LBNL-52698

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Policy Modeling for Industrial Energy Use

Editors: Ernst Worrell and Hi-Chun Park

Workshop hosted by
Professional Network for Engineering Economic Technology Analysis
International Network for Energy Demand Analysis in the Industrial Sector

Organized by
Korea Energy Economics Institute (KEEI),
Korea Resource Economics Association (KREA) and
Lawrence Berkeley National Laboratory (LBNL)

Sponsors
Korea Power Exchange
Korea Western Power
SK Corporation

Seoul, Republic of Korea
November 7 – 8th, 2002

Environmental Energy Technologies Division

This work was supported by the Climate Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

Professional Network for
Engineering Economic
Technology Analysis

Policy Modeling for Industrial Energy Use

A Workshop by
International Network for
Energy Demand Analysis in the Industrial Sector and
Professional Network for
Engineering Economic Technology Analysis

Organized by
Korea Energy Economics Institute (KEEI),
Korea Resource Economics Association (KREA) and
Lawrence Berkeley National Laboratory (LBNL)

Seoul, Republic of Korea
November 7 – 8th, 2002

한국전력거래소
KOREA POWER EXCHANGE

SK Corporation

Policy Modeling for Industrial Energy Use

Editors
Ernst Worrell
Hi-Chun Park

Workshop hosted by
Professional Network for Engineering Economic Technology Analysis
International Network for Energy Demand Analysis in the Industrial Sector

Organized by
Korea Energy Economics Institute (KEEI),
Korea Resource Economics Association (KREA) and
Lawrence Berkeley National Laboratory (LBNL)

Sponsors
Korea Power Exchange
Korea Western Power
SK Corporation

Seoul, Republic of Korea
November 7 – 8th, 2002

Acknowledgements

The organizers of the workshop wish to thank the sponsors (Korea Power Exchange, Korea Western Power and SK Corporation) for their financial support, as well as the participants for their contribution to the workshop. We also thank KEPCO for providing the venue for the workshop. Finally, we thank the members of KEEI, KREA and the students of Inha University for their support before and during the workshop.

Table of Contents

Acknowledgements ……..……..……..…iii

Workshop Results

Ernst Worrell, Lawrence Berkeley National Laboratory, USA and Hi-Chun Park, Inha University, Republic of Korea ……...1

Keynote address

Energy Sector Reform and Energy Conservation Policies in Korea
Sang-Gon LEE, President, Korea Energy Economics Institute ……..……..……11

I. State of the Art in International Scenario Modeling and Challenges……..…15

APEC Energy Demand and Supply Outlook for 2020 and its Policy Implications
Yonghun Jung, Asia and Pacific Energy Research Centre, Japan……..……..15

World Energy Outlook 2002: Using Bottom-Up Models in Global Energy Trend
Hiroyuki Kato, International Energy Agency, France ……..21

Towards Improved Policy Relevance in Engineering-Economic Analysis
Ernst Worrell, Lawrence Berkeley National Laboratory, USA, Stephan Ramesohl, Wuppertal Instiute for Climate, Environment & Energy, Germany and Gale Boyd, Argonne National Laboratory, USA ……..…..…41

II. Opportunity Assessment …… ..……..……53

Energy Efficiency Improvements in the Korean Manufacturing Sector
Hi-chun Park, Inha University, Korea ……53

Energy Efficiency Benchmarking
Wolfgang Eichhammer, Fraunhofer Institute - ISI, Germany ……67

Assessing the Cost of GHG Abatement Policies: A Cost Curve Analysis
John Nyboer and Mark Jaccard, Simon Fraser University, Canada ……79

Three big C's: Climate, Cement, and China
Joakim Nordqvist, Christopher Boyd, and Howard Klee ……97

III. Decision Making Behaviour ……111

Opportunities and Barriers to Energy Efficiency Implementation in the Italian Industrial Sector: An Open Matter
Norma Anglani et al., University of Pavia, Italy …….…….. 111

Modelling Industrial Technology Evolution: Capturing Behaviour in a Bottom-Up Model
John Nyboer and Mark Jaccard, Simon Fraser University, Canada …….……..121

IV. Modeling …….…….……131

Economic Analysis on Energy Conservation Policies in Korea: A CGE Modeling Approach
Jaekyu Lim, Korea Energy Economics Institute, Korea …….…131

Modeling Policies in the Clean Energy Futures Study
Ernst Worrell and Lynn Price, LBNL, USA ……143

Energy Efficiency Modeling and Policy Simulation
Gijs Biermans, Ecofys, The Netherlands ……..155

Appendix A: Workshop Program ……...168

Appendix B: Attendees ……170

Workshop Results

Ernst Worrell, Lawrence Berkeley National Laboratory, USA
Hi-Chun Park, Inha University, Republic of Korea

EETA (Professional Network for Engineering Economic Technology Analysis) and INEDIS (International Network for Energy Demand Analysis in the Industrial Sector) organized a joint international workshop on Policy Modeling for Industrial Energy Use. The workshop was organized jointly by the Korea Energy Economics Institute (KEEI), Korea Resource Economics Association (KREA) and Lawrence Berkeley National Laboratory (LBNL). The international workshop was endorsed by the International Energy Agency. The workshop was sponsored by the Korea Power Exchange, Korea Western Power and SK Corporation. This meeting was a follow-up workshop of the successful international workshop on "Industrial Energy Efficiency Policies: Understanding Success and Failure" held in June 1998 in Utrecht, The Netherlands. The meeting was held on November 7-8, 2002 at the Headquarters of the Korea Electric Power Company (KEPCO), Seoul, Republic of Korea.

Objectives of the Workshop

Energy policy is at a crossroads. In recent years the importance of energy policy has been demonstrated around the world. Climate change, deregulation, economic supply of energy services, other environmental challenges; all have an impact on energy policy. Energy efficiency is likely to play an important role in any future policy development, which has led to interesting experiments and developments in energy efficiency policies. Policymakers rely on scenario studies to evaluate, ex-ante, the potential effects of certain developments and policy-choices. This is frequently done using models that try to estimate the effect of the choices on e.g., energy use and economic welfare. However, all models, almost by definition, have shortcomings. One of the main shortcomings of current models is the lack of the capability to properly assess the effect of policies on energy use, especially now that policies change to non-monetary instruments. Historically most tools were reasonably equipped to assess the impact of a subsidy or change in taxation. However, these tools are insufficient to assess the impact of a voluntary program, or that of revenue recycling. A critical evaluation of the models used to assess future industrial energy use is needed and to discuss new developments in the complex industrial sector.

The objectives of the workshop were:

- to exchange experiences and results of industrial energy efficiency policy evaluation;
- to strengthen the analytical capabilities for evaluating industrial energy efficiency policies;
- to discuss policy-modeling efforts for industrial energy use (bottom-up as well as top-down models);
- to discuss experiences with technology databases for policy analysis;
- to improve the analytical energy modeling capabilities of Asian countries.

At the workshop 12 papers were presented reporting on recent modeling experiences from different countries and different international organizations (IEA, APERC). The workshop was organized around the following lines:

- state of the art of international scenario modeling

- challenges to improve energy policy modeling
- improved assessment of the opportunity of energy-efficiency improvement
- understanding decision-making behavior from the firm to the model
- learning from policy through evaluation
- modeling of policy impacts

The workshop participants represent only a small fraction of the modeling community. However, the organizers and participants hope that the proceedings and presented work will contribute to future improvement and collaboration in efforts to make energy models useful to the users of these models, and to address the future challenges faced by the policymakers in a relevant manner.

State of the Art in International Scenario Modeling

At the workshop, two presentations highlighted the current state-of-the-art of the development of international modeling using scenarios to assess future energy demand and the potential effect of policies on energy demand. Dr. Jung (Asia Pacific Energy Research Center, Tokyo, Japan) presented the model and findings of the APEC Energy Demand and Supply Outlook for 2020. The APERC assessment focuses mainly on the energy supply implications by estimating energy demand under expected business-as-usual conditions. The model pays less attention to the implications on energy policy, nor does the study focus on alternative policy scenarios. The model calculations are based on a macro-economic outlook (WEFA, provided by DRI), which are used to estimate final energy demand in the APEC region. Through the transformation sector, the primary energy demand is estimated. Combined with domestic energy production, the 2020 Outlook provides a picture on the energy import needs for the APEC region. As such, the model represents the typical scenario analysis methods used in many forecasting-studies around the world. It also demonstrates, barring any additional energy-efficiency policy developments that the dependence on regional oil imports and greenhouse gas emissions will increase dramatically within the region. However, the model is less suitable for developing alternative scenarios, due to the lack of sector-detail (especially in industry) and the lack of feedbacks between the economic and energy-parts of the model.

Hiroyuki Kato (International Energy Agency, Paris, France) presented the new approach used in the World Energy Outlook 2002. The IEA produces every year the WEO. For the 2002 WEO a combined ‘top-down’ and ‘bottom-up’ approach has been developed, which allowed the development of an alternative policy scenario for OECD. The new WEO is the result of collaboration of two departments within the IEA. The new model has more detail for energy transformation (power sector, refineries) and a new industry sector model. The industry sector model for OECD countries has six sectors. Energy demand in each sector is the function of energy intensity and output value. It was impossible to develop such models for other regions yet, due to data availability. The alternative policies were modeled by estimating the impact that policies may have efficiency of new technologies. The penetration rate of these technologies is used in a stock turnover model (using 4 technology classes) to estimate the impact of policy. However, there is no direct feedback between the reduced energy demand and macro-economic scenario assumptions.

By 2030, the baseline scenario shows increasing primary energy demand, and increasing CO2 emissions in all regions, except economies in transition. Although most of the growth is found in developing countries (mainly in Asia), the emissions from OECD countries grow as well. The alternative policy scenario focused on this aspect, by estimating the impact that new policies and measures, currently being considered by OECD countries, may have on energy use and CO2 emissions. This results in 8% lower energy use by 2030 compared to the baseline scenario. Most of the energy savings and emission reductions were achieved in electricity supply, because electricity savings are accounted as savings in this sector. This

leads to a stabilization of CO2 emissions towards the end of the projection period, which is due to the relative slow technology-stock turnover.

The WEO-2002 demonstrates an interesting hybrid approach to be able to include policy effects in a typical (top-down) forecasting model, and used for a large set of countries. It also raises some important issues on data availability and the role of stock turnover (and retrofit). In the model they used different life times for different countries, which demonstrates on the need for further study of this important assumption in modeling (as also demonstrated in the CEF study, discussed by Ernst Worrell in a later presentation).

Challenges

The results and challenges met by the IEA-team in developing the industry model as part of the WEO 2002 and the assumptions on policy impact are evidence of the challenges to improve our modeling efforts. Ernst Worrell (Lawrence Berkeley National Laboratory, Berkeley, USA) outlined the preliminary results of a paper authored in collaboration with Stephan Ramesohl (Wuppertal Institute, Wuppertal, Germany) and Gale Boyd (Argonne National Laboratory, Argonne, USA) on challenges and important new directions to improve the policy relevance of economic-engineering models. The presentation identified four major areas for model improvement: the modeling framework, technology representation, policy evaluation, and modeling of an appropriate decision-making framework. The development of a uniform but public modeling framework to integrate existing and future modules/models is seen as a major step forward by the authors. Object oriented programming allows transparency and at the same time flexibility in modeling approaches. Research should determine a common structure and the information needed to facilitate communication between the 'objects'. Technology representation in modeling has to focus on two main items, firstly, the technical description of the technology/measure, and, secondly, the relationship between technology and the implementation trajectory, including the non-energy benefits in the quantitative description of a technology, capturing the learning effect, and definition at an level of disaggregation. Full policy evaluations are rare in the field of industrial energy policy. Research should aim at innovative ways to study the effectiveness and efficiency of policies. New modeling approaches for the decision-making framework and process are needed, including barrier representation (e.g. lack of information), decision-making behavior, as well as the effect of policies (see above) on decision-making. Especially the impact of non-monetary policies and policies aiming to reduce certain barriers are important areas that are in need of innovative modeling techniques.

The presentation gave a long list of challenges, which seems daunting, especially given the difficulties of "day-to-day" energy modeling. The discussion focused on identifying these areas in which important and fast improvements are possible. To determine the important areas for improvement we have to look at the questions asked by the policymakers. This may lead to different challenges, then looking to opportunities to just reduce the uncertainties in the model. Also, the proposed approach to develop an open modeling framework is seen as a good way to overcome some of the problems of the pat. In the past large sums of money have been spend on short-lived models. It will also help to reduce the complexity of the many challenges by focusing on a few selected areas, but still be able to integrate them in a broader framework.

Opportunity Assessment

One of the challenges to improve engineering-economic models, as identified by Worrell et al. (see above), was the proper characterization of the potential for energy efficiency improvement, and the definition of a realistic baseline scenario. At the workshop several papers were presented on different approaches to model the potential for energy efficiency improvement (or CO_2 emission reduction) and the costs and benefits. The study varied from the use of indicators to assess past achievements and future directions (Korea, China), the use

of benchmarking to find the potential for efficiency improvement (Thailand, Malaysia), to the use of cost-curves to assess the costs of attaining a certain GHG emission reduction goal (Canada).

Decomposing past trends in its elements can not only help to understand the drivers of changes in energy intensity but also help to improve forecasts, as well as the assessment of achievable potential. The latter is true, as long as a reliable decomposition method is used. Hi-Chun Park (Inha University, Korea) discussed the results of detailed decomposition results of energy use in selected energy-intensive industries in South Korea. The analysis shows that Korean industry has grown rapidly, and energy-efficiency improvement has not been able to offset the production growth, leading to increasing energy use. Hence, future policies to restrain CO_2 emissions, should not only look at energy-efficiency policies, but also restructuring the industry, which now has an over-emphasis on a number of very energy-intensive products. Prof. Park used a decomposition analysis method based on physical indicators. This allows a direct link to technologies used in each of the sectors, and hence a better understanding of its historical and current performance, provide a sound basis for estimates of the technical potential (e.g. by using benchmarking, see presentation by Wolfgang Eichhammer). The historical trend allows to also estimate the achievable potential, assuming similar economic conditions. However, given the economic crisis in the 1990's, and the need for industry restructuring, history may not be good guidance for the future in South Korea.

Various methods exist to estimate the (technical) potential for energy efficiency improvement. One method that is receiving more attention worldwide is the use of benchmarks to assess the performance of an industrial energy user, or even a specific industry in a country. Benchmarking underlies also the approach developed by the INEDIS-partners for international comparisons of energy efficiency. Benchmarking can be used in different ways. By comparing to a best-available technology it can be used to estimate the technical potential at the current level of technical development. It can also be used to compare the performance against that of peers, if based on similar production structures. In the latter approach, it allows to identify the 'best-practice' performer within the group analyzed. While the first method helps to assess the technical potential, the latter method helps to assess the achievable potential within the studied set of peers. Both methods can help individual companies to evaluate their relative performance, and help improve energy management practices by increasing awareness and introducing a reality-check. Wolfgang Eichhammer (Fraunhofer Institute, Germany) reported on benchmarking efforts in Thailand and Malaysia to help improve energy-management practices in plants in various sectors. Although the programs have a different background (legislated vs. voluntary participation), the programs are similar in methods and approach. The (preliminary) results demonstrate the existence of major differences in energy-efficiency and performance, and hence the existence of a potential for energy efficiency improvement. However, the applied benchmarking method does not provide information on how to achieve the potential, and at what level of costs and benefits. For this, additional studies and audits may be necessary. The benchmarking tool is a good tool to demonstrate the need to a plant-operator to perform such an analysis, while it may help the policymaker to improve the effectiveness of policy instruments by providing focus.

For modeling, we not only need to understand the historic drivers, and the potential for energy efficiency improvement, but also the potential costs and benefits. In many engineering-economic models supply curves are used to model the costs of achieving a given amount of energy savings. However, the construction of supply curves can be done in various ways, while also the definition of costs may vary. John Nyboer (Simon Fraser University, Canada) presented the results of an analysis in Canada to support the policy development in Canada as part of the ratification of the Kyoto Protocol. The basis for the economic assessment was a detailed supply curve developed for Canada. Nyboer objected to the traditional presentation

of a curve as "steps" at a certain costs, but was in favor of presenting it as a continuous curve, due to the range in actual costs found when implementing a technology. He furthermore focused on the definition of the costs, and introduced different cost perspectives (e.g. a social perspective (or techno-economic costs), the "real" costs accounting for risks and inefficiencies, and the perceived private costs). While the techno-economic costs are based on analysis of individual measures and technologies, the "real" costs is based on a general mark-up for each technology cost. The perceived private cost is not related to the actual technical costs, but rather on the willingness to pay using a shadow price for emission reductions. Using the different cost-perspectives will provide different answers. The analysis helped to better estimate the potential for emission reduction within and emission reductions to be acquired through flexible mechanisms abroad. The analysis also helped to look into the 'slowness' of the system to react to changes, and the design of new policies to accelerate the uptake of new technologies and ways to reduce the inefficiencies in the system. A discussion item remains how one should define the transaction and opportunity costs, generally not included in the technical-economic costs. A general mark-up may not be reflective of the real conditions under which different technologies are implemented. Secondly, while using a general markup, what should the level of markup be? To reduce these problems, it was assumed that the "mark-up" is not a fixed value but it is determined probabilistically. We can never know what the "mark-up" will be because it is never the same for all people, but it can be estimated probabilistically, using the limited literature that exists and research in progress. Finally, in most cost curves the full benefits of implementing a technology are often not accounted correctly. These are important directions in trying to improve the economic assessment of the energy-efficiency improvement potential.

The calculation of the policy target for emission reduction within Canada, and the amount of emission reduction to be achieved through emission reduction abroad underlines the importance of knowledge on the costs of emission reductions in a diverse range of regions. Often these assessments assume a certain (shadow) price for GHG emission reduction. However, these analyses are often not complete, and may exclude the potentially large transaction costs of projects implemented under the Clean Development Mechanism (CDM). The global nature of the climate change problem and the flexibility mechanisms in the Kyoto Protocol demonstrate the need for sound analysis of the emission reduction opportunities in many (developing) countries. Joakim Nordqvist (Lund University, Sweden) presented a paper on the opportunities for energy-efficiency improvement in the cement industry in China. The global cement industry emits about 5% of all global anthropogenic CO_2 emissions. Global initiatives in the cement industry aim to improve the sustainability of the industry. The paper demonstrates the large potential for efficiency improvement and emission reduction in the Chinese cement industry within the framework of sustainable development. However, it also stresses the uncertainties and how little we actually know about the (transaction) costs to reduce emissions in a country that produces 40% of the cement in the world. Hence, the paper should not only seen as a plea to learn more about the opportunities for energy efficiency improvement, but also in different parts of the world to improve the increasingly global modeling efforts.

Decisionmaking Behavior

While a many models have included a thorough analysis of the technologies and the potential for energy-efficiency improvement, most models lack a good representation of the decision-making framework. Most models use a certain cut-off criteria based on the costs of conserved energy or payback period. In practice, we see that not all technologies with the specified payback period are picked up, or other technologies are implemented than the model expected. However, we lack a full understanding of the decision-making framework to fully include the characteristics of the firm behavior. While market studies of household behavior are available, we need improved assessment and attempts to model firm behavior in a more realistic way to improve simulation models and *ex-ante* policy effectiveness forecasts. At the

workshop one paper was presented looking at the behavior of a specific group of firms (plastic processing) in relation to a technology (compressed air) to understand the barriers and the uptake of efficient technologies. A second paper aimed at simulating decsionmaking behavior in a model.

Norma Anglani (University of Pavia, Italy) presented a study of the opportunities and barriers to improve energy-efficiency in a number of Italian companies. Focusing on compressed air systems in the production of expanded polystyrene (EPS) it is trying to estimate the potential for efficiency improvement, as well as the barriers, and distilling policy lessons from the case study. The study showed a variation in the costs of a specific measure (see discussion above). The main barriers were found to be the lack of information on demand-side options, the lack of attention to the use of compressed air as a cost-factor, as well as the need for capital. The paper proposes the outsourcing of compressed air system maintenance and operation as a potentially successful way to improve energy efficiency in compressed air systems. While the authors were not yet able to quantify the barriers, the paper demonstrates the importance of other factors than costs in the decisionmaking model. Currently, hardly any model is able to integrate non-monetary barriers (and hence policies) in the model. This is an area where a lot of empirical studies as well as modeling attempts are necessary.

The Energy and Materials Research Group (EMRG) at Simon Fraser University (Canada) is trying to integrate decisionmaking behavior in energy models, using a discrete choice analysis method. Discrete choice analysis comes from the marketing research field, and has been used in consumer behavior analysis. In a discrete choice elements technologies compete, and the choice between the competing technologies is based on a number of parameters that place value on a certain element of the technology (e.g. first costs, maintenance, etc.). The authors (Nyboer et al.) acknowledge that there are many uncertainties in these parameters (and in the technology characteristics). Acknowledging the uncertainty by using distributions for the input variables, would allow the user to get an improved understanding of the overall uncertainty, and the uncertainty in policy outcomes. In the paper the authors propose to run Monte Carlo simulations, with distributions of input parameters based on market analysis. Finally, by integrating a discrete choice module in an engineering-economic energy simulation model, an improved understanding of the uncertainty will be generated. Nyboer at al. are currently studying the approach, but have not yet applied this to industrial energy modeling. The difficulty will be in the determination of the distribution of the model input parameters. Given, available data it may be difficult to establish representative distributions for technology groups. John Nyboer proposed to test the methodology on the case of cogeneration, as it is an important policy field in many countries, with a limited number of technology options.

Modeling

In the workshop the participants focused on the challenges of including policies in an appropriate way in energy models. The first sessions focused on the efforts to improve (international) energy modeling, challenges, needs, data for policy representation in models, as well as methods to include decisionmaking behavior in models. In this session the workshop focused on the attempts to include policies in industrial energy-efficiency modeling. The discussed models vary in the way they incorporated policies or policy effects. Four different papers were presented within this session. The first two papers focused on national studies to assess different scenarios, while the last two presentations proposed mechanisms to include the interaction between decisionmaking behavior and policymaking.

The first paper was presented by Jaekyu Lim (Korea Energy Economics Institute, Korea) and focused on the use of CGE model to estimate the effects of different policies, including energy taxes, financial support instruments, and R&D policy. The effects on energy consumption and the economy are estimated. The CGE model KORTEM is a dynamic multi-

sector model developed for South Korea. It includes a large number of commodities, industries and energy carriers. It allows for inter-fuel substitution and energy-capital substitution, and includes stock depreciation. In the reference scenario energy use is expected to grow dramatically between 2000 and 2010, while overall energy of society is expected to decrease slightly. Five policy scenarios were developed; energy tax, financial incentives, R&D investment, energy efficiency standards (on consumer products), and improved fuel economy of motor vehicles. The model does not allow for tax revenue recycling through reduced corporate taxes, only by (general) income tax reduction. The policy scenarios provided some interesting results. For example, the scenario using energy-efficiency standards led to increased energy consumption, as households were changing their consumption patterns, as the more efficient appliances were assumed to be more expensive. The R&D scenario showed the largest savings and most positive effect on the economy. Also, financial support incentives gave positive results for energy use. This is remarkable given the short timeframe modeled. In reality, policy may consist of a combination of options from this menu. The authors of the study did not assess a combination of policies. The study was an interesting way to model policies of which some are often not included in CGE-models. The disadvantage of a CGE model is that it is difficult to include barriers in the model. However, the authors have tried to include non-monetary instruments in the model. It demonstrated the importance of the assumptions.

Ernst Worrell (Lawrence Berkeley National Laboratory, USA) reported on the Scenarios for a Clean Energy Future (CEF)-study, which was published by the US Department of Energy about 2 years ago. The CEF-study studied the role that efficient clean energy technologies can play in meeting the economic and environmental challenges for future energy supply in the U.S. The study describes a portfolio of policies that would motivate energy users and businesses to invest in innovative energy efficient technologies. On the basis of the portfolios, two policy scenarios have been developed, i.e. a moderate scenario and an advanced scenario. The presentation focuses on the industrial part of the CEF-study. The studied policies include a wide scope of activities, which are organized under the umbrella of voluntary industrial sector agreements. The policies for the policy scenarios have been modeled using the National Energy Modeling System (CEF-NEMS). In NEMS energy use can be modeled at the energy service demand, or process stage, level, while for other sectors no equipment is explicitly modeled nor are there any engineering links between process stages, and technology is represented parametrically. The CEF-NEMS Industrial Module contains no explicit equipment characterizations, but the parameters can be calculated based on assumptions of technology performance and penetration. These estimates are an exogenous input to the model. For the CEF policy scenarios, new inputs were developed for the CEF-NEMS model. Under the reference scenario industrial energy use would grow to 43.3 EJ in 2020, compared to 36.7 EJ in 1997, with an average improvement of the energy intensity by 1.1% per year. In the Moderate scenario the annual improvement is about 1.5%/year, leading to primary energy use of 40.0 EJ in 2020. In the Advanced scenario the annual improvement increases to 1.8% per year, leading to primary energy use of 36.1 EJ in 2020, and 29% lower CO_2 emissions.

The papers discussed above were limited by the way models typically operate, and the modeling frameworks were designed before the need was identified to include policies explicitly in models. Groups around the world make different attempts to more explicitly model energy policies. Two approaches were discussed at the workshop. The first one is the use of discrete choice modeling, using a modeling technique used in marketing studies (see also above); while the second one focuses on the representation of (non-financial) barriers to energy-efficiency improvement.

John Nyboer (Simon Fraser University, Canada) presented the potential use of Discrete Choice Analysis in the improvement of the national Canadian energy model CIMS (see above). The paper explores the opportunities and advantages of this integration, but is has not

yet been implemented in CIMS. The use of discrete choice analysis would allow improved competition between technology choices by valuing the preferences of the technology users. As some users may value first costs more than others, they will react differently to new products with increased capital, but lower life cycle costs. The difficulty will lie in the proper definition and determination of the parameters of the values given by different groups. Surveys may help to provide these insights, but will keep a large degree of uncertainty. John Nyboer stressed the importance of recognizing the uncertainty, and not to bury it in the model results. In the discussion of the paper, the possibility of using multi-agent modeling in combination with discrete choice modeling as way to capture the different behavior of different users within the same sector was brought up. This could be a promising opportunity to work with the uncertainty in the survey results of technology user preferences. Several groups in North America and Europe are exploring the use of multi-agent modeling in industrial energy efficiency (policy) modeling.

Gijs Biermans (Ecofys, The Netherlands, and visiting researcher at LBNL, USA) presented a different approach to model energy-efficiency policies by explicitly recognizing the barriers to implementation of energy efficient technology. Gijs Biermans presented the vision on the larger model structure, and discussed the preliminary results of a module focusing on the steel industry in the United States. The larger model is being developed as a model to assess policies and strategies for GHG emission reduction, and specifically focusing on ways to include non-monetary policies. A first pilot module is under development to test some of the model characteristics. The model builds on a curve that is supposed to simulate decisionmaking behavior. The curve depicts the degree to which a technology or measure with a given payback period will be implemented. The curve can be based on surveys of industrial decisionmaking behavior, as well through calibration of the model to knowledge on technology penetration rates. The curve assumes that even with a very low payback period, only a part of the potential will be implemented (using an annual cycle). The shape of the curve can be influenced by policies, e.g. improved access to information, while financial policy instruments influence the payback period. However, determining the quantitative effect of the changing the shape of the curve is difficult. The model includes stock turnover and retrofit, and includes a learning effect for new technologies. The calculation of the payback period can include non-energy benefits. The model does not account for policy implementation costs, or for transaction or opportunity costs. The approach seems a good way to explicitly account for (non-monetary) barriers to energy-efficiency improvement, although it necessarily simplifies the decisionmaking behavior. The choice of using the payback period is based on a survey of the used decisionmaking tools in industry in The Netherlands. The difficulty will be in determining the shape of the curve for different types of decisionmakers (e.g. sectors) and the effect of policy on the shape of the curve.

Conclusions & Recommendations

The international workshop on Policy Modeling for Industrial Energy Use was jointly organized by EETA (Professional Network for Engineering Economic Technology Analysis) and INEDIS (International Network for Energy Demand Analysis in the Industrial Sector). The workshop has helped to layout the needs and challenges to include policy more explicitly in energy-efficiency modeling. The current state-of-the-art models have a proven track record in forecasting future trends under conditions similar to those faced in the recent past. However, the future of energy policy in a climate-restrained world is likely to demand different and additional services to be provided by energy modelers. In this workshop some of the international models used to make energy consumption forecasts have been discussed as well as innovations to enable the modeling of policy scenarios. This was followed by the discussion of future challenges, new insights in the data needed to determine the inputs into energy models, and methods to incorporate decisionmaking and policy in the models. Based on the discussion the workshop participants came to the following conclusions and recommendations:

- Current energy models are already complex, and it is already difficult to collect the model inputs. Hence, new approaches should be transparent and not lead to extremely complex models that try to "do everything".
- The model structure will be determined by the questions that need to be answered. A good understanding of the decisionmaking framework of policymakers and clear communication on the needs are essential to make any future energy modeling effort successful.
- There is a need to better understand the effects of policy on future energy use, emissions and the economy.
- To allow the inclusion of policy instruments in models, evaluation of programs and instruments is essential, and need to be included in the policy instrument design.
- Increased efforts are needed to better understand the effects of innovative (non-monetary) policy instruments through evaluation and to develop approaches to model both conventional and innovative policies.
- The explicit modeling of barriers and decisionmaking in the models seems a promising way to enable modeling of conventional and innovative policies.
- A modular modeling approach is essential to not only provide transparency, but also to use the available resources most effectively and efficiently. Many large models have been developed in the past, but have been abandoned after only brief periods of use.
- A development path based on modular building blocks needs the establishment of a flexible but uniform modeling framework. The leadership of international agencies and organizations is essential in the establishment of such a framework.
- A preference is given for "softlinks" between different modules and models, to increase transparency and reduce complexity.
- There is a strong need to improve the efficiency of data collection and interpretation efforts to produce reliable model inputs. The workshop participants support the need for the establishment of an (in-)formal exchanges of information, as well as modeling approaches.
- The development of an informal network of research institutes and universities to help build a common dataset and exchange ideas on specific areas is proposed. Starting with an exchange of students would be a relative low-cost way to start such collaboration. It would be essential to focus on specific topics. It is also essential to maintain means of regular exchange of ideas between researchers in the different focus points.

EETA

The Engineering-Economic Technology Analysis (EETA[1]) Network is a multi-disciplinary, worldwide network of experts involved in the assessment of energy-efficient and climate-friendly technologies from an engineering, economic and public policy perspective. The Network's aim is to improve the quality, relevance and visibility of technology analyses in order that they become a more useful tool for energy and climate change policymaking. The EETA Network's membership target is a techno-economic analyst, economists, policy evaluation specialists, top-down and bottom-up modelers and socio-economic specialists.

The EETA's networking activities and collaborative work will be defined by the terms: analysis, technology and policy. First, the Network will focus only on analysis, and will take due care to not become a platform for commercial promotion of specific products or a vehicle for political manipulation. Second, EETA will concern itself with only on those types of analyses having substantial and concrete technology detail. The family of EETA methodologies includes: micro-economic analysis of cost and potential of clean, energy-efficient technologies as well as systems-engineering models for studies of technology links, competition among technologies and interaction between technology and macro-economy. And last, the ultimate goal is to improve the role of technology analysis as a policy making tool. EETA will emphasize activities and work with clear and substantial policy relevance. EETA was founded by the International Energy Agency in 1999, with assistance of U.S. Department of Energy, U.S. Environmental Protection Agency, and Netherlands Ministry of Housing, Spatial Planning and Environment.

INEDIS

The International Network for Energy Demand Analysis in the Industrial Sector (INEDIS) was founded in 1997 by five institutes from Europe and the U.S. with initial financial support of the European Commission, the US Department of Energy, and the US Environmental Protection Agency. It now comprises more than 20 member institutes around the world in as many countries, as well as multi-national research institutes.

The goals of INEDIS involve in-depth global assessment of energy use in the industrial sector, establishment of an international network of industrial energy use and efficiency specialists, and strengthening international analytic capabilities for industrial energy demand, especially for developing countries and countries with economies in transition. Network participants compile, exchange, and analyze data on all aspects of industrial energy use and efficiency. It is envisioned that this collaborative network will become a permanent analytical activity, with network members updating data annually and serving as a reliable resource for energy analysts and policymakers. INEDIS has successfully organized efforts to establish indicators for energy efficiency in industry, a workshop on experiences with evaluation of industrial energy policy.

[1] The Greek letter eta "η," is the engineering sign for efficiency.

Energy Sector Reform and Energy Conservation Policies in Korea

Sang-Gon LEE[1]
President, Korea Energy Economics Institute

The President of Korea Resource Economics Association, and distinguished scholars of International Network for Energy Demand Analysis in the Industrial Sector and Professional Network for Engineering Economic Technology Analysis, I highly appreciate your academic achievements and contributions to energy conservation all of you have made thus far. And I would like to express my sincere gratitude to organizers of this fourth workshop, Korea Resource Economics Association, Lawrence Berkeley National Laboratory, the International Energy Agency, and Korea Energy Economics Institute. I feel deeply honored to take this opportunity speaking about new paradigms and policies on the Korean energy market and energy conservation.

