An Integrated Analysis of Policies that Increase Investments in Advanced Energy-Efficient/Low-Carbon Technologies

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ABSTRACT

A new analysis by the EPA Office of Atmospheric Programs and the Argonne National Laboratory (ANL), using the *All Modular Industry Growth Assessment* (AMIGA) system, indicates that a technology-led investment strategy, can secure substantial domestic reductions of carbon emissions at a net positive impact on the U.S. economy. However, a moderate energy policy, even supported by a carbon charge ranging from $48 to $93 per metric ton, is insufficient to reach the so-called Kyoto targets.

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INTRODUCTION

The evidence is slowly accumulating that increased atmospheric concentrations of heat-trapping gases are causing global climate change. Concerns over the potentially adverse impacts of global climate change led to the Kyoto Protocol to the United Nations Framework Convention on Climate Change in December 1997. The agreement was a watershed event in the history of environmental policy. For only the second time in history, national governments have agreed to seek binding targets for pollutants that have global effects. Because of serious economic concerns, however, the United States has chosen not to ratify the treaty which would require greenhouse gas (GHG) emissions reductions to seven percent below the nation's 1990 levels within the five-year period from 2008 to 2012. Nonetheless, there is growing recognition that cost-effective energy policies may reduce carbon emissions in ways that benefit the economy and that provide significant reductions in greenhouse gas emissions.

In this article we quantify some of the macroeconomic benefits that can result from increased investments in energy-efficient and renewable energy technologies by the year 2050. Such investments are the result of a moderate set of programs and policies designed to overcome the many institutional and organizational barriers that slow the adoption of energy-efficient, low-carbon technologies. We also compare these results with a scenario that largely emphasizes pricing policies rather than other cost-effective program options.

For the analysis presented in this article, we used the Argonne National Laboratory's general equilibrium model, the *All Modular Industry Growth Assessment* (AMIGA) system, to evaluate the effects of a successful expansion of well-designed energy efficiency and renewable energy policies and programs (Hanson and Laitner, 2000). The results from numerical simulations show that: (1) although the policies and programs evaluated in this review never achieve the Kyoto targets, energy-related carbon emissions are substantially reduced compared to the reference case; and (2) the investments in cost-effective energy efficiency and low-carbon energy supply technologies will tend to provide a small increase in overall economic activity within the United States.

SCENARIO OF A MODERATE ENERGY POLICY

Driven by an average annual economic growth rate of 2.7 percent between the years 2000 and 2050 (measured by changes in the nation's Gross Domestic Product, or GDP), the reference case projections developed for this exercise indicate that carbon emissions will increase from 1,582 million metric tons (MtC) in 2000 to 2,342 MtC by 2050 (see Table 1). Following an analysis by Edmonds (2002), it appears the reference case projections are following a path that would lead to carbon dioxide (CO_2) concentrations of about 550 parts per million by volume (ppm) if his calculated least-cost carbon reduction path were adopted by all nations in the future.[1] The question posed in this analysis is what economic impacts and climate benefits might be expected should the United States implement a series of moderate energy policies and programs that lower energy use by

1. This compares to pre-industrial CO_2 concentrations of 280 ppm, and to present day concentrations of about 380 ppm.

businesses and consumers? In this case, a "Moderate Energy Policy" is defined as one in which cost-effective technology investments are made that increase the nation's overall energy efficiency, and that reduce the carbon intensity with respect to the nation's energy supply technologies.

To provide a context for such an analysis, we used the policy and program cost information specified in the U.S. Department of Energy (DOE) sponsored study, *Scenarios for a Clean Energy Future* (Interlaboratory Working Group, 2000) as the basis to reduce carbon emissions approximately to 1990 levels by 2050. In other words, while the business-as-usual (BAU) scenario assumes a continuation of current energy policies and a steady pace of technological progress, the Moderate Energy Policy scenario is defined by a set of program options that are consistent with increasing levels of public commitment and political resolve to solving the nation's energy-related challenges. Some of the public policies and programs that define the scenarios are cross-cutting; others are designed individually for each sector (buildings, industry, transportation, and electric generators). A broad number of policies are examined, including increased fiscal incentives, expanded voluntary programs, efficiency performance standards and regulations, improved vehicle choice and information programs, and increased research and development activities. Figure 1, below, illustrates the GDP, personal consumption, and primary energy impacts of these assumptions over the period 2000 through 2050 compared to the reference case.

