Tripling the Nation's Clean Energy Technologies: A Case Study in Evaluating the Performance of Energy Policy Models

Donald A. Hanson, Argonne National Laboratory
John A. "Skip" Laitner, U.S. Environmental Protection Agency

ABSTRACT

The economic discussions of national energy policies have usually been driven by scenarios from the Energy Information Administration (EIA) and the Stanford University's Energy Modeling Forum (EMF). The modeling results from these groups very often suggest negative economic impacts as a result of any deviation from the standard reference case projections of the U.S. economy. Yet, there is a strong literature that offers a significantly different set of modeling results. In the case of clean energy technologies that pay for themselves over (say) a 5-10 year period, one might reasonably conclude that an accelerated investment in such technologies would generate a small but net positive benefit for the overall U.S. economy. After an overview of the relevant literature, we explore this idea in a thought experiment that assumes a tripling of combined heat and power technologies with overall system efficiencies that exceed 70 percent (compared to the current U.S. electric system grid efficiency of 31 percent). We first map all spending changes into an input-output spreadsheet model (based on the IMPLAN database for the US) to determine the likely impact on the nation's total value-added production. We then map similar assumptions into Argonne National Laboratory's AMIGA Modeling System, a 200-sector equilibrium model of the U.S. energy system and economy. In comparing these results, we find a small but net positive impact on GDP in both instances. The comparison suggests that standard input-output analysis might provide a useful diagnostic tool to evaluate the performance of other well-known energy policy models.

Introduction

With the growing concern about energy and climate policy, decision makers turn increasingly to the economics community for insights about opportunities and costs associated with policy-driven changes in energy production and consumption as well as reduced greenhouse gas emissions. The economic reviews of national energy policies have usually been defined by modeling exercises undertaken by the Energy Information Administration (see, for example, EIA 1998) and the Stanford University's Energy Modeling Forum (e.g., EMF 1999). The results from these groups very often suggest negative impacts as a result of any deviation from standard reference case projections. Yet, there is a strong literature that offers a significantly different and more positive set of modeling results (Energy Innovations 1997; Laitner et al. 1998; Barrett et al. 2002; and Krause et al. 2002).

In this paper we review and contrast several previous studies to highlight significant modeling differences. One set of studies, using engineering assessments with macroeconomic feedbacks, suggest that deployment of cost-effective energy technologies can provide small but net positive impact on the U.S. economy (for example, the Interlaboratory Working Group or IWG 1998 as modeled by Barrett et al. 2002; and also Hanson and Laitner 2004). A second set of studies that rely on stylized technology representation in an equilibrium modeling framework suggest that alternative energy policies might have negative impacts on the U.S. economy (again, see Weyant et al. 1999). Following a brief review of these studies, we then set up a diagnostic exercise to highlight and explore these differences. To accomplish this purpose, we use a combination of engineering cost data associated with an expansion of combined heat and power and renewable distributed generation technologies, mapping a reasonable cost and performance characterization into an input-output modeling framework to determine their potential GDP impacts. We then compare those results with outputs from a similar exercise using the AMIGA modeling system, a technology-rich, computable general equilibrium model of the US economy (Hanson and Laitner 2005). We finally draw some conclusions on how combining engineering assessments with an input-output modeling tool might provide a useful diagnostic assessment to help policy makers evaluate the results of the larger energy policy models.

Background

One might imagine that successful modeling would "reflect what people and organizations actually do" (Laitner, DeCanio, and Peters 2000). One might also imagine that modeling exercises should reflect the investments likely to be made under alternative policy scenarios as well as the energy savings and returns on those investments. Unfortunately, the EMF models generally appear to mischaracterize technology opportunities and market dynamics which might otherwise yield improved outcomes from their various policy-driven scenarios. For example, the standard assumption of most EMF models appears to be one in which all resources are fully employed and efficiently allocated in the reference case assumption. By definition, then, any change in the mix of resources will lead to a less efficient and more costly outcome.

