Production Rank | Monetary Benefit of $CO_2$ | Crop | Production Rank | Monetary Benefit of $CO_2$ |
|---|---|---|---|---|---|
| Rice, paddy | 4 | $579,013,089,273 | Carrots and turnips | 35 | $36,439,812,318 |
| Wheat | 2 | $274,751,908,146 | Cucumbers and gherkins | 29 | $33,698,222,461 |
| Grapes | 13 | $270,993,488,618 | Watermelons | 16 | $32,553,055,795 |
| Maize | 3 | $182,372,524,324 | Pears | 41 | $31,577,067,767 |
| Soybeans | 11 | $148,757,417,756 | Fruit Fresh Nes | 34 | $29,182,817,600 |
| Potatoes | 5 | $147,862,516,739 | Fruit, tropical fresh nes | 44 | $28,837,991,342 |
| Vegetables fresh nes | 9 | $143,295,147,644 | Millet | 23 | $24,748,422,190 |
| Tomatoes | 12 | $140,893,704,588 | Eggplants (aubergines) | 32 | $22,794,746,004 |
| Sugar cane | 1 | $107,420,713,630 | Cassava | 7 | $21,850,017,436 |
| Apples | 19 | $98,329,393,797 | Onions, dry | 22 | $20,793,394,925 |
| Sugar beet | 6 | $69,247,223,819 | Sorghum | 14 | $20,579,850,257 |
| Barley | 8 | $63,046,887,462 | Tangerines, mandarins, clem. | 38 | $18,822,174,419 |
| Bananas | 15 | $58,264,644,460 | Coconuts | 20 | $17,949,253,896 |
| Yams | 26 | $56,163,446,226 | Sunflower seed | 31 | $17,585,395,685 |
| Groundnuts, with shell | 27 | $51,076,843,461 | Plantains | 25 | $17,384,141,669 |
| Olives | 42 | $50,604,186,875 | Lettuce and chicory | 39 | $15,029,691,577 |
| Oranges | 17 | $50,173,178,154 | Pumpkins, squash and gourds | 40 | $13,140,422,653 |
| Beans, dry | 33 | $47,240,266,167 | Oats | 21 | $12,615,396,815 |
| Mangoes, mangosteens, guavas | 30 | $40,731,776,757 | Rye | 24 | $8,981,587,998 |
| Sweet potatoes | 10 | $39,889,080,598 | Peas, dry | 45 | $5,667,935,087 |
| Chillies and peppers, green | 37 | $39,813,008,532 | Other melons (inc.cantaloupes) | 36 | $2,477,799,109 |
| Rapeseed | 28 | $38,121,172,234 | Pineapples | 43 | $1,779,091,848 |
| Cabbages and other brassicas | 18 | $37,501,047,431 | Sum of all crops = $3,170,050,955,544 | | |

Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

As can be seen from Table III-3, the financial benefit of Earth's rising atmospheric $CO_2$ concentration on global food production is enormous. Such benefits over the period 1961-2011 have amounted to at least $1 billion for each of the 45 crops examined; and for nine of the crops the monetary increase due to $CO_2$ over this period is well over $100 billion. The largest of these benefits is noted for rice, wheat and grapes, which saw increases of $579 billion, $274 billion and $270 billion, respectively.

Another interesting aspect of these calculations can be seen in Figure III-1, which shows the annual total monetary value of the $CO_2$ benefit for all 45 crops over the 50-year period 1961-2011. As seen there, the annual value of the $CO_2$ benefit has increased over time. Whereas it amounted to approximately $18.5 billion in 1961, by 2011 it had grown to over $140 billion annually. In summing these annual benefits across the entire 50-year time period, the total $CO_2$-induced benefit on global food production since 1961 amounts to $3.2 trillion.

**Figure III-1**
**Total Annual Monetary Value of the**
**Direct $CO_2$ Benefit on Crop Production, 1961-2011**
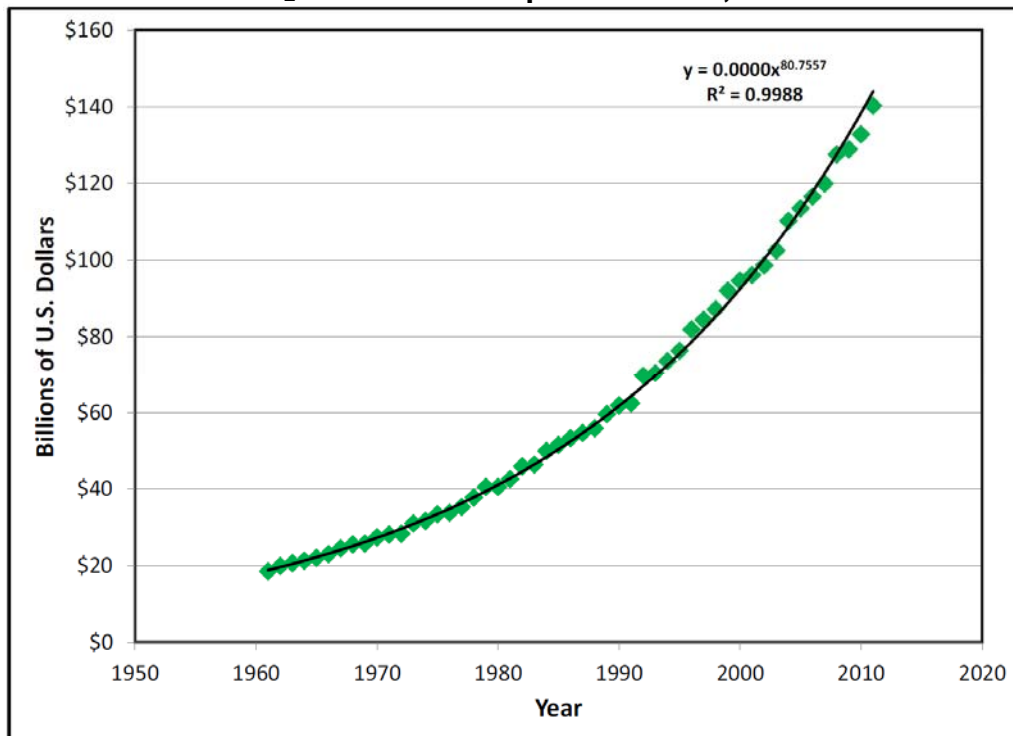


Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

## III.D. Future Monetary Benefit Estimates and Results

The methods of estimating future monetary benefits of rising atmospheric $CO_2$ concentrations on crop production were slightly different from those used in calculating the historic values of the previous section. In explaining these methods, sugar cane will serve as the example.

First, the 1961-2011 historic yield data for sugar cane are plotted as the solid blue line in Figure III-2. Next, that portion of each year's annual yield that was due to rising carbon dioxide, as per calculations described in the prior section (the solid green line), was subtracted out. The resultant values are depicted as the solid red line in

Figure III-2.  These yield values represent the net effect of everything else that tended to influence crop yield over that time period.  Although many factors play a role in determining the magnitude of this latter effect, it is referred to here as the *techno-intel effect*, as it derives primarily from continuing advancements in agricultural technology and scientific research that expand our knowledge or intelligence base.

**Figure III-2**
**Plot of the Total Yield of Sugar Cane, 1961-2011 (blue line), Along With Plots of That Portion of the Total Yield Attributed to Advances in Agricultural Technology and Scientific Research (Techno-Intel Effect, red line) and Productivity Increases From Rising Atmospheric $CO_2$ Concentrations (green line)**
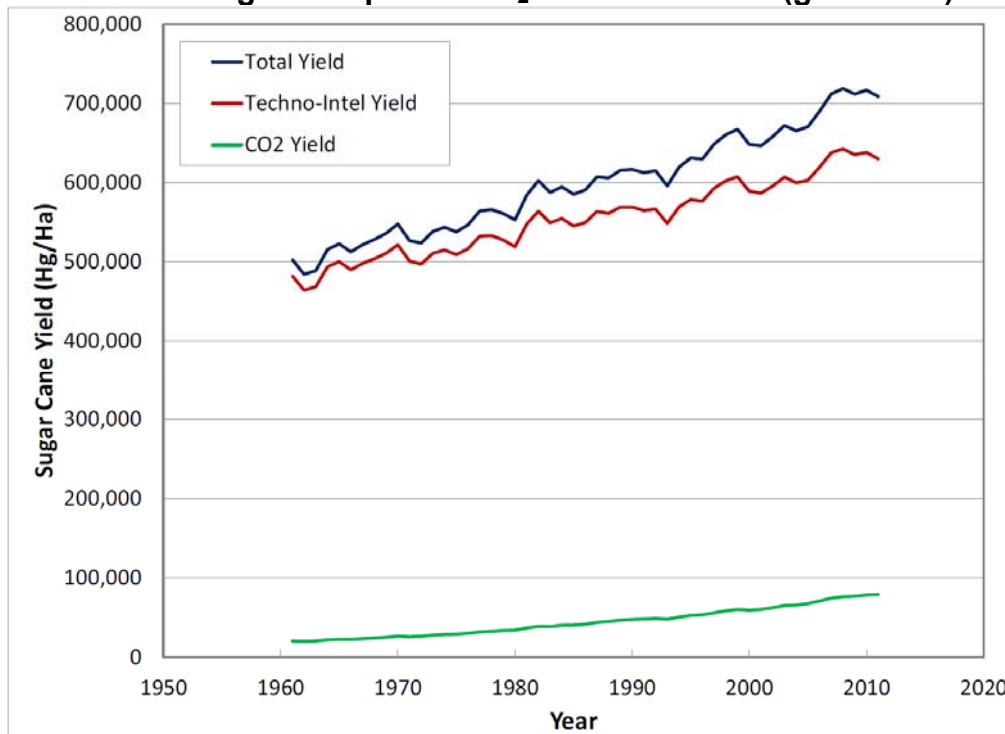


Source:  Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

The difference between the techno-intel line and the observed yield line above it represents the annual yield contribution due to rising atmospheric $CO_2$, which difference is also plotted in Figure III-2 as the green line.  As depicted there, the relative influence of atmospheric $CO_2$ on the total yield of sugar cane is increasing with time.  This fact is further borne out in Figure III-3, where techno-intel yield values are plotted as a percentage of total sugar cane yield.  Whereas the influence of technology and intelligence accounted for approximately 96 percent of the observed yield values in the early 1960s, by the end of record in 2011 it accounted for only 89 percent.[169]

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[169]The methodology utilized here has been reviewed and validated by independent researchers.

Focusing on the future, the 1961-2011 linear trend of the techno-intel yield line is next projected forward to the year 2050.  Depicted as the dashed red line in Figure III-4, this line represents the best estimate that can be made of the effect of technology and innovation on future sugar cane crop yields.  Following this step, a second-order polynomial has been fitted to the data depicted in Figure III-3, and this relationship is projected forward in time (Figure III-5) to obtain an estimate of the annual contribution of the techno-intel effect on the total yield through 2050.  Next, the total yield for each year between 2012 and 2050 can be calculated by dividing the linear projection of the techno-intel line in Figure III-4 (dashed red line) by the corresponding yearly forecasted percentage contribution of the techo-intel line to the total yield, as depicted by the polynomial projection fit to the data and extended through 2050 in Figure III-5.  These resultant values, plotted in Figure III-4 as the dashed blue line, provide an estimate of the total annual crop yield from 2012 through 2050.  By knowing the annual total yield, as well as the portion of the annual total yield that is due to the techno-intel effect between 2012 and 2050, the part of the total yield that is due to $CO_2$ can be calculated by subtracting the difference between them.  These values are also plotted in Figure III-4 as the dashed green line.

**Figure III-3**
**The Percentage of the Total Annual Yield of Sugar Cane**
**1961-2011 That Is Attributed to the Techno-Intel Effect**
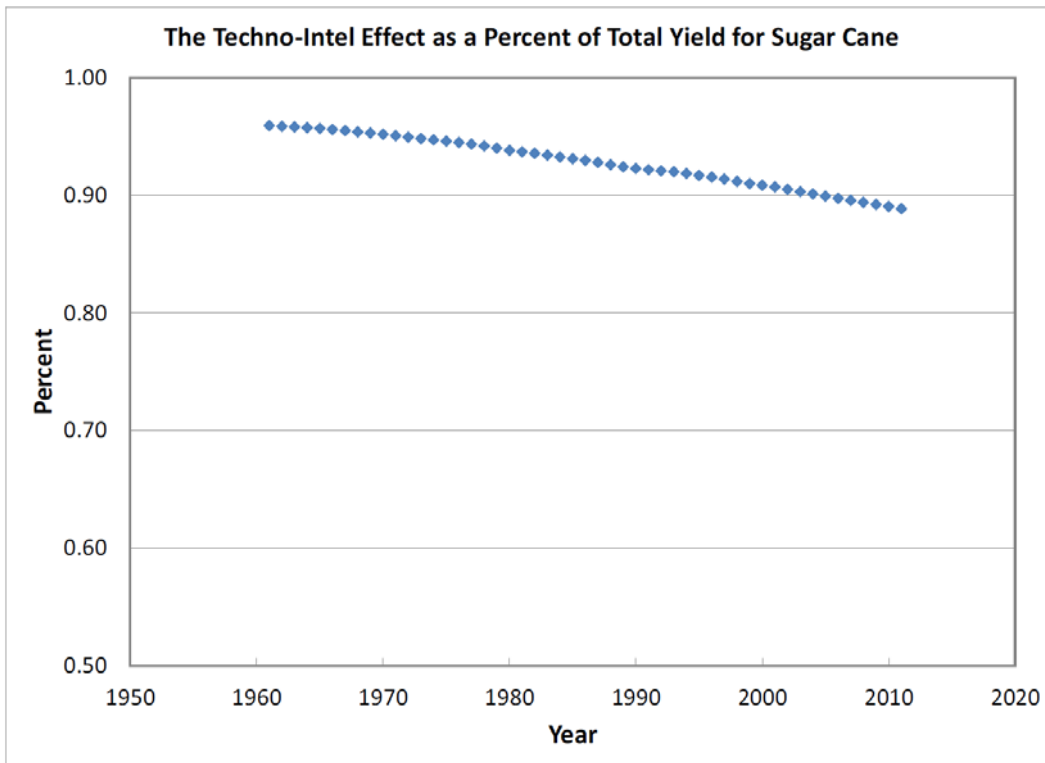


Source:  Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

In order to apply the future estimates of the $CO_2$ influence on crop yields to future estimates of crop production, linear trends in each of the 45 crops' 1961-2011 production data were extended forward in time to provide projections of annual production values through 2050. As with the historical calculations discussed in the previous section, these production values were multiplied by the corresponding annual percentage influence of $CO_2$ on 2012-2050 projected crop yields. The resultant values were then multiplied by an estimated gross production value (in constant 2004-2006 U.S. dollars) for each crop per metric ton. And as there are several potential unknowns that may influence the future production value assigned to each crop, a simple 50-year average of the observed gross production values was applied over the period 1961-2011. The ensuing monetary values for each of the 45 crops over the 2012 through 2050 period are listed in Table III-4.

**Figure III-4**
**Same as Figure III-2, but With the Added Projections of the Total Yield and the Portion of the Total Yield Due to the Techno-Intel and $CO_2$ Effects Estimated For the Period 2012-2050 (Dashed Blue, Red, and Green Lines, Respectively).**
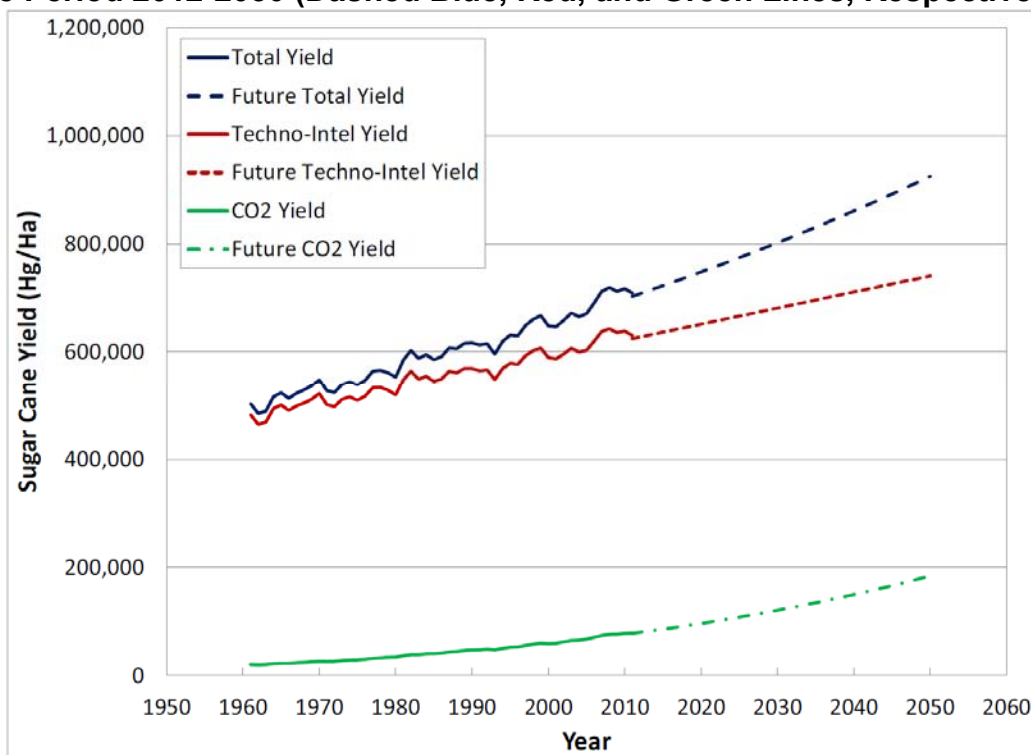


Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

The results of the above set of calculations once again reveal a very substantial financial benefit resulting from the effect of Earth's rising atmospheric $CO_2$ concentration on global food production. Over the period 2012 through 2050, the projected benefit amounts to $9.8 trillion, which is much larger than the $3.2 trillion that was observed in the longer 50-year historic period of 1961-2011.

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**Figure III-5**
**Same as Figure III-3, But With a Second Order Polynomial Equation Fit
to the 1961-2011 Data, Projecting the Data Forward Through 2050**
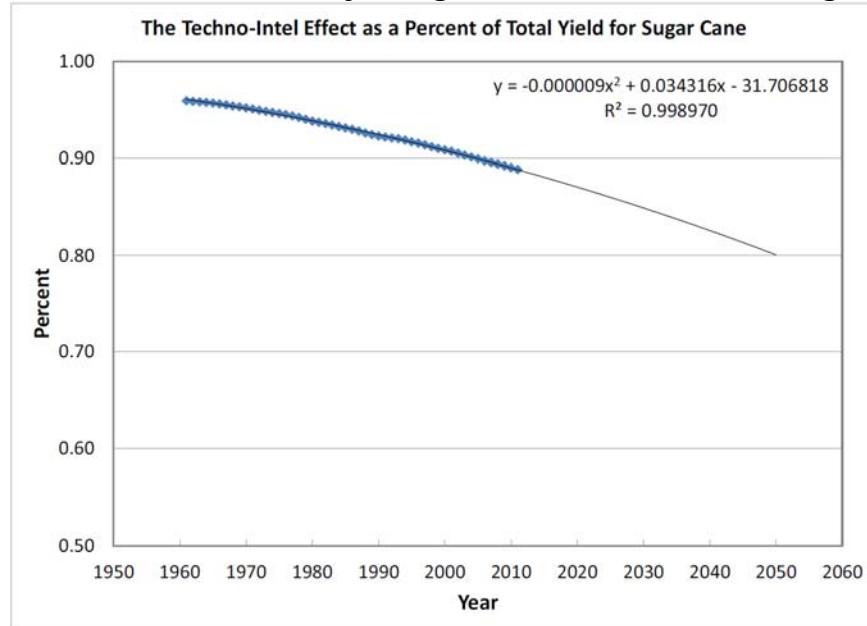


Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

**Table III-4**
**The Total Monetary Benefit of Earth's Rising Atmospheric $CO_2$ Concentration on
Each of the Forty-Five Crops Listed in Table III-1 For the Period 2012-2050**
(Values in Constant 2004-2006 U.S. Dollars)

| Crop | Production Rank | Monetary Benefit of $CO_2$ | Crop | Production Rank | Monetary Benefit of $CO_2$ |
|---|---|---|---|---|---|
| Rice, paddy | 4 | $1,847,162,847,355 | Beans, dry | 33 | $121,672,752,990 |
| Wheat | 2 | $731,810,134,138 | Eggplants (aubergines) | 32 | $121,040,127,404 |
| Soybeans | 11 | $622,840,779,401 | Sugar beet | 6 | $118,016,992,389 |
| Vegetables fresh nes | 9 | $603,158,136,300 | Pears | 41 | $106,648,093,649 |
| Maize | 3 | $582,352,695,047 | Fruit Fresh Nes | 34 | $96,939,989,779 |
| Tomatoes | 12 | $538,622,004,026 | Tangerines, mandarins, clem. | 38 | $94,049,613,976 |
| Grapes | 13 | $507,943,670,190 | Fruit, tropical fresh nes | 44 | $92,676,868,053 |
| Sugar cane | 1 | $366,333,858,080 | Onions, dry | 22 | $83,094,062,469 |
| Apples | 19 | $306,866,752,703 | Sweet potatoes | 10 | $70,623,018,596 |
| Potatoes | 5 | $268,944,859,065 | Cassava | 7 | $66,454,408,155 |
| Yams | 26 | $206,504,638,016 | Pumpkins, squash and gourds | 40 | $65,141,087,416 |
| Bananas | 15 | $200,878,216,972 | Lettuce and chicory | 39 | $54,406,821,316 |
| Rapeseed | 28 | $176,560,583,707 | Coconuts | 20 | $52,278,524,212 |
| Cucumbers and gherkins | 29 | $165,126,686,871 | Sunflower seed | 31 | $50,554,512,301 |
| Oranges | 17 | $165,014,960,801 | Plantains | 25 | $45,996,854,219 |
| Chillies and peppers, green | 37 | $162,527,401,900 | Millet | 23 | $43,337,359,355 |
| Olives | 42 | $157,323,187,194 | Sorghum | 14 | $38,314,226,074 |
| Groundnuts, with shell | 27 | $148,440,689,387 | Other melons (inc.cantaloupes) | 36 | $11,163,081,357 |
| Watermelons | 16 | $144,909,503,686 | Peas, dry | 45 | $10,484,435,272 |
| Barley | 8 | $127,842,645,165 | Pineapples | 43 | $6,926,670,057 |
| Carrots and turnips | 35 | $126,282,174,308 | Rye | 24 | $5,804,121,850 |
| Mangoes, mangosteens, guavas | 30 | $124,067,842,115 | Oats | 21 | $4,904,374,119 |
| Cabbages and other brassicas | 18 | $122,664,616,192 | | Sum of all crops = | $9,764,706,877,630 |

Source: Craig Idso, "The Positive Externalities of Carbon Dioxide," 2013.

**III.E.  Future CO₂ Benefits or Damages:  Which is More Likely to Occur?**

Although determining the net monetary effect of rising atmospheric $CO_2$ is beyond the scope of this analysis, some general comments can be made with respect to the likelihood of damages or benefits occurring as a result of higher $CO_2$ concentrations in the future.

With respect to damages, as discussed in Chapter IV, it is important to note that all SCC studies rely heavily on computer model projections of future climate and climate-related indices.  Analyses of such state-of-the-art models, however, have consistently revealed multiple problems in their abilities to accurately represent and simulate reality.[170]  Spencer, for example, has highlighted an important model vs. observation discrepancy that exists for temperatures in the tropical troposphere.[171]  In written testimony before the U.S. Environment and Public Works Committee, he noted that the magnitude of global-average atmospheric warming between 1979 and 2012 is only about 50 percent of that predicted by the climate models.  He also reported that the temperature trend over the most recent 15-year period was not significantly different from zero (meaning that there has been no temperature rise), despite this being the period of greatest greenhouse gas concentration increase.  Lastly, he notes that the level of observed tropical atmospheric warming since 1979 is dramatically below that predicted by climate models.  With respect to this last point, Spencer's graph of mid-tropospheric temperature variations for the tropics (20°N to 20°S) in 73 current (CMIP5) climate models versus measurements made from two satellite and four weather balloon datasets is plotted here as Figure III-6.

The level of disagreement between the models and observations of tropical mid-tropospheric temperatures in Figure III-6 is quite striking.  It reveals, for example, that the models' projected average values are 0.5°C higher than observations at the end of the record.  Although these data are restricted to the tropics (from 20°N to 20°S), Spencer notes that "this is where almost 50 percent of the solar energy absorbed by the Earth enters the climate system."

The sensitivity of temperature to carbon dioxide, which is the amount of total warming for a nominal doubling of atmospheric carbon dioxide, is the core parameter that ultimately drives climate model temperature projections.  The magnitude of this parameter used in the models is likely the reason for their overestimation of recent (and likely future) projections of temperature observations.  Although most models incorporate a mean sensitivity of 3.4°C (range of 2.1 to 4.7°C), several recent studies indicate the true sensitivity is much lower.[172]  Until such problems are resolved, SCC

[170]A. Lupo and Kininmonth, W., "Global Climate Models and Their Limitations."  In: *Climate Change Reconsidered II: Physical Science.*  C.D. Idso, R.M. Carter And S.F. Singer, (Eds.). Chicago, IL: The Heartland Institute, 2013.

[171]R.W. Spencer, "Statement to the Environment and Public Works Committee," 19 July 2013, Washington, DC.

[172]Annan, J.D. and Hargreaves, J.D., "On the Generation and Interpretation of Probabilistic Estimates of Climate Sensitivity."  *Climatic Change* 104: 324-436, 2011; R.S. Lindzen and Choi, Y.-S., "On the Observational Determination of Climate Sensitivity and Its Implications*." Asia-Pacific Journal of*

damage estimates relying on future temperature projections should be considered to be significantly inflated.

**Figure III-6**
**Mid-tropospheric Temperature Variations For the Tropics (20°N To 20°S)**
**in 73 Current (CMIP5) Climate Models Versus Measurements From**
**Two Satellite Datasets and Four Weather Balloon Datasets**
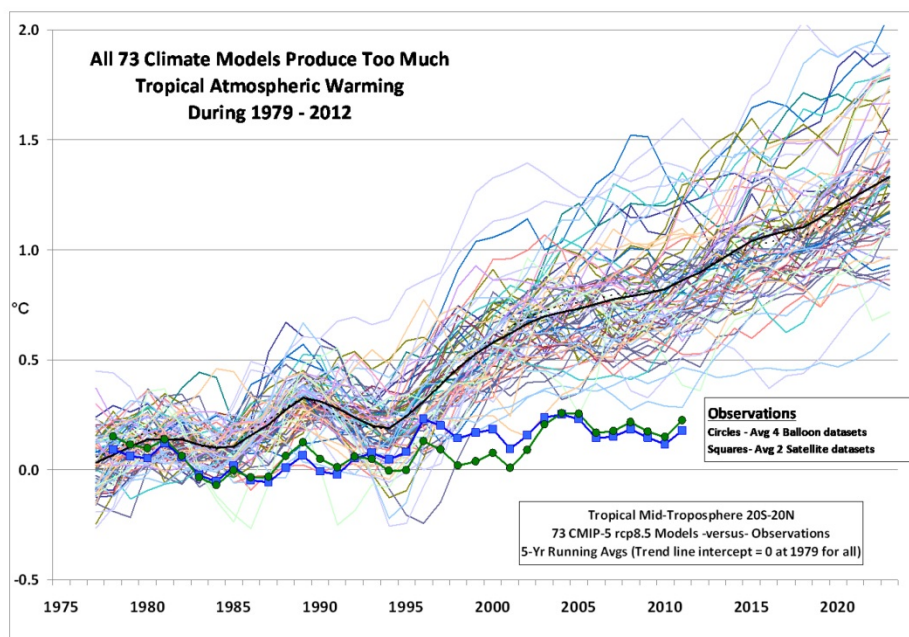


Source: Spencer, 2013.

In concluding his discussion of the topic, Spencer states "It is time for scientists to entertain the possibility that there is something wrong with the assumptions built into their climate models. The fact that all of the models have been peer reviewed does not mean that any of them have been deemed to have any skill for predicting future

*Atmospheric Science* 47: 377-390, 2011; A. Schmittner et al., "Climate Sensitivity Estimated From Temperature Reconstructions of the Last Glacial Maximum." *Science* 334: 1385-1388, 2011; Holden M. Aldrin et al., "Bayesian Estimation of Climate Sensitivity Based on a Simple Climate Model Fitted To Observations of Hemispheric Temperature and Global Ocean Heat Content," *Environmetrics* 23: 253-271, 2012; J.C. Hargreaves et al., "Can The Last Glacial Maximum Constrain Climate Sensitivity?" *Geophysical Research Letters* 39: L24702, Doi: 10.1029/ 2012GL053872, 2012; M.J. Ring et al., "Causes of the Global Warming Observed Since the 19th Century." *Atmospheric And Climate Sciences* 2: 401-415, 2012; J.H. Van Hateren, "A Fractal Climate Response Function Can Simulate Global Average Temperature Trends of the Modern Era and the Past Millennium." *Climate Dynamics,* Doi: 10.1007/S00382-012-1375-3, 2012; Lewis, N., "An Objective Bayesian, Improved Approach For Applying Optimal Fingerprint Techniques to Estimate Climate Sensitivity." *Journal Of Climate*, Doi: 10.1175/JCLI-D-12-00473.1, 2013; Masters, T., "Observational Estimates of Climate Sensitivity From Changes in the Rate of Ocean Heat Uptake and Comparison to CMIP5 Models. *Climate Dynamics*, Doi:101007/S00382-013-1770-4, 2013; A. Otto et al., "Energy Budget Constraints on Climate Response." *Nature Geoscience* 6, 415-416, 2013.

temperatures. In the parlance of the Daubert standard for rules of scientific evidence, the models have not been successfully field tested for predicting climate change, and so far their error rate should preclude their use for predicting future climate change."[173]

A somewhat related problem with SCC calculations is their inclusion of costs due to sea level rise. Here, it is presumed that rising temperatures from $CO_2$-induced global warming will result in an acceleration of sea level rise that will result in a host of economic damages. There are two problems with this projection. First, temperatures are not rising in the manner or degree projected by the models. Second, observations reveal no acceleration of sea level rise over the past century. In fact, just the opposite appears to be occurring. For example, Holgate derived a mean global sea level history over the period 1904-2003.[174] According to his calculations, the mean rate of global sea level rise was "larger in the early part of the last century (2.03 ± 0.35 mm/year 1904-1953), in comparison with the latter part (1.45 ± 0.34 mm/year 1954-2003)." In other words, contrary to model projections, the mean rate of global sea level rise (SLR) has not accelerated over the recent past. If anything, it has done just the opposite. Such observations are striking, especially considering they have occurred over a period of time when many have claimed that (1) the Earth warmed to a degree that is unprecedented over many millennia, (2) the warming resulted in a net accelerated melting of the vast majority of the world's mountain glaciers and polar ice caps, and (3) global sea level rose at an ever increasing rate.