Figure 1 about here

OVERVIEW OF THE AMIGA SYSTEM

Over the last few years, a new economic impact modeling system, the *All Modular Industry Growth Assessment* (AMIGA) system, has been developed with the capability to represent many of the specific policy options for reducing carbon emissions. The system has household and government demand modules, a transportation vehicle choice module, gas supply and electricity generation modules, a unit inventory of power plants in the United States, and five other modules in which various production activities and industrial processes are represented, including demand functions for energy.

The system represents capital stock accumulation, depreciation and utilization for transportation equipment including forty-eight types of light-duty vehicles, for twenty categories of electrical generation equipment, and for a broad range of buildings, appliances, and industrial processes. Capital is *not* treated as homogeneous; rather many separate stocks are included providing different services and having different characteristics. Stock characteristics include equipment vintage, energy efficiency, and operating costs. Some key capital services are energy-intensive such as transportation services or industrial processes. Capital investment can be directed at expanding the quantity of service or lowering its energy-intensity through substitution.

The full set of modules that make up the AMIGA system provide a comprehensive representation of more than 200 production sectors and the absorption of goods and services within the U.S. economy. The modules include additional detail on technology, employment, and trade. Flows of these goods and services are modeled from production to consumption, investment, or trade. In most cases these flows are measured by constant dollar indices, but where appropriate for energy commodities the flows are measured in physical units such as kilowatt-hours (kWh) or British thermal units (Btus). An aggregation module calculates various performance measures and macroeconomic concepts, such as national income and consumer price indices. The system is run annually, in this case from the years 2000 to 2050.

An important feature of the system is that the household demand module uses a household production function approach, based on the consumer demand theory of Kelvin Lancaster (1971). Consumer demand related to durable goods depends on the attributes of the services derived from the use of these goods, i.e., vehicles, housing, and appliances. Thus, if an attribute such as home heating comfort can be provided with less energy and at lower cost with improved technology, then the household would be financially better off. Some household income will become available to save or to spend on other goods and services. The functional forms used to specify demand are consistent with microeconomic theory and are structured hierarchically. As an example, transportation services can be met with different size vehicles that are not perfect substitutes. Resulting changes in consumer welfare from policies that promote the development and adoption of energy efficient technologies can be measured by equivalent variation, the change in income at which the representative consumer would have the same welfare. The demand functions are estimated using the Department of Commerce National Income and Product Account (NIPA) time series data. These NIPA accounts provide annual data by detailed product categories with adjustments made to impute services derived from stocks of durable goods.

In all the modules, purchased energy and capital can combine to provide energy-related services and to represent opportunities for pushing the technology and decision-making frontiers in these areas. Hence, specific modeling routines have been developed for energy-capital substitution opportunities and technology adoption that supports the demand for major energy services. Trends in government spending are exogenously determined, except for programs related to climate and energy policy as well as changes in energy demand that results from the government's own energy efficiency measures.

All the AMIGA modules are programmed in C-code. The operating shell for the AMIGA system controls the execution of all the modules. First, a preprocessor module sets up the base year databases for each module. A modified, enhanced Gauss-Seidel type algorithm is used to find a general equilibrium solution to the system of equations. After convergence, information can be accessed from any of the modules and output reports are prepared.

In AMIGA, price and quantity indices are associated with each activity; expenditures equal price times quantity. Quantities are measured either in terms of real dollars or, where appropriate, in physical units. The AMIGA system passes price data into a module that purchases an external material and puts back the total quantity of intermediate demand. Total costs of producing each product are calculated. In equilibrium, supply and demand balance for each good or service.

For production sectors, a constant elasticity of substitution (CES) aggregator function is used to combine labor in efficiency units with capital services from producer durable equipment and structures, creating value added as the output. The standard theory of expenditure functions is used to obtain the derived demands for the factors of labor and capital. Investment demand is derived from demand for capital services.

Regarding international trade, some goods, such as crude oil, are considered perfect substitutes whether they are produced domestically or abroad. However, AMIGA uses the Armington assumption that most final and semi-finished goods are differentiated, i.e., that these imports are close but not perfect substitutes for domestically produced goods. The model also uses elasticity of substitution values based on the MIT Emission Prediction and Policy Analysis (EPPA) model. Then demand for a sector's product is interpreted as a demand for the aggregated combination of the domestic and imported goods. Again, the CES function is used as the aggregator for the imported and the domestic goods. The elasticity of substitution is taken in most cases to be 0.70, somewhat less elastic than what is assumed in the MIT EPPA model, which uses a Cobb-Douglas (C-D) function as the Value-Added aggregator (Babiker, et al., 2001).