Yet, the presumption of a trade-off between environmental and economic benefits may not provide an entirely appropriate framework for analysis of alternative energy policies (DeCanio 1997). In fact, the evidence in the economic literature indicates that the economy has the capacity to respond to a variety of policy initiatives in a more robust fashion than energy models generally credit. Boyd (2001), for instance, cites a large body of literature to conclude that improvements in energy efficiency should result in net benefits to businesses and consumers. The success of EPA's Energy Star programs underscores this point (CPPD 2004). Moreover, the models do not appear to reflect the many social and environmental impacts that are not otherwise reflected in the prices and transactions that are conducted within the market.

The idea of net energy bill savings associated with energy efficiency gains may be at odds with "traditional" EMF economic models, but the evidence for improved energy and non-energy efficiency (as well as larger productivity gains) dates back to the 1950s. Indeed, as Sanstad and his colleagues have documented (Sanstad et al. 2005), the evidence points to a frequent underestimation of the role of technological change in energy models. Moreover, a number of analysts are finding attendant productivity gains that are at least on the same order as the energy efficiency benefits for a large number of manufacturing sectors (Lung et al. 2005; Worrell et al. 2003; Finman and Laitner, 2001; Sullivan, Roop & Schultz 1997; and Elliott, Laitner & Pye 1997). Without a better representation of both behavioral response and technological detail in the standard models, they will continue to provide an incomplete and likely inaccurate picture of possible outcomes.

Brief Review and Comparison of Past Modeling Results

Krause et al. (2002) completed a review of major assessments of the Kyoto treaty that provides us with a minimum framework to examine a wide variety of policy scenarios for their economic impacts. In this case, Krause and his colleagues identified six major categories of abatement strategies or impacts that should be integrated into a meaningful cost assessment before any conclusion might be drawn about an alternative trajectory for greenhouse gas emissions. The first is a uniform and consistent price signal through some form of tax and/or emission caps that are linked to a cap-and-trade market mechanism. The second is domestic market reform that includes organizational, institutional, and regulatory mechanisms to promote cost-effective technology options. The third is a shift in revenues from emission taxes or permit auctions to offset other forms of taxation. The fourth is a set of flexibility mechanisms such as international emissions trading and support for cost-effective emissions reductions within developing countries. The fifth is an assessment of health and air quality co-benefits associated with greenhouse gas emission reductions. The final category is the additional flexibility created with the policies to capture the full mix of other, non-energy greenhouse gas emissions. This latter category of flexibility might also include sinks and other sequestration strategies that can reduce costs compared to an energy-related carbon emissions only strategy.

The surprising result of the study by Krause and his co-authors is that none of the major assessments of the Kyoto treaty originally included more than two of the cost minimization categories identified above. As they note, this "observation calls into question claims that the U.S. lacks affordable domestic mitigation options." To illustrate how a more complete assessment can substantially alter the conclusions of a specific policy evaluation, Table 1 summarizes the results of nine different policy scenarios. Each scenario purports to be an evaluation of either the Kyoto Protocol or some form of greenhouse gas emission reduction strategy as it might contribute to the Kyoto target, and the subsequent economic impact of scenario on the U.S. economy as measured by changes in the nation's GDP. As each scenario captures more of the major categories of impacts identified above, the impact on GDP also begins to change.

The nine scenarios shown in Table 1 are taken from three primary sources, including Krause et al. (2002), IWG (2000), and Hanson and Laitner (2000) with supplemental information taken from the additional references as noted. The specific studies include:

(1) The study of the Kyoto Protocol by the U.S. Energy Information Administration, performed in response to a Congressional request (EIA 1998);
(2) The results of the 16th Energy Modeling Forum (EMF 1999), an academic forum in which a number of energy-economic models implemented different scenarios based upon normalized model assumptions;
(3) The economic analysis of the Kyoto Protocol produced by the Council of Economic Advisers (CEA 1998) on behalf of the Clinton Administration;
(4) A recent study completed for the U.S. Department of Energy (IWG 2000) that evaluated more than 50 policy options designed to achieve cost-effective reductions in carbon emissions;
(5) A macroeconomic assessment of the IWG assumptions using the AMIGA general equilibrium modeling system (Hanson and Laitner 2000); and finally,

(6) The assessment undertaken by the International Project for Sustainable Energy Paths (IPSEP) as discussed in Krause et al. (2002).

