7. Comparing Cost Estimates for the Kyoto Protocol

Introduction

This chapter provides a comparison of recent publicly available estimates of the costs of achieving the Kyoto Protocol carbon reduction targets in the United States for the period 2008 to 2020. The projections are compared for the years 2010 and 2020, when the information is available, for the following projection sources: the Energy Information Administration (EIA) using the National Energy Modeling System (NEMS), WEFA,[85] Charles River Associates (CRA) using the Multi-Regional Trade model (MRT),[86] the Pacific Northwest National Laboratory (PNNL) using the Second Generation Model (SGM),[87] the Massachusetts Institute of Technology (MIT) using the Emissions Prediction and Policy Analysis Model (EPPA),[88] Electric Power Research Institute (EPRI) using the MERGE model[89] and Data Resources, Inc. (DRI).[90] Differences between studies are related, to the extent possible, to the features of the modeling systems used (e.g., level of aggregation, level of geographic coverage), important assumptions employed, and the particular points of view embodied in the models.[91]

Two cases were solicited for analyses from each group: a 7-percent-below-1990 (1990-7%) case in which the United States is assumed to reduce carbon emissions to 1990-7% levels for the period 2008-2020 without the benefit of sinks, offsets, international carbon permit trading, or the Clean Development Mechanism (CDM); and a best estimate of the impact on U.S. energy markets if sinks, offsets, and Annex I emissions trading were allowed, but not global trading or CDM.

Differences in the cost estimates for meeting the Kyoto Protocol targets can be related to important differences in assumptions about (1) economic growth in the reference cases without the Kyoto Protocol, (2) the status of the resources available (e.g., resource base, world oil prices, and the slate of technologies available to the marketplace), (3) the sensitivity of energy demand to price changes, (4) the degree of foresight that decisionmakers have in the marketplace, (5) the structure and function of the economy (e.g., how quickly the economy can shift to less energy-intensive industries when the price of energy relative to capital and materials increases), (6) the degree and speed of substitution for factors of production (capital, labor, energy, and materials) when their relative prices change, and (7) the representation of technology (i.e., representation of vintaged energy equipment and the penetration of new technologies).

Summary of Comparisons

Because the information available varies considerably, a detailed comparison among the sources is virtually impossible. Therefore, a comparison of common variables is provided in this section, with an explanation for the differences between the sources. Comparisons are provided for three of the cases analyzed in this report: the 1990-7% case and two cases—9 percent above 1990 (1990+9%) and 14 percent above 1990 (1990+14%)—that are comparable in some respects to the Annex I trading case. The variables compared are carbon price, change in actual gross domestic product (GDP) from the respective reference case in each study,

[85] WEFA, Inc., *Global Warming: The High Cost of the Kyoto Protocol, National and State Impacts* (Eddystone, PA, 1998).

[86] Both the CRA and WEFA studies have been supported to some extent by industry groups, including the American Petroleum Institute.

[87] J.A. Edmonds et al., *Modeling Future Greenhouse Gas Emissions: The Second Generation Model Description* (Washington, DC: Pacific Northwest National Laboratory, September 1992). Runs using PNNL's SGM model formed the basis for the testimony provided by Dr. Janet Yellen, chairman of the Council of Economic Advisers, on March 4, 1998, before the House Commerce Committee, Energy and Power Subcommittee.

[88] H.D. Jacoby, R. Eckhaus, A.D. Ellerman, et al. "CO_2 Emission Limits: Economic Adjustments and the Distribution of Burdens," *Energy Journal*, Vol. 18, No. 3 (1997), pp. 31-58. MIT's analysis is part of a much larger integrated assessment methodology funded by the Office of Energy Research, U.S. Department of Energy.

[89] A.S. Manne and R.G. Richels, "On Stabilizing CO_2 Concentrations—Cost Effective Emissions Reduction Strategies," *Energy and Environmental Assessment*, Vol. 2 (1997), pp. 251-265. EPRI's work is self-funded and is part of the research agenda of electric utilities.

[90] Standard and Poors DRI, *The Impact of Meeting the Kyoto Protocol on Energy Markets and the Economy* (July 1998).

[91] Information used in this chapter was contributed by Dr. Montgomery and Dr. Bernstein of Charles River Associates, Dr. Richels of the Electric Power Research Institute, Dr. Edmonds of Pacific Northwest National Laboratory, and Professor Jacoby of MIT.

actual and potential GDP loss, expenditures for purchases of carbon emission permits, change in carbon intensity from the respective reference case, and change in fossil fuel consumption. Tables 30 and 31 provide comparisons of the results for 2010 and 2020. Further details are provided in Appendix C.

For the WEFA study, comparisons are provided only with the 1990-7% case. For DRI comparisons are provided only for a trading case (Case 2). WEFA does not believe that sinks, offsets, or trading will be agreed upon and implemented before the target period of 2008 to 2012, nor by 2020. As noted earlier in the report, EIA does not have the capability to analyze international trading and thus is unable to provide a most likely estimate of the impacts of the international trading provisions of the Kyoto Protocol, or of sinks and offsets, on the level of the energy-related carbon reductions required to meet the 1990-7% reduction in greenhouse gases. EIA's 1990+9% and 1990+14% cases are used in Table 31, because the carbon emissions levels of those cases were most closely aligned with the other studies presented.

Some of the major factors that result in differences in the projected carbon prices and costs to achieve the 1990-7% carbon reduction level are:

- **Relative differences in reference GDP and carbon emissions growth rates through 2020.** For example, if the GDP or carbon emissions growth rate in a given reference case is lower than that in EIA's reference case, a smaller carbon reduction will be needed, and it will generally be easier to achieve the emissions target. If the reference GDP growth or carbon emissions growth is higher than in EIA's reference case, the carbon price and GDP impacts relative to those projected by EIA in this study will generally be higher. Most of the major differences among the analyses are attributable to differences in the reference case projections.

- **Differences in assumptions about the potential for economical life extension or refurbishment of existing nuclear power plants beyond their normal licensing period.** If, for example, no existing nuclear plants were retired by 2020, about 40 million metric tons of carbon emissions would be avoided from the combustion of fossil fuel used in plants to replace them.

- **The amount of knowledge about future events assumed for decisionmakers.** For example, models that assume that decisionmakers have perfect knowledge about future prices, demands, or policies could underestimate compliance costs, because all future events would be anticipated with certainty and responded to at minimum cost. Analyses that assume that all decisionmakers are myopic will tend to overstate transition costs.

- **The amount of lead time decisionmakers are assumed to have to adjust to the Kyoto Protocol.** For example, if a model starts to begin the adjustment process in 1985, 1990 or 1995, it could underestimate the costs of complying with the Kyoto Protocol, because it has more time to adjust. Models that wait until the last moment to begin the adjustments could overstate adjustment costs.

- **The level of aggregation in the model for technologies and goods.** A model that deals only with aggregate products such as oil, gas, or coal without the benefit of an explicit technology representation may not capture important variables that can significantly affect energy efficiency and intensity or the changing mix of industries that may result from compliance efforts.

- **The amount of focus on the transition process and the associated costs.** For example, a model that assumes that all capital and labor can be immediately switched from one use to another cannot capture the short-term or medium-term impacts of complying with the Kyoto Protocol, because those costs are not reflected in the model.

- **The assumed speed and extent of changes that consumers can make in energy consumption or demand for energy services in response to changing prices (price elasticities of demand).** Higher assumed elasticities make it easier to achieve the carbon target through demand reductions. Lower elasticities make it more difficult.

Among the studies compared in Table 30, the projected carbon prices in 2010 fall into three groups. MIT, EPRI, CRA, and WEFA project prices in the range of $265 (WEFA) to $295 (CRA) per metric ton of carbon. PNNL projects carbon prices of about $221 per metric ton. EIA projects carbon prices of $348 per metric ton.