In terms of programming implementation, a module consists of one or more files containing C-code programs (or in older terminology, "subroutines"). Each module has at least one "header" file, which defines the names of variables and structural groups of variables, to be used within the module (but these variables are not accessible to other modules unless the two modules are explicitly linked). User control inputs may be attached as arguments to the execution command or read in from a user inputs control file in text data format. The module may also read in data tables from other text files to initialize its data base structures. The model has a flexible, user friendly interface.

There are hundreds of different materials, semi-finished goods, business services, and production processes modeled in AMIGA. Currently, the model takes the simple approach of using Leontief technologies regarding the demand for these intermediate inputs, but with the opportunity for time trends and with the introduction and materials characterization of future products, e.g., hybrid vehicles, hydrogen infrastructure, or carbon capture and sequestration. Hence, materials substitution occurs through the choice of substitute products with different materials composition.

Product outputs, material inputs, labor, capital, and energy are all related though production processes and technology. Expansion of labor input, investment, and technical advances drive economic growth over time.

The basic representation for the model of "ideal" factor demands is obtained from the following production structure: for each sector *i*:

$$\textit{Sector Output} = f^{CES}\ (\textit{Utilized Capital, Labor Input})$$

$$\textit{Utilized Capital} = f^{LEON}\ (\textit{Production Capital, Energy Services})$$

$$\textit{Energy Services}_j = f_j^{CES}\ (\textit{Energy-Saving Capital, Energy Input})$$

where *Energy Services* can be provided by multiple energy forms, denoted by *j*.

Sector output is given by a CES functional form, with industry-specific substitution elasticities obtained from estimates in the literature (Varian 1992). Services from utilized capital are represented by a quantity index number calibrated to the base year (1992), with the price index normalized to one in the base year. This index number includes both capital rental plus energy services, where energy services themselves are given by combining energy-saving capital with energy input. The equation above for *Utilized Capital* can be taken in the long run to be Leontief, since the capital-energy substitution possibilities are captured in the third equation. The management of energy flows to a process is slightly sensitive to the price of energy with short-run price elasticities of energy demand between 0.10 and 0.15.

The CES energy service equation is adapted from the Ross 18-sector LIEF model (Ross, et al, 1993). These equations are specific to the sector and energy form (electricity and fossil fuels). Side conditions are used to account for combined heat and power (cogeneration) systems. Some electricity can be self-generated by using by-product fuels or purchased natural gas. Also, some of the heat demands otherwise supplied by gas-fired furnaces can be met from the waste heat from cogeneration systems.

The production model shown above combined with technology penetration equations gives rise to investment demands. Investment spending is a component of GDP. This model is sensitive to energy prices and to information and voluntary agreement programs. The latter are represented by increased penetration rates for energy-efficient capital and/or by reduced hurdle rates, which reflect the higher priority being attached to energy management. The programs are win-win opportunities, since the voluntary agreements encourage adoption of cost effective measures.

As we noted earlier, AMIGA uses a household production function approach to represent consumer energy demand. This is analogous to using industry production functions (Lancaster 1971). Household transportation services are "produced" using vehicle capital stocks and fuel. Energy-related housing services such as heating, cooling, and hot water are also viewed as being produced by the household. When the technology used to provide energy-related services improves (e.g., more efficient electric heat pumps or vehicles with greater fuel economy), then these household services can be provided with less energy and possibly at lower life-cycle costs.

INVESTMENT-LED EFFICIENCY IMPROVEMENTS

The scenario evaluated in this analysis is driven by the technology resource potentials characterized in the CEF study. The authors of that report describe their analysis as an attempt to "assess how energy-efficient and clean energy technologies can address key energy and environmental challenges facing the US" (Brown, et al, 2001). In that regard, they evaluated a set of about 50 policies to improve the technology performance and characterization of the residential, commercial, industrial, transportation, and electricity generation sectors. The policies include increased research and development funding, equipment standards, financial incentives, voluntary programs, and other regulatory initiatives. These policies were assumed to change business and consumer behavior, result in new technological improvements, and expand the success of voluntary and information programs.

The selection of policies in the CEF study began with a sector-by-sector assessment of market failures and institutional barriers to the market penetration of clean energy technologies in the U.S. For buildings, the policies and programs include additional appliance efficiency standards; expansion of technical assistance and technology deployment programs; and an increased number of building codes and efficiency standards for equipment and appliances. They also include tax incentives to accelerate the market penetration of new technologies and the strengthening of market transformation programs such as Rebuild America and Energy Star labeling. They further include so-called public benefits programs enhanced by electricity line charges.