In another paper, Boretti applied simple statistics to the two decades of information contained in the TOPEX and Jason series of satellite radar altimeter data to "better understand if the SLR is accelerating, stable or decelerating." In doing so, the Australian scientist reports that the rate of SLR is reducing over the measurement period at a rate of -0.11637 $mm/year^2$, and that this *de*celeration is *also* "reducing" at a rate of -0.078792 $mm/year^3$ — Figure III-7.[175] In light of such observations, Boretti concludes that the huge deceleration of SLR over the last 10 years "is clearly the opposite of what is being predicted by the models," and that "the SLR's reduction is even more pronounced during the last 5 years."[176] To further illustrate the importance of his findings, he notes that "in order for the prediction of a 100-cm increase in sea level by 2100 to be correct, the SLR must be almost 11 mm/year every year for the next 89 years," but he notes that "since the SLR is dropping, the predictions become increasingly unlikely," especially in view of the facts that (1) "not once in the past 20 years has the SLR of 11 mm/year ever been achieved," and that (2) "the average SLR of 3.1640 mm/year is only 20 percent of the SLR needed for the prediction of a one meter rise to be correct."[177]

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[173]B.E. Harlow, and Spencer, R.W., "An Inconvenient Burden of Proof? $CO_2$ Nuisance Plaintiffs Will Face Challenges in Meeting the Daubert Standard." *Energy Law Journal* 32: 459-496, 2011.
[174]Holgate, S.J., "On The Decadal Rates of Sea Level Change During the Twentieth Century." *Geophysical Research Letters* 34: 10.1029/2006GL028492, 2007.
[175]Boretti, A.A., "Short Term Comparison of Climate Model Predictions and Satellite Altimeter Measurements of Sea Levels." *Coastal Engineering* 60: 319-322, 2012.
[176]Ibid.
[177]Ibid.

The real world, data-based results of Holgate and Boretti, as well as those of other researchers, all suggest that rising atmospheric $CO_2$ emissions are exerting no discernible influence on the rate of sea level rise.[178]  Clearly, SCC damages that are based on model projections of a $CO_2$-induced acceleration of SLR must be considered inflated and unreliable.

**Figure III-7**
**Comparison of Mean Sea Level (MSL) Predictions From Rahmstorf (2007) With Measurements From the TOPEX and Jason Series***
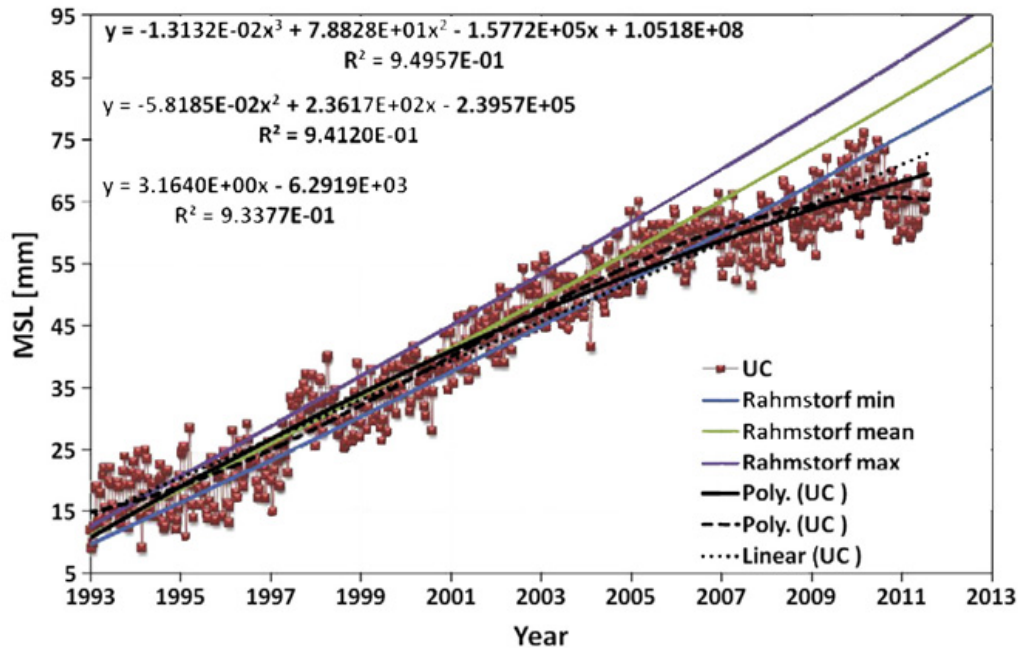


***Adapted from Boretti (2012) who states in the figure caption that "the model predictions [of Rahmstorf (2007)] clearly do not agree with the experimental evidence in the short term."

Additional observations apply to other model-based projections of economic damages resulting from various climate- and extreme weather-related maladies.  As reported in the most recent assessment of the Nongovernmental International Panel on Climate Change, in almost all instances model projections of climate and climate-related catastrophes are not borne out by observational data.[179]  Thus, SCC estimates, which are based on (and even necessitated by) the fulfillment of such computer-projected

[178]N.A. Morner, "Estimating Future Sea Level Changes From Past Records."  *Global and Planetary Change* 40: 49-54, 2004; S. Jevrejeva et al., "Nonlinear Trends and Multiyear Cycles in Sea Level Records."  *Journal Of Geophysical Research* 111: 10.1029/ 2005JC003229, 2006; G. Wöppelmann et al., "Rates of Sea-Level Change Over the Past Century in a Geocentric Reference Frame."  *Geophysical Research Letters* 36: 10.1029/2009GL0 38720, 2009; J.R. Houston, and Dean, R.G., "Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses."  *Journal Of Coastal Research* 27: 409-417, 2001.
[179]C.D. Idso et al., (Eds.) *Climate Change Reconsidered II: Physical Science.*  Chicago, IL: The Heartland Institute, 2013.

catastrophes, must be considered highly suspect and inflated. In contrast, the monetary benefits of rising carbon dioxide estimated here are far more likely to result, because they are based on hundreds of laboratory and field observations. It should also be noted that the benefit estimates derived here, although very large, may yet be found to be conservative.

Recognizing these positive impacts of rising $CO_2$ concentrations, some researchers have begun to explore ways in which to increase the influence of atmospheric $CO_2$ on crop yields even more. Many of these efforts are devoted to identifying "super" hybrid cultivars.[180] For example, De Costa et al., for example, grew 16 genotypes of rice (*Oryza sativa* L.) under standard lowland paddy culture with adequate water and nutrients within open-top chambers maintained at either the ambient atmospheric $CO_2$ concentration (370 ppm) or at an elevated $CO_2$ concentration (570 ppm).[181] Their results indicated that the $CO_2$-induced enhancement of the light-saturated net photosynthetic rates of the 16 different genotypes during the grain-filling period of growth ranged from +2 percent to +185 percent in the yala season (May to August) and from +22 percent to +320 percent in the maha season (November to March). Similarly, they found that the $CO_2$-induced enhancement of the grain yields of the 16 different genotypes ranged from +4 percent to +175 percent in the yala season and from -5 percent to +64 percent in the maha season.

In commenting on the findings, the five Sri Lanka researchers say their results "demonstrate the significant genotypic variation that exists within the rice germplasm, in the response to increased atmospheric $CO_2$ of yield and its correlated physiological parameters," and they suggest that "the significant genotypic variation in this response means that genotypes that are highly responsive to elevated $CO_2$ may be selected and incorporated into breeding programs to produce new rice varieties which would be higher yielding in a future high $CO_2$ climate."[182] Selecting such genotypes, as per the results experienced in the De Costa et al. study, has the potential to increase the $CO_2$ monetary benefit per ton of rice by a factor of four or more.

Atmospheric $CO_2$ enrichment also tends to enhance growth and improve plant functions in the face of environmental constraints. For example, Conway and Toenniessen, describe how ameliorating four such impediments to plant productivity – soil infertility, weeds, insects and diseases, and drought – significantly increases crop yields.[183] Therefore, reducing the negative consequences of each of these yield-reducing factors via human ingenuity should boost crop productivity in an additive manner. And a continuation of the historical increase in the air's $CO_2$ content should boost crop productivity even more.

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[180]L. Yang et al., "Yield Formation of $CO_2$-Enriched Inter-Subspecific Hybrid Rice Cultivar Liangyoupeijiu Under Fully Open-Air Condition in a Warm Sub-Tropical Climate." *Agriculture, Ecosystems And Environment* 129: 193-200, 2009.
[181]W.A. De Costa et al. "Genotypic Variation In The Response of Rice (*Oryza Sativa* L.) to Increased Atmospheric Carbon Dioxide and Its Physiological Basis." *Journal Of Agronomy & Crop Science* 193: 117-130, 2007.
[182]Ibid.
[183]G. Conway and G. Toenniessen, "Science for African Food Security." *Science* 299: 1187-1188, 2003.

In the case of soil infertility, many experiments have demonstrated that even when important nutrients are present in the soil in less than optimal amounts, enriching the air with $CO_2$ still boosts crop yields. With respect to the soil of an African farm where their "genetic and agro-ecological technologies" have been applied, for example, Conway and Toenniessen speak of "a severe lack of phosphorus and shortages of nitrogen." Yet even in such adverse situations, atmospheric $CO_2$ enrichment has been reported to enhance plant growth.[184] And if supplemental fertilization is provided as described by Conway and Toenniessen, even larger $CO_2$-induced benefits above and beyond those provided by the extra nitrogen and phosphorus applied to the soil would likely be realized.

In the case of weeds, Conway and Toenniessen speak of one of Africa's staple crops, maize, being "attacked by the parasitic weed Striga (*Striga hermonthica*), which sucks nutrients from roots." This weed also infects many other $C_4$ crops of the semi-arid tropics, such as sorghum, sugar cane and millet, as well as the $C_3$ crop rice, particularly throughout much of Africa, where it is currently one of the region's most economically damaging parasitic weeds. Here, too, studies have shown that atmospheric $CO_2$ enrichment greatly reduces the damage done by this devastating weed.[185]

In the case of insects and plant diseases, atmospheric $CO_2$ enrichment also helps prevent crop losses. For example, in a study of diseased tomato plants infected with the fungal pathogen *Phytophthora parasitica*, which attacks plant roots inducing water stress that decreases yields, the growth-promoting effect of a doubling of the air's $CO_2$ content completely counterbalanced the yield-reducing effect of the pathogen.[186] Similarly, in a review of impacts and responses of herbivorous insects maintained for relatively long periods of time in $CO_2$-enriched environments, as described in some 30-plus different studies, Whittaker noted that insect populations, on average, have been unaffected by the extra $CO_2$.[187] And since plant growth is nearly universally stimulated in air of elevated $CO_2$ concentration, Earth's crops should therefore gain a relative advantage over herbivorous insects in a high-$CO_2$ world of the future.

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[184]D.J. Barrett, Richardson, A.E. and Gifford, R.M., "Elevated Atmospheric $CO_2$ Concentrations Increase Wheat Root Phosphatase Activity When Growth is Limited by Phosphorus," *Australian Journal of Plant Physiology,* 25: 87-93, 1998; P.A. Niklaus, Leadley, P.W., Stocklin, J. and Korner, C., "Nutrient Relations in Calcareous Grassland Under Elevated $CO_2$," *Oecologia,* 116: 67-75, 1998; H.Y. Kim, Lieffering, M., Kobayashi, K., Okada, M., Mitchell, M.W. and Gumpertz, M., "Effects of Free-Air CO2 Enrichment And Nitrogen Supply On The Yield Of Temperate Paddy Rice Crops," *Field Crops Research* 83: 261-270, 2003; A. Rogers, Gibon, Y., Stitt, M., Morgan, P.B., Bernacchi, C.J., Ort, D.R. and Long, S.P., "Increased C Availability at Elevated Carbon Dioxide Concentration Improves N Assimilation in a Legume," *Plant, Cell and Environment* 29: 1651-1658, 2006.

[185]J.R. Watling and Press, M.C., "How is the Relationship Between the $C_4$ Cereal *Sorghum Bicolor* and the $C_3$ Root Hemi-Parasites *Striga Hermonthica* and *Striga Asiatica* Affected by Elevated $CO_2$?" *Plant, Cell and Environment* 20: 1292-1300, 1997; J.R. Watling, and Press, M.C., "Infection With the Parasitic Angiosperm *Striga Hermonthica* Influences the Response of the $C_3$ Cereal *Oryza Sativa* to Elevated $CO_2$." *Global Change Biology* 6: 919-930, 2000.

[186]N.S. Jwa, and Walling, L.L., "Influence of Elevated $CO_2$ Concentration on Disease Development in Tomato." *New Phytologist* 149: 509-518, 2001.

[187]J.B. Whittaker, "Impacts and Responses at Population Level of Herbivorous Insects to Elevated $CO_2$." *European Journal Of Entomology* 96: 149-156, 1999.

Finally, in the case of drought, there is a nearly universal bettering of plant water use efficiency that is induced by atmospheric $CO_2$ enrichment. For example, Fleisher et al., for example, grew potato plants (*Solanum tuberosum* cv. Kennebec) from "seed tubers" in soil-plant-atmosphere research chambers maintained at daytime atmospheric $CO_2$ concentrations of either 370 or 740 ppm under well-watered and progressively water-stressed conditions.[188] And in doing so, they found that "total biomass, yield, and water use efficiency increased under elevated $CO_2$, with the largest percent increases occurring at irrigations that induced the most water stress." In addition, they report that "water use efficiency was nearly doubled under enriched $CO_2$ when expressed on a tuber fresh weight basis." These results indicate, in the words of the three researchers, that "increases in potato gas exchange, dry matter production and yield with elevated $CO_2$ are consistent at various levels of water stress as compared with ambient $CO_2$," providing what is currently required and what will be even more urgently required as the world's population continues to grow: Significantly enhanced food production per unit of water used.[189]

The same situation exists with respect to excessive heat, ozone pollution, light stress, soil toxicity and most any other environmental constraints. Atmospheric $CO_2$ enrichment generally tends to enhance growth and improve plant functions to minimize or overcome such challenges.[190] As researchers continue to explore these benefits and farmers select cultivars to maximize them, the monetary value of this positive externality of raising the global $CO_2$ concentration of the atmosphere will increase.

It is thus far more likely to expect the monetary benefits of rising atmospheric $CO_2$ to accrue in the future than it is to expect the accrual of monetary damages and that the modern rise in the air's $CO_2$ content is providing a significant economic benefit to global crop production. As Sylvan Wittwer, the father of agricultural research on this topic, so eloquently stated nearly two decades ago:

"The rising level of atmospheric $CO_2$ could be the one global natural resource that is progressively increasing food production and total biological output, in a world of otherwise diminishing natural resources of land, water, energy, minerals, and fertilizer. It is a means of inadvertently increasing the productivity of farming systems and other photosynthetically active ecosystems. The effects know no boundaries and both developing and developed countries are, and will be, sharing equally," for "the rising level of atmospheric $CO_2$ is a universally free

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[188]D.H. Fleisher et al., "Elevated Carbon Dioxide And Water Stress Effects On Potato Canopy Gas Exchange, Water Use, And Productivity." *Agricultural And Forest Meteorology* 148: 1109-1122, 2008.

[189]There are numerous studies that have produced similar results, including (J. De Luis et al., "Elevated $CO_2$ Enhances Plant Growth in Droughted N2-Fixing Alfalfa Without Improving Water Stress." *Physiologia Plantarum* 107: 84-89, 1999; S. Kyei-Boahen, et al., "Gas Exchange of Carrot Leaves in Response to Elevated $CO_2$ Concentration. *Photosynthetica* 41: 597-603, 2003. 2003; S.H. Kim et al., "Canopy Photosynthesis, Evapotranspiration, Leaf Nitrogen, and Transcription Profiles of Maize In Response to $CO_2$ Enrichment. *Global Change Biology* 12: 588-600, 2003.

[190]Idso and Singer, 2009, op.cit; Idso and Idso, op.cit.

premium, gaining in magnitude with time, on which we all can reckon for the foreseeable future".[191]

The relationship described above by Wittwer is illustrated below in Figure III-8, where data pertaining to atmospheric $CO_2$ emissions, food production, and human population are plotted. Standardized to a value of unity in 1961, each of these datasets has experienced rapid and interlinked growth over the past five decades. Rising global population has led to rising $CO_2$ emissions and rising $CO_2$ emissions have benefited food production.

The very real positive externality of inadvertent atmospheric $CO_2$ enrichment must be considered in all studies examining the SCC, and its observationally-deduced effects must be given premier weighting over the speculative negative externalities presumed to occur in computer model projections of global warming. Until that time, little if any weight should be placed on current SCC estimates and dire predictions derived from them.

**Figure III-8**
**Global Population, $CO_2$ Emissions, and Food Production Data Over**
**the Period 1961-2010, Normalized to a Value of Unity at 1961***
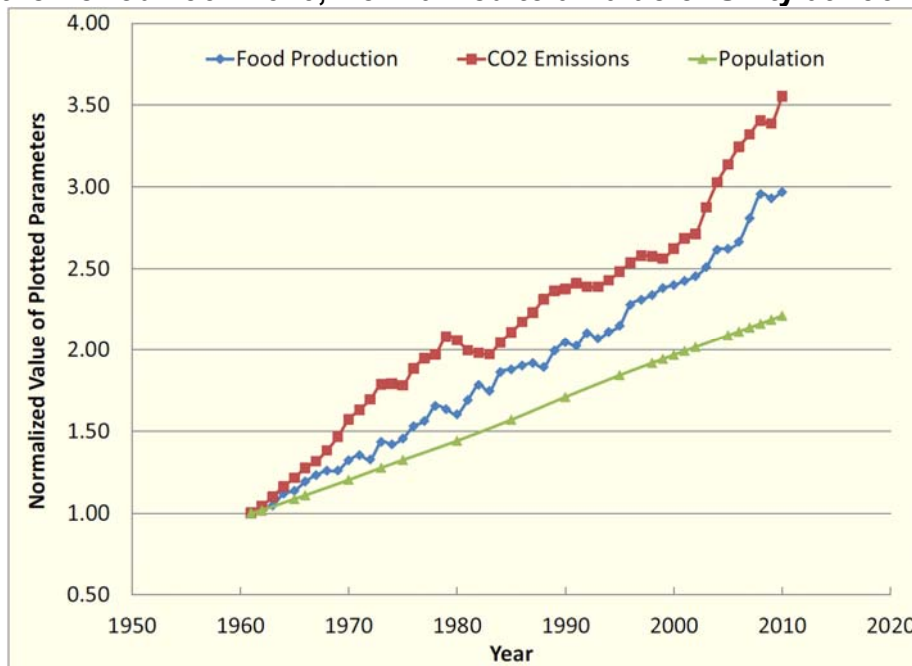


*Food production data represent the total production values of the forty-five crops that supplied 95% of the total world food production over the period 1961-2011, as listed in Table III-1.

[191]S.H. Wittwer, "*Food, Climate, And Carbon Dioxide: The Global Environment And World Food Production.*" Lewis Publishers, Boca Raton, FL, 1995.

## IV.  THE FEDERAL INTERAGENCY WORKING GROUP REPORTS

### IV.A.  The Federal Interagency Working Group

The Federal Interagency Working Group (IWG) on Social Cost of Carbon is comprised of the following 12 agencies:  Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of the Treasury.  The process it used to develop the SCC estimates involved technical experts from numerous agencies meeting on a regular basis to consider public comments, exploring the technical literature in relevant fields, and discussing key model inputs and assumptions.  The objective was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures.  In this way, the IWG felt that key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.[192]

The first IWG report was published in February 2010 and it contained four SCC values for use in regulatory analyses – Table IV-1.  Three values are based on the average SCC from three integrated assessment models (IAMs) — DICE, PAGE, and FUND, at discount rates of 2.5, 3, and 5 percent.  The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, was included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.[193]

In May 2013, the IWG published an updated report which contained SCC estimates, shown in Table IV-2, based on new versions of each IAM.  It did not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Changes in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.[194]

The 2013 SCC estimates using the updated versions of the models are higher than those in the 2010 report.  By way of comparison, the four 2020 SCC estimates reported in the 2010 TSD were $7, $26, $42 and $81 (2007$). The corresponding four updated SCC estimates for 2020 are $12, $43, $65, and $129 (2007$).[195]

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[192]Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010.
[193]Ibid.
[194]Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Support Document:  Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," May 2013.
[195]Ibid.

**Table IV-1**
**Original (2010) Social Cost of CO2, 2010 – 2050**
(In 2007 dollars per metric ton of $CO_2$)

| Discount Rate | 5% | 3% | 2.5% | 3% |
|---|---|---|---|---|
| Year | Avg | Avg | Avg | 95th |
| 2010 | 4.7 | 21.4 | 35.1 | 64.9 |
| 2015 | 5.7 | 23.8 | 38.4 | 72.8 |
| 2020 | 6.8 | 26.3 | 41.7 | 80.7 |
| 2025 | 8.2 | 29.6 | 45.9 | 90.4 |
| 2030 | 9.7 | 32.8 | 50.0 | 100.0 |
| 2035 | 11.2 | 36.0 | 54.2 | 109.7 |
| 2040 | 12.7 | 39.2 | 58.4 | 119.3 |
| 2045 | 14.2 | 42.1 | 61.7 | 127.8 |
| 2050 | 15.7 | 44.9 | 65.0 | 136.2 |

Source:  Interagency Working Group on Social Cost of Carbon, United States Government, 2010.


**Table IV-2**
**Revised (2013) Social Cost of CO2, 2010 – 2050**
(In 2007 dollars per metric ton of $CO_2$)

| Discount Rate | 5.0% | 3.0% | 2.5% | 3.0% |
|---|---|---|---|---|
| Year | Avg | Avg | Avg | 95th |
| 2010 | 11 | 33 | 52 | 90 |
| 2015 | 12 | 38 | 58 | 109 |
| 2020 | 12 | 43 | 65 | 129 |
| 2025 | 14 | 48 | 70 | 144 |
| 2030 | 16 | 52 | 76 | 159 |
| 2035 | 19 | 57 | 81 | 176 |
| 2040 | 21 | 62 | 87 | 192 |
| 2045 | 24 | 66 | 92 | 206 |
| 2050 | 27 | 71 | 98 | 221 |

Source:  Interagency Working Group on Social Cost of Carbon, United States Government, 2013.


The model updates relevant to the SCC estimates included an explicit representation of sea level rise damages in the DICE and PAGE models; updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages in the PAGE model; an updated carbon cycle in the DICE model; and updated damage functions for sea level rise impacts, the agricultural sector,

and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions in the FUND model.  Of these changes, only the inclusion in the FUND model of impacts on the agricultural sector and impacts from reduced space heating requirements represent attempts to include any potential positive impacts from higher concentrations of $CO_2$ and warmer global temperatures.


## IV.B. Analysis of the IWG Methodology

IAMs form the basis for the IWG SCC estimates, and the IWG ran simulations of three different IAMs, with a range of parameter values, discount rates, and assumptions regarding GHG emissions, to derive its SCC estimates.[196]  However, as Pindyck notes the IAM models "are so deeply flawed as to be close to useless as tools for policy analysis.  Worse yet, their use suggests a level of knowledge and precision that is simply illusory, and can be highly misleading."[197]  In his 2008 Richard T. Ely lecture at the annual meeting of the American Economic Association, Sir Nicholas Stern stated: [198]

> However, as the Stern Review stressed, such analysis (IAM) has very serious weaknesses and must not be taken too literally. It is generally forced to aggregate into a single good, and in so doing misses a great deal of the crucial detail of impacts — on different dimensions and in different locations — which should guide risk analysis.  It is forced to make assumptions about rates and structures of growth over many centuries.  Further, it will be sensitive to the specification of ethical frameworks and parameters.  Thus its estimates of marginal social costs of damages provide a very weak foundation for policy.  This type of modeling does have an important supplementary place in an analysis, but all too often it has been applied naively and transformed into the central plank of an argument.

As discussed below, the IWG methodology requires that a large number of assumptions be made to complete the linkages between levels of human activity, today and in the future, and the environmental consequences of that activity today and for generations to come.  However, even small variations in the size of the assumed inputs can lead to very large and significant differences in the results produced by the IWG's

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[196]For a detailed review and analysis of IAMs, see Richard S.J. Tol, "Integrated Assessment Modeling," Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, Germany, Working Paper FNU-102, 2006, https://fnu.zmaw.de/ fileadmin/fnu-files/publication/working-papers/efieaiamwp.pdf, and Edward Parson and Karen Fisher-Vanden, "Integrated Assessment Models of Global Climate Change," *Annual Review of Energy and the Environment 1997*, 22:589–628.

[197]Robert S. Pindyck, "Climate Change Policy:  What Do The Models Tell Us?" National Bureau of Economic Research, Working Paper 19244, July 2013; © 2013 by Robert S. Pindyck.

[198]Stern is professor of economics at the London School of Economics and Political Science and the lead author on the 2006 Stern Report on Global Warming. The source for this quote is found in Stern, "The Economics of Climate Change," *American Economic Review:  Papers and Proceedings*, Vol. 98, No. 2, p. 3, 2008.

methodology — differences in results that are so great as to leave the IWG's policy recommendations highly questionable. Below, we briefly outline the structure of IAMs, and then describe the strengths and weaknesses of the models. One of the more important conclusions about these models, as discerned through a review of the literature, it that they are not yet robust enough to play a role in environmental or regulatory policy formulation.

### IV.B.1. What are IAMs?

IAMs are constructed for different purposes and emphasize different aspects of the global climate change issue, and there are currently about 50 IAMs.[199] Some of their major limitations include:[200]

- The simplicity in their approach, using only one or two equations associating aggregate damage to one climate variable, in most cases temperature change, which does not recognize interactions between different impacts,
- Capturing only a limited number of impacts, often omitting those difficult to quantify and those showing high levels of uncertainty,
- Presenting damage in terms of loss of income, without recognizing capital implications, and
- The application of willingness to pay quantification, which could lead to relatively low results in the context of developing countries.

The description and purposes of IAMs have changed little over the two decades since their use became common in the analysis of global climate change. In an early description and review of these models John Weyant and colleagues concluded that integrated assessments are convenient frameworks for combining knowledge from a wide range of disciplines.[201] These efforts address three goals:

- Coordinated exploration of possible future trajectories of human and natural systems,
- Development of insights into key questions of policy formation, and
- Prioritization of research needs in order to enhance our ability to identify robust policy options — the integration process helps the

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[199]Elizabeth Stanton, et al, "Inside the Integrated Assessment Models: Four Issues in Climate Economics," *Climate and Development*, 1 (2009). P.168.
[200]Swenja Surminski, Ana Lopez, Joern Birkmann, and Thorsten Welle, "Current Knowledge on Relevant Methodologies and Data Requirements as Well as Lessons Learned and Gaps Identified at Different Levels, in Assessing the Risk of Loss and Damage Associated With the Adverse Effects Of Climate Change," technical paper, FCCC/TP/2012/1. 2012, United Nations Framework Convention on Climate Change, Bonn, Germany, p. 23, http://unfccc.int/resource/docs/2012/tp/01.pdf.
[201]See Tol, op. cit.; Stanton, op. cit.; and John P. Weyant, et.al, "Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results," p. 371, in J. P. Bruce, et al. (eds), *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Cambridge University Press, Cambridge, 1996.

analyst coordinate assumptions from different disciplines and introduce feedbacks absent in conclusions available from individual disciplinary fields.

Prior to the use of mathematical computer models (IAMs) to link knowledge from divergent disciplines together using explicit behavior assumptions, questions involving cross-disciplinary issues were usually addressed by convening panels or commissions of experts from the various fields to provide their collective judgment on the issue at hand. The first application of a formal IAM effort on a global environmental issue was the Climate Impacts Assessment Program (CIAP) at the U.S. Department of Transportation to examine the potential environmental impacts of supersonic flight in the early 1970s. Other efforts to assess global issues using IAM's followed, but it was not until the 1990's that IAMs to address climate change began to proliferate.[202]

As described above, the primary goal of these models is to assess a broad range of science across several disciplines to provide policy makers with answers to questions involving the potential problems of global climate change. The models can be relegated to two broad classes of models: i. policy optimization models and ii. policy evaluation models.

In climate research, policy optimization models solve for an optimal policy that trades off expected costs and benefits to maximize, for example, social welfare. Alternatively, optimization models can be used to find the optimal (least cost) approach to reaching a particular goal, e.g. a future, stable level of climate $CO_2$. Policy evaluation models, on the other hand, are used to assess the impact of a particular policy variable on the environment. Importantly, the models differ in the degree of complexity found in their respective sectors. Policy evaluation models tend to be much more complex, especially in their treatment of the physical sciences, whereas policy optimization models contain economic and climate sectors that are relatively simple.[203]

Figures IV-1 and IV-2 illustrate the basic integrated assessment model showing both economic and climate modules and the interactions between them.[204] The four-module structure depicted in Figure IV-2 contains the basic "building blocks" for an IAM. The "Economic Dynamics" block contains the human activities that generate carbon emissions. This block usually contains a fairly robust energy sector as well as a sector representing agriculture forestry and livestock. The "Carbon Cycle" block contains a model of the carbon cycle which estimates the net increase of carbon in the atmosphere (carbon atmosphere concentration). Changes in carbon concentrations are then used as an input into a "Climate Dynamics" module that predicts changes in temperature. Next, changes in temperature impact economic sectors are determined by the "Damage

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[202]See Wayant, op cit. p. 376.

[203]See David L. Kelly and Charles D.Kolstad, "Integrated Assessment Models For Climate Change Control," US Department of Energy grant number DE-FG03-96ER62277, www.econ.ucsb.edu/papers/wp31-98.pdf.

[204]From N. Edwards, H.Grepin, A.Haurie and L.Viguier, "Linking Climate and Economic Dynamics," in *The Coupling of Climate and Economic Dynamics: Essays on Integrated Assessment*, Alain Haurie and Laurent Viguier (eds), Amsterdam: Springer, 2005.

Function" module.  Finally, any adverse impacts on GDP are fed back into the Economic Dynamic module, resulting in a lower starting level of GDP for calculating impacts in the next period.

