Re-estimating the Annual Energy Outlook 2000 Forecast Using Updated Assumptions about the Information Economy

John A. "Skip" Laitner
EPA Office of Atmospheric Programs
202/564-9833, laitner.skip@epa.gov
Washington, DC

Jonathan G. Koomey, Ernst Worrell, and Etan Gumerman
510/486-5974, JGKoomey@lbl.gov
Lawrence Berkeley National Laboratory
Berkeley, CA

Presented at the

Allied Social Science Association Meetings
Society of Government Economists Session
American Economics Association

January 7, 2001
New Orleans, LA

Introduction

In the period 1950 to 1996 the U.S. economy, measured by gross domestic product (in 1996 constant dollars), grew by an average 3.4 percent per year. In that same period, the nation's primary energy use grew 2.2 percent annually. In effect, the nation's energy intensity — in other words, the amount of energy needed to support the nation's economic activity — declined by an average rate of 1.2 percent per year. In the period 1996 to 2000, however, it appears the nation's energy intensity will decline at a rate of 3.4 percent annually. In absolute terms this is significantly greater than the 2.6 percent rate of decline that occurred in the "oil crisis" years of 1973 to 1986 (Energy Information Administration, 2000a and 2000b). What is remarkable about the trend in the last four years is that it has occurred in the absence of either significant price signals or major policy shifts.[1]

The sharp decrease in the nation's energy intensity in the past three years has generated strong interest among analysts. Some analysts attribute the majority of the change to weather. A separate analysis by Laitner (1999), however, indicates that, at most, weather accounts perhaps for only 25 percent of the change in the nation's energy intensity. Boyd and Laitner (2000), suggest structural change rather than weather as a major influence. A forthcoming analysis by Davis et al (2001) applies a divisia analysis to influences behind the changes in energy intensity and concludes very little weather-related contribution. Although four years of data are insufficient to establish a meaningful trend, the emerging evidence suggests that the rapidly growing influence of an information-based economy may account for at least a significant influence in the structural change (Romm, Rosenfeld, and Herrmann, 1999; and Laitner, 2000a).

This paper is part of a continuing effort to examine the potential influence of the emerging "Information Economy" on the nation's forecasted energy use and related carbon emissions. Following this introduction, the next section outlines the broad structural changes that seem to be emerging as a result of the growth in the information and communication technologies sectors. The paper then discusses the reference case of the Energy Information Administration's Annual Energy Outlook 2000 (AEO2000) with particular attention to assumptions about the information-based economy. Next we discuss our assumptions with respect to how the AEO2000 reference case might change if it better reflected the identified structural changes. Finally, we offer some conclusions with respect to our findings and outline potential directions for research.

The Emerging Information-Based Economy

Recent papers by Sanstad et al (2001), Laitner (2000), and Koomey (2000) indicate a tendency to underestimate the role of technological change in estimating future energy demand within the U.S. economy. In a similar vein, the evidence is strong that the economy may be changing in ways that are not fully incorporated into mainstream energy forecasts as a result of the transition to an information-based economy. Indeed, information and communication technologies are now a leading economic driver within the United States (Greenspan, 1999; Meyer, 2000; Jorgenson and Stiroh, 2000; and Brynjolfsson and Hitt, 2000). As an example, the rate of growth in the nation's

[1] This is not to ignore the impact of rising prices for imported petroleum which have climbed above $30 per barrel in recent months. In constant dollar terms, however, this is still less than half the record oil prices seen in the early 1980s when imported petroleum rose to a peak of $64 per barrel (in constant 1999 dollars). Moreover, the impact of these prices in the year 2000 does not impact the overall trend in the period 1996-2000.

economy averaged 2.6% per year in the period 1990 through 1997. In contrast, the information and communication technology (ICT) sectors – not including Internet and electronic commerce sales – grew at an average rate of 13.5%, according to the Department of Commerce (Henry et al, 1999). The trends appear to be continuing (Price et al, 2000).