The energy consumption of Korea has doubled for the past 10 years, although the current primary energy consumption of Korea is about a third of that of Japan. Apparently, major forces behind this trend of increasing energy consumption are high economic growth and the large share of energy-intensive industries of the national economy.

Regarding the overall energy efficiency of the Korean economy, there are both bright and dark stories. In terms of energy intensity, Korea consumes about 0.31 tons of oil equivalent to generate every 1,000 US dollars worth of GDP in the real price of 1995. In contrast, however, the energy intensity of Japan is 0.10 tons of oil equivalent while the average energy intensity of OECD is 0.20 tons of oil equivalent. It may not be persuasive to evaluate the energy efficiency status of a country in terms of only the absolute level of energy intensity. As you may agree, energy intensity is an ex post aggregate statistic reflecting a combined effect of the volume of economic activities, the industry structure, and the technology level. Nevertheless, we cannot deny that Korean energy intensity appears too high in comparison with other countries.

In order to look at a different angle of the energy efficiency of the Korean economy, let me introduce GDP elasticity of energy demand. GDP elasticities of energy consumption over years have varied in a wide range around 1.0 during the past three decades in Korea. Fortunately, however, GDP elasticity has been on the decreasing trend since 1990. When estimating from elasticity values between peaks or troughs in the GDP elasticity cycle, the elasticity has been decreasing by about 3 to 5% annually. According to the prediction of Korea Energy Economics Institute, the recent trend of decreasing GDP elasticity is expected to continue into the future so that GDP elasticity would be stabilized at about 0.5 in the long run. Together with future economic growth, which is forecast to be lower than the past, the favorable expectation of energy efficiency will act as a check on a high increase in energy consumption. Thus, the future energy consumption of Korea is expected to get another double in the next 30 years or so. This period of time is three times longer than experienced in the latest doubling of energy consumption.

The energy conservation policy of Korea has systematically started from 1980's. The Rationalization of Energy Use Act came into effect in 1979, and Korea Energy Management Corporation was established in 1980 as a sole public organization for the implementation of

[1] E-mail: sanglee@keei.re.kr

energy conservation policies. The parent body of the present Korea Energy Economics Institute was also founded at that time. On the other hand, energy efficiency from the viewpoint of the energy supply system has also attracted public attention since liquefied natural gas, and district heating and cooling energy were introduced in the middle of 1980's. I would say, however, that the energy conservation policy became in full blossom after 1993 when the First Basic Plan for Rationalization of Energy Use was formulated and began to be implemented.

After going through these developing processes, Korea has instituted most of energy conservation policy measures and programs you can see in major developed countries. For example, it is conducting such programs as the energy audit, support for energy service companies, energy efficiency labeling and standards, and the voluntary agreement. In the meantime, we are still waiting for the more comprehensive evaluation of how effective energy conservation policies and programs are in Korea. I think, however, that they have to some degree contributed to the recent improvement of energy efficiency, which I mentioned before.

Now, I would like to share with you directions, and strong and weak points of the Korean energy conservation policy. As specified in the Second Basic Plan for Rationalization of Energy Use, the Korean policy in principle supports the free decision making of the private sector. In this context, the voluntary agreement program is employed as a main device for improving industrial energy efficiency. Energy conservation policies are also directed toward fostering the energy efficiency market to a great extent. Major energy conservation programs to that direction include energy efficiency labeling and standards, and development and support programs for energy service and venture companies. In addition, the Korean policy intends to make the best possible use of performance achieved by the technology development program for the promotion of energy savings and alternative energy. For this purpose, the Korean government has developed a performance management system for technology development. Moreover, energy conservation policies aim to establish a comprehensive data and information system for energy savings. I do believe that this system will be indispensable and useful for designing policies and programs mitigating energy-related greenhouse gases in accordance with the United Nations Framework Convention on Climate Change. Under these directions of energy conservation policies, Korea has set the goal of energy savings for the average annual rate of about 2%.

The energy conservation policy of Korea shows some strong features and a few weak points as well. Looking at strong points, Korea has to some extent accumulated technical and managerial know-how to plan, implement and evaluate energy conservation policies by utilizing firm organizations and financial resources. Highly qualified manpower and expertise are available in public organizations such as the Ministry of Commerce, Industry and Energy, Korea Energy Management Corporation, and government-affiliated economics and technology research institutes, and they are also available in private establishments such as energy service companies. Furthermore, utilizing Special Fund for Energy and Resources, the Korean government financially assists private agents to carry out energy saving facility projects and to install district energy facilities. According to the provisional analysis of Korea Energy Economics Institute, the benefit-cost ratio of the loan program for energy saving facility projects is estimated at 2.6, which proves the financial assistance program to be socially economic.

The current energy conservation policies of Korea also have some weak points as well. The energy conservation policy is in general to bridge the gap between private and social efficiency. To that end, it is critically important to prepare and coordinate all the stages of planning, implementation, and evaluation, which are basic elements of the energy conservation policy and program. Nevertheless, the energy conservation policy of Korea shows weaknesses regarding these stages. First of all, quite a few energy conservation policies and programs were not based on sufficient ex ante evaluation in the planning stage.

This drawback was the major cause that policy targets were not clear sometimes. As you know, the energy conservation policy that cannot change the inefficient energy consumption behavior of private economic agents will not be sustainable any longer.

As the energy conservation policy of Korea lacks distinct connection among detailed energy efficiency programs, it is possible that similar programs are implemented repeatedly. For instance, the Korean government has been executing the energy audit, the voluntary agreement, and the replacement of inefficient boiler, furnace, and kiln in order to improve energy efficiency in the industrial sector. Under this circumstance, the value of energy saved by one program could be easily counted again in the energy savings value of other programs. This double counting potential clearly implies the inefficient distribution of scarce resources of the country. As I said before, energy conservation policies and measures are mostly implemented by the government, energy-related public corporations, energy service companies, and Korea Energy Management Corporation. In case that the energy industry will be reformed in the future, it is inevitable that the function of public corporations implementing energy saving programs should be adjusted. In addition, even though the ex ante and ex post evaluation of the efficiency policy and program is a prerequisite for their success, such evaluation is not given due consideration.

Besides weaknesses mentioned before, Korea faces economic, social, and cultural challenges to energy conservation policies. The restructuring of energy industry is expected to influence conservation policies considerably. Moreover, there are many new trends in front of us, for example, a continuing shift to a digital economy, the increased impact of the green round such as the United Nations Framework Convention on Climate Change, the demand for greater roles of local governments, and the expansion of citizens' participation. These new trends can be opportunistic factors to enhance energy saving potential, and they can also be threatening factors. I would like to take this opportunity to talk about how the restructuring of energy industry would influence energy conservation policies and programs in Korea.

To promote competition in the energy market, the Korean Government has pursued programs of the structural reform and privatization of government-owned electricity, natural gas, and district heating companies. First, the Korea Electric Power Corporation, a vertically-integrated monopoly, was unbundled into 6 generating companies, and transmission and distribution sectors. Five non-hydro-nuclear generating companies are planned to be privatized in the near future. The distribution part of the Korea Electric Power Corporation will also be split into a number of subsidiary companies and privatized in next 10 years or so. After the completion of this plan, the Korea Electric Power Corporation will involve in only hydro-nuclear power generation and transmission activities. To encourage competition in the market, the Korean government already established the Korea Power Exchange in 2002. The Korea Electricity Commission, a regulatory body, was also set up within the Ministry of Commerce, Industry and Energy, which will become fully independent after the completion of the restructuring.

In the natural gas industry, it is planned to separate the import and wholesale arms of the Korea Gas Corporation into 3 trading companies, one of which will remain to be a subsidiary of the Korea Gas Corporation. Other 2 trading companies will be privatized in the near future. The gas plan calls for gas-to-gas competition based on open access to the gas-pipeline network and LNG terminals that will be managed by the Korea Gas Corporation. On the other hand, the Korea District Heating Corporation that currently occupies 66% of the total supplying capacity of district heating will also be privatized by selling dominant shares in the stock market. In order to secure fair trading of natural gas and heating energy, a number of measures including the establishment of an independent regulatory body such as a gas committee are under consideration.

The structural reform and privatization of the energy sector is expected to recover the role of the energy market by allocating resources under the market mechanism. Energy suppliers will try to maximize profit with cost minimization while energy consumers will react more sensitively to the movement of energy prices. Under these circumstances, energy regulators may strengthen the energy market mechanism by relaxing or removing the existing distortion of the energy taxation system and cross-subsidies provided between energy sources or energy services. In addition, energy regulators will be able to induce energy consumers to behave in an energy-efficient way by designing competitive rules of game on a marginal cost basis. I believe that this new environment will create more opportunities and potentials for energy conservation.

The new environment surrounding the energy market will require fundamental changes in directions of the energy conservation policy and program. Energy suppliers and consumers who are responsive to the movement of energy prices will assess the energy conservation policy and program in view of net financial benefit. Any policy and program that cannot guarantee net financial benefit will no longer be sustainable. In particular, the energy conservation policy and program appealing to citizens' sentiments or patriotism need to be streamlined.

With the structural reform of the energy sector, private energy companies will replace most of public energy corporations. The current public energy corporations such as Korea Electric Power Corporation, Korea Gas Corporation, and Korea District Heating Corporation have duties to plan, implement, and evaluate demand-side management programs under the Rationalization of Energy Use Act. The demand-side management program carried out by private energy companies will promote to form consumer loyalty by enhancing their company image. In general, however, it seems to be difficult for private energy companies to conduct the demand-side management program effectively. Thus, the Korea government is critically reviewing and revitalizing the present mechanism of the demand-side management program, especially focusing on the introduction of a new public surcharge on energy.

In the competitive energy market in line with the structural reform of the energy sector, we will see considerable volatility of energy prices reflecting energy market conditions at home and abroad. This volatility will add more economic risks to the decision making of energy conservation, which will act as one of barriers to energy conservation efforts. As a result, economic agents that are usually short-sighted or risk-averse will focus more on short-term energy conservation activities. As every scholar here knows, long-term views really matter to energy conservation decisions, which should take into consideration the life cycles of energy-using equipment and facilities. Thus, it may be necessary to develop a risk-sharing program among all concerned parties including energy consumers, energy service companies, and suppliers of energy-using equipment and facilities.

Ladies and Gentlemen! I have no doubt that this workshop will make a notable contribution to the improvement of energy conservation policies and programs of Korea as well as other countries. I wish all of you a great success with this workshop. Thank you very much for your time.

I. State of the Art in International Scenario Modeling & Challenges

APEC Energy demand and supply Outlook 2002 and its policy implications

Yonghun Jung, Ph.D [1]
Asia Pacific Energy Research Centre

1. Introduction

The energy sectors of APEC economies continue to change rapidly in response to income growth, population growth, resource availability, environmental concerns, changing technology and the need for regulatory reform and sector restructuring that will attract investment capital to fund supply infrastructure. This paper describes the result of the APEC energy demand and supply forecast which covers 21 member economies for the period from 1999 to 2020. These 21 member economies are aggregated into seven regional groupings, North America, Latin America, Northeast Asia, Southeast Asia, Oceania, China and Russia. Our forecast result shows that the expected economic development of the region, with annual average GDP growth at 3.5 percent along with population growth of 0.8 percent per annum is translated into increase in total primary energy demand of 2.1 percent per annum from 5,659 Mtoe in 1999 to 8,777 Mtoe in 2020 (Figure 1).

2. Outlook by Fuel Type

Over the forecast period, **oil** is projected to grow from 2,023 Mtoe in 1999 to 3,106 Mtoe in 2020, an annual growth rate of 2.1 percent. Oil is expected to maintain the highest share in total primary energy supply (TPES) of APEC at around 36 percent throughout the outlook period. The transport sector will lead oil demand growth, contributing 72 percent to incremental oil demand growth in 1999-2020.

The oil import dependency of the APEC region is forecast to increase from 36 percent in 1999 to 55 percent in 2020. For APEC economies in Asia including Oceania it will rise from an already high 60 percent in 1999 to 80 percent in 2020, most of which will be sourced from the Middle East. In other words, APEC Asia will become more vulnerable to oil supply disruptions.

The second-largest energy source in TPES is projected to be **coal**, maintaining a 27 percent share throughout the outlook period. Coal shows annual growth of 2.1 percent (1999-2020). Most of the increase in coal demand will come from power generation, accounting for 83 percent of incremental growth. By region, China is expected to continue to be a major coal consumer in the APEC region, accounting for 41 percent of TPES for coal in 2020. This is driven by coal's cost competitiveness relative to other fossil fuels, and to its availability.

Coal production in the APEC region is concentrated in the six economies with the largest reserves, Russia, USA, China, Australia, Canada and Indonesia. These six economies account for almost 99 percent of APEC's total coal reserves and production. Coal demand has increased substantially in recent years, a rise matched by increased production. However, APEC is expected to change from being a net coal exporter in 1999 to a marginal net importer of coal by 2020.

[1] Yonghun Jung: jung@aperc.ieej.or.jp

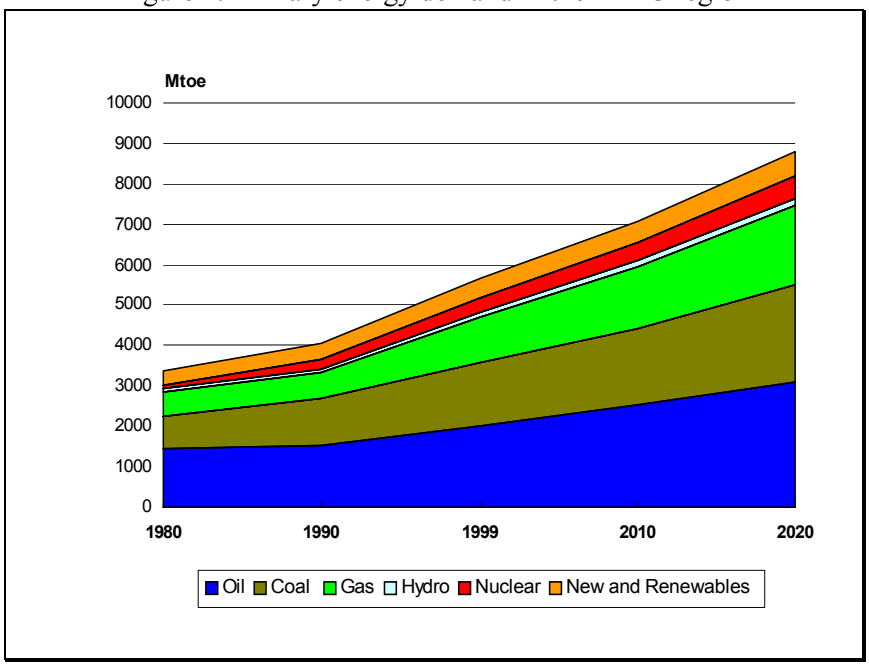
Table 1. Primary energy demand in the APEC region (1999, 2010 and 2020)

Unit: Mtoe

	Coal	Oil	Natural Gas	Hydro	Nuclear	NRE	Total
1999	1,540	2,023	1,135	106	379	478	5,659
2010	1,905	2,522	1,537	146	425	539	7,074
2020	2,402	3,106	1,951	185	537	595	8,777
Average Growth Rate (%)							
1999-2010	2.0%	2.0%	2.8%	2.9%	1.0%	1.1%	2.0%
2010-2020	2.3%	2.1%	2.4%	2.4%	2.4%	1.0%	2.2%
1999-2020	2.1%	2.1%	2.6%	2.7%	1.7%	1.1%	2.1%

(Source) History: IEA(2001), Projection: APERC(2002a)

Figure 1. Primary energy demand in the APEC region



(Source) History: IEA(2001), APERC(2002a)

Natural gas is projected to constitute the third-largest part of TPES increasing from 20 percent to 22 percent over the forecast period. In the first half of the period it will experience faster growth at 2.8 percent per annum, followed by growth of 2.4 percent yearly in the second half. The Asian region, including Northeast Asia, Southeast Asia and China, is expected to see growth in natural gas demand of 4.6 percent per year. The current share of natural gas in TPES of Asia is low at 8 percent compared with North America (24 percent), Latin America (19 percent) and Oceania (18 percent). Rising per capita income combined with ease-of-use will be the key factor in its expansion. In future, technological development and environmental concerns will have a major influence on natural gas consumption.

To meet growing demand for natural gas, massive investment in supply infrastructure is crucial – transport either by pipeline or as LNG and distribution networks for industrial and residential use.

NRE (new and renewable energy) is defined to include biomass, solar, wind, tidal and wave energy. In the APEC region, the residential sector in rural areas of less-developed regions relies heavily on biomass for cooking and heating. The current share of biomass accounts for almost all of the NRE consumed in the APEC region. Over the coming two decades, NRE is expected to grow at 1.1 percent per annum, which is lower than the annual growth rate of TPES at 2.1 percent per annum. The share of NRE is expected to fall from 8.4 percent in 1999 to 6.8 percent in 2020 due to a shift to commercial fuel sources as a result of socio-economic development.

The share of **nuclear** energy in TPES is expected to decline slightly from 6.7 percent in 1999 to 6.1 percent in 2020. In terms of growth rate, nuclear power will expand at an annual rate of 1.7 percent per year. Northeast Asia (Japan, Korea and Chinese Taipei) will contribute to 70 percent of total incremental growth of nuclear power (1999-2020) to meet the rising electricity demand. By contrast, North America will see a decline in nuclear power of 0.3 percent per annum as a result of the retirement of existing reactors.

Hydropower shows the fastest growth in TPES at 2.7 percent per annum (1999-2020), though its share is expected to be low at two percent for the entire forecast period. Endowed with the largest potential for hydropower, China will see the fastest annual growth of 6.9 percent, accounting for around 70 percent of the total incremental growth of hydropower in APEC.

3. Outlook for Electricity

Electricity generation is projected to increase by 82.4 percent, or a rate of 2.9 percent per annum, between 1999 and 2020. This is a lower growth rate than 3.2 percent per annum for final electricity demand, as transmission and distribution losses are projected to fall from 17.1 percent of generation in 1999 to 12.8 percent in 2020. China is expected to account for 30 percent of the increase in demand, with the USA accounting for 24.2 percent. Russia is projected to account for 9.9 percent of the increase and may compete with Japan as the third-largest electricity consuming economy in APEC by 2020.

Natural gas should become the fuel of choice for electricity generation, given a combination of price, thermal efficiency and environmental considerations. It increases from 373 Mtoe in 1999 to 873 Mtoe in 2020, a growth rate of 4.1 percent per annum. Its fuel share is projected to increase from 17.8 percent in 1999 to 24.8 percent in 2020, at the expense of oil and nuclear. Coal's fuel share should remain stable at just over 47 percent. In many economies it is the preferred fuel based on price and availability. It will get the largest absolute increase in input energy, increasing from 989 Mtoe in 1999 to 1,659 Mtoe in 2020.

4. Energy Security

Energy security has been one of the most important energy issues facing APEC member economies, and it will be increasingly so in the years to come. The APEC Outlook 2002 indicates that oil import dependency in the APEC region will continue to increase particularly in Asia, where most of the supply may come from the Middle East. In view of the growing demand for fossil fuels, environmental challenges are becoming an indispensable part of broadly defined energy security as well. Therefore, APEC economies look at energy security from the short and long-term perspectives. The former focuses on preventing and mitigating against interruptions of supply as a consequence of contingencies such as accidents, war or

terrorism. The latter encompasses policies and measures to enable flexible and sustainable energy supply with the minimum of environmental impacts.

5. Environmental Impact and Mitigation

Coal is forecast to remain the dominant fuel in the power generation sector, despite impressive increases in demand for natural gas. Demand for oil will remain strong in the transport sector, with increasing private car ownership in populous economies being a key driver. This expected large growth in fossil fuel consumption could have very serious environmental impacts. One of the critical factors, in this context, is the extent of acceptability of environmental impacts to both local and global communities. Increasing wealth has lead historically has led to increasing demand for clean air and water, and a general increase in environmental awareness. Over time, public pressure will accelerate the adoption and active implementation of appropriate policies, measures, and technologies by the APEC member economies to mitigate environmental impacts.

6. Investment Requirement

Increases in energy demand indicated in this Outlook will require substantial infrastructure to extract, transport and receive energy and process it into a consumable form. This requires massive investments. Governments and the private sector will need to ensure that investment and regulatory environments are equitable and transparent in order for this needed investment to be realised. Energy supply at levels demanded will not be sustainable without massive investments.

Total investment needed in energy infrastructure between 2000 and 2020 is estimated to be roughly in a range of $2.2-2.8 trillion. In annual terms, this represents a requirement of $130 billion to $170 billion.

7. Implications

Energy demand in the APEC region will increase in a robust manner for the next 20 years. Conventional energy will still maintain their dominance in the energy scene. There is a slight change in energy mix: natural gas consumption will increase faster relative to coal and oil. However their share ranking would not change.

In order to meet the growing demand, supply structure has to be built on time. To developing economies, securing adequate level of investment for the infrastructure development poses serious challenges because domestic capital formation is far from enough to finance required investment and financial markets in these economies are not well developed. In particular, bond markets are usually near insolvent or non-existent as we have observed especially after the financial fallout of the late 1990s in Asia.

Concern on energy security and environment will add more financial burden to APEC economies, which they have to shoulder in future to meet the projected energy demand.

Among all economies in the region, China is likely to tell at least one quarter of the whole energy story in the future till 2020. Any drastic changes in Chinese energy development has a potential to shake up not only the regional market, but also the world market as their share in all major conventional energies will rise substantially over the next twenty years.

Reference

APERC., 2000. Natural Gas Pipeline Development in Northeast Asia. Tokyo.
APERC., 2002a. APEC Energy Demand and Supply Outlook 2002. Tokyo.
APERC., 2002b. APERC database on infrastructure investment.
IEA., 2001. Energy Balances of OECD and Non-OECD Countries. OECD/IEA, Paris.

World Energy Outlook 2002
Using Bottom-Up Models in Global Energy Trend

Hiroyuki Kato[1]
International Energy Agency, Paris

[1] E-mail: Hiroyuki.Kato@iea.org

WORLD ENERGY OUTLOOK 2002

World Energy Outlook 2002

Major Findings and World Energy Model

Hiroyuki Kato
Economic Analysis Division, IEA
November 7, 2002

WORLD ENERGY OUTLOOK 2002

Outline

- Introduction
- Global Energy Trends
- OECD Alternative Policy Scenario
- Key Messages and Conclusion
- WEO2002 Model Description
- WEO2002 Industry Sector Model

WORLD ENERGY OUTLOOK 2002

Introduction

WORLD ENERGY OUTLOOK 2002

World Energy Outlook Series

- World Energy Outlook 1998
- World Energy Outlook - 1999 Insights: *Looking at Energy Subsidies: Getting the Prices Right*
- World Energy Outlook – 2000
- World Energy Outlook – 2001 Insights: *Assessing Today's Supplies to Fuel Tomorrow's Growth*
- World Energy Outlook – 2002
- World Energy Outlook – 2003 Insights: *Global Energy Investment Outlook* (forthcoming)

WORLD ENERGY OUTLOOK 2002

Structure of WEO2002

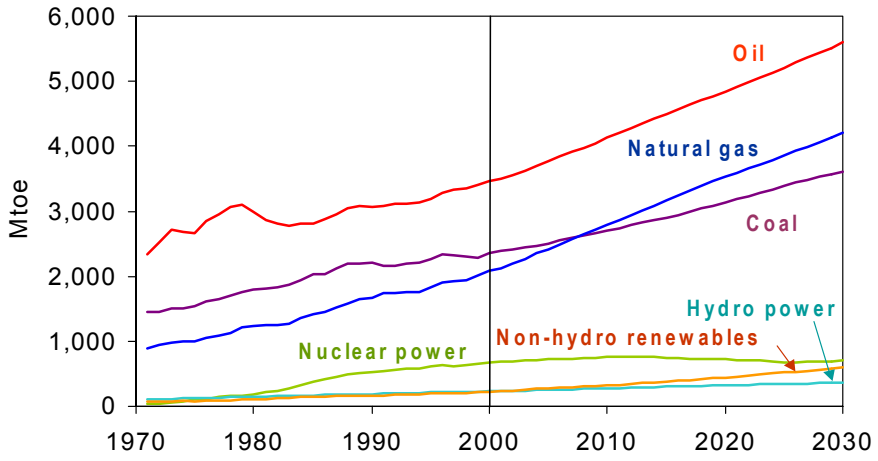
- Part A: Global Prospects
  - Analytical framework
  - Global trends
  - Outlook for each fuel
- Part B: Regional Outlooks
- Part C: Special Issues
  - OECD Alternative Policy Scenario
  - Energy & Poverty

WORLD ENERGY OUTLOOK 2002

Global Energy Trends

WORLD ENERGY OUTLOOK 2002

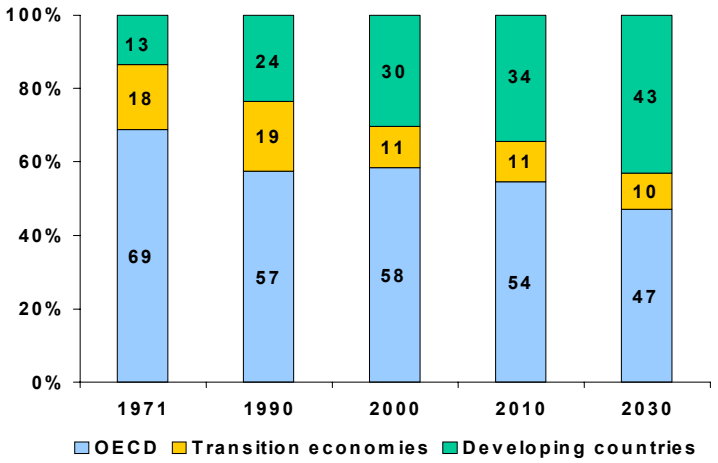
World Primary Energy Demand



Gas grows fastest in absolute terms & non-hydro renewables fastest in % terms, but oil remains the dominant fuel in 2030

WORLD ENERGY OUTLOOK 2002

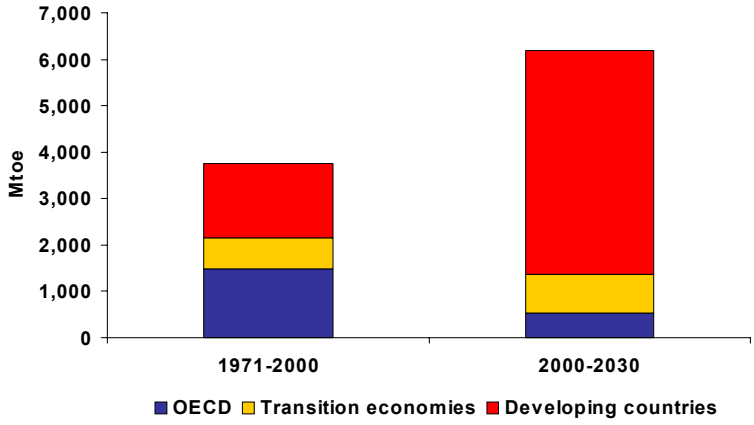
Regional Shares in World Primary Energy Demand



62% of the increase in world demand between 2000 and 2030 comes from developing countries, especially in Asia

WORLD ENERGY OUTLOOK 2002

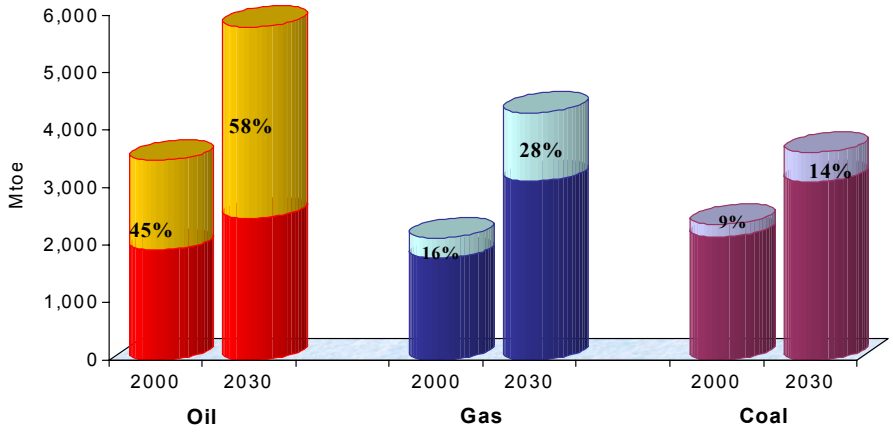
Increase in World Primary Energy Production



Almost all the increase in production occurs outside the OECD, up from 60% in 1971-2000

WORLD ENERGY OUTLOOK 2002

Share of Trade in World Fossil-Fuel Production

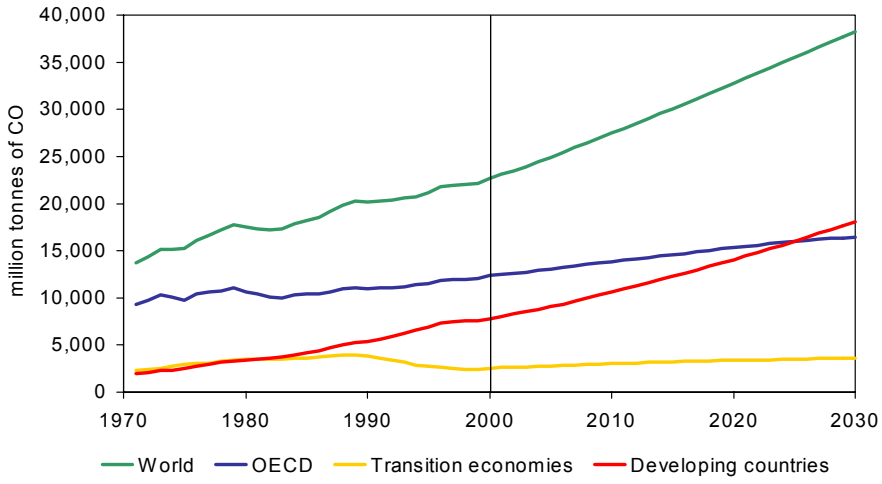


Share of inter-regional trade (%)

Energy trade between regions more than doubles between now and 2030, most of it in the form of oil

WORLD ENERGY OUTLOOK 2002

Energy-Related CO_2 Emissions



World emissions increase by 1.8 % per year to 38 billion tonnes in 2030 – 70% above 2000 levels

WORLD ENERGY OUTLOOK 2002

OECD Alternative Policy Scenario

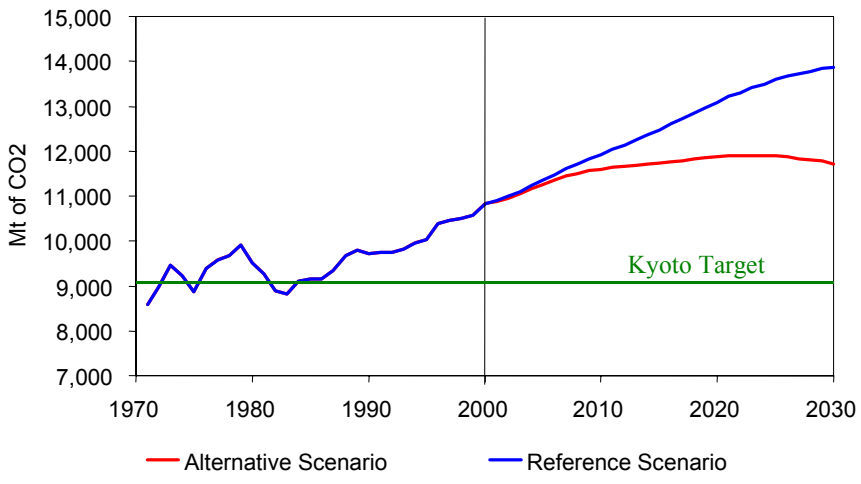
WORLD ENERGY OUTLOOK 2002

OECD Alternative Policy Scenario

- AS analyses impact of new policies & measures being considered by OECD countries on energy use & CO_2 emissions
- World Energy Model supplemented by "bottom up" models
- Explicit assumptions on pace of capital stock turnover

WORLD ENERGY OUTLOOK 2002

OECD CO_2 Emissions

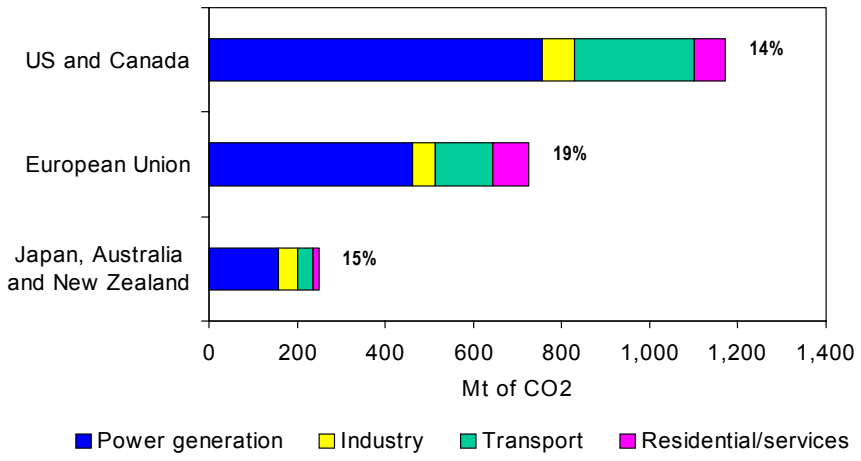


Emissions in the Alternative Scenario stabilise towards the end of the projection period

WORLD ENERGY OUTLOOK 2002

CO_2 Emission Reductions by Sector

Reduction in Emissions Compared to Reference Scenario

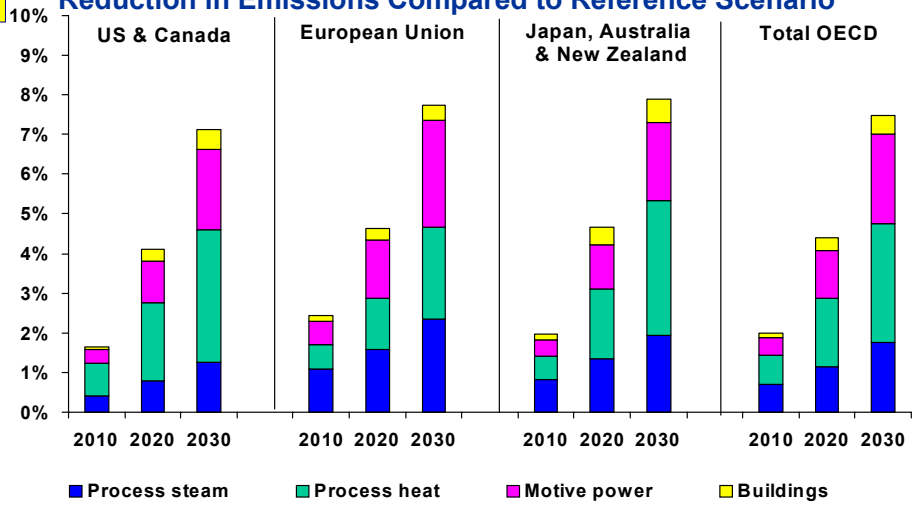


Emission reductions come mainly from power generation, because of more renewables use and electricity savings

WORLD ENERGY OUTLOOK 2002

Industrial Energy Demand in the Alternative Scenario

Reduction in Emissions Compared to Reference Scenario

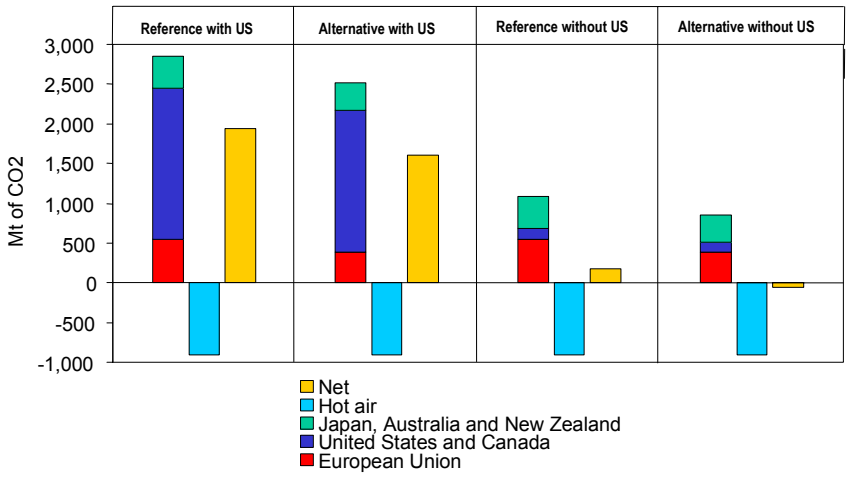


Industrial energy use will be lower by 2% in 2010 and 8% in 2030, compared to the Reference Scenario.