In the PNNL study, assumptions about consumer price responsiveness (demand elasticities and capital / energy substitution elasticities) are consistent with a long-term time frame where everything is changeable.[92,93] Applying the long-term elasticities to the short-term andmid-term period can overstate the ease and willingness with which consumers change their equipment or reduce their consumption in response to price increases.[94]

Further contributing to the low carbon price projection is the amount of lead time consumers have to respond, as well as differences in the reference case economic growth rates. The PNNL and EIA reference case GDP projections are very similar. However, PNNL's end-use representation does not explicitly represent technologies, and PNNL's assumed consumer responsiveness to prices (prompting lower energy service demand) and interfuel substitution potential appear to be substantially higher in the medium term (through 2010) than the implicit elasticities in EIA's explicit representation of technologies and consumer choices. The PNNL model begins solving in 1985 in 5-year increments. The PNNL reference case is calibrated to *AEO98*. In the PNNL policy runs, the carbon policy was phased in over a 10-year period beginning in 2000. Consequently, policy adjustments begin in 2001, consumers and producers begin to anticipate the Kyoto Protocol in that year, making the appropriate adjustments. In the PNNL analysis, electricity demand grows by 0.4 percent annually in the reference case between 2010 and 2020. This is a significant departure from the annual growth rate of more than 2 percent in recent years. Most electricity demand projections have annual growth in excess of 0.9 percent between 2010 and 2020, as compared with PNNL's 0.4 percent.[95] Offsetting these factors are factors that tend to overstate cost. For example, in the PNNL analysis, primary renewable use for generation changes only slightly from the reference case in 2020, even with a carbon price of $286 per metric ton.

The group of models projecting costs between $265 per metric ton and $295 per metric ton in 2010 for the 1990-7% case include transitional processes and costs—either in the macroeconomy or in the energy system—through a detailed representation of the cost, performance, and market adoption of technologies.[96] This group includes the CRA model. Through 2010, CRA projects that, in the reference case, U.S. GDP will grow by $270 billion more than projected in most of the other studies compared. The higher growth rate of GDP normally makes the reduction in emissions harder and more costly to the U.S. economy.

If differences in the reference cases were the only factor accounting for the different estimates of the costs of complying with the Kyoto Protocol, then CRA's costs would exceed EIA's and WEFA's in 2010; however, large econometric models of the U.S. economy like those of WEFA and DRI tend to focus on the transitional process, including the method of recycling any carbon fees that may be collected by the Federal Government, and unemployment that may be increased as a result of policy implementation. The WEFA, EIA, and DRI analyses assume that labor can be dislocated, whereas most other analyses assume full employment[97] despite the sudden reduction of energy resources. More aggregated world analyses, including the CRA, PNNL, EPRI, and MIT studies, omit such details, because the inclusion of global regional coverage and trade flows requires simplifications (some important) in the detail with which each region is represented. Model aggregation tends to underestimate the macroeconomic costs; on the other hand, a lack of global coverage (as in the EIA, DRI, and WEFA models) may overstate transition costs, particularly if international trading is implemented efficiently. Also, fossil fuel consumption in 2010 in the CRA analysis is about 6 quadrillion British thermal units (Btu) less than in the EIA reference case, with virtually identical carbon emissions levels, suggesting an accounting difference in emissions coefficients.

92 The PNNL study uses a dynamic-recursive, computable general equilibrium (CGE) model with neoclassical elements. A model is a “general equilibrium” model if it represents all parts of the economy, both energy and non-energy, and all markets clear (supply equals demand at the prices determined). The model is “computable” if a computer is used to solve for the equilibrium; it is “dynamic” if it keeps track of variables over time. A model is “neoclassical” if the model structure assumes that (1) its economic agents have perfect foresight and knowledge of all past, present, and future events, (2) there is perfect and instantaneous ability of capital and labor to move between uses and sectors, and (3) such transitions are costless and instantaneous.

93 The PNNL model (SGM) can be run with either perfect or imperfect foresight. Labor and new capital move freely.

94 A carbon price of $221 per metric ton in 2010 would increase the delivered electricity price by 49 to 69 percent and reduce electricity consumption by 22 percent relative to PNNL's reference case. This implies that, on average, consumers will reduce consumption of electricity by 3.2 to 4.5 percent for every 10-percent increase in the price of electricity. In 2020, a carbon price of $286 per metric ton translates to an electricity price increase of 59 to 66 percent, resulting in a 28-percent reduction in electricity consumption. This implies that consumption will decline by about 4.2 to 4.7 percent for every 10-percent increase in price. (The estimated electricity price changes were derived from comparable EIA cases.)

95 For example, WEFA's annual electricity growth rate is 1.7 percent and EIA's is 0.9 percent.

96 The WEFA, CRA, MIT, and DRI models are econometric, general equilibrium, macroeconomic models. WEFA and DRI model the United States, CRA and MIT model the world.

97 The full employment assumption means that the unemployment rate is unchanged from reference case levels.

Table 30. Comparison of Results for Reducing Carbon Emissions to 7 Percent Below 1990 Levels Without Trading, Sinks, Offsets, or Clean Development Mechanism

Projection	MIT	EPRI[a]	CRA	EIA	PNNL	WEFA
			2010			
Carbon Price (1996 Dollars per Metric Ton)	**266**	**280**	**295**	**348**	**221**	**265**
Change in Actual Gross Domestic Product From Reference Projection						
Percent	-1.5[b]	-1.0	-2.1	-4.2	NA	-3.2
Billion 1996 Dollars	-156	-102	-227	-437	NA	-332
Loss in Potential Gross Domestic Product Relative to Reference Projection (Billion 1996 Dollars)	NA	73	82	79 to 94[c]	65	60
Change in Carbon Intensity (Percent)	NA	-27.9	-32	-26	-31	-24.5
Change in Fossil Fuel Consumption (Percent)	NA	-19.3 to -23.9[d]	-30.3	-22.1	-24.5	-20.9
			2020			
Carbon Price (1996 Dollars per Metric Ton)	**147**	**251**	**316**	**305**	**286**	**360**
Change in Actual Gross Domestic Product From Reference Projection						
Percent	-1.5[b]	-0.96	-2.4	-0.8	NA	-2.0
Billion 1996 Dollars	-156	-120	-311	-91	NA	-257
Loss in Potential Gross Domestic Product Relative to Reference Projection (Billion 1996 Dollars)	NA	81	111	75 to 103[c]	109	130
Change in Carbon Intensity (Percent)	NA	-32.2	-31.0	-38.9	-36.9	-35.9
Change in Fossil Fuel Consumption (Percent)	NA	-24.0 to -32.3[e]	-35.1	-25.7	-29.6	-28.4

[a]EPRI allows 50 million metric tons for sinks in this case.

[b]The percentage represents MIT's upper bound estimate, including some macroeconomic adjustment costs. MIT provided a range from -0.5 to -1.5 percent for change in GDP, to be interpreted as minimum and maximum losses to the economy. For the purposes of this chapter, the lowest range is the irreducible economic loss. Because GDP was not provided for the MIT reference case, the reader may assume a central value for GDP of $9,400 billion in 2010 and $10,900 in 2020 (1992 dollars). Consequently, the range of losses is $52 billion to $156 billion in 2010 (1996 dollars).

[c]The losses in potential GDP for EIA shown in Tables 30 and 31 use two different concepts, which give slightly different results. One uses the computation of potential GDP that is derived from the DRI model as described in Chapter 6 of this report. The second uses the approximation method under the carbon reduction versus carbon price curve, also discussed in Chapter 6. The two calculations produce nearly identical results for the 1990-3% case. For the 1990-7% case, the DRI calculation produces a smaller estimate of potential GDP losses. For all other cases, the DRI calculation produces a higher estimate of potential GDP losses. Because the projections from analyses other than EIA's were calculated using the approximation method related to the carbon reduction versus carbon price curve, estimates from both the DRI and approximation methods are provided for the EIA study.