**Figure IV-1**
**Simplified schematic of a typical IAM**[205]
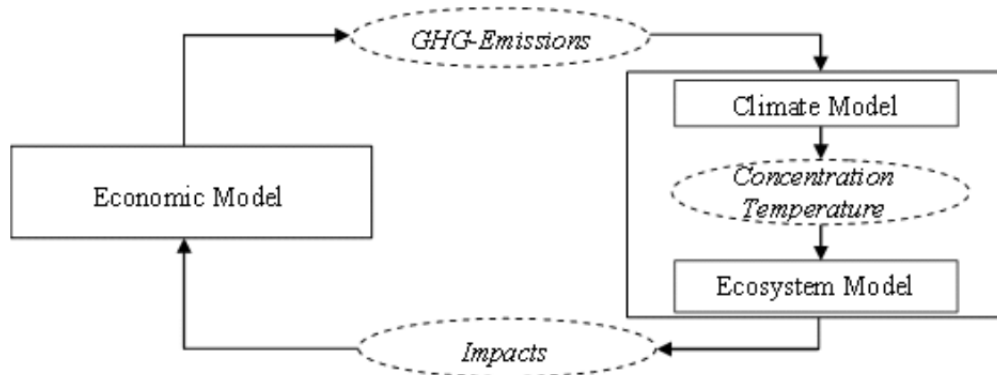


**Figure IV-2**
**Representation of a Basic Integrated Assessment Model**
**Showing Interactions Between Economic and Climate Systems.**[206]
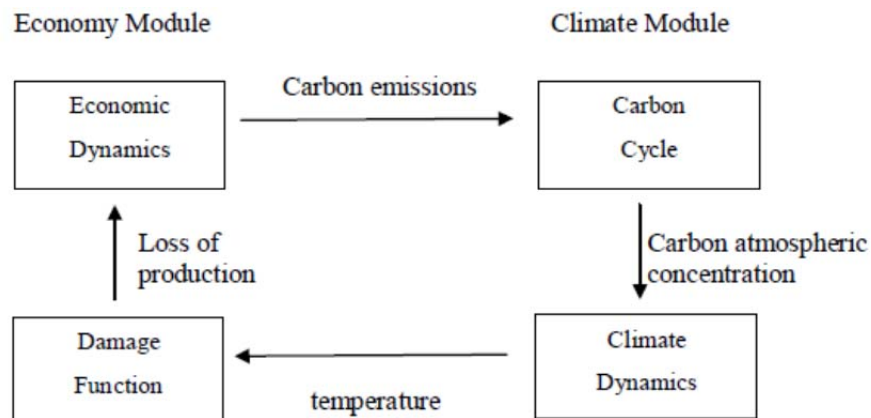


More sophisticated models will contain more elements in each model as well as additional feedback effects – see Figure IV-3 and IV-4.  For example, the Carbon Cycle module may contain an Ocean Carbon Cycle model as well as an atmospheric model. Climate Dynamics modules may contain ocean temperature and sea level models as

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[205]Christoph Böhringer, Andreas Löschel and Thomas F. Rutherford, *Decomposing the Integrated Assessment Climate Change,* Centre for European Economic Reserch, Discussion Paper No. 05-07, p. 3. ftp://ftp.zew.de/pub/zew-docs/dp/dp0507.pdf.
[206]From Edwards, N.; H.Grepin, A.Haurie and L.Viguier, "Linking Climate and Economic Dynamics", In *The Coupling of Climate and Economic Dynamics: Essays on Integrated Assessment*, Alain Haurie and Laurent Viguier (eds), Amsterdam: Springer. 2005.

well. Conceptually, there is no limit to the degree of sophistication that can be built into the models. Computational limits, however, are another matter and these weigh heavily in fully integrated optimization IAMs based on CGE (computable general equilibrium) economic modules, such as the DICE model, which compute optimal growth paths by computing thousands of iterations over hundreds of periods.

**Figure IV-3**
**Simplified Schematic of a Typical Welfare Optimizing IAM**[207]
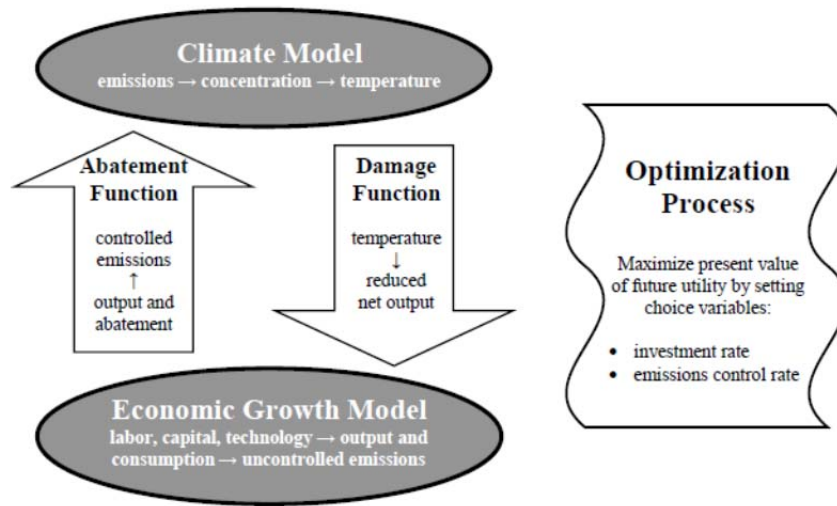


**Figure IV-4**
**Key Components of Full Scale IAMs**[208]



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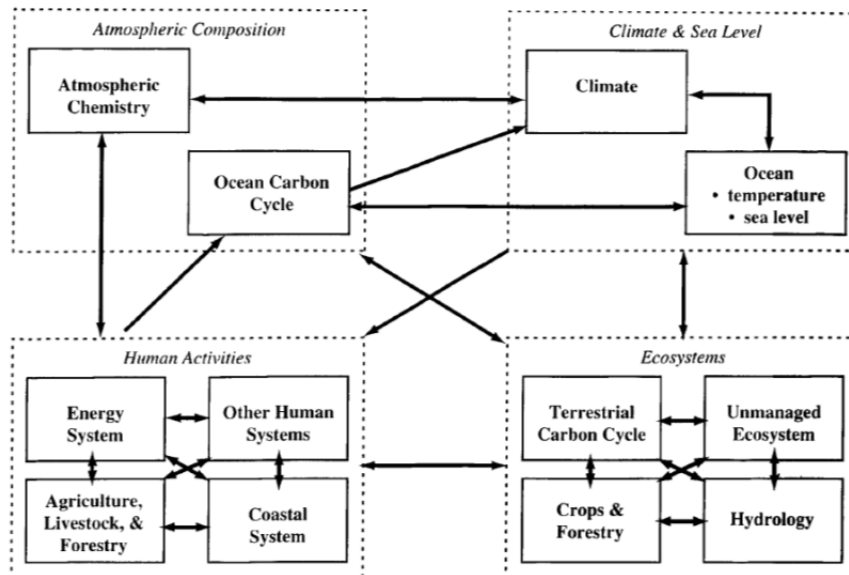
[207]From Elizabeth Stanton, et al, Inside the Integrated Assessment Models: Four Issues in Climate Economics," *Climate and Development*, 1 (2009). p.168.
[208]From John p. Weyant, et.al, "Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results," p. 377 in *Climate Change 1995: Economic and Social Dimensions of Climate Change*, op. cit.

James Risbey and colleagues likened the art of building an IAM to building a house where the blocks represent the substantive knowledge found in the different disciplines that are represented in the various modules while the mortar that links the modules together:

> . . . . frequently takes the form of the practitioner's subjective judgments linking the disparate knowledge blocks. Unfortunately, while the bricks may be quite sound and well described, the subjective judgments (glue) are often never made explicit. As a result, it is difficult to judge the stability of the structure that has been constructed. Thus, in the case of integrated assessment, not only do we need criteria for assessing the quality of the individual components of the analysis, we also need criteria that are applicable to the glue or the subjective judgments of the analyst, as also for the analysis as a whole. While criteria for adequacy for the individual components may be obtained from the individual disciplines, a similar situation does not exist for the "glue" in the analysis.[209]

In reality, it is not only the "mortar" that is suspect in the building of IAMs, but the content of the blocks themselves. Below we highlight the most problematic parts of a typical IAM, beginning with the estimates of carbon emissions through each step up to and including the estimation of the economic costs and benefits of those emissions. Troubling and unresolved issues at each stage of an IAM include: [210]

- What is the rate of carbon emissions, from natural and human sources?
- How is the carbon cycle specified: The processes that impact the net change of the amount of carbon in the atmosphere? If more carbon enters the atmosphere than is absorbed by ocean and terrestrial carbon "sinks", then the concentration of carbon will increase.
- How does the concentration of carbon in the atmosphere impact the climate, e.g. climate dynamics? What are the interactions between climate and oceans, between climate and land mass?
- How do changes in temperature impact the oceans and the land?

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[209]See James Risbey, et al, "Assessing Integrated Assessments," *Climatic Change*, 1996, Volume 34, Issue 3-4, pp 369-395.

[210]This list is based on an analysis of various studies of the issue, but draws most heavily from Risbey, op.cit; and Stephen H. Schneider, "Integrated Assessment Modeling of Global Climate Change: Transparent Rational Tool For Policy Making or Opaque Screen Hiding Value-Laden Assumptions?" *Environmental Modeling and Assessment*, Issue 2, October 1997, pp. 229-49. http://stephenschneider. stanford.edu/Publications/PDF_Papers/Integr_Ass.pdf; and J. Weyant, et al, "Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results," pp. 367-439 in J. P. Bruce, et al. (eds), *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Cambridge University Press, Cambridge (1996). http://www.ipcc.ch/publications_and_data/publications_and_data_ reports.shtml#1.

- What evidence is there that increasing temperatures will cause damages?
- How much will those damages impact current and future rates of growth?
- Finally, if there are expected damages to future economic growth and output, how do we compare the current, or present value of those future damages to the costs — present and future — of slowing or stopping, (i.e., "mitigating") the emission of carbon into the atmosphere. This issue hinges on the very sensitive and controversial question of selecting the "correct" discount rate to convert future costs and benefits into current costs and benefits in order to establish an SCC.

In his critique of the use of IAMs for policy decision making, Stern focused on several of the above issues.[211] Of the key elements in the parameters of IAMs he broadly classified them into two groups which he labeled structural elements and ethical elements. Among the former he considered the following structural parameters to be crucial: The flow of emissions; "climate sensitivity", the link between carbon stocks and temperature changes; the functioning of the carbon cycle that links carbon flows to carbon stocks – the concentration level of carbon in the atmosphere; and the estimation of damages from temperature changes. As far as the ethical elements that concern Stern, his argument is that they are far broader than the one or two issues that are "shoehorned" into the standard economic growth module of a typical IAM.

The structural elements of major concern include:

- The flow of carbon into the atmosphere,
- Climate sensitivity and the functioning of the carbon cycle, and
- Damage estimates – the damage functions.

### IV.B.2.  The Flow of Carbon Into the Atmosphere

The assessment of potential impacts of climate change in an IAM begins with an emission stream generated by a scenario of economic growth, and the IWG selected five different scenarios developed by the Energy Modeling Forum (EMF) at Stanford University.[212]  Figure IV-5 shows several areas of climate research that are often subject to the creation of "scenarios" – essentially "what if" exercises based on sets of assumptions about the structure of the models within the socio-economic module and variables that drive the creation of various climate model scenarios.[213]  In the case of

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[211]See Nicholas Stern, "The Economics of Climate Change," op. cit., pp. 17-18.

[212] A description of the specific EMF scenarios selected by the IWG can be found in Michael Greenstone, et al., "Developing a Social Cost of Carbon for US Regulatory Analysis: A Methodology and Interpretation", *Review of Environmental and Economic Policy* (Winter 2013) 7 (1): 23-46.

[213]Found in Edward Parson, et al, "Global-Change Scenarios: Their Development and Use", U.S. Department of Energy, 2007, p. 23.

emission scenarios, exogenously determined trends for economic growth, population growth, and technological change are inputs into the socio-economic module to create scenarios of emissions that are compatible with the structure of the energy system. The remaining sectors in the diagram – "Atmosphere & Climate" and "Impacts" are modeled as part of the IAMs. The scenarios are not to be considered forecasts of future emissions, but are developed to create a range of plausible trends for future emissions given the underlying assumptions about economic and population growth and technological change.

**Figure IV-5**
**Anthropogenic Climate Change: Simplified Linear Causal Chain[214]**
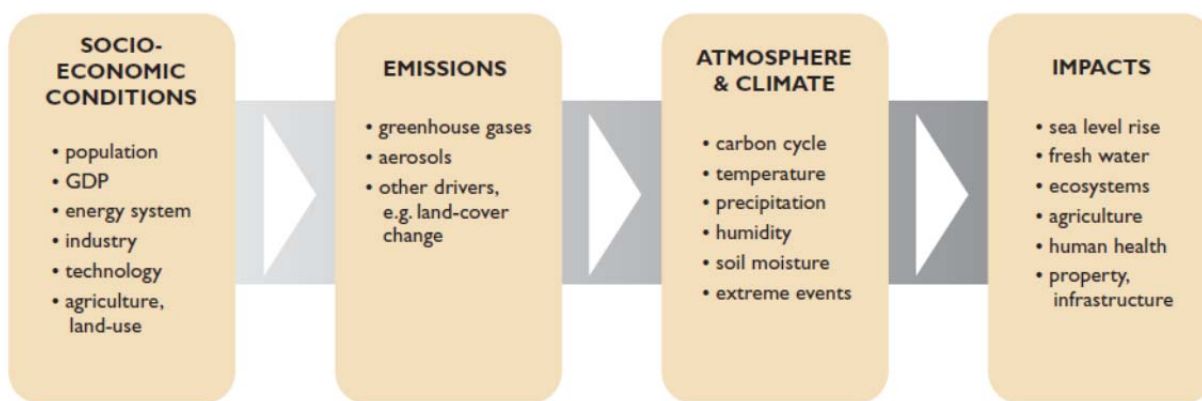


In critiques of the socio-economic scenario creation for IAM calculations, attention has been focused primarily on the assumed rate of economic growth, on the treatment of technological change, the treatment of non-$CO_2$ sources of GHG emissions, and the treatment on non-anthropogenic sources of GHG emissions. In the scenarios of economic growth from the EMF, compound annual rates of global economic growth between 1995 and 2100 ranged between a low of 1.48% and a high of 2.45%. The average "reference" (baseline) rate of growth was 2.17%.[215] These rates of growth are not particularly high, especially when compared to global growth rates over the last fifty years, but they are typical of scenario modeling at the EMF as well as at other organizations. Projected slowing rates of population growth and of technological improvements over coming decades are responsible for this trend.[216]

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[214] Found in Ibid.
[215]Spreadsheets with the various parameters for the created scenarios can be found at the Energy Modeling Forum website, http://emf.stanford.edu/.
[216]A 2012 paper by Robert J. Gordon is especially pessimistic with regard to future technology leading to much if any productivity gain and economic growth. See Gordon, "Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds", op. cit.

Of the three IAM models used by the IWG in their computations of SCC, the FUND and PAGE models treat economic growth as an exogenous variable, while the DICE model uses an optimal growth model based on a Cobb-Douglas production function to forecast GDP.  Technological change is treated exogenously in all three models.  Critics of IAMs consistently cite the failure of IAMs to treat technological change (productivity) as well as population growth as endogenous variables as an important weakness in these models.[217]

## IV.B.3.  Climate Sensitivity

The term "Climate Sensitivity" refers to the change in global temperature in reaction to changes in the atmospheric content of Greenhouse Gases (GHG).  This component is composed of at least three elements

- First, the long-term increase in global temperature given an increase in GHG.  Usually this reaction is expressed in terms of the change in global temperature relative to a pre-industrial base temperature, given a doubling of the concentration of $CO_2$ in the atmosphere.
- Second, the rate at which the temperature changes over the period being assessed.
- Third, the assessment of potential feedback effects that occur because of climate change – feedbacks that may either increase or decrease the concentration of atmospheric GHGs and thereby either speed or slow the rate of GHG concentration and the subsequent impact on global temperature.

The long-term change in global temperature in reaction to changes in atmospheric $CO_2$ concentration is one of the first important uncertainties related to climate science and IAM efforts to model the causal linkage between anthropogenic activities and possible adverse economic and/or ecological impacts. In 2007 the Intergovernmental Panel on Climate Change (IPCC) reported its estimate of climate sensitivity – the change in predicted temperature change given a doubling of $CO_2$ — at between $2.0^{\circ}$ and $4.5^{\circ}$ C, with a best estimate of $3.0^{\circ}$ C.[218]  The IPCC range of estimates resulted from a peer review of over twenty individual studies of climate sensitivity.[219]  IAM modelers who have tested for impact of climate change generally

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[217]A description and evaluation of the three IAMs used by the IWG as well as other IAMs can be found in Ramon Arigoni Ortiz and Anil Markandya, "Integrated Impact Assessment Models of Climate Change with an Emphasis on Damage Functions: a Literature Review," BC3 Working Paper Series 2009-06, Basque Center for Climate Change (BC3), October 2009. http://www.bc3research.org/d7H9dfT3Re2/2009102002 04231130584436.pdf.

[218]IPCC, "2.3 Climate Sensitivity and Feedbacks". In R.K. Pachauri and Reisinger, A. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Geneva, Switzerland: Intergovernmental Panel on Climate Change, 2007.

[219]See Pindyck, op. cit., p.9.

have experimented with different change values, usually within the IPCC estimated range.

The speed at which global temperatures increase toward their estimated equilibrium temperature is also very important in the estimation of the total impact. A slower path toward equilibrium will result in lower estimated impact costs, since the discounted present value of more immediate increases (and impacts) would be lower — as would the more distant impacts. Although impacts in the far future would be more severe, their present value would be reduced owing to their value being discounted over a more lengthy time period. IAM modelers have addressed this issue through assuming different time paths and comparing results, again, with no solid data or science to indicate what the actual path might be.

Further, the rate at which $CO_2$ is emitted is not the rate at which it enters into and increases the GHG concentration in the atmosphere owing to the natural action of the carbon cycle, which immediately acts to remove some emitted carbon while more dissipates over time into ocean and agricultural sinks. While sophisticated global climate models often incorporate elaborately calibrated carbon cycles within their models, most IAMs deal with the problem by utilizing simplifying assumptions about how much and how rapidly emitted $CO_2$ is subtracted from the current emission flows. While the limiting factor in an IAM model is computational time, it is important to note that there is significant uncertainty among climate science as to how the current cycle operates and how it will continue to operate in the future under increasing emissions of $CO_2$.

Thus, in this first step of an IAM impact estimation, there are significant unknowns for which science is unable to provide answers. When IAM modelers craft various assumptions about the impact of $CO_2$ emissions on global temperatures, their assumptions can produce a wide range of impact values depending on those assumptions and upon the structure of the individual IAMs that they employ.

### IV.B.4. IAM Damage Functions

One of the most contentious elements of IAM SCC estimates concerns how estimates of damage are related to projected global temperature changes. In general, most IAMs relate damages to increases in temperature, T, using a quadratic equation that calculates damages as a function of temperature changes. There is no economic basis for using a quadratic equation, nor is there any scientific justification for the parameters of the equations that determine how fast damages increase as temperatures climb. The result is that the structural of these equations contain the unstated assumption that damages increase at an increasing rate as temperatures increase. In their review of IAMs, Rachel Warren and her colleagues concluded that: "The assumption of a quadratic dependence of damage on temperature rise is even less grounded in any empirical evidence. Our review of the literature uncovered no rationale, whether empirical or theoretical, for adopting a quadratic form for the damage

function – although the practice is endemic in IAMs.[220]   Similarly, in his review of IAMs Pindyck also noted that the "loss functions" are not based on any economic theory, but, rather, "They are just arbitrary functions, made up to describe how GDP goes down when T goes up."[221]

The damage functions used by the three models used by the IWG – DICE, FUND and PAGE – have little or no disaggregation with regard to sectors and/or regions in their estimations.  For example, the DICE model uses a single total damage function based on estimates of temperature related damages in several sectors including agriculture, forestry, coastal vulnerability, health, and outdoor recreation to name a few.  The PAGE model includes three damage functions that cover economic sectors, noneconomic sectors, and potential climate discontinuities.  The damage function in the FUND model is the most disaggregated of the three and it includes damage functions for several sectors:  Agriculture, forestry, water resources, sea level increases, health, and several others.  In addition, the FUND model includes regional impacts for the various sectors.[222]

While the simplicity and arbitrariness of the structure of the damage functions raises concerns regarding their accuracy, also troubling is the fact that these functions are usually based on only one country or region because the literature on the topic of environmentally induced costs (or benefits) is very limited, except in agriculture.  For example, as described by Mastrandrea:[223]

> Market and non-market damages in DICE are based on studies of impacts on the United States that are then scaled up or down for application to other regions. Many of the estimates to which market damages in PAGE are calibrated are also based on an extrapolation of studies of the United States.  Only FUND uses regional and sector-specific estimates.   However, in some sectors these estimates also originate in one country, or may be dominated by estimates from one region.  For example, in the energy sector, the sector which accounts for most of the economic damages in FUND, estimates for the UK are scaled across the world.

In short, we are asked to accept that very limited assessments of damages to one sector in one region, for example the energy sector in the UK, can be extrapolated to assess the impact on the same sector in other regions without acknowledging first, that the structure of these sectors differ significantly from one region to another and that, second, global climate science cannot predict with any accuracy at all what

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[220]Also see Rachel Warren, et al, "Spotlighting Impacts Functions in Integrated Assessment," Research Report Prepared for the Stern Review on the Economics of Climate Change, Tyndall Centre for Climate Change Research Working Paper 91, September 2006, p. 172.
[221]Pindyck, op cit. p. 11.
[222]A more complete description of the damage functions in the three models can be found on pp. 13-21 in Michael D. Mastrandrea, *Calculating the Benefits of Climate Policy: Examining the Assumptions of Integrated Assessment Models,* The Pew Center on Global Climate Change, 2009.  Also see Rachel Warren, et al, Spotlighting Impacts Functions in Integrated Assessment, op cit.
[223]Mastrandrea, Op cit, p. 17.

countries or regions may be impacted more or less than any others, given an increase in average global temperatures.

While some progress is being made in estimating the potential damages from climate change, at present the research is still so limited that one would be hard pressed to describe the results as little more than educated guesses. Or, as Mastrandrea states: "Although the differences in formulation across models do not allow a perfectly parallel comparison, it is clear that the relationship between temperature increase and climate damages varies significantly among IAMs."[224]

Finally, Pindyck notes that while the IAM damage functions relate changes in GDP levels to changes in global temperature, a more persuasive argument is that temperature changes would impact the rate of GDP growth and not the level. Currently most IAMs estimate an impact on income, but not capital. Concerning this issue, Pindyck states:

> First, some effects of warming will be permanent; e.g., destruction of ecosystems and deaths from weather extremes. A growth rate effect allows warming to have a permanent impact. Second, the resources needed to counter the impact of warming will reduce those available for R&D and capital investment, reducing growth. Third, there is some empirical support for a growth rate effect. Using data on temperatures and precipitation over 50 years for a panel of 136 countries, Dell, Jones and Olken have shown that higher temperatures reduce GDP growth rates but not levels. Likewise, using data for 147 countries during 1950 to 2007, Bansal and Ochoa show that increases in temperature have a negative impact on economic growth.[225]

Elizabeth Stanton and her colleagues[226] also note that subtracting damages from output with no effect on capital, production or consumption in following periods is an "unrealistic assumption." Specifically:

> In recognition of the fact that the parameters of the damage functions are questionable at best, IAM models increasingly include probability distributions of the parameters to explicitly address the issue of uncertainty. While the use of probability distributions – using a range of values around a norm – serves to acknowledge that we have no real scientific evidence to support one value over another – their use introduces another bias into IAM results. Since the structure of the damage functions are quadratic equations, the results of using probability distributions of equation parameters results in so-called "fat tail" impacts that are larger for higher temperature increases than for lower increases.[227]

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[224]Mastrandrea, Op cit. p. 20.
[225]Pindyck, op cit., p. 12.
[226]See Elizabeth Stanton, et al, op. cit.
[227]Mastrandrea, op cit., p. 48.

As for the fact that the models include only a limited number of sectors in their assessments, the modelers argue that any unrepresented sectors would result in even greater damage assessment if included. Also, admitting that that there may be some positive impacts from climate change, most modelers argue that any positive impacts would undoubtedly be outweighed by the negatives.[228] However, little evidence is presented to support these claims.

An interesting example of the uncertainty and arbitrariness of damage functions can be shown in a comparison of the results of IAM impact studies conducted by Joseph Aldy and his colleagues. They found that there was a significant amount of consistency among several disparate studies of the economic impact of a 2.5C$^{\circ}$ warming of average global temperatures, compared to pre-industrial levels, by 2100: Five different models predicted economic damages of between 1% and 2% of global GDP. However, although the gross damages estimates were similar, there were huge differences in the studies' estimates of the sources of the damages, as shown in Figure IV-6.[229] As illustrated, the total damages, although similar, reveal large differences in the source of the damages – market impacts, non-market impacts, or catastrophic impact[230] Thus, it must be concluded that the similar results for the total damage estimates occurs because the selection of damage structures and parameters for the different sectors – economic and noneconomic – in the five model results just happened to aggregate to similar total damage values.

## IV.B.5. The Discount Rate:

Of the many parameters found in IAMs, including everything from decisions about model structure to the value of key variables, none attracts as much attention and criticism as the choice of the discount rate used to estimate the present value of future impacts. The discount rate is a lightening-rod for criticism, first, because of the heavy ethical baggage that it carries. Unlike the majority of benefit-cost studies that use discount rates to assess values only a few years or even decades into the future, IAMs that are developed to evaluate the impacts of climate change must look generations ahead. This characteristic of IAMs raises important ethical issues, and one of the most basic ethical arguments is that to use any rate of discount other than zero would be a violation of intergenerational neutrality. That is, a positive value of the discount rate is an indication that future generations are held to be less valuable than the current or "present" one.[231] Second, and more important, in simulations of the sensitivity of IAM

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[228]See, for example, Richard S.J. Tol, "Why Worry About Climate Change? A Research Agenda," *Environmental Values*, 17 (2008): 437–470, p.448.

[229]Only market damages were estimated in these studies, and the figure is the midpoint of a range of damage estimates. Damage categories are not precisely de-lineated in these studies.

[230]The figure and related discussion are included here to illustrate that, in general, IAM's produce inconsistent results (as to where and why damages might occur) even though there may be an (apparent) consistency in the level of the overall level of damages calculated by the different models.

[231]The arguments on this issue are long and involved. See Stern, Op cit, 2009, pp. 12-17 for his arguments of the justification for using a low discount rate in "The Stern Review of the Economics of

results using different variable values, the choice of the values of the discount rate causes greater variation in model results than do other model parameters.

**Figure IV-6**
**Selected Estimates of Contemporaneous World GDP**
**Damages From Global Warming Occurring Around 2100**[232]
(Estimates derived by indicated researchers)
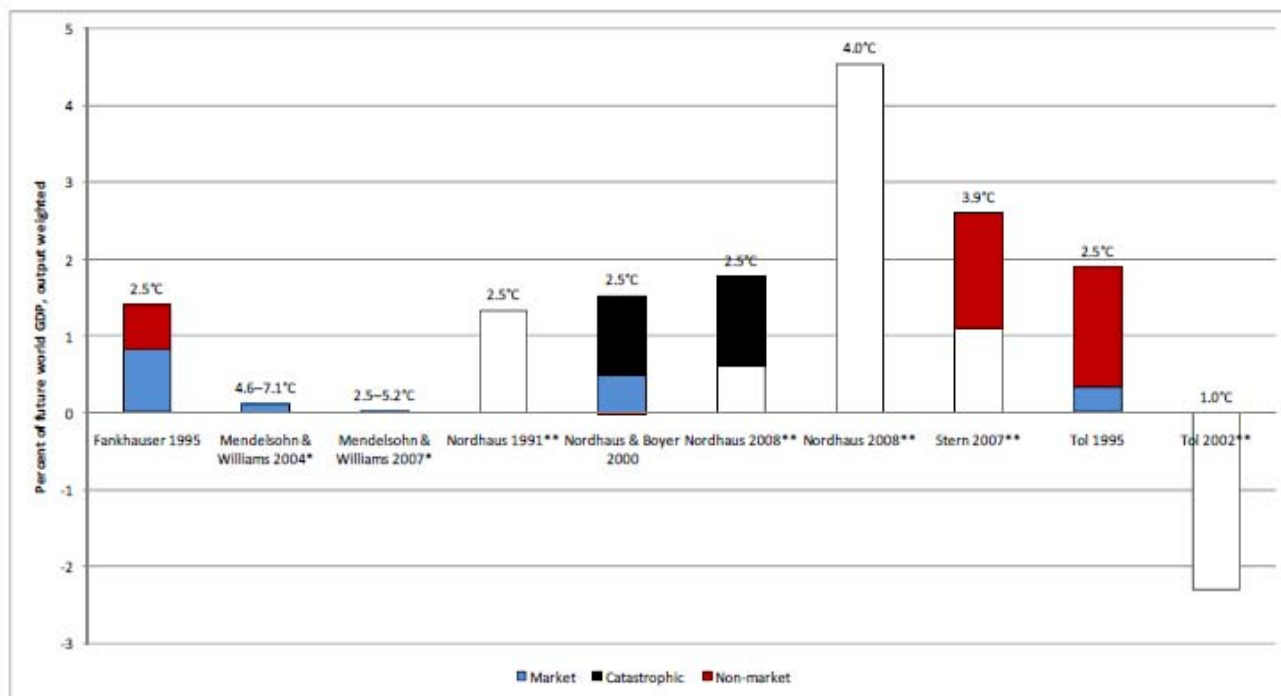


For example, in the summary of results of the latest IWG report, the ranges of estimated SCC values are huge even though the range of discount rates tested is not.[233]  For the three discount rates considered (2.5%, 3% and 5%) using the PAGE IAM and the IMAGE scenario (for projections of economic growth and $CO_2$ emissions), the model results extended over a range of average values for the SCC of from $28 per metric ton of $CO_2$ at a 5% discount rate to $129 at a 2.5% rate.  Using the FUND model and the same IMAGE scenario of growth, the results ranged from $3 (at 5%) to $44 (at 2.5%).  The results in these two examples show that cutting the discount rate in half, from 5% to 2.5%, produces SCC values that range from five times to twelve times as large when computed at 2.5% rather than 5%.

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Climate Change" and a rebuttal by William D. Nordhaus, "A Review of the Stern review on the Economics of Climate Change," *Journal of Economic Literature*, V. XLV, September 2007, pp. 689-97.
[232]See Joseph E. Aldy, et al, "Designing Climate Mitigation Policy", Resources For the Future, RFF DP 08-16, May 2009. P. 50.  http://www.rff.org/RFF/Documents/RFF-DP-08-16.pdf.
[233]See "Technical Support Document:  Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis," Interagency Working Group on the Social Cost of Carbon, The White House, the United States Government, Under Executive Order 12866, Washington, D.C., May 2013, pp. 19-20.

The question thus arises, if relatively small changes in the discount rate produce such large differences in the estimated values of the SCC, why not settle on a value for the discount rate that is closest to the "correct" value?  On this point the entire enterprise of using IAMs to set policy targets is revealed for what it is:  A sophisticated and opaque exercise in creating forecasts far into the future that are based on guesses and subjective assumptions. Literally hundreds of papers have been written that address the issue of how to select the "correct" discount rate, but there is no "correct" answer.