WORLD ENERGY OUTLOOK 2002

Bridging the Kyoto Gap

CO_2 Emissions in 2010



Emissions in each OECD region would still be above target, but "hot air" would fill the gap if the US is excluded

WORLD ENERGY OUTLOOK 2002

Key Messages & Conclusions

WORLD ENERGY OUTLOOK 2002

Central Findings of WEO 2002

- *Unless policies change*, energy demand will continue to grow steadily
- Fossil fuels will continue to dominate the energy mix
- Most of the growth in demand will come from developing countries
- Global resources are adequate to meet growing demand for at least the next 3 decades, but prices will need to rise

WORLD ENERGY OUTLOOK 2002

Implications of the WEO-2002 Projections

- The projections raise serious policy concerns:
  - security of energy supplies
  - investment in energy infrastructure
  - threat of environmental damage caused by energy use
  - uneven access of the world's population to modern energy
- Governments will have to take strenuous action if these concerns are to be addressed

WORLD ENERGY OUTLOOK 2002

WEO 2002
Model Description

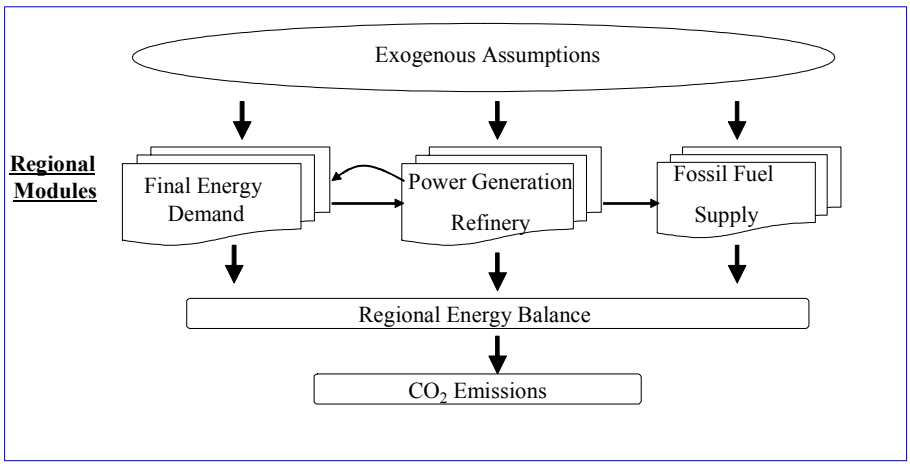
WORLD ENERGY OUTLOOK 2002

World Energy Model 2002

- Top-down model with incorporation of bottom-up approach
- 7th version
- It is to analyze:
  - Global energy prospects;
  - Environmental impacts of energy use; and
  - Effects of policy actions or technological changes
- Five main sub-modules: *final demand, power generation, refinery and other transformation, fossil fuel supply, and emission trading.*

WORLD ENERGY OUTLOOK 2002

WEM 2002 Structure



WORLD ENERGY OUTLOOK 2002

Technical Aspects

- Data sources:
  - *Energy*: IEA, NEA, IAEA, USGS, Cedigas, etc.
  - *Macroeconomic Activity and demography*: OECD, the World Bank, UN, regional development banks, international industrial organizations, etc.
  - *Technology*: IEA, NEA, USEIA, EU etc.
- The parameters of each equation are estimated econometrically, usually using data for the period 1971-2000.
- Simulations are carried out on an annual basis, and modules can be isolated for sensitivity analyses.

WORLD ENERGY OUTLOOK 2002

WEO 2002: New Developments

- 4 new country/regional models:
  - EU-15
  - South Korea
  - Mexico
  - Indonesia
- Greater sectoral disaggregation:
  - more industrial sub-sectors
  - separation of residential and services sectors
- Reconciliation of top-down & bottom-up approaches to:
  - improve accuracy of projections
  - enable policy analysis

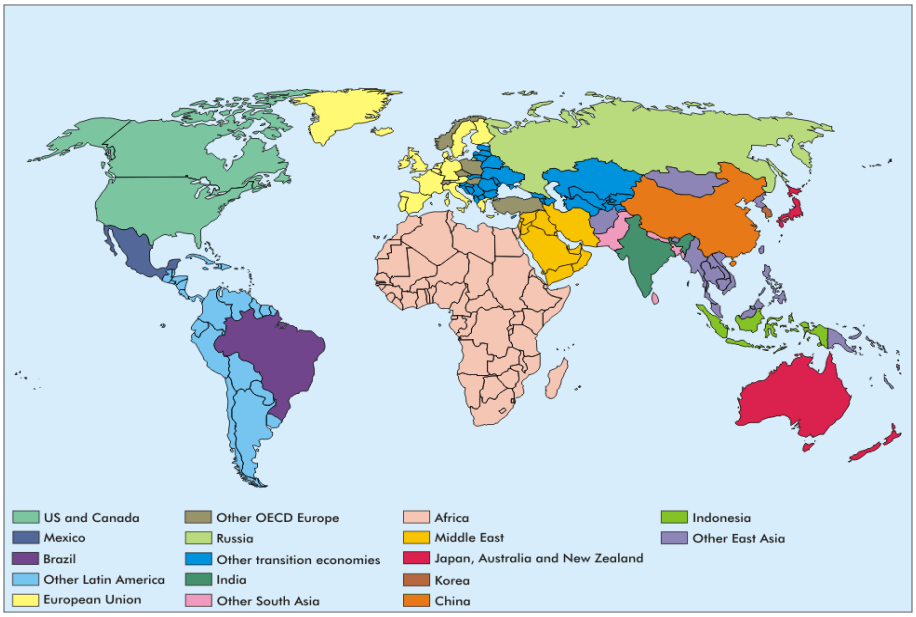
WORLD ENERGY OUTLOOK 2002

New Developments (continued)

- Power generation model:
  - more technologies considered
  - renewables modelled explicitly
  - distributed generation module added
- Refinery model added
- New software
- Time horizon extended to 2030
- Peer-review process

WORLD ENERGY OUTLOOK 2002

WEO 2002 Regions



WORLD ENERGY OUTLOOK 2002

WEO 2002
Industry Sector Model

WORLD ENERGY OUTLOOK 2002

Reference Scenario

- Six sub-sectors for OECD regions
  - Iron and steel, chemicals, non-metallic minerals, paper, food, and others
- Energy demand is projected as a function of energy intensity and output in the econometric equations.
  - Energy intensity = *f*(own and competing energy prices, previous year's level)
  - Output value = *f*(GDP, previous year's level)
- Data Sources
  - Energy consumption and prices: IEA
  - Output data series: OECD's STAN Industry Data Base

WORLD ENERGY OUTLOOK 2002

Alternative Policy Scenario

- A detailed capital stock turnover model was developed.
- Four principal end-uses in each sub-sector
  - Steam generation, process heat, machine drives, and buildings
- Policy impacts translated into:
  - Efficiency improvements of new technologies
  - Increasing penetration rate
- Other parameters affecting results:
  - Efficiency of base-year stock vintage
  - Growth in new capacity

WORLD ENERGY OUTLOOK 2002

Alternative Policy Scenario:
Steps in the Analysis

- Survey of relevant policies under discussion in OECD countries
- Estimation of policy impact on technology development
- Calculating of impact over time using a bottom-up capital stock turnover model
- Feedback of results from bottom-up policy impact analysis into WEM to calculate price and system effects

WORLD ENERGY OUTLOOK 2002

Alternative Policy Scenario:
Policies Evaluated

Policy category	End-uses impacted	Technology Impact
Regulations Standards and certification for new motor systems.	Motive power	Improved efficiency of new motor systems
Voluntary programs Expansion of existing and establishment of new ones	Process steam Process heat Motive power Buildings	Improved efficiency of new technologies and accelerated deployment
Investment enabling programs Tax incentives and loans for investment in new efficient technologies	Process steam Process heat Motive power	Accelerated deployment of new boilers, machine drives, and process heat equipment.
R&D programs Increased funding to R&D and demo programmes.	Process steam Process heat Motive power	Improved efficiency of new equipment entering the market after 2010-2015

WORLD ENERGY OUTLOOK 2002

Alternative Policy Scenario: Translation of WEM Results into Capital Stock Model

- Reference Scenario results disaggregated into four end-uses in each sub-sector
  - Steam generation, process heat, machine drives, and buildings
- Base year end-use shares
  - US and Canada: EIA
  - Japan, Australia and NZ: METI
  - EU: Misc. sources
- Projection of end-uses:
  - Steam: Assumptions on useful energy and boiler efficiencies
  - Other: Assumed base year shares of total industrial RS energy less steam demand

WORLD ENERGY OUTLOOK 2002

Alternative Policy Scenario: Calculation of Policy Impacts

- Efficiency improvements of new technologies
  - Steam: Increased thermal efficiency compared to Reference Scenario
  - Process heat and machine drives: Increased efficiency based on data from Hi-tech case from EIA-NEMS and other sources
  - Buildings: Savings based on Alternative Scenario results for commercial sector
- Increased penetration rate of new technologies
  - Faster capital stock-turnover for some types of equipment

WORLD ENERGY OUTLOOK 2002

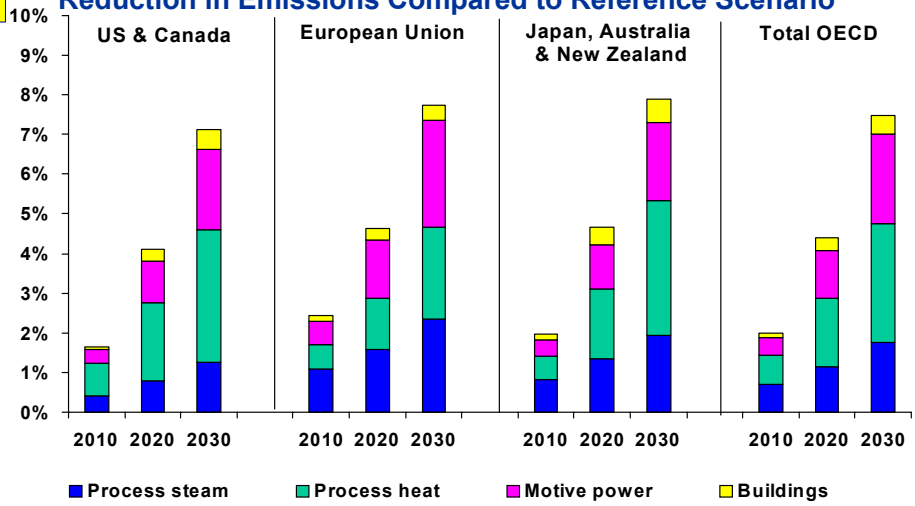
Alternative Policy Scenario:
Regional Differences

- Policy impact by region:
  - Global improvement of *new* technologies
  - Life time of equipment regional dependent
- Other parameters affecting results:
  - Efficiency of base-year stock vintage
  - Industrial growth
  - Split between end-uses

WORLD ENERGY OUTLOOK 2002

Industrial Energy Demand in the Alternative Scenario

Reduction in Emissions Compared to Reference Scenario



Industrial energy use will be lower by 2% in 2010 and 8% in 2030, compared to the Reference Scenario.

Towards Improved Policy Relevance in Engineering-Economic Analysis

Ernst Worrell[1], Lawrence Berkeley National Laboratory, USA
Stephan Ramesohl, Wuppertal Institute for Climate, Environment & Energy, Germany
Gale Boyd, Argonne National Laboratory, USA

Abstract. Historically most energy models were reasonably equipped to assess the impact of a subsidy or change in taxation. However, these tools are insufficient to assess the impact of more innovative policy instruments. In this paper we evaluate the models used to assess future industrial energy use. We explore approaches to engineering-economic analysis that could help improve the realism and policy relevance of engineering-economic modeling frameworks. We also explore solutions to strengthen the policy usefulness of engineering-economic analysis that can be built from a framework of multi-disciplinary cooperation. We focus on the so-called 'engineering-economic' (or 'bottom-up') models, as they include the amount of detail that is commonly needed to model policy scenarios. We identify research priorities for the modeling framework, technology representation in models, policy evaluation and modeling of decision-making behavior.

1. Introduction

In recent years the importance of energy policy has been demonstrated around the world. Climate change, deregulation, economic supply of energy services, other environmental challenges; all have an impact on energy policy. Energy efficiency is likely to play an important role in any future policy development. At the same time energy policy instruments are departing from the traditional instruments. New policy developments increase the need for effective tools to evaluate the impact of these policies.

Policymakers rely on scenario studies to evaluate, ex-ante, the potential effects of certain developments and policy-choices. This is frequently done using models that try to estimate the effect of the choices on e.g. energy use and economic welfare. However, all models, almost by definition, have shortcomings. One of the main shortcomings of current models is the lack of the capability to properly assess the effect of policies on energy use, especially now that policies change to non-monetary instruments. Historically most tools were reasonably equipped to assess the impact of a subsidy or change in taxation. However, these tools are insufficient to assess the impact of a voluntary program, or that of revenue recycling. Hence, a critical evaluation of the models used to assess future energy use is needed to assess the value of the scenario-results.

This paper is based on a more elaborate (forthcoming) report by the same team of authors. In the report we explore promising pathways for pursuing complementary or alternative approaches to engineering-economic analysis that could help improve the realism and policy relevance of modeling frameworks. We also explore solutions to strengthen the policy usefulness of engineering-economic analysis that can be built from a framework of multi-

[1] Corresponding author. E-mail: Eworrell@lbl.gov

disciplinary cooperation (sharing of theories, data, techniques and methods across different disciplines). To this purpose we try to address three research questions:

1. What are the (new) requirements for engineering-economic analysis posed by non-price energy and alternative regulation climate change policies?
2. What are the strengths and limitations of conventional engineering-economic approaches in addressing non-price and alternative regulation policy measures?
3. What are promising areas to focus research and model development to help accelerate improvements in the realism and policy relevance of engineering-economic analysis?

We focus on the so-called 'engineering-economic' (or 'bottom-up') models, as they include the amount of detail that is commonly needed to model policy scenarios. Kydes et al. (1995) have reviewed a number of econometric models for long-term energy modeling but have not addressed technology-rich engineering-economic models. We focus on the industrial sector, as this is one of the most challenging sectors for (policy) modeling due to its wide variety in economic, technical and policy characteristics within a single sector. We also focus on models and studies that have a limited time horizon, i.e. approximately 20 years. Although long-term models have certain advantages (e.g. effect of R&D, and stock turnover), they are less helpful for the (often) short-term interests of policy design. We use a multi-disciplinary team with a long experience in energy modeling from different perspectives. The team represents authors with a background in the economic, technical and social sciences.

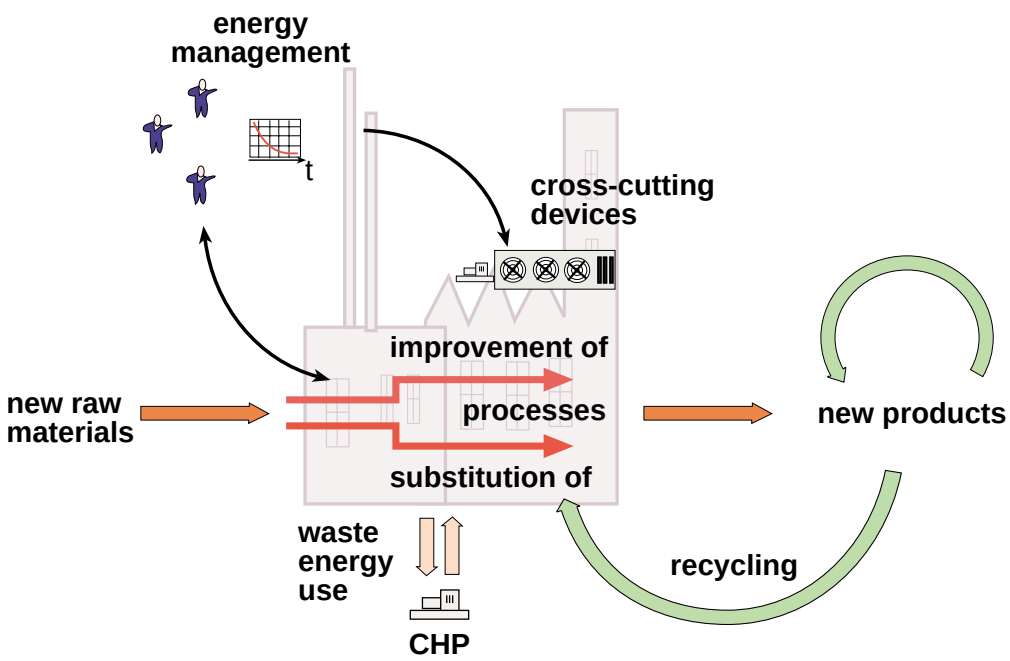


Figure 1. Different options to influence energy use in industry

2. Energy Efficiency Policy in Industry

The practical design and implementation of energy policy strategies aiming to improve energy efficiency in industry represent a demanding task. Measures have to be adopted that account for the complex technical, economical and organizational structures which distinguish industry from other end-use sectors. Taking this complexity into account, there are various options to influence energy use in industry (see also Figure 1). Important parameters include the level and nature of commercial activity in the target group; nature of inputs; supply of heat and power; state of process technology; state of cross-cutting, and; the quality of operation and maintenance.

A considerable variety of policy instruments have been created in the past decades, challenging the standard modeling approaches. On the one hand, there is an increasing number of energy/CO_2 tax schemes mainly in Europe, which provide market-based price incentives to reduce energy use in industry. However, these schemes are often combined with exemption rules or they are designed as hybrids, opening a range of possibilities for industry to mitigate the tax burden. On the other hand, during the 1990's a series of new policy instruments have been simultaneously developed that represent a changed philosophy towards policy intervention:

- First, there has been a growing acknowledgement into the complexity of cause-impact relationships in industry that impede an efficient policy intervention, especially under a situation of asymmetric information. Triggered by a new spirit of public-private-partnerships, different voluntary approaches emerged in various countries. Especially in the case of negotiated agreements, a tax break or regulatory relief is bargained in relation to the industry's commitment to achieve a certain energy efficiency or emission reduction target. Many of the voluntary schemes include (classical) supportive public policies such as financial assistance, audits and information dissemination.
- Second, there is a growing understanding of the socioeconomic dimension of industrial energy efficiency action. As any other aspect of production, energy use in industry is a result of company decision-making and corporate behavior. Acknowledging the changing demand for policy support, various non-market based instruments have been introduced to reduce the relative influence of these barriers. Hence, besides the economic aspects of decision-making, the informational, organizational and cultural dimensions gain importance as policy issues.
- Finally, considering the current energy policy practice in OECD countries it can be concluded, that in most cases policy instruments are not applied as a stand-alone option but combined within a mix, aiming at increased benefits from synergies of the particular strengths while compensating for weaknesses of individual policy instruments.
- Because of the increasing variety in policy-industry interactions and the introduction of new policy approaches there is an increased need for a sound assessment of policy impacts and program effects, effectiveness and efficiency. The methodological framework for policy analysis and modeling has to be adapted to the specific characteristics of industrial energy use as well as to the changing policy environment. Special emphasis has to be put on the analysis of impacts as the prime criterion for political effectiveness.

Some important implications for policy analysis are:

- Many of the new instruments do not result into a direct effect on energy consumption but contribute to an indirect impact that materializes gradually over time.
- Implementation processes within organizations take time and cause a delay of reaction that adds to technical restrictions resulting from vintages and investment cycles (stock turnover). A time gap can be found between the moment of policy intervention and an observed response.
- Policy measures can contribute to accelerated diffusion of energy efficiency technologies, e.g. through enhanced dissemination of know-how and experience.
- The combination of policy instruments within a portfolio opens the possibility to increase the effectiveness and efficiency of action.

3. Conventional Engineering Modeling

The role of energy modeling in decision-making and policy design has increased in recent years, especially with the debate on climate change and GHG emission mitigation. Simplistic models with limited technology representation are replaced with more complex models with more comprehensive technology representation, as well as representation of economic feedbacks. Previously, engineering-economic models focused on estimating the technical potential for cost-effective energy savings, while the currently the models are challenged to better estimate what is achievable taking into account the effect of behavioral aspects as well as policies. Policy modeling has been focused on price-based and regulatory policies, but today is challenged to include non-price policy instruments (Dowd and Newman, 1999). To this aim, the models need to build on interdisciplinary analysis of past experiences, including policy evaluations by social, economic and engineering sciences.

The so-called 'engineering-economic' (or 'bottom-up') approach is rooted in engineering principles to account for physical flows of energy and the use of capital equipment. This is coupled with economic information to account for energy expenses and investment in capital that is processed through some decision-making rules. The form of the decision-making and the way to represent the activities in "industry" are very diverse among the various modeling approaches that have been used to model industrial energy use. The approaches vary in the degree of activity representation, technology representation and technology choice (stylistic or explicit), the goal (simulation or optimization), and degree of macro-economic integration. Table 2 provides a characterization of selected models.

Table 2. Characterization of selected energy-engineering models.

Model	Country of Origin	Technology Representation	Goal of Model	Macro-Economic Integration
AMIGA	US	Explicit	Simulation	Yes
EERA	New Zealand	?	Simulation	No
EFOM	EU	Explicit	Optimization	No
ENUSIM	UK	Explicit	Simulation	No
ENPEP	US[1]	Explicit/Stylistic	Simulation	No
ICARUS	Netherlands	Explicit	Simulation	No
IKARUS	Germany	Explicit	Optimization	?
ISTUM (ITEMS)	Canada/US	Explicit	Simulation	No
LEAP	US	Explicit/ Stylistic	Simulation	No
LIEF	US	Stylistic	Simulation	No
MARKAL	OECD/IEA	Explicit	Optimization	No
MARKAL-MACRO	OECD/IEA	Explicit/ Stylistic	Optimization	Yes
NEMS	US	Stylistic	Simulation	Yes

Barriers for energy efficiency improvement are generally not captured in the models. The implementation and transfer of energy-efficient technologies and practices is often hampered by barriers that slow their market penetration. The movement towards considering these aspects contributes to the discussion of creating energy scenarios, but at the present time there is little understanding of how to translate these factors quantitatively into an analysis framework. In principle, these factors can be included in engineering-economic models, as long as they are understood and clearly quantified.

Most models have historically addressed policy through addressing the implementation costs of measures for energy efficiency improvement. The relatively simple modeling approaches

[1] The model was developed in the US but is most widely used in Eastern Europe, Central/South America, and Asia. The level of technology detail for the industrial sector varies widely.

included the effect of subsidies and energy taxes on the costs and the degree of implementation. Some models included the effect of RD&D policies through assuming 'learning-by-doing' curves for energy conversion technologies. The latter modeling approach has not yet been used for energy efficiency technologies. This also demonstrates the need for a better understanding of the effects of energy efficiency policies (Martin et al., 1998). Comprehensive evaluations of energy efficiency policies are necessary to improve modeling approaches. Especially, modeling of new policy developments like voluntary programs and non-fiscal policies remain a challenge for the energy modeling community. We are just at the beginning of modeling the contributions policies make toward improving energy efficiency (Worrell et al., 2001).

4. Challenges

In scenario construction the modeler is challenged by a number of problems in defining the basic assumptions of the model. The *choice of available technology* under BAU conditions is critical, as shown by the CEF study (IWG, 2000) as well as Roop and Dahowski (2000). In scenario studies focusing on longer-term scenarios the assumptions on technology development under future policy conditions are even more important. *Structural change* has been recognized as another major driver for change in overall industry energy intensity (Schipper et al. 2001, Farla 2000). Structural change can be separated in inter-sectoral (e.g. a change to a larger fraction of light industry in the economy) and intra-sectoral (e.g. a change in feedstocks without a substantial effect on product quality). Generally, the same structural development pattern is assumed for all policy scenarios as well, even when the modeled changes may have a profound effect on the energy system (such as long-term GHG concentration stabilization scenarios). While this makes it possible to compare the results of the policy scenarios in a systematic way, it underestimates the flexibility of economic responses to important challenges to the energy and economic systems (Jorgenson et al., 2000), and hence may lead to overestimating the costs of policy scenarios.

Modelers try to capture the *achievable potential* for energy efficiency improvement given the economic and policy assumptions for each scenario. In most engineering-economic models there is a two-stage approach to estimating the achievable potential, starting with a database of options and a selection-method, using economic criteria, to estimate the potential under different scenario conditions. However, there is a wide range of production processes that use energy in myriad ways so that end-use classifications are more complex than in other sectors. Another technical issue of great importance concerns industrial *cogeneration* (CHP): although CHP is recognized in many countries as an important energy efficiency option, and is the subject of specific policies in as many countries, we found that often the integration of CHP in the model is rather limited. Sometimes, CHP is an 'afterthought', where models first assume implementation of cost-effective end-use measures before evaluating the use of CHP. In modeling as well as in business practice emphasis has to be put on integrated approaches aiming at optimizing energy use at production sites in a holistic manner.

The selection to estimate the achievable potential, however, is often done in a simplified way using a discount rate, varying from a social discount rate (e.g. the EU study) to one that closely matches hurdle rates (e.g. CEF). The assumptions on actual *performance of existing capacity and stock turnover* are of equal importance. Some industrial technologies have long economic and technical lifetimes. Because relative large energy efficiency improvements can be achieved when existing capacity is replaced by new, the assumptions on lifetime, age distribution and turnover rate are essential. Furthermore, market *penetration* patterns of energy efficient technologies may not be as smooth as the typical S-curve may suggest. These market penetration patterns may arise from differences between potential adopter characteristics, like costs and energy savings, or as the result of exposure. A few studies start to address the learning-by-doing effects by incorporating cost-development curves for power generation equipment, (Joskow, 1985; Zimmerman, 1982; Boyd et al 2002). Speed of

adoption estimates based on diffusion models have been made for energy efficiency technologies (Harrington, 1999), but these estimates have not made much impact on engineering-economic models, nor have those estimates made substantial inroads to understanding policy impacts.

As discussed above, firm *decision-making behavior* is often incorporated in a simplified way, disregarding any differences in technology characteristics or target group features. The challenge faced by modelers is that there is limited experience and empirical data on how to translate qualitative knowledge on decision-making behavior for energy efficiency into quantitative parameters. Tied in closely to decision-making behavior is the economic evaluation of energy-efficient technologies. Most models do not include a full description of the *costs and benefits* of energy efficiency measures but rely on a limited set of economic information, excluding transaction costs, opportunity costs, as well as productivity benefits.

The ultimate challenge for all energy models remains the representation of policies and policy impacts in the scenarios. As standard engineering-economic (and econometric) models are restricted to model the likely impact of price-based policies (e.g. energy price increases, subsidies), the policy demand for modeling non-price based policies remains a challenge for energy modeling. Most important, impacts on energy-related decision-making and barrier removal need to be analyzed that underlines the importance of a sound representation of company behavior discussed above. In addition to this core topic, several other issues need to be mentioned:

- Special attention is needed for the modeling of *R&D policies* because R&D investments will likely lead to improved performance of existing and new technology and develop future technologies. Challenges are the link between (current) R&D expenditures and the speed of R&D progress and future technology availability and performance.
- *Economic feedbacks* can have an important impact on the effectiveness of energy efficiency policy, e.g. the "rebound effect" (Schipper, 2000). Most studies of the rebound effect have focused on non-industrial energy use, and show a limited impact on the achieved savings. Also, revenue recycling is a relatively new phenomenon in energy taxation and used in the new taxation schemes in Europe. Generally, models have difficulty to fully estimate the potential impacts of these economic feedbacks.
- In policy scenarios the *program costs* are often not fully considered, as data on the effectiveness and efficiency of industrial energy policies is difficult to find in the literature (Martin et al., 1998).

Finally, there are some general challenges that affect any modeling effort. Foremost of all, is the *uncertainty* in data and data quality. Although many studies mention the problems with respect to data quality, there seems to be no systematic analysis of the impact of data uncertainties on the scenario results other than for costs of the policy scenarios. This will remain a challenge for the energy analysis community and the policymaker. The problem of data quality and data use in the model is also related to the *transparency* of the model.[1] A transparent model makes it easy for the user and policymaker to evaluate and value the quality of the scenario results. On the other hand, the increasing complexity to deal with the difficult relationships between energy use, environment and economy, makes it very difficult to maintain transparency. The trade-off between transparency and complexity remains essential to the users of these studies to value the results. Typically, models focus on regions or countries, while a few integrated models include the global economy (subdivided in a varying number of regions). With the changing dynamics of energy policy the *system boundaries* of these studies may not be sufficient. For example, the opportunity of emission

[1] There is anecdotal information demonstrating how modelers themselves became the "victim" of the lack of transparency of their own models. However, this is generally not reported in the scientific literature.

trading or the clean development mechanism under the Kyoto Protocol will likely affect the costs of emission reduction for different regions, as demonstrated by many models.[1] Still, energy efficiency policy may only affect a specific region and hence the user/policy maker may only be interested in the specific country or region for the assessment.

5. Pathways to Improve Energy Models

Models have been constructed principally as forecasting tools focused on energy market questions of what quantity and type of energy will be consumed in the future. Having origins in the economics of resource depletion and having grown in substantial use after the oil price shocks of the seventies, these models have price (costs) as their principle drivers. The modeler is rarely asked to predict what policies will be in place in the future, so policy regarding energy markets that do not *directly* influence prices or costs, e.g. excise taxes or environmental controls, are incorporated as part of the status quo and are rarely explicitly represented in the models. In this section we identify and distill the directions and trends that can revalue the contribution of engineering-economic models to energy analysis in order to meet the challenges discussed above. The diversity of remaining challenges can be condensed to two complementary problems:

- approaching the complex and dynamic nature of behavior of decision makers and related transformation effects in the market systems, as well as the impact of policy on the behavior, and;
- coping with the technical diversity and complexity of the industrial production system.