[d]Only total primary energy was provided. Fossil fuel consumption was derived by subtracting an estimate for nuclear energy and renewable energy ranging from 13 to 17 quadrillion Btu from total primary energy for 2010.

[e]Only total primary energy was provided. Fossil fuel consumption was derived by subtracting an estimate for nuclear energy and renewable energy of 12 to 20 quadrillion Btu from total primary energy for 2020.

NA = not available.

Sources: **EIA:** National Energy Modeling System, run FD07BLW.D080398B. **WEFA:** WEFA, Inc., *Global Warming: The High Cost of the Kyoto Protocol, National and State Impacts* (Eddystone, PA, 1998). **PNNL:** E-mail of data from PNNL with explanation of GDP effect received from Ronald Sands of PNNL on August 26, 1998. **CRA:** Paul M. Bernstein, Charles River Associates, e-mail communications, August 24, 1998. **EPRI:** E-mail provided by R. Richels of EPRI on July 6, 1998. **MIT:** Facsimile dated July 10, 1998, from Prof. Henry Jacoby, MIT, Cambridge Massachusetts.

Table 31. Comparison of Results for Reducing Carbon Emissions to 7 Percent Below 1990 Levels With Annex I Trading, Sinks, and Offsets

Projection	MIT	EPRI[a]	CRA	DRI Case 2	EIA[b] 1990+9%	EIA[b] 1990+14%	PNNL
2010							
Carbon Price (1996 Dollars per Metric Ton)	**175**	**114**	**109**	**110**	**163**	**129**	**100**
Change in Actual Gross Domestic Product From Reference Projection							
Percent	-1.5	-0.5	-1.3	-1.1	-2.0	-1.7	NA
Billion 1996 Dollars	NA	-56	-133	-118	-207	-177	NA
Loss in Potential Gross Domestic Product Relative to Reference Projection (Billion 1996 Dollars)	NA	17	15	16	27 to 36	17 to 29	38
Irreducible Losses (Billion 1996 Dollars)	NA	43	46	32	53 to 62	47 to 59	55
Expenditures on Annex I Trading (Billion 1996 Dollars)	NA	-26	-31	-16	-26	-30	-17
Purchased Emissions Credits (Million Metric Tons)[c]	NA	229	288	147	161	229	171
Change in Carbon Intensity (Percent)	NA	-15.7	-15.8	-15.8	-15.8	-12.9	NA
Change in Fossil Fuel Consumption (Percent)	NA	-13.2	-14.6	-11.7	-12.7	-10.3	-16.8
2020							
Carbon Price (1996 Dollars per Metric Ton)	**119**	**188**	**175**	**131**	**141**	**123**	**142**
Change in Actual Gross Domestic Product From Reference Projection							
Percent	-1.5	-0.96	-1.7	-0.3	-0.6	-0.5	NA
Billion 1996 Dollars	NA	-120	-226	-41	-76	-63	NA
Loss in Potential Gross Domestic Product Relative to Reference Projection (Billion 1996 Dollars)	NA	44	42	31	33 to 43	24 to 35	71
Irreducible Losses (Billion 1996 Dollars)	NA	73	82	46	56 to 66	52 to 63	102
Expenditures on Annex I Trading (Billion 1996 Dollars)	NA	-33	-40	-15	-23	-28	-31
Purchased Emissions Credits (Million Metric Tons)[c]	NA	177	228	111	161	229	219
Change in Carbon Intensity (Percent)	NA	-22.8	-18.8	-23.5	-22.2	-20.1	NA
Change in Fossil Fuel Consumption (Percent)	NA	-18.7	-23.3	-19.3	-16.2	-14.2	-20.6

[a]EPRI allows some contribution from the CDM.

[b]The 1990+9% and 1990+14% cases are shown for comparison only, because the carbon emissions levels projected in these cases are near those of the other studies shown.

[c]For EIA and EPRI, purchased carbon emissions credits equal the difference between the emissions target and 1,306 million metric tons (3 percent below the 1990 carbon emissions level).

NA = not available.

Sources: **EIA:** National Energy Modeling System, runs FD09ABV.D080398B and FD14ABV.D080398B. **CRA:** Paul M. Bernstein, Charles River Associates, e-mail communications, August 24, 1998. **EPRI:** E-mail provided by R. Richels of EPRI on July 6, 1998. **DRI:** Standard and Poors DRI, *The Impact of Meeting the Kyoto Protocol on Energy Markets and the Economy* (July 1998). **MIT:** Facsimile dated July 10, 1998, from Prof. Henry Jacoby, MIT, Cambridge Massachusetts. **PNNL:** Ronald Sands, PNNL, e-mail communication, August 26, 1998.

Because of the aggregation of sectors and outputs in the CRA analysis, CRA's analytical approach is likely to underestimate the costs of the Kyoto Protocol.[98] In the CRA reference case GDP grows rapidly from 2010 to 2020, making it more difficult to comply with the Kyoto Protocol in the 1990-7% case. Hence, the carbon price is projected to rise to $316 per metric ton in 2020.

WEFA projects reference case GDP that is about 1.3 percent lower than EIA's in 2010 but then rises above EIA's by about $670 billion, or about 6 percent, by 2020. The difference in the carbon prices in 2010 between the two studies ($265 per metric ton for WEFA and $348 per metric ton for EIA) is largely attributable to (1) a lower reference case GDP and lower emissions in the WEFA study, so that smaller reductions are needed to comply with the 1990-7% target, and (2) differences in the mix of fuels used in the reference case to generate electricity. WEFA's analysis projects less coal and more gas use for electricity generation than EIA's analysis, with basically the same electricity demands in 2010.

In 2020, the WEFA carbon price rises to about $360 per metric ton—about $55 per metric ton higher than the EIA carbon price for the same case. The reason for this difference is based on three factors. Differences in the reference case GDP growth rates (WEFA's GDP grows much faster than EIA's from 2010 to 2020) lead to the need for higher fuel prices in the WEFA projection to comply with the 1990-7% case. WEFA assumes that nuclear life extensions would not be economical or feasible, whereas EIA allows economical nuclear refurbishments. WEFA projects that renewables cannot contribute significantly to electricity generation: renewable use for generation increases by only 11 percent in 2020 relative to the baseline, even with a carbon price of $360 per metric ton, whereas EIA projects a 115-percent increase in the use of renewables for electricity generation in the 1990-7% case relative to the EIA reference case.

The EPRI analysis begins to react to the Kyoto Protocol in 1990, resulting in lower carbon prices and GDP losses than in the EIA analysis for 2010.[99] Further, since the model does not have end-use technology detail, the rate of autonomous energy efficiency improvement is assumed as a policy lever and is based on the analyst's judgement or on calibration with other midterm, technology-rich models.

The pattern of carbon prices in the MIT study is similar to that in the EIA and EPRI studies. In the MIT analysis, decisionmakers do not see future prices or the impending Kyoto Protocol. In addition, capital stock is vintaged—i.e., once capital is invested in equipment, that capital is sunk and the technology's efficiency and use cannot change during its survival period.

Carbon prices in 2020 for the 1990-7% case are more evenly distributed among the studies, ranging between $147 per metric ton for MIT to about $360 per metric ton for WEFA. The declining carbon prices in the EPRI and EIA studies result from the projected increasing penetration of carbon-free or low-carbon generation technologies, coupled with greater selection of more efficient technologies that become economical with higher end-use fuel prices. MIT's carbon price in 2020, $147 per metric ton, is the lowest because this study implicitly has greater optimism than EIA and EPRI that the economy will produce and adopt low-carbon or carbon-free technologies by 2020.

As already mentioned, the lead time that decisionmakers have to anticipate the Kyoto Protocol and the assumed responsiveness of consumers and equipment (demand elasticities and fuel substitution elasticities) can significantly affect the projections of how costly and difficult the transition will be. Most of the studies compared, with the exception of WEFA and EIA, allow the transitions to begin as early as 1990 or 1995.[100] Since starting earlier allows consumers and producers to react earlier, the economy has more time to adjust to the Kyoto Protocol. This may result in an underestimation of the carbon prices and the midterm actual GDP losses to the economy that will be required to achieve the 1990-7% case.