In their initial estimation of the SCC, the IWG devoted nearly a quarter of their "Technical Support Document" to the subject of the discount rate.[234]  In this long section the IWG explains and justifies their choice of the three rates that they used, 2.5%, 3% and 5%, but only two short paragraphs[235] on why they did not use a 7% rate that should have been considered according to OMB Circular A-4 — which is the directive that provides official guidance on how federal government regulatory benefit-cost analysis should be conducted.[236]  Unstated, but clearly a factor, is that if the IWG had used a 7% discount rate in their analysis, much smaller estimates of the value of the SCC would have resulted.  Instead, the IWG defends its use of the 3% rate as the "central value" in its analysis because it "...is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest."[237]

However, almost nothing in the literature of IAMs could be less certain than having a discount rate that is "consistent with estimates provided in the economics literature."  Rather, the choice of the discount rate is the most contentious issue in the IAM literature.  In 2007 when Nicholas Stern published "The Economics of Climate Change:  The Stern Review,"[238] the report was notable because it was the first major report from a well-respected economist that forcefully argued for immediate and major actions to slow the growth of $CO_2$ emissions.  The report was met with a barrage of criticism, most of which pointed out that the major reason for the report's conclusions was it has used a discount rate near zero to generate its gloomy outlook.[239]

## IV.C.  Aggregation and the Cascade of Uncertainty

While some progress has been made in global science and in the understanding of how human activity interacts with and impacts the biosphere, the remaining areas of uncertainty are significant, especially and obviously because of the inability to foresee

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[234]See "Technical Support Document:  Social Cost of Carbon for Regulatory Impact Analysis", Interagency Working Group on the Social Cost of Carbon, The White House, the United States Government, Under Executive Order 12866, Washington, D.C., February 2010, pp. 17-23.
[235]Op cit., IWG, 2010, p.19.
[236]Regulatory Planning and Review, Executive Order 12866 of September 30, 1993," op. cit.
[237]Op cit., IWG, 2010, p. 23.
[238]Nicholas Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge, U.K. 2007.
[239]See William Nordhaus, "A Review of the Stern Review on the Economics of Climate Change", op. cit. for an good example of a rebuttal to the Stern Review's conclusions.

future developments.   With respect to integrated assessment modeling, the uncertainties confronted at each stage of the process are magnified as the uncertainties surrounding each variable in the chain of computations are compounded by the uncertainties found in the next step, creating a "cascade of uncertainties" as one moves through the chain towards final conclusions.   Figures IV-7 and IV-8 show the "uncertainty explosion" as these ranges are multiplied to encompass a comprehensive range of future consequences, including physical, economic, social, and political impacts and policy responses.[240]   Each set of uncertainties through the IAM process gets magnified at each step until, by the end, it is unclear what reality is.

**Figure IV-7**
**Range of Major Uncertainties Typical in Impact Assessments**
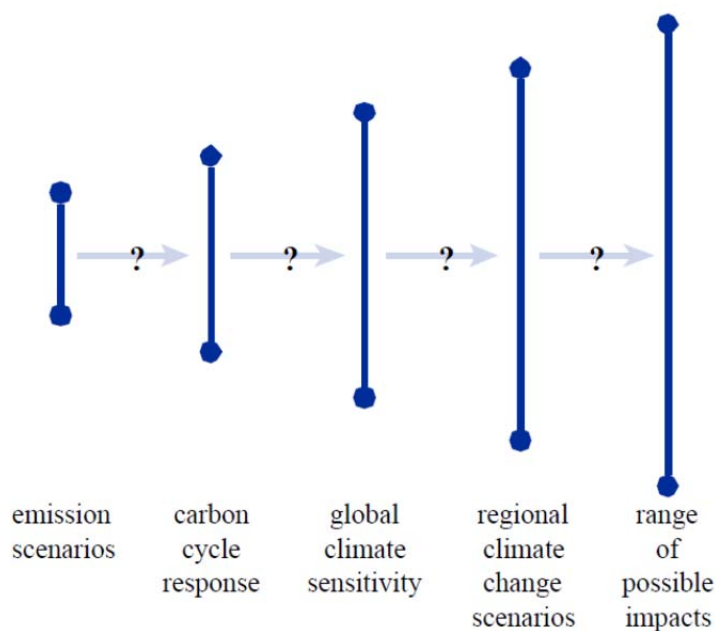


The authors of the IPCC Second Assessment report state "A single aggregated damage function or a 'best guess' climate sensitivity estimate is a very restricted representation of the wide range of beliefs available in the literature or among lead authors about climate sensitivity or climate damages. . . .  The cascade of uncertainty implied by coupling the separate probability distributions for emissions and biogeochemical cycle calculations to arrive at concentrations needed to calculate radiative forcing, climate sensitivity, climate impacts, and valuation of such impacts into climate damage functions has yet to be produced in the literature." [241]

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[240]See IPCC, *Third Assessment Report: Climate Change 2001* (TAR), Chapter 2:  "Method and Tools," p. 130.  http://www.ipcc.ch/ipccreports/tar/wg2/pdf/wg2TARchap2.pdf.
[241]Ibid., p. 130.

In addition, the level of uncertainty does not remain constant over time. As Kelly and Kolstad note in their review of IAMs, there are two kinds of uncertainty, which they label stochastic uncertainty and parametric uncertainty. [242] The latter can be expected to decline over time as scientists learn more about the operation of the global climate system and the value for parameters such as "climate sensitivity" become more accurate. Stochastic uncertainty refers to those phenomena that impact economic or geophysical processes but are not included in the model, processes such as earthquakes, volcanic eruptions, or abrupt economic downturns such as the Global Financial Crisis. A major element of stochastic uncertainty is the fact that we cannot know the future trend of technology or the economy and are, therefore, always susceptible to "surprises".

**Figure IV-7**
**Cascade of Uncertainties: With Each Additional Box the Uncertainties Increase**



Figure 1. Cascade of Uncertainties. With each additional box the uncertainty increases. Source: Intergovernmental Panel on Climate Change (IPCC), Working Group I Third Assessment Report. 2001.

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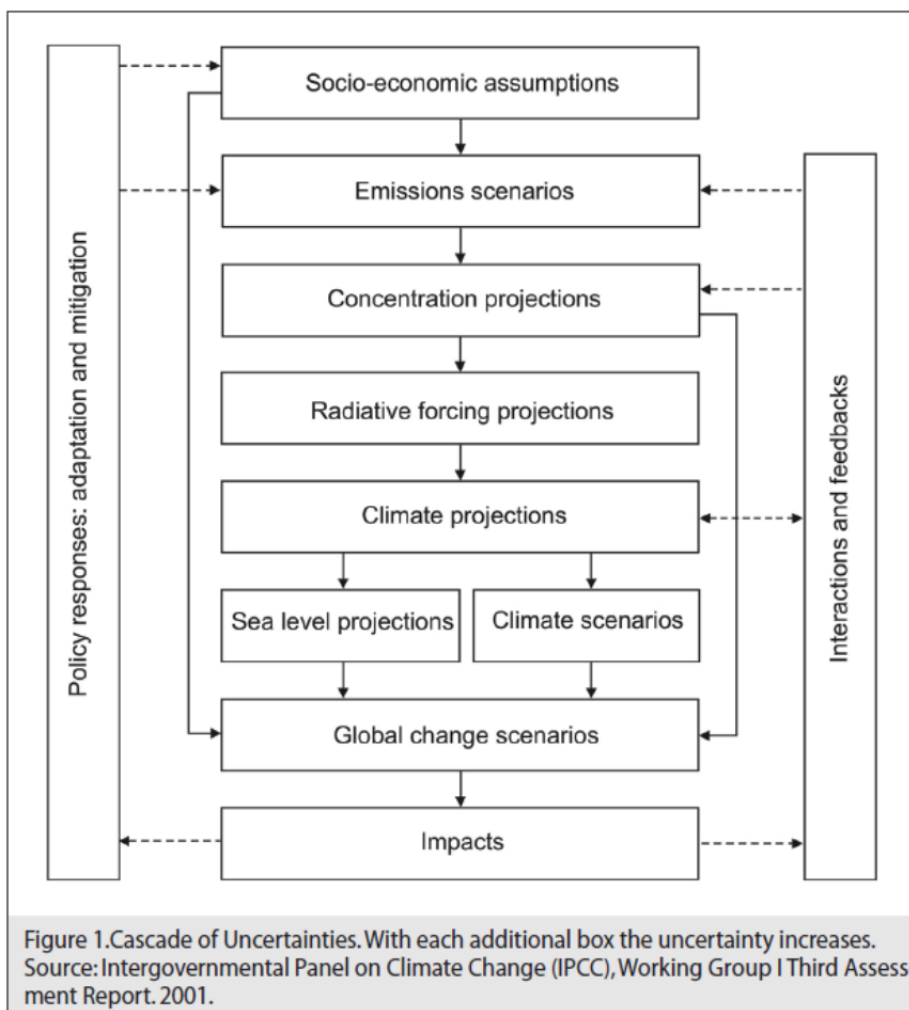
[242]See David L. Kelly and Charles D. Kolstad, "Integrated Assessment Models For Climate Change Control", US Department of Energy grant number DE-FG03-96ER62277, Current Version: November 1998. Pp. 8-9. http://www.econ.ucsb.edu/papers/wp31-98.pdf.

Some of the uncertainty currently present in IAMs may gradually lesson over time, and IAM model builders are including modeling techniques such as Monte Carlo analysis and stochastic simulation within their models to address the uncertainties. Nevertheless, for the foreseeable future IAM analysis will be saddled with the fact that the degree of uncertainty within the process is immense and renders any IAM results highly questionable.

## IV.D.  IWG SCC Estimates:  "Close to Useless"

IAMs have been in use for over two decades and progress has been made in their sophistication and in the insights they provide about the interaction between human activities and the biosphere.  In a background note for the Overseas Development Institute, Nicola Cantore summarized some of the positive results that arise from using IAMs to help design climate policies.[243]  He noted that compared to other less sophisticated complex scientific tools, IAMs offer a number of benefits when designing policy:

- They allow the setting up of simulations based on scenarios for the future.
- They incorporate mechanisms governing the complex link between economy and environment.
- They can deal with uncertainty about the future evolution of economic and environmental parameters (e.g. technology, degree of absorption of pollution from the atmosphere).
- They can be used to isolate the effects of a particular parameter on other mechanisms governing economic and environmental processes (e.g. the effect of China's population growth on the rest of the world economy).
- They provide a large amount of information about the path of significant policy variables over time.

Nevertheless, despite the progress that has been made in the building and use of IAMs, perhaps most importantly in bringing together scholars and scientist in a joint effort to assess global climate change, the IAM process remains a very questionable tool for establishing explicit policy goals.  In a recent assessment of the limitations of IAMs for use in policy, Granados and Carpintero conclude:[244]

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[243]See Nicola Cantore, "The Relevance of Climate Change Integrated Assessment Models," in *Policy Design*," Overseas Development Institute (ODI), Background Note, December 2009, p. 3, www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/5060.pdf.
[244]Jose A. Tapia Granados and Oscar Carpintero, "Dynamics and Economic Aspects of Climate Change", Chapter 3 in *Combating Climate Change: An Agricultural Perspective*, edited by Manjit S. Kang & Surinder S. Banga, CRC Press, 2013. Pp. 37-38.

The lack of robustness of results of different IAMs indicates the limitations of the neoclassical approach, which constitutes the theoretical base of most IAMs; the variety of so-called ad hoc assumptions (often qualified as "heroic" by their own authors), and the controversial nature of the methods to estimate the monetary value of non-market costs and benefits (mortality, morbidity, damage to ecosystems, etc.). These features explain why many contributions of this type of macroeconomics-oriented IAMs have been criticized for their dubious political usefulness and limited scientific soundness.

They then list several important shortcomings of IAMs, most of which have been discussed above:

- Lack of transparency to explain and justify the assumptions behind the estimates,
- Questionable treatment of uncertainty and discounting of the future,
- Assumption of perfect substitutability between manufactured capital and "natural" capital in the production of goods and services, and
- The way IAMs estimate monetary costs of non-market effects, which can lead to skepticism about policies based on the results of the models.

In an overview of questions of ethics and uncertainty that are endemic in the construction and application of IAMs to questions of global climate change, Frank Ackerman and his colleagues make the following points regarding the appropriateness of IAMs for policy choices:[245]

There are two take-home messages here. The first is that policy makers and scientists should be skeptical of efforts by economists to specify optimal policy paths using the current generation of IAMs. These models do not embody the state of the art in the economic theory of uncertainty, and the foundations of the IAMs are much shakier than the general circulation models that represent our best current understanding of physical climate processes. ***Not only do the IAMs entail an implicit philosophical stance that is highly contestable, they suffer from technical deficiencies that are widely recognized within economics.*** Second, economists do have useful insights for climate policy. While economics itself is insufficient to determine the urgency for precautionary action in the face of low-probability climate catastrophes, or make judgments about inter-generational and intragenerational justice, it does point the way towards achieving climate stabilization in a cost-effective manner. ***IAMs cannot, however, be looked to as the ultimate arbiter of climate policy choices.*** *(Emphasis added by authors.)*

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[245]Frank Ackerman, et al, "Limitations of Integrated Assessment Models of Climate Change," *Climatic Change*, 2009, 95:297–315, p. 312.

Thus, there is a limited amount of research linking climate impacts to economic damages, and much of this is speculative, at best. Even the IWG admits that the exercise is subject to "simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships."[246] Further, the IWG also admits that each model uses a different approach to translate global warming into damages, and that transforming the stream of economic damages over time into a single value requires "judgments" about how to discount them.[247]

This chapter began with a quote from Nicholas Stern, and it is appropriate to conclude with a quote from him. Here he summarizes the many of the weaknesses of integrated assessment modeling discussed here.[248]

As I have argued, it is very hard to believe that models where radically different paths have to be compared, where time periods of hundreds of years must be considered, where risk and uncertainty are of the essence, and where many crucial economic, social, and scientific features are poorly understood, can be used as the main quantitative plank in a policy argument. Thus, IAMs, while imposing some discipline on some aspects of the argument, risk either confusing the issues or throwing out crucial features of the problem.

In conclusion, we find that, to paraphrase Robert Pindyck,[249] the IWG SCC estimates are based on IAMs containing fatal flaws and that the IWG estimates are thus "close to useless" as tools for policy analysis.

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[246]Interagency Working Group, 2010, op. cit.
[247]Ibid.
[248] Stern, op cit., "The Economics of Climate Change", p. 17.
[249]Pindyck, op. cit.

## V.  CARBON BENEFITS COMPARED TO CARBON COSTS

### V.A.  Fossil Fuels, $CO_2$, and World GDP

In Chapter II, we noted the critical role played by fossil fuels in the development of the world economy over the past two centuries.[250]  This was summarized in Figure II-5, reproduced below as Figure V-1, which illustrates the relationship between GDP per capita and the $CO_2$ emissions resulting from fossil fuel utilization.

**Figure V-1**
**Global Progress, 1760–2009 — as Indicated by Trends in World Population, GDP Per Capita, Life Expectancy, and $CO_2$ Emissions From Fossil Fuels**
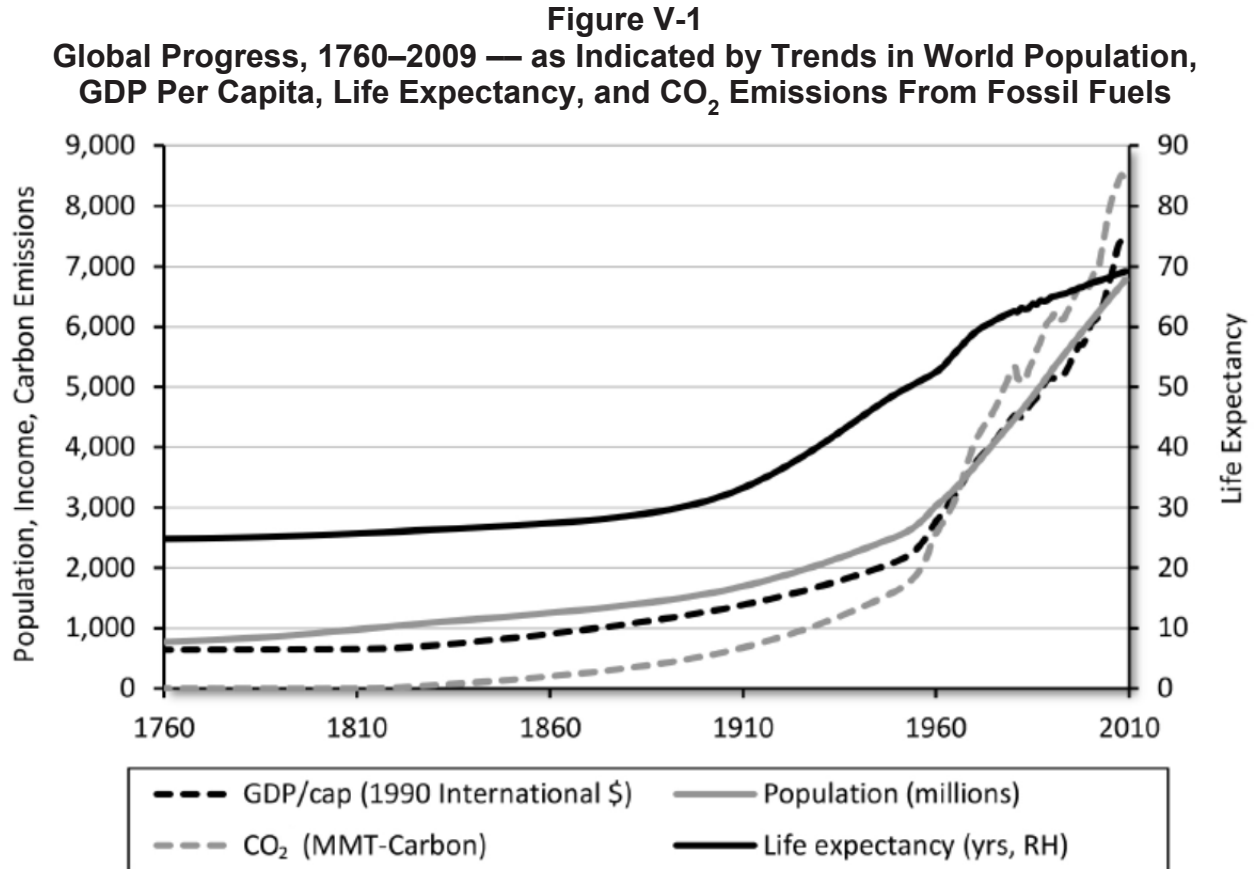


Source:  Goklany, 2012.

There may be an imperfect link between fossil fuel consumption and GDP and, as discussed in Section V.D, marginal benefits differ from average benefits and not all energy is fossil-based.  Nevertheless:

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[250]As noted in Section II.B, not all of future world energy will be derived from fossil fuels.  See the discussion in Section V.D.

- As Vaclav Smil states: "The most fundamental attribute of modern society is simply this: Ours is a high energy civilization based largely on combustion of fossil fuels."[251]
- As Robert Ayres concludes: "The rather standard assumption that economic growth is independent of energy availability must be discarded absolutely. It is not tenable. It implies, wrongly, that energy-related emissions (GHGs) can be reduced or eliminated without consequences for growth."[252]
- As James Brown, et al. conclude: "The bottom line is that an enormous increase in energy supply will be required to meet the demands of projected population growth and lift the developing world out of poverty without jeopardizing current standards of living in the most developed countries."[253]
- As David Stern finds, "The theoretical and empirical evidence indicates that energy use and output are tightly coupled, with energy availability playing a key role in enabling growth. Energy is important for growth because production is a function of capital, labor, and energy, not just the former two or just the latter as mainstream growth models or some biophysical production models taken literally would indicate."[254]
- And Robert Ayres and Benjamin Warr find that economic growth in the past has been driven primarily not by "technological progress" in some general and undefined sense, but specifically by the availability of ever cheaper energy – and useful work – from coal, petroleum, or gas."[255]

Gail Tverberg notes that historical estimates of energy consumption, population, and GDP are available for many years, and she also found a close connection between energy growth, population growth, and economic growth.[256] She utilized the population and GDP estimates of Angus Maddison and the energy estimates of Vaclav Smil, BP, EIA, and other sources to estimate average annual growth rates for various historical periods – Figure V-2. Using these data, she explored the implications of reducing fossil fuel use by 80 percent by 2050 and rapidly ramping up renewables at the same time –

[251]Vaclav Smil, *Energy at the Crossroads: Global Perspectives and Uncertainties*, MIT Press, 2005.
[252]Robert U. Ayres, Jeroen C.J.M. van don Bergh, Dietmar Lindenberger, and Benjamin Warr, "The Underestimated Contribution of Energy to Economic Growth," INSEAD, Fontainebleau, France, 2013.
[253]James H. Brown, William R. Burnside, Ana D. Davidson, John P. DeLong, William C. Dunn, Marcus J. Hamilton, Jeffrey C. Nekola, Jordan G. Okie, Norman Mercado-Silva, William H. Woodruff, and Wenyun Zuo, "Energetic Limits to Economic Growth," *BioScience*, January 2011, Vol. 61, No. 1.
[254]David I. Stern,"The Role of Energy in Economic Growth," The United States Association for Energy Economics and the International Association for Energy Economics, USAEE-IAEE WP 10-055, November 2010.
[255]Robert U. Ayres and Benjamin Warr, *The Economic Growth Engine: How Energy and Work Drive Material Prosperity*, Northampton, MA: Edward Elgar. 2009.
[256]Gail Tverberg, "An Energy/GDP Forecast to 2050," http://www.resilience.org/stories/2012-08-14/ energygdp-forecast-2050.

an unrealistic, but widely advocated goal.[257]  The question she posed is "If we did this, what would such a change mean for GDP, based on historical energy and GDP relationships back to 1820?"[258]

**Figure V-2**
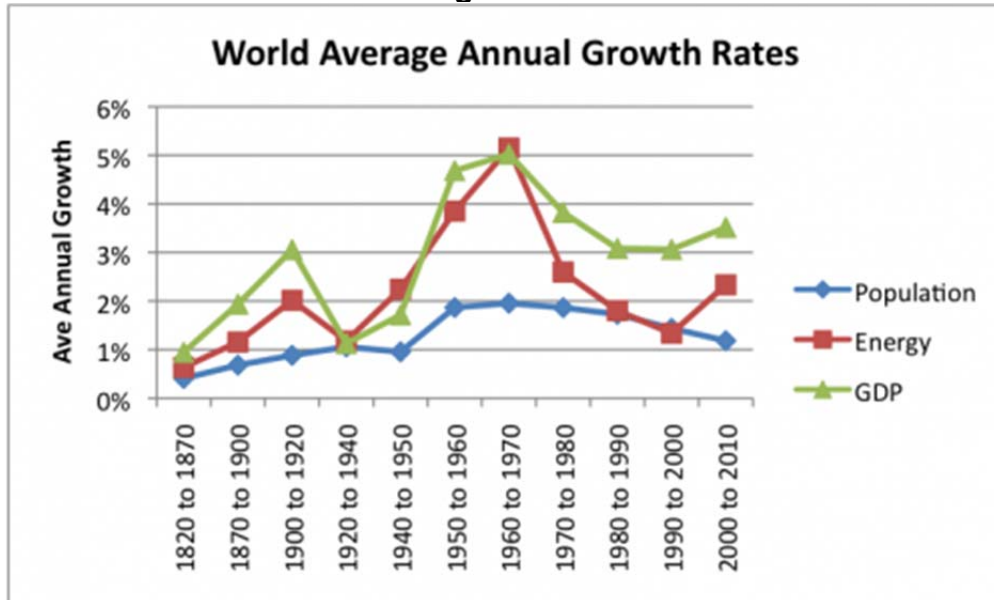


Source:  Tverberg, 2012

She utilized regression analysis to create what she termed a "best-case" estimate of future GDP if a decrease in energy supply of the magnitude hypothesized were to take place.  She considered it a best-case scenario because it assumes that the patterns observed on the up-slope of the trends will continue on the down-slope.  For example, it assumes that financial systems will continue to operate as currently, international trade will continue as in the past, and that there will not be major problems with overthrown governments or interruptions to electrical power.  It also assumes that the world will continue to transition to a service economy, and that there will be continued growth in energy efficiency.

Her results are sobering.  Specifically, based on her regression analysis she found that, with the assumptions made:[259]

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[257]The idea of reducing world fossil fuel use 80 percent by 2050 may be unrealistic, but it is a widely advocated goal.  See, for example:  European Commission, "Roadmap For Moving to a Low-Carbon Economy in 2050," Brussels, March 2011; Jane C. S. Long and Jeffery Greenblatt, "The 80% Solution: Radical Carbon Emission Cuts for California," *Issues in Science and Technology*, September 2012; U.S. National Academies of Science, *Transitions to Alternative Vehicles and Fuels*, Washington, D.C., National Academies Press, 2013; World Energy Council, "Goal of Fossil Fuel Independence by 2050," 2013, www. worldenergy.org/wp-content/uploads/2013/09/ Pack-Leaders-goals-A4.pdf.
[258]Tverberg, op.cit.
[259]Ibid.

- World per capita energy consumption in 2050 would be about equal to world per capita energy consumption in 1905.
- World economic growth would average a negative 0.59 percent per year between 2012 and 2050, meaning that the world would be more or less in perpetual recession through 2050. Given past relationships, this would be especially the case for Europe and the U.S.
- Per capita GDP would decline by 42 percent for the world between 2010 and 2050, on average.
- The decrease in per capita GDP would likely be greater in higher income countries, such as the U.S. and Europe, because a more equitable sharing of resources between rich and poor nations would be needed, if the poor nations are to have enough of the basics.

Since, as noted, these are optimistic best case estimates, it is likely that fossil fuel reductions of this magnitude by 2050 would more likely result in decreases in world per capita GDP in the range of 50 – 70 percent. As Tverberg notes, "The issue of whether we can really continue transitioning to a service economy when much less fuel in total is available is also debatable. If people are poorer, they will cut back on discretionary items. Many goods are necessities: Food, clothing, basic transportation. Services tend to be more optional — getting one's hair cut more frequently, attending additional years at a university, or sending grandma to an Assisted Living Center. So the direction for the future may be toward a mix that includes fewer, rather than more, services, and so will be more energy intensive."[260]

Further, she asks "If our per capita energy consumption drops to the level it was in 1905, can we realistically expect to have robust international trade, and will other systems hold together? While it is easy to make estimates that make the transition sound easy, when a person looks at the historical data, making the transition to using less fuel looks quite difficult, even in a best-case scenario." She concludes that such a worldwide reduction in fossil fuels is "very unlikely."[261]

Using similar data, Robert Zubrin analyzed the relationship between global GDP per capita and carbon use from 1800 through 2010.[262] He found that the relationship is generally linear, with GDP per capita and carbon use both increasing by a factor of ten between 1910 and 2010. What is even more important, however, is the fact that the carbon-use benefits identified are enormous. Zubrin notes that just in the past 55 years — well within living memory — in line with a fourfold increase in carbon use, the average global GDP per capita has quadrupled. Accordingly, "That is an economic

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[260]Ibid.

[261]Ibid. For an illustration of the difficulties of implementing even minimally restrictive carbon policies, see Roger H. Bezdek, "Carbon Policy Around the Globe: Degrees of Disaster," presented at The Energy Council 2013 Global Energy and Environmental Issues Conference, Lake Louise, Alberta, Canada, December 2013.

[262]Robert Zubrin, The Cost of Carbon Denial," *National Review*, July 31, 2013.

miracle that has lifted billions of people out of hopeless poverty — and not just in the Third World."[263]

To assess the economic value of fossil fuels in dollar terms, Zubrin compared absolute GDP to carbon utilization — Figure V-3. This illustrates that "The relationship between GDP and carbon utilization is not merely linear, but is more nearly quadratic, with total economic output rising as roughly the square of carbon use."[264]  For example, Zubrin estimates that since 1975, carbon use has doubled, in conjunction with a quadrupling of global GDP.  Further, taking the ratio of current global GDP to carbon use and dividing it out indicates that, at present, each ton of carbon used produces about $6,700 of global GDP.[265]

**Figure V-3**
**Global GDP vs. Carbon Utilization, 1800 - 2010**
(2010 Dollars)
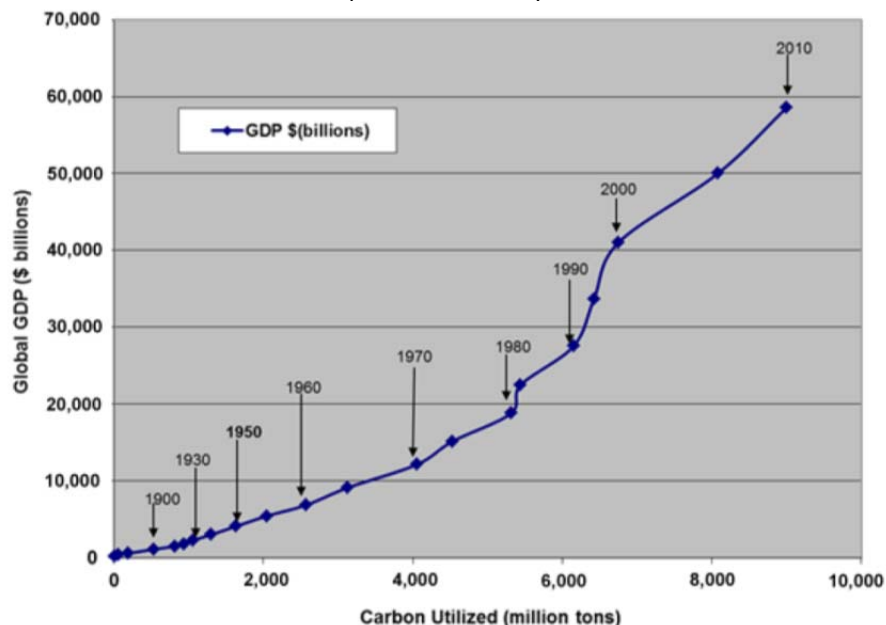


Source:  Zubrin, 2013.

Zubrin thus estimates that each ton of carbon denied to the world economy destroys about $6,700 worth of wealth, and:  "That is the difference between life and death for a Third World family.  Seven tons denied corresponds to a loss of $47,000, or

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[263]Zubrin concludes:  "To claim that this came at a comparable "social cost," one would have to show that there has been a climatic catastrophe.  Has there?  How much better was the weather in the 1950s than it is today?  If you don't know, there are plenty of people who were around then whom you can ask.  But I'll save you the trouble.  The answer is: Not at all.  So there was no climatic social cost to the carbon-driven miracle of the 20th century, but there would have been economic cost of genocidal dimensions had carbon deniers been around and able to prevent it."  Ibid.
[264]Zubrin, ibid.
[265]Specifically, Zubrin used the ratio of a recent estimate of global GDP ($60 trillion) to carbon use (9 billion tons) to derive the estimate of about $6,700.  Ibid.

a good American job.  Since 2007, the combination of high oil prices and a depressed economy has reduced the United States' use of carbon in the form of oil by about 130 million tons per year.  At a rate of $6,700 per ton, this corresponds to a GDP loss of $870 billion, equivalent to losing 8.7 million jobs, at $100,000 per year each.  Were we to implement the program of the Kyoto treaty, and constrict global carbon use to 1990 levels, we would cut global GDP by $30 trillion per year, destroying an amount of wealth equal to the livelihood of half of the world's population.  Such are the costs of carbon denial."[266]

In this chapter we are concerned with comparing the Social Cost of Carbon (SCC) as defined by the IWG[267] with the social or economic benefits produced by the fossil fuels which generate $CO_2$.  Accordingly, to conform to IWG conventions we use $CO_2$ emissions rather than carbon emissions,[268] and we utilize EIA and IEA economic data normalized to 2007 dollars to be consistent with the base year dollars used by the IWG in developing its SCC estimates.  The relationship between world GDP and $CO_2$ emissions over the past century is illustrated in Figure V-4.  This figure shows a similar strong relationship between world GDP and the $CO_2$ emissions from fossil fuels as indicated in Figures V-1 through V-3.