With regard to both challenges, new modeling approaches can mitigate existing deficiencies of economic-engineering modeling but cannot fully overcome conceptual limitations of modeling per se. Given this perspective, models will hardly be able to fully cover all relevant aspects of industrial energy policy, and important missing parameters need to be addressed by other tools. Accordingly, policy analysis needs to be grounded on a kind of "heuristic competence" that allows it to master a cleverly composed methodological diversity (a network/cluster of ‘micro models’), rather than "celebrating a worship of bigger and better modeling" (‘mega models’). Hence, due to the inevitable restrictions models cannot stand alone but need to be explicitly embedded in a more comprehensive analytical strategy, which recognizes the strengths and weaknesses of the different tools.

Among others, two general aspects are of importance for designing such a strategy. *Sound specification of modeling tasks and system boundaries*, i.e. an appropriate choice of analytical questions in relation to the capability of a modeling tool. A sound specification of policy questions and analytical tasks together with the choice of a suitable modeling tool is needed. *Data uncertainty* is an essential element in interpreting the results of a model calculation - and data can always be improved. In certain areas it is needed to develop the statistical foundation of modeling. At the same time, however, it has to be acknowledged that perfect data sets cannot be achieved so that efforts need to be concentrated on crucial areas. Empirical work, therefore, should be directed to parameters that turned out to be of greatest relevance to sensitivity analysis in order to identify possible biases. However, it will not be possible to reduce all uncertainties (Beck, 2002), and hence, presentation of modeling results acknowledging the uncertainties is essential.

The development of new modeling approaches start with a critical assessment of the policy needs and the impacts of these needs on the modeling tools needed. A careful analysis of the policy questions raised to modelers is essential to develop the right tools. These tools include

[1] It should be noted, that often the reduction in emission mitigation costs due to (international) emission trade or other ‘flexible mechanisms’ as defined under the Kyoto Protocol, is the result of simplified or uncertain assumptions on the costs of emission reduction opportunities in the other regions.

‘micro-models’ developed to understand a specific policy- and research-question. The micro-models would be better equipped to answer specific questions, than the ‘mega-models’. The lessons learned from micro-models can be used to “re-integrate” the micro-models into larger models using modern computing and modeling techniques, such as object-oriented programming and agent-based simulation models. These techniques allow a diversity of approaches being used within a larger framework.

The consequences of an improved interface between user and modeler for modeling include:

- Playing down the importance of models as such, but instead focus on the interfaces of appropriateness, inputs, assumptions, *and* model structure. The choice of the appropriate model structure, and careful analysis of input and assumptions for the questions asked is essential.
- Less emphasis on normative approaches in terms of optimization, due to a relatively weak foundation of a strong message.
- More emphasis on a supportive role in terms of policy simulation, i.e. through quantitative assessment of impacts and interdependencies. These models would be better equipped to simulate the effects of policies and improve understanding for the policymakers.
- Improved modeling of interaction mechanisms between scenario development and technology. Policy scenarios reflect not only changes in the energy demand and supply, but also changes in the relationship with other important scenario parameters.
- A multi-disciplinary view at technology and its implementation mechanism in modeling will help to improve understanding of technology diffusion patterns, and hence of the role that policy plays in shaping energy use.
- More dynamic representation of technology with an emphasis on technological learning and side-effects of technology is an other reflection of the policy environment of the scenarios assumed.

Figure 2. Matrix of challenges, recent advances in modeling and remaining open questions. Symbols: ++ symbolizes a direct contribution; + symbolizes a potential contribution; – means a problem or possible negative effects.

New approaches from research	enhanced technological flexibility	endogenous technical learning	incorporation of material flows	enhanced economic flexibility	adaptation of discount/ hurdle rates	estimation of program costs	macro-economic integration	Integration of stochastic elements	Integration of other disciplines	***open questions and tasks***
Challenges to modelling: scenario construction and basic assumptions:										
Definition of BAU case		+	+	++					+	How much change / flexibility is already BAU?
choice of available technology	++	++	+							What is the future set of options?
representation of structural change	+		++	++			+		+	What are drivers, trends, directions, interde-pendencies?
technology and opportunity representation:										
degree of technology specification	++		++							What degree is appropriate?
Cogeneration	+		+							How to give a complete picture of business practice?
market and institutional barriers	+	+	+		+				+	How do market actors interact?
socio-economic barriers	+	+			+				++	Why, when and under what conditions is behavior changed?
assumptions on actual performance	+	+			+			+	+	Actual treatment of technologies in business practice?
market penetration patterns	+	+			+				+	How to aggregate individual adoption behavior?
Definition of costs and benefits	+	+	+	+	++				+	Nature, dimension and persistence of costs/benefits?
Representation of policies and instruments										
barrier related instruments	+	+			+	+			++	What are the impacts, synergies and persistence of effects?
R&D policies	+	++	+	+	+	+			+	What are impacts, synergies and persistence of effects
economic feedbacks		+	+	++	+	+	+		+	Role of energy efficiency as source of economic change?
Program costs		+			+	++			+	Nature, dimension and persistence of costs/benefits?
general aspects										
data uncertainty	+		-		-	+		+		Scope and limits for better data?
Transparency	-	-	-	-	-					Trade-off between accuracy, complexity and simplification?
system boundaries	-		-				+			Appropriate choice of questions and tools?
open issues	treatment of technical complexity	learning with EE technologies	modeling material flows		representing economic behaviour	Evaluation methodology			transfer of knowledge	

Improving Models: Technology and Opportunity Representation. To make better use of the technical diversity in industrial production models a suggested research agenda would be:

- Conducting empirical and quantitative studies that investigate technical and economic aspects and provide data to improve modeling assumptions but that cannot be integrated directly into modeling (including negative cost options). As a major benefit, the work will improve the underlying competence of estimating model parameters more realistically;
- Including technological learning effects on the performance, costs and diffusion of industrial energy (end-use and conversion) technologies;
- Using detailed modeling of production functions (either in physical or economic terms) to study the role of structural change within the economy, including economic flexibility to respond to policy challenges;
- Detailed understanding of the assumptions in the reference scenario.

Current advances in research that hold particular promise in this research area include (see Figure 2), incorporation of material flows, enhanced economic flexibility, and inclusion of learning effects in models. In addition, endogenous technical learning and integration of stochastic elements have potential contributions.

Improving Models: Behavioral Representation. With regard to the behavior of decision makers and the development of markets, more insights are needed in the following fields:

- Qualitative and quantitative studies on decision behavior and the socio-cultural background which determines the effectiveness of instruments, providing the basis for modeling assumptions;
- Improved understanding of technology diffusion and penetration patterns, as a function of firm behavior.

Current advances in research to improve the understanding of decision-making behavior in firms, and modeling thereof, adaptation of discount rates/ hurdle rates, analysis of technology diffusion patterns, evaluation of energy-efficiency and other policies on technology diffusion, evaluation on effectiveness and efficiency of energy policies, as well as estimating program costs contribute to this pathway.

Improving Models: Policy Representation. A sufficient representation of policies and instruments demands a proper definition of policy instruments and a sound analysis of real world implementation features (i.e. likely degree of implementation and administrative deficiencies, free riders, interrelations with other policies, etc.). More precisely, this means realistic representation of the practice of implementation, representation of non-energy policy background in scenario definition, assessment of policy mixes, determining the policy and program effects, and including program costs.

6. Conclusions & Recommendations

The development of a uniform but public **modeling framework** to integrate existing and future modules/models would be a major step forward. Similar to an open software development environment, it would allow for innovation in different parts (e.g. policy modeling) of the total model, and allow easy integration in existing models. We propose to base this framework on object-oriented programming/modeling. Object oriented programming allows transparency and at the same time flexibility in modeling approaches. This would allow researchers to focus on a selected part of the larger model, without the need to construct a total model. It would ease the communication of different modelers from various backgrounds, and help to focus modelers to focus on their strengths, and reduce

weaknesses of an overall model. Research should determine a common structure and the information needed to facilitate communication between the 'objects'.

Technology representation has shown to be a key area, in which short-term efforts can make an important impact. Technology representation in modeling has to focus on two main items, firstly, the technical description of the technology/measure, and, secondly, the relationship between technology and the implementation trajectory. The technical description of a technology should appropriately reflect the full nature and the dynamics of the technology. Researchers should include the non-energy benefits in the quantitative description of a technology. Research in the learning effect of energy-efficient end-use technologies is needed to accurately reflect the dynamics of technology development in energy models. Finally, the level of disaggregation (or number of technologies) will depend on the purpose of the modeling effort. A drive towards models relevant for policymakers will increase the need to include more technologies, rather than fewer. Research should aim to improve the understanding of the diffusion of technologies, so to better link technologies to a specific decision-making/implementation trajectory. Current models apply a similar diffusion model to most energy-efficient technologies. In reality, other benefits than energy may drive implementation. This is linked to a proper quantification of the non-energy benefits, but is also linked to other non-energy related regulation that may affect implementation of a specific technology. The improved understanding should lead to categories or groups of technologies with specific characteristics allowing improved modeling of technology diffusion.

To allow improved modeling of policies and its effects on technology diffusion and behavior we need a better understanding of technology diffusion and of the effectiveness and efficiency of policy instruments, through **policy evaluation**. However, full policy evaluations are rare in the field of industrial energy policy. Research should aim at innovative ways to study the effectiveness and efficiency of policies. Innovative ways are needed to translate the impact of policies on the micro (or firm)-level to macro-levels on the technology diffusion process. Especially important is the need to account for synergies or unintended consequences of energy policy mixes, or non-energy policy. This research item is also a plea to policymakers to include policy evaluation in the development of new policies as an integral part of that policy.

New **modeling approaches for the decision-making framework** and process are needed, which can be used in the economic-engineering models. These approaches need to be able to include barrier representation (e.g. lack of information), decision-making behavior, as well as the effect of policies (see above) on decision-making. Especially the impact of non-monetary policies and policies aiming to reduce certain barriers are important areas that are in need of innovative modeling techniques. Such modeling approaches need to be translated from the behavior of individual firms to the larger model. Innovative economic research may offer different potentially successful approaches, such as multi-agent modeling and other approaches. The contributions of social sciences in the debate on firm behavior (e.g. corporate culture) need to be included to come to successful modeling approaches.

Acknowledgements. This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. This paper does not reflect the opinion of the U.S. Department of Energy or any other U.S. government agency.

7. References

Beck, M.B. (editor), 2002. Environmental Foresight and Models; A Manifesto. Elsevier, Amsterdam/New York, 2002, 473 pages.

Boyd, G.A., J.C. Molburg, and J.D. Cavallo, Estimates of Learning by Doing in Gas Turbine Electric Power Systems. *Energy Studies Review*. Forthcoming

Dowd, J. and J. Newman. 1999. *Challenges and Opportunities for Advancing Engineering-Economic Policy Analysis. Highlights of the IEA International Workshop on Technologies to Reduce Greenhouse Gas Emissions: Engineering-Economic Analyses of Conserved Energy and Carbon, 5 – 7 May 1999, Washington,, DC.* http://www.iea.org/workshop/engecon.

Harrington, W., R. Kopp, et al. (1999). *Public Policy, Technology Adoption, and Aggregate Energy Efficiency*. Washington DC, working paper Resources for the Future.

Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies. 2000. *Scenarios for a Clean Energy Future*. Oak Ridge National Laboratory/Lawrence Berkeley National Laboratory, Oak Ridge, TN / Berkeley, CA.

Jorgenson, D.W., R.J. Goettle, P.J. Wilcoxen and M.S. Ho. 2000. *The Role of Substitution in Understanding the Costs of Climate Change Policy*. Pew Center for Global Climate Change, Washington, DC.

Joskow, P. L. and N. L. Rose. 1985. The Effects of Technology Change, Experience, and Environmental Regulation on the Construction Cost of Coal-burning Generating Units." *Rand Journal of Economics* 1 **16** pp.1-26.

Kydes, A.S., S.H. Shaw and D.F. McDonald. 1995. Beyond the Horizon: Recent Directions in Long-Term Energy Modeling. *Energy* 2 **20** pp.131-149.

Martin, N., E. Worrell, A. Sandoval, J-W. Bode, and D. Phylipsen. 1998. *Industrial Energy Efficiency Policies: Understanding Success and Failure, proceedings of a workshop organized by the International Network for Energy Demand Analysis in the Industrial Sector*, Lawrence Berkeley National Laboratory, Berkeley, CA.

Roop JM and Dahowski RT. 2000. Comparison of Bottom-Up and Top-Down Forecasts: Vision Industry Forecasts with ITEMS and NEMS. *Proceedings 22nd National Industrial Energy Technology Conference*, Houston, TX, April 5-6, 2000.

Schipper, L. 2000. (Ed.) On the Rebound: The Interaction of Energy Efficiency, Energy Use and Economic Activity. *Energy Policy* 6-7 **28** pp.351-501

Worrell, E., L. Price and M. Ruth. 2001. Policy Modeling for Energy Efficiency Improvement in US Industry. *Annual Review of Energy and the Environment* **26** pp.117-143.

Zimmerman, M. (1982). Learning Effects and the Commercialization of New Energy Technologies: The Case of Nuclear Power. Bell Journal of Economics **13**(Autumn): 297-310.

II. Opportunity Assessment

Energy Efficiency Improvements in the Korean Manufacturing Sector

Hi-chun Park[1]
Inha University, Inchon, Korea

Abstract
This study applies physical energy efficiency indicators to assess energy efficiency improvements in the Korean manufacturing sector in the period 1992 to 2000. As expected, iron & steel, cement, petrochemical and pulp & paper industries recorded energy efficiency improvements. Furthermore, iron & steel, cement and paper & pulp industries in Korea became less energy intensive. As the energy efficiency improvement together with the production structure improvement could not compensate the production growth, the energy consumption of the Korean manufacturing sector grew very fast. Ultimately, the energy service demand growth should be drastically reduced. Energy conservation policies alone cannot cope with growing demand for energy in the manufacturing sector. There is a need for restructuring in energy intensive subsectors.

1. Introduction

In the energy conservation and GHG emission reduction policies, it is very important to know exactly whether there have been energy efficiency improvements and to what extent the energy efficiency can be improved in the future. Although substantial efforts have been made to improve the energy efficiency in the Korean manufacturing sector, studies using economic energy efficiency indicators (energy intensity method) show that the energy intensities of most manufacturing subsectors increased (energy efficiency deteriorated) in the 1990s.

First, this study discusses the question whether an increase in the energy intensity (energy/ value added production ratio) would mean a deterioration of energy efficiency and the question why the energy intensities increased (energy efficiency deteriorated) from 1992 to 2000.

Then, this study applies apart from economic energy efficiency indicators physical energy efficiency indicators as to answer the question whether there have been energy efficiency improvements in energy intensive manufacturing subsectors which were responsible for about 75 percent of the manufacturing sector's energy consumption in 2000.

[1] E-mail: hi-chun.park@inha.ac.kr

2. Energy consumption and efficiency

2.1 Energy consumption

The primary energy consumption of the manufacturing sector grew yearly by 6.7 percent on average in the period 1992 to 2000, as shown in Table 1. This growth rate was very high in the light of the Asian economic crisis of 1997, which lead to a drastic economic downturn until 1999. Indeed, the manufacturing sector's primary energy consumption increased at an annual rate of 10.2 percent from 56.9 Mtoe in 1992 to 92.3 Mtoe in 1997. In contrast, Korea's manufacturing sector grew yearly at 8.4 percent on average from Won 85.316 trillion in 1992 to Won 163.014 trillion in 2000, faster than the primary energy consumption. As a result, the income elasticity of energy consumption was with 0.798 much lower than 1. This was possible, because the share of the energy intensive industries like paper & pulp, petrochemicals, pottery (cement) and basic metal (iron & steel) in the production of value added decreased from 42.4 percent in 1992 to 33.3 percent in 2000, while the share of the less energy intensive 'fabricated metal products and machinery' (automobiles, electronics, telecommunications etc.) increased from 32.1 percent in 1992 to 54.3 percent in 2000.

Table 1. Production and primary energy consumption by subsector

(Unit: Won trillion, Mtoe, %)

	Value added production			Primary energy consumption		
	1992	2000	Average growth	1992	2000	Average growth
1. Food & beverage	10.690 (12.5)	12.637 (7.8)	2.1	2.226 (3.9)	2.620 (2.8)	2.1
2. Textiles	9.942 (11.7)	6.657 (4.1)	-4.9	4.166 (7.4)	6.064 (6.4)	4.8
3. Wood products	1.002 (1.2)	0.786 (0.5)	-3.0	0.266 (0.5)	0.370 (0.4)	4.2
4. Paper & pulp	4.365 (5.1)	5.181 (3.2)	2.2	2.257 (4.0)	3.493 (3.7)	5.6
5. Petrochemicals	16.722 (19.6)	28.848 (17.7)	7.1	21.049 (37.3)	40.052[3)] (42.3)	8.4
6. Pottery	4.302 (5.0)	4.618 (2.8)	0.9	6.276 (11.1)	7.110 (7.5)	1.6
7. Basic metal	10.865 (12.7)	15.755 (9.7)	4.8	13.726 (24.3)	20.714 (21.9)	5.3
8. Fabricated metal products & machinery	27.429 (32.1)	88.533 (54.3)	15.8	4.789 (8.5)	10.519 (11.1)	10.3
9. Other manufacturing	2.557 (3.0)	1.904 (1.2)	-3.6	1.678 (3.0)	3.736 (3.9)	10.5
Manufacturing	85.316 (100.0)	163.014 (100.0)	8.4	56.432 (100.0)	94.660 (100.0)	6.7
Country's total	303.384	478.533	5.9	116.010	192.439	6.5
Manufacturing/total	(28.1)	(34.1)		(48.6)	(49.2)	

Sources: KEEI and BOK.

Notes: 1) Figures in parentheses are shares.

2) Value added productions are at 1995 prices.

3) This includes naphtha consumption of 19.511 Mt or 22.086 Mtoe as feedstock for 2000, for instance.

The manufacturing sector's share in the country's primary energy consumption was very high

with 49.2 percent in 2000. As shown in Table 2, such a share is the largest among the OECD countries.[1] Large investments were made in energy intensive industries such as petrochemical, iron and steel, and cement industries. For instance, the production capacity of ethylene, major petrochemical feedstock, increased from 0.505 Mt (million tons) in 1988 to 5.150 Mt in 2000. Indeed, Korea's manufacturing sector is very energy intensive. Korea's iron and steel industry ranks fourth and Korea's petrochemical industry measured in ethylene production ranks sixth in the world.

Four energy-intensive manufacturing subsectors, paper & pulp, petrochemicals, pottery and basic metal, consumed 43.308 Mtoe (76.7 percent of the manufacturing sector's total) in 1992 and 71.174 Mtoe (75.4 percent).[2]

Table 2. Final energy consumption by sector in comparison, 1999

	Korea	France	Germany	Japan	UK
Industrial[1)]	54.89 (43.9)	46.58 (27.4)	69.99 (29.2)	134.85 (39.4)	41.71 (26.1)
Transport	27.70 (22.2)	51.79 (30.5)	68.29 (28.5)	93.64 (27.4)	51.57 (32.3)
Commercial	18.72 (15.0)	22.42 (13.2)	23.57 (9.8)	43.83 (12.8)	16.74 (10.5)
Residential	13.58 (10.9)	39.76 (23.4)	63.51 (26.5)	49.63 (14.5)	42.42 (26.5)
Others	10.15 (8.1)	9.19 (5.4)	14.38 (6.0)	20.04 (5.9)	7.35 (4.6)
Total	125.04	169.74	239.74	341.99	159.79
Per capita[2)] industrial	1.171	0.773	0.853	1.064	0.701

Source: IEA (2001), *Energy Balances of OECD Countries 1998-1999*.
Notes: 1) Final energy consumption in Mtoe.
2) per capital final energy consumption in toe.

The heavy industrialization has been the result of low energy price policies for the industry. This has been especially the case for the electricity tariffs. As shown in Table 3, the residential and commercial sectors paid in 2001 Won 112.55 and Won 108.70 per kWh respectively, while the industry sector paid only Won 60.80 per kWh. As the costs for generation, distribution and administration of KEPCO were Won 73.56 per kWh in 2001, large cross-subsidies (additional payments as stated in Table 3) took place from the residential and commercial sectors to the industry sector.

[1] Final energy consumption data is used for a comparison purpose.
[2] According to a recent study, the Korean petrochemical industry used naphtha in the amount of 19.511 Mt or 22.086 Mtoe as feedstock (naphtha consumption less external backflows to the refinery and internal backflows (fuel use in the petrochemical process). H. Park (2002).

Table 3. Average electricity tariffs and additional payments for 2001

	Power consumption	Average tariffs	Additional payments
Unit	TWh	Won/kWh	Won billion
Residential	39.67	112.55	1,146.7
Commercial	50.78	108.70	1,784.4
Industrial	143.34	60.80	-1,829.0
Night electricity	9.95	24.05	-492.6

Source: Information is provided by MOCIE.
Note: Additional payments mean cross-subsidies. Plus (+) and minus (-) payments mean cross-subsidies paid and received respectively.

2.2 Energy Intensity

Table 4 shows the trend of energy intensities of the manufacturing subsectors in the period 1992 to 2000.[1] The energy intensity increased from 0.661 (toe/Won million) in 1992 to 0.732 in 1997, but decreased to 0.581 in 2000. It seems that relatively low energy prices in early 1990s caused the increase in energy intensity in the first period 1992 to 1997. But a substantial fall in the energy intensity of the fabricated manufacturing products and machinery subsector from 0.202 in 1997 to 0.119 in 2000 was responsible for the manufacturing sector from 0.661 in 1992 and 0.732 in 1997 to 0.581 in 2000. Other subsectors excluding the food & beverage subsector recorded an increase in the energy intensity. Restructuring of overinvested energy intensive industries in the aftermath of the Asian economic crisis in 1997 resulted probably in the decrease in the energy intensity in the second period 1997 to 2000, too.

Table 4. Energy intensity trend by manufacturing subsector

	1992	1997	2000	Change in energy intensity, 1992-2000 (%)
1. Food & beverage	0.208	0.237	0.207	-0.4
2. Textiles	0.419	0.742	0.908	116.7
3. Wood products	0.266	0.500	0.471	77.4
4. Paper & pulp	0.517	0.636	0.674	30.4
5. Petrochemicals	1.259	1.378	1.388	10.3
6. Pottery	1.459	1.691	1.540	5.5
7. Basic metal	1.263	1.249	1.315	4.1
8. Fabricated metal products	0.175	0.202	0.119	-31.9
9. Other manufacturing	0.657	1.902	1.962	198.9
Manufacturing	0.661	0.732	0.581	-12.2

Source: same as Table 1.
Note: Energy intensity is calculated as primary energy consumption per Won million at 1995 prices.

However, it is rather difficult to accept the outcome of this analysis that the energy intensities

[1] The energy intensity is defined as energy consumption per production in monetary terms, while the term specific energy consumption (*SEC*) is used for energy consumption per production in physical terms.

of four energy intensive industries like paper & pulp, petrochemicals, pottery and base metal increased (deteriorated) in the period in discussion, as substantial energy conservation investments were made in the energy intensive industries. This poses the question whether such deterioration does mean energy efficiency deterioration in the manufacturing subsectors considered.

2.3 Energy intensity and energy efficiency

Energy efficiency is often related to energy intensity (energy consumption per production in monetary terms) or to specific energy consumption *SEC* (energy consumption per physical production). Lower energy intensity means higher energy efficiency. Thus, energy efficiency (energy service per energy consumption) can be defined as the reverse of energy intensity. This holds for the energy efficiency of an operation or a product, but not for that of an economic sector or a manufacturing subsector. This is because the change in the energy intensity is influenced apart from the energy efficiency by the production structure.

For instance, the energy intensity can increase (deteriorate) despite of energy efficiency improvements, if the share of an energy intensive manufacturing subsector rises. At the same time, the energy intensity can decrease (improve) despite of energy efficiency deterioration, if the share of less energy intensive manufacturing subsector rises. As a result, the simple energy intensity is not a good indicator for energy efficiency. To single out the energy efficiency effect, energy efficiency indicators (decomposition analyses) are often applied. Such indicators decompose the change in the energy consumption in production, structural and efficiency effects or the change in the energy intensity in structural and efficiency effects.

Thus, the decrease in the energy intensity of the manufacturing sector in the period 1992 to 2000 does not necessarily mean energy efficiency improvement. At the same time, the increase in the energy intensity of energy intensive subsectors in the same period does not necessarily mean energy efficiency deterioration in the subsectors in discussion. The following chapter will use energy efficiency indicators to see whether there was an energy efficiency improvement in the manufacturing sector in the period 1992 to 2000.

3. Energy efficiency indicators

3.1 Economic energy efficiency indicators

To single out the energy efficiency effect from the change in the energy consumption of the manufacturing sector (ΔE) from 1992 ($t=o$) to 2000 ($t=n$) the following equation is used:[1]

$$\Delta E = (An - Ao)\Sigma Sio\ Iio + Ao\Sigma(Iin - Iio)\ Sio + Ao\Sigma(Sin - Sio)\ Iio + \text{residuals} \qquad (1)$$

(production effect) (efficiency effect) (structure effect)

where

Et : Manufactruring sector's energy consumption in period t

At : Manufacturing sector's value added production in constant prices in t

Eit : ith subsector's energy consumption in t

Ait : ith subsector's value added production in constant prices in t

It : $\frac{Eit}{Ait}$, energy intensity of ith subsector

Sit : $\frac{Ait}{At}$, structural parameter

A minus (-) and a plus (+) sign of the second factor of the right side of equation (1) mean

[1] H. Park (1998 I), pp. 140-142.

energy efficiency improvement and energy efficiency deterioration respectively. A minus (-) sign of the third factor of the right side of equation (1) means a change of the manufacturing sector towards less energy intensive structure, while a plus (+) sign indicates a change towards more energy intensive structure.

Table 5. Decomposition results of the energy consumption of the manufacturing sector (1992-2000)

		Effects in Mtoe	
1. Production effect			51.394 (134.4)
2. Energy efficiency effect			10.628 (27.8)
3. Production structure effect			-10.393 (-27.2)
4. Residuals	a. Production - Efficiency b. Production - Structure c. Efficiency - Structure d. Production - Efficiency - Structure	9.679 -9.465 -7.125 -6.489	-13.401 (-35.1)
5. Total (change in energy consumption			38.228 (100)

Notes: - Figures in parentheses are shares of effects of the change in the energy consumption.
- Plus (+) signs mean increases in the energy consumption and minus (-) mean decreases in the energy consumption.
- Energy consumptions are in primary energy terms.

Source: - Same as Table 1.

The result of the decomposition analysis according to equation (1) shows in Table 5 that there was energy efficiency deterioration in the period under investigation. This resulted in an energy consumption increase of 10.628 Mtoe (27.8 percent of the energy consumption increase of the manufacturing sector from 1992 to 2000). However, the manufacturing sector's production structure became less energy intensive due to a big increase of the less energy intensive fabricated metal products and machinery subsector, as discussed earlier. This is responsible for an energy consumption decrease of 10.393 Mtoe (27.2 percent). The positive (meaning minus sign) production structure effect together with large positive residuals was responsible for the fact than the energy consumption grew slower than the value added production.

Economic energy efficiency indicators (derived from the energy intensity) are useful for comparing subsectors with each other and for adding up subsectors. However, the classification of the manufacturing sector in nine subsectors is too aggregated to identify accurately energy efficiency improvement (deterioration). In the iron & steel subsector, for instance, there are more energy intensive basic oxygen furnace (BOF) and less energy intensive electric arc furnace (EAF) processes. A BOF process and an EAF process require for the production of one ton of steel about 15.3 GJ and 5.4 GJ respectively. Thus, the energy efficiency of the steel subsector will depend not only on the efficiency of the individual processes but also on the production structure of the subsector. The higher share of the BOF steel the lower energy efficiency of the steel subsector.

Therefore, there is a need to remove the intra-subsectoral (for instance, within the steel subsector) production structure effect from the change in the energy intensity. On top of this,

GDP (value added) is not a good indicator to relate with the energy consumption, which arises from production and distribution of goods and services, living and personal transportation. GDP is the sum of investment, consumption and net exports. As such, GDP is not directly related with the energy consumption in the personal transportation and residential sectors. Thus, physical energy efficiency indicators will be used in the following section.

3.2 Physical energy efficiency indicators

There are two kinds of physical energy efficiency indicators. These are derived all from the so-called 'adjusted specific energy consumption'.

First, an 'adjusted specific energy consumption' $SEC_{adjusted}$ singles out the structure effect from the change in the specific energy consumption. The adjusted *SEC* is derived from the simple *SEC,* which is defined as

$$SEC_{simple} = \frac{E}{P} \qquad (2)$$

SEC_{simple}: simple specific energy consumption
E : energy consumption (toe, J)
P : production (ton)

The energy consumption *E* in the numerator can be expressed in mechanical energy like Joule or thermal energy like Gcal and toe. It does not matter much, what kinds of energy are used for the production. But in the case of electric and oxygen steel, clinker and cement, and paper and pulp, the physical production *P* in the denominator cannot be added, as their energy requirement to produce are quite different. Therefore, it is advisable to replace *P* by so-called physical production index *PPI* (Farla et al., 1997a, pp. 5-6).

$$PPI = \Sigma\ (P_i * SEC_i) \qquad (3)$$

P_i : production by process *i* or product *i*
SEC_i: specific energy consumption by process *i* or product *i* in a single year

PPI is the sum of major products or processes weighted with *SEC* of products or processes. *PPI* decreases, if the share of relatively less energy intensive electric steel production rises. And it increases, if the share of relatively more energy intensive oxygen steel production rises. For instance, by assuming the energy consumption per ton of electric and oxygen steel as 5 GJ/t and 15 GJ/t respectively, the production of 3 tons electric steel equals to the production of 1 ton oxygen steel in energy consumption terms. *PPI* can easily be calculated, if *SEC* of products or processes for a single year or of best practice are known.

An adjusted *SEC* can be formed replacing *P* by *PPI* in equation (2).

$$SEC_{adjusted} = \frac{E}{PPI} \qquad (4)$$

The adjusted *SEC* calculated by removing structural effects is capable to analyze energy efficiency changes.

Second, the change in the energy consumption of a manufacturing subsector can be decomposed in production, structure and energy efficiency effects by using the following equation:

$$\Sigma\ E = \Sigma\ P * \frac{PPI}{\sum P} * \frac{\sum E}{PPI} \qquad (5)$$

$\Sigma\ P$: Physical production in ton
PPI : Physical production index

The second factor $\frac{PPI}{\sum P}$ of the right side of the equation (5) means a structure effect. Increasing *PPI* results in higher fraction and thus more energy intensive production structure. The third factor $\frac{\sum E}{PPI}$ of the right side of equation (5) represents an energy efficiency effect. Increasing *PPI* results in higher energy efficiency.

By decomposing the differential of equation (5):

$$\Delta E = \Delta E\ (Production) + \Delta E\ (Structure) + \Delta E\ (Efficiency) + residuals \qquad (6)$$

A simple average parametric Divisia method 2 (AVE-PDM2) is used as to minimize the residuals.[1]

a. Production effect:

$$\Delta E\ (Production) = (P_1 - P_0) * (\frac{PPI_1}{P_1} + \frac{PPI_0}{P_0}) * (\frac{E_1}{PPI_1} + \frac{E_0}{PPI_0}) / 4^2 \qquad (7)$$

b. Production structure effect:

$$\Delta E\ (Structure) = (P_1 + P_0) * (\frac{PPI_1}{P_1} - \frac{PPI_0}{P_0}) * (\frac{E_1}{PPI_1} + \frac{E_0}{PPI_0}) / 4 \qquad (8)$$

c. Energy efficiency effect

$$\Delta E\ (Efficiency) = (P_1 + P_0) * (\frac{PPI_1}{P_1} + \frac{PPI_0}{P_0}) * (\frac{E_1}{PPI_1} - \frac{E_0}{PPI_0}) / 4 \qquad (9)$$

At the given data availability the physical energy efficiency indicators (*SEC* method) enables to analyze the energy efficiency improvements at the subsectoral level like at the level of iron & steel industry.

4. Energy efficiency improvements in four manufacturing subsectors

The physical energy indicators of four energy intensive industries, paper & pulp, petrochemicals, pottery (cement) and basic metal (iron & steel) are assessed. These industries consumed 54.4 million toe or 75.4 percent of the energy consumption of the manufacturing sector and 28.2 percent of Korea's primary energy consumption in 2000.