The CRA, WEFA, and PNNL studies exhibit a rising trend in the carbon prices required over time to maintain the 1990-7% emissions target, because technological improvements do not occur quickly enough relative to demand growth. The technology-rich studies reach their peak carbon price in the early part of the compliance period, followed by a flat or declining carbon price to 2020 as more efficient technologies are adopted. The relatively high energy prices make higher-efficiency and higher-cost equipment more competitive in the early part of the compliance period and give rise to normal learning through manufacturing experience, which

[98] The CRA model uses perfect foresight for investment behavior, which may also contribute to underestimating the costs. It assumes that products (like gas and coal) are not perfect substitutes and capital is not perfectly malleable. Further, the demand for energy is only moderately responsive to price changes, compared to the PNNL model. CRA develops its model parameters using the GTAP database from Purdue University and the International Energy Agency (IEA) database.

[99] EPRI's MERGE model is an Aggregate Optimization Model and has perfect foresight. The EPRI model is being rebenchmarked to start in 2000 and should result in higher carbon prices and higher GDP losses in 2010 than are shown in their current analysis.

[100] For PNNL, since the model begins solving in 1985, policy instruments could be introduced as early as 1990. For this study, PNNL reports that the policy instruments for the Kyoto Protocol were phased in beginning in 2001.

helps to reduce equipment costs in the later part of the compliance period.

The other major area of disagreement among the projections is the impact on actual GDP. In 2010, actual GDP losses relative to each reference case range from -1.0 percent (EPRI) at the low end to about 4.2 percent (EIA) at the high end. Some economists have noted that the total GDP impact on the U.S. economy of regulatory programs such as the Kyoto Protocol are large, and that the true costs typically exceed direct costs by a factor of two to four, particularly in the few years following implementation.[101] CRA projects a 2.1-percent loss in GDP in 2010 and a 2.4-percent loss in GDP in 2020. This contrasts with the EIA projection of a 4.2-percent loss in GDP in 2010 and a 0.8-percent loss in 2020, a trend returning to the reference case GDP. The EIA projected recovery trend is due to declining real prices after 2012, whereas increasing GDP losses for CRA are due to continued increasing delivered energy prices throughout the projection period and the relative high GDP level in the reference case from which the reductions must be made.

Most of the reasons for the differences in carbon prices also contribute to the differences in GDP losses. For example, perfect foresight and long lead times allow the economy to adjust at minimum cost as in the PNNL, EPRI, and CRA models. In the WEFA analysis, lower GDP growth in the early period allows for lower carbon prices and smaller GDP losses relative to the EIA study. CRA's lower carbon price and smaller GDP losses are attributable to four factors: (1) the lack of representation of a revenue recycling mechanism, (2) the high level of aggregation of the U.S. energy-economy, (3) the length of the adjustment period, and (4) the incorporation of international trade flows.

The GDP losses portrayed in the analyses are not based on the same definitions. EIA, DRI, and WEFA report losses in potential GDP[102] and full macroeconomic adjustment costs. CRA and EPRI report losses to potential GDP plus some but not all of the macroeconomic adjustment costs, because the level of aggregation used to represent the U.S. macroeconomy does not permit a full representation of the macroeconomic adjustment costs. PNNL reports only the direct cost of meeting the required commitment level, i.e., losses in potential GDP. The loss in potential GDP can be estimated for all the studies except MIT and can be combined with payments for international permits to develop “irreducible” losses to the economy arising from compliance with the Kyoto Protocol for each of the two cases (no trading and Annex I trading).[103] Estimates of irreducible losses to GDP in the 1990-7% case in 2010 are remarkably close, ranging from $60 billion for WEFA to about $94 billion for EIA (in 1996 dollars). The range of irreducible losses in 2020 is $75 billion for EIA to $130 billion for WEFA. WEFA projects the largest potential loss in 2020 because it has the highest carbon prices and its reference case projection of GDP in 2020 is one of the two highest.

The GDP comparisons imply that there is a great deal of uncertainty about the actual economic losses that could result from adherence to the Kyoto Protocol, with actual economic losses rising to as high as 4.2 percent of reference case GDP in 2010—particularly for analyses that use highly disaggregated representations of the U.S. economy (EIA and WEFA). The difference between actual losses and potential GDP losses represents macroeconomic adjustment costs, which are viewed by economists as *theoretically* reducible by optimal fiscal and monetary policies. This may be another factor leading to the wide variation in estimates of macroeconomic adjustment costs. Nevertheless, there is considerable agreement on the level of the potential GDP losses.

All the studies are in close agreement on the change in carbon intensity that must occur relative to each reference case. Reductions in carbon intensities are between 24 percent and 29 percent in 2010 and between 32 percent and 39 percent in 2020.

[101] Jorgenson and Wilcoxen, “Impact of Environmental Legislation on U.S. Economic Growth and Capital Costs,” in *U.S. Environmental Policy and Economic Growth: How Do We Fare?* (Washington, DC: American Council on Capital Formation, 1992); “Reducing U.S. Carbon Emissions: An Econometric General Equilibrium Assessment,” *Resource and Energy Economics*, Vol. 15 (1993), pp. 7-25; and P.M. Bernstein and W.D. Montgomery, “How Much Could Kyoto Really Cost? A Reconstruction and Reconciliation of Administration Estimates” (Charles River Associates, 1998).

[102] The curve shown in Figure 114 in Chapter 6 of this report summarizes the relationship between the level of control and the marginal cost of that level of control. Hence, at each increment of control, the marginal cost is by definition equal to the economic resources that must be forgone in order to achieve the increment in control. It follows, therefore, that the sum of the marginal costs must equal the total cost of the controls that would be internalized in markets. This is the integral of the area under the curve, shown as area A in Figure 114. Conceptually, this is essentially the same effect that is measured by the unavoidable cost in the reduction of potential GDP in the macroeconomic models. As shown in Figure 115, this measure of the unavoidable costs using the results of the NEMS model is nearly identical to the similar estimate from the DRI macroeconomic model.

[103] Furthermore, for the balance of total emissions needed to meet the Kyoto targets, permits would be purchased on the international market. If the marginal cost of control in the United States and the international prices of permits are in equilibrium, then the area B in Figure 114 will represent the total payments for permits, and the sum of the two parts will represent the irreducible losses to the economy under that trading regime to meet the Kyoto requirements.

Comparisons of Annex I Trading Cases

Only five analyses—MIT, EPRI, CRA, PNNL, and DRI—provided simulations of the impacts of sinks, offsets and Annex I trading. DRI's Case 2 is compared with the other Annex I trading cases because carbon permits purchased abroad are closest, falling in the range of 147 to 288 million metric tons.[104] Two EIA cases—1990+9% and 1990+14%—are compared with those studies in Table 31, because both of these cases yield carbon emissions in the range of the other studies. Internationally purchased carbon credits in 2020 fall in the range of 111 to 229 million metric tons for all these analyses. EIA's carbon prices in the 1990+9% case is $163 per metric ton[105] in 2010 and $141 per metric ton in 2020. The EIA carbon price in the 1990+14% case is $129 per metric ton in 2010 and $123 per metric ton in 2020. MIT provided only carbon prices and a range of GDP losses; thus, further comparisons are not possible.

EIA's purchased carbon credits in 2010 (229 million metric tons) in the 1990+14% case are closest to the projected international purchased credits by EPRI and CRA (229 and 288 million metric tons, respectively). The carbon price projected in these cases ranges from $109 per metric ton for CRA to $129 per metric ton for EIA, a statistically insignificant variation. While there is considerable agreement on the carbon price and credit purchases in these analyses, actual GDP losses projected in EIA's 1990+14% case are more than 200 percent higher than the actual GDP losses projected by EPRI and more than 33 percent higher than CRA's. It is also about 50 percent higher than DRI's.