In 1999 testimony before Congress, Federal Reserve Board Chairman, Alan Greenspan, underscored the transition to the information economy. In his testimony, Chairman Greenspan noted: "Something special has happened to the American economy in recent years. An economy that twenty years ago seemed to have seen its better days, is displaying a remarkable run of economic growth that appears to have its roots in ongoing advances in technology. I have hypothesized on a number of occasions that the synergies that have developed, especially among the microprocessor, the laser, fiber-optics, and satellite technologies, have dramatically raised the potential rates of return on all types of equipment that embody or utilize these newer technologies. But beyond that, innovations in information technology – so-called IT – have begun to alter the manner in which we do business and create value, often in ways that were not readily foreseeable even five years ago" (Greenspan, 1999).

Further evidence suggests that this trend will continue. Forrester Research (1999), for example, projects that U.S. business to business electronic commerce will grow from $48 billion in 1998 to $1.3 trillion by 2003. According to a new report issued by SPS/Spectrum Economics, worldwide spending for ICT products and services will total nearly $2.6 trillion in 2005 (SPS/Spectrum Economics, 2000). Other estimates show similar levels of growth.[2] Romm et al (1999) completed an extensive review of the potential energy impacts of the transition from a commodity-based economy to one based more on the flow of information. At the same time, Laitner (2000) reported a first approximation of what the structural change in the economy might mean if information and communication technologies continue the current growth pattern. According to that preliminary analysis, there is a real possibility that these changes imply a somewhat smaller level of energy consumption compared to current economic projections. In other words, while energy use will grow, that growth will be somewhat slower than previous forecasts have indicated.

If the anticipated pattern of structural change continues to hold, then the information economy, together with more investments in energy efficient technologies, will benefit the nation's air quality and the global climate while continuing to increase the nation's overall competitiveness. Laitner's "first approximation" indicated that mainstream projections of annual energy and carbon emissions by 2010 may be overestimated by about 5 quads and 80 million metric tons of carbon. This is about 5 percent lower than the most recent 2010 projections published by the Energy Information Administration EIA, 1999). These results suggest the importance of measuring and evaluating the direct and indirect impact of IT sectors on the nation's energy use (and the resulting emission of

[2] A summary prepared by *The Industry Standar*d forecasts the dollar value of electronically conducted transactions between U.S. businesses as ranging from $634 billion to $2.8 trillion by 2003. The wide range of estimates is due to a combination of methodological and definitional factors (Lawrence, 2000). To be sure, some have suggested that the "new economy" may not be living up to expectations of the late 1990s. This appears to be supported by recent evidence of a weakening of economic growth. Indeed, if we define the new economy only in terms of the impact of the Internet, then such an assessment may be appropriate. For purposes of this inquiry, however, we are reframing the discussion as an effort to evaluate the impact of information and communication technologies on the many ways the nation produces goods and services. By definition, this also implies a reexamination of the way businesses have access to information and how they make decisions. It is in that context that it seems there is a new economic landscape that may not be understood with respect to energy and climate policy. Although it is not within the framework of this paper, for further readings on the difference between the new economy and the impact of the information technologies on the performance of the overall economy, see Greenspan (1999), Meyer (2000), Brynjolfsson and Hitt, 2000, and Rauch (2000), among others.

energy-related carbon emissions). Before we examine the issue further, we next describe the conventional forecast against which we will evaluate further changes in as a result of the structural changes.

A Conventional Forecast

In its release of the Annual Energy Outlook 2000 (EIA, 1999), the Energy Information Administration indicated that the economy would grow at a rate of 2.2 percent annually between the years 1998 and 2020. This forecast is based upon assumptions used within EIA's National Energy Modeling System (NEMS). As a result of this projected growth rate, and combined with a 1.0 percent decrease in the nation's energy intensity, the nation's energy use might be expected to increase from 95 quads in 1998 to 121 quads in 2020, an annual growth rate of 1.1 percent. At the same time, the nation's carbon intensity is anticipated to increase slightly so that total carbon emissions are projected to rise from 1485 million metric tons (MtC) in 1998 to 1979 MtC by 2020 for an annual growth rate of 1.3 percent over that same period.[3]

However, a close examination of the AEO2000 forecast indicates that it may not adequately pick up the trends away from a commodity-based to an information-based economy. This can have two different implications. First, as we confirm below, the accelerated growth and use of information technologies may lower the conventional forecast of energy use and resulting carbon emissions. Second, if the nation's decision makers are calibrating a variety of policies to AEO2000, they may well be designing programs and policies for an economy that may already be significantly different than the conventional forecast, and that may be even more different than is characterized for 2005 and beyond. Hence, the nation's energy and climate policies may be considerably less effective over the longer term.