4.1 Iron and steel

Table 6 shows that the crude steel production grew at 53.7 percent from 28.055 Mt in 1992 to 43.107 Mt in 2000. At the same time period, the energy consumption increased only at 40.7 percent from 532.4 PJ to 748.9 PJ. As a result, the simple SEC decreased at 8.7 percent in 8 years. But this decrease was due to the increased of the production of less energy intensive electric steel at 177.8 percent. The share of electric steel in the crude steel production rose from 30.2 percent in 1992 to 42.8 percent in 2000. As PPI grew at 43.1 percent less than the crude steel production in the same period, the adjusted *SEC* decreased only at 1.3 percent. Thus, the energy efficiency improvements were marginal in the iron and steel industry.

[1] Ang (1999), pp. 1081 –1095.
[2] The right side of the equation is divided by 4 in order to have the average of the last two factors.

Table 6. Specific energy consumption in the steel industry

	Reference *SEC* GJ/ton	Unit	1992(A)	2000(B)	(B-A)/A %
Oxygen steel (1)	15.3	Mt	19.587 (69.8)	24.666 (57.2)	25.9
Electric steel (2)	5.4	Mt	8.467 (30.2)	18.441 (42.8)	177.8
Crude steel production (1+2)		Mt	28.055 (100)	43.107 (100)	53.7
Hot rolled products	2.9	Mt	26.419	39.537	49.7
Cold rolled products	3.8	Mt	6.841	14.256	108.4
Specialty steel	4.9	Mt	2.584	5.394	108.7
PPI			469.6	672.2	43.1
Energy consumption		PJ	532.4	748.9	40.7
SEC_{simple}			18.978	17.320	-8.7
$SEC_{adjusted}$			1.173	1.158	-1.3

Sources: - Korea Iron and Steel Association.
- POSCO.
- Worrell et al. (1997), p. 731.

Notes: - Figures in parentheses are shares.
- In primary energy consumption.
- 1 PJ = 10^{15} J = ca. 23,885toe.
- 1 Mtoe = 41.87 PJ.

4.2 Cement industry

Table 7 shows the simple SEC of the cement of the cement industry decreased at 12.2 percent in the period 1992 to 2000. As less clinker was used for the cement production, the adjusted *SEC* decreased at 10.2 percent. In fact, there were substantial efficiency improvements in the cement industry.

Table 7. Specific energy consumption in the cement industry

	Reference *SEC* GJ/ton	Unit	1992(A)	2000(B)	(B-A)/A %
Cement	0.36	Mt	42.650 (91.4)	51.255 (89.2)	20.2
Clinker	2.89	Mt	39.000	45.719	17.2
PPI			128.0	150.5	17.5
Energy consumption		PJ	180.9	191.0	5.6
SEC_{simple}			4.242	3.726	-12.2
$SEC_{adjusted}$			1.413	1.269	-10.2

Source: - Korea Cement Industry Association.

Notes: - Figures in parentheses are shares of clinker in the cement production.
- In primary energy consumption.

4.3 Petrochemical industry

As the petrochemical production volume and PPI grew at about 105 percent in the period considered, there was no structural effect in the petrochemical industry. There were energy efficiency improvements of 12.9 percent in the petrochemical industry.

Table 8. Specific energy consumption in the petrochemical industry

	Reference *SEC* GJ/ton	Unit	1992(A)	2000(B)	(B-A)/A %
Ethylene	61	Mt	2.810	5.537	97.0
Propylene	61	Mt	1.628	3.602	121.3
Butadiene	67	Mt	0.376	0.730	94.1
Styrene monomor (SM)	16	Mt	1.215	2.466	103.0
Production (total)		Mt	6.029	12.335	104.6
PPI			315.4	645.9	104.8
Energy consumption		PJ	117.4	209.2	78.2
SEC_{simple}			19.473	16.959	-12.9
$SEC_{adjusted}$			0.372	0.324	-12.9

Sources: - Korea Petrochemical Industry Association.
- Farla et al. (1997a).

Note: - In primary energy consumption.

4.4 Paper and pulp industry

In the case of the paper and pulp industry, there was also little structural effect. The industry recorded energy efficiency improvements of 18.4 percent in 8 years from 1992 to 2000.

Table 9. Specific energy consumption in the paper and pulp industry

	Reference *SEC* GJ/ton	Unit	1992(A)	2000(B)	(B-A)/A %
Mechanical pulp	11.2	Mt	0.161	0.176	9.3
Chemical pulp	16.3	Mt	0.150	0.419	179.3
Recycled pulp	3.9	Mt	3.933	7.119	81.0
Newsprint (1)	6.0	Mt	0.613	1.770	188.7
Printing (2)	12.0	Mt	1.040	2.014	93.7
Sanitary paper (3)	11.0	Mt	0.268	0.289	7.8
Packaging paper (4)	8.8	Mt	2.807	4.356	55.2
Other paper (5)	10.5	Mt	0.776	1.215	56.6
Paper production (1 to 5)		Mt	5.504	9.308	69.1
PPI			71.5	123.7	73.0
Energy consumption		PJ	92.1	129.8	40.9
SEC_{simple}			16.735	13.457	-19.6
$SEC_{adjusted}$			1.183	1.136	-18.4

Sources: - Korea Paper Industry Association.
- Farla et al. (1997b), pp. 745-758.

Note: - In primary energy consumption.

4.5 Efficiency improvements in the manufacturing sector

Table 10 summarizes results of the energy intensity and *SEC* analyses. In contrast to the increases in energy intensity (energy efficiency deterioration) of the subsectors considered, the *SEC* analyses have shown that there were substantial efficiency improvements in cement, petrochemical and paper and pulp industries, which corresponds to expert assessments. Furthermore, iron & steel, cement and paper & pulp industries in Korea became less energy intensive, as the structure effect (difference between simple *SEC* and adjusted *SEC*) is negative.

Table 10. Energy efficiency improvements (1992-2000)

(Unit: %)

	Changes in energy intensity	Changes in *SEC*			Decomposition using *SEC*	
		Simple *SEC* (A)	Adjusted *SEC* (B)	Structure effect (A-B)	Efficiency effect	Structure effect
Iron & steel	4.1	-8.7	-1.3	-7.4	-2.1	-8.7
Cement	5.5	-12.2	-10.2	-2.0	-11.1	-2.3
Petrochemicals	10.3	-12.9	-12.9	0.0	-19.8	1.8
Paper & pulp	30.4	-19.6	-18.4	-1.2	-25.3	-1.7

Sources: - Tables 6 to 9.

Note: Minus (-) signs mean energy efficiency or production structure improvements.

Similar results are obtained from a decomposition analysis using physical production index (*PPI*). The energy efficiency effects were larger than the production structure effect in the cement and paper & pulp industries in the period 1992 to 2000. The reverse is the case for the iron &steel industry. The petrochemical industry became a little more energy intensive.

How can the fact be explained that the energy intensities of most manufacturing subsectors increased (deteriorated), although substantial energy efficiency improvements occurred in physical terms? Energy intensity deterioration means that the energy consumption grows faster than the value added (GDP) production. In fact, the energy intensities deteriorated due to price falls of bulk products in the world market. This was the result of overinvestment in the energy intensive industries, which was one of the causes of the Asian crisis in Korea in 1997.

As the energy consumption increases with growing energy service demand (production effect) and decreases with improving energy efficiency improvements (efficiency effect) and production structure (structure effect), the energy consumption increase in the period 1992 to 2000 was the result of higher production effect than combined efficiency and structure effects. The energy service demand grew faster than the energy efficiency improved. Energy conservation policies alone cannot cope with growing demand for energy in the industry. There is a need for restructuring in energy intensive industries.

5. Conclusion

This study has first looked at the question whether an increase in the energy intensity (energy/GDP ratio) would mean a deterioration of energy efficiency. The answer is not necessarily. This is because the change in the energy intensity is influenced apart from the energy efficiency by the production structure.

This study has used simple specific energy consumption *SEC* (energy consumption/ production ratio) and adjusted *SEC* created by replacing production in the denominator by so-called physical production index *PPI* as to answer the question whether there were energy efficiency improvements in energy intensive manufacturing subsectors. The analysis with the adjusted *SEC* method on petrochemical, iron & steel, cement and paper & pulp industries has shown that there were substantial energy efficiency improvements in three industries excluding the iron & steel industry. Energy efficiency improvements in the iron & steel industry were marginal. These results contradict the one carried out with the energy intensity method, which has found energy efficiency deterioration in all industries considered. Moreover, iron & steel, cement and paper & pulp industries in Korea became less energy intensive.

Energy intensities in most manufacturing subsectors deteriorated (increased) due to price fall of bulk products in the world market. This was the result of overinvestment in the energy intensive industries, which was one of the causes of the Asian crisis in Korea in 1997.

Indeed, there were energy efficiency improvements in the manufacturing sector. As the energy consumption increases with growing energy service demand (production effect) and decreases with improving energy efficiency improvements (efficiency effect) and production structure (structure effect), the energy consumption increase in the period 1992 to 2000 was the result of higher production effect than combined efficiency and structure effects. The energy service demand grew faster than the energy efficiency improvement. Ultimately, the energy service demand growth should be drastically reduced. Energy conservation policies alone cannot cope with growing demand for energy in the manufacturing sector. There is a need for restructuring in energy intensive subsectors.

It is the lack of sufficiently accurate data rather than the lack of methods, which impedes to assess energy efficiency improvements. A good energy database consisting of detailed information on energy consumption and energy using technologies should be developed to support energy conservation policies.

References

- Ang, B.W. (1995), "Decomposition Methodology in Industrial Energy Demand Analysis", *Energy*, Vol. 20, No. 11, pp. 1081-1095.
- Farla, J., Blok, K. and E. Worrell (1997a), *Monitoring of Sectoral Energy Efficiency Improvements in the Netherlands, 1980-1994*, Department of Science, Technology and Society, Utrecht University.
- _____ (1997b), "Energy Efficiency Developments in the Pulp and Paper Industry", *Energy Policy*, Vol. 25, Nos. 7-9, pp. 745-758.
- International Energy Agency (2001), *Energy Balances of OECD Countries 1998-1999.*
- _____ (2002), *Energy Policies of IEA Countries: The Republic of Korea 2002 Review*, Paris, June.
- Korea Energy Economics Institute, *Energy Balances of Korea*, Seoul, various years.
- Korea National Oil Corporation, *Korea Oil Statistics*, Seoul, various years (in Korean).
- Korea Petrochemical Industry Association, *Petrochemical Annual*, Seoul, various years (in Korean).
- Ministry of Commerce, Industry & Energy (2002), *White Book of Industry and Energy 2001*,

Seoul.
- Park, Hi-chun (1996), “Perspectives of Electric Power Consumption in the Korean Service Sector”, in *Proceedings of the International Conference on the Perspectives of Energy Demand and Efficient Energy Use*, the Korea Resource Economics Association and the Korea Energy Economics Institute, Seoul, October, pp. 45-67.
- _____ (1998 I), “Strategies for Assessing Energy Conservation Potentials in the Korean Manufacturing Sector”, in Park, Hi-chun and Jeong-Shik Shin (ed.), *Proceedings of the 1998 Seoul Conference on Energy Use in Manufacturing: Energy Savings and CO_2 Mitigation Policy Analysis*, the Korea Resource Economics Association and the Korea Energy Economics Institute, Seoul, May, pp. 135-170.
- _____ (1998 II), “Energy Efficiency Indicators for Industry in Korea”, Paper presented at the Workshop on Energy Efficiency Indicators for Industry, the Asia Pacific Energy Research Centre, September 21-22, Tokyo, pp. 1-27.
- _____ (2002), “Fossil Fuel Use and CO_2 Emissions in Korea”, *Environment and Resource*, Korea Resource Economics Association, to be published in December.
- Park, Se-Hark (1992), "Decomposition of Industrial Energy Consumption: An Alternative Method", *Energy Economics*, October, pp. 265-270.
- Park, Se-Hark, Dissman, Bruno and Kee-Yung Nam (1993), "A Cross-Country Decomposition Analysis of Manufacturing Energy Consumption", *Energy*, Vol. 18, No. 8, pp. 843-858.
- Park, Se-Hark and Walter C. Labys (1994), "Divergences in Manufacturing Energy Consumption Between the North and the South", *Energy Policy*, Vol. 22, No. 6, pp. 455-469.
- Reitler, M. Rudolph, M. and H. Schaefer (1987), "Analysis of the Factors Influencing Energy Consumption in Industry: A Revised Method", *Energy Economics*, July, pp. 145-148.
- Schipper, L., Meyers, S., Howarth, R.B. and R. Steiner (1992), *Energy Efficiency and Human Activity: Past Trends, Future Prospects*, Cambridge University Press, Cambridge.
- Worrell, E., Price, L., Martin, N., Farla, J. and R. Schaeffer (1997), "Energy Intensity in the Iron & Steel industry: A Comparison of Physical and Economic Indicators", *Energy Policy*, Vol. 25, Nos. 7-9, pp. 727-744.

Energy Efficiency Benchmarking

Wolfgang Eichhammer[1], Dirk Köwener, Edelgard Gruber
Fraunhofer Institute for Systems and Innovation Research (FhG-ISI)

Abstract

Benchmarks are widely used in many different areas of the society as well as in industrial practice to improve performances through competition and comparison with others. This paper discusses concrete examples of energy efficiency benchmarking (the Thai-German Energy Efficiency Promotion Project ENEP and the Malaysian Industrial Energy Efficiency Project MIEEIP), as well as some concepts, tools (such as the Electronic Energy Efficiency Benchmarking programme e^3-Bench developed at FhG-ISI) and methodologies being developed for energy efficiency benchmarking purposes without pretending, however, of being complete. From the practice, especially from an engineering perspective which sees each company as an "individual" that cannot be compared, a variety of methodological issues are raised that favour the further development of tailored benchmarks in order to take better into account the individuality of companies. Nevertheless many arguments speak in favour to develop more these methodologies in the future, in particular the fact that energy efficiency benchmarking is starting to take on a very important international role in energy and climate policy, evidenced by numerous national policy programmes around the world as well as industry efforts. The benchmarking process has the potential to satisfy a variety of different targets ranging from economic performance to energy efficiency and environment targets.

1. Introduction

Energy efficiency benchmarking consists in the establishment of energy indicators that are related to the activity of an industrial company and allow in principle to compare the energetic performance of a single company with other companies in the same field of activity. Examples in practice have shown that differences in energy efficiency practice from simple to double are possible for the same type of activity.

Benchmarking, which can be found in many different areas outside the energy efficiency field, is an ongoing process of continuous improvement:

- Finding out how the "best" companies meet these standards
- Setting targets for business activities according to the "best practice" that can be found
- Adapting and applying lessons learned from these approaches and ideas to meet and exceed the standards
- Identification of areas where improvement would make the greatest difference to the bottom line, to key areas of the business or to customer relationships
- Establishing what makes a difference in customers' perceptions between a run-of-the-mill and an excellent supplier

Why Benchmarking?

- It significantly reduces waste, rework and duplication

[1] Wolfgang Eichhammer: FhG-ISI, Breslauer Str. 48, 76139 Karlsruhe, Germany, Tel. +49/721/6809-158, Fax +49/721/6809-272, Email: wolfgang.eichhammer@isi.fhg.de

- It increases awareness of what you do and how well you are doing it
- Process understanding leads to more effective management
- It helps set credible targets
- It identifies what to change and why
- It removes blinkers and attitudes

The following sections introduce concrete examples of energy efficiency benchmarking, as well as some concepts, tools and methodologies being developed for energy efficiency benchmarking purposes without pretending, however, of being complete.

2. Energy Efficiency Benchmarking in the Thai-German Energy Efficiency Promotion Project (ENEP)

In 1992 the Thai Government passed the Energy Conservation Promotion Act B. E. 2535 to improve energy efficiency in Thai industry and commerce. The exact procedure for factories is laid down in four Royal Decrees. They describe the forms and schedules for submitting data on energy consumption and energy conservation activities. A corresponding programme exists for large buildings. Both are managed by Thailand's Department of Energy Development and Pro-motion (DEDP).

The implementation of the Energy Conservation Act has occurred step by step according to company size which is measured by their electricity consumption:

- companies with more than 10 MW electric power (reporting started January 1998)
- companies 3–10 MW (January 1999)
- companies 2–3 MW (January 2000)
- companies 1–2 MW (January 2001).

After the final step, reached in 2001, roughly 2,500 factories in the manufacturing sector are so-called Designated Companies. They fall under the compulsory programme if they have an installed capacity of 1 MW and above or consume annually 20 million MJ or more of electricity, steam power and other non-renewable energy sources. Their managers are obliged to report their energy consumption data every six months to DEDP. Every three years registered energy consultants have to carry out energy audits in the designated companies in order to identify energy saving opportunities, to set saving tar-gets and to recommend energy conservation measures. Investments in energy-efficient technologies are subsidised from an Energy Conservation Fund.

The companies' owners or managers have some additional duties such as assigning at least one qualified person in a full-time position as a "Person Responsible for Energy" (PRE) and keeping records on monthly energy consumption and data on other energy-related matters. The practise of regularly reporting energy consumption to DEDP forces the owners or managers to continually quantify their energy consumption and encourages them to think of options to reduce it. This is expected to help them evaluate the impacts of energy-saving projects in the future. Data from the energy consumption reports are collected in DEDP's database for further processing. The database is structured according to the Thai Standard Industrial Classification. Making use of these data through the establishment of energy efficiency indicators, benchmarks and feedback is crucial for monitoring energy efficiency improvements, structural changes, the impacts of certain energy policy measures and the overall performance of the Audit Programme. The statistical data can be used as performance indicators for the respective industrial and commercial sectors, for further promotional activities, and to provide energy users, consultants, administrators, politicians and the general public with information needed to further improve energy efficiency in Thailand.

In this context, an energy efficiency benchmarking programme (e3-Bench) was developed (see section 4) that should make use of the data accumulated within the frame of the compulsory Thai energy reporting and energy auditing scheme by providing a means to the data-collecting authority to give a feedback to the companies on their energetic performance in comparison to other similar companies in the same industrial subsector. Given the dynamic nature of the mandatory programme for energy reporting and energy auditing in Thailand (by early 2002 within the reporting scheme about 2500 companies had reported their overall energy consumption while still only very few had carried out detailed audits at the process level it was decided to adapt the introduction of benchmarking to this situation by providing means to DEDP to give a feedback to companies at the overall company level (see Figure 1). In the future, in might in principle be feasible to realise the other feedback loops also indicated in Figure 1 concerning the process level, energy saving practices (which were also to be collected for the energy audits), as well as the overall achievements of the mandatory auditing programme itself. Concerning the process level it appears most useful to introduce benchmarking also gradually by concentrating first on electric auxiliary utilities (such as compressors, lighting, air conditioning) and on fuel-fired boilers as electric energy consumption is easier to measure or as the data for boilers were already collected with the data on the overall energy consumption. Benchmarking on the level of electric or fuel/steam consuming process equipment should occur at the latest level given the fact that these data are not yet often monitored in detail.

For the purpose of the Thai energy reporting and auditing scheme, three principle types of benchmarks were defined:

- Internal Benchmark: the energetic performance of the company (or of an equipment) is monitored and compared over time in order to follow energy saving measures or the achievements of targets
- Competitive Benchmark at the national level: the comparison with similar companies in the same subsector at the national level
- Competitive Benchmark at the international level: the comparison of companies at the national level with international practices. This latter benchmark appears most useful in the early phases of the benchmarking process when relatively little information is available yet from the national level

Examples for data from the energy reporting scheme and benchmarks at the overall company level are provided in Figures 2-5 (see the discussion in section 4) and in Figure 6 at the level of fuel-fired boilers in the sugar industry. Details for many individual branches can be found in Gruber et al. 2002).

3. Energy Efficiency Benchmarking in the Malaysian Industrial Energy Efficiency Project (MIEEIP)

In contrary to the Thai compulsory energy reporting and auditing scheme, which gave the advantage that a fairly large number of companies was immediately available for benchmarking purposes, the Malaysian Industrial Energy Efficiency Project MIEEIP developed as the basic philosophy to rely on voluntary participation of companies. The total number of companies participating was limited to a total of thirty. Eight different sectors were chosen for the comparison by benchmarks (iron/steel, cement, pulp&paper, ceramics, food, rubber, glass, wood). Given the small number of companies and the larger number of sectors, the comparison within the country among companies was limited to a fairly small number of 4-5 companies which was at the lower end of what might be considered as useful in a benchmarking exercise. Interesting are however the following elements in the dynamics of the introduction of benchmarking:

- Energy efficiency benchmarking should in general be one component in a more important addressed to industrial companies comprising other elements such as energy auditing, energy technology support etc. (see Figure 7).
- Voluntary participation of companies has the disadvantage that at the beginning of the process fairly little useful information is available for the individual company which might reduce their interest in the process. On the other hand, companies might through a voluntary participation be more motivated to go beyond the differences observed in the benchmarking process and to seek for the exact reasons why the company might perform less well with respect to energy efficiency.
- In the early phase of the benchmarking process, when little national information is available, databases with international comparison data have a very important role to play.

4. The Electronic Energy Efficiency Benchmarking Programme (e^3-Bench)

Within the framework of the Thai-German Energy Efficiency Promotion Project (ENEP), a software has been developed to evaluate the data on an individual company level and to give feedback to the companies (the Electronic Energy Efficiency Benchmarking Programme - e^3-Bench, see Figure 8). This software was also used for the Malaysian MIEEIP. The programme presents key figures for the evaluation of the energy consumption, such as production, capacity use, fuels and electricity consumption, specific energy consumption per production unit, and estimates for energy costs over all reported periods. The data are compiled in the form of a feedback report to the companies (see Figure 9). The figures do not only indicate the status quo and the development of the energy situation, but also the effectiveness of the steps that were taken. On this basis it is possible to define an individual energy-saving target. However, these internal data do not suffice to pinpoint all energy efficiency potentials. Key figures established for a company prove their worth only if compared with similar companies. Many companies think that they are already exploiting all the possible profitable energy saving potentials, but empirical evidence shows that there may be significant differences between comparable companies.

e^3-BENCH is not able to replace a full scale energy audit. In fact the programme indicates with its results a possible need for an energy audit and helps to identify the crucial points for such an audit.

Table 1. Main features of e^3-BENCH at a glance.

➢ Microsoft-Excel based programme
➢ Monitoring of energy carriers, physical / economic production, energy costs
➢ Monitoring of specific energy consumption, energy costs and CO_2 emissions over time and in comparison with companies in a similar field of activity
➢ Graphics and table presentation of results
➢ Establishment of a Feedback Reports on the performance of the companies based on aggregate comparison data from other companies
➢ International comparison values for a variety of industrial branches
➢ Possibility to generate own indicators
➢ Automatic validity control of data entered
➢ Easy possibility to switch to other languages (currently English, Spanish, Portuguese, Thai, German)

5. The Engineering View on Energy Efficiency Benchmarking

Figures 2-5 show that energy indicators at the company level are influenced not only by differences in energy efficiency but by many different factors of influence such as:

- Production volume (see Figure 4)
- Use of production capacity over time (see Figures 2 and 3)
- Changes in the process mix of the company
- Differences in product type and quality
- Energy efficiency measures
- Non-production related energy use
- Storage of energy carriers (solid and liquid fuels)

In a carefully designed benchmark process, it is possible to take into account a variety of these factors though much methodological development and experience with the establishment of benchmarks still is necessary with respect to the correction of such factors of influence. Nevertheless, benchmarking appears as limited, especially when no detailed knowledge on energy consumption is available at the process level in the company. In this context, benchmarking can be seen as a pre-screening step towards an energy audit. It gives a quick result and can be performed on a large number of companies. Benchmarking and energy audit are therefore complementary exercises.

From an engineering point of view, very often critics is manifested towards benchmarks by stating that "all companies are individuals and that they cannot be compared with each other". On this basis, benchmarking is considered as useless. See the example of Figure 10 which tries to "explain" the differences observed within subsectors of the milk industry and comes to the conclusion that they are not necessarily triggered by differences in energy efficiency but that there are still a lot of structural differences among companies with respect to their production mix.

Although this argument can be debated on more general grounds:

- we are well using benchmarks in many different occasions of daily life, starting from the grades received at school without taking care of the individuality of each person;
- we are using benchmarks in companies well in other fields, example to compare their economic performance without paying attention either to the individuality of companies;
- we underestimate the dynamics of improvement triggered by the comparison with others which leads us to detailed questions, why we are different with respect to the energetic performance elsewhere observed and possible measures for improvement...

Increasingly there are also methodologies in development to design individually tailored benchmarks for each company. In fact, for this purpose the really observed energy consumption within the company is compared to a hypothetical company that has the same process mix but good practice processes. The advantage of this concept is that it is not necessary in particular to have detailed knowledge of the real energy consumption within the company at the process level. The disadvantage is however, that extended knowledge has first to be provided to define and evaluate quantitatively process chains and basic processes for the comparison. This requires a lot of experience with benchmarking and a lot of knowledge accumulated with individual industrial processes and might be an obstacle at an early level of the benchmarking process such as in the MIEEIP in Malaysia. Nevertheless, the so developed tailored benchmarks are possible the most convincing ones from an engineering perspective.

6. Conclusions

Benchmarking for Energy Efficiency has limitations, as evidenced by the differences observed between companies, which cannot be fully explained by differences in energy efficiency but rather by differences in the internal production structure that is not resolved at the

overall company level. Also system inefficiencies are much more difficult to benchmark than component inefficiencies (e.g. losses in steam pipes versus boiler efficiencies). However:

- Substantial information can be drawn from comparisons even at overall company level
- Benchmarking is based on spirit of competition and stimulates progress by comparison - even if the comparison does not always take into account all specificities of the individual company
- One important purpose of Energy Efficiency Benchmarking is to prepare and pre-screen the field for energy audit schemes
- Benchmarking methodologies can be developed considerably further on the basis of individually tailored benchmarks that take into account the production structure of the company considered, however at the price to develop and compile beforehand detailed knowledge on industrial process chains.
- The introduction of benchmarking is a dynamic process where in an early phase the comparison with international data appears very important and advocates the establishment of suitable databases.
- Benchmarking is starting to take on a very important international role in energy and climate policy, evidenced by numerous national policy programmes (see for example the Dutch benchmarking programme) around the world as well as industry efforts. In particular the role that basic elements of the benchmarking process such as the internal benchmarks might play in the development of baselines for project based Kyoto flexibility instruments such as Clean Development Mechanism CDM (see Figure 11) must be strongly emphasised here. The benchmarking process has therefore the potential to satisfy a variety of different targets ranging from economic performance to energy efficiency and environment targets.

References

Eichhammer, W., Gruber, E., Cremer, C., 2000. Selecting Appropriate Energy Efficiency Indicators for the Thai Energy Conservation Promotion Programme. Karlsruhe: Fraunhofer Institute ISI.

Gruber, E., Eichhammer, W., Mannsbart, W., 2002. Energy Efficiency in Thai Industry 2002, Karlsruhe, FhG-ISI.

Kruska, M., 2002. Bewertung und Vergleich der Energieeffizienz – Kennzahlen und Benchmarking (Evaluation and comparison of energy efficiency – indicators and benchmarking). Presentation in the frame of the VDI working group Energy Indicators, Karlsruhe, FhG-ISI, 27.September 2002.

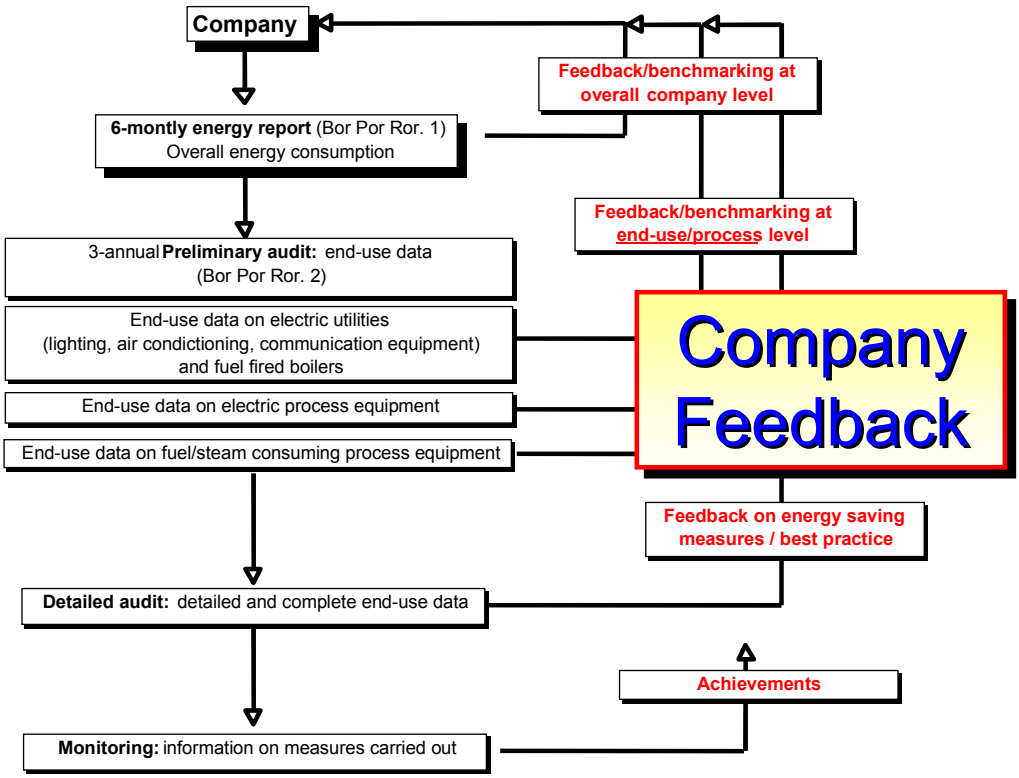


Figure 1. The role of energy efficiency benchmarking and feedback in the Thai energy reporting and auditing programme .