In the Annex I trading cases, only the DRI and EIA analyses consider how the domestic funds will be recycled back to the economy. EIA assumed that the revenues from domestic sales of carbon emission permits would be recycled back to consumers through a personal income tax rebate, as described in Chapter 6,[106] and DRI assumes a return of funds to business. The DRI choice of returning the carbon revenues to business provides a significant boost to business investment in the economy, which implies higher business profits and lower real incomes for consumers in the medium term. According to the DRI analysis, returning carbon revenues to business ultimately would accelerate recovery and lead to stronger economic growth in the longer term than would recycling the carbon revenues to consumers. The impacts of the two recycling mechanisms account for most of the differences in macroeconomic results between the EIA and DRI analyses.

The DRI approach also phases in the carbon policy over a 10-year period (an approach necessitated by the structure of the DRI energy model), whereas EIA phases in the policy over a 3-year period. This factor adds to the difference between the EIA and DRI analyses of macroeconomic costs. In the DRI study, the 10-year phase-in and the assumption that consumers will anticipate and respond to the Kyoto Protocol early results in a smoother economic transition and tends to give a lower carbon price than analyses with shorter phase-in periods like EIA's.

The estimates of unavoidable (irreducible) losses—income losses that cannot be recovered—for the U.S. economy range from $32 billion (DRI Case 2) to about $62 billion (EIA) in 2010. There are many frictions that can increase costs above the irreducible minimum. These include business cycles, international trade and capital constraints, regulation, use of imperfect instruments instead of auction permits, coal subsidies, CAFE standards, exemptions, efficiency losses from taxation, etc.[107] Various Federal Reserve and Federal Government policies might mitigate actual GDP losses. There is considerable uncertainty regarding all the above actions.

The EPRI analysis, because of its perfect foresight and optimizing framework, yields actual GDP losses that are closest to its estimated unavoidable losses. CRA estimates actual GDP losses that are almost 3 times its unavoidable losses in 2010, and estimated actual GDP losses in 2010 for the DRI and EIA 1990+14% cases are 3 to 4 times the unavoidable losses. Because DRI's and EIA's actual GDP losses are based on a detailed macroeconomic model that has limited foresight, focuses on the transitional process rather than the steady-state condition of the economy, their projected GDP losses are expected to be the largest and perhaps more appropriate in the mid term (through 2010). WEFA and EIA incorporate revenue recycling, while DRI redirects the revenues through higher profits to business.

[104] Standard and Poors DRI recently analyzed three cases for the UMWA-BCOA LMPCP Fund. Case 1 assumed that 8 percent of the necessary carbon reduction in 2010 would be accomplished from sinks and offsets, 15 percent from trading, and 77 percent domestically. Case 2 assumed that sinks and offsets would account for 12 percent of the required reduction from baseline in 2010, 30 percent would be purchased from abroad, and 58 percent would be accomplished domestically. Case 3 assumes that sinks and offsets would generate 16 percent of the required reductions from baseline, 55 percent of the reduction would be purchased from abroad, and 29 percent of the reduction to be accomplished within domestic energy markets. Given that the DRI baseline for 1990 carbon emissions is 1,336 million metric tons, the domestic target for Case 1 in 2010 (1,354 million metric tons) is about 1 percent above 1990 levels, Case 2 (1,452 million metric tons) is about 9 percent above 1990 levels, and Case 3 (1,593 million metric tons) is about 19 percent above 1990 levels.

[105] For simplicity and ease of exposition, it is assumed in this chapter that the carbon price, the price at the margin that the United States is willing to pay to reduce carbon emissions, equals the internationally traded permit price.

[106] In Chapter 6, EIA also considers a social security tax rebate.

[107] Tom Tietenberg, *Environmental and Natural Resource Economics*, Third Edition (Harper Collins Publishers, 1992).

The DRI and EIA analyses share the same DRI macroeconomic model; however, they differ in the way they represent the energy market. DRI uses a largely econometric approach, with some technology components to simulate equipment turnover. Responses of energy demand to energy prices are approximated through demand elasticities. Elasticity estimates can vary dramatically and are a major factor in determining results.

Because DRI and EIA share the same macroeconomic model, the reference case[108] estimates of macroeconomic variables are nearly identical for 2010. The differences in the reference case energy projections are primarily due to differences in fuel prices. By 2020, the differences between the DRI and EIA macroeconomic projections widen as differences in fuel prices widen.

The EIA 1990+9% case reduces more emissions domestically (325 million metric tons) than the 1990+14% case at an average carbon price of $159 per metric ton (peaking at $163 per metric ton) for the 2008-2012 period. The unavoidable losses to the U.S. economy for 2010 are estimated to be slightly ($3 to $6 billion) more than in the 1990+14% case. The actual GDP losses are more than 3.5 times the unavoidable losses in the EIA cases.

The carbon price in the two EIA cases and the MIT trading case declines from 2010 to 2020, unlike the carbon prices in the EPRI, CRA, and DRI analyses that increase over the decade. Most of the reasons for these differences have already been described in the 1990-7% comparison case and will not be repeated here. However, one noteworthy difference remains—the availability and cost of Annex I carbon permits and international trade. In the EPRI model, inexpensive permits are presumed to be available from Russia in the early part of the Kyoto Protocol implementation period but are assumed not to be available in the later part of the period. The elimination of the easy Russian permits makes it harder for the United States to meet its commitments in 2020 through Annex I trading and raises the carbon permit price by 65 percent relative to 2010. The reason for the 60-percent increase in 2020 in the CRA carbon price is related to the differences in the representation of advanced technologies, the level of aggregation of the CRA model as previously discussed, and the absence of easy carbon permits from Russia.

The Administration's estimate of the costs of implementing the Kyoto Protocol[109] has been developed, in part, by using the PNNL model. The Administration's analysis does not provide sufficient data to be included in Tables 30 and 31; however, the Administration asserts in Table 4 of the analysis (page 52) that under Annex I trading, the carbon price would be reduced by 72 percent and the resource cost would be decreased by 57 percent relative to a case in which all carbon reductions are achieved domestically. Using Tables 4 and 5 on pages 52 and 53 of the Administration's report on the Kyoto Protocol, the carbon price for the 1990-7% case can be calculated to be $192 per metric ton (in 1996 dollars), and the irreducible economic losses can calculated to be $60 billion. When Annex I trading is assumed, the Administration projects that carbon prices would be reduced to $54 per metric ton, with $26 billion dollars of irreducible losses.[110] The relatively lower GDP growth rate from 1995 to 2010 in the Administration's reference case analysis—2.1 percent annually, compared with 2.3 percent in the *AEO98* reference case, is a major factor that results in a lower carbon price and lower economic costs needed to achieve a carbon target.

Based on Tables 30 and 31, the following can be summarized:

- There is no clear consensus on how effective Annex I trading will be in reducing carbon prices and the costs to the United States. WEFA believes that Annex I trading will not be effective at all because of

[108] Other reference case differences that influence the Kyoto analysis include: (1) The DRI reference case projects 3.1 quadrillion Btu lower primary energy consumption and 1.8 quadrillion Btu lower fossil fuel consumption in 2010 than does EIA. By 2020, the differences grow to 4.2 quadrillion Btu of primary energy and 2.4 quadrillion Btu of fossil fuel consumption. Associated carbon emissions are also lower. Consequently, it should be less costly for the economy to achieve the same carbon target (1,452 million metric tons) in the DRI analysis than in the EIA analysis (1,461 million metric tons in 1990+9% case), as Table 31 confirms. (2) The DRI reference case projects higher world oil prices, higher delivered coal prices, and lower gas prices than the EIA reference case and greater coal, lower gas, and lower oil consumption than the EIA reference case for 2010 and 2020. The differences in the mix of fuel consumption are related to the differences in fuel prices in the cases. Because the delivered price that consumers react to is the sum of the fuel costs plus the carbon price, when oil and coal prices are higher (without the carbon price), the additional carbon price required to achieve the same delivered coal and petroleum product prices will be lower. Higher reference case prices imply lower required carbon prices to induce an energy demand or mix change. Lower carbon prices usually result in lower economic losses.