For industry, the policies include voluntary agreements with industry groups to achieve defined energy efficiency and emissions goals, combined with a variety of government programs that strongly support such agreements. These programs include expansion and strengthening of existing information programs, financial incentives, and energy efficiency standards on motors systems. Policies in the CEF analysis were assumed to encourage the diffusion and improve the implementation of combined heat and power (CHP) in the industrial sector. For electricity, the policies include extending the production tax credit of 1.5 cents/kWh over more years and extending it to additional renewable technologies.

Broadly speaking, the CEF moderate scenario can be thought of as increasing the funding for programs that promote a variety of both demand-side and supply-side technologies. They include, for example, increased funding for cost-shared research, development, and demonstration of efficient and clean-energy technologies. These also include production incentives and investment tax credits for renewable energy, energy efficiency and transportation technologies. They further include increased spending for programs such as DOE's Industrial Assessment Centers and EPA's Energy Star programs.

The combined effect of the R&D and program expenditures, together with other policies described in the CEF report, implies a steady reduction in total energy requirements over the period 2000 through 2050.[2] By the year 2050, for example, the nation's primary energy consumption and electricity sales as summarized in Table 1 were projected to decrease by 30 percent and 22 percent, respectively, compared to the reference case.

Table 1 on incremental spending goes about here

Table 1, above, summarizes the changed spending patterns that emerge from the funded programs and resulting technology investments. The moderate scenario anticipates increased program spending of $4 billion for the year 2010, rising to about $17 billion in 2020, and then declining somewhat to $12 billion by 2050. Consumer and business efficiency investments increase from $16 billion in 2010 and rise steadily throughout the time horizon, reaching $78 billion by 2050. At the same time, however, the efficiency gains tend to offset the need for additional electricity supply technology which, although still growing, is about $15 billion less in 2050 compared to the reference case. Similarly, Table 1 also shows reduced energy-related investment in other sectors of the economy. In the year 2010, when efficiency savings have yet to accumulate, the investment savings are on the order of $3 billion. By 2050 this rises to $30 billion when energy bill savings (including the carbon payments) peak at $257 billion.

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2. The Clean Energy Future Study actually covers a time horizon through 2020. For purposes of this analysis, however, we extend the assumptions of the moderate energy policies through the year 2050.

Yet, even with the technology assumptions reflected in this scenario, programs alone are not enough to reduce carbon emissions to 1990 levels even by 2050. Hence, a further policy introduced into the scenario is an auction of carbon permits beginning in 2007 and phased in over a 7-year period such that it is fully in place by 2014. In Table 2, the decadal permit prices are shown as $48 and $69 per metric ton for the years 2010 and 2015, respectively. This is assumed to increase approximately one percent per year through 2050 which, together with the other programs and policies reflected in the CEF study, is sufficient to reduce carbon emissions to roughly their 1990 levels by the year 2050.[3]

Under the design of this scenario it is assumed that permits are auctioned which, in turn, generates a revenue stream from the sales of the permits which can be used to pay for the programs and policies. The balance of the revenue is then returned to consumers and businesses either as lump sum rebates or as incentives to increase their production or consumption efficiencies. Table 1 shows the magnitude of those revenues, rising from $85 billion in 2010 to $126 billion by 2050.

But lower energy consumption can also mean reduced energy bills for businesses and consumers. Table 1 also shows that energy expenditures, with the carbon charge embedded within the cost of energy, first increases by $29 billion in 2010 and then decreases by $257 billion in 2050. Since the carbon revenues are used to provide either

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3. Again following the Edmonds analysis, it appears the emissions of the Moderate Energy Policy scenario will put the U.S. on a trajectory that will stabilize at a 450 ppm CO_2 concentration by 2100. This assumes, of course, that other nations achieve similar reductions.

technology investment incentives or consumer and business rebates, the net energy expenditures are shown to decline more significantly. In 2010 the energy expenditures net of carbon payments are reduced by $56 billion. The savings continue to grow throughout the period, reaching $383 billion by 2050. Reduced petroleum import expenditures provide yet another benefit to the economy.