The nine sets of results summarized in Table 1 are designed to capture the range of impacts reflected in perhaps more than 100 different data sets. The range extends from the EIA assumptions of a largely non-responsive economy that incurs significant economic costs of 4.2 percent of GDP using a domestic-only carbon reduction strategy to meet the Kyoto targets to the AMIGA and IPSEP assumptions of a more responsive economy that can actually increase economic activity by about 0.5 percent while meeting the Kyoto targets.

Table 1. Comparing the Impact of Policy Gaps in Assessments of the Kyoto Targets

Scenario	Market Reform and Technology Programs	Tax Shift	International Flexibility	Inclusion Other Gases	Air Quality Co-Benefits	Realization of Kyoto Target	Percent Change in GDP for 2010
EIA Domestic Only	No	No	No	No	No	100%	-4.2%
EIA International	No	YES	YES	No	No	100%	-0.8%
EMF-16 Global Trading	No	No	YES	YES	No	100%	-0.2%
CEA Best-case Trading	No	No	YES	YES	No	100%	-0.07%
IWG Domestic Only	YES	No	No	No	No	58%	0.1%
IWG International*	YES	YES	YES	No	No	100%	0.0%
AMIGA Domestic Only	YES	No	No	No	No	52%	0.6%
AMIGA International*	YES	YES	YES	No	No	100%	0.4%
IPSEP	YES	YES	YES	YES	YES	100%	0.5%

Notes: The original data sources contained more than 100 sets of scenario results compared to the nine reflected in the table above. The purpose of this table was only to reflect the range of alternative scenarios to show how the results of a policy analysis might change when models begin to reflect more of the complete set of impacts than is typically evaluated within standard models. Since all scenarios reflect some form of a price increase as a result of either a carbon tax or a cap-and-trade mechanism that raises energy prices, no separate column shows that impact. The asterisk refers to scenarios extended from the original "domestic only" categories to include an estimated GDP impact assuming that some form of international trading provided the additional emission reductions to meet the full obligation of the Kyoto target.
Source: The information within this table is adapted from Krause et al. (2002), with supplemental data taken from IWG (2000), and Hanson and Laitner (2000).

Two important lessons emerge from a review of Table 1. The first is that the single largest influence in moving the assessments from a negative to a positive GDP impact is whether the scenario reflected a set of market reforms and technology investments that close existing energy efficiency gaps identified by Boyd (2001) and others. The second is that by including the other categories of impacts (e.g., tax shifting, international flexibility, and co-benefits) within a scenario assessment, costs are significantly reduced compared to a "price-only" mechanism favored by the standard EIA and EMF modeling exercises. Indeed, as one reviewer of this paper suggested, it is almost as if the EIA and EMF models rule out by assumption any possibility of GDP benefits from what we designate here as "Market Reform and Technology Programs."

Another Perspective on Evaluating GDP Impacts

.

Recall that GDP impacts are a function of changes in investment, personal consumption, government spending, and net exports. In the case of cost-effective clean energy technologies, one might reasonably conclude, therefore, that an accelerated investment path should generate a small but net positive benefit for the overall U.S. economy. A substantial technology investment that saves money and lowers natural gas prices should provide a significant boost to the nation's economy. But is this possibility one that energy policy models might appropriately recognize as a positive impact? This question provides us with a real world hypothesis that might be tested. We explore this possibility in the discussion that follows.

Setting the Stage: A CHP/DG Diagnostic Scenario

On the one hand we have standard economic projections which suggest that combined heat and power (CHP) and renewable distributed generation (DG) resources might double by 2025 from their year 2000 levels of output. But we might then ask: How would the economy be affected if the CHP/DG output were tripled instead of doubled? A tripling means that such resources provide about one-quarter of all electricity needs by 2025. To explore the possibility of net positive benefits on the economy, we set up an analytical framework that: (i) uses an IMPLAN-based input-output diagnostic tool driven by engineering cost assumptions for this CHP/DG scenario, and (ii) then uses a computable general equilibrium model to evaluate a similar set of changes in spending and investments driven by the changes in technology.