**Figure V-4**
**Relationship Between World GDP and $CO_2$ Emissions**
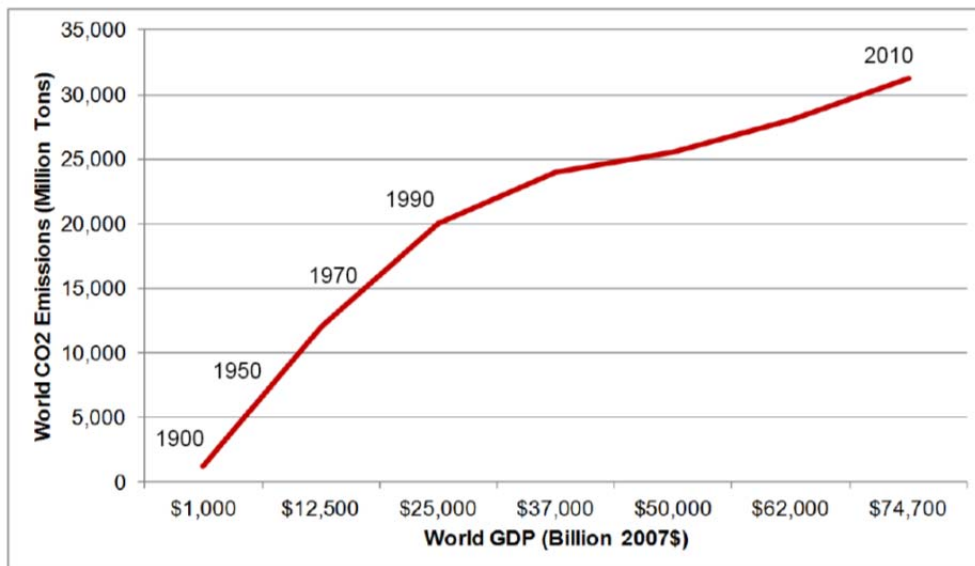


Source:  U.S. Energy Information Administration, International Energy Agency, U.S. Bureau of Economic Analysis, and Management Information Services, Inc.

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[266]Ibid.
[267]U.S. Government Interagency Working Group, 2010 and 2013, op.cit.
[268]A ton of $CO_2$ contains 0.2727 tons of carbon.

## V.B.  $CO_2$ Benefits and Costs in 2010

Basically, Figure V-4 shows that in 2010, expressed in 2007 dollars, a ton of $CO_2$ resulting from fossil fuel utilization "created" about $2,400 in world GDP.  This is a reasonable and defensible estimate of the indirect benefit of $CO_2$ – indirect because it is the result of the energy produced by the fossil fuels from which the $CO_2$ derives.[269]  It thus does not include the direct $CO_2$ benefits discussed in Chapter III.  We can compare these indirect benefits with the SCC estimates derived by the IWG.

As discussed in Chapter IV, the SCC is an estimate of the monetized damages associated with an incremental increase in carbon (or $CO_2$) emissions in a given year. That is, it is the increase in aggregate income that would make society just as well off as a one unit decrease in carbon emissions in a particular year.[270]  The IWG selected four SCC values for use in regulatory analyses, and the benefits from reduced $CO_2$ emissions can be estimated by multiplying changes in emissions in any year by the SCC value for that year.[271]  To estimate SCC, the IWG used three discount rates to span a range of "certainty-equivalent" constant discount rates:

- 2.5 percent per year, which was selected to incorporate concern that interest rates are highly uncertain over time,
- 3.0 percent per year, which was selected because it is consistent with estimates in the economics literature and OMB Circular A-4 guidance for the consumption rate of interest,[272] and
- 5.0 percent per year, which was selected to represent the possibility climate damages are positively correlated with market returns.

In addition, the IWG included a fourth extreme value:  "The 95th percentile at a 3.0 percent discount rate, representing higher than-expected economic impacts further out in the tails of the distribution."[273]

As discussed in Chapter IV, the first IWG SCC estimates were published in February 2010, but these were subsequently revised significantly upward in May 2010.[274]  The most recent SCC estimates are given in Table V-1 and the original

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[269]See the discussion at the beginning of Section V.A.

[270]It includes (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.  See Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Support Document:  Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," May 2013; Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010; and Charles Griffiths, "The Social Cost of Carbon for Regulatory Impact Analyses, the National Center for Environmental Economics, February 17, 2011.

[271]Ibid.

[272]U.S. Office of Management and Budget, "Regulatory Impact Analysis: A Primer," Circular A-4, September 17, 2003.

[273]Interagency Working Group, op. cit.

[274]Prior to 2010 the "official" U.S. government SCC estimate was, presumably, zero.

estimates are given in Table V-2.  Table V-I shows that the revised (2013) SCC estimates for 2010 are (in 2007 dollars):

- 5.0% — $11,
- 3.0% — $33,
- 2.5% — $52, and
- 3.0% 95th — $90.

Table V-2 shows that the original (2010) SCC estimates for 2010 are (in 2007 dollars):

- 5.0% — $4.7,
- 3.0% — $21.4,
- 2.5% — $35.1, and
- 3.0% 95th — $64.9.

**Table V-1**
**Revised (2013) Social Cost of CO2, 2010 – 2050**
(In 2007 dollars per metric ton of $CO_2$)

| Discount Rate Year | 5.0% Avg | 3.0% Avg | 2.5% Avg | 3.0% 95th |
|---|---|---|---|---|
| 2010 | 11 | 33 | 52 | 90 |
| 2015 | 12 | 38 | 58 | 109 |
| 2020 | 12 | 43 | 65 | 129 |
| 2025 | 14 | 48 | 70 | 144 |
| 2030 | 16 | 52 | 76 | 159 |
| 2035 | 19 | 57 | 81 | 176 |
| 2040 | 21 | 62 | 87 | 192 |
| 2045 | 24 | 66 | 92 | 206 |
| 2050 | 27 | 71 | 98 | 221 |

Source:  Interagency Working Group on Social Cost of Carbon, United States Government, 2013.

**Table V-2**
**Original (2010) Social Cost of CO2, 2010 – 2050**
(In 2007 dollars per metric ton of $CO_2$)

| Discount Rate | 5% | 3% | 2.5% | 3% |
|---|---|---|---|---|
| Year | Avg | Avg | Avg | 95th |
| 2010 | 4.7 | 21.4 | 35.1 | 64.9 |
| 2015 | 5.7 | 23.8 | 38.4 | 72.8 |
| 2020 | 6.8 | 26.3 | 41.7 | 80.7 |
| 2025 | 8.2 | 29.6 | 45.9 | 90.4 |
| 2030 | 9.7 | 32.8 | 50.0 | 100.0 |
| 2035 | 11.2 | 36.0 | 54.2 | 109.7 |
| 2040 | 12.7 | 39.2 | 58.4 | 119.3 |
| 2045 | 14.2 | 42.1 | 61.7 | 127.8 |
| 2050 | 15.7 | 44.9 | 65.0 | 136.2 |

Source: Interagency Working Group on Social Cost of Carbon, United States Government, 2010.

Combining this information with that shown in Figure V-4 permits the derivation of $CO_2$ benefit-cost (B-C) ratios, which are simply the ratio of $CO_2$ benefits to $CO_2$ costs in a particular year. A B-C ratio is derived by dividing the benefit estimate by the cost estimate: A ratio of less than 1.0 indicates that costs outweigh benefits, and a B-C ratio greater than one indicates that benefits exceed costs.[275]

The $CO_2$ B-C ratios for 2010 based on the 2013 IWG report are shown in Figure V-5 and the $CO_2$ B-C ratios for 2010 based on the 2010 IWG report are shown in Figure V-6. These figures indicate that $CO_2$ benefits exceed any estimates of $CO_2$ costs by – literally — orders of magnitude:

- Based on the 2013 IWG report, the B-C ratios for the three discount rates range between about 50-to-1 and 250-to-1.
- Based on the 2010 IWG report, the B-C ratios for the three discount rates range between about 70-to-1 and 500-to-1.
- Even using the extreme 3.0% 95th estimates, the B-C ratios range between about 30-to-1 and 40-to-1.

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[275]See, for example, Gerald Shively and Marta Galopin, "An Overview of Benefit-Cost Analysis," Purdue University, www.agecon.purdue.edu/staff/shively/COURSES/AGEC406/reviews/bca.htm.

**Figure V-5**
**2010 CO$_2$ Benefit-Cost Ratios**
(Based on 2013 IWG Report)
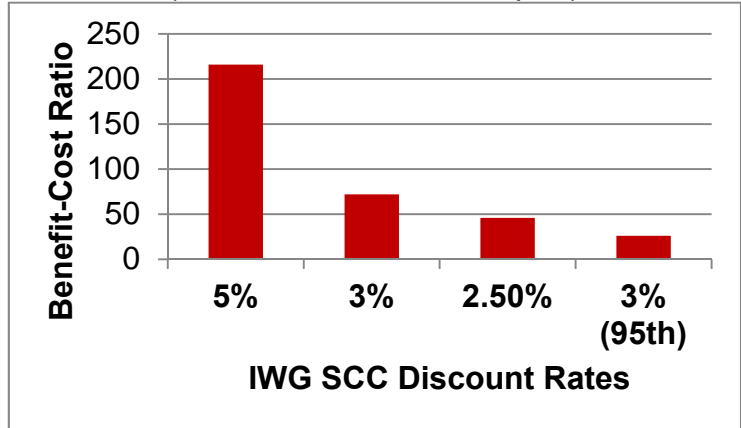


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

**Figure V-6**
**2010 CO$_2$ Benefit-Cost Ratios**
(Based on 2010 IWG Report)
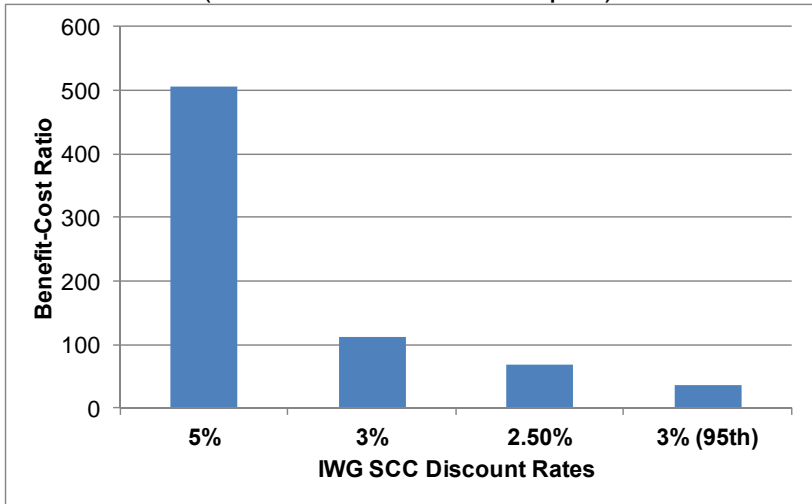


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

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It should be noted that, normally, B-C ratios in the range of 2-to-1 or 3-to-1 are considered very favorable.[276]   Thus, in other words, the 2010 benefits of $CO_2$ overwhelmingly outweigh the estimated $CO_2$ costs no matter which IWG report or discount rates are used.  In fact, for 2010, any of the IWG SCC estimates are relatively so small as to be in the statistical noise of the estimated $CO_2$ benefits.


## V.C.  Future $CO_2$ Costs and Benefits

Section V.B indicates that recent and current $CO_2$ benefits are orders of magnitude larger than any SCC estimates.  Since much of the relevant SCC debate concerns future emissions, future potential costs, and future policies, here we analyze forecast $CO_2$ benefits compared to available SCC forecasts.   We thus examine forecasts of world economic growth, fossil fuel utilization, and $CO_2$ emissions.

IEA notes that its forecasts are highly sensitive to the underlying assumptions about the rate of growth of GDP; that is, GDP growth requires energy and energy demand is driven by economic growth.[277]  IEA assumes that world GDP, in purchasing power parity (PPP), will grow by an average of 3.5 percent annually over the period 2010-2035.[278]   It finds that most forecasts of economic growth at the world level and regional levels over the long terms fall within a relatively narrow range, even if there may be significant divergence between countries.[279]

Similarly, as shown in Figure V-7, EIA forecasts that from 2010 to 2040, real world GDP growth averages 3.6 percent in its Reference case.[280]   The growth rate slows over the period, peaking at 4.0 percent between 2015 and 2020 and declining to 3.5 percent between 2020 and 2040.  Global economic growth in the Reference case is led by the emerging economies:  Real GDP growth from 2010 to 2040 averages 4.7 percent for the non-OECD region, compared with 2.1 percent for the OECD region — Figure V-8.  Slower global economic growth after 2020 is primarily a result of slower growth in the emerging economies, particularly China.

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[276]Ibid.
[277]International Energy Agency, *World Energy Outlook*, 2012, op. cit.
[278]Ibid.
[279]IEA bases its medium-term GDP growth assumptions primarily on IMF forecasts, and its longer term GDP assumptions are based on forecasts made by various economic forecasting organizations, as well as IEA's assessment of prospects for the growth in labor supply and improvements in productivity.
[280]On a purchasing power parity (PPP) basis.  U.S. Energy Information Administration, *International Energy Outlook*, op. cit.

**Figure V-7**
**World GDP Forecast**
(EIA Reference Case)
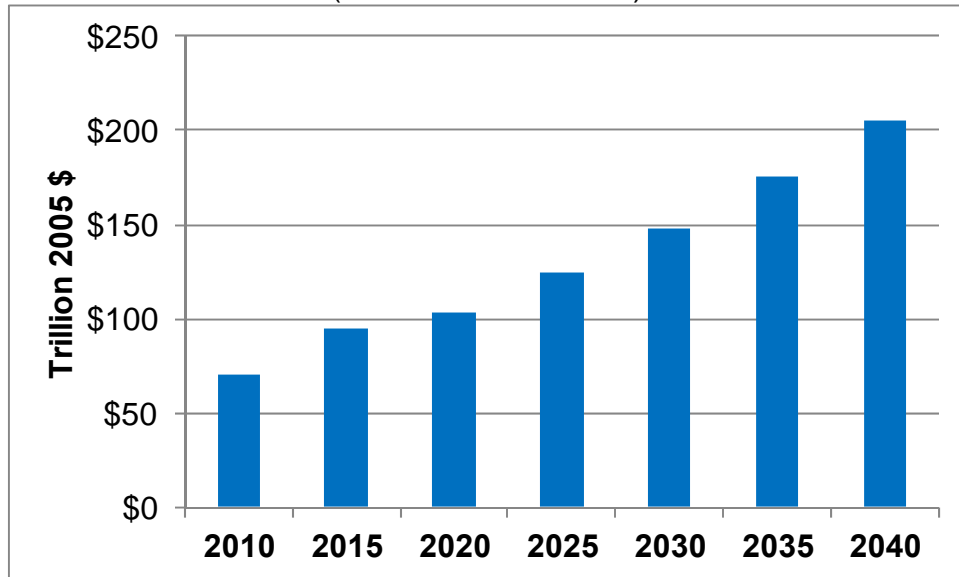
**Figure V-8**
**World total GDP by Region 1990-2040**
(Trillion 2005 dollars — EIA Reference Case)

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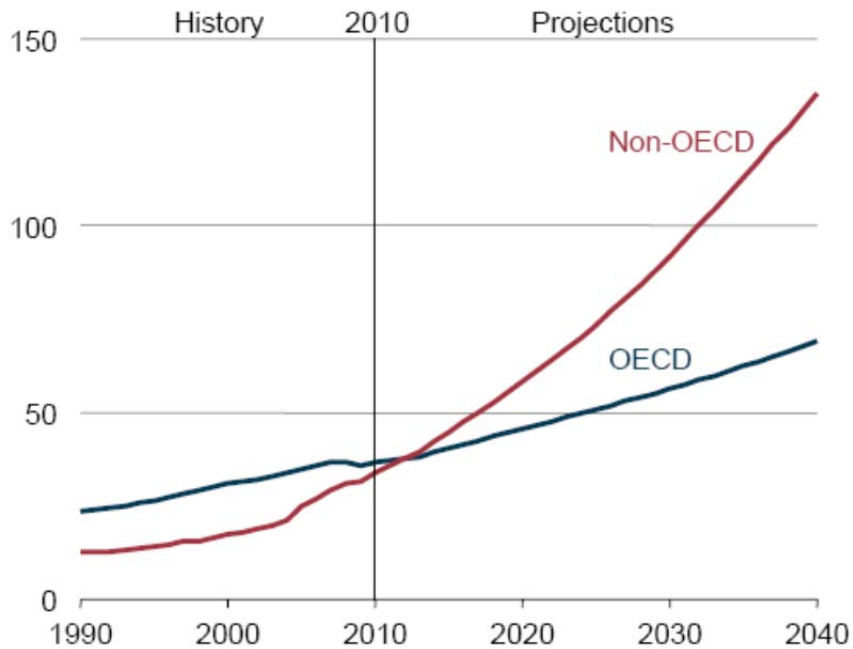
EIA notes that energy-related carbon dioxide emissions — emissions produced through the combustion of liquid fuels, natural gas, and coal — account for much of the world's anthropogenic greenhouse gas emissions (GHG).[281]   And, as a result, energy consumption is an important component of the global climate change debate.  In the EIA *IEO 2013* Reference case, which does not assume new policies to limit GHG, world energy-related carbon dioxide emissions increase from 31.2 billion metric tons in 2010 to 36.4 billion metric tons in 2020 and to 45.5 billion metric tons in 2040 – Figure V-9.

**Figure V-9**
**Forecast World Energy-related CO$_2$ Emissions**
(EIA Reference case)
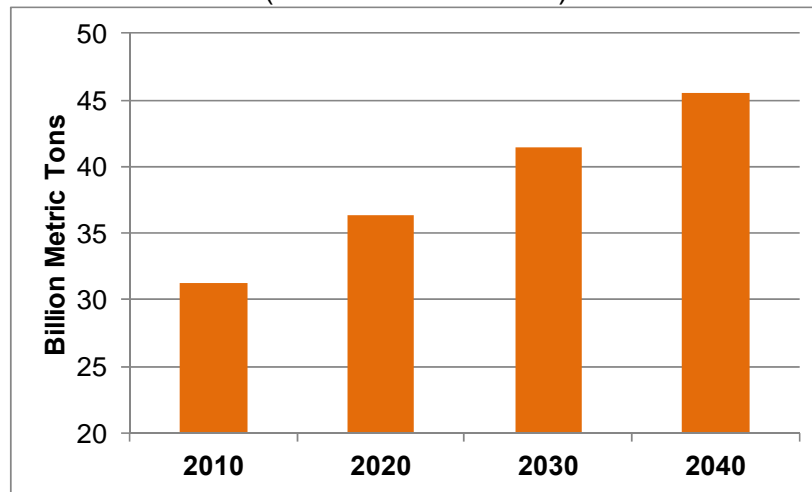


Source:  U.S. Energy Information Administration.

As shown in Figure V-10, EIA forecasts that much of the growth in CO$_2$ emissions is attributed to the developing non-OECD nations that continue to rely heavily on fossil fuels to meet rapidly growing energy demand.  Non-OECD carbon dioxide emissions total 31.6 billion metric tons in 2040, or 69 percent of the world total.  In comparison, OECD CO$_2$ emissions total 13.9 billion metric tons in 2040 — 31 percent of the world total.  EIA also cautions that near-term events can have a substantial impact on year-to-year changes in energy use and the corresponding CO$_2$ emissions, and notes that recent years have seen fluctuations in economic growth and, as a result, energy demand and CO$_2$ emissions.[282]

During the 2008-2009 global economic recession, world energy consumption contracted, and as a result total world carbon dioxide emissions in 2009 were about one percent lower than in 2008.  In 2010, as the world economy rebounded — especially among the emerging economies – total CO$_2$ emissions increased by about 5.1 percent.

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[281]Ibid.

[282]The *IEO 2013* Reference case projections are, to the extent possible, based on existing laws and policies, and EIA notes that projections for carbon dioxide emissions could change significantly if new laws and policies aimed at reducing greenhouse gas emissions were implemented in the future.

**Figure V-10**
**World Energy-related CO$_2$ Emissions, 1990-2040**
(Billion metric tons – EIA Reference case)
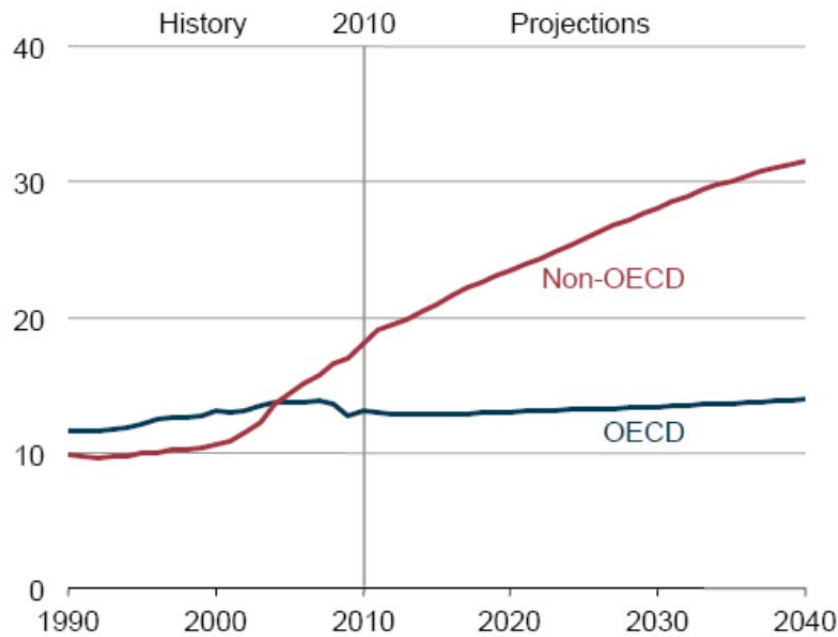


Source: U.S. Energy Information Administration.

As is the case with IEA, for EIA expectations of future rates of economic growth are a major source of uncertainty in the *IEO 2013* projections. To illustrate the uncertainties associated with economic growth trends, IEA's *IEO2013* includes a High Economic Growth case and a Low Economic Growth case in addition to the Reference case — Figure V-11. The two alternative growth cases use different assumptions about future economic growth paths, while maintaining the oil price path of the *IEO 2013* Reference case.[283]

In the High Economic Growth case, real GDP in the OECD region increases by 2.3 percent per year from 2010 to 2040, as compared with 2.1 percent per year in the Reference case. In the non-OECD region — where uncertainty about future growth is higher than in the developed OECD economies, the High Economic Growth case assumes GDP growth of 5.2 percent per year, or 0.5 percentage points higher than in the Reference case. In the Low Economic Growth case, OECD GDP increases by 1.9 percent per year, or 0.3 percentage points lower than in the Reference case. GDP growth in the non-OECD region is assumed to average 4.1 percent per year, or 0.6 percentage points lower than in the Reference case.

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[283]U.S/ Energy Information Administration, *International Energy Outlook*, op. cit.

**Figure V-11**
**Alternate Forecasts of Word GDP: 2010 - 2040**
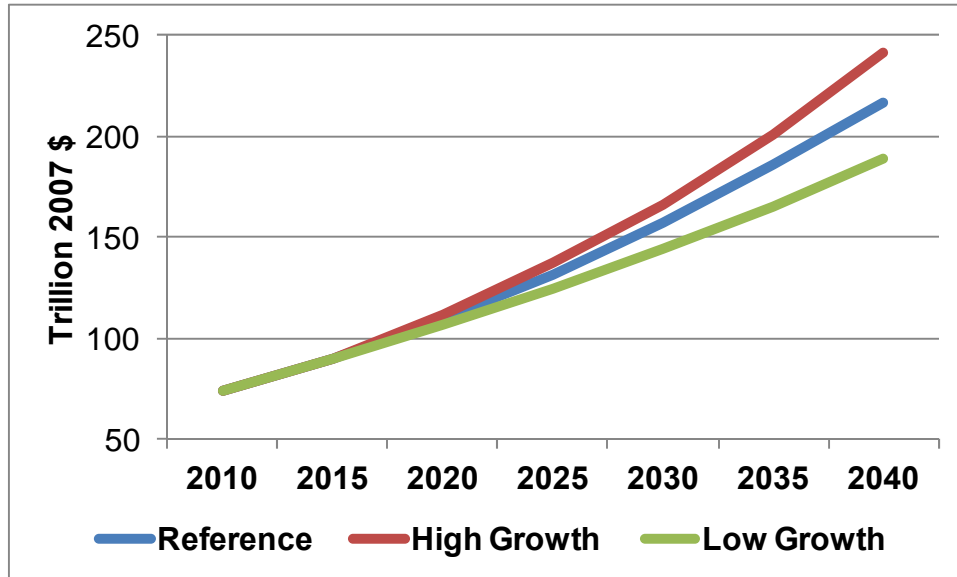
As shown in Figure V-12, in the Reference case world energy consumption totals 820 Quads in 2040 — 285 Quads in the OECD countries and 535 Quads in the non-OECD countries. In the High Economic Growth case, world energy use in 2040 is 760 Quads — 127 Quads (about 63 million barrels oil equivalent per day) higher than in the Reference case. In the Low Growth Case, total world energy use in 2040 is 733 Quads — 87 Quads (about 43 million barrels oil equivalent per day) lower than in the Reference case.[284] Thus, the projections for 2040 in the High and Low Economic Growth cases span a range of uncertainty equal to 213 Quads, equivalent to 41 percent of total world energy consumption in 2010. These EIA forecasts illustrate, once again, that future fossil fuel consumption is determined by future economic growth and that future economic growth will be critically dependent on fossil fuel utilization.[285]

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[284]Ibid.
[285]Ibid

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**Figure V-12**
**Alternate Forecasts of Word Fossil Fuel Consumption:  2010 - 2040**

EIA does not publish alternate $CO_2$ emissions forecasts corresponding to the high economic growth and low economic growth cases.  Here we derived these alternate forecasts by assuming that the relationship between fossil fuel consumption and $CO_2$ emissions forecast by EIA for the Reference case would be about the same in the high growth and the low growth scenarios.  Our results are given in Figure V-13, which shows that:

- In 2020, $CO_2$ emissions total over 37 billion tons in the high growth case and about 35.5 billion tons in the low growth case.
- In 2030, $CO_2$ emissions total over 44 billion tons in the high growth case and about 39 billion tons in the low growth case.
- In 2040, $CO_2$ emissions total over 52 billion tons in the high growth case and less than 41 billion tons in the low growth case.
- Thus, by 2040 the difference in world $CO_2$ emissions between the high growth and the low growth cases totals about 11 billion tons.

**Figure V-13**
**Alternate Forecasts of World CO$_2$ Emissions:  2010 - 2040**



Source:  U.S. Energy Information Administration and Management Information Services, Inc.

The preceding information allows us to forecast world GDP (2007 dollars) per ton of energy-related CO$_2$ according to each of the three scenarios – Figure V-14. Because both world GDP and world CO$_2$ emissions are forecast to change over time, this figure indicates that the ratios of GDP to CO$_2$ emissions do not vary significantly until about 2035.  Therefore, in the analyses below we use the forecast Reference case ratios.

**Figure V-14**
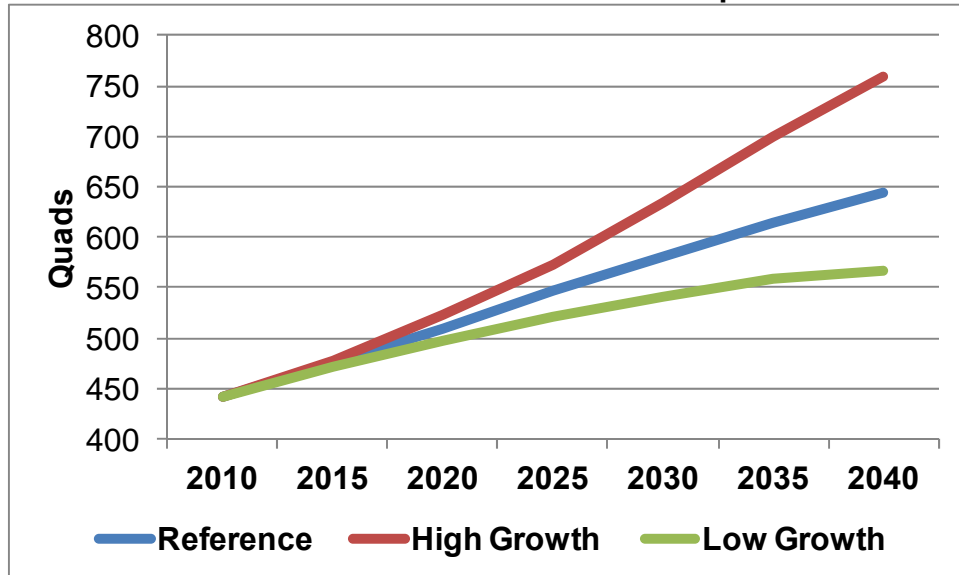**Alternate Forecasts of World GDP Per Ton of Energy-Related CO$_2$**
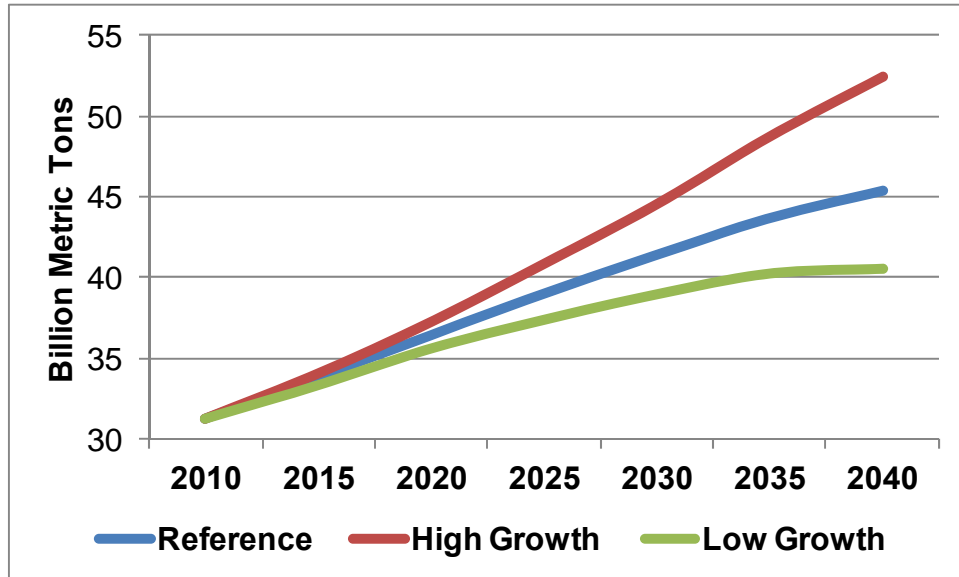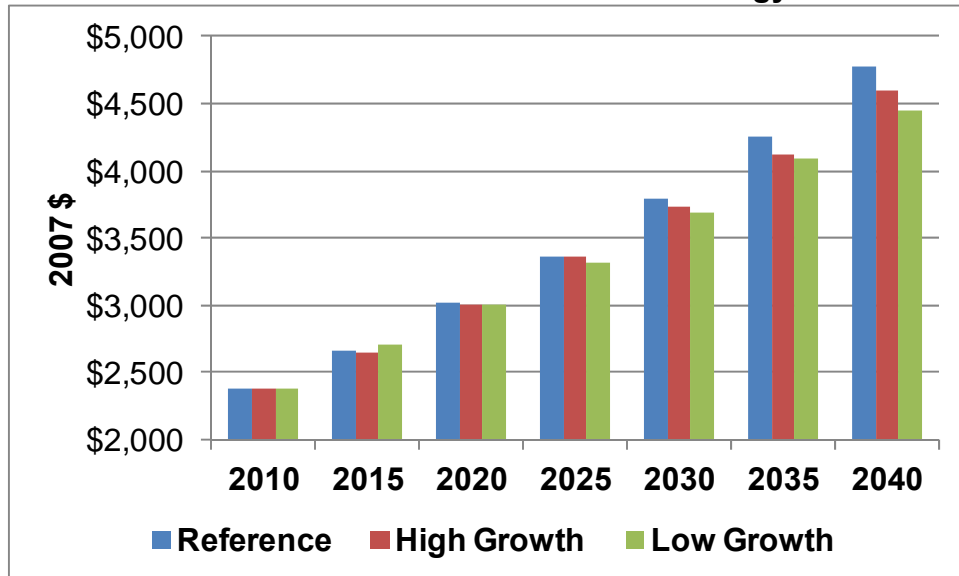


Source:  U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, and Management Information Services, Inc.