Adjustments Reflecting the "Information Economy"

Building on the work of Romm et al (1999), and other emerging evidence (Economist, 2000), we have decided to test the "energy and carbon significance" of structural changes brought about the growth in the information economy. Specifically, we have examined to date six discrete changes to test their potential impact on the AEO 2000 forecast. These include: (1) reduced production of paper and cement products in the industrial sector; (2) changes related to transportation behavior (vehicle miles traveled); (3) improved penetration of combined heat and power technologies as the new economy opens up greater opportunities for outsourcing of supply chain management; (4) a larger than expected success of voluntary programs, including the EPA and DOE Energy Star programs; (5) the possibility of reduced commercial floorspace; and finally (6) a further inquiry into the effect of possible structural change. This last effect assumes that the less energy-intensive part of the economy grows more rapidly than the more energy-intensive core sectors of the economy. Related changes also incorporated into this analysis is a higher penetration of combined heat and power technologies within the industrial sector.

[3] The December 22, 2000 release of the Energy Information Administration's AEO2001 was too late to provide a meaningful update to this analysis. On the one hand, AEO2001 anticipates a significantly higher economic growth rate, increasing from 2.1 to 3.0 percent. On the other hand, it also anticipates a greater annual decline in the nation's energy intensity. Hence, carbon emissions in AEO2001 are expected to be less than 2 percent higher in the year 2010 compared to the AEO2000 (EIA, 2000c). It is unclear at this point to what extent the new AEO2001 projections will reflect improved information and technology assumptions, especially assumptions regarding the information economy and greater levels of investment within the new economy. This will be explored more closely in months to come.

Changes in the Industrial Sector

We develop new scenarios by assessing historic trends for industrial commodities since 1970 with the scenarios developed in the AEO2000. We focus on aluminum, cement, paper, and steel as these are measured in physical terms in the NEMS model. All figures are given in millions of short tons (Mtons).

Total Commodity Production

Comparing historic production of commodities with the assumptions in AEO2000 shows some potential disconnects for the total production volumes of cement, paper and steel. Aluminum production in NEMS includes aluminum processing but excludes secondary aluminum production. This makes it impossible to compare to historically available data for primary or total aluminum production. While steel production in 1999 for the AEO2000 is lower than the actual 1998 production, the 1999 production assumed for paper and cement in AEO2000 is substantially higher. Table 1 provides an analysis of the material intensity trends as well.

Based on the historic trends and other studies we created alternative scenarios. For *paper making* we assume that the trend as reported by Romm et al. (1999), based on the report of the Boston Consulting Group, will continue after 2008. This assumes similar growth for office and cut paper, but slower growth for newsprint, fiberboard and other grades of paper. Fitting the paper production reductions estimated in that report with historic data provides a new estimate of growth in the total volume of paper production of 123 Mtons in 2020, compared to 138 Mtons in the AEO2000 scenario.

Based on historic trends for *cement making* and the difference in assumed AEO2000 production and actual production in 1998 we assume that the 2020 production will be corrected for the 1998 difference. Hence, 2020 cement production is estimated at 108 Mtons instead of the AEO2000 forecast of 120 Mtons.

There are several industrial subsectors where data were not available in sufficient details, or where the mechanics of modeling within the NEMS framework were too involved to complete the analysis for this paper. For those reasons, we did not treat trends in the steel and aluminum industries. Nor did we treat the potential of dematerialization (due to economic structural changes) of other materials. The preliminary evidence suggests this would further return the need for such commodities per unit of economic activity.

Even within the limitations of the analysis, however, the revised assumptions provide significant changes in energy and carbon emissions when the new production trends are incorporated into a standalone run of the NEMS industrial model. The resulting impact of making these changes in the paper and cement industries is a reduction in carbon emissions of 6 MtC in 2010 and 11 MtC in 2020 compared to AEO2000.

Table 1. Comparison of Historic Trends and NEMS AEO2000 Assumptions for Materials in the Industrial Sector.