[109] *The Kyoto Protocol and the President's Policies To Address Climate Change: Administration Economic Analysis* (Washington, DC, July 1998).

[110] According to Table 5, page 53, of the Administration's report, Annex I trading with participation by key developing countries would result in a permit price of $23 per metric ton and irreducible losses of $12 billion. Table 4 on page 52 of the report indicates that the permit price in that case would be reduced by 88 percent and the resource cost would be reduced by 80 percent relative to a "domestic only" case. This means that 12 percent of the carbon price for the domestic only case would be $23, and thus the carbon price in the domestic only case would equal $192 per metric ton. Similarly, 20 percent of the domestic only resource cost would be $12 billion, meaning that the domestic only resource cost would be $60 billion. Using the percentages for Annex I trading in Table 4, the carbon price and the irreducible losses can also be derived for the Annex I trading case.

political and implementation difficulties. Others, like CRA, EPRI, and PNNL, suggest that carbon prices in 2010 can be reduced by about 60 percent.

- All the studies project irreducible losses to the economy that are small (less than 1 percent of GDP in 2010 and 2020) in absolute magnitude—between $32 billion and $62 billion in 2010 and between $46 billion and $102 billion in 2020. The wider differences in 2020 reflect the different perspectives on production losses to the economy associated with forced reductions in fossil fuel energy use.
- With Annex I trading, estimated actual GDP losses relative to each reference case range from 0.5 percent to about 2 percent.
- If the United States is required to achieve stabilization at the 1990-7% levels, the estimate of carbon prices required for stabilization in 2010 range from a low of $221 per metric ton to $348 per metric ton, with the vast majority in the $265 to $295 per metric ton range. Actual GDP losses are projected to range from 1.0 percent to 4.2 percent. However, since all the studies except EIA's and DRI's assume early U.S. action (before 1998) to limit carbon emissions, their estimates of carbon prices and GDP estimates are likely to be low.

The “Five-Lab Study”

Five U.S. Department of Energy Laboratories were asked in the winter of 1996-97 (before the Kyoto conference) to develop technology-oriented strategies for reducing U.S. carbon emissions to 1990 levels by 2010.[111] To represent the potential impact of new technology strategies on carbon emissions, the study assumes increased performance and lower costs for new technologies, new government policies that promote their adoption into the market, and a greater propensity by consumers to buy them than they have shown in the past. In addition, the Five-Lab Study assumes the lower economic growth (and lower carbon emissions) in the *Annual Energy Outlook 1997* than the EIA analysis described in this report.

The principal components of the Five-Lab Study focus on the adoption of energy-efficient technologies under the assumption of a $25 and $50 per metric ton domestic carbon price; an aggressive research and development (R&D) program; and aggressive but unspecified new policies to facilitate adoption of energy-efficient technologies. The analysis was produced using a series of independent end-use sector models that were manually coupled to an electricity market model that assumes a deregulated electricity market.[112] Thus, feedback between energy markets and the rest of the economy were not captured. Consequently, the individual sector solutions may be inconsistent with each other and most likely do not represent a market equilibrium.

The Five-Lab Study is not directly comparable with any of the analyses compared above, because it was not prepared using an integrated modeling framework that simultaneously balances the energy demand for equipment and consumption made by consumers in all segments of the economy with the supply and prices of fuels and economic growth. Therefore, simple comparisons between the Five-Lab Study and EIA's analysis can be misleading.

Given all the above qualifications, three comparisons are made between the Five-Lab Study and the EIA analysis (Tables 32 and 33). The Five-Lab Study is compared in terms of (1) the EIA case that comes closest to achieving a carbon price of $50 per metric ton in 2010 (the 1990+24% case), (2) the EIA case that comes closest to reducing carbon emissions by about the same amount relative to its baseline (the 1990+9% case), and (3) the EIA case that focuses on advanced technologies (the 1990+9% high technology sensitivity case). By design, none of the Five-Lab Study scenarios results in carbon emissions that are below 1990 levels, because they were targeted to achieving stabilization at 1990 levels.

The Five-Lab Study defines three scenarios: (1) an efficiency case, (2) a high efficiency / low carbon case with a $25 per metric ton carbon price (25 HE / LC), and (3) a high efficiency / low carbon case with a $50 per metric ton carbon price (50 HE / LC). The efficiency case assumes better technology and improved cost competitiveness as compared to the business-as-usual case,

[111] Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low Carbon Technologies by 2010 and Beyond* (Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Argonne National Laboratory, September 1997).

[112] For the buildings sector (residential and commercial), a spreadsheet model was used for the Five-Lab Study, and it was calibrated to yield the results of the *Annual Energy Outlook 1997 (AEO97)* for a business-as-usual case. For the industrial sector, the Long-Term Industrial Energy Forecasting model was used, and it was calibrated to the *AEO97* results for the business-as-usual case. For the transportation sector, the transportation model of the National Energy Modeling System (NEMS) was used, and the *AEO97* baseline was modified based on the judgment of analysts at Oak Ridge National Laboratory to develop the business-as-usual case. For the electricity sector, a new model was developed by Oak Ridge National Laboratory, which assumed a deregulated electricity industry.

Table 32. Comparison of Energy Consumption, Gross Domestic Product, and Energy Intensity Results for EIA and Five-Lab Study Analyses

Projection	1990	1996	2010 Five-Lab Study Business as Usual	2010 Five-Lab Study 50 HE/LC	2010 EIA Reference	2010 EIA 1990+24%	2010 EIA 1990+9%	2010 EIA 1990+9% High Technology
Energy Use by Sector (Quadrillion Btu)								
Buildings	29.8	34.3	36.0	32.0	38.6	36.1	32.2	33.3
Industrial	31.4	34.6	37.4	33.6	40.0	38.5	36.9	34.6
Transportation	22.7	24.9	32.3	27.8	32.6	31.9	30.5	29.8
Total	83.9	93.8	105.7	93.4	111.2	106.5	99.6	97.7
Gross Domestic Product								
Billion 1992 Chain-Weighted Dollars	6,139	6,928	9,185	9,185	9,429	9,333	9,241	9,277[a]
Change From Reference Projection (Percent)	—	—	—	0.0	—	-1.0	-2.0	-1.65
Energy Intensity								
Thousand Btu per Dollar of GDP	13.67	13.54	11.51	10.17	11.79	11.42	10.78	10.54[a]
Annual Percent Change, 1996-2010	—	—	-1.2	-2.0	-1.0	-1.25	-1.65	-1.78

[a]The GDP and intensity values are approximations derived without using the full DRI model.

— = not applicable.

Sources: **Five-Lab Study**—Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low Carbon Technologies by 2010 and Beyond* (Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Argonne National Laboratory, September 1997), Table 1.1. **EIA**—National Energy Modeling System, runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and HITECH09.D080498B.

Table 33. Comparison of Carbon Emissions Results for EIA and Five-Lab Study Analyses (Million Metric Tons)

Projection	1990	1996	2010 Five-Lab Study Business as Usual	2010 Five-Lab Study 50 HE/LC	2010 EIA Reference	2010 EIA 1990+24%	2010 EIA 1990+9%	2010 EIA 1990+9% High Technology
Carbon Emissions by Sector[a]								
Buildings	457	516	571	509	615	545	424	462
Industrial	454	476	548	455	559	519	462	437
Transportation	434	471	616	513	617	605	576	562
Total	1,346	1,463	1,735	1,340	1,791	1,668	1,462	1,461
Electricity Generation[b]	477	517	636	500 (-136)[c]	657	567	409	446
Change From Reference Emissions	—	—	—	395	—	127	342	342
Carbon Price (1996 Dollars per Metric Ton)	—	—	—	50	—	67	163	121

[a]Carbon emissions in each sector include a share of the carbon emitted from electricity generation.