Ideally, we would set up a four-step comparison for perhaps the beginning, middle, and end years of a diagnostic scenario exercise. For this review, however, we examined only the last year of the analysis. Step one: Set up a year 2025 spending scenario to approximate a desired level of CHP and other DG resources. Step two: Match changes in spending with appropriate sector multipliers — in this case, the value-added multipliers (note that we can also provide the similar comparison for output, income, and employment multipliers as well). Step three: Run the same, or perhaps more appropriately, a *comparable scenario* within a CGE modeling framework. In this case we will use Argonne National Laboratory's AMIGA modeling system (briefly described below). Step four is to then compare and evaluate the results from both the diagnostic and the CGE modeling exercises.

Electricity Generation in Context

The current mix of electric generation resources in the U.S. today provides about 3600 billion kilowatt-hours of electricity at about 7.0 cents/kWh. The nation's annual electricity bill is now ~$250 billion out of a total annual energy expenditure of ~$700 billion. Conventional fossil-fuel and nuclear central station power plants provide about 86 percent of total electricity use. The remainder is generated by a diverse combination of distributed generation (DG) technologies using both fossil fuels and renewable energy resources (primarily wind, biomass, and hydropower resources). Combined heat and power (CHP) systems, using a variety of primary energy resources, provide thermal, mechanical, and electrical power with system efficiencies of 70-90 percent. This compares to the 31 percent efficiency of our nation's overall electricity system. What the United States wastes in the production of electricity is greater than Japan uses for all of its end-use energy needs, and greater than the total combined uses of the Central and South American economies. Analysts believe that DG technologies, including CHP and renewable resources, could provide a substantially larger fraction of the nation's total energy needs at costs comparable to or less than conventional electricity resources.

Details of the CHP Thought Experiment

Drawing generally from the EIA description of CHP resources (EIA 2004), we assume for this scenario exercise that a medium-sized manufacturer now uses a combination of natural gas for steam boilers as well as separate electricity purchases, with total annual energy costs of \$19 million. If the plant manager, instead, installs a 40 megawatt CHP system, the firm might incur a \$32 million capital cost with the following annual expenses:

- Financial costs of \$3 million (assuming 7 percent interest rate over 20 years),
- Natural gas expenses of \$12 million (to provide both electricity and thermal load),
- Other operating and maintenance (O&M) costs of \$1 million, with a
- Net total annual savings of \$3 million per year (compared to the previous \$19 million).

In this scenario, then, total energy expenditures for the manufacturing plant are down \$7 million per year. This revenue loss would likely reduce GDP impacts. However, the investment, interest payments, and net energy bill savings are all up by an amount that should offset and perhaps increase overall contributions to GDP. In this case, to approximate the magnitude of economywide impacts by 2025 the spending from the single 40 MW plant would have to be scaled upward for ~2,400 CHP systems. In that case, total CHP output would then represent ~9 percent of total electric generation capacity. Based on current data, about 4 percent of 2025 electricity generation is from a variety of non-hydro renewable energy resources and is reflected in current cost projections. For this exercise, new renewable resources are anticipated to increase this to about 10 percent. Overall natural gas consumption is expected to be reduced by about 8 percent as a result of the changed generation mix. Setting up a working gas supply function, the wellhead price of natural gas might be reduced by about 6 percent for all consumption. With appropriate calculations, each set of spending changes driven by this scenario are mapped into IMPLAN as sector-specific changes in final demand.

The IMPLAN Modeling Framework

IMPLAN is both an accounting database and a standard input-output model (MIG 2000). An input-output model divides a region's economy (in this case the United States) into various economic sectors and then tracks how much each sector buys and sells to all other sectors. From this system of accounts, we can derive the value-added that each sector contributes to the national (or regional) economy for each change in spending associated with a given policy scenario.[1]

An economic input-output table is a snapshot of an economy, in dollar terms, for one particular year. The IMPLAN input-output tables for the United States contain a significant amount of sectoral detail with detailed data on over 500 producing sectors. In our exercise, the tables are aggregated to 15 sectors as shown in tables 2 and 3 which follow. Table 2 shows the direct, indirect, and induced value-added effects for each dollar of revenue received by a given sector. For example, for every dollar of revenue received by electric utilities, a total of \$0.64 in