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Figure V-15 is analogous to Figure V-4 and shows the forecast relationship between world GDP and $CO_2$ emissions in the EIA reference case through 2040. This figure indicates that the relationship is forecast to be roughly linear. Once again, future economic growth – as measured by world GDP – requires fossil fuels which, in turn, generate $CO_2$ emissions. Figures V-11 through V-13 shown that this strong relationship exists across all forecast years in each of the three scenarios. Thus, according to EIA data and forecasts, fossil fuels, which generate $CO_2$ emissions, are essential for world economic growth, and significant $CO_2$ emissions reductions will be associated with significant reductions in economic growth.

**Figure V-15**
**Forecast Relationship Between World GDP and CO$_2$ Emissions**
(EIA Reference Case)
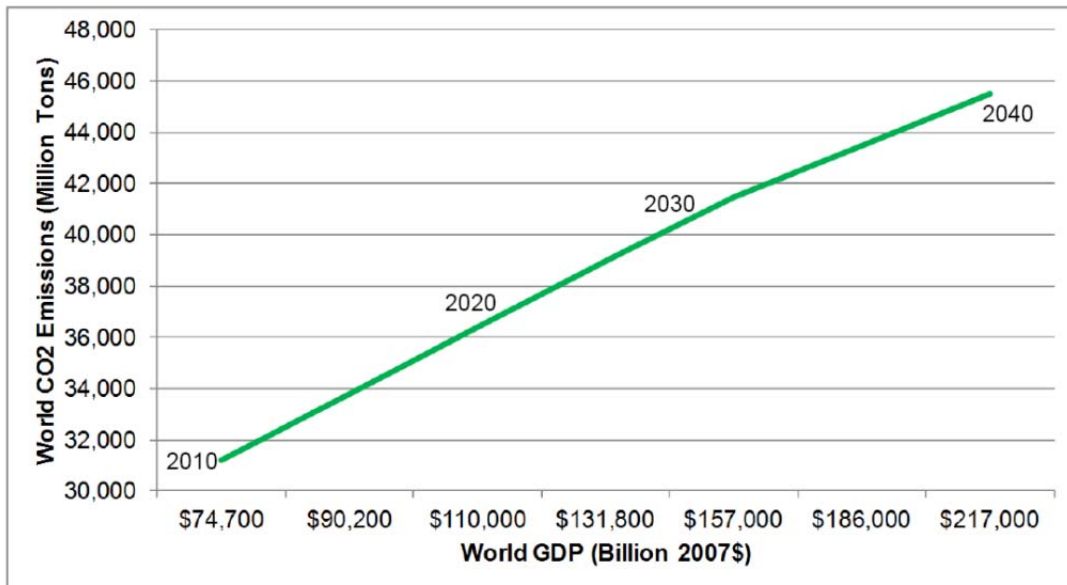


Source: U.S. Energy Information Administration, International Energy Agency, U.S. Bureau of Economic Analysis, and Management Information Services, Inc.

We can utilize the information shown in Figure V-15 with the forecast SCC estimates given in Tables V-1 and V-2 to develop estimated future $CO_2$ B-C ratios. These reference case estimates are shown for the three 2013 IWG report discount rates in Figure V-16.

This figure indicates that the $CO_2$ B-C ratios remain extremely high through 2040 using each of the three discount rates:

- With a 5.0% discount rate, over the forecast period the B-C ratios range from about 180-to-1 to about 250-to-1.
- With a 3.0% discount rate, over the forecast period the B-C ratios are about 70-to-1.

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- With a 2.5% discount rate, over the forecast period the B-C ratios are about 50-to-1.

**Figure V-16**
**Forecast Reference Case CO$_2$ Benefit-Cost Ratios**
(Based on 2013 IWG Report)
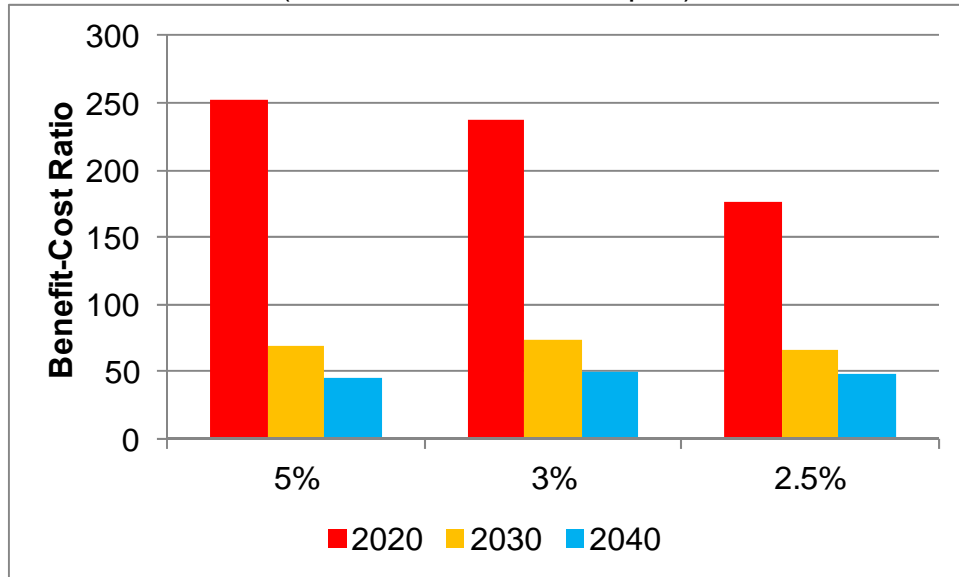


Source:  U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

The reference case estimates are shown for the three 2010 IWG report discount rates in Figure V-17.  This figure indicates that, using the 2010 SCC estimates, the CO$_2$ B-C ratios are even higher through 2040 under each of the three discount rates:

- With a 5.0% discount rate, over the forecast period the B-C ratios range from nearly 400-to-1 to about 500-to-1.
- With a 3.0% discount rate, over the forecast period the B-C ratios are in the range of about 110-to-1 to about 120-to-1.
- With a 2.5% discount rate, over the forecast period the B-C ratios are in the range of about 70-to-1 to about 80-to-1.

**Figure V-17**
**2010 and Forecast Reference Case CO$_2$ Benefit-Cost Ratios**
(Based on 2010 IWG Report)
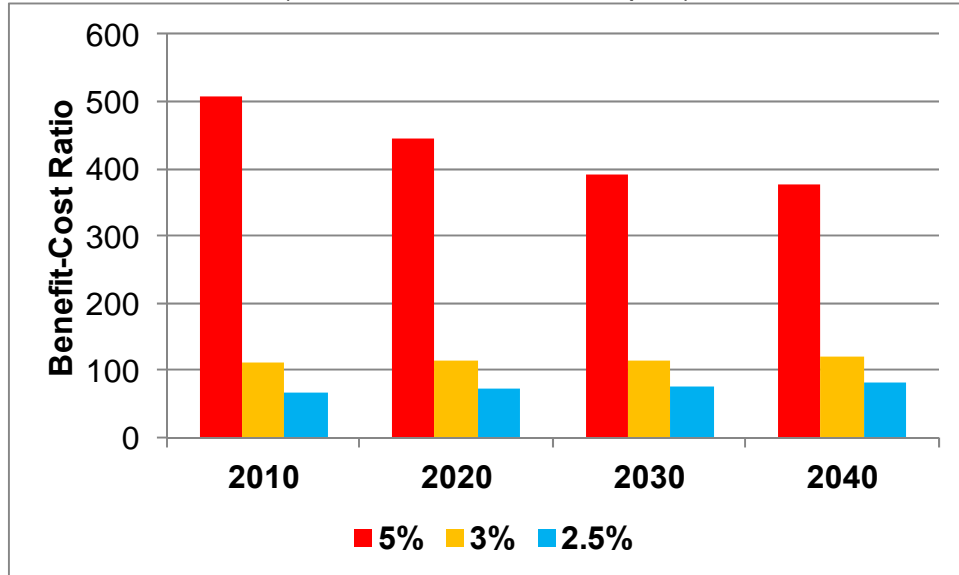
## V.D.  Average, Marginal, and Differential Benefits

Figures V-16 and V-17 may be somewhat misleading because they indicate, basically, the average CO$_2$ B-C ratio for each year.  The question thus arises of how marginal CO$_2$ benefits may compare to marginal costs.  To estimate this, using the EIA reference case we computed the marginal CO$_2$-related change in world GDP, 2010-2011, and compared this with the 2010 SCC estimates from the 2013 and 2010 IWG reports.  The results are shown in Figure V-18.  As anticipated, these "marginal" B-C ratios are larger than those given in Figures V-5 and V-6 or figures V-16 and V-17. Specifically, Figure V-18 shows that:

- Using the 5.0% discount rate, the B-C estimates range from about 540-to-1 to about 1,260-to-1.
- Using the 3.0% discount rate, the B-C estimates range from about 180-to-1 to about 290-to-1.
- Using the 2.5% discount rate, the B-C estimates range from about 110-to-1 to about 170-to-1.

Thus, the marginal CO$_2$ B-C ratios are significantly higher than those estimated above.[286]

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[286]The estimated marginal CO$_2$ benefits will change over time depending on the forecast period, but the argument remains valid.

**Figure V-18**
**2010-2011 Reference Case Marginal CO$_2$ Benefit-Cost Ratios**
(Based on 2010 and 2013 IWG Reports)
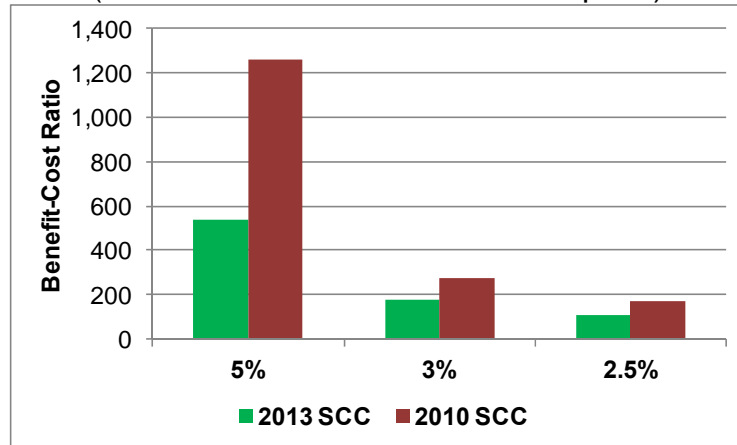
In our work thus far, we have essentially attributed all of the increase in world GDP to increases in fossil fuel utilization. This approach can be criticized because not all of the world's energy is derived from fossil fuels: In 2010 about 81 percent of world energy was comprised of fossil fuels, while forecasts indicate that in 2040 somewhere between 75 percent and 80 percent of world energy will be comprised of fossil fuels – see the discussion in Sections II.B and II.C. To determine how taking this into consideration may affect the B-C estimates, we developed a scenario where the portion of world energy comprised of fossil fuels decreased gradually from 80 percent in 2010 to 75 percent in 2040. Thus, under this scenario in the EIA reference case:

- In 2010, 80 percent of total world GDP is attributed to fossil fuels – approximately $59.8 trillion in 2007 dollars.
- In 2040, 75 percent of total world GDP is attributed to fossil fuels – approximately $162.8 trillion in 2007 dollars.

The results of this simulation are shown in Figure V-19, based on the SCC estimates from the IWG 2013 report, and in Figure V-20, based on the SCC estimates from the IWG 2010 report. These figures indicate that, while the scaling of CO$_2$ benefit estimates somewhat decreases the B-C ratios, the ratios remain very high. Specifically, Figure V-19 shows that, on the basis of the SCC estimates from the IWG 2013 report:

- Using the 5.0% discount rate, the B-C estimates for both 2010 and 2040 are in the range of about 170-to-1.
- Using the 3.0% discount rate, the B-C estimates for both 2010 and 2040 are in the range of about 60-to-1.

- Using the 2.5% discount rate, the B-C estimates for both 2010 and 2040 are in the range of about 40-to-1.

**Figure V-19**
**2010 and Forecast 2040 Reference Case Scaled CO$_2$ Benefit-Cost Ratios**
(Based on 2013 IWG Report)
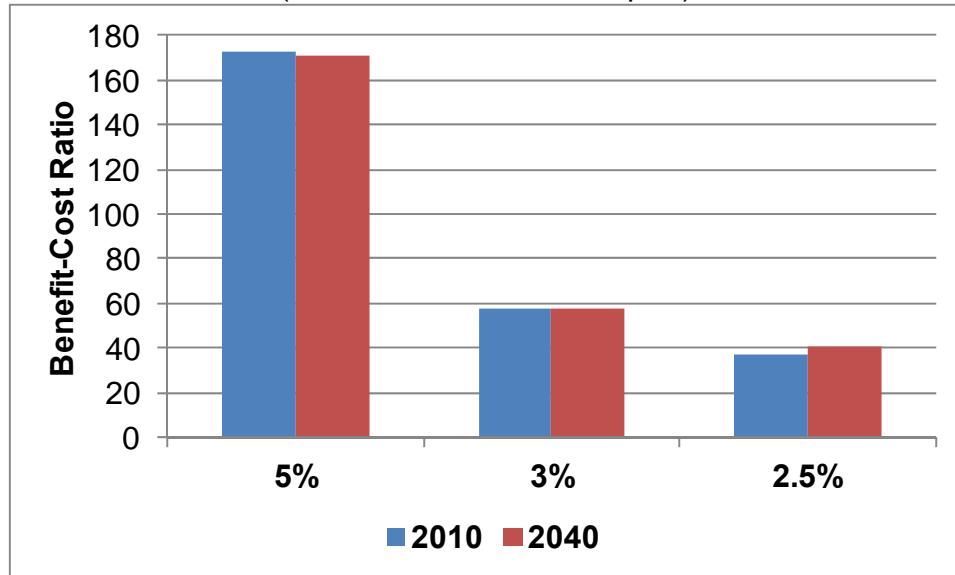


Source: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

Figure V-20 shows that, on the basis of the SCC estimates from the IWG 2010 report:

- Using the 5.0% discount rate, the B-C estimate for both 2010 is about 170-to-1 and for 2040 is about 280-to-1.
- Using the 3.0% discount rate, the B-C estimates for both 2010 and 2040 are in the range of nearly 100-to-1.
- Using the 2.5% discount rate, the B-C estimates for both 2010 and 2040 are in the range of about 50-to-1.

**Figure V-20**
**2010 and Forecast 2040 Reference Case Scaled CO$_2$ Benefit-Cost Ratios**
(Based on 2010 IWG Report)
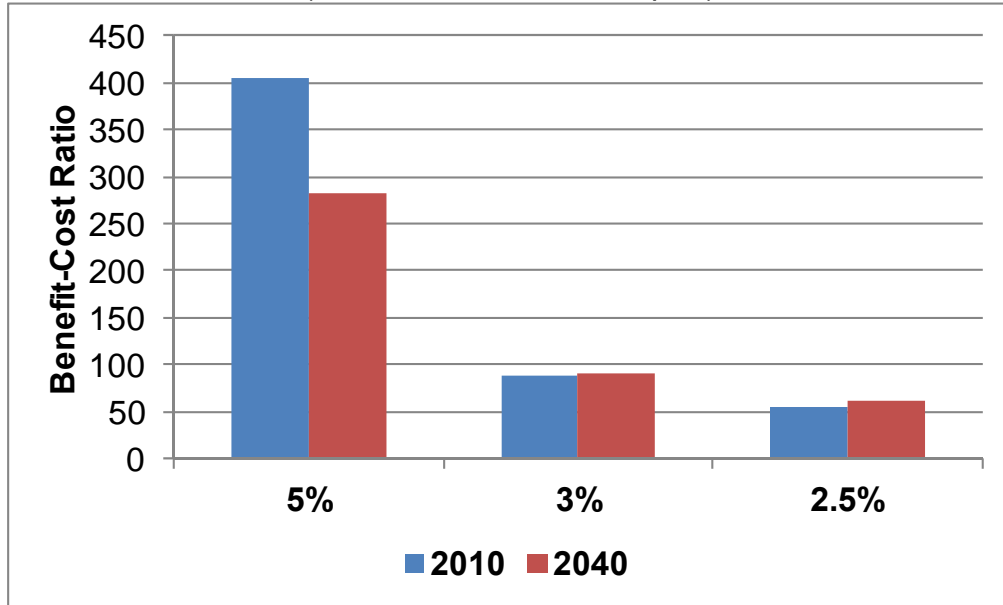


Source: U.S. Energy Information Administration, U.S. Bureau of Economic
Analysis, U.S. Interagency Working Group, and Management Information Services, Inc.

In other words, even assuming that by 2040 fossil fuels represent a somewhat smaller portion of total world energy supply, the benefits of carbon based energy still exceed the IWG SCC estimates by orders of magnitude. This is true even given the questionable validity of the IWG SCC estimates and, as discussed in Section V.A, it may not even be possible to significantly reduce future fossil fuel utilization without causing unacceptable reductions in world economic growth and standards of living.

# VI.  CAVEATS AND IMPLICATIONS

The B-C ratio is simply the ratio of benefits to costs, and its validity depends on the veracity of the benefit estimates and of the cost estimates.  How viable are these estimates?  We argue below that the benefit estimates are, if anything, more understandable, believable, and robust than the cost estimates.

## VI.A.  The Cost Estimates

With respect to the SSC estimates, as discussed in Chapter IV, these are questionable because they are based on highly speculative assumptions, forecasts, integrated assessment model (IAM) simulations, damage functions, discount rates, etc. Numerous IAMs have been developed and used to estimate the SCC and evaluate alternative abatement policies.  Indeed, the IWG relied critically on IAMs to develop its SCC estimates.  However, as Robert Pindyck notes, these models have crucial flaws that make them "close to useless" as tools for policy analysis; for example:[287]

- Certain inputs (e.g. the discount rate) are arbitrary, but have huge effects on the SCC estimates the models produce.
- The models' descriptions of the impact of climate change are completely ad hoc, with no theoretical or empirical foundation.
- The models can tell us nothing about the most important driver of the SCC, the possibility of a catastrophic climate outcome.
- IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading.
- The damage functions used in most IAMs are completely made up, with no theoretical or empirical foundation — and yet those damage functions are taken seriously when IAMs are used to analyze climate policy.

Pindyck concludes that IAMs are of little or no value for evaluating alternative climate change policies and estimating the SCC.  On the contrary, an IAM-based analysis suggests a level of knowledge and precision that is nonexistent, and allows the modeler to obtain almost any desired result because key inputs can be chosen arbitrarily.[288]

A study by the National Academies of Science (NAS) found that an SCC assessment suffers from uncertainty, speculation, and lack of information about:[289]

- Future emissions of greenhouse gases,

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[287]Robert S. Pindyck, "Climate Change Policy:  What Do The Models Tell Us?" op. cit.
[288]Ibid.
[289]National Research Council, *Hidden Costs of Energy:  Unpriced Consequences of Energy Production and Use*, Washington, D.C.:  National Academies Press, 2009.

- The effects of past and future emissions on the climate system,
- The impact of changes in climate on the physical and biological environment, and
- The translation of these environmental impacts into economic damages.

NAS thus concludes that "As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional."[290]

Further, the differences in the 2010 and 2013 SCC estimates are so large and of such immense potential significance as to raise serious questions as to their validity – especially since, prior to February 2010 the "official" Federal government estimate of the value of SCC was zero.[291] If any valid government economic estimates, such as GDP or unemployment, were revised by 30 - 50 percent within a three year period it would represent a scandal and a farce. For example, in 2010, U.S. GDP was estimated to be about $14.6 trillion.[292] While BEA always makes slight revisions to its GDP estimates in subsequent years, it is inconceivable that in 2013 it would have published a revised estimate of 2010 U.S. GDP in the range of $22 trillion.

Finally, as noted in the introduction, EPA stated that "The U.S. government has committed to updating the current estimates as the science and economic understanding of climate change and its impacts on society improves over time."[293] Thus, it is likely that the current SCC estimates will be repeatedly and substantially revised over time – perhaps even in both directions. How useful or relevant can the SCC estimates be if they continually change over time? This also raises the question of whether regulatory decisions based on one set of SCC estimates will be revisited as the estimates change.

Nevertheless, despite these overwhelming theoretical and empirical difficulties, the IWG proceeded to develop precise SCC estimates (the 2010 IWG report published SCC estimates in tenths of dollars)[294] that it contends are useful in estimating the social benefits of reducing carbon dioxide emissions. The IWG even admitted that "The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult" and that the exercise is subject to "simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize

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[290]Ibid.

[291]"Official" government estimates vary widely. For example, in 1996 the Minnesota PUC established a range of $0.28 to $2.92 per ton (1993 dollars) as the environmental cost of carbon dioxide. Translated into 2007 dollars to be consistent with the IWG estimates, this is a range of $0.38 to $3.97 per ton. See State Of Minnesota, Office of Administrative Hearings For the Minnesota Public Utilities Commission, "In the Matter of the Quantification of Environmental Costs Pursuant to Laws of Minnesota 1993, Chapter 356, Section 3 Findings of Fact, Conclusions, Recommendation," March 22, 1996.

[292]Obtained from the U.S. Bureau of Economic Analysis web site www.bea.gov.

[293]U.S. Environmental Protection Agency, "The Social Cost of Carbon: Estimating the Benefits of Reducing Greenhouse Gas Emissions," www.epa.gov/climatechange.

[294]See Table V-2.

the available scientific and economic research characterizing these relationships."[295] Notwithstanding all of the problems and uncertainties, the IWG recommended that the SCC estimates developed be incorporated by federal agencies into cost-benefit analyses of regulatory actions.[296]

In short, the SCC estimates developed and utilized by the IWG have little or no validity and are, as Pindyck concluded, "close to useless."[297]


## VI.B.  The Benefit Estimates

The benefit estimates developed here are simple, straightforward, logical, understandable, and based on two centuries of historical fact.  The $CO_2$ benefits are almost entirely indirect:  They derive from the fossil fuels which produce $CO_2$.  There is extensive literature verifying the critical and essential role of fossil fuels in creating current technology, wealth, and high standards of living:  It is a truism; a statement of fact.  Further, as discussed here and in Chapter II, this relationship will remain well into the foreseeable future.  At present, about 81 percent of world energy is derived from fossil fuels and in 2040 between 75 and 80 percent of world energy will still be derived from fossil fuels.[298]  To sate it succinctly:  Fossil fuels, including coal, have been, are currently, and will be in the future absolutely essential for world economic growth and well-being.

The benefit estimates derived here are extremely large compared even to the questionable IWG SCC estimates, and thus the B-C ratios are very high.  The benefit estimates can be modified:  They can be scaled, adjusted, forecast, expressed as average or marginal values, be converted to different base year dollars, estimated for past, current, or future years, etc.  Nevertheless, they will remain orders of magnitude larger than any reasonable SCC estimates and, therefore, the B-C ratios will remain very high.

Under Executive Order 12866, agencies are required to assess both the costs and the benefits of a proposed regulation and "agencies should proceed only on the basis of a reasoned determination that the benefits justify the costs."[299]  The implications of our research for such assessments are obvious, and these findings must be used to inform energy, environmental, and regulatory policies.

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[295]U.S. Interagency Working Group, 2010 and 2013, op. cit.
[296]Ibid.
[297]Pindyck, op. cit.
[298]This is true in both the EIA and the IEA forecasts.
[299]"Regulatory Planning and Review, Executive Order 12866 of September 30, 1993," op. cit. OMB cautions that "Prospective estimates may contain erroneous assumptions, producing inaccurate predictions."  U.S. Office of Management and Budget, "2013 Draft Report to Congress on the Benefits and Costs of Federal Regulations and Agency Compliance With the Unfunded Mandates Reform Act," op. cit.

## VI.C.  The Technology Imperative

It must be realized that, for the foreseeable future, there is no alternative to the widespread and increasing use of fossil fuels and thus increasing $CO_2$ emissions. Virtually all of "renewable energy" is heavily dependent on the fossil fuel system.  For example, wind turbines and solar photovoltaic (PV) panels require fossil fuels for their manufacture, transport, and maintenance.  Biomass and biofuels require fossil fuels to produce, wind, solar, and PV electricity options require fossil fuel plants for back-up and base load, and hydroelectric projects cannot be constructed and maintained without fossil fuels.   Even nuclear energy requires fossil fuels for its construction and maintenance, and for decommissioning old power plants, as well as for mining, transporting, and processing uranium.  Electric cars require fossil fuel inputs as well.  In fact, some renewable energy initiatives may have the unforeseen consequence of increasing fossil fuel utilization – especially coal.[300]

The renewable energy that is not fossil fuel dependent (mostly wood and other biomass that can be burned) will be rapidly consumed if fossil fuels are not available. There are a few energy possibilities that are less fossil fuel dependent, such as solar thermal (hot water bottles left in the sun to warm) and biofuels made in small quantities for local use, and better insulation may also be a possibility.  But these solutions cannot come close to substituting the huge loss of fossil fuels.[301]

Further, as Gail Tverberg notes, "We can talk about rationing fuel, but in practice, rationing is extremely difficult, once the amount of fuel becomes very low.  How does one ration lubricating oil?  Inputs for making medicines?  To keep business processes working together, each part of every supply chain must have the fuel it needs.  Even repairmen must have the fuel needed to get to work, for example.  Trying to set up a rationing system that handles all of these issues would be nearly impossible.[302]   As other authors have noted, fossil fuel rationing would be virtually impossible and would involve a "rat's nest of complications."[303]

In sum, prodigious amounts of fossil fuels will be required to sustain future economic growth, especially in the non-OECD nations.  In fact, as shown in Figure II-15, reproduced below as Figure VI-1, in terms of recoverable reserves coal will be the fossil fuel of the future – just as it has been the fossil fuel of the present and of the past. Advanced supercritical technology is currently available and is the best commercial technology to keep electricity affordable and achieve desired environmental goals.  U.S. utilities alone have invested $100 billion in clean coal technologies in recent years to improve efficiency and reduce emissions.   As the IEA stated in October 2013:

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[300]See, for example, Roger H. Bezdek and With Robert M. Wendling, "Not-So-Green Superhighway: Unforeseen Consequences of Dedicated Renewable Energy Transmission," *Public Utilities Fortnightly*, February 2012, pp. 34 - 42.
[301]Tverberg, 2012, op. cit.
[302]Ibid.  See also Roger H. Bezdek "Administrative Options for Dealing With the Onset of Peak Oil," Presented at the 2011 ASPO-USA Meeting: Truth in Energy*, Washington, D.C., November 2011.
[303]This issue is discussed in Chapter X of Robert L. Hirsch, Roger H. Bezdek and Robert M. Wendling, *The Impending World Energy Mess*, Toronto, Canada:  Apogee Prime Press, 2010,

"Supercritical and high efficiency technologies offer significant benefits in the long term (including) substantial savings of fuel and their associated costs as well as reduced local air pollution and lower $CO_2$ emissions."[304]

Thus, if the world is serious about maintaining and increasing economic growth, reducing energy poverty, lessening persons' energy burdens, and increasing standards of living in the non-OECD nations while at the same time limiting $CO_2$ emissions, advanced technologies and meaningful carbon capture and sequestration (CCS) polices are required.

**Figure VI-1**
**Fossil Energy Resources by Type**
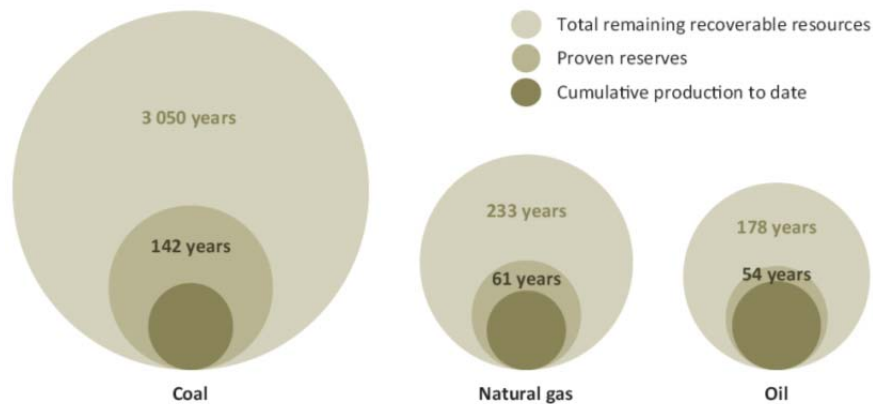


Source: International Energy Agency

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[304]International Energy Agency, *Southeast Asia Energy Outlook*, October 2013, p. 47; © OECD/IEA 2013.

## APPENDIX I:  THE 2008 AND 2009 ENERGY COST SURVEYS

**The 2008 Energy Cost Survey**

In 2008, the Energy Programs Consortium and the National Energy Assistance Directors conducted a comprehensive survey to develop an understanding of the sacrifices and tradeoffs that low, moderate, and middle income households have made in response to rising energy costs.[305]  The purpose of the study was to examine how increasing home energy and gasoline prices have impacted low- and moderate-income households in the U.S.  The study examined the extent to which households have been impacted by the higher prices and how they have coped with these increased prices. Households were asked about beneficial behaviors such as energy conservation and investment in more efficient appliances, and about dangerous sacrifices such as going without food and medicine and keeping the home at an unsafe temperature.[306]

Respondents were asked whether they had taken various actions related to their basic needs as a result of increased home energy or gasoline costs.  Table A.I-1 shows that many households reported major sacrifices due to these increased costs:

- 43 percent reported that they reduced purchases of basic household necessities.
- 43 percent reported that they reduced purchases of food.
- 18 percent reported that they reduced purchases of medicine.
- 11 percent said that they changed plans for their education or their children's education.

Respondents with children were more likely to report that they had taken all of these actions.

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[305]"2008 Energy Costs Survey, op. cit.
[306]The sample, purchased from Genesys Sampling Systems, was developed from an unduplicated list of over 97 million households in the U.S. with listed telephone numbers. The list was developed from multiple sources to increase coverage rates, including telephone directories, automobile and motorcycle registrations, real estate listings, and driver's license data.  The database is updated bimonthly to provide current data on active households.  This survey attempted to collect data from lower and middle lower income households.  To accomplish that goal, the requested sample targeted households with estimated annual income at or below $60,000. The sample income data were developed by the sample vendor from self reports to a panel survey within the past two years and through multiple regression analysis using home value, occupation, and automobile data, as well as other variables as predictors.  The listed sample does not include households without telephones or with unlisted telephone numbers.