	HISTORIC TREND DATA						***AEO2000***		
	Long Term (1970 –1998)			Short Term (1988 – 1998)			1997 - 2020		
	Production (%/year)	Production Per Capita (%/year)	Production per unit GDP (%/year)	Production (%/year)	Production Per Capita (%/year)	Production per unit GDP (%/year)	Production (%/year)	Production Per Capita (%/year)	Production per unit GDP (%/year)
Population	1.0			1.0			0.8		
GDP	3.2			3.0			2.2		
Aluminum	1.7	0.7	-1.5	1.7	0.7	-1.3			
Primary Aluminum	0.1	-0.9	-0.9	-0.6	-1.6	-3.5	0.54	-0.27	-1.7
Cement	0.8	-0.2	-2.3	1.9	0.9	-1.1	0.88	-0.06	-1.35
Steel	-0.7	-1.7	-3.8	0.8	-0.3	-2.2	0.51	-0.003	-1.7
Ammonia	1.3	0.3	-1.8	1.6	0.6	-1.3			
Chlorine	1.0	0.0	-2.1	1.3	0.3	-1.6			
Ethylene	3.9	2.8	2.7	3.4	2.4	0.4			
Bulk Chemicals	1.19			2.56			1.19		

Notes:

Trend data and Scenario assumptions are based on physical production data, except for bulk chemicals which is based on economic production data

Aluminum in the NEMS model is defined as primary aluminum production and aluminum processing, but excludes secondary aluminum production. Most of the energy in the NEMS sector is consumed by primary production; hence we assume that the AEO2000 trend can best be compared to the trends in primary aluminum production.

Bulk chemicals in the NEMS model is defined as SIC 281, 282, 286 and 287. This is about half of the output of the total chemical industry (SIC 28) expressed as gross output. For comparison we give the physical trend data for the most energy intensive products, i.e. ammonia (SIC 2873), chlorine (SIC 2812) and ethylene (SIC 2869).

Changes in the Transportation Sector

Romm et al. (1999) explored the potential effects of the information economy on personal and business travel, focusing on teleconferencing, telecommuting, e-commerce, and freight transportation. In this initial exploration, we focus solely on vehicle miles traveled per dollar of GDP. In the AEO2000, the projection is that this ratio will decline by an average 0.45 percent annually between the years 2000 and 2020. However, in the period 1996 through 1999, actual VMT intensity declined by 1.6 percent per year. While this value is too large to anticipate as an on-going trend, following the logic outlined in the Romm et al analysis, we believe it is indicative of changes that are already beginning to occur. As a result, we've adjusted the rate of change to double that suggested in the reference case forecast, which implies a 0.9 percent annual change.

The effect of this trend is to lower VMT by about 9 percent compared to the year 2020 forecast. In other words, instead of VMT growing from 2,511 billion vehicle miles in 2000 to 3,498 billion vehicle miles in 2020, the increase will be to only 3,191 billion vehicle miles under the alternative scenario. The resulting impact on carbon emissions is a reduction of 16 MtC in 2010 and 38 MtC in 2020 in a standalone run of the NEMS transportation module. We were not able to use the NEMS model to assess changes in freight shipping volumes, but that is an obvious area for future research. The direction of the effects here is less clear than for personal transportation. Increased use of on-line shopping could lead to more airplane and truck traffic if overnight shipping becomes the norm. If shipping by the U.S. Postal Service is more prevalent, the additional energy use would be relatively small. In either case, use of the Internet will reduce personal travel to local stores.

Changes in the Commercial Sector Floorspace

We also considered the commercial sector implications of the emerging Internet economy. Some analysts believe that the economy is already "overstored." The competitive pressures of the Internet economy may have a tendency to reduce retail buildings and warehouses. Moreover, companies such as IBM and AT&T are looking to reduce office space needed by employees through a variety of telecommuting arrangements (Romm et al., 1999). To capture this emerging trend, we modeled the future where total commercial floor space is only 90% of AEO 2000 reference case. This reduction begins in 2000 and phases in over a six-year period. The reduced commercial floor space results in carbon reductions of 18 MtC in 2010 and 21 MtC in 2020, about a 6 percent savings compared to the standard reference case.