[1] We can also generate similar impacts for employment, wage and salary income, and personal income. For purposes of this paper, however, we are focusing only on the contribution of spending changes to the nation's value-added.

direct value-added is returned to the U.S. economy. But in generating or even expanding their own output, electric utilities draw on other sectors of the economy. This indirect effect amounts to $0.28 per dollar of revenue. Finally, the money that households earn through the direct and indirect effects is said to "induce" additional spending as people purchase other goods and services. Hence, the total value-added impact of a dollar spent on electricity is $1.29.

Table 2. Value-Added Multipliers by Sector

Implan Sector #	Sector Name	Direct Effect	Indirect Effect	Induced Effect	Total Effect
1	Agriculture	0.37	0.48	0.46	1.32
19	Oil and Gas Extraction	0.41	0.42	0.43	1.26
20	Coal mining	0.43	0.45	0.48	1.36
21	Other Mining	0.53	0.36	0.52	1.41
30	Electric Utilities	0.64	0.28	0.37	1.29
31	Natural gas distribution	0.33	0.43	0.38	1.15
32	Construction	0.42	0.45	0.67	1.54
46	Manufacturing	0.34	0.48	0.46	1.28
390	Wholesale trade	0.67	0.28	0.51	1.46
391	Transportation, Other Utilities	0.51	0.41	0.60	1.52
402	Retail Trade	0.61	0.34	0.61	1.56
413	Services	0.65	0.29	0.51	1.45
425	Finance	0.60	0.37	0.54	1.51
494	Private households	1.00	0.00	0.69	1.69
496	Government	0.95	0.04	0.76	1.75

Each of the sectors has a different rate of contribution to the nation's total stock of value-added purchases or contribution to the nation's Gross Domestic Product (GDP). While the very capital intensive nature of electric utilities shows one of the higher direct contributions to value-added or GDP, the total impact provides a smaller benefit than many other sectors.

Given this framework, we might hypothesize that a cost-effective redeployment of resources and expenditures away from the nation's electric utilities (and energy-related sectors more generally) to other sectors of the economy should provide a small but net positive benefit to total valued-added contributions to the economy. This point is shown in table 3 as the CHP/DG scenario changes the energy purchase patterns (shown as changes in final demand) for manufacturing plants (which provide the thermal host for the CHP systems), construction sectors (which install the new systems), the financial community (which underwrites the new construction), and the gas and electric sectors which lose revenue as a result of the growth in CHP and DG systems (compared to the reference case). These initial changes in final demand ripple through the economy producing sector-by-sector changes in value-added as shown in the far right column of table 3 on the following page.[2]

As we look through the results shown in table 3 we can identify a number of sectors which appear to lose overall revenue in addition to the two utility sectors. These include oil and gas extraction and coal mining (for obvious reasons), but also transportation and other utilities (notably water and sewer). But the negative impact here is the result of reduced transportation

[2] For a more complete and general review of this analytical approach, see Miller and Blair (1985). For a review of a detail energy scenario analysis using this technique, see Laitner et al. (1998).

revenues from coal mines and natural gas pipelines. Even construction is down slightly, even with a boost from an initially positive increase in final demand. The reason is likely the reduction in utility-related construction as a result of the increased CHP/DG units being brought on-line. But also, the lower revenues for natural gas and coal mining imply less overall construction in those sectors as well. These losses, however, are sufficiency offset by gains in manufacturing, services, and financial sectors such that the change in value-added under this alternative scenario is a small but net positive $2 billion dollars.

With these scenario results now both mapped and reported using the input-output accounting framework, and giving us a preliminary sense of how an alternative technology scenario might benefit the national economy, we can turn our attention to mapping the results into a standard CGE model to compare results. We discuss this next.