**Table A.I-1**
**Actions Taken as a Result of Increased Home Energy**
**or Gasoline Costs — Actions Related to Basic Needs**

|  | All Respondents | Households With Members ≥ 60 | Households With Children ≤ 18 |
|---|---|---|---|
| **Reduced purchases of basic household necessities** | 43% | 43% | 52% |
| **Reduced purchases of food** | 43% | 42% | 56% |
| **Reduced purchases of medicine** | 18% | 17% | 24% |
| **Changed plans for your education or your children's education** | 11% | 5% | 25% |

Source: 2008 Energy Costs Survey (NEADA).

Figure A.I-1 shows that lower income households were more likely to report that increased home energy and gasoline costs impacted their purchases of basic necessities, food, medicine, and education plans:

- 70 percent of low-income respondents stated that that they reduced purchases of food due to these increased costs.
- 31 percent said that they reduced purchases of medication.
- Nine percent said that they had changed plans for their education or their children's education.

**Figure A.I-1**
**Percent of Respondents Who Stated That Increased**
**Energy and Gas Costs Impacted Purchases and Plans**
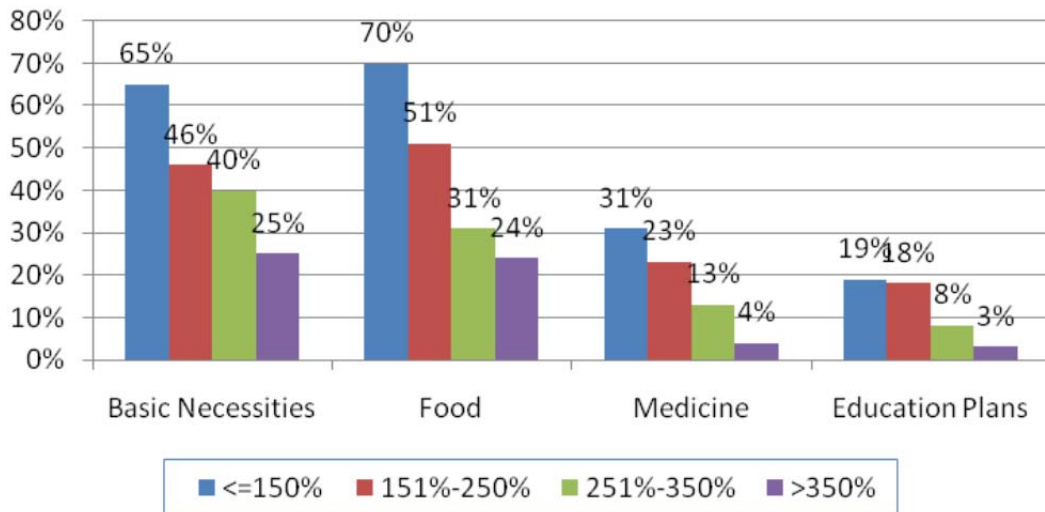


Source: 2008 Energy Costs Survey (NEADA).

Even high-income households said that these increased costs impacted their behavior. One quarter of households with income above 350 percent of poverty said that they reduced purchases of basic necessities.

Table A.I-2 provides additional detail on actions households have taken by income and poverty level.

**Table A.I-2**
**Actions Taken as a Result of Increased Home Energy or Gasoline Costs –**
**Actions Related to Basic Needs by Income and Poverty Level**

| | Annual Income | | | Poverty Level | | | | No Income Provided |
|---|---|---|---|---|---|---|---|---|
| | <$25,000 | $25,000-$50,000 | >$50,000 | <=150% | 151%-250% | 251%-350% | >350% | |
| Reduced purchases of basic household necessities | 61% | 43% | 28% | 65% | 46% | 40% | 25% | 32% |
| Reduced purchases of food | 64% | 39% | 30% | 70% | 51% | 31% | 24% | 26% |
| Reduced purchases of medicine | 29% | 16% | 7% | 31% | 23% | 13% | 4% | 14% |
| Changed plans for your education or your children's education | 15% | 15% | 6% | 19% | 18% | 8% | 3% | 4% |

Source:  2008 Energy Costs Survey (NEADA).

Respondents were also asked about the impact of increased home energy and gasoline costs on their energy usage.  Table A.1-3 shows that large percentages of households made sacrifices due to increased energy costs:

- 28 percent said they had closed off part of their home because they could not afford to heat or cool it.
- 19 percent said that they kept their home at a temperature they felt was unsafe or unhealthy.
- 11 percent said that they left the home for part of the day because it was too hot or too cold.

**Table A.1-3**
**Actions Taken as a Result of Increased Home Energy or**
**Gasoline Costs — Actions Related to Energy Usage**

|  | All Respondents | Households with Members 60 or Older | Households with Children 18 or Younger |
|---|---|---|---|
| Close off part of your home because you could not afford to heat or cool it | 28% | 28% | 26% |
| Keep your home at a temperature you thought was unsafe or unhealthy at any time of the year | 19% | 19% | 20% |
| Leave your home for part of the day because it was too hot or too cold | 11% | 8% | 15% |

Source: 2008 Energy Costs Survey (NEADA).

Figure A.I-2 shows that lower income households were more likely to report that they had changed their behavior related to energy use due to increased home energy and gas costs:

- 38 percent of low income households said that they closed off part of their home.
- 31 percent said they kept their home at an unsafe temperature.
- 19 percent said that they left their home for part of the day.

**Figure A.I-2**
**Percent of Respondents Who Stated That Increased**
**Energy and Gas Costs Impacted Energy Behavior**



Source: 2008 Energy Costs Survey (NEADA).

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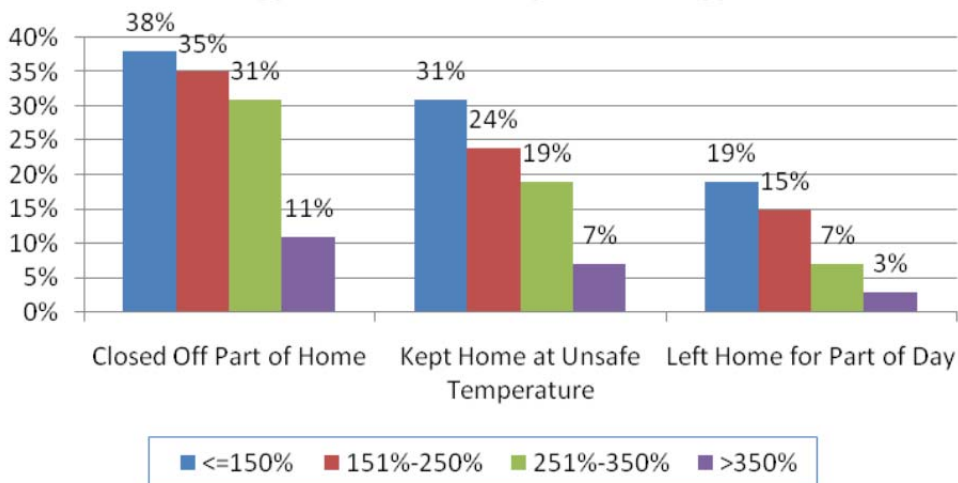
Table A.1-4 provides additional detail on energy-related actions households have taken due to increased home energy and gasoline costs by income and poverty level.

**Table A.1-4**
**Actions Taken as a Result of Increased Home Energy or Gasoline**
**Costs — Actions Related to Energy Usage by Income and Poverty Level**

| | Annual Income | | | Poverty Level | | | | No Income Provided |
|---|---|---|---|---|---|---|---|---|
| | <$25,000 | $25,000-$50,000 | >$50,000 | <=150% | 151%-250% | 251%-350% | >350% | |
| Close off part of your home because you could not afford to heat or cool it | 37% | 33% | 13% | 38% | 35% | 31% | 11% | 22% |
| Keep your home at a temperature you thought was unsafe or unhealthy at any time of the year | 30% | 22% | 6% | 31% | 24% | 19% | 7% | 12% |
| Leave your home for part of the day because it was too hot or too cold | 17% | 12% | 5% | 19% | 15% | 7% | 3% | 4% |

Source:  2008 Energy Costs Survey (NEADA).


Respondents were also asked about the impact of increased home energy and gasoline costs on their energy bill payments.  Table A.1-5 shows that many households were unable to pay energy bills and had their service terminated due to increased costs:

- 15 percent stated that they skipped paying or paid less than a full home energy bill.
- Four percent stated that they had their electricity shut off.
- Five percent stated that they had their natural gas shut off.
- Households with children were more likely to experience all of these.

**Table A.1-5**
**Actions Taken as a Result of Increased Home Energy or**
**Gasoline Costs — Actions Related to Energy Bill Payment**

| | All Respondents | Households with Members 60 or Older | Households with Children 18 or Younger |
|---|---|---|---|
| Skip paying your home energy bill or pay less than your full home energy bill | 15% | 9% | 29% |
| Have your electricity shut off because you were unable to pay your bill | 4% | 2% | 10% |
| Have your natural gas shut off because you were unable to pay your bill | 5% | 2% | 11% |

Source:  2008 Energy Costs Survey (NEADA).

Figure A.I-3 shows that for the most part it is low- and moderate-income households who sacrifice their energy bill payments when home energy and gasoline costs increase:

- 29 percent of low-income and 20 percent of moderate-income households skipped paying or paid less than a full energy bill.
- Eight percent of low-income and eight percent of moderate-income households had their electricity shut off.
- 12 percent of low-income and four percent of moderate-income households had their natural gas shut off.

Table A.I-6 provides additional detail on energy bill payment actions households have experienced due to increased home energy and gasoline costs by income and poverty level.

**Figure A.I-3**
**Percent of Respondents Who Stated that Increased**
**Energy and Gas Costs Impacted Energy Payments**



Source:  2008 Energy Costs Survey (NEADA).

**Table A.1-6**
**Actions Taken as a Result of Increased Home Energy or Gasoline Costs —**
**Actions Related to Energy Bill Payment By Income and Poverty Level**
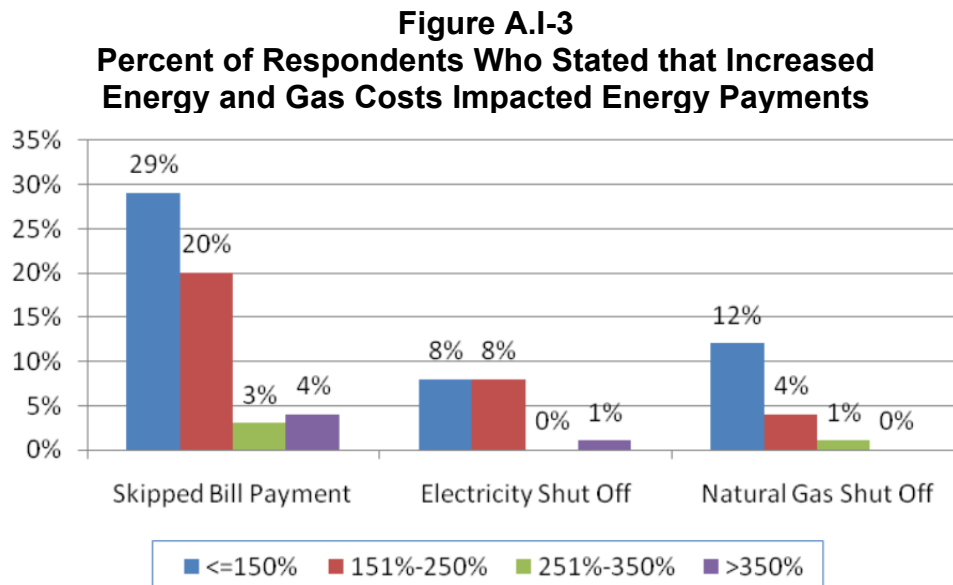
| | Annual Income | | | Poverty Level | | | | No Income Provided |
|---|---|---|---|---|---|---|---|---|
| | <$25,000 | $25,000-$50,000 | >$50,000 | <=150% | 151%-250% | 251%-350% | >350% | |
| Skip paying your home energy bill or pay less than your full home energy bill | 25% | 14% | 6% | 29% | 20% | 3% | 4% | 8% |
| Have your electricity shut off because you were unable to pay your bill | 6% | 4% | 2% | 8% | 8% | 0% | 1% | 3% |
| Have your natural gas shut off because you were unable to pay your bill | 10% | 3% | 2% | 12% | 4% | 1% | 0% | 0% |

Source:  2008 Energy Costs Survey (NEADA).

## The 2009 National Energy Assistance Survey

In 2009, the National Energy Assistance Directors Association, representing state Low Income Home Energy Assistance Program (LIHEAP) directors, conducted a survey to update the information about LIHEAP-recipient households that was collected in the 2003, 2005, and 2008 surveys.  This national energy assistance survey documented changes in the affordability of energy bills, the need for LIHEAP, and the choices that low-income households make when faced with unaffordable energy bills.  The 2009 survey selected a new sample of 2009 LIHEAP recipients to document changes in the need for LIHEAP and changes in the choices that low-income households make when faced with unaffordable energy bills.[307]

### Low Income Home Energy Assistance Program

LIHEAP is administered by the U.S. Department of Health and Human Services (HHS).  The purpose of LIHEAP is "to assist low-income households, particularly those with the lowest incomes, that pay a high proportion of household income for home energy, primarily in meeting their immediate home energy needs."[308]  Federal funds for LIHEAP are allocated by HHS to the grantees (i.e., the 50 states, District of Columbia, 128 tribes and tribal organizations, and five insular areas) as a block grant.  Program funds are distributed by a formula, which is weighted towards relative cold-weather conditions.  Program funds are disbursed to LIHEAP income-eligible households under programs designed by the individual grantees.

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[307]National Energy Assistance Directors' Association, *2009 National Energy Assistance Survey, Final Report*, Washington, D.C., April 2009.

[308]See "Low Income Home Energy Assistance Program. Report to Congress for Fiscal Year 2001." U.S. Department of Health and Human Services, Administration for Children and Families, Office of Community Services, Division of Energy Assistance.

LIHEAP grantees can use two income-related standards in determining household eligibility for LIHEAP assistance:  Categorical eligibility for households with one or more individuals receiving Temporary Assistance for Needy Families, Supplemental Security Income payments, Food Stamps, or certain needs-tested veterans and survivors payments, without regard for household income.  Income eligibility is for households with incomes that do not exceed the greater of an amount equal to 150 percent of the federal poverty level, or an amount equal to 60 percent of the state median income.  Grantees may target assistance to poorer households by setting lower income eligibility levels, but grantees are prohibited from setting income eligibility levels lower than 110 percent of the poverty level.  Eligibility priority may be given to households with high energy burden or need.

The statutory intent of LIHEAP is to reduce home heating and cooling costs for low-income households.[309]  However, information on total residential energy costs is more accessible and more apparent to LIHEAP-recipient respondents.  Most states use the 150 percent of federal poverty level maximum as the guideline — 150 percent of federal poverty in FY 2008 was $16,245 for a single person and $33,075 for a family of four.

The 2009 survey collected the following information from LIHEAP-recipient households:

- Demographic, energy expenditure, and income information,
- Healthy home behaviors,
- History of LIHEAP participation,
- Constructive actions taken to meet energy expenses,
- Signs of unaffordable energy bills,
- Health and safety consequences of unaffordable energy bills,
- Effects of unaffordable energy bills on housing,
- Changes in financial situation and affordability of home energy bills, and
- Impact and importance of LIHEAP benefits for recipient households.

The 2009 survey included the 12 states that were included in the 2008 survey and a larger sample of Connecticut LIHEAP recipients.

**Detailed Findings**

Table A.1-7 shows the percent of respondents who had to go without showers due to lack of hot water, had to go without hot meals due to lack of cooking fuel, or had to use candles or lanterns due to lack of lights.  The table shows that seven to ten percent of respondents faced these problems.

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[309]Ibid.

**Table A.1-7**
**Had to Go Without Showers, Hot Meals, or Lights During the Past Year**

|  | Percent of Respondents |
|---|---|
| Had to Go Without Showers or Baths Due to Lack of Hot Water | 10% |
| Had to Go Without Hot Meals Due to Lack of Cooking Fuel | 7% |
| Had to Use Candles or Lanterns Due to Lack of Lights | 8% |

Source: National Energy Assistance Directors' Association, 2009.

Table A.1-8 shows the percent of respondents who had to go without showers, hot meals, or lights during the past year by vulnerable group. It shows that households with children and households without vulnerable members were most likely to face these problems.

Table A.1-9 shows the percent of households who had these problems by poverty group, and illustrates that households in the lower poverty groups are most likely to face these problems.

**Table A.1-8**
**Had to Go Without Showers, Hot Meals, or Lights**
**During the Past Year, By Vulnerable Group**

|  | Senior | Disabled | Child Under 18 | Non-Vulnerable |
|---|---|---|---|---|
| Number of Respondents | 757 | 788 | 778 | 152 |
| Had to Go Without Showers or Baths Due to Lack of Hot Water | 5% | 12% | 13% | 14% |
| Had to Go Without Hot Meals Due to Lack of Cooking Fuel | 3% | 8% | 10% | 10% |
| Had to Use Candles or Lanterns Due to Lack of Lights | 4% | 9% | 12% | 13% |

Source: National Energy Assistance Directors' Association, 2009.

**Table A.1-9**
**Had to Go Without Showers, Hot Meals, or Lights**
**During the Past Year By Poverty Group**

|  | Poverty Level | | | |
|---|---|---|---|---|
|  | 0-50% | 51-100% | 101-150% | >150% |
| Number of Respondents | 286 | 673 | 557 | 312 |
| Had to Go Without Showers or Baths Due to Lack of Hot Water | 14% | 11% | 5% | 10% |
| Had to Go Without Hot Meals Due to Lack of Cooking Fuel | 12% | 8% | 3% | 6% |
| Had to Use Candles or Lanterns Due to Lack of Lights | 14% | 9% | 5% | 5% |

Source: National Energy Assistance Directors' Association, 2009.

Many respondents faced housing problems due to unaffordable energy bills. Table A.1-10 shows that:

- 31 percent skipped a mortgage payment.
- Five percent were evicted.
- Four percent had a mortgage foreclosure.
- Twelve percent moved in with friends or family.
- Three percent moved into a shelter or were homeless.

Table A.1-11 shows the results by vulnerable group, and illustrates that households with children were most likely to face these problems:

- 45 percent of these households skipped a mortgage payment.
- Eight percent were evicted.
- 17 percent moved in with friends or family.

**Table A.1-10**
**Housing Problems Due to Energy Bills in the Past Five Years**

|  | Percent of Respondents |
|---|---|
| Did not Make Full Rent or Mortgage Payment | 31% |
| Evicted from Home or Apartment | 5% |
| Had Mortgage Foreclosure | 4% |
| Moved in With Friends or Family | 12% |
| Moved into Shelter or Was Homeless | 3% |

Source:  National Energy Assistance Directors' Association, 2009.

**Table A.1-11**
**Housing Problems Due to Energy Bills in the**
**Past Five Years, by Vulnerable Group**

|  | Senior | Disabled | Child Under 18 | Non-Vulnerable |
|---|---|---|---|---|
| Number of Respondents | 757 | 788 | 778 | 152 |
| Did not Make Full Rent or Mortgage Payment | 16% | 32% | 45% | 39% |
| Evicted from Home or Apartment | 3% | 5% | 8% | 3% |
| Had Mortgage Foreclosure | 2% | 4% | 6% | 2% |
| Moved in With Friends or Family | 6% | 12% | 17% | 15% |
| Moved into Shelter or Was Homeless | 1% | 4% | 5% | 3% |

Source:  National Energy Assistance Directors' Association, 2009.

**Problems Meeting Energy Needs**

Table A.1-12 presents the results by poverty group, and shows that the lowest poverty group was most likely to face these problems.

**Table A.1-12**
**Housing Problems Due to Energy Bills in the**
**Past Five Years, by Poverty Group**

| | Senior | Disabled | Child Under 18 | Non-Vulnerable |
|---|---|---|---|---|
| Number of Respondents | 757 | 788 | 778 | 152 |
| Did not Make Full Rent or Mortgage Payment | 16% | 32% | 45% | 39% |
| Evicted from Home or Apartment | 3% | 5% | 8% | 3% |
| Had Mortgage Foreclosure | 2% | 4% | 6% | 2% |
| Moved in With Friends or Family | 6% | 12% | 17% | 15% |
| Moved into Shelter or Was Homeless | 1% | 4% | 5% | 3% |

Source:  National Energy Assistance Directors' Association, 2009.

Table A.1-13 shows the percent of respondents with housing problems by whether or not they own their home.  The table shows that respondents who do not own their homes were more likely to face these problems.

**Table A.1-13**
**Housing Problems Due to Energy Bills in the**
**Past Five Years, by Home Ownership**

| | Own Home | Does Not Own Home |
|---|---|---|
| Number of Respondents | 826 | 990 |
| Did not Make Full Rent or Mortgage Payment | 27% | 36% |
| Evicted from Home or Apartment | 3% | 7% |
| Had Mortgage Foreclosure | 4% | 3% |
| Moved in With Friends or Family | 7% | 16% |
| Moved into Shelter or Was Homeless | 1% | 6% |

Source:  National Energy Assistance Directors' Association, 2009.

**Medical and Health Problems**

Table A.1-14 shows that, of the respondents:

- 30 percent went without food for at least one day.
- 41 percent went without medical or dental care.
- 33 percent did not fill a prescription or took less than their full dose of prescribed medication.
- 22 percent were unable to pay their energy bill due to medical expenses.

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**Table A.1-14**
**Medical and Health Problems Due to Energy Bills**
**in the Past Five Years**

|  | Percent of Respondents |
|---|---|
| Went Without Food for at Least One Day | 30% |
| Went Without Medical or Dental Care | 41% |
| Didn't Fill Prescription or Took Less Than Full Dose | 33% |
| Unable to Pay Energy Bill Due to Medical Expenses | 22% |

Source: National Energy Assistance Directors' Association, 2009.

Table A.1-15 examines medical and health problems by vulnerable group. It illustrates that households without vulnerable members are most likely to go without food and to go without medical or dental care, and almost three quarters of this group said that they went without medical or dental care in the past five years.

**Table A.1-15**
**Medical and Health Problems Due to Energy Bills**
**in the Past Five Years, By Vulnerable Group**

|  | Senior | Disabled | Child Under 18 | Non-Vulnerable |
|---|---|---|---|---|
| Number of Respondents | 757 | 788 | 778 | 152 |
| Went Without Food for at Least One Day | 20% | 36% | 33% | 49% |
| Went Without Medical or Dental Care | 29% | 41% | 45% | 72% |
| Didn't Fill Prescription or Took Less Than Full Dose | 26% | 40% | 37% | 40% |
| Unable to Pay Energy Bill Due to Medical Expenses | 16% | 28% | 26% | 24% |

Source: National Energy Assistance Directors' Association, 2009.

Table A.1-16 shows responses to questions about medical and health problems by poverty group. It shows that there is not a strong relationship between poverty level and the presence of these problems.

## Table A.1-16
## Medical and Health Problems Due to Energy Bills
## in the Past Five Years, By Poverty Group

| | Poverty Level | | | |
|---|---|---|---|---|
| | 0-50% | 51-100% | 101-150% | >150% |
| Number of Respondents | 286 | 673 | 557 | 312 |
| Went Without Food for at Least One Day | 33% | 33% | 23% | 30% |
| Went Without Medical or Dental Care | 43% | 40% | 40% | 42% |
| Didn't Fill Prescription or Took Less Than Full Dose | 33% | 33% | 32% | 35% |
| Unable to Pay Energy Bill Due to Medical Expenses | 23% | 23% | 20% | 25% |

Source: National Energy Assistance Directors' Association, 2009.

Table A.1-17 shows the percent of respondents who did not take prescribed medication by the presence of a serious medical condition. The table shows that 37 percent of households with a serious medical condition skipped taking their prescription medication, compared to 16 percent without a serious medical condition.

Table A.1-18 shows the percent of respondents who skipped taking prescription medication by the presence of necessary medical equipment that uses electricity. It shows that 45 percent of those with medical equipment skipped taking their medication, compared to 29 percent without the equipment.

## Table A.1-17
## Did Not Fill Prescription or Took Less Than the Full Dose of
## Prescribed Medicine Due to Energy Bills in the Past Five Years,
## By Presence of Serious Medical Conditions

| | Didn't Fill Prescription or Took Less Than the Full Dose of Prescribed Medicine | |
|---|---|---|
| | Household Member with Serious Medical Condition | No Household Member With Serious Medical Condition |
| Number of Respondents | 1,509 | 307 |
| Yes | 37% | 16% |
| No | 63% | 84% |
| Don't Know/ No Answer | <1% | 0% |

Source: National Energy Assistance Directors' Association, 2009.

**Table A.1-18**
**Did Not Fill Prescription or Took Less Than the Full Dose of**
**Prescribed Medicine due to Energy Bills in the Past Five Years,**
**By Presence of Necessary Medical Equipment the Uses Electricity**

| | Didn't Fill Prescription or Took Less Than the Full Dose of Prescribed Medicine | |
|---|---|---|
| | Necessary Medical Equipment That Uses Electricity | No Necessary Medical Equipment That Uses Electricity |
| Number of Respondents | 448 | 1,364 |
| Yes | 45% | 29% |
| No | 55% | 70% |
| Don't Know/ No Answer | <1% | <1% |

Source:  National Energy Assistance Directors' Association, 2009.

Table A.1-19 shows the percent of respondents who said that they were unable to pay their energy bill due to medical expenses by the presence of a serious medical condition.  It shows that 25 percent of those with a serious medical condition were unable to pay their energy bill and nine percent without a serious medical condition were unable to pay their energy bill due to medical expenses.

**Table A.1-19**
**Unable to Pay Energy Bill Due to Medical Expenses**
**in the Past Five Years, By Presence of Serious Medical Conditions**

| | Unable to Pay Energy Bill Due to Medical Expenses | |
|---|---|---|
| | Household Member with Serious Medical Condition | No Household Member With Serious Medical Condition |
| Number of Respondents | 1,509 | 307 |
| Yes | 25% | 9% |
| No | 74% | 89% |
| Don't Know/ No Answer | 1% | 2% |

Source:  National Energy Assistance Directors' Association, 2009.

Table A.1-20 shows the percent of respondents who became sick and needed to go to the doctor or hospital because the home was too cold.  The table shows that 17 percent became sick and needed to go to the doctor or hospital because the home was too cold, and three percent became sick and needed to go to the doctor or hospital because the home was too hot.

**Table A.1-20**
**Someone in Household Became Sick Because Home**
**was Too Cold or Too Hot in the Past Five Years**

|  | Became Sick | Became Sick and Needed to Go to the Doctor or Hospital |
|---|---|---|
| Home Was Too Cold | 25% | 17% |
| Home Was Too Hot | 4% | 3% |

Source:  National Energy Assistance Directors' Association, 2009.

Table A.1-21 shows the percent of respondents who became sick and needed to go to the doctor or hospital because the home was too cold by vulnerable group.  It shows that households without vulnerable members were most likely to become sick, but that households with disabled members, households with children, and households with no vulnerable members were most likely to become sick and need to go to the doctor or hospital because the home was too cold.

**Table A.1-21**
**Someone in Household Became Sick Because Home was Too Cold**
**in the Past Five Years, By Vulnerable Group**

|  | Didn't Fill Prescription or Took Less Than the Full Dose of Prescribed Medicine | |
|---|---|---|
|  | Necessary Medical Equipment That Uses Electricity | No Necessary Medical Equipment That Uses Electricity |
| **Number of Respondents** | 448 | 1,364 |
| **Yes** | 45% | 29% |
| **No** | 55% | 70% |
| **Don't Know/ No Answer** | <1% | <1% |

Source:  National Energy Assistance Directors' Association, 2009.

Table A.1-22 shows the percent of respondents with a serious medical condition who became sick because the home was too hot or too cold and needed to go to the doctor or hospital.  The table shows that 26 percent of respondents with a serious medical condition became sick because their home was too hot or too cold and 18 percent needed to go to a doctor or to the hospital due to this illness.

**Table A.1-22**
**Household Member With Allergies, Asthma, Emphysema, or COPD,**
**High Blood Pressure, Heart Disease, or Stroke Got Sick**
**Because the Household was Too Hot or Too Cold**
**and Needed to Go to the Doctor or Hospital in the Past Year**

|  | Became Sick | Needed to Go to the Doctor or Hospital |
|---|---|---|
| **Number of Respondents** | 1,509 | 1,509 |
| Yes | 26% | 18% |
| No | 74% | 8% |
| Don't Know | <1% | 0% |
| Did no Become Sick | -- | 74% |

Source:  National Energy Assistance Directors' Association, 2009.


These tables confirm the extremely regressive nature of rising energy prices, and increased energy costs have further encroached upon the already-strained resources of the lowest-income households.  These families have experienced a diminishing quality of life as they become increasingly unable to provide for their most basic needs.

# APPENDIX II: THEORETICAL ANALYSIS OF THE RELATIONSHIP BETWEEN ENERGY COSTS AND THE ECONOMY

Beginning with the oil supply shocks of the 1970's, analyses that have addressed the impact of energy price shocks on economic activity have produced, and continue to produce, a steady stream of reports and studies on the topic.[310] Here we first analyze the issues surrounding attempts to gauge the short-run impacts of energy price changes and then examine some of the issues involved in studies of the long-run impacts.

## Short-Run Effects

Following the disruptive oil shocks of the 1970's, what began as a seemingly straight forward attempt to establish the quantitative relationship between oil price changes and the economy has evolved over the last three decades into an ongoing scholarly debate. While most economists who have examined this issue agree that there is an inverse relationship between energy prices and economic activity, there is little agreement as to the size of the relationship, the channels through which energy price changes alter economic activity, or how stable the relationship might be.

James Hamilton is generally credited with writing the first influential paper to demonstrate that there was causality that ran from oil price increases and U.S. recessions.[311] Hamilton argued that oil price increases had been responsible for all but one of the U.S. recessions since the end of WWII. Other scholars produced studies that supported Hamilton's findings, either with respect to the U.S. economy or to the economies of other countries.

However, researchers began to find anomalies in the published research that raised questions about how solid the economic relationship between oil prices and economic activity actually was. Some of the more contentious issues concerned the mechanisms through which oil price changes impacted economic activity, the reason or reasons why oil price impacts apparently were asymmetric — causing economic recessions when prices increased, but producing no economic boom when prices declined, as they did during much of the 1980's, and whether or not it was oil price shocks or something else (monetary policy) that caused the reaction.