Changes in the Penetration of Combined Heat and Power

Combined Heat and Power (CHP) is an emerging technology that tends to be poorly characterized in most energy-economic models. A number of studies are beginning to emerge, however, which indicate stronger performance characteristics associated with CHP systems, in both the industrial and commercial/institutional settings (Onsite Sycom, 2000; Elliott and Spurr, 1999). A recent analysis by Shipley, et al (2000) outlined a market diffusion approach to estimating market penetration of CHP systems. At the same time, Forrester Research (1999) suggests that as much as $266 billion of energy services may be brokered through a variety of Internet transactions by 2004. Adapting a market-based perspective that integrates these trends indicate a 20 gigawatt (GW) increase in CHP capacity by 2010 compared to the AEO2000 reference case. In other words, instead of CHP capacity growing from 53 GW in the year 2000 to only 57 GW in 2010, the assumption is that CHP capacity might increase to as much as 77 GW by 2010.[4] Translating this additional capacity into a carbon equivalent provides an 8 MtC benefit from the higher penetration of CHP units.

Changes Driven by the Success of Voluntary Programs

Through voluntary programs that promote cost-effective energy efficiency and greenhouse gas emissions reductions, the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA), among other federal agencies, have forged a series of partnerships with private and public organizations. These programs, greatly facilitated by both the Internet and the tools of the information economy, have demonstrated significant reductions in greenhouse gas emissions with net economic savings or very low costs. As but one example, the U.S. EPA's *ENERGY STAR*® and other voluntary programs exceeded their combined 1999 reduction goal of 21 million metric tons of carbon equivalent (MMTCE) by 10 percent. The agency's Climate Protection Division (CPD), the group that operates these programs, projects total reductions of more than 120 MMTCE by 2010 at current funding levels (Climate Protection Division, 2000). The documented success of EPA's voluntary programs prompted one group of researchers to conclude that such successes "cannot be reconciled with the view that energy-use decisions are made in efficient markets" (Howarth et al., 1999).

Despite these growing successes, conventional models tend to ignore or undervalue the successes of these marketing programs. For example, the Energy Information Administration credits voluntary programs operated under the U.S. Climate Change Action Plan with reductions of only 35-40 MMTCE (EIA, 1999). Since an evaluation of the voluntary programs continues, the assumption for this analysis is that the AEO2000 reference case might be reduced by only 50 percent of the difference between the CPD goal and the amount now apparently incorporated by EIA. Hence, the reference case for 2010 would be reduced further by about 40 MtC.

Changes in Structural Growth of the Economy

Laitner (2000) completed an analysis that asked the question "how would the nation's energy use grow if the information and communication technology (ICT) sectors grew more rapidly than the balance of the economy?". Drawing from detailed input-output data, he suggested that the ICT sectors were actually 5 times less energy intensive per dollar of economic activity than the balance of the economy. Hence, if these sectors provide a greater level of value added in the years to come, the nation's GDP will grow in a way that uses less energy than perhaps only 5-10 years ago. Laitner determined that if the ICT sectors grew between 8 and 10 percent annually while the total economy grew at a rate of 2.6 percent per year (well above the AEO2000 forecast of 2.2 percent per year), then total energy use in the year 2010 might be 0.7 and 3.2 quads less compared to the reference case projection. In other words, while the faster growth in overall economic activity will tend to increase energy use, the source of that growth — the much less energy intensive ICT sectors — will tend to dampen energy growth to the point where consumption actually drops compared to the reference case.[5] In carbon equivalents, this represents a reduction of 11 to 51 MtC. For purposes of this analysis we adopt the average value of 31 MtC.

---

[4] Interestingly, the AEO2001 does show a better characterization of CHP technologies within the industrial module of NEMS. As a result, capacity increases to 63 GW by 2010 compared to the AEO2000 estimate of 57 GW. Two points in this regard. First, improved information about the performance of technology clearly indicates greater penetration rates. Second, these initial results do not appear to reflect: (a) the outsourcing trends referenced above, (b) the increased use of third-party investors which reduces the need for investment and, therefore, high rates of returns by the host facility, or (c) the growth of niche markets for distributed generation technologies, district energy systems, and other on-site applications of such technologies. The implications of these trends will be explored more completely in a future analysis.