Table 3. Net GDP Impacts

Implan #	Sector	Final Demand*	Value-Added*
1	Agriculture	0	195
19	Oil and Gas Extraction	0	(1,354)
20	Coal mining	0	(1,040)
21	Other Mining	0	(51)
30	Electric Utilities	(32,150)	(20,505)
31	Natural gas distribution	(4,540)	(1,468)
32	Construction	1,500	348
46	Manufacturing	7,000	3,564
390	Wholesale trade	0	646
391	Transportation, Other Utilities	0	(837)
402	Retail Trade	0	481
413	Services	22,610	19,150
425	Finance	3,350	3,240
494	Private households	0	12
496	Government	0	64
	Total	(2,230)	2,445

* in millions of 2001 dollars.

Now to Test the Idea Using a CGE Model

In this experiment we mapped the reference case from EIA's Annual Energy Outlook 2003 into the AMIGA Modeling System, a 200 sector equilibrium model of the U.S. energy system and economy (for more details on the model, see Hanson and Laitner 2005). Next, we mapped a policy-independent tripling of CHP and DG renewable energy resources as an alternative scenario through the year 2025. Note that all other energy and economic assumptions are tied initially to their reference case values, but we allowed them to vary in response to the higher penetration of the clean energy technologies. The combined output for CHP and DG renewable resources is estimated at just under 400 billion kWh in the year 2000, rising to nearly 800 billion kWh by 2025 in the reference case (for roughly a 70-30 split between CHP and DG output). In the testing of our modest thought experiment, we allow the output to rise to just over 1300 billion kWh by 2025 (for roughly a 60-40 split between CHP and DG resources).

Both the traditional input-output model and the AMIGA CGE model are able to capture the essential efficiency improvements from CHP and other DG. All DG saves on net transmission costs. CHP is a particularly efficient form of DG because it provides both heat and power at a lower overall cost than a gas-fired boiler combined with purchased electricity. In a CGE model, the cost savings will result in greater profits (i.e., value added) in industry and higher real income for households (to the extent that some of the cost savings from providing more efficient energy services is passed on to consumers in terms of lower prices for goods and services). The higher industrial value added and the higher household income both result in additional spending opportunity and higher GDP.

Key Results from the AMIGA Model

In the AMIGA test scenario total primary energy use remains about the same, but renewable resources grow from 8.8 to 11.5 quads by 2025. Natural gas use drops by about 1.6 quads. This is only slightly less than our IMPLAN-based modeling assumptions which suggested a reduction of 2 quads. With the lower demand, wellhead gas prices drop about 10 percent compared to the reference case. This is also similar to the IMPLAN assumptions which indicated a reduction of 6 percent. The nation's net investment increases by about $2 billion while GDP increases by about $3 billion (again by 2025). IMPLAN-based modeling assumptions suggested a GDP increase of perhaps a $2.4 billion.

The net positive GDP impacts of both modeling exercises make sense intuitively. The very small difference between AMIGA and the IMPLAN-based model can be explained perhaps in two ways. First, we used a simplistic, single investment cost figure in the IMPLAN exercise while the AMIGA model contains a greater array of CHP/DG technologies, each with a difference cost per kilowatt of installed capacity. Second, other sectoral interactions and slightly larger reductions in natural gas prices in the AMIGA model may tend to slightly increase the GDP impacts as they might be compared to the more static approach in the IMPLAN model.[3]

Finally, and although not explored here in more detail, AMIGA suggests that total carbon emissions in 2025 would be reduced by about 48 MtC. This is consistent with what might be expected from the IMPLAN-based model. In an additional analysis not examined in the IMPLAN-based model, however, AMIGA indicates that conventional air pollutants are also reduced (perhaps not surprisingly) by about 200,000 and 100,000 tons for SO2 and NOx, respectively. Given the reasonably close agreement with IMPLAN in other ways, and reviewing other modeling exercises, this additional level of detail offered by the larger framework of the AMIGA modeling seems to provide a reasonable response.