One of the earliest questions raised asked how increases in the price of oil, even as large as those experienced during the 1970's, could cause such disproportionally large decreases in economic output, since the value of oil consumed in the economy

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[310]See, for example, Donald E. Jones, Paul N. Leiby and Inja K. Paik, "Oil Price Shocks and the Macroeconomy: What Has Been Learned since 1996", *The Energy Journal*, Vol. 25, No. 2, 2004. (This paper is an update of an earlier review that Jones and Leiber authored in 1996.); Lutz Kilian, "The Economic Effects of Energy Price Shocks", *Journal of Economic Literature*, Vol. 46, No. 4, 2008, pp. 871-909; Stephen P.A. Brown, et al, "Business Cycles: The Role of Energy Prices", FRB of Dallas Working Paper, Number 0304; Paul Segal, "Why Do Oil Price Shocks No Longer Shock?" WPM 35, Oxford Institute for Energy Studies, New College, Department of Economics, University of Oxford. October 2007.
[311]James D. Hamilton, "Oil and the Macroeconomy since World War II," *Journal of Political Economy*, vol. 91, 1983, pp. 228-248.

was such a small share of total output — around three to five percent.  The standard model for assessing the impact of an oil change was a neoclassical production function that related real economic output, Y, to inputs of capital, K, labor, L, and energy, E.

$$Y = F(K,L,E)$$

In a competitive market, firms would buy a resource input, say energy, up to the point where the price of the input was equal to the marginal value product of the input,

$$P_E = pF_E(L,K,E)$$

where   $P_E$ is the partial derivative of F with respect to E.   Multiplying both sides of this equation by E (Energy) and dividing by pY (the value of total output) results in the equation

$$P_E\ E/pY = pF_E(L,K,E)E/Y$$

The left side of the equation shows the value of energy as a share of total output and the right side is the elasticity of output with respect to energy use.  Since the share of energy in total output was relatively small, how could the analysis explain the relatively large changes in output?  As a result of the conundrum, research turned to looking for alternative routes by which oil price changes could impact output.

The description above of the anticipated impact of an oil price shock operating through production, as an increase in the price of an input, is an example of a supply shock to a market.  The increase in the input price results in a supply-side impact to the market.  In a competitive equilibrium, one can then analyze what the expected change in output, prices and other variables, such as the interest rate might be.   In a classical macro model, a decrease in aggregate supply caused by an increase in oil prices would be expected to raise prices, lower output (GDP) and raise interest rates.  Interest rates would increase as consumers, faced with higher prices, save less or borrow more, increasing real interest rates.

These changes – lower output, higher prices, and higher interest rates – describe the changes in the economy that followed the oil price shocks of the 1970's.  Thus, the prediction of the theory seemed to be corroborated by the historical record.   To match results of the theory with the historical record and to compare these findings with alternative ideas about how oil shocks impact the economy, Brown, et al.[312] created a table which is reproduced below as Table A.II-1.

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[312]Steven Brown, Mine K. Yucel and John Thompson, "Business Cycles: The Role of Energy Prices", in *Encyclopedia of Energy*, C.J. Cleveland, ed., New York, Academic Press, 2004.  A review article is available as a FRB of Dallas Working Paper, Number 0304, 2006.  The chart is found on page 3 of the working paper.

**Table A.II-1**

**Expected Responses to Rising Oil Price**

| | Real GDP | Price Level | Interest Rate |
|---|---|---|---|
| Historical Record | Down | Up | Up |
| Classic Supply Shock | Down | Up | Up |
| Aggregate Demand Shock | Down | Down | Down |
| Monetary Shock | Down | Down | Up |
| Real Balance Effect | Down | Down | Up |

Source:  Steven Brown, Mine K. Yucel, and John Thompson, 2004.

One obvious channel through which energy price impacts might operate is through a decrease in demand, since much oil is imported and the income from the higher prices results in a transfer from domestic consumers to foreign producers who may or may not spend the earnings in the U.S.  The loss of real income is comparable to a tax increase and it reduces aggregate demand through four possible channels: [313]

- Higher energy prices reduce discretionary income leading to less spending
- The price shock may create uncertainty and cause consumers to postpone discretionary spending
- Consumers may increase precautionary saving
- Consumers may decrease the consumption of goods that are complementary with the use of energy intensive products.

The result is less aggregate demand, leading to falling prices and output.   Also, foreign oil producers tend to save more than U.S. consumers, which results in downward pressure on interest rates.  Thus, the anticipated impacts of a reduction of aggregate demand produces results that may not agree with the historical record, except for the reduction in output.

The third item in the table, "Monetary Shocks," has a long and contentious history in the literature on energy price shocks.  Some of the early dissenters from the oil-shock theory of post-WWII recessions have argued that it has been monetary policy rather than changes in the price of oil that has caused the downturns in output that seem follow most episodes of oil price hikes.   A seminal paper that argues this point is the 1997 paper by Bernanke, et al. which concluded that the recessions that followed the 1973, 1979-80, and 1990 oil price increases could be almost entirely attributable to monetary policy and not oil shocks.[314]    Their argument is that it was restrictive monetary policy that caused interest rates to increase and aggregate demand to fall leading to the recessions, and that the oil price increases had little influence on the

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[313]These reactions to higher oil prices are spelled out in Lutz Kilian, "The Economic Effects of Energy Price Shocks," *Journal of Economic Literature*, Vol. 46, 2008, pp. 871–909 – see page 881.
[314]Ben S. Bernanke, Mark Gertler, and Mark Watson, "Systematic Monetary Policy and the Effects of Oil Price Shocks," *Brookings Papers on Economic Activity*, Issue 1, pp.  91–142, 1997.

downturn. While two of the three highlighted variables in this theoretical construct of events do move in the same direction as the historical record, a monetary tightening would tend to reduce prices, not increase them.

The final item in the chart, the "Real Balance Effect" is an argument that was offered as a possible explanation as to why seemingly small oil price changes had such large impacts on the economy. It was argued that increasing energy prices led to increased demand for money to restore a desired level of portfolio liquidity. Unless monetary authorities recognized this increased demand for funds and increased the money supply, the increased demand for money would drive up interest rates, reduce aggregate demand, and lead to a decrease in output. Table 1 shows that a "Real Balance Effect" would have the same impact as a tightening of monetary policy. As in the case of a tightening of monetary policy, the resulting impacts parallel the historical record in only two of the three variables – interest rates and output.

The above approaches to accounting for energy price shocks make the standard assumptions regarding market competitiveness. However, there have been other approaches to explaining the outsized impact of energy price shocks that rely on market imperfections. Most of these approaches involve imperfections on the supply side of the economy and, therefore, would create impacts that mirror the historical record.

Rotemberg and Woodford assume collusive pricing powers that allow mark-ups to the original energy-price spike throughout the manufacturing chain.[315] Their theoretical model can duplicate the impact on output found in the data, but their assumption of such widespread collusive power is problematic. Another widely cited paper by Finn accepts perfect competition, but adds to the increasing cost of energy inputs large increases in the cost of capital depreciation as high energy costs render energy-using capital non-productive. [316] Reductions in capital utilization reduce efficiency and decrease output. Models of this type are called "putty-clay" meaning that once decisions are made to install a certain type of capital technology – the "putty" stage, the decisions are not then alterable – the "clay" stage — despite changes in the operating environment (e.g., changing energy prices).

Other research has considered friction in labor markets to account for the size of downturns following energy price spikes. For example, energy price increases have exceptionally large adverse impacts on the transportation industry.[317] Idled workers (and capital) in the industry cannot be shifted easily to other employment owing to structural issues and, perhaps, sticky wages. This increase in unemployed resources owing to allocative inefficiencies magnifies the direct, aggregate effects of the energy price change. Hamilton estimated that the downturn in the auto industry during the

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[315]See J.J. Rotemberg and M. Woodford, "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, Vol. 28, 1996, pp. 549-577.
[316]See Mary G. Finn, "Perfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, Vol. 32, 2000, pp. 400-416.
[317]See, for example, Timothy F. Bresnahan and Valerie A. Ramey, "Segment Shifts and Capacity Utilization in the U.S Automobile Industry," *American Economic Review*, 83 (2), 1993, pp. 213–18.

1980 and 1990-91 recessions was enough to push the economy into recession from what might well have been periods of "sluggish" growth.[318]

**Asymmetric Impact**

Various other controversies have also characterized the research on the energy shock-output relationship. One such issue is the apparent asymmetry of energy shocks – they apparently have a greater negative impact when prices increase than positive impacts when prices decline. This issue came to the forefront during the 1980's when a decline in energy prices failed to result in an acceleration in growth similar to the decline in growth after the 1970's energy price increases.

Mork found that when he introduced separate oil price variables for price increases and price declines, the price increases had more of an effect than the price decreases. [319] Other researchers found similar results, although the classic aggregate supply-aggregate demand model predicts that there should be no difference in response whether the oil price shock is positive or negative. Several explanations have been suggested for the anomaly, including an asymmetry of the price pass-through of oil price changes to retail product (e.g., gasoline) price changes – price increases are passed through more rapidly than are decreases.[320] Another possibility suggested was that monetary policy responses to oil price increases were different than the responses to an oil price decreases, and that it was this policy asymmetry that caused the apparent difference in positive versus negative energy price changes.[321]

Another possible explanation hypothesized that the same allocative frictions that were identified as the cause of the size of oil price shock impacts could be responsible for the asymmetrical effects. The reasoning is that although the aggregate impact of a price decrease would shift the supply curve to the right resulting in increased output, the same allocative adjustment problems that accompany price increases would be present during price decreases, operating to slow growth and partially offset any positive aggregate effect. Finally, Lutz Kilian, who generally disputes the argument that energy price shocks are responsible for shifts in economic activity, offers the explanation that the apparent asymmetry was caused by policy changes (e.g., the 1986 Tax Reform Act) and not differences in the way that oil prices changes impact the economy.[322]

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[318]James D. Hamilton, "Causes and Consequences of the Oil Shock of 2007-08", presented at the Brookings Panel on Economic Activity, April 2009; James D. Hamilton, Department of Economics, UC San Diego, Working Paper, 2009, p. 29.

[319]See Knut A. Mork, "Business Cycles and the Oil Market," *Energy Journal*, Vol. 15, No. 4, Special Issue (1994): pp. 15-38.

[320]Nathan S. Balke, et al., "Oil Price Shocks and the U.S. Economy: Where Does the Asymmetry Originate?" Federal Reserve Bank of Dallas, Working Paper No. 9911, 1999.

[321]See John Tatum, "Are the Macroeconomic Effects of Oil-Price Changes Symmetric?" *Carnegie-Rochester Conference Series on Public Policy*, Volume 28, Spring 1988, pp. 325-368.

[322]See Kilian, op.cit., p. 891.

**A Weakening Relationship**

Aside from the possible explanation discussed above, some analysts contend that the reason for the weak response of output to energy prices decreases during the 1980's was caused by a general weakening of the relationship, that the structure of the economy had changed. Brown, et al. offers several possible reasons for the diminishing impact of oil price changes. They discuss the role of a fall in the energy-to-GDP ratio, the growing experience with oil price changes (In the 1970's the changes were a "shock," but by the 1980's and 1990's oil price changes were not so novel.), the fact that strong productivity gains in the late 1990's tended to hide the oil price-output relationship and, finally, that the increases in energy prices in the 1990's came from an increase in aggregate demand and not from a decrease in aggregate supply.[323,324]

The last explanation became popular during the run-up of energy prices in the late 2000's, prior to the onset of the financial crisis in 2008. There were numerous articles and commentaries pointing to the fact that despite increasing oil prices, the economy continued to grow. Perhaps most notable among these papers is one by William Norhaus, in which he offered several of the factors discussed above as to why higher oil prices failed to derail the economic expansion.[325] Following the financial crises of the summer and fall of 2008 and the subsequent economic implosion, most economic commentary focused on the role of the financial sector as the primary cause of the sharp downturn. There were those, however, who argued that the run-up in oil prices was a significant factor behind the recession, pointing out that the economy began to slow and that the NBER marked the start of the recession in December 2007 – months before the financial crises caused the bottom to fall out.[326]

**What is the Size of the Relationship?**

Not surprisingly, given the dozens of studies that have examined the relationship between oil price shocks and the economy, there are numerous estimates of the size of the response in GDP to a one percent change in the price of oil or energy. One generalization that can be made from the results of these studies is that those estimates that are the result of more simple time-series estimates of the impact of oil and energy prices on the macroeconomy tend to be larger than estimates made using large

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[323]See Brown, et al., op.cit., p. 14.
[324]In addition to possible structural changes as explanations for the reduction of the force of oil price shocks, several analysts considered other, more technical, reasons including the structure of equations used to estimate impacts and the precise definition of what an "oil price shock" really was. See Jones, et al., op. cit. p. 10, for a discussion if these issues.
[325]William D. Nordhaus, "Who's Afraid of a Big Bad Oil Shock?" *Brookings Papers on Economic Activity*, Issue 2 (Fall 2007), p. 219-240.
[326]See James D. Hamilton, "Causes and Consequences of the Oil Shock of 2007-08," presented at the Brookings Panel on Economic Activity, Department of Economics, UC San Diego, April 2009. Also, see Joe Cortright, "Driven to the Brink: How the Gas Price Spike Popped the Housing Bubble and Devalued the Suburbs", White Paper, CEOs for Cities, May 2008.

disaggregated macroeconomic models of the economy.  In the former case, estimates tend to range from around 2.5 percent to up to 11 percent in an estimate by Hamilton.[327]

In contrast, disaggregated models, such as the models of the IMF, OECD and Federal Reserve, tend to derive estimates that are much smaller, in the range of 0.2 percent to 1.0 percent.  Jones, et al. explains the difference by pointing out that much of the overall impact on GDP that results from an energy price shock comes as a result of the friction in inter-sectoral resource allocation, and the large, disaggregated models are not able to gauge these effects.[328]  Nevertheless, the salient point is that all estimates indicate a negative relationship between energy prices and the economy.

## Long-Run Impacts

In the above discussion of the impact of changes in energy prices in the short run, energy, E, was introduced as an explicit factor – along with labor and capital – in the production function that described the structure of the aggregate supply curve.  In the mainstream theories of long-term economic growth, energy plays no such role.  Rather, growth is theorized as being a function of labor (population), capital, and technological change.[329]

A seminal article by Robert Solow in 1956 marked the beginning of mainstream neoclassical growth theory.[330]  Although his work on the issue of economic growth earned Solow the Nobel Prize, the construct that he used to describe growth $Q = f(L,K)$ had a major flaw in that the two explicit exogenous variables, labor and capital, explained little of the actual growth in the U.S. economy.  A large "Solow residual," introduced as an exogenous unexplained variable accounted for most of the growth in per capita income.  Since this residual, that Solow identified as "technological progress" was unexplained, or exogenous, this class of models came to be known as exogenous growth models.

During the 1980s, Pail Romer, Robert Lucas, and others initiated a new phase of growth theory that has come to be known as "modern" or "endogenous" growth theory.  Their models were structured to include variables such as R&D and human capital to explain the sources of Solow's "technological progress."[331]  While these new

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[327]See James D. Hamilton, "What is an Oil Shock?" *Journal of Econometrics*, v.113, April 2003, pp. 363 – 398.  Jones, et al, op.cit, p. 12, has a discussion of some of the results of these estimates.

[328]See Jones, et al, op.cit, p. 12.  Also see Hilliard G. Huntington, "The Economic Consequences of Higher Oil Prices," final report for the U.S. Department of Energy, EMF SR 9, October 2005.

[329]This brief introduction and summary of mainstream economic growth theory draws heavily on the review of the subject by Robert Ayres.  See Robert U. Ayres, "Lecture 5: Economic Growth (and Cheap Oil)", presentation made at the Lisbon, Portugal 2005 meeting of the ASPO Fourth International Workshop on Oil and Gas Depletion.

[330]See Robert M. Solow, "A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economics*, vol. 70, 1956, pp. 65-94.

[331]Fairly non-technical reviews of the development of endogenous growth theory can be found in Robert W. Arnold, "Modeling Long-Run Economic Growth", Technical Paper Series No. 2003-4, Congressional Budget Office, Washington D.C. June 2003; Lars Weber, "Understanding Recent Developments in Growth Theory", Brandenburg University of Technology Cottbus, 2007; and Joseph Cortright, "New

approaches have advanced growth theory, they have not served to answer some of the fundamental questions about growth, such as why different economies grow at different rates. Robert Ayres notes that while the neoclassical endogenous growth models have "interesting features," he also states "......all of the so-called endogenous growth models share a fundamental drawback: They are and are likely to remain essentially theoretical because none of the proposed choices of core variables (knowledge, human capital, etc.) is readily quantified, and the obvious proxies (like education expenditure, years of schooling, and R&D spending) do not explain growth."[332]

### Growth Theory and Energy

In a 2002 paper Ayres and Benjamin Warr asked "Why should capital services be treated as a "factor of production" while the role of energy services is widely ignored or minimized?"[333]   They then discussed what they see as the two primary reasons behind the fact that mainstream neoclassical economics ignores energy (and other resource) inputs when creating models of economic growth. First, neoclassical theory assumes that the productivity of a factor of production must be proportional to that factor's share of national income. Labor and capital receive, by far, the largest shares of national income, with payments to energy receiving very little. Theory thus concludes that energy must be a negligible factor of production and can be ignored.

A second reason that neoclassical economists ignore energy is because of the problem of causation. Correlation between energy use and growth may be the result of growth leading to more energy use and not because energy use results in growth.[334] The standard mainstream model, such as the EIA NEMS model, makes just this assumption in its forecasts. That is, NEMS assumes that growth in the macroeconomy is determined by exogenous factors such as population growth, technology growth, and monetary, and fiscal policies. Demand for energy products is the result.[335]

As an alternative approach, Ayres and others recommend that growth models include an energy variable as an explicit input. They contend that energy is an example of an "engine of growth" that provides positive feedback cycles in the growth process as depicted in the so-called Salter cycle – see Figure A.II-1.[336]   Increases in low-cost energy translate into lower prices for products and services, and this leads to greater demand. The lower energy prices result from new discoveries, economies of scale, and

Growth Theory, Technology and Learning: A Practitioners' Guide," *Reviews of Economic Development Literature and Practice*, No. 4, report done under contract (99-07-13801) for the U.S. Economic Development Administration by Impresa, Inc. 1424 NE Knott St, Portland, Oregon.

[332] See Ayres, op.cit, p. 8.

[333] See Robert U. Ayres and Benjamin Warr, "The Economic Growth Models and the Role of Physical Resources,", INSEAD Working Paper, No. 2002/53/EPS/CMER, 2002, p. 4.

[334] Ayres and Warr, op.cit., pp. 4-6.

[335] See U.S. Energy Information Administration, "The National Energy Modeling System: An Overview 2003", report No. DOE/EIA-0581 (2003).

[336] Ayres, op.cit., p. 26.

technical progress in the efficiency of energy use. In other words, as in the case of capital, energy is a factor of production and should be treated as such.[337]

Models that have included energy variables in the standard neoclassical production function explain most of the growth left unexplained in the standard two-variable Solow model.[338]

**Figure A.II-1**
**Representation of the Slater Cycle**
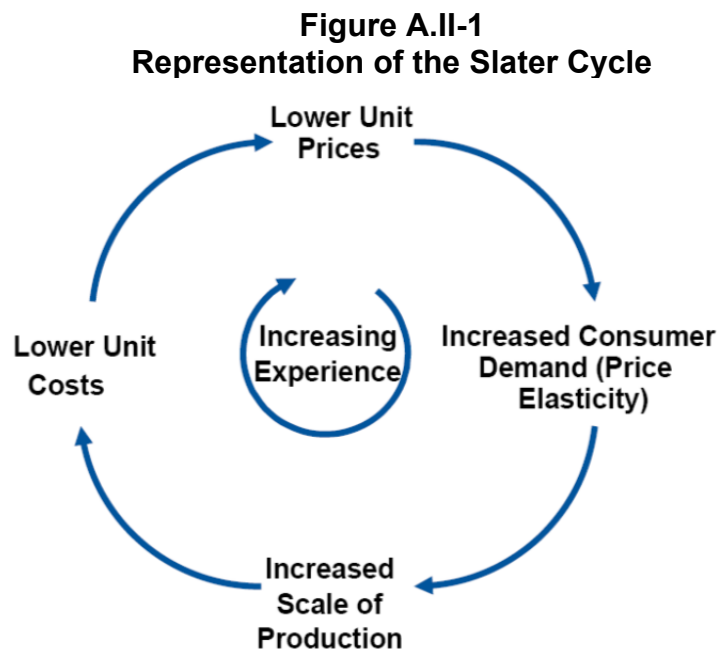


Source: Robert U. Ayres, "Lecture 5: Economic Growth (And Cheap Oil)," INSEAD, Boulevard de Constance, F-77305 Fontainebleau Cedex, France

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[337]Ayres, ibid., p. 4.

[338]Ayres, ibid. p.4. notes the work of Bruce Hannon and John Joyce, "Energy and Technical Progress", *Energy*, vol. 6, pp. 187-195, 1981; Reiner Kummel, "Energy, Environment and Industrial Growth," in *The Economic Theory of Natural Resources*, Physica-Verlag, Wuerzberg, Germany, 1982; Cutler J. Cleveland, et al., "Energy and the U.S. Economy: A Biophysical Perspective," *Science*, v. 255, pp. 890-97, 1984; and others.

# APPENDIX III:  ELECTRICITY-GDP ELASTICITY ESTIMATES

A number of studies have developed estimates of the elasticity of GDP with respect to energy and electricity prices.  Examples of these are summarized in Table A.III-1, and include the following:.

- In 2010, Lee and Lee analyzed the demand for energy and electricity in OECD countries.  They estimated that the elasticities range between -0.01 and -0.19.[339]
- In 2010, Baumeister, Peersman, and Van Robays examined the economic consequences of oil shocks across a set of industrialized countries over time.  They estimated that the elasticity was approximately -0.35.[340]
- In 2010, Brown and Hunnington employ a welfare-analytic approach to quantify the security externalities associated with increased oil use, which derive from the expected economic losses associated with potential disruptions in world oil supply.  They estimated that the elasticity ranged between -0.01 and -0.08.[341]
- In 2009, Blumel, Espinoza, and Domper used Chilean data to estimate the long run impact of increased electricity and energy prices on the nation's economy.[342]  They estimated that the elasticity ranged between -0.085 and -0.16.
- In 2008, in a study of the potential economic effects of peak oil, Kerschner and Hubacek reported elasticities in the range of -0.17 to -0.03 – although they noted that sectoral impacts are more significant.[343]

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[339]Chien-Chaing Lee and Jun-De Lee, "A Panel Data Analysis of the Demand for Total Energy and Electricity in OECD Countries," *The Energy Journal*, Vol. 31, No 1 (2010), pp. 1-23.

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**Table III-1**
**Summary of Energy- and Electricity-GDP Elasticity Estimates**

| Year Analysis Published | Author | Elasticity Estimate |
|---|---|---|
| | | |
| 2010 | Lee and Lee (energy and electricity) | -0.01 and -0.19 |
| 2010 | Brown and Huntington (oil) | -0.01 to -0.08 |
| 2010 | Baumeister, Peersman, and Robays (oil) | -0.35 |
| 2009 | Blumel, Espinoza, and Domper (energy and electricity) | -0.085 to -0.16 |
| 2008 | Kerschner and Hubacek (oil) | -0.03 to -0.17 |
| 2008 | Sparrow (electricity) | -0.3 |
| 2007 | Maeda (energy) | -0.03 to -0.075 |
| 2007 | Citigroup (energy) | -0.3 to -0.37 |
| 2007 | Lescaroux (oil) | -0.1 to -0.6 |
| 2006 | Rose and Wei (electricity) | -0.1 |
| 2006 | Oxford Economic Forecasting (energy) | -0.03 to -0.07 |
| 2006 | Considine (electricity) | -0.3 |
| 2006 | Global Insight (energy) | -0.04 |
| 2004 | IEA (oil) | -0.08 to -0.13 |
| 2002 | Rose and Young (electricity) | -0.14 |
| 2002 | Klein and Kenny (electricity) | -0.06 to -0.13 |
| 2001 | Rose and Ranjan (electricity) | -0.14 |
| 2001 | Rose and Ranjan (energy) | -0.05 to -0.25 |
| 1999 | Brown and Yucel (oil) | -0.05 |
| 1996 | Hewson and Stamberg (electricity) | -0.14 |
| 1996 | Rotemberg and Woodford (energy) | -0.25 |
| 1996 | Gardner and Joutz (energy) | -0.072 |
| 1996 | Hooker (energy) | -0.07 to -0.29 |
| 1995 | Lee and Ratti (oil) | -0.14 |
| 1995 | Hewson and Stamberg (electricity) | -0.5 and -0.7 |
| 1982 | Anderson (electricity) | -0.14 |
| 1981 | Rasche and Tatom (energy) | -0.05 to -0.11 |

Source:  Management Information Services, Inc.

- In 2008, Sparrow analyzed the impacts of coal utilization in Indiana, and estimated electricity elasticities in the range of about -0.3 for the state.[344]
- In 2007, in a study of energy price GDP relationships, Maeda reported a range of elasticity estimates between -0.03 to -0.075.[345]
- In 2007, in a study of the relationship between energy prices and the U.S. economy, Citigroup found that in the long run, protracted high energy prices can have an economic impact and reported elasticities in the range of -0.3 to -0.37 between 1995 and 2005.[346]
- In 2007, in a study of oil-price GDP elasticities, Lescaroux reported a range of elasticities between -0.1 and -0.6.[347]
- In 2006, in an analysis of the likely impacts of coal utilization for electricity generation on the economies of the 48 contiguous states in the year 2015, Rose and Wei estimated the electricity elasticity to be -0.1[348]  They also reported that more recent studies for the state of Georgia and the UK yield similar results.
- In 2006, in a study of energy price impacts in the UK, Oxford Economic Forecasting found elasticities to range between about -0.11 and -0.21.[349]
- In 2006, in a study that analyzed the economic impacts from coal Btu energy conversion, Considine estimated an electricity elasticity of -0.3.[350]
- In 2006, in a study of the impact of energy price increases in the UK, Global Insight estimated the elasticity to be -0.04.[351]
- In 2004, IEA employed energy-economic model simulation to calculate how much the increase in oil prices reduces GDPs in several countries.  It found that the elasticity estimates ranged between -0.08 to -0.13.[352]

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- In 2002, in a study of the economic impact of coal utilization in the continental U.S. Rose and Yang estimated the GDP electricity price elasticity of at -0.14.[353]
- In 2002, Klein and Kenny analyzed the results of six studies of the impacts of energy prices on the U.S. economy conducted between 1997 and 2002 and reported electricity elasticity estimates that ranged between -0.6 and -1.3.[354]
- In 2001, Rose and Ramjan analyzed the impact of coal utilization in Wisconsin. They calculated a price differential between coal and natural gas in electricity production, and then estimated how much economic activity is attributable to this cost saving. They used an economy-wide elasticity of output with respect to energy prices, which they estimated to be -0.14.[355]
- In 2001, Rose and Ranjan surveyed recent studies of the impacts of energy prices on GDP and reported elasticities in the range of -0.5 to -0.25.[356]
- In 1999, Brown and Yucel surveyed a number of studies and reported an average elasticity of about -0.05.[357]
- In 1996, Rotemberg and Woodford analyzed the effects of energy price increases on economic activity and reported an elasticity of -0.25.[358]
- In 1996, Gardner and Joutz analyzed the relationship between economic growth, energy prices, and technological innovation, found that the real price of energy is negatively related to output in the US , and estimated that the elasticity is -0.72.[359]
- In 1996, in a study of the impact of electricity prices on manufacturing, Hewson and Stamberg estimated an electricity elasticity of -0.14.[360]
- In 1996, in studying postwar energy-GDP relationships, Hooker estimated that the elasticity ranges between -0.07 and -0.29.[361]

[353]A Rose and B. Yang, "The Economic Impact of Coal Utilization in the Continental United States," Center for Energy and Economic Development; 2002.

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[355]Adam Rose and Ram Ranjan, "The Economic Impact of Coal Utilization In Wisconsin," Department of Energy, Environmental, and Mineral Economics, Pennsylvania State University, August 2001.

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[358]Rotemberg, Julio J., and Michael Woodford. 1996. "Imperfect Competition and the Effects of Energy Price Increases on the Economy." *Journal of Money, Credit, and Banking*, 28(4): 550–77.

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- In 1995, in a study of macroeconomic oil shocks, Lee and Ratti estimated the elasticity to be -0.1.4.[362]
- In 1995, in a study of the impact of $NO_x$ control programs in 37 states, Hewson and Stamberg estimated electricity elasticities ranging between -0.5 and -0.7.[363]
- In 1982, in a study of industrial location and electricity prices, Anderson estimated the elasticity to be -0.14.[364]
- In 1981, Rasche and Tatom found that an energy price shock modifies the optimal usage of the existing stock of capital, modifying the optimal capital-labor ratio and generating an upward shift on the aggregate supply curve and a decline in potential output. They estimated that the elasticity of output with respect to the real price of energy ranges between -0.05 and -0.11.[365]

In addition, numerous studies have examined the relationship between energy prices and GDP and found strong causality; for example:

- In 2008, Chontanawat found that the causality relationship is stronger in developed countries rather than developing countries.[366]
- In 2008, Bekhet and Yusop examined the long run relationship between oil prices, energy consumption, and macroeconomic performance in Malaysia over the period 1980-2005. Their findings indicated that there is a stable long-run relationship between oil prices, employment, economic growth, and the growth rate of energy consumption and also substantial short run interactions among them. The linkages and causal effects among prices, energy consumption and macroeconomic performance have important policy implications, and they found that the growth of energy consumption has significant impacts on employment growth.[367]

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- In 2006, Soytas and Sari analyzed the causal relationship between energy consumption and GDP in G-7 countries and found that causality runs from energy consumption to GDP in these countries. They argued that energy conservation in some countries could negatively impact economic growth.[368]

- In 2006, Chontanawat, Hunt, and Pierse tested for causality between energy and GDP using a consistent data set and methodology for 30 OECD and 78 non-OECD countries.[369] They found that causality from aggregate energy consumption to GDP and GDP to energy consumption is found to be more prevalent in the developed OECD countries compared to the developing non-OECD countries. This implies that a policy to reduce energy consumption aimed at reducing GHG emissions is likely to have greater impact on the GDP of the developed rather than the developing world.

- In 1995, Finn found that in the U.S. the Solow residual tends to fall when energy price rises, implying a direct link between energy and production.[370]

- In 1987, Erol and You found a causal relationship running from energy consumption to output in a large set of industrialized countries.[371]

Other studies that came to similar conclusions include Al-Faris,[372] Al-Iriani,[373] Apergis, and Payne,[374] Burniaux and Jean Chateau,[375] Chien-Chiang and Jun-De

[368]U. Soytas and R. Sari, "Energy Consumption and GDP:  Causality Relationship in G-7 Countries and Emerging Markets", *Energy Economics*, Vol. 25, 2006, pp. 33-37.

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Lee,[376] Coffman,[377] Cournède,[378] Davis and Haltiwanger,[379] Gausden,[380] Gronwald,[381] Harris,[382] Lee,[383] Manjulika and Koshal,[384] Narayan and Smyth,[385] Oligney,[386] Soytas and Sari,[387] Stern,[388] Stern and Cleveland,[389] and Wolde-Rufael.[390]

Dahl has conducted extensive studies of NEMS elasticities and provided summaries of the elasticities within NEMS.[391] She noted that, since elasticities are a convenient way to summarize the responsiveness of demand to such things as own prices, cross prices, income, or other relevant variables, a substantial amount of resources have been devoted to estimating demand elasticities, at various levels of aggregation using a variety of models. Nevertheless, she found that considerable variation in the estimates at the aggregate and disaggregate levels remains.

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