[5] There is at least one analysis suggesting that the internet economy would actually increase the nation's energy consumption. However, at EPA's request, researchers at the Lawrence Berkeley National Laboratory (LBNL) evaluated the assumptions

Net Changes in an Integrated Analysis

The results reported in the previous six subsections add to a total saving of 119 MtC for 2010. However, these are essentially standalone estimates. By this we mean that there have been no price or income interactions nor supply and demand feedbacks that might otherwise affect these individual totals. We used the NEMS model to assess the effects of an integrated analysis in the results for the commercial, industrial, and transportation sectors, but we have not yet been able to assess the other changes within the NEMS framework.

The identified commercial, industrial, and transportation sector effects together save 40 MtC in 2010 and 70 MtC in 2020, based on standalone runs for each of these sectors. The integrated run with all three sectors, together with full macroeconomic interactions, shows a net savings of 38 MtC in 2010 and 60 MtC in 2020, yielding a reduction of 5 to 15 percent in savings compared to the standalone runs. In other words, the integrated run generates a net saving of only 85 to 95 percent compared to the standalone modeling runs.

To estimate the impact of changes in the remaining three changes we have evaluated – including the penetration of combined heat and power technologies, the impact of voluntary programs, and estimated structural change – we estimated the feedback effect using assessments of the feedback, substitution, and rebound effects found in the recent literature. Greening et al (2000) found, for example, that a 10 percent improvement in energy efficiency would lead to a rebound and substitution effect that would leave a net benefit of between 70 and 90 percent of the initially estimated impact. Laitner (2000b) provided an example that suggests a 97 percent net impact. For purposes of this exercise, and incorporating the findings of the integrated run described above, we therefore adopt an estimate of a 90 percent net impact.

Multiplying the combined standalone savings of 119 MtC from each of the six different categories discussed above by 0.90 yields net savings of 107 MtC of integrated savings compared to the standard reference case assumptions.

Table 2. Information Economy Adjustments in the AEO2000 Reference Forecast for 2010

Sector Category	Carbon Emissions (MtC)
Reference Case Forecast	1787
Industrial Commodity Production	-6
Transportation	-16
Commercial Floorspace	-18
Combined Heat and Power	-8
Voluntary Programs	-40
Structural Change	-31
Integrating/Rebound Effect	+12
Adjusted Reference Case Forecast	1680

behind such a conclusion. The LBNL review found that the analysis overestimated the energy intensity of the internet by a factor of eight. See Koomey et al (1999). At http://enduse.lbl.gov/Projects/InfoTech.html

Findings, Discussion, and Further Research

The six small changes discussed above have a small but significant impact on the nation's energy use and the resulting carbon emissions. Based upon this initial review, and if the trends described in the text continue to hold, carbon emissions in the year 2010 might be 107 MtC lower than suggested by conventional forecasts. The implication is that instead of carbon emissions rising to 1,787 MtC by 2010, they would increase to only 1,680 MtC, about 6.0 percent lower than otherwise projected. Two points are important in this regard. First, even with the reductions ascribed to the impact of the new economy, carbon emissions are still forecasted to increase by about 10 percent above the levels expected in the year 2000. Second, from a policy perspective, a base case that is 107 MtC lower than originally estimated should be more manageable with respect to encouraging policies that support greenhouse gas reductions. Yet this analysis and many others raise more questions than they answer. Some shortcomings of this assessment, in no particular order, are illustrated by the following questions:

(1) The analysis addresses the potential benefits from large-scale structural change, but it does not reflect any significant substitution effects. For example, if households order more groceries, books, clothing and other consumer goods through the growing electronic commerce channels, can we expect their own energy expenditures to be reduced when compared to their previous purchasing patterns?

(2) Would a better definition and measurement of the ICT-sectors, from both an economic and an energy perspective, either weaken or improve the supposed benefits that are described in the scenario analysis above?

(3) What are reasonable estimates of the anticipated ICT-sector growth rates, especially at the sub-sector level of the economy? How will these growth rates influence economic activity in other sectors of the economy?

(4) How will competition and innovation within the ICT-sectors affect productivity gains throughout the nation's economy? How will they impact other inflationary pressures?

(5) Are there other tradeoffs not anticipated by the transition to an information-age economy, including a change in distributional benefits, a change in consumer or producer surpluses, the increased reliance on imported or critical materials, and other environmental and economic impacts?

(6) Will the resources devoted to ICT-infrastructure improvements reduce the opportunities for improvement in other sectors of the economy?