Conclusions

Although IMPLAN and AMIGA are significantly different modeling systems, they both show reasonably comparable results — given the technology characterizations and assumptions of the scenarios that have been described. This very preliminary exercise suggests that a better

[3] This is not to say, however, the input-output models are always static in their estimation techniques. Indeed, they can also employ dynamic price and quantity adjustments as easily as equilibrium models. However, the application of the IMPLAN-based model in this heuristic exercise was purposely kept simple to provide a more useful illustration of how diagnostic scenarios might help understand and evaluate the results of the larger family of models.

alignment of assumptions will have to be developed in order to use IMPLAN as a diagnostic tool for large CGE or other models. Yet, the accounting logic of an IMPLAN diagnostic tool can help modelers and policy makers understand the kind of technology interactions which ought to occur within those larger, more complex general equilibrium models.

Contrary to the findings of some modeling exercises, the deployment of existing, cost-effective clean energy technologies should provide a small but significant boost to the nation's economy. This positive impact is the result of productive investments in more efficient technology and a reduction in the demand for natural gas. The failure of other EMF or EIA modeling exercises to produce similar results suggests they might not be properly reflecting an appropriate technology characterization. Their accounting framework may also be overlooking the greater returns and energy bill savings associated with productive investments in CHP/DG and other energy supply and energy end-use technologies. The evidence is sufficiently strong to warrant further investigation by extending the use of the diagnostic tools described above as a means to validate the results of the standard economic policy models.

Acknowledgements

We thank Tom Kerr, Alan Sanstad, Fran Sussman, and two anonymous reviewers for their helpful comments. While they greatly improved the presentation quality of this paper, we did not always choose to follow their advice. To that extent, any errors remain the responsibility of the authors. And although we took every effort to rely on credible information and modeling techniques, the results of this paper should not be construed as reflecting the opinion of the Argonne National Laboratory or the U.S. Environmental Protection Agency.

References

[AEA 1998] Administration Economic Analysis, 1998. *The Kyoto Protocol and the President's Policies to Address Climate Change*, Council of Economic Advisers, Washington, DC.

Bailie, Alison, Stephen Bernow, William Dougherty, Michael Lazarus, and Sivan Kartha, 2001. *The American Way to the Kyoto Protocol: An Economic Analysis to Reduce Carbon Pollution*, Tellus Institute and Stockholm Environment Institute, Boston, MA, July.

Barrett, James P., Andrew Hoerner, Steve Bernow, and Bill Dougherty, 2002. *Clean Energy and Jobs: A Comprehensive Approach to Climate Change and Energy Policy*, Economic Policy Institute and Center for a Sustainable Economy, Washington, DC.

Bernow, Stephen, Karlynn Cory, William Dougherty, Max Duckworth, Sivan Kartha, Michael Ruth, 1999. *America's Global Warming Solutions,* World Wildlife Fund and Energy Foundation, Washington, DC. August.

Bernow, Stephen, Rachel Cleetus, John A. ("Skip") Laitner, Irene Peters, Aleksandr Rudkevich, and Michael Ruth, 2002. "A Pragmatic CGE Model for Assessing the Influence of Model Structure and Assumptions in Climate Change Policy Analysis." In Lawrence A. Kreiser, editor, *Critical Issues in International Environmental Taxation*, CCH Incorporated, Chicago, IL, pp. 503-522.

Boyd, Gale. 2001. Boyd, Gale, 2001. "Economic Models of Efficiency," a working memo prepared for the EPA Office of Atmospheric Programs, Argonne National Laboratory, Argonne, IL, July 2001.

[CPPD 2004] Climate Protection and Partnership Division, 2004. The 2003 Annual Report for Energy Star and Other Voluntary Programs. Office of Atmospheric Programs, Environmental Protection Agency, Washington, DC.

DeCanio, Stephen J., 1997. "Economic Modeling and the False Tradeoff Between Environmental Protection and Economic Growth," *Contemporary Economic Policy*, Vol. 15 (October): 10-27, 1997.

[EIA 1998] Energy Information Administration, 1998. *Impacts of the Kyoto Protocol on U.S. Energy Use and Economic Activity*, SR/OIAF/98-03, U.S. Department of Energy, Washington, DC.

[EIA 2004] Energy Information Administration, 2004. *Industrial Sector Demand Module of the National Energy Modeling System,* DOE/EIA-M064(2004), U.S. Department of Energy, Washington, DC.