Table 2 on key price changes goes about here

Part of the reason for the lower energy expenditures is that the efficiency investments create a downward pressure on energy prices. Table 2 highlights these trends. By 2050, for example, world oil prices are down by $5.14 per barrel of oil, a 17 percent decline compared to the reference case. Electricity prices are up 1.4 cents per kilowatt-hour, an increase of 18 percent over the reference case, while natural gas prices at the wellhead are down $1.35 thousand cubic feet, a drop of 25 percent compared to the reference case.[4]

Incorporating the set of cost-effective policies and technologies characterized in the CEF study's Moderate Energy Policy, AMIGA estimates a total carbon reduction of 113 million metric tons of carbon (MtC) by the year 2010, growing to 992 MtC by 2050. In

4. Since energy expenditures are a function of both prices and quantities, total electricity expenditures might be lowered if the efficiency gains are sufficient to offset the price increase. Reviewing the electricity consumption figures for 2050 in Table 1 suggests that total electricity use is reduced by nearly 22 percent compared to the reference case. Hence, we would expect that under this scenario electricity expenditures would be reduced. And although these totals are not provided separately in this analysis, this is the case.

effect, this allows carbon emissions to fall to 1990 levels by 2050.[5] These macroeconomic impacts are summarized in Table 3. Almost all of the emission reductions are due to gains in energy efficiency by 2010. By 2050, however, about two-thirds of the carbon reductions are from efficiency improvements while one-third are the result of low- or non-carbon energy supply technologies. Though less aggressive than other scenarios, both the savings and the macroeconomic impacts are similar to the results published in other recent studies done elsewhere. See, especially, Bailie, *et al*., 2001; Peters, *et al*., 2002; Hanson and Laitner, 2000; Koomey, *et al*., 2001; Laitner, 1997; Barrett, *et al*., 2001; and Krause, *et al*. 2002. The section that follows describes the macroeconomic impacts in more detail.

Table 3 on macroeconomic results goes about here

IMPACT ON ECONOMIC ACTIVITY

In addition to both energy and carbon savings, Table 3 also shows that an investment-led strategy can lead to slightly higher gains in the nation's Gross Domestic Product (GDP). By 2010, GDP is up $10 billion (0.08 percent). By 2050 this grows to $94 billion (0.26 percent). At the same time, household personal consumption also increases significantly (See also Figure 1).

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5. Assuming a 7 percent below 1990 level to comply with the Kyoto protocol — in effect, lowering U.S. domestic emissions to about 1252 MtC in 2010 — the domestic mitigation strategies outlined in this analysis would provide the United States with about 18 percent of its needed energy-related carbon reductions.

Three features about the incremental investment paths are important. First, both the programs and the price signal grow over time which encourages an increase in the level of private sector spending for new technology. Second, there is a tendency to select the least-cost measures (with the highest rates of return) first. By taking the opportunities with the highest payoffs early, a substantial savings on energy bills is realized within the first few years. This savings in energy expenditures from the initial energy efficiency investments is available to re-invest in additional energy efficiency measures, basically leading to "internal financing" of future measures for many firms. Finally, the revenues generated from a \$48-93 per metric ton carbon charge (see Table 2) are used to support R&D programs as well as a variety of other policies designed to accelerate investment in energy-efficient, low-carbon technologies. This positive investment, together with reduced oil imports and lower energy expenditures (from Table 1), all tend to increase, albeit it in a very small way, the overall level of GDP within the U.S. economy. The key macroeconomic impacts of the Moderate Energy Policy scenario, compared to the reference case analysis, are described more fully in the paragraphs that follow.

Gross Domestic Product. Overall efficiency improvements in the economy imply that more goods and services can be produced from the labor and other resources that are available. The growth path in incremental GDP (i.e., changes from a business-as-usual scenario) closely follows the growth path in total efficiency investments, avoided investments in energy supply, energy expenditure savings, and reduced petroleum imports. These are all shown in Table 1. There is an economic rationale for this close relationship. These expenditures represent the economic value (at least approximately) of the inputs used to produce energy. Hence, the reduction in the cost of energy services (including utilized capital and energy consumption) approximates the opportunity cost of the input factors that are freed up to produce other goods and services. This relationship is only approximate because of different sectoral factor intensities and adjustment costs. Compared to the reference case, this entire set of changes generates a net increase of $10 billion for the nation's GDP in 2010, rising to $94 billion by 2050. But again, the changes are relatively small, amounting to an increase of only 0.08 percent and 0.26 percent in years 2010 and 2050, respectively. GDP is not a strict welfare concept; rather, it is a measure of the total value of output of the goods and services produced within a country. Output includes investment goods produced as well as consumption goods and services. Therefore, the incremental investment in energy efficient technologies adds to the investment component of GDP.

Household Consumption and Savings. The net energy-related savings shown in Table 2 does not translate into household consumption increases as a fixed share over time because households tend to borrow to smooth out their consumption paths (or add to their wealth if they receive a transient increase in income). A vast amount of theoretical and empirical literature supports this smoothing behavior (Merton 1992). In the year 2010, household consumption increases only slightly as a consequence of the more efficient durable goods purchased by consumers and the energy-related savings (net of the carbon payments) in that year. Thereafter, the increase in consumption continues to grow, but not as quickly as the net energy-related savings because of the consumption smoothing effect. Soon the first-year borrowing by households is paid back, and after that, some of the net energy-related savings go into increases in accumulated wealth (Shell 1969).