Attempting to answer these and related questions will suggest additional avenues for further research that are both tractable and illuminating. We will continue to seek out additional such examples to add to the list of effects we capture in this present analysis. Some of these effects may increase carbon emissions, others may decrease emissions, but it is clear that these effects are probably large enough that they can't be ignored.

Conclusions

Our analysis shows small but significant differences in projections from just three modest changes in assumptions about the Internet and/or information-based economy. Other changes that could be important include changes in other materials utilization, a greater trend toward outsourcing of energy services, and greater improvements in energy efficiency made possible by the new economy. Although the scale of impact for these initially analyzed effects is small, expansion of the scope of inquiry, as suggested by the Romm et al. analysis, may open up new and fruitful areas of research.

Acknowledgements

This work was supported by the U.S. Environmental Protection Agency, Office of Air and Radiation, under U.S. Department of Energy Contract No. DE-AC03-76SF00098. The opinions expressed in the paper do not necessarily reflect those of either the U.S. Environmental Protection Agency or the U.S. Government.

References

[Boyd and Laitner, 2000] Boyd, Gale, and John A. “Skip” Laitner, “Recent Trends in the U.S. Energy Intensity (1977-1998): An Index Number Analysis, EPA Office of Atmospheric Programs, Washington, DC, January 2000 (forthcoming).

[Brynjolfsson and Hitt, 2000] Brynjolfsson, Erik, and Lorin M. Hitt, “Beyond Computation: Information Technology, Organizational Transformation and Business Performance,” Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts, 2000.

[Climate Protection Division, 2000] *The Power to Make a Difference: Energy Star® and Other Voluntary Programs*. Washington, DC: U.S. Environmental Protection Agency, EPA-430-R-00-006, July.

[Davis, et al, 2001] Davis, W.B., A.H. Sanstad, and J.G. Koomey, “A Divisia Analysis of Recent Changes in the Nation’s Energy Intensity,” Lawrence Berkeley National Laboratory, Berkeley, CA, 2001 (forthcoming).

[Economist, 2000] “Internet Economics,” *The Economist*, April 1, 2000, pages 64-66.

[EIA, 1999] Energy Information Administration, *Annual Energy Outlook 2000*, DOE/EIA-0383(2000). U.S. Department of Energy, Washington, DC, December 1999.

[EIA, 2000a] Energy Information Administration, *Annual Energy Review 1999*, DOE/EIA-0384(99), U.S. Department of Energy, Washington, DC, July 2000.

[EIA, 2000b] Energy Information Administration, *Short Term Energy Outlook*, U.S. Department of Energy, Washington, DC, December 2000.

[EIA, 2000c] Energy Information Administration, *Annual Energy Outlook 2001*, DOE/EIA-0383(2001). U.S. Department of Energy, Washington, DC, December 2000.

[Elliott and Spurr, 1999] Elliott, R. Neal and Mark Spurr, *Combined Heat and Power: Capturing Wasted Heat.* American Council for an Energy-Efficient Economy, Washington, D.C., June 1999.

[Federal Reserve, 1999] Federal Reserve Bank of Dallas, “The New Paradigm,” *1999 Annual Report*, Dallas, TX.

[Forrester, 1999] Forrester Research, Inc., “Online Energy Industry To Reach $266 Billion By 2004,” October 5, 1999. http://www.forrester.com.

[Greening, 2000] Greening, Lorna A., David L. Greene, and Carmen DiFiglio, “The Rebound: Potential Responses to Improvements in the Technical Efficiency of Energy Consumption,” forthcoming in a special issue of *Energy Policy*, 2000.

[Greenspan, 1999] Greenspan, Alan, “High-tech industry in the U.S. economy,” Testimony before the Joint Economic Committee, U.S. Congress, June 14, 1999.

[Henry et al, 1999] Henry, David, Sandra Cooke, Patricia Buckley, Jess Dumagan, Gurmukh Gill, Dennis Pastore, and Susan LaPorte, *The Emerging Digital Economy II*, U.S. Department of Commerce, Economics And Statistics Administration, Office of Policy Development, Washington, DC, June 1999.

[Howarth, et al 2000] Howarth, Richard B., Brent M. Haddad, and Bruce Paton, “The Economics of Energy Efficiency: Insights from Voluntary Participation Programs, *Energy Policy* 28 (2000) 477-486.