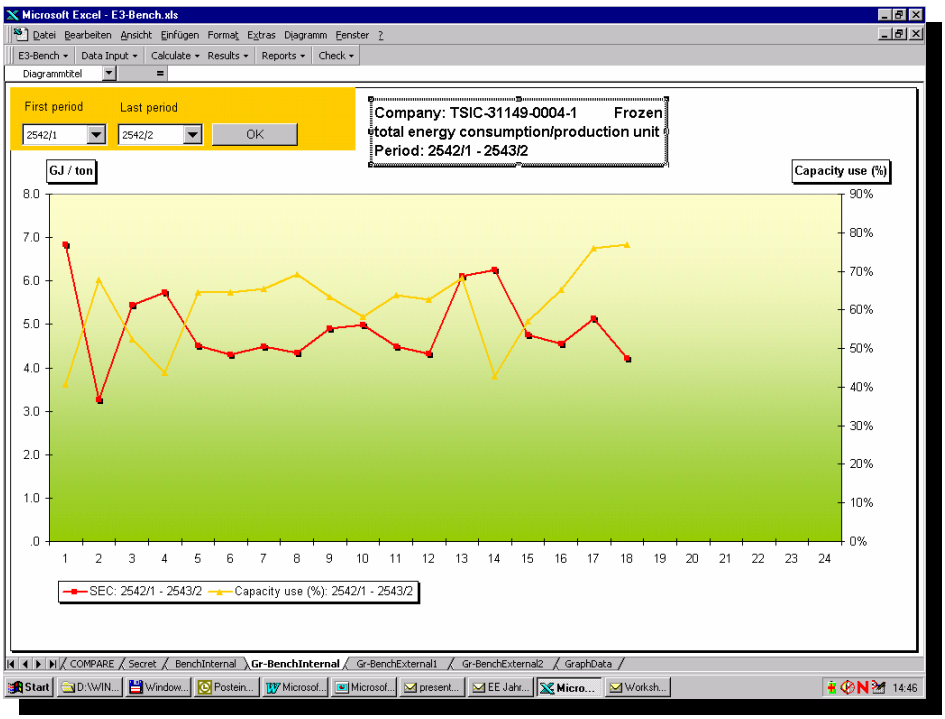
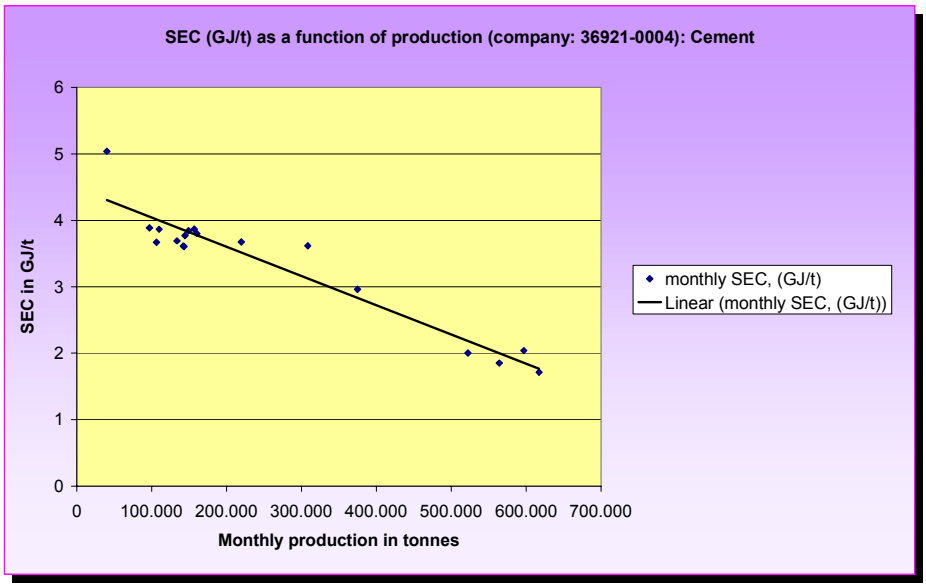


Figure 2. Internal benchmarking (comparison of the company's performance over time) and the impact of capacity variations. The period covered are the years 1998/1999



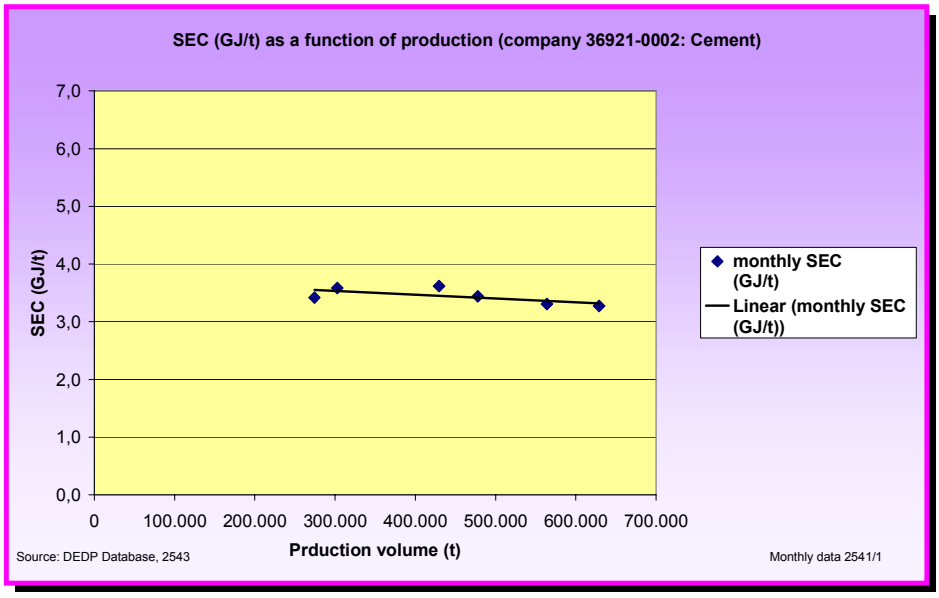


Figure 3. Influencing production variations with organisational measures ? Example of two cement companies during the Asian economic crisis 1997/1998

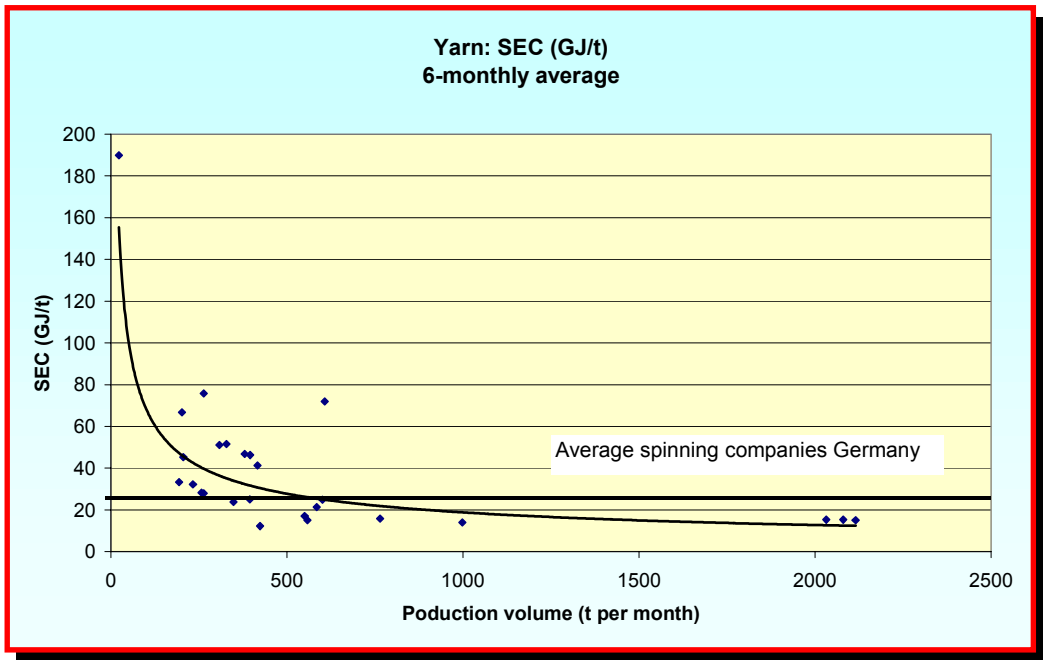


Figure 4. Influence of the company size on energy efficiency performance

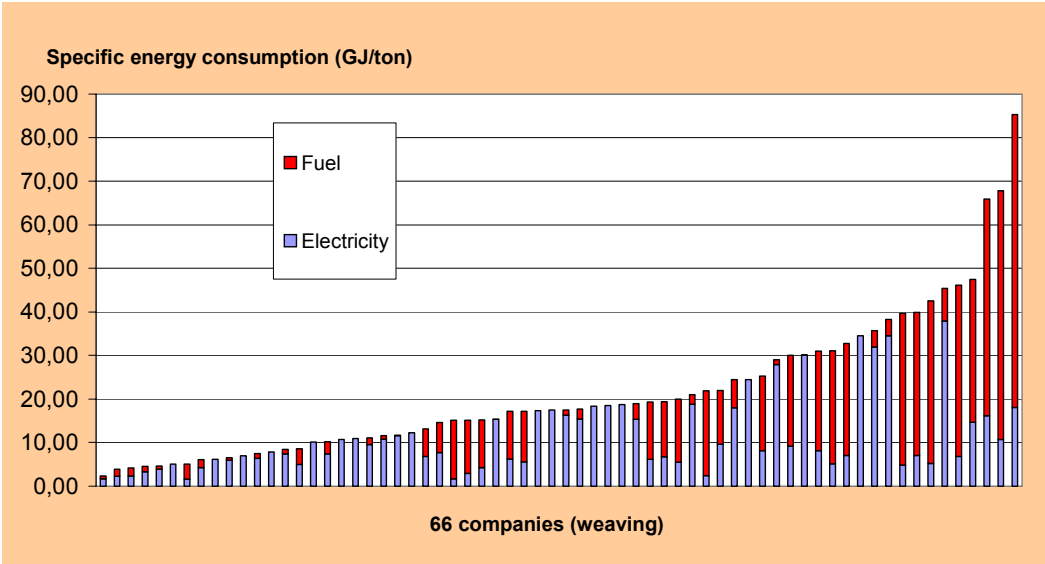


Figure 5. Competitive energy efficiency benchmarking in the Thai weaving sub-sector

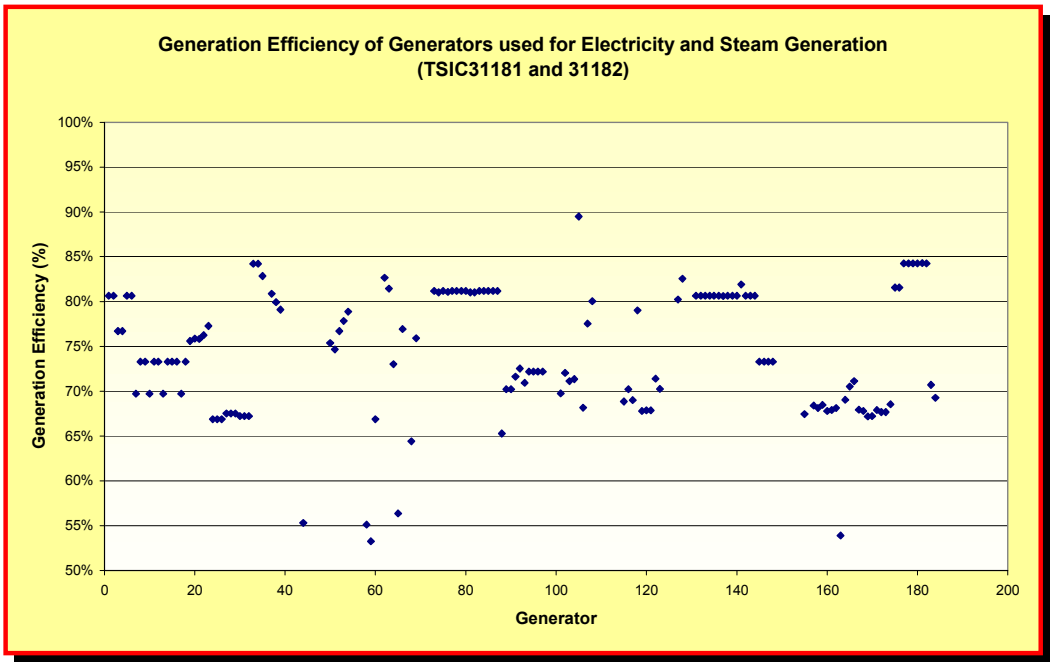
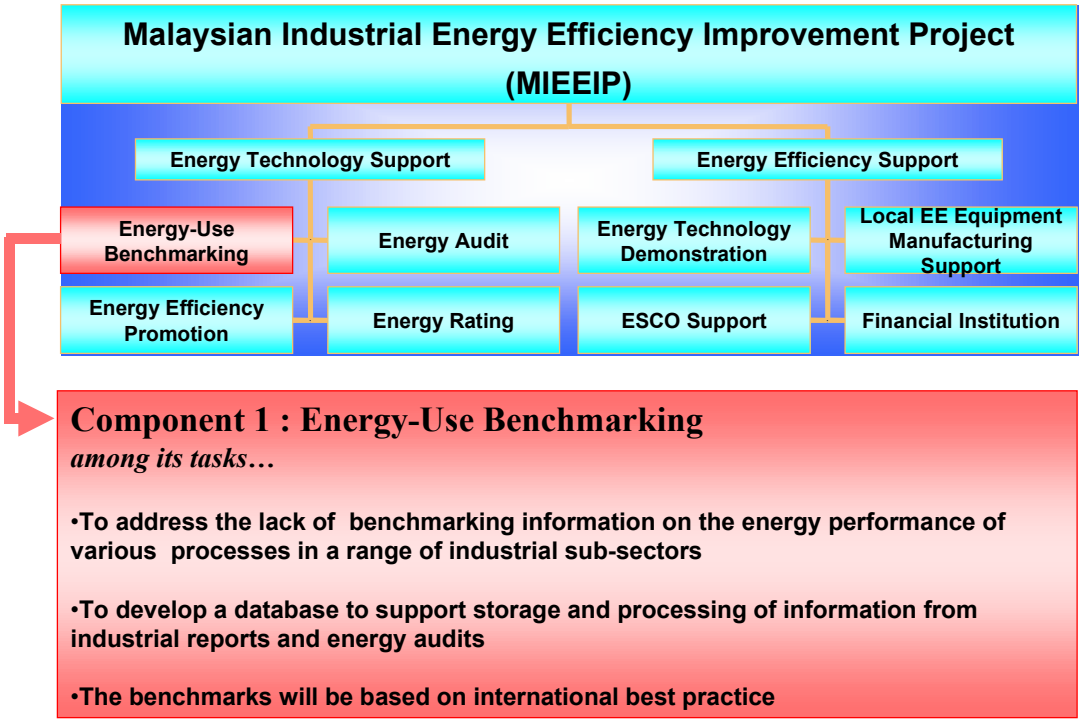


Figure 6. Conversion efficiency of bagasse-fired CHP boilers in the Thai sugar industry



Source: Fichtner (2002)

Figure 7. Energy efficiency benchmarking in the Malaysian Industrial Energy Efficiency Project (MIEEIP)

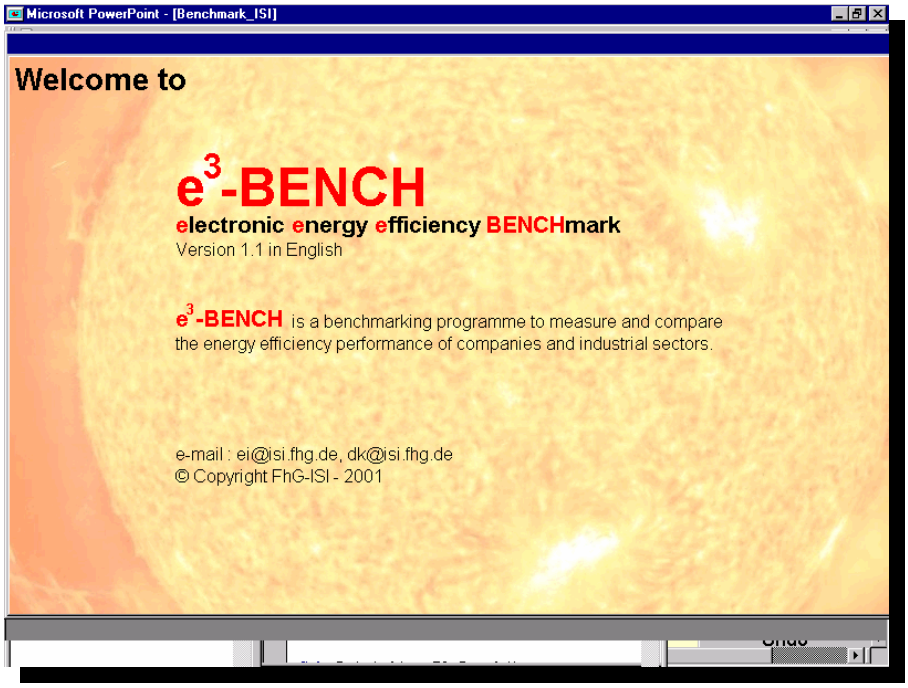


Figure 8. The electronic energy efficiency Benchmarking (e3-Bench) software developed for the Thai ENEP programme

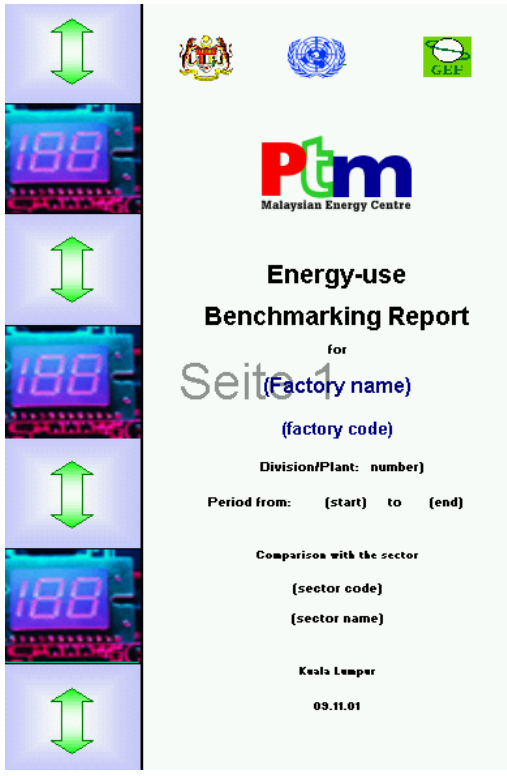
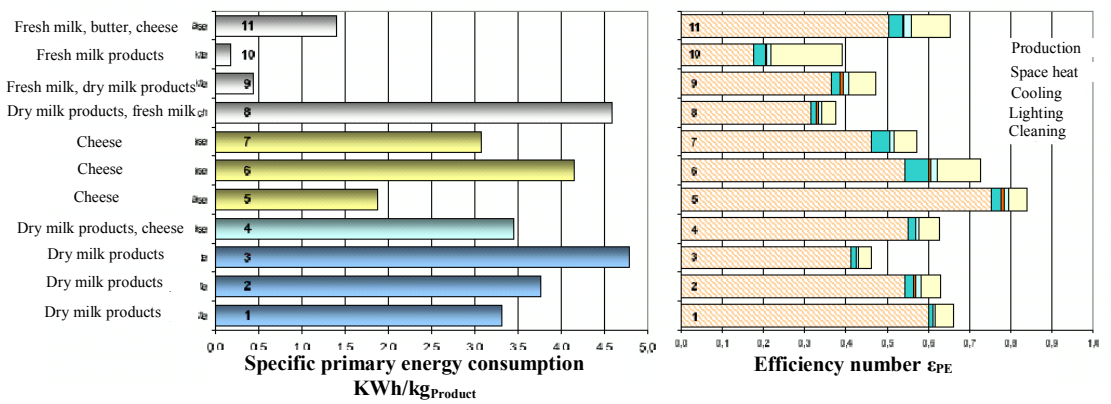


Figure 9. Title page benchmarking feedback report to companies (Malaysian MIEEIP)



Source: translated from Kruska (2002)

Figure 10. The engineering view on energy efficiency benchmarking: explaining the differences (left: energy indicators, right: efficiency calculated by comparing the theoretically used energy in an efficient process with the actually observed)

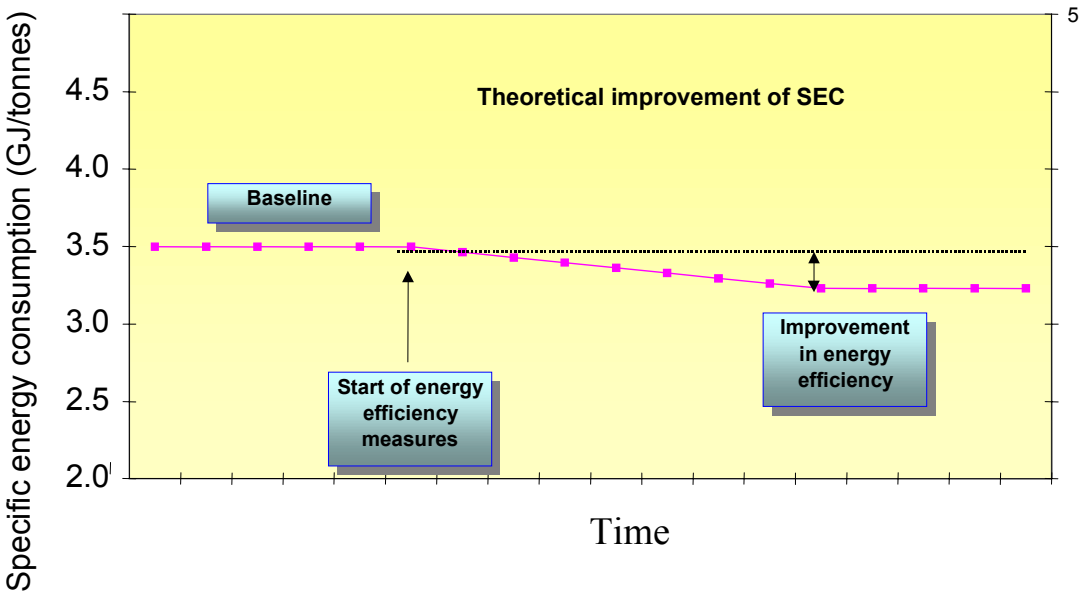


Figure 11. Internal energy efficiency benchmarking and project based Kyoto flexibility instruments

Assessing the Cost of GHG Abatement Policies: A Cost Curve Analysis.

John Nyboer,[1] Mark Jaccard, Chris Bataille, Alison Laurin

Energy and Materials Research Group (EMRG)
School of Resource and Environmental Management
Simon Fraser University

Abstract

In analyses completed for the National Climate Change Process in Canada, a committee established to assess how Canada might meet its Kyoto commitments, the EMRG first did an assessment of what Canada must do to reach its target both unilaterally and under conditions where it could "obtain" its reductions abroad (permit trading, JI, CDM). Analysts used the Canadian Integrated Modelling System (CIMS), a detailed integrated end use model to determine the degree and costs associated with Canada meeting it commitments. The assessment suggested Canadians would see a price of about \$120 / t CO_2e to meet its commitment unilaterally.

EMRG then completed a second project to assess the shape of the cost curve to get to the point of meeting the target. Again CIMS was used to estimate the degree to which emissions would be reduced at different costs per tonne. Improvements were made in model design and more of what had once been exogenous to the model were now endogenized. Again the outputs were compared to an optimization end use model. The detailed cost curve (CIMS simulated 11 different costs for GHG reductions and generated detailed outputs included shifts in technologies) provided decision makers with direction on policy focus and development. With the modifications and updates, the assessment suggested Canadians would see a price of about \$150 / t CO_2e to meet its commitment unilaterally.

The assessments were carried out in conjunction with another end use model, an optimization model (MARKAL). The analysis brought to light a number of elements that required review. These included:

1 assessment of possible technological options, including behavioural criteria for actions

2 definition and determination of costs, including financial, welfare, total, etc.

3 impact of using models with different technology choice philosophies – optimization vs. market simulation.

We will discuss these various issues in the light of our analysis, and its implication for decision making and policy development including alternative GHG-focused policies.

---

[1] Author can be reached at jnyboer@sfu.ca

[2] Much of this description (sections 1, 2,and 3) were taken from EMRG / MKJA 2002.

1 Introduction

Since 1998, governments at the national and provincial / territorial level in Canada have embarked on a process aimed at achieving an understanding of the impact, cost and benefits of the Kyoto Protocol's implementation and of the various implementation options open to Canada. This National Climate Change Implementation Process (NCCIP) involved the establishment of more than a dozen consultative Issue Tables composed of experts, interest groups and government officials mandated to estimate the cost and amount of greenhouse gas (GHG) emissions that could be prevented or captured in Canada in their particular area.

Once the work of the Issue Tables was completed, the AMG was mandated to integrate, or 'roll up', the table's results as reported in their Options Papers. For this task, the AMG called on the services of two teams of micro-modelling consultants, the Energy and Materials Research Group / M.K. Jaccard and Associates (EMRG / MKJA) being one of these groups.[1] Results were published as *Integration of GHG Emission Reduction Options Using CIMS* (EMRG / MKJA June 30, 2000). The results of this integration exercise, which established two 'boundary' estimates of the micro-economic level expenditures necessary to meet Kyoto, were then forwarded to two macro-modelling groups who analyzed the macro-economic level effects of the expenditures reported in the previous exercise. The cumulative results of this analysis are reported in AMG / NCCIP, November 2000.

MKJA was subsequently requested by the AMG and NRCan to use the same modelling system, including improvements, to construct and analyze a set of sectoral, regional and national cost curves of GHG abatement in Canada based on GHG shadow prices of 10, 20, 30, 40, 50, 75, 125,150, 200 and 250 dollars / t of CO_2 equivalent (CO_2e). Like the first AMG Roll Up the 'Cost Curves' project was to be a micro-economic exercise; to accomplish this all of CIMS' macroeconomic elements were shut off. This paper summarizes the main report (EMRG / MKJA 2002) and describes the GHG reduction curves obtained at the various GHG shadow prices, estimates the costs associated with the curves and concludes with some policy implications.

2 Method

2.1 CIMS

MKJA used the Canadian Integrated Modelling System (CIMS) for both the analyses. CIMS is designed to provide information to policy makers on the likely response of firms and households to policies that influence their technology acquisition and technology use decisions. It is a technology simulation model that seeks to reflect how people actually behave rather than how they ought to behave.

CIMS covers the entire Canadian economy and can connect to an aggregated representation of the US economy. It currently models six provinces and an aggregation of the Atlantic provinces. While the model is simple in operation, it can appear complex because it is technologically explicit and covers the whole economy. This means that all technologies (fridges, cars, light bulbs, industrial motors, steel furnaces, buildings, power plants, etc.) must be represented in the model, including their inter-linkages. Because there is a great diversity of technologies in industry, the model is especially large for that sector.

[1] The other micro-modelling consultants were HALOA. They used MARKAL, an optimization model. We will refer to MARKAL throughout this document to outline some of the differences between it and CIMS, and provide a brief comparison of model result under section 4.

As a technology simulation model, CIMS need not focus only on energy. However, the version of CIMS described here highlights the interplay of energy supply and demand because energy-related GHG emissions are a key policy concern. Thus, the model focuses on the interaction between sectors that use energy (the industrial, residential, commercial / institutional and transportation sectors) and sectors that produce or transform energy (electricity generation, fossil fuel supply, oil refining, and natural gas processing). A policy that seeks to influence energy supply and demand may also have indirect effects such as impacts on intermediate and final product demands (the structure of the economy) and on total economic output. To assess this, CIMS includes a macro-economic feedback loop, which was turned off for this study.

A CIMS simulation involves seven basic steps.

1. *Assessment of demand:* Technologies are represented in the model in terms of the quantity of service they provide. This could be, for example, vehicle kilometres travelled, tonnes of paper, or m^2 of floor space heated and cooled. A forecast is then provided of growth in energy service demand.[1] This forecast drives the model simulation in five year increments.

2. *Retirement*: In each future period, a portion of the initial-year's stock of technologies is retired. Retirement depends only on age.[2] The residual technology stocks in each period are subtracted from the forecast energy service demand and this difference determines the amount of new technology stocks in which to invest.

3. *Retrofitting*: In each time period, a competition occurs with residual technology stocks to simulate retrofitting. Financial and non-financial information is required; the capital costs of residual technology stocks are excluded, having been spent earlier when the residual technology stock was originally acquired.

4. *Competition for new demand*: Prospective technologies compete for new investment. The objective of the model is to simulate this competition so that the outcome approximates what would happen in the real world. Hence, while the engine for the competition is the minimization of annualized life cycle costs, these costs are substantially adjusted to reflect market research of past and prospective firm and household behaviour.[3] Thus, technology costs depend not only on recognised financial costs, but also on identified differences in non-financial preferences (differences in the quality of lighting from different light bulbs) and failure risks. Even the determination of financial costs is not straightforward, as time preferences (discount rates) can differ depending on the decision maker (household vs. firm) and the type of decision (non-discretionary vs. discretionary). The model allocates market shares among technolgoies probabilistically.[4] Three parameters, then, define the acquisition of stock: "*v*" – variability in purchasing behaviour, "r" – time preference or discount rate, and "*i*" – intangible costs associated with a technology (stated or revealed).

5. *Equilibrium of energy supply and demand*: Once the demand model has chosen technologies based on the base case and policy case energy prices, the resulting demands

---

[1] The growth in energy service demand (e.g., tonnes of steel) must sometimes be derived from a forecast provided in economic terms (e.g., dollar value of output from the steel sector).

[2] There is considerable evidence that the pace of technology replacement depends on the economic cycle, but over a longer term, as simulated by CIMS, age is the most important and predictable factor. There are ways in CIMS to prematurely retire technologies if desired.

[3] With existing technologies there is often ready data on consumer behaviour. However, with emerging technologies (especially the heterogeneous technologies in industry) firms and households need to be surveyed (formally or informally) on their likely preferences. These latter are referred to as stated preferences whereas preferences derived from historic data are referred to as revealed preferences.

[4] In contrast, the optimizing MARKAL model will tend to produce outcomes in which a single technology gains 100% market share of the new stocks.

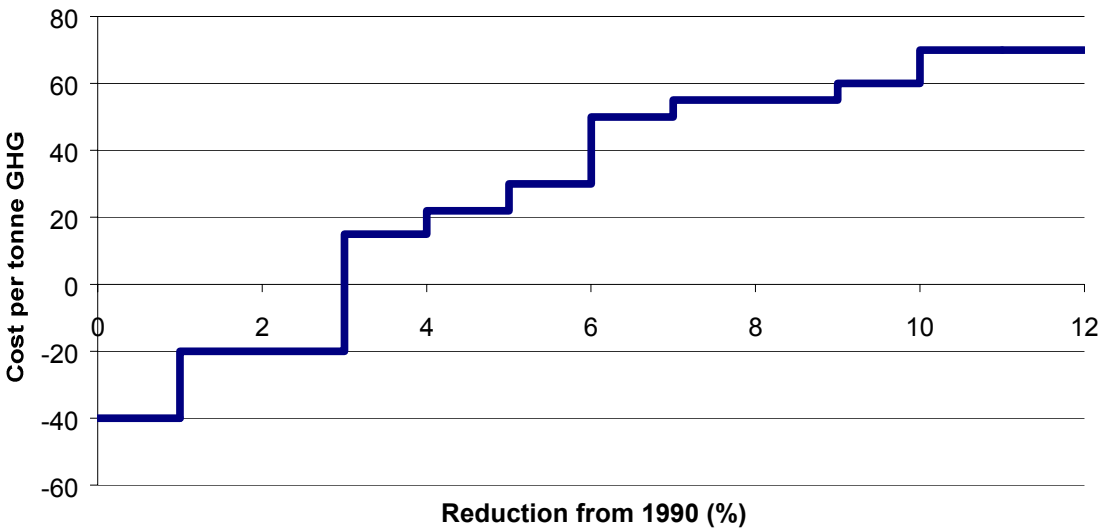
for energy are sent to the energy supply models. These models then choose the appropriate supply technologies, assess the change in the cost of producing energy, and if it significant send the new energy prices back to the demand models. This cycle goes back and forth until energy prices and energy demand have stabilised at an equilibrium.[1]

6. *Equilibrium of energy service demand*: Once the energy supply and demand cycle has stablized, the macro-economic cycle is invoked (if turned on). Currently, it adjusts demand for energy services according to their change in overall price, based on price elasticities. If this adjsutment is significant, the whole system is rerun from step 1 with the new demands.
7. *Output*: Since each technology has net energy use, net energy emissions and costs associated with it, the simulation ends with a summing up of these. The difference between a business-as-usual simulation and a policy simulation provides an estimate of the likely achievement and cost of a given policy or package of policies.

2.2 A Note About Cost Curves

Cost curves have historically been viewed as a sequential set (cost wise) of possible actions that can be invoked to reduce emissions in a stepwise way. One can enlist these various actions up until the target has been reached. Figure 2.1 provides a typical example where action 1 is actually beneficial, as is action 2, and these two combined would provide for a 3% reduction from 1990 levels of emissions were they invoked. There follows the usual sorts of questions about why they wouldn't be invoked if, indeed, they were cost effective (we return to this later) and how many of these actions would have to be taken to meet the target.

Figure 2.1: Typical Cost Curve



But such a stepwise, distinct set of actions belies what would actually occur. Actions do not occur in this way because:

- Different consumers see the cost of an action in different ways, and make decisions on invoking the action based on this (intangible values, perceived costs).

[1] This convergence procedure, modelled after the US DoE model, NEMS, stops the iteration once changes in energy demand and energy prices fall below a threshold value. In contrast, the MARKAL model does not need this kind of convergence procedure; iterating to equilibrium is intrinsic to its design.

- Actions are not independent; they affect each other and the demand on energy supply to affect fuel costs, etc.
- Penetration rates of actions vary under different economic conditions, i.e., consumers change their choices.
- Options for applicable actions change under different economic conditions. A technology that penetrates well under one scenario may not under another.

Therefore, there is no single cost associated with an action, nor is it feasible that a particular action will provide a certain defined quantity of reductions. In fact, each technology has it own set of possible costs curves (and the set could number 1000s simply by changing some other actions' penetration elsewhere). The sum of all these curves, all interdependent, provides the cumulative cost curve seen below (figure 3.1). Depending on both economic and non-economic conditions, the contribution of a certain action to overall reduction can vary widely. For this reason, we need models that allow actions to interact (i.e., they must be integrated) and reflect consumer behaviour.

2.3 Scenario Conditions Set by the AMG

The AMG set preconditions for the simulation of five scenarios, known as "Paths" in the initial Roll Up. These were continued in this Cost Curve exercise. The key preconditions are:

- All key assumptions are based on Canada achieving the Kyoto target through domestic actions alone. Canada can buy international carbon emission credits and the US does not enact policies to reduce emissions.
- Non-energy output or activity levels remain unchanged with one exception: the demand for vehicle transportation was allowed to respond to measures aimed directly at reducing vehicle use.
- There is no change in output of domestic oil and natural gas. Changes in demand that arise from fuel switching and enhanced efficiency are met through export and import changes.
- The domestic production of electricity alters to reflect changes in demand. Imports and exports of electricity between regions (inter-provincial and international) are held constant in all simulations.[1] Changes in coal demand resulting from changes in electricity production were passed on to the coal sub-model.

2.4 Cost Methodology

The analysis and its review generated a lot of discussion about costs and what they are. We needed to assess costs under many different headings including financial costs only (capital, operating, fuel, etc.), welfare costs and other intangible costs. Table 2.1 attempts to name and summarize the costs, each of which is further defined below.

[1] In MARKAL runs, inter-provincial electricity trade was allowed to adjust in response to changing costs.

Table 2.1: Types of costs

Type of cost:	**Notes:**
Perceived private cost. This is based on the concept of private avoided costs; firms and households were willing to reduce X tonnes of GHGs when faced with Y shadow price and all other taxes and real prices in the economy	Established as direct plus indirect emissions reductions times shadow price[1].
Expected resource cost (ERC). This may be conceived as the "real" cost or as the perceived private cost adjusted for risk and general inefficiency.	Costs provided in first Roll Up exercise. ERC = (TEC+(PPC-TEC)*0.75). The missing 0.25 is our estimate of the 'inefficient' resistance of the economy to price signals. ERC is TEC plus the real risk associated with actions.
Techno-economic costs (TEC)	Includes change in capital, energy and operations costs (with no uncertainty, no variability and no consumers' surplus). Most comparable to 'risk-free' financial cost. It can be reported with or without electricity price changes. These electricity price changes result in a transfer to electricity, considered neutral at the regional level.