[b]In the EIA cases, carbon emissions reduced from electricity generation are accounted for in the end-use sectors.

[c]For the 50 HE/LC case, 136 million metric tons saved in electricity generation must be subtracted from the emissions in the end-use sectors, which do not incorporate the saved emissions for generation.

— = not applicable.

Sources: **Five-Lab Study**—Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low Carbon Technologies by 2010 and Beyond* (Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Argonne National Laboratory, September 1997), Table 1.2. **EIA**—National Energy Modeling System, runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and HITECH09.D080498B.

as a result of additional government spending on R&D and new, unspecified government programs and policies encouraging adoption of energy-efficient technologies. The HE/LC cases assume even more aggressive government spending, policies, and programs with regard to development and deployment of energy-efficient and low-carbon technologies. These cases assume that government policies and programs will be phased in gradually beginning in 2000 and implemented by 2010, with a carbon price that begins in 2000 and rises until 2010. The two HE/LC cases differ only in the carbon prices assumed, one reaching $25 per metric ton in 2010 and the other $50 per metric ton. The Five-Lab Study focuses on the $50 per metric ton case because that analysis finds that carbon emissions can be stabilized at 1990 levels by 2010. This case is equivalent to 5 percent above 1990 levels when adjusted for the carbon emission and economic baseline used in the EIA analysis.

Comparison of EIA Cases With the Five-Lab Study 50 HE/LC Case

The principal factors that explain differences between the EIA cases and the Five-Lab Study results include (1) lower reference case economic growth (1.9 percent annually for the Five-Lab study versus 2.2 percent annually for EIA) and carbon emissions growth (70 million metric tons lower in 2010) than the EIA reference case; (2) a more aggressive menu of technologies in the 50 HE/LC case than in either the 1990+24% case or the 1990+9% case, due to the assumption of aggressive R&D; (3) a more aggressive consumer response—assumed through changes to their purchase behavior for energy-efficient equipment and changes to energy conservation—than has been seen historically, as the result of new, unspecified government policies; and (4) a non-integrated analysis, in which the feedback between markets is not captured and some double counting of benefits is probable.

As illustrated below, differences in the reference GDP and carbon emission growth rates can have an enormous impact on the difficulty or ease of achieving target carbon emissions, the carbon prices needed to achieve a carbon emissions target, and the emissions reductions achieved.

Comparison With the EIA 1990+24% Case: This comparison is made because the carbon prices are similar in the two cases ($60 per metric ton for EIA and $50 per metric ton for the Five-Lab Study.) At $67 per metric ton, EIA projects carbon emissions will be reduced by 123 million metric tons (7 percent relative to the reference case) in 2010. The Five-Lab Study projects a carbon emissions reduction of 395 million metric tons (23 percent) from its baseline in 2010 at the carbon price of $50 per metric ton. EIA projects a GDP loss of about $14 billion in 2010 and an annual 1.25-percent rate of decline in energy intensity from 1996 to 2010. The Five-Lab Study estimates no GDP losses and an annual energy intensity decline rate of 2.0 percent. Although the EIA cases assume a dynamically changing menu of technologies, the differences in energy intensity result from the assumed penetration of even more efficient technologies in the Five-Lab Study due to the more aggressive technology assumptions and consumer behavior.

Comparison With the EIA 1990+9% Case: The EIA 1990+9% case reaches a carbon target of 1,467 million metric tons—about 325 million metric tons below EIA's reference case—in 2010. The Five-Lab Study 50 HE/LC case reduces carbon emissions by 396 million metric tons below the business-as-usual case. If the two studies had used EIA's reference levels of emissions in 2010, then 1,416 million metric tons would have been the adjusted carbon emissions in the Five-Lab Study 50 HE/LC case. Nevertheless, the carbon price required in the EIA 1990+9% case is about $163 per metric ton, compared with $50 per metric ton in the Five-Lab Study. The combination of more advanced technologies and consumer behavior, coupled with a lower reference case economy and carbon emissions, allows the Five-Lab Study to achieve comparable carbon emission reductions at a much lower carbon price.

GDP losses are estimated to be close to zero in the Five-Lab Study. GDP losses in the EIA 1990+9% case are estimated to be about 2.0 percent relative to the EIA reference case. GDP in the EIA 1990+9% case in 2010 is about $80 billion above that in the Five-Lab Study' business-as-usual case. Consequently, a significant portion of the difference in the carbon prices required to achieve the respective carbon emission targets can be explained by differences in reference GDP and carbon emission levels.

Comparison With the EIA 1990+9% High Technology Case: In the 1990+9% high technology case, EIA's projected energy intensity reduction rate approaches 1.8 percent annually and requires a carbon price of $110 per metric ton. The technological progress assumed is roughly similar to that in the Five-Lab Study, but EIA's consumer decisionmaking remains unchanged. The annual rate of change in energy intensity, due primarily to technological change, in the 50 HE/LC for 1996-2010 is about 2 percent per year, a rate that is historically unprecedented for any 14-year period when energy prices are relatively stable, illustrating the study's more aggressive assumptions about cost-effective technology and consumer behavior. Some of the assumptions of the Five-Lab Study that explain the major differences from the EIA results presented in this report are discussed below.

Differences in Assumptions

The following list identifies representative differences between the major assumptions between the EIA reference case—a minor modification of the *Annual Energy Outlook 1998* (*AEO98*) reference case—and those used for the Five-Lab Study. The EIA reference case assumes that current policies continue unchanged for the entire forecast period and that technology continues to evolve as represented by EIA's assessment of the best engineering estimates of their cost and performance during the forecast period. The Five-Lab Study is based on the assumption that technological advances are supported by various new governmental policies; therefore, it is expected that penetration rates of new energy-efficient technologies will generally be higher in the Five-Lab Study.

Buildings Sector Assumptions

Technological Optimism and Adoption: The EIA reference case technology menu for the buildings sector improves over time in terms of both costs and efficiencies, including future technologies that are unavailable today. Market penetration is determined by economics and observed consumer behavior. For the commercial sector, available technologies are selected on the basis of annualized life-cycle costs and specified replacement equipment behavior rules (e.g., same fuel or no constraints). For the residential sector, technologies are selected on the basis of first cost and first-year operating cost, using observed market discount rates. The EIA reference case and carbon reduction cases use a distribution of implicit discount rates developed from observed consumer behavior, ranging from 15 percent to more than 200 percent in real terms; energy-efficient investments must earn returns greater than these discount rates in order to be adopted by consumers.

The Five-Lab Study 50 HE/LC case includes implementation of most of the cost-effective efficiency improvements, using a life-cycle cost calculation based on a 7-percent real discount rate for both the residential and commercial sectors. By assumption, in the Five-Lab Study 50 HE/LC case, 65 percent of the cost-effective potential is achieved. The 7-percent discount rate implies that consumers on average are willing to wait about 15 years to get their payback on the incremental investments required to acquire more energy-efficient equipment. Currently, residential and commercial consumers tend to have payback periods of 6 months to 5 years, and residential homeowners tend to move about every 7 years. Further, the assumption that 65 percent of all equipment that is cost-effective at a 7-percent discount rate is purchased assumes that dramatic changes will occur in consumer behavior as a result of government policy. Because the EIA cases assume no new government policies, these Five-Lab Study assumptions make a dramatic difference in the efficiency of equipment purchased in the buildings sector and in the carbon price required to achieve a specified carbon target.

Miscellaneous Electricity Growth: In the EIA cases, miscellaneous electricity use in the buildings sector, measured in primary terms, grows at 2.8 percent per year from 1997 to 2010. In the Five-Lab Study, buildings sector miscellaneous electricity growth is 0.9 percent per year from 1997 to 2010 in the HE/LC cases. The difference is significant because it means that electricity demand is lower in the Five-Lab Study HE/LC cases than in the EIA cases, requiring a lower carbon price in the Five-Lab Study to achieve the target.