The Capital Stock. The incremental investments in energy-efficient and renewable energy capital add to the nation's total capital stock. The composition of the capital stock also changes somewhat. There is less investment in conventional energy supply capacity, which represents intended commitments to produce more energy in the future. But there is more investment in "clean energy supply technologies" such as combined cycle natural gas generation units, combined heat and power systems, and renewable energy technologies. There is also more investment in energy efficient buildings, appliances, vehicles, and industrial processes. Without these incremental investments in energy efficiency, there would be less efficient buildings, appliances, vehicles, and industrial processes that would require increased future streams of energy production.[6] Investments in energy efficient technologies promote energy security and hedge against situations of higher energy prices in the future.

6. Strictly speaking, consumer investments in more energy efficient cars and appliances are purchases of durable goods which increase consumption rather than add to the nation's capital stock. However, the larger point remains.

PRICE VERSUS NON-PRICE POLICIES

Much of the modeling emphasis to date has been one of generating the correct price signal as a means of promoting the more efficient use of technology or correcting for so-called "missing markets." In contrast, the approach taken by this analysis provides a framework in which both price and non-price programs might be seen as a complementary approach toward achieving more cost-effective emission reductions.

To test the effectiveness of this "complementary approach" with a price only approach, we developed two sensitivity runs. The Low Price scenario eliminates all programs, but institutes a carbon charge equal to that found in the Moderate Energy Policy scenario. The High Price scenario again eliminates all program impacts but doubles the carbon charge found in the Moderate Energy Policy scenario. For example, a pure carbon pricing approach would have the carbon charge flowing through into fuel prices. Anticipating higher fuel expenditures, consumers would then purchase vehicles with improved fuel economy, followed by reduced miles traveled. Whereas a new vehicle efficiency program, as was included in our moderate case simulation, could be designed around the cap-and-trade concept, using tradeable equipment efficiency permits. It would focus the choice process on the important vehicle purchase decision since, once on the road, a light duty vehicle is typically driven for fourteen years. Table 4 summarizes the key comparisons of these different approaches.

Table 4 on Policy Effectiveness goes about here

Several important results emerge in comparing moderate policy scenario with the price only runs. First, and perhaps most intuitive, total emission reductions are generally greater in the Moderate Energy Policy scenario, especially in the later years. In 2050, for example, the moderate case reaches total emission reductions of 992 MtC compared to 365 MtC in the Low Price case and 629 MtC in the High Price case. At the same time, the High Price case obtains about the same level of reductions in the year 2020 as the moderate case, 551 MtC versus 564 MtC for the two cases, respectively. But as we shall see, the cost-effectiveness of the moderate policy reductions is significantly greater than for the high price reductions.

The test for cost-effectiveness is straightforward. It is the sum of carbon revenues (permit price times the quantity of emissions) plus program costs (if any) divided by the tons reduced.   As Table 4 illustrates, the Moderate Energy Policy case shows a cost-effectiveness of $139 per ton of carbon saved in 2050 (compared to the reference case in that same year). The low price case has a cost-effectiveness of $185/tC while the high price increases the cost to $321/tC. In other words, the combination of both price and program policies achieves larger reductions for a significantly greater level of cost-effectiveness. This makes sense when we recall that price elasticities tend to remain low, and that energy costs are a very small part of the overall cost of living or the cost of doing business. Given the existence of the many little inefficiencies in the economy (Krause et al, 2001), and the success of voluntary programs that encourage emission reductions (Laitner and Sullivan, 2001), it seems reasonable to conclude that reducing the size of both the inefficiency and the information gaps may generate a higher level of return compared to an economy that remains relatively unresponsive to pricing signals alone.

CONCLUSION

For understandable reasons the United States has chosen not to ratify the Kyoto Protocol which would require greenhouse gas emission reductions to seven percent below 1990 levels in the period 2008 through 2012. Yet, the analysis summarized briefly in this article indicates that a Moderate Energy Policy, supported by a technology-led investment strategy, can secure substantial domestic reductions of carbon emissions at a small but net positive impact on the U.S. economy. Although shown to be cost-effective, the policies as described here provide an insufficient basis to reach the so-called Kyoto targets.