2.4.1 The techno-economic cost (TEC) estimates in this report

The AMG wished to know the financial costs associated with the various shadow price levels and requested an estimate of *techno-economic costs* (TEC), or the change in expenditures on capital, energy and operations between the reference and policy case. While provided as single cost estimates, CIMS generates TEC costs probabilisticly; they cannot be perfectly represented as a single value and should therefore be thought of as a condensed or point estimate of a range.

The techno-economic costs are the difference in the net present value of techno-economic costs in 2000 (Cdn $ 1995), for the period 2000-2010 between the reference and policy case. TEC costs are the sum of capital, energy, operations and maintenance costs. The capital costs reported are the new purchase and retrofit 'sticker price' expenditures over the ten-year span. If the life of a piece of equipment extends beyond 2010, the capital costs include only the costs occurring up to 2010. Operations and energy costs are yearly costs over the ten-year span.

Techno-economic costs represent only firms and households' financial cost of adaptation to policy change; welfare costs may be, and usually are, much higher and *are embodied in the technology choices of firms and households*. The choices made determine the technology stock changes from which we generate our techno-economic costs.

[1] The GHG emissions reductions and costs of some of the tables' actions were modeled exogenous to CIMS because they were not technology-based or could not be incorporated into the model's framework. In this report, these exogenous emissions reductions are included in the total GHG reductions reported, and in the calculation of perceived private and expected resource costs.

2.4.2 Expected Resource (ERC) and Perceived Private Cost (PPC) Estimates

We include here an estimate of welfare costs. The welfare cost measures are *expected resource cost* and *perceived private cost*. In order to understand these costs, we will define them in relationship to each other.

Perceived private costs (PPC) include all costs faced by the private entity. It is the cost the private entity would feel they are facing. This cost drives the consumer to make their choices and, thus, determines the compensation required to have consumers do something differently (i.e., move from one technology to another).

Expected resource costs (ERC) are the probabilistic financial costs the private entity would incur, including risk and cost of capital, etc. It is generally less than PPC because we do not include the less tangible component of consumers' surplus. CIMS tries to capture, at the higher tax rates, even those most reluctant to make the switch to the alternative technology / process that is lower in GHG emissions. It would be inappropriate to include these last dollars that were spent to convert the otherwise unconvertible – what we loosely called a "bribe" – in the ERC. Since we have no means of determining the size of that "bribe", we have made an educated guess that it would be about 25% of the difference between the tech costs and the perceived cost. This decision was based on substantial literature review but there is a high degree of uncertainty surrounding this value. It requires sensitivity analysis and additional research.

All non-environmental taxes are redistributed and thus are just transfers. Welfare cost would not include these. The GHG taxes are here deigned to be a surrogate for the value / benefits foregone by having chosen an alternative technology. The actual dollars collected through the tax are also recycled and not included.

3 Canada's Cost Curve for Emissions Reduction

The primary purpose of this exercise was to define an emissions reduction cost curve for Canada. Figure 3.1 provides such a curve where, at any particular shadow price associated with GHG emissions (y-axis), the quantity of emissions reduced can be determined (x axis). It is followed by table 3.1 that defines more clearly the quantity of energy saved, the emissions reduced and the techno-economic, expected resource and perceived private costs associated with this reduction. While such curves are available by sector, region and by sector / region pair, such detail is not provided in this paper.

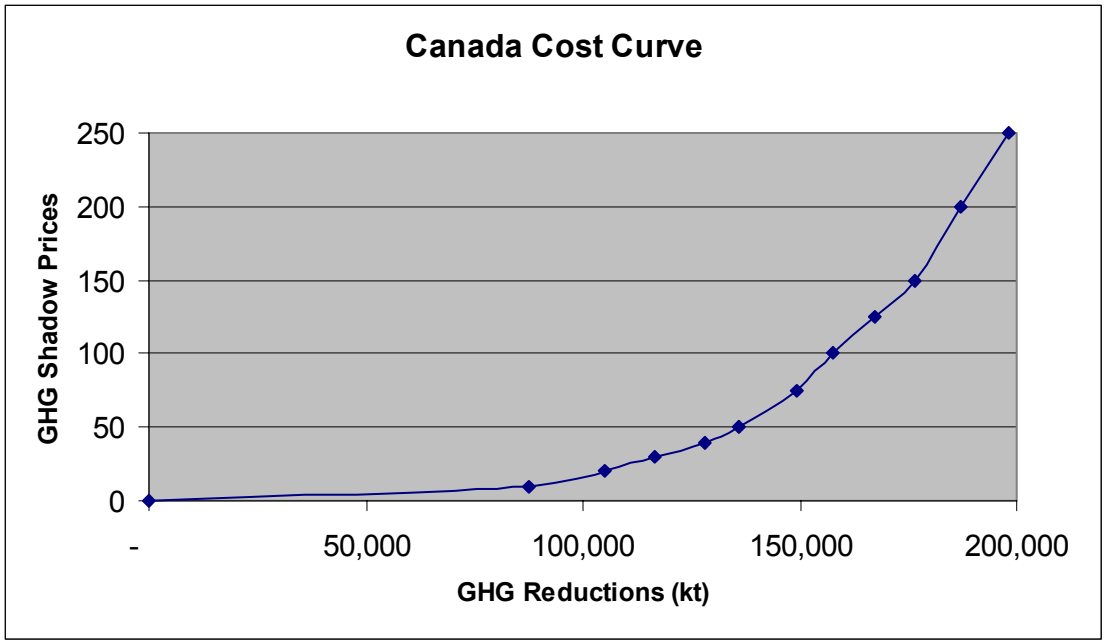


Figure 3.1: Cost Curve of GHG Emissions for Canada, 2010.

3.1 General Commentary for Canada

The cost curve simulation that reaches the Kyoto target, a reduction of 178.7 Mt, is the $150 run which induces a reduction of 176.6 Mt. At this shadow price, the electricity sector delivers 83 Mt (47%), mainly through sequestration and switching to natural gas turbines in Alberta and Saskatchewan, transportation 28.7 Mt (16%), industry 26.2 Mt (14.8%), NG extraction 10.4 Mt (5.9%), commercial 9.7 Mt (5.5%), residential 8.0 Mt (4.5%), agriculture 8.5 Mt (4.8%) and afforestation 2 Mt (1.1 %). Transportation achieved its reductions through mode and fuel switching. Industry found its reductions mainly through process changes, fuel switching and energy efficiency. Commercial gets much of its reductions through flaring landfill gas, from which it makes electricity in some cases. It also gets large reductions from energy efficiency actions. Residential gets it reductions through fuel switching, as the relative fuel prices in each region dictate, and through energy efficiency.

Table 3.1 defines energy saved, GHG emissions reduced, techno-economic costs (TEC), expected resource costs (ERC) and perceived private costs (PPC) associated with the reductions. In this table all TEC values include the electricity sector's techno-economic costs but exclude the cost of changing electricity prices.

Table 3.1:Energy, Emissions and costs associated with emissions reduction in Canada, 2010

Shadow price	**Energy Saved**	**Emissions Reduced**	**TEC w/o Trans Sector**	*TEC, All Sectors*	**TEC w/ Parked Vehicle Costs**	*ERC, All Sectors*	*ERC w/ Parked Vehicle Costs*	*Perceived Private Costs*
($ / t CO_2e)	**(PJ)**	*(Mt)*	**('95$ billion)**	**('95$ billion)**	**('95$ billion)**	**('95$ billion)**	**('95$ billion)**	**('95$ billion)**
10	941	87.6	(25.2)	(30.0)	(28.7)	(5.9)	(5.6)	2.1
20	1,028	105.0	(23.6)	(30.5)	(28.0)	(2.5)	(1.8)	6.9
30	1,098	116.7	(21.3)	(30.3)	(26.5)	1.8	2.8	12.5
40	1,172	128.0	(19.1)	(29.9)	(24.8)	6.5	7.8	18.6
50	1,232	136.2	(16.4)	(29.2)	(22.9)	11.6	13.2	25.2
75	1,298	149.1	(10.7)	(28.0)	(18.7)	25.3	27.6	43.0
100	1,354	157.6	(7.1)	(28.7)	(16.4)	39.4	42.4	62.1
125	1,402	167.2	(3.7)	(28.7)	(13.5)	54.4	58.2	82.1
150	1,450	176.6	0.2	(25.9)	(7.9)	70.7	75.2	102.9
200	1,539	187.2	9.7	(22.9)	0.4	104.2	110.0	146.5
250	1,627	198.0	18.9	(17.6)	10.8	140.1	147.3	192.7

We represent costs in transportation differently than the other sectors. Transportation reports very large negative techno-economic costs (i.e., benefits) because walking, cycling, transit and higher occupancy private vehicles cost less than single occupancy private vehicles. In the first TEC column in table 3.1, we exclude the financial savings in the transportation sector in order to give a sense of the costs facing other sectors. The second TEC column, which includes transportation, includes the negative TEC of *not* buying vehicles. These "benefits" are, however, accompanied by a very large loss of consumers' surplus. We are uncertain about the degree to which consumers who switch away from single occupancy vehicles continue to invest in vehicles and provide the reader with national level TEC and ERC costs reflecting two contrasting assumptions. The costs in columns labelled "All Sectors" assume that a change in vehicle kilometres is accompanied by a corresponding change in vehicle ownership. The costs in columns labelled "with Parked Vehicle Costs" assume that individuals continue to purchase vehicles despite switching to other modes of transportation for portions of their travel. These are extremes to the range of possibilities.

In the AMG Roll Up, a shadow price of $120 in CIMS achieved the Kyoto target. Here, it requires at least $150. The gap can be attributed to upgrades to the transportation model that endogenise more of tested actions. Overall, CIMS found a third less reductions in transportation when compared to the first Roll Up. In research subsequent to the Roll Up, we found that, while there may be great potential for mode switching in transportation, there is almost no indication of willingness to reduce overall distance traveled. At this point, we cannot answer questions regarding what would happen to disposable income, savings, investment, trade and other macroeconomic dynamics at a shadow price of $150. CIMS has some capability in this regard but, as with the Roll Up, the macroeconomic portion of the model was shut off for this study.

3.2 The Significant Actions for Canada

Table 3.2 outlines the significant actions for Canada as a whole at the $150 level; the importance of these actions at $10 is also provided. This list was established by setting a criterion of a minimum 1% contribution to total reductions at the $150 level. The reader should note that the relative importance of the actions could be different for every shadow price level; sequestration, for example, doesn't exist at $10 but is the second most important action at $150.

The most striking phenomenon is that the top four actions are from electricity production; the switch from coal boilers to high efficiency NG fired turbines and combined cycle turbines delivers the largest amount of reductions of any action. Of these actions, sequestration presents perhaps the most questions concerning its maturity and costs. Another striking phenomenon is the importance of exogenously specified actions such as commercial landfill gas, truck speed controls and sequestration of CO_2 produced during hydrogen production. These actions penetrate fully once the shadow price level reaches its specified cost; if they were modelled in CIMS, their advent would likely be at a lower shadow price and their penetration much more gradual.

4 Comparison of CIMS and MARKAL

As mentioned earlier, this national process in Canada for greenhouse gas abatement selected contrasting models to estimate costs, providing a rare opportunity to assess the importance of methodological differences in cost estimates when other input assumptions are the same. MARKAL is a well-known optimization model of the energy-economy system; CIMS is a policy simulation model developed initially for Canada. The models require the same technology and financial data, but CIMS, which does not assume financial cost minimization, also requires information on technology preferences, risk perceptions, tax effects and other critical factors in the decision making of firms and households in order to simulate their likely response to policies.

Table 3.2: The Significant Actions for Canada

All actions over 1% of total reductions at $150	$10 Mt	% total at $10	$150 Mt	% total at $150	Source
Switch to high eff. boilers and gas turbines for elec. Prod.	35.2	39.6%	30.0	16.9%	CIMS
Sequestration in electricity production	nil	nil	24.5	13.8%	CIMS
Switch to hydroelectric electricity production	5.0	5.6%	16.0	9.0%	CIMS
Electricity demand reductions	9.8	11.0%	7.6	4.3%	CIMS
NG transmission - Replace turbines with electric drivers	4.1	4.6%	7.4	4.2%	CIMS
Commercial landfill gas	6.0	6.8%	6.0	3.4%	EXOG
Transportation mode switching	0.4	0.5%	4.9	2.8%	CIMS
Residential high efficiency furnaces and shell improvements	1.6	1.8%	3.8	2.1%	CIMS
Switch to non-hydro renewables in electricity	2.4	2.7%	3.7	2.1%	CIMS
Personal car efficiency improvements	0.3	0.3%	3.3	1.9%	CIMS
Transportation: F2B truck speed control	nil	nil	3.2	1.8%	EXOG
Sequestration of CO2 from hydrogen plants	2.8	3.2%	2.8	1.6%	EXOG
Agricultural grazing strategies	2.6	2.9%	2.6	1.5%	EXOG
Other manufacturing: Fuel switching for water boilers	nil	nil	2.5	1.4%	CIMS
Other manufacturing: Fuel switching for space heating	0.8	0.9%	2.4	1.3%	CIMS
Transportation: F8C accelerated truck scrappage	2.2	2.5%	2.2	1.2%	EXOG
Agriculture: Increased no-till	nil	nil	2.1	1.2%	EXOG
Fuel switching in residential space heating	1.2	1.4%	2.0	1.1%	CIMS
Transportation: K1 Off road efficiency standards	nil	nil	2.0	1.1%	EXOG
Transportation: F10 truck driver training in energy eff.	1.9	2.1%	1.9	1.1%	EXOG
Residential hot water efficiency improvements	0.5	0.6%	1.8	1.0%	CIMS
Sum of national total reductions		86.5%		74.6%	

Given the market inertia that is incorporated in a CIMS simulation, it estimates higher costs of emission reduction than MARKAL. CIMS' present value cost estimate for Canada to achieve its Kyoto target of 6% below 1990 emissions by 2010 is $70 billion (CDN) while MARKAL's is $20 billion.[1] When linked to a macro-economic model, the GDP impact of CIMS is 3% while that of MARKAL is less than 1%. This difference would have been slightly larger had all target assumptions of the two models been identical. Furthermore, CIMS sees the point at which the Kyoto target would have been met, given that Canada acted

[1] In the first analysis, called the Roll Up analysis, CIMS' cost of reaching the target was about $45 billion (Jaccard et al. 2002). The costs reflected here have been updated to reflect the more recent cost curve set of analyses completed in 2002. As noted, these updates included corrections in model details and the endogenisation of a number of erstwhile exogenous factors in transportation and other sectors. It is true that this increase from the initial analysis might have affected the degree to which GDP may have been impacted, but the GDP analysis looked primarily at financial costs (TEC) rather than economic resource or perceived private costs. The net change in TEC costs between the two analyses was minimal.

unilaterally, at \$150 / t CO_2e while MARKAL shows that such a point would have been reached at just under \$50 / t CO_2e (see Jaccard et al. 2002).

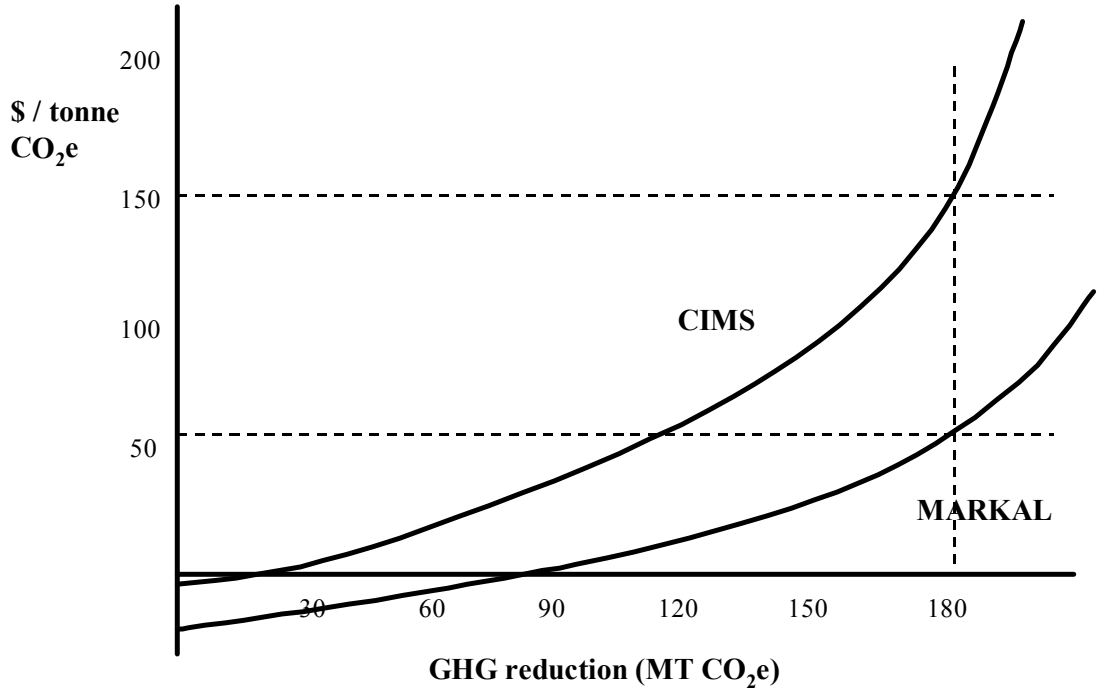


Figure 4.1: Comparison of cost curves, CIMS and MARKAL

5 Policy Implications of the Analysis[1]

Reducing GHG emissions is a major challenge facing humanity. Although policy making in any domain is rarely easy, the objective of environmental sustainability, including GHG emissions, has several attributes that make it a special concern for policy making in modern democracies:

1) It is difficult for people to connect their actions as consumers with the local environmental impacts that concern them as citizens
2) The environmental effects of human activity are increasingly global and intergenerational – the current generation in one region does not see the impacts on those of future generations or other regions. Furthermore, these "impacts" may be highly uncertain.
3) The current economic system is monolithic and slow to change; it does not include means to address the environmental issues we face because the environment has been treated as a free and unlimited waste receptacle.

In estimating the costs of reducing Canada's GHG emissions, we applied a simplifying assumption about the policy instrument that government would use to reduce these emissions – we tested an economy-wide emission cap and tradable permit system. Applied to the entire country, this policy can provide a single financial signal to all decision-makers in the economy and should improve the chances of an economically efficient outcome. We also assumed that the policy causes no transfers of wealth, although some sectors and regions will face higher marginal costs than others. However, the ideal policy, from an economic efficiency perspective, may be politically difficult to implement for any number of reasons:

[1] This section is a summary of Jaccard, Nyboer, Sadownik, 2002, chapter 8.

- public and media suspicions when governments intervene with economy-wide policies
- the difficulty of getting the public to understand and support the costly or otherwise unpopular aspects of a policy
- complex implementation
- concentration of impacts on certain sectors and regions or unintended transfers of wealth
- great uncertainties about the pace and character of technological developments
- the potential for significant shifts in consumer preferences.

5.1 A Framework for GHG policy options

Figure 5.1 provides a framework for the broad categories of policy instruments for pursuing environmental improvement. These instruments are arranged along a continuum in terms of their *degree of compulsoriness*. This term best expresses the extent to which a certain behaviour is required by an external force. A fully compulsory policy specifies exactly what must be done and non-compliance is not an option because of the severity of the penalty. A less compulsory policy may require action by society in aggregate, but confers some degree of choice on the firm or household. Policies are fully non-compulsory if the firm or household has the option to do nothing without suffering any negative consequences.

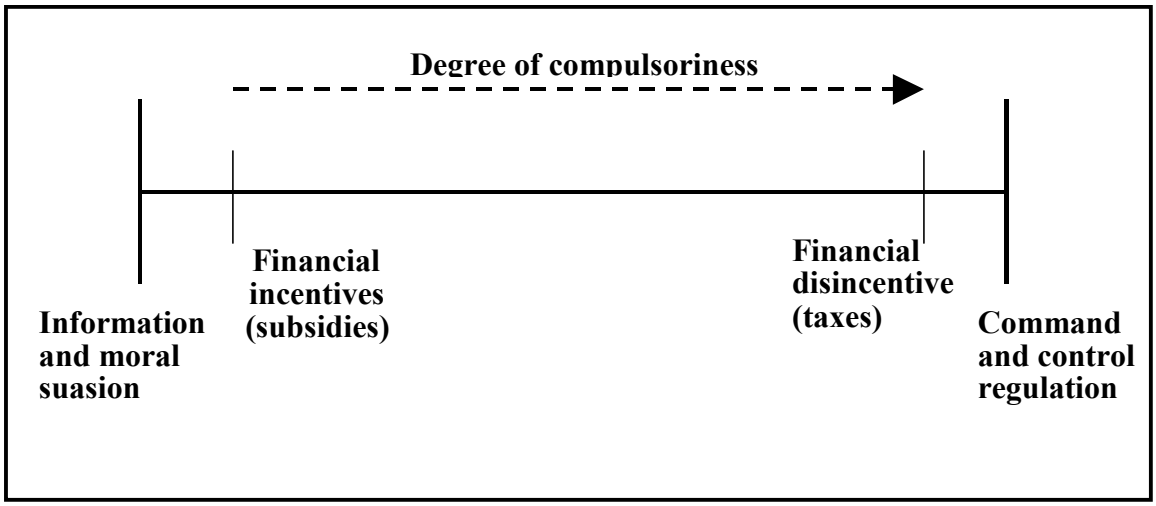


Figure 5.1 Continuum of policy instruments according to degree of compulsoriness

Non-compulsory policies are on the left side of the continuum. This includes policies in which government facilitates or initiates the development and dissemination of information (research and development, advertising, labelling, certifying, providing demonstration projects) that might influence the decisions of households, firms and perhaps other levels of government. It represents a decentralized approach to policy making and a non-coercive role for government. Thus, consumers might include environmental performance alongside financial considerations in their product selection. We also place financial incentives (subsidies) on this side of the continuum, although not at the far left. These are grants, loans,

tax credits and similar policy instruments that improve the financial returns for consumers, businesses and even other levels of government who take actions to improve the environment.

Traditional, command-and-control regulations are on the right side of the continuum. These include mandatory building codes, equipment specifications, vehicle and appliance standards, technology requirements, emission limits, prohibitions on the production and use of certain chemicals, and other kinds of regulations. These regulations are enforced by financial penalties and even legal sanctions for non-compliance, and are therefore at the extreme end of the policy continuum. Often criticized as an unnecessarily expensive way of achieving environmental objectives, such policies are insensitive to cost differences of pollution abatement between different consumers and different firms, or between locations. Usually, all participants are required to behave in a similar manner (technology choice, emission level) even though some may be able to do more at a lower cost than others. To economists, this approach prevents application of the equi-marginal principle, under which total costs of environmental improvement are minimized because every agent has the same marginal costs.

Environmental taxes, such as GHG emission taxes, are unit charges for emissions that force firms and households to pay for some or all of the damages they cause to the environment. They are situated toward the compulsory end of the policy continuum because either action or tax payment is required. Indeed, the use of taxes as a policy instrument is often portrayed today as evidence of a coercive and intrusive government. Additional suspicion is generated by the concern that taxes reflect government revenue needs rather than economic efficiency goals.

As the above discussion suggests, progression along the continuum from left to right is not only associated with increasing compulsoriness, but also generally with decreasing policy acceptability. Governments recognize this, or soon learn from painful experiences, and quite naturally prefer the left side of the continuum. Unfortunately, the continuum also appears to correlate roughly with another dimension—policy effectiveness. The challenge for policy making is to find policy designs that do better than others in trading off the conflicting factors of the continuum. The ideal policy, then, is one that is highly effective and yet passes the test of public and corporate acceptability (i.e., is not seen as unfair or overly compulsory). Some policies will do better than others in meeting this challenge.

5.2 Promising New Policy Instruments

Two new types of policy instruments that have emerged over the past decade are positioned in about the middle of the continuum of Figure 5.1 in that they both include some degree of compulsoriness, yet also allow considerable flexibility to firms and households. We refer to one as environmental tax shifting and the other as market-oriented regulation.

Environmental tax shifting involves levying environmental taxes and recycling all of the tax revenue as rebates to those who pay the taxes or as reductions in general taxes or charges. While the idea of governments linking the increase of some taxes with the decrease of others is not new, its application to environmental policy has only recently been articulated as a comprehensive strategy. Thus far, there have been several tentative initiatives in environmental tax shifting in most industrialized countries as well as more serious applications by some European governments (Svendsen et al. 2001). Modest initiatives include policies like deposit-refund schemes and *vehicle feebates* while more ambitious initiatives under consideration involve the application of greenhouse gas tax revenue to reduce government payroll charges, income taxes or other broad levies (Taylor, et al, 1999).

Market-oriented regulation is a form of regulation in that an aggregate target, such as an economy-wide emissions cap or a level of technology market penetration, is compulsory. Also, all firms and households are involved in some way and non-compliance has dramatic

cost and / or legal consequences. However, market-oriented regulation is unlike traditional, command-and-control regulation, and more like an environmental tax, in that the manner of participation is at the discretion of the firm or household. Some of them may contribute to the achievement of the aggregate target by reducing emissions or acquiring the designated technology, while some may instead pay others to do more in order to make up for their unwillingness to reduce emissions or to acquire a technology.

The best-known example of a market-oriented regulation is the *cap and tradable permit*. This is a regulation that sets a total emission limit, or cap, for whatever entity is being regulated—several firms or an entire country or the globe. Shares of this emission limit are allocated as permits by some method (historical levels, auction, some combination of these) to individual participants (businesses, provinces, even countries depending on the scope of the program). The regulation would include rules for decreasing the total cap over time and for determining how new participants in the program would access permits. The shares are tradable, in effect providing a specified right to pollute that can be traded just like any property right.

The cap and trade regulation has attractive features from a policy design perspective. First, as a form of regulation, albeit aggregate regulation, the policy has a high likelihood of achieving the environmental target. In contrast, voluntary programs and environmental taxes are substantially more uncertain in terms of target achievement because a specific outcome is not compulsory. The outcome depends on the shifting motives of firms and households (voluntary) or their responsiveness to changing prices (price elasticity in response to fiscal policies). Second, by allowing trading among participants, the cap and trade regulation can function like a tax in providing a uniform cost signal to all participants—the permit trading price—that helps minimize the total costs of achieving the target.[1] Third, as long as there is a positive price for permits, there remains an incentive for further innovations that profitably reduce emissions; in contrast, once one has satisfied a regulation that specifies a certain technology or emission level for each emitter, there is no incentive to do more. Fourth, the policy has the flexibility of a tax in allowing each emitter to determine their optimal combination of emission reduction and permit purchasing. In this sense, it does not seem to be as compulsory as conventional command-and-control regulations. Thus, the policy can be situated along with environmental taxes in about the middle of the policy continuum of Figure 5.1.

Two other market-oriented regulations are briefly defined here. The *renewable portfolio standard* (RPS) requires that providers of electricity guarantee that a minimum percentage of their electricity is produced using renewable energy. The *vehicle emission standard* (VES) requires automobile manufacturers to guarantee that a minimum percentage of vehicle sales meet different categories of maximum emission levels. This policy originated in California and is the central focus of that state's efforts to improve local air quality.

5.3 Assessment of Policy Options for GHG Emission Abatement in Canada

Environmental policy is almost inevitably a package of different policy instruments working in combination. Government policies reflect the competing preferences of politicians and interest groups, and these are not static over time. Also, there is usually a life cycle to policy issues. In the early stages of issue awareness, governments are less likely to operate on the compulsory side of the continuum. There is still too much uncertainty about the environmental risks and the public's perception of the issue for government to push ahead with policies that will impose costs on some. GHG emission abatement policy is influenced by these factors.

---

[1] In practice, several conditions need to be met for cost-minimization, a critical one being the existence of fully competitive permit trading markets.

While regulatory approaches have been downplayed, they have not been entirely absent. First, ongoing processes since the 1970s to tighten various regulations have continued over the past decade. Governments now link these to their GHG actions. Examples include stricter energy efficiency standards for buildings, appliances, industrial equipment and vehicles. But these regulations are not pursued as a leading instruments for GHG abatement; their role is more to consolidate technology transformation by ushering out the least energy efficient equipment, processes and buildings.

Because of this, the present period is dominated by governments appearing to take action while avoiding initiatives that would incur the kinds of costs for firms and households that appear to be necessary according to our cost estimates in this study. This preference favours information and voluntary policies over others. The major focus of Canadian GHG policy over the last decade has been to explore how far the country might get with actions that are driven mostly by policies from the non-compulsory side of the policy continuum. But is voluntarism and information to improve your profit potential enough? Our cost analysis suggests that while meeting a target such as Kyoto may not be cataclysmic to the Canadian economy, it will have not insignificant financial and intangible costs to firms and households. In other words, our results, and those of other models that incorporate consumer preferences, suggest that much more will be required.

5.4 Our Preferred GHG Abatement Policies

This review of policy options and the results of our cost estimation leads us to develop our own list of key criteria for designing GHG abatement policy in Canada. We present these criteria and then follow with a suggested package of policies that would best meet them.

5.4.1 Criteria for Policy Design

- The GHG challenge is a long-term challenge and as such calls for policies that operate on the long-term determinants of GHG emissions.
- GHG policy should reflect the information from cost analyses, such as ours, for determining how much can be realistically achieved in what time frame by firms and households.
- GHG policy should be realistic about consumer preferences if it is to succeed in terms of public acceptability.
- GHG policy should be realistic about the relative long-term importance of value and preference changes versus financial incentives and technology changes.
- GHG policy should, wherever possible, seek synergies with other non-GHG values and objectives.
- Setting GHG policy is a classic case of decision-making under uncertainty and this reality should be embraced instead of ignored or used as an excuse for inaction. This means that policies should be selected based on how well they perform (their robustness) under highly variable outcomes and even highly variable reference cases.
- GHG policy design must be especially sensitive to regional and sectoral cost incidence.

5.4.2 Preferred Policies

- **An Enthusiastic Yet Sober Approach to Voluntarism** - While there is great potential for voluntarism, we are sceptical that firms and households will voluntarily take on the magnitude of costs and preference changes shown by our study to be necessary. Supporting policies will be required.
- **Selected Command-And-Control Regulations -** Conventional, command-and-control regulations can serve as follow-up policies, but will serve a fairly modest role.
- **Subsidies to Support Technologies, Buildings and Infrastructure, especially via Tax Credits -** Tax credit policies are often criticized by economists because they: may involve governments in selecting the winning and losing technologies; do not result in prices that reflect pollution costs, thereby missing the incentive benefits of pollution taxes; and require that undesirable taxes be higher than they otherwise need to be in order to offset the resulting lost government tax revenue. But tax credits score well on public acceptability and can be quite effective if designed carefully and with an understanding of relative costs in different sectors and activities in the economy.
- **Sector-Specific, Market-Oriented Regulations to Drive Fundamental Change** - Sector and technology-specific policies risk uneconomic outcomes to the extent that they may cause some unnecessarily high cost actions to be taken. However, a target in the range of the Kyoto Protocol is so far below the level needed just to stabilize atmospheric GHG concentrations that small movements up the marginal cost curves in almost any sector of the economy are likely to be economic in terms of the long-term environmental objective. This provides an opportunity for those sector-specific policies that can be applied in a cautious and flexible manner that minimizes the risk of uneconomic outcomes (e.g., RPS and the VES).
- **A Modest Economy-wide Cap and Tradable Permit System that Operates Initially Like a Tax** - The Canadian public is not yet ready for environmental tax shifting to play the leading role in GHG emission abatement. Likewise, the singular use of an aggressive cap and tradable permit system, as assumed in our cost analysis, will fail the political acceptability test. However, voluntary initiatives by industry would be encouraged by at least some indication from government that GHG emissions will one day have a cost. A modest, economy-wide cap and tradable permit system could be established fairly quickly if it were structured with an upper cost limit in its early years.

5.5 Conclusion

Of the range of policy options for GHG emission abatement, governments today are especially enamoured with non-compulsory approaches such as information programs, voluntary initiatives, public-private partnerships and modest public subsidies in the form of tax credits. However, our cost estimates suggest that these approaches alone will not be enough if Canada is to achieve a GHG abatement target such as Kyoto. Some integration of more compulsory policies will be required. The challenge is that such policies generally involve a significant increase in energy prices and this will quickly provoke a reaction of consumers and the media that politicians will not be able to overlook.

Fortunately, there may be another way of providing long-term signals to technological innovation and product marketing. A new generation of market-oriented regulatory policies can provide a significant, long-run financial signal without substantially increasing energy costs and budgets in the short-term. Early implementation of such policies can help to provide information about technological opportunities that, in turn, can reduce major cost uncertainties.

6 Literature Cited

AMG / NCCIP. 2000. *An Assessment of the Economic and Environmental Implications for Canada of the Kyoto Protocol.* Natural Resources Canada, Analysis and Modelling Group, National Climate Change Implementation Process, Ottawa. November 2000)

EMRG / MKJA. 2000. *Integration of GHG Emission Reduction Options Using CIMS.* Simon Fraser University, Burnaby BC.