Transportation Sector Assumptions

Light-Duty Vehicle Cost and Performance: The EIA reference case achieves a new car efficiency of 30.6 miles per gallon by 2010. In EIA's 1990+24% case, with a carbon price of $67 per metric ton, new car efficiency increases to about 32.0 miles per gallon in 2010. In comparison, new car efficiencies reach 50.2 miles per gallon in the Five-Lab Study HE/LC cases. The Five-Lab Study achieves the higher efficiency by reaching 73-percent diesel penetration, 11-percent electric hybrid penetration, and a small penetration of fuel cell vehicles by 2010. The Five-Lab Study higher efficiencies and penetration rates were achieved through a variety of assumptions: (1) a major breakthrough of diesel NO_x catalysts was assumed; (2) the characteristics of advanced diesel vehicles (vehicle price, vehicle range, fuel availability, commercial availability, etc.) were assumed to be the same as those of gasoline vehicles and to be accepted by consumers; (3) the incremental costs of advanced vehicles were assumed to be substantially lower than those in the EIA cases; and (4) with a price increase of 12.5 cents per gallon, consumers were assumed to prefer vehicles with much lower horsepower in the Five-Lab Study in 2010 (182 horsepower) than projected in the EIA cases (258 horsepower).

Industrial Sector Assumptions

Model Methodology and Calibration: For the Five-Lab Study, the Long-Term Industrial Energy Forecasting (LIEF) model was calibrated to yield *AEO97* results for the business-as-usual case. Variations from the business-as-usual case involved changing two major assumptions in the LIEF model. For the HE/LC cases, the capital recovery factor (the implicit discount rate used to evaluate investment alternatives) was reduced from 33 percent to 15 percent, and the market penetration factor (the rate at which cost-effective investments are undertaken) was doubled from 3 percent to 6 percent. Both assumptions accelerate adoption of advanced technologies in the Five-Lab Study.

Additional Assumptions: The HE/LC cases in the Five-Lab Study included additional reductions of 31 million metric tons of carbon-equivalent greenhouse gas emissions, based on results that were not part of the LIEF modeling exercise. The additional reductions included 14 to 24 million metric tons from advanced turbine systems and 12 to 16 million metric tons of biomass and black liquor gasification, cement clinker replacement, and aluminum technologies. The cement clinker replacement and advanced aluminum production cells were assumed to reduce emissions by 1 to 2 million metric tons and 3.5 million metric tons of carbon equivalent, respectively, by 2010. These technologies were not included in the EIA cases.

Electricity Sector Assumptions

Electricity Competition: In each of the Five-Lab Study cases, greenhouse gas emission reductions in the utility sector result from lower electricity demand in the end-use sectors, the assumed deregulation of the electric power industry, an assumed carbon permit trading price of $50 per metric ton, and utility supply-side assumptions for fossil, nuclear, and renewable technologies. The Five-Lab Study assumes competitive prices in 2010 in all regions. The competitive pricing assumption tends to raise the price of electricity relative to the regulated cost-of-service price when a carbon price is applied to the carbon content of the fuels. The EIA reference case assumes competitive prices in 2010 in only three regions—New York, California, and New England.

Electricity Demand Growth: In the EIA reference case, electricity demand is expected to grow by 1.6 percent per year from 1996 to 2010. In the EIA carbon reduction cases, electricity demand initially falls in response to higher electricity prices and then recovers as more efficient units are constructed and brought on line to displace uneconomical units. In the Five-Lab Study 50 HE/LC case, electricity demand is assumed to grow by just 0.2 percent per year. In 2010, total electricity demand in the 50 HE/LC case is 17 percent lower than in the EIA reference case.[113] The lower electricity demand growth in the Five-Lab Study results from its estimates of efficiency improvements in the end-use sectors and lower growth for new electricity uses.

Coal Retirements: The EIA reference case determines when and if any generation plants should be retired based on economics. In the Five-Lab Study, external assumptions are used in the business-as-usual and HE/LC cases to determine whether coal plants should be retired and whether coal units should be co-fired with biomass. In the 50 HE/LC case, 75 gigawatts of coal-fired capacity was assumed to be retired by 2010. In the EIA 1990+24% case, only 2.5 gigawatts of coal capacity and about 30 gigawatts of oil and gas steam were economically retired by 2010. In the EIA analysis, a carbon price of $50 per metric ton is insufficient to cause large-scale retirements of coal plants and replacement by natural-gas-fired advanced combined-cycle plants.

An Integrated Estimate of the Five-Lab Study

The U.S. Environmental Protection Agency, Office of Atmospheric Programs, contracted with Lawrence Berkeley Laboratory to modify the *AEO98* version of the National Energy Modeling System to analyze the technology and policy assumptions of the Five-Lab Study within an integrated accounting system.[114] Substantial modifications were made to the NEMS to model the variations of the Five-Lab Study. For example, the NEMS demand models were used as an accounting tool to represent the aggressive research and development program that facilitates adoption of energy-efficient technologies in the Five-Lab Study. Major assumptions regarding the retirement of fossil fuel units were implemented manually in the NEMS electricity module to make room for advanced, low-carbon technologies. The NEMS integrated framework was retained so that interactions between the supply and demand sectors could be consistently represented.

The EPA/LBNL study analyzes two of the Five-Lab Study cases: a high efficiency/low carbon case with a carbon price of $23 per metric ton and a high efficiency/low carbon case with a carbon price of $50 per metric ton. All the technology and behavioral assumptions in the Five-Lab Study, with a few exceptions listed below, were adopted by the EPA/LBNL study. A scenario approach was used to determine the impact of each major group of assumptions.

The major exceptions included: (1) the hurdle rates assumed in the residential and commercial sectors were reduced from the *AEO98* baseline to 15 and 18 percent, respectively, instead of 7 percent in the Five-Lab study—roughly matching energy consumption in the HE/LC cases in the Five-Lab Study; (2) 16 gigawatts of coal-fired capacity and 100 gigawatts of oil- and gas-fired steam were retired by 2008, whereas the Five-Lab Study retired about 75 gigawatts of older coal plants and repowered an additional 45 gigawatts of coal plants as combined-cycle units; (3) cogeneration capacity was increased between 2000 and 2010 by 35 gigawatts instead of the 42 to 51-gigawatt capacity increase assumed in the 50 HE/LC case of the Five-Lab Study; (4) wind received an extension of the renewable tax credit of 1.5 cents per kilowatthour rather than assuming the penetration of wind in the Five-Lab Study; and (5)power plant efficiencies were not improved relative to the baseline, unlike the Five-Lab Study.

The EPA/LBNL preliminary results indicate that, when all the efficiency and capacity improvements, fossil generation retirements, other technology enhancements, electricity demand reductions, and behavioral assumptions are used simultaneously with a carbon price of $50 per metric ton, carbon emissions can be reduced in 2010 to 1,491 million metric tons (11 percent above 1990) and 1,461 million metric tons (9 percent above 1990) in 2020. Energy intensity declines by a projected annual rate of 1.9 percent in this case. In

[113] Total electricity demand in 2010 in the 50 HE/LC case is projected to be 9.7 percent lower than in the 1990+9% case and 4.5 percent lower than in the 1990+24% case.

[114] J.G. Koomey, R.C. Richey, S. Laitner, A.H. Sanstad, R.J. Markel, and C. Marnay, *Technology and Greenhouse Gas Emissions: an Integrated Scenario Analysis Using the LBNL-NEMS Model*, LBNL-42054 (Lawrence, CA: Lawrence Berkeley Laboratory, Energy Analysis Department, September 1998).

comparison, the EIA 1990+9% high technology case yields the equivalent carbon emissions with an energy intensity decline rate of -1.78 percent and a carbon price of $110 per metric ton but without the additional behavioral assumptions used in the EPA/LBNL analysis.