At the same time, the estimation of economic benefits provided in this analysis tend to be understated in the sense that attendant co-benefits from adopting energy efficient technologies are not yet included in the exercise (Mills and Rosenfeld, 1994). For example, improved lighting and HVAC systems increase comfort in houses and increase worker productivity in businesses, yet these benefits are not accounted for with the standard accounting framework of policy models. Moreover, technologies are evaluated on the basis of many different attributes. There is a high probability that at least several characteristics of the adopted technologies are improvements over previously available models. One type of investment that often yields a particularly high economic return is one that improves the overall process efficiency of an existing industrial facility as well as its energy efficiency. A recent study of process industries by the Lawrence Berkeley National Laboratory's identified a number of these technology opportunities, especially in the heavy industries (Laitner, et al, 2001). More broadly, a series of papers have indicated that including energy savings alone does not account for the full economic returns to industry when evaluating the cost-effectiveness of energy efficiency improvements (Finman and Laitner, 2001; Elliott, et al., 1997; and Sullivan, et al., 1997).

There are also substantial conventional air pollution reduction benefits associated with carbon emission reductions. In light of these co-benefits, it is likely that further measures than those embodied in the moderate policy case described here would be desirable. From an insurance perspective as to what level of stabilization will ultimately be necessary, the moderate case described here would leave the economy better positioned at the end of the 2050 time horizon, having developed improved technologies and having passed through the early phases of learning and market transformation as well as having a capital stock that embodies substantially lower energy intensity than in the reference case. The modeling framework used in this paper can be a useful tool for fleshing out the details of a well-designed policy mix to achieve the full set of potential economic and environmental benefits. A key dimension for the development of an optimal energy (climate) policy mix will be the relative (and complementary) roles of pricing policies and other programs in inducing an investment-led technology strategy.

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Figure 1. Key Energy and GDP Changes for a Moderate Energy Policy Scenario

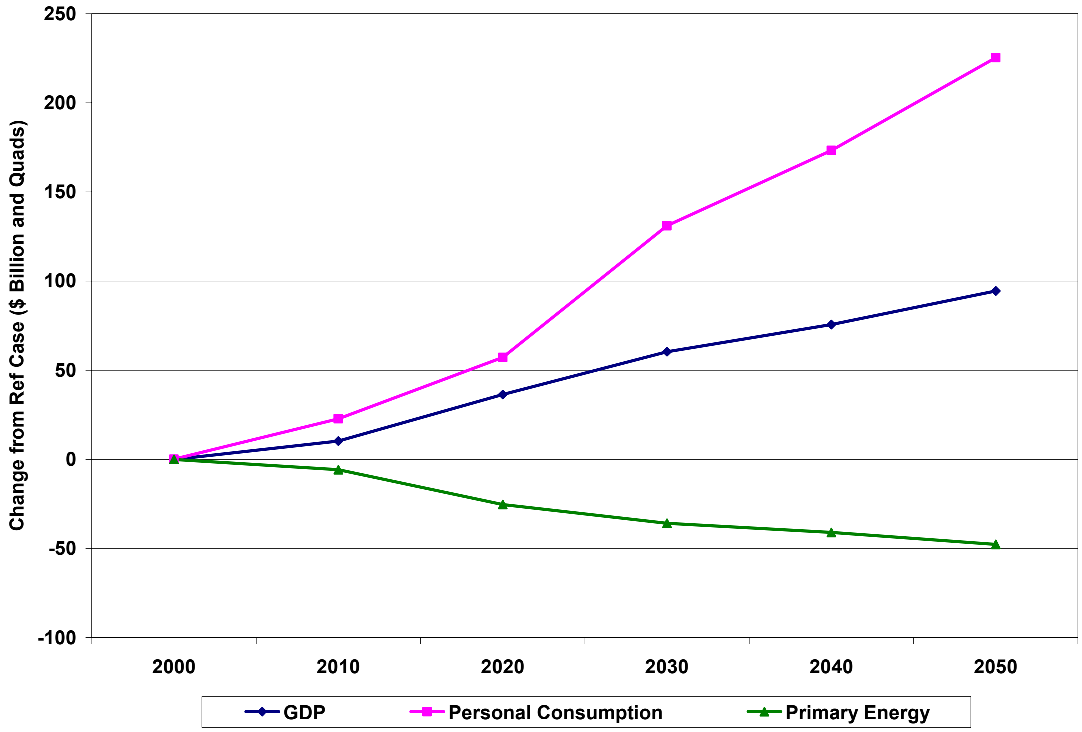

Table 1. Incremental Expenditures in the Moderate Energy Policy Scenario Compared to the Reference Case

Variable (in billions of 2000 dollars)	Moderate Policy Case 2000	2010	2020	2030	2040	2050
Government Program Expenditures	0	4	17	15	14	12
Efficiency Investments	0	16	66	69	66	78
Power Generation Investments	0	-11	-8	-14	-12	-15
Other Business Investments	0	-3	-6	-16	-24	-30
Carbon Revenues	0	85	106	110	118	126
Energy Expenditures	0	29	-29	-124	-191	-257
Energy Expenditures Net of Carbon Payments	0	-56	-135	-230	-308	-383
Petroleum Imports	0	-12	-49	-93	-125	-159

Source: EPA Office of Atmospheric Programs, Argonne National Laboratory AMIGA Modeling System Moderate Policy Runs, 08-12-2002.