EMRG / MKJA. 2002. *Construction and Analysis of Sectoral, Regional and National Cost Curves of GHG Abatement in Canada*. Simon Fraser University, Burnaby BC.

Jaccard, M., R. Loulou, A. Kanudia, J. Nyboer, A. Bailie, M. Labriet. 2002. *Methodological contrasts in costing greenhouse gas abatement policies: Optimization and simulation modeling of micro-economic effects in Canada*. European Journal of Operational Research, In Print.

Jaccard, M., J. Nyboer, B. Sadownik. 2002. *The Cost of Climate Policy*. UBC Press, Vancouver BC.

Svendsen, G., C. Daugbjergand and A. Pedersen. 2001. Co*nsumers, Industrialists and the Political Economy of Green Taxation: CO_2 Taxation in OECD.* Energy Policy 29, no. 6 (2001): 489-497.

Taylor, A., M. Jaccard and N. Olewiler, *Environmental Tax Shift: A Discussion Paper for British Columbians*, Green Economy Secretariat, Government of British Columbia, Victoria, 1999

Three big C's: Climate, Cement, and China

Joakim Nordqvist[1], Lund University, Sweden
Christopher Boyd, Lafarge, France
Howard Klee, World Business Council for Sustainable Development, Switzerland

Abstract

Cement is a low-cost construction material whose manufacture generates significant carbon dioxide emissions. As these emissions enter a carbon-constrained world, they may ultimately have a significant impact on the industry's financial performance. Consequently, the cement industry is developing a response to climate change management and the connected political process. In 1998, world-wide cement production caused carbon dioxide emissions of roughly 760 million tonnes, not counting the industry's use of fuels and electricity. In comparison, UK, the seventh largest carbon dioxide emitting country in 1998, contributed, in total, some 540 million tonnes.

Following an extensive research and stakeholder consultation program, ten of the world's leading cement-producing corporations, representing more than one-third of global cement production, have published in 2002 a joint Agenda for Action to address sustainability issues for the industry. These include, as one of the cornerstones, climate change. Other highlighted issues are emissions reduction, use of fuels and raw materials, employee health and safety, local impacts on land and communities, and internal business processes. Examining the rationale and effects of proactive climate initiatives in the cement sector, this article elaborates on the conditions for diffusion of cement-related climate action to China, where more than one-third of global cement production occurs, 80 percent of which in inefficient kilns using outdated, highly polluting technology.

1. Introduction

In 2000, the *Cement Sustainability Initiative* was launched, involving ten corporations that together produce one-third of all the world's cement. Under the watchword of "Toward a sustainable cement industry", and co-ordinated by the World Business Council for Sustainable Development (WBCSD), the initiative resulted, in July 2002, in the publication of an Agenda for Action (WBCSD 2002b), signed by the business leaders of all the participating companies. Through this agenda, a first five-year action plan has been drafted to define short-term ambitions, as well as necessary partnerships for joint and individual actions, identified in the process. Climate protection constitutes a core component of the Agenda.

This paper relays insights and experiences learned so far from these combined efforts. It aims to show and discuss the rationale for, and consequences of, this proactive initiative based on

[1] Environmental and Energy Systems Studies, Lund University, Gerdagatan 13, SE-223 62 Lund, Sweden
Joakim.Nordqvist@miljo.lth.se

the perspectives of both the programme manager and a participating party, namely the French transnational building materials group Lafarge. Another objective is to elaborate on what possible effects the initiative may or may not have on Chinese cement production, hitherto structurally and technically separated from the otherwise largely internationalised stage of actors, yet supplying more than one-third of global cement. The study thus provides a perspective on the issue of industrial development of the third world and of the extent to which corporate environmental responsibility and stewardship may become an integral part of such development. As the Cement Sustainability Initiative continues into its subsequent phases, cement production in China could become an appropriate stage for studies and analyses of theories about sustainability and development in the third world.

2. Cement, the industry

Cement is the basic constituent of concrete, used in construction of buildings, roads, and other types of infrastructure all over the world. The principal raw material for manufacture of cement is limestone, which, crushed and ground, is fed through a kiln to produce an intermediate material called clinker. Clinker production is an energy intensive process, which requires extremely high temperatures: typically between 1200 and 1600 degrees Celsius inside the kiln. After the clinker is cooled, it is mixed with various proportions of additives, such as gypsum, to make cement.

The predominant use of fossil fuels in cement making contributes to emissions of considerable quantities of carbon dioxide. But this is less than half the story. Emissions from fuel combustion typically amount to only 40 to 50 percent of total carbon emissions from cement production. In addition, large amounts of carbon dioxide are released from the raw material itself, in a process called calcination, making the sector the largest, non-energy source of anthropogenic greenhouse gas emissions. According to Marland et al. (2001), calcination of lime stone in cement kilns produced, in 1998, world-wide emissions exceeding 200 million tonnes of carbon, or, in total, 760 million tonnes of carbon dioxide (c.f. Hendriks et al. 1999). This corresponds to over three percent of the emissions from global burning of fossil fuels. Table 1 shows, for comparison, the world's top ten carbon dioxide emitting countries in 1998.

Table 1. World's top ten countries by 1998 total CO_2 emissions from fossil-fuel burning, cement production, and gas flaring (Marland et al. 2001).

	Mt C	Mt CO_2
World total	6 610	24 200
United States	1 490	5 450
China	848	3 110
Russia	392	1 440
Japan	309	1 130
India	290	1 060
Germany	225	826
United Kingdom	148	543
Canada	128	468
Italy	113	415
Mexico	102	374

In relation to the cost of production, transportation of cement is expensive and quickly becomes uneconomical as distances increase. The competitive range for road transport is roughly 200 km, and about the double for rail. Therefore, exports and imports of cement or

clinker are limited compared with local or domestic production. Freight by ship is the only way to profitably transport cement over large distances. As a consequence, production of cement is spread out across the globe to serve local markets. Even so, there is a clear consolidation trend among actors, and a circle of transnational groups now dominates large parts of the sector. Table 2 displays the sales volumes and world market shares of the five largest cement corporations in 2001.

Table 2. Cement sales volumes and world market shares of the world's top five cement producing corporations. Lafarge estimates for 2001.

	World total	Lafarge	Holcim	Cemex	Heidelberger	Italcementi
Mt	1700	88	84	61	47	42
Share	100 %	5.2 %	4.9 %	3.6 %	2.8 %	2.5 %

3. Cement producers' proactive responses to climate change

The high carbon intensity of the industry provides international cement producers with a strong rationale for proactive responses to climate change. The implications on industry of commitments by the governments of countries in Annex B to the Kyoto Protocol remain to be seen, but policies and regulations are to be expected, that penalise heavy emitters, and that benefit those who perform better. Moreover, and regardless of present controversies and debates about the Protocol as such, the awareness of carbon constraint has entered the worlds of both politics and business (Stigson 2001). New opportunities to increase markets and intangible assets, as well as to avoid costs, emerge for actors who can adapt. Such reasoning supports first-mover strategies and proactivity, especially—in the short term—among actors who have a large stake in markets in Annex B countries that claim to adhere to their Kyoto commitments. In their Agenda for Action, the participants of the Cement Sustainability Initiative state: "We have chosen to adopt an agenda for sustainable development for three reasons: to prepare ourselves for a more sustainable future; to meet the expectations of stakeholders; and to individually identify and capitalize on new market opportunities" (WBCSD 2002b; c.f. WBCSD 2002a, and Sprigg and Klee 2002).

3.1 The Cement Sustainability Initiative

In 1999, three of the largest cement groups—Cimpor, Holcim, and Lafarge—approached WBCSD, requesting assistance in organising a structured evaluation of the important issues facing the industry in terms of sustainable development. From this request, the Cement Sustainability Initiative grew and was launched in February 2000, by which time the group of producer participants had come to encompass the following ten corporations, together forming the so-called Working Group Cement:

Cemex, Mexico
Cimpor, Portugal
Heidelberg Cement, Germany
Holcim, Switzerland
Italcementi, Italy
Lafarge, France
RMC, United Kingdom
Siam Cement, Thailand
Taiheiyo Cement, Japan
Votorantim, Brazil

Alongside the Working Group, key parties of the Initiative include a Sponsoring Group to provide intellectual and funding support, a Lead Consultant to organise research and produce reports, an objectively reviewing Assurance Group, and, not least, the WBCSD Secretariat serving as Programme Manager.

During the two years following the launch of the Initiative, seven Stakeholder Dialogues were arranged (in Brazil, Thailand, Portugal, Egypt, USA, Belgium, and China) and thirteen substudy reports were published, resulting, in March 2002, in a concluding report (Battelle 2002). The Agenda for Action, published a few months later, represents the reaction of the Working Group members on this report.

In the concluding report eight key issues for the industry are presented against the background of the so-called triple bottom-line of sustainable development, which comprises economic prosperity, environmental stewardship, and social responsibility. The eight issues, identified and selected as a result of the work presented in the substudies, are: Resource productivity, Climate protection, Emissions reduction, Ecological stewardship, Employee well-being, Community well-being, Regional development, and Shareholder value. The issue of climate protection is specifically elaborated on in substudy 8 (Humphreys and Mahasenan 2002). Here, potential actions are suggested for the sector to improve its performance in the short as well as the medium and long terms, involving several types of actors including the industry, authorities, and non-governmental organisations. Specific carbon dioxide reductions (in tonnes CO_2 per tonne product) of approximately 30 percent by 2020 (compared with aggregated levels in 1990) are assumed possible. However, as country-specific conditions vary considerably, opportunities and requirements to reduce emissions will also vary among individual companies.

Based on the above key issues, the concluding report presents benefits of progress, and the current sustainability status of the industry. It also suggests a vision for the future, as well as goals and key performance indicators, and derives a set of ten recommendations for the industry. The second of these recommendation addresses climate change, calling for the establishment of corporate carbon management programmes, statements of medium-term CO_2 reduction targets, both company-specific and industry-wide ones, and the initiation of long-term processes within areas such as product innovation.

In response to all of these proposals, the Agenda for Action highlights six priority areas, within which collaborative and individual actions will be focused during the subsequent and implementing phases of the Initiative:

- Climate protection
- Fuels and raw materials
- Employee health and safety
- Emissions reduction
- Local impacts
- Internal business process

Why, then, has the industry undertaken this multi-year effort of so far approximately 4 million USD? To understand this, it is important to see how sustainable development issues match those of the cement industry. Figure 1 illustrates how the triple bottom-line of sustainable development is coherent with current industry concerns. In short, sustainable development provides the industry with a comprehensive framework for tackling some of the biggest issues it faces today, including climate change, and therefore, the industry's business leaders believe it is central to their progress towards creating effective and efficient businesses in the 21st century.

Applying this view to the specific issue of climate protection highlights the value of taking a comprehensive viewpoint. From a financial perspective, one might estimate carbon costs at currently 5-25 USD per tonne of CO_2. These values may equal or exceed the average margin of today's cement producer. Reducing carbon dioxide emissions will require a variety of strategies including energy efficiency improvements and using different fuels and raw materials in the cement manufacturing process. Yet some of these substitutions remain controversial, indicating an urgent need for better understanding and communications with stakeholders (including employees) about the risks, benefits and management of these alternative materials.

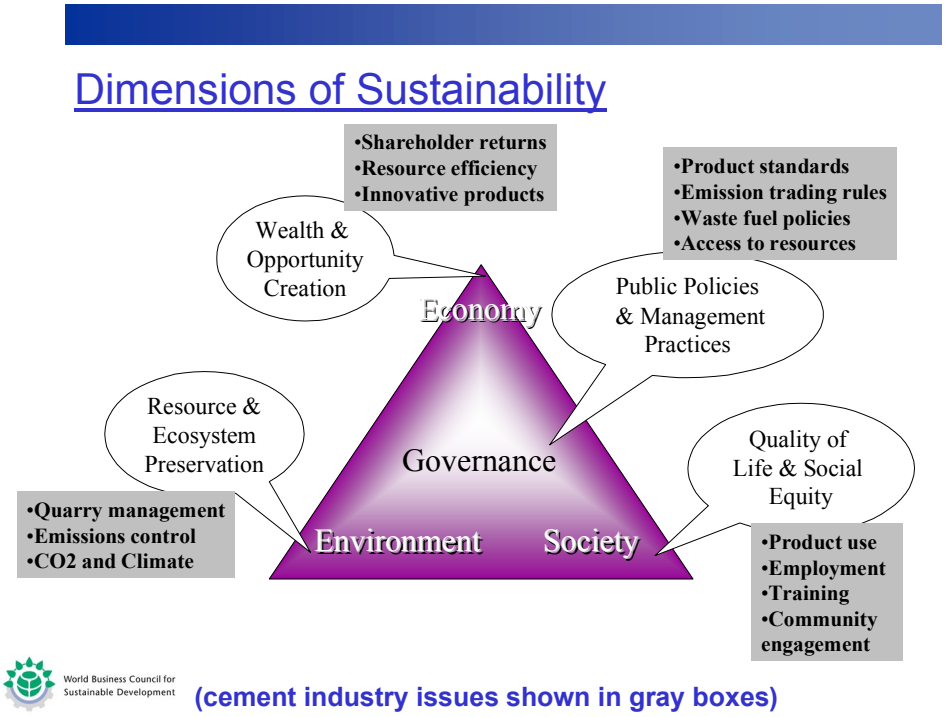


Figure 1. Illustration of confluence between sustainable development goals and important priorities for the cement industry.

One early output from the Cement Sustainability Initiative has been the production of a Carbon Dioxide Accounting Protocol to provide a common framework for monitoring and reporting carbon dioxide emissions (Vanderborght and Brodmann 2001). The framework, developed in consultation with the World Resources Institute and the WBCSD, now provides an agreed and well accepted methodology for dealing with carbon dioxide in this industry; an essential first step before trading and other market mechanisms might be used successfully. It is also an essential first step for any company to understand both the quantities and costs of their carbon dioxide emissions.

3.2 Lafarge corporation

Founded in France in 1833, Lafarge is now a world-leading transnational corporation within the construction materials industry, present in 75 countries across the world (Lafarge 2001). Since 1999 its operation is organised into four autonomous divisions, of which Cement is the dominating one. Through several mergers and acquisitions, the latest of which in 2001 when the British manufacturer Blue Circle was acquired, Lafarge's Cement Division has become the world's largest cement producer with around 160 production sites, and a total production

in 2001 of close to 90 million tonnes. A large share of this production is located in developing countries.

Lafarge prides itself of its management strategy—the "Lafarge Way"—based on a model of participatory and social, human-oriented management. Not only the group's own employees, but a wide array of external stakeholders are included in the scope of its efforts in this area. As a result, this corporate tradition has evolved and been developed over the decades to include a high level of awareness of, and a proactive approach towards, environmental issues. A measure of the importance attributed to such issues by Lafarge in later years is given by the corporation's participation as co-founder of several initiatives: the WBCSD (1991), the French association Enterprises pour l'Environnement (1992), and, most recently, as the first major industrial participant in WWF's (the World Wide Fund for Nature) Conservation Partnership Programme (2000).

Admittedly a troublesome concern for a cement manufacturer, Lafarge recognises both the environmental and the business-strategic importance of climate-change mitigation. Hence, within the framework of its partnership with WWF, the group has taken on a clear and proactive approach, declaring its preparedness to shoulder its climate responsibility by making a unilateral commitment. In November 2001, Lafarge announced its intention to decrease its absolute carbon dioxide emissions in industrialised countries by 10 percent from 1990 to 2010 (see Note 1). This initiative might be compared with the Kyoto commitment of the European Union to reduce its greenhouse gas emissions by 8 percent. In addition to this first target, which is related to but not dependent on production volume, Lafarge also makes a more general commitment of decreasing globally by 20 percent from 1990 to 2010 its specific carbon dioxide emissions (in kg CO_2 per tonne cement).

Three principal strategies are brought forward as means through which to fulfil these reduction objectives:

- Energy efficiency,
- Energy substitution, and
- Materials substitution.

Where applicable, greater energy efficiency may be realised through investments in technical upgrades or process changes to reduce losses of heat and calcined particulate matter. Energy substitution, meaning a switch to less carbon-rich fuels than presently predominating coal and petroleum coke, may reduce greenhouse gas emissions by considerable amounts. In particular, Lafarge considers waste-derived alternative fuels as an interesting option, whereas natural gas and renewable energy such as biomass are less attractive from a cost perspective. Due to the intense heat in a cement kiln, it is quite suitable for waste incineration of, for example, used engine oils, solvents, and tires, a process for which there is an increasing need not least in Europe, where stricter regulations on waste disposal are being introduced. Since such incineration would reduce overall consumption of primary fossil fuels, Lafarge, in its own bookkeeping, considers it to be carbon dioxide neutral. On this point, opinions differ between the company and its partner WWF (see Note 1). Also, the use of waste as an alternative fuel source can be problematic as it may worry local stakeholders, causing emotional debates (c.f. WBCSD 2002a, and Sprigg and Klee 2002). Materials substitution, finally, involves making use of cementitious properties mainly in by-products from other industries, thereby replacing partly the clinker used in cement. Blast-furnace slag from steel production and fly ash from coal-fired power generation are two well-known and established examples of such by-products. Reducing the need to produce clinker obviously reduces carbon dioxide emissions.

3.3 Outcome

The Cement Sustainability Initiative has provided a rich set of reference materials about the cement industry and sustainable development. More than 1500 pages of research reports were developed during the study phase. Since March of 2002, when the results were released (and until October 2002), more than 100 000 documents have been downloaded from the project web site, indicating quite a remarkable interest in such a specialised topic in an industry with a very low public profile.

More importantly, the Initiative has provided a possible model of changing industrial performance by following a process of independent expert research, extensive stakeholder consultation, co-operative industry planning, and peer review of the entire process. It is noteworthy both for its magnitude and its timing in the absence of crisis "firefighting" or industry failure. Moreover, the risks of being a single first-mover have been handled by adopting a united front, although a line has also had to be drawn between co-operation and competition. This aspect is evident in the Agenda for Action, the first comprehensive, voluntary plan in the cement sector to address real industry needs: commitments for each of the six priority areas presented are split into joint and individual actions to be taken over an extended timeframe. These actions include developing sets of good practice guidelines in several areas, agreeing on common standards for measurement and public reporting of performance, improving stakeholder engagement, and communicating publicly about progress. Of course, the real proof of a successful approach will be in the results achieved, not in the plans made, and it is still too early to assess results. The formal publication of the action plan and time line has just occurred in July 2002.

The members of the Working Group Cement only form part, albeit a substantial one, of the global cement sector. In order to really live up to their motto of "making a difference", a wider stance is necessary, and therefore the Sustainability Initiative is designed to be inclusive. Creation of enterprise value, importance of stakeholders, and developing country concerns are topics that have been brought forward. Not least from such perspectives will the longer-term outcome of this Initiative be interesting to monitor (c.f. Nicholls 2002).

As a commodity, cement is limited to regional markets, but as actors, cement producers operate globally. Therefore, it can be argued that this sector offers a particularly suitable stage for observations of the effects of proactive, industrial sustainability strategies. In some trade theories, concepts such as *pollution havens* and *race for the bottom* imply that mechanisms exist that compel authorities (not least in developing countries) to use lax environmental standards for industry as a means of encouraging foreign investments and relocations of industry (Rauscher 1999). The real effects of such mechanisms are disputed, but cannot be expected to interfere with cement production, which will not move easily from local markets. Instead, and as a consequence, the sector presents an opportunity for investigations of the conditions for, and possible effects of, a converse relation: the *pollution halo*. Through this mechanism, it is assumed that sound environmental practises may diffuse among local actors, producers as well as authorities, once fore-runners demonstrate the potentials for new corporate values to create business advantages (OECD 2002, 584).

Though there may be no immediate crisis for the international cement industry, it is clear that the climate issue poses real, potential risks for the future, including risks of business impediments. The ongoing political and scientific processes of the United Nations Framework Convention for Climate Change (UNFCCC) and the Kyoto Protocol make this evident. It is not explicitly stated in the documentation of the Initiative, still it is not misleading to point out these factors as driving forces for many Working Group members to participate. Not surprisingly, the corporations with large markets in Europe have been among the most active ones within the Initiative.

3.4 By-standers

Not all cement companies participated in the Sustainability Initiative. The research phase involved substantial contributions of both time and funds, and many companies lack the resource base to make these contributions. This is not surprising. After all, the Initiative is one of leadership, through which major and leading companies are trying to set a long-range programme in place. Not everyone can nor wants to be a leader, but in its effort to be inclusive, the Initiative is making all of its results publicly available and promoting them via consultation with trade associations and others, hoping that other companies will adopt parts of the programme that suit their circumstances and capabilities. That way, they will not have to spend their resources developing other approaches or solutions. It is encouraging to note that several other cement companies now express interest in joining the Initiative, including Uniland from Spain, Secil from Portugal, Titan from Greece, and several others.

4. Developing countries

Within the Cement Sustainability Initiative, three corporate members are based in developing countries (Cemex, Siam, and Votorantim), and others, like Lafarge, have substantial business interests in the third world, where opportunities for growth and expansion still are significant. Issues of particular importance to developing countries are naturally brought forward within the Initiative.

Perhaps even more acutely than in other parts of the world, the triple bottom-line of sustainability, as a whole, represents a pressing challenge for authorities as well as for business in developing countries. Economic prosperity and socially secure living conditions are urgent needs for people in poverty-stricken areas. When the pursuit for development occurs at the expense of environmental stewardship, however, serious problems that are detrimental to sustained improvements in economy and welfare alike will ensue in the longer run. Common barriers to balanced development in developing countries are lack of capital and capacity, and inefficient governance. Through their expressed commitment to the triple bottom-line, as well as through their stakes and interest in third world countries, the Initiative members might contribute, in line with theories such as the pollution halo hypothesis, in lowering somewhat the thresholds of such barriers.

Meant to reinforce and strengthen this kind of incentives in business, the Kyoto Protocol provides industry with the so-called Clean Development Mechanism (CDM). The CDM allows for the generation of Certified Emission Reductions (CERs) when a project, undertaken in a non-Annex B country, results in reductions of greenhouse gas emissions compared to a baseline scenario in absence of that same project. After being issued, the CERs may be traded and used in countries that need them to stay in compliance with their commitments to limit emissions as stated in Annex B to the Protocol. Many details remain to be settled before CDM projects can get under way, and there is a lot of justified uncertainty about what real effects they might get in reducing greenhouse gas emissions and promoting sustainable business initiatives in the third world. Still, among transnational cement corporations, the evident and considerable potentials for emission reductions that exist in developing countries today are reasons enough for a serious interest in future CDM projects to be expressly stated. Technical facilities, know-how, and equipment, as well as developed practices and transparency in management, may diffuse through business investments and lead to real improvements within the global cement sector. Although uncertainty remains about the mechanism as such, the CDM framework does currently represent an additional spur for cement corporations to consider such investments for the future.

For the cement industry, China is a particularly important developing country, interesting from a CDM perspective but also because of the sheer size of its market. From a sustainability point of view, opportunities for improvements are also great. The next few sections of the article expand on this topic.

4.1 China's cement sector

Since China began its economic reform policy in 1978, Chinese cement production has increased more than seven-fold. Today, around 600 million tonnes of cement are produced every year in China alone, representing more than one-third of global cement production. Figure 2 illustrates the magnitude of China's cement sector in 1998 compared with the aggregated shares of the twelve next largest cement-producing countries.

Chinese cement production attracts attention not only due to its volume. The unusual structural and technical profiles of China's cement industry are also a characteristic feature. In contrast to the large-scale plants, in terms of production capacity, and the high degree of corporate consolidation that are seen elsewhere, enterprises in China are generally very small, as well as scattered both geographically and in terms of ownership. And, whereas rotating cement kilns dominate internationally, Chinese output is mainly generated in vertical shaft kilns, which are rare in most other parts of the world.

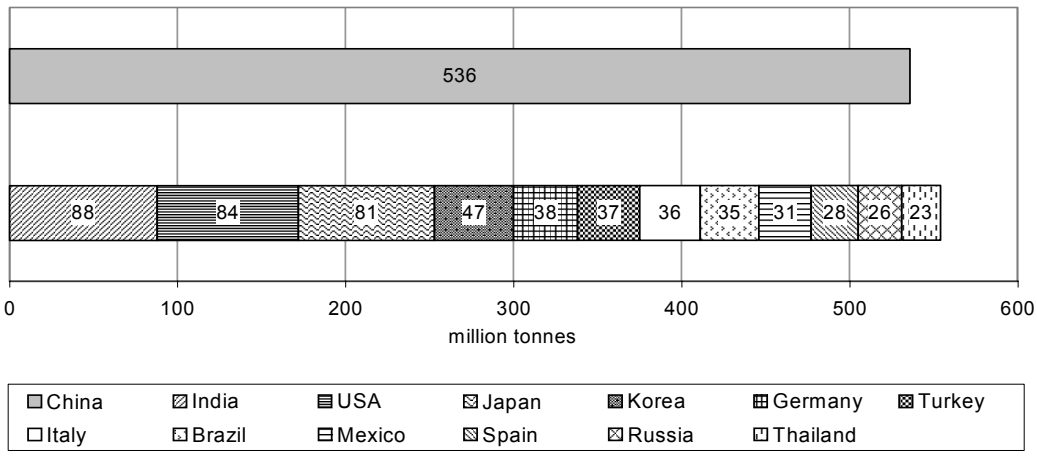


Figure 2. Cement production by country in 1998 (see Note 2): China compared with the aggregated production of the twelve next largest cement-producing countries (UN 2001).

Prior to market reforms, regional self-sufficiency was highly promoted in China, both in agricultural and industrial production. A tradition of small-scale, rural industrialism was established. In the 1980s and 1990s, soaring demand for cement led to massive but uncoordinated rural investments in new production capacity. Thousands of so-called township and village enterprises, or TVEs, emerged. Owned collectively and by local authorities at different levels, or even privately, installations were typically low-tech and labour intensive shaft-kiln plants, needing far less capital for up-front investments than do modern, automated plants using rotary kilns with pre-heaters and precalciners. As a result, close to 80 percent of all cement in China is now produced by small enterprises, often suffering severely from inefficient use of energy and other resources, problems with high variability in output quality, and high pollution levels. Dust emissions, in particular, constitute a major threat to the local environment, and energy inefficiency contributes to unnecessarily excessive emissions of carbon dioxide from fossil coal.

Authorities and the industry acknowledge most of these problems, and measures are being taken to overcome them. China's influential State Economic and Trade Commission has black-listed old and outdated technology, and modern production methods are promoted. A domestic consolidation trend can be observed and is being encouraged. Dust emissions, resource inefficiency, deficient product quality, and the plethora of technically and financially weak producers are targeted ailments within the sector. Despite apparent connections and the potential opportunities at hand, however, the climate change issue does usually not enter into this equation at all when regarded or commented on by domestic actors (Nordqvist and Nilsson 2001).

4.2 The Sustainability Initiative entering China

Due to its size, as well as in light of its need for structural reforms, the Chinese cement market is a stage with great expansion potential for the transnational actors of the Sustainability Initiative. Several of the corporations of the Working Group already operate in China. So far, however, their activities within this huge market remain marginal. A brief overview of important actors in Chinese cement production is presented in ZKG International (2002). To the foreign companies that are most involved and most active belongs Lafarge, which currently operates two joint-venture cement production facilities in the country: Chinefarge near Beijing (since 1994), and Dujiangyan near Chengdu in the south-central province of Sichuan (commissioned in 2002). Both plants represent illustrative cases of improvements in sustainability performance compared with prevalent conditions in the sector. Heidelberger, Holcim, and Taiheiyo have also established themselves within China. The importance placed by the Cement Sustainability Initiative on China is evident and demonstrated not only through the fact that the concluding workshop in a series of Stakeholder Dialogues was held in Beijing in December 2001. Also, complementing the series of thirteen substudy reports, a special, regional study was conducted to illuminate the conditions specifically in China (Soule et al. 2002).

Although Chinese authorities claim to welcome foreign investments, there are many obstacles that impede participation in the market by foreign-owned actors; and hence their possible halo effect as well. Clashes in management cultures and the importance of strong good-will relations, so-called *guanxi*, with local authorities are part of the explanation. National and local protectionism also plays a role. There are, nevertheless, encouraging signs showing that, in some parts of administration, issues referring to sustainability are gaining recognition. For example, the China Council for International Co-operation on Environment and Development, an advisory group to China's State Council, is addressing a number of such issues. Composed equally of senior Chinese and foreign experts, the China Council has recently set up a task force for Industry and Sustainability, co-chaired by Björn Stigson, President of the WBCSD.

4.3 Rings on the water?

At central government levels, local pollution is recognised as a major industrial problem for China, and efforts are being directed at curbing it. Also transboundary and global environmental problems are acknowledged. For local authorities, the overriding development goals, however, are increasing volumes and short-term economic growth. In the current study case, the cement industry, less money is spent on pollution abatement than in other industrial sectors in China (Soule et al. 2002, 26). One important environmental concern, which is widely recognised by all sector actors, however, is particulate emissions. Since the late 1990s, the cement industry is responsible for more than 40 percent of all industrial particulate emissions in China. As a consequence, other pollutants receive little or no attention.

Especially carbon dioxide is a non-issue. Awareness about greenhouse gases and possible implications of China's active participation in the UNFCCC is very low within the industry.

In wording and intention, China's regulations and laws for environmental protection in industry are strict, but their application falters, which means that, in effect, the regulatory framework is lax. At the same time, a general condition for foreign companies to be allowed to operate in China is their willingness and ability to comply with existing regulations, which tend to be emphasised more with new and foreign parties than with established enterprises. In themselves, these regulations are not a barrier for foreign investments in cement production. International actors usually operate under even stricter regulations than the Chinese ones. A problem in China, however, is the inconsistency with which such regulations are enforced. Although China's cement market is huge, profitability is almost non-existent as the market overflows with cheap, low-grade cement. Moreover, local protectionism and *guanxi* generally favour domestic actors over foreign ones. Still, foreign investments in cement production are increasing, but from an extremely low level.

Currently, the possible opportunities for CDM projects contribute in fuelling the interest of foreign actors for further investments, but within China, such lines of thinking do not create much of a response. There are several reasons for this. The most immediate one might be the lack of awareness within the Chinese cement sector about the climate issue. Carbon dioxide, although a major pollutant from the industry, is simply not recognised as a problem. Dust remains the all-overshadowing concern. Therefore, local actors, even if they are aware about the mechanism, do not appreciate it as an opportunity to attract investments. On a political level, the dominant view in China on the CDM so far has been one of scepticism. There are concerns that it would provide a means for Annex B interests to exploit the situation in developing countries, thereby allowing them to avoid actions at home. Of late, however, a shift in official positions towards a more open one can be discerned. Within the important State Development and Planning Commission, for example, arguments in favour of China hosting CDM projects are brought forth. Still, opposing views or lacking awareness remain dominant in many parts of the complex Chinese structure of administrative bureaucracy, as well as in business. Therefore, though hoping for a constructive mechanism to be put into place eventually, potential CDM investors see many uncertainties that need to be sorted out before anything can actually happen. The question of ownership of CERs produced in China is one such concern being voiced, to which, at present, there is no answer.

Against this background, the prospects at present for diffusion of cement-related climate action within China may seem bleak. Still, it is not unfeasible to think that domestic actors, if recognition increases of climate as a concern in industry, can pick up speed and adopt appropriate action using the momentum already gained within the Cement Sustainability Initiative. Further studies and evaluations in and around this field may contribute to better informed policy decisions, by administrative as well as corporate actors, in order to encourage such a development. They may also contribute to the building of a broader base for academic theories on technology diffusion, trade, and corporate behaviour in transitional and developing countries.

5. Summary and conclusions

A group of progressive and heavy actors within global cement production have set out to "make a difference" in a move toward a more sustainable cement industry. This move entails efforts in scrutinising and adjusting their own activities, individually and in co-operation among each other, as well as with stakeholders in local communities and with authorities. Such aspects are important not least in developing countries, where the potential for really making a difference is considerable, and where, due to infrastructural and construction needs, there is still room for significant market growth. The largest and fastest growing market is

China, but it is isolated and only beginning to be penetrated by international influences. Whether and how the momentum for sustainability can be picked up by Chinese enterprises and policy-makers in the on-going and fundamental, sectoral restructuring process of domestic cement production are important questions and a field for future studies to analyze.

It is a sometimes heard argument that concerns about sustainable performance by industry are a luxury afforded only in developed countries, and that corporate actors in the third world, due to weak protective regulation by governments, are compelled by market mechanisms to neglect their moral responsibilities by overexploiting labour, resources, and the environment alike. The members of the Cement Sustainability Initiative, however, argue that creation of enterprise value must include social concerns and environmental stewardship. Through their Agenda for Action, therefore, these ten cement corporations have formalised a framework in order to realise their visions for the future: that cement companies integrate sustainable development into their global operations, and that they be known as leaders in industrial ecology and innovators in carbon dioxide management. Furthermore, they shall be regarded as attractive employers, and have established relationships of trust with the communities in which they operate (WBCSD 2002b).

The cement industry differs from many