[Jorgenson and Stiroh, 2000] Jorgenson, Dale W., and Kevin J. Stiroh, *Raising the Speed Limit:U.S. Economic Growth in the Information Age*, Federal Reserve Bank of New York, May 2000.

[Koomey, 2000] Koomey, Jonathan, “Avoiding the Big Mistake in Forecasting Technology Adoption,” Energex Conference, Las Vegas, NV, April 12, 2000. The paper is available for downloading at http://enduse.lbl.gov/projects/forecasting.html.

[Koomey, et al 2000] Koomey, Jonathan, Kaoru Kawamoto, Bruce Nordman, Mary Ann Piette, and Richard E. Brown, “Initial comments on ‘The Internet Begins with Coal,’ A memo from Lawrence Berkeley National Laboratory to EPA’s Skip Laitner, December 9, 1999. Available for downloading at http://enduse.lbl.gov/projects/infotech.html. Also see http://enduse.lbl.gov/n4e for further information on energy use and the Internet economy.

[Laitner, 1999] Laitner, John A. “Skip”, unpublished analysis on the impact of weather on changes in the nation’s energy intensity, EPA Office of Atmospheric Programs, Washington, DC, October 1999.

[Laitner, 2000a] Laitner, John A. “Skip”, “The Information and Communication Technology Revolution: Can It Be Good for Both the Economy and the Climate?”, a working paper for the EPA Office of Atmospheric Programs, Washington, DC, January 2000.

[Laitner, 2000b] Laitner, John A. “Skip”, “Energy Efficiency: Rebounding to a Sound Analytical Perspective, *Energy Policy*, 28 (2000) 471-475.

[Laitner, 2000c] Laitner, John A. “Skip”, 2000. “Exploring the Climate Change Impacts of Emerging Industrial Technologies: Some Preliminary Insights**,** *Proceedings of the 2000 Earth Technologies Forum*, Washington, DC, November 2000.

[Lawrence, 2000] Lawrence, Stacy, “Behind the Numbers: The Mystery of B2B Forecasts Revealed,” *The Industry Standar*d, February 21, 2000 (http://www.thestandard.com).

[Meyer, 2000] Meyer, Laurence H., “The New Economy Meets Supply and Demand,” Remarks by Governor Laurence H. Meyer before the Boston Economics Club, Boston, MA, June 6, 2000.

[OECD, 1999] *The Economic and Social Impact of Electronic Commerce*, Paris, France, The Organisation of Economic Co-operation and Development, February 1999.

[Onsite Sycom, 2000] Onsite Sycom Energy Corporation. *The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector*. Washington, DC: Energy Information Administration, January 2000.

[Rauch, 2000] Rauch, Jonathan, "The New Old Economy: Oil, Computers, and the Reinvention of the Earth, *The Atlantic Monthly*, January 2000.

[Romm et al, 1999] Romm, Joseph, Arthur Rosenfeld, and Susan Hermann, *The Internet Economy and Global Warming: A Scenario of the Impact of E-Commerce on Energy and the Environment*, The Center for Energy and Climate Solutions, The Global Environment and Technology Foundation, Arlington, VA, December 1999. Available for downloading at http://www.cool-companies.org.

[Sanstad et al, 2001] Sanstad, Alan H., John A. "Skip" Laitner, and Jonathan G. Koomey, "Back to the Future: Long-range Energy Price and Quantity Projections in Retrospect," Lawrence Berkeley National Laboratory, Berkeley, CA, and EPA Office of Atmospheric Programs, Washington, DC, 2001, in review.

[Shapiro, et al, 2000] Shapiro, Robert, Lee Price, and Jeffrey Mayer, editors, *Digital Economy 2000*, Economics and Statistics Administration, Department of Commerce, Washington, DC, June 2000.

[Shipley, et al, 2000] Shipley, Anna Monis, Skip Laitner, and R. Neal Elliott, "Market Diffusion Theory and the Penetration of Combined Heat and Power," *2000 ACEEE Summer Study Proceedings on Energy Efficiency in Buildings*, American Council for an Energy Efficient Economy, Washington, DC, August 2000.

[SPS/Spectrum Economics, 2000] *Global Economic and Information Technology Market Forecasts, 2000-2005*, September 2000. See also http://www.spececon.com.