[EMF 1999] Weyant, John, Henry Jacoby, James Edmonds, and Richard Richels, eds., 1999. *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, a special issue of *The Energy Journal*, Spring.

[Energy Innovations 1997] Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists. 1997. *Energy Innovations: A Prosperous Path to a Clean Environment*. Washington, D.C.: American Council for an Energy-Efficient Economy.

Hanson, Donald A. and John A. "Skip" Laitner, 2000. "An Economic Growth Model with Investment, Energy Savings, and CO_2 Reductions," *Proceedings of the Air & Waste Management Association*, Salt Lake City, UT.

Hanson, Donald A. and John A. "Skip" Laitner, 2004. "An Integrated Analysis of Policies that Increase Investments in Advanced Energy-Efficient/Low-Carbon Technologies, *Energy Economics*, Volume 26(4), pp. 739-755.

Hanson, Donald A. and John A. "Skip" Laitner, 2005. "A General Equilibrium Framework for Analyzing Energy and Climate Change Policies: Overview of the AMIGA Modeling System. Argonne National Laboratory, Argonne, IL (forthcoming).

[IWG 2000] Interlaboratory Working Group, 2000. *Scenarios for a Clean Energy Future*, Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory. ORNL-476 and LBNL-44029, Oak Ridge, TN and Berkeley, CA. November. http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm.

Koomey, Jonathan G., R. Cooper Richey, Skip Laitner, Robert J. Markel, and Chris Marnay, 2001. "Technology And Greenhouse Gas Emissions: An Integrated Scenario Analysis Using the LBNL-NEMS Model," in Darwin Hall and Richard Howarth, editors, *Beyond A Doubling: Issues In The Long-Term Economics Of Climate Change*, Elsevier, pp. 175-219.

Krause, Florentin, Stephen J. DeCanio, Andrew J. Hoerner, and Paul Baer, 2002. "Cutting Carbon Emissions at a Profit: Opportunities for the U.S.", *Contemporary Economic Policy*, Vol. 20, No. 4, pp. 339-365.

Laitner, Skip, Stephen Bernow, and John DeCicco, 1998. Employment and Other Macroeconomic Benefits of an Innovation-Led Climate Strategy for the United States, *Energy Policy*, Volume 26, No. 5, pp 425-433.

Laitner, John A. "Skip," Stephen DeCanio, and Irene Peters, 2000. "Addressing Behavioral and Social Relationships in Climate Mitigation Assessments," in Eberhard Jochem, et al, editors, *Society, Behavior, and Climate Change Mitigation*, Kluwer Academic Publishers.

Laitner, John A. "Skip", Stephen J. DeCanio, Jonathan G. Koomey, and Alan H. Sanstad, 2003. "Room for Improvement: Increasing the Value of Energy Modeling for Policy Analysis, *Utilities Policy*, Volume 11, pp. 87-94.

Lung, Robert, Aimee McKane, Robert Leach, and Don Marsh, 2005. "The Role of Non-Energy Savings and Production Benefits in the Evaluation of the Worthiness of Industrial Energy Efficiency Projects," *Proceedings of the 2005 ACEEE Summer Study on Energy Efficiency in Industry*, Washington, DC.

Miller, Ronald E. and Peter D. Blair, 1985. *Input-Output Analysis: Foundations and Extensions*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

[MIG 2000] Minnesota IMPLAN Group. 2000. IMPLAN Professional User's Guide, Analysis Guide, and Data Guide. Stillwater, MN. June.

Nadel, Stephen, and Howard Geller, 2001. *Energy Efficiency Policies for a Strong America*, Washington, DC: American Council for an Energy Efficient Economy, September.

National Energy Strategy, 1991. U.S. Department of Energy, Washington, DC.

Sanstad, A., S. DeCanio, and G. Boyd, 2001. "Estimating the Macroeconomic Effects of The Clean Energy Future Policy Scenarios," *Energy Policy*, Volume 29, pp. 1299-1311.

Sanstad, Alan, John A. "Skip" Laitner, and Jonathan G. Koomey, 2005. "Back To The Future: Long-Range U. S. Energy Price and Quantity Projections in Retrospect," *International Journal of Energy Technology Policy* (forthcoming).