Table 2. Key Price Variables in the Reference and Moderate Energy Policy Scenarios

	Reference Case						Moderate Policy Case					
Variable	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Carbon Charge (2000 dollars per metric ton)	0	0	0	0	0	0	0	48	69	76	84	93
World Oil Price (2000 dollars per barrel)	27.72	23.36	24.68	26.20	27.82	29.53	27.72	22.89	22.87	22.91	23.57	24.39
(Change from Reference Case)	-	-	-	-	-	-	0.00	-0.47	-1.81	-3.39	-4.25	-5.14
Electricity Price (2000 cents per kilowatt-hour)	6.7	6.0	6.1	6.2	7.0	7.9	6.7	6.6	7.5	7.6	8.5	9.3
(Change from Reference Case)	-	-	-	-	-	-	0.0	0.6	1.4	1.4	1.5	1.4
Wellhead Natural Gas Price (2000 dollars/1000 cubic feet)	3.60	2.75	2.93	3.95	4.81	5.38	3.60	2.45	2.48	2.97	3.65	4.03
(Change from Reference Case)	-	-	-	-	-	-	0.00	-0.30	-0.45	-0.98	-1.16	-1.35

Source: EPA Office of Atmospheric Programs, Argonne National Laboratory AMIGA Modeling System Moderate Policy Runs, 08-12-2002.

Table 3. Summary of Key Macroeconomic Variables in the Reference and Moderate Energy Policy Scenarios

	Reference Case						Moderate Policy Case					
Variable	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Gross Domestic Product (Billion 2000 Dollars)	9,870	13,174	17,681	22,577	28,828	36,811	9,870	13,184	17,717	22,637	28,904	36,905
(Change from Reference Case)	-	-	-	-	-	-	-	10	36	60	76	94
Personal Consumption (Billion 2000 Dollars)	6,696	8,834	11,760	14,762	18,531	23,262	6,696	8,857	11,817	14,893	18,704	23,487
(Change from Reference Case)	-	-	-	-	-	-	-	23	57	131	173	225
Total Energy Consumption (Quadrillion Btu)	100.3	115.6	129.6	140.7	149.3	159.9	100.3	109.7	104.3	104.8	108.3	112.2
(Change from Reference Case)	-	-	-	-	-	-	-	-5.9	-25.3	-35.9	-41.0	-47.7
Total Electricity Consumption (Billion kilowatt-hours)	3,569	4,371	5,078	5,778	6,575	7,481	3,569	4,143	4,151	4,390	5,067	5,853
(Change from Reference Case)	-	-	-	-	-	-	-	-228	-927	-1388	-1508	-1628
Carbon Emissions (Million Metric Tons)	1,582	1,893	2,100	2,222	2,255	2,342	1,582	1,780	1,536	1,453	1,400	1,350
(Change from Reference Case)	-	-	-	-	-	-	-	-113	-564	-769	-855	-992

Source: EPA Office of Atmospheric Programs, Argonne National Laboratory AMIGA Modeling System Moderate Policy Runs, 08-12-2002.

Table 4. Evaluating Scenario Effectiveness

Variable	Reference Case 2020	Reference Case 2050	Moderate Policy Case 2020	Moderate Policy Case 2050	Low Price Case 2020	Low Price Case 2050	High Price Case 2020	High Price Case 2050
Carbon Emissions (MtC)	2,100	2,342	1,536	1,350	1,781	1,977	1,549	1,713
Carbon Permit Price ($/tC)	-	-	69	93	69	93	138	186
Program Spending (billion $)	-	-	17	12	0	0	0	0
Tons Saved Compared to Reference Case (MtC)	-	-	564	992	319	365	551	629
Policy Effectiveness ($/tC Saved)	-	-	124	139	124	185	215	321

Source: EPA Office of Atmospheric Programs, Argonne National Laboratory AMIGA Modeling System Moderate Policy Runs, 08-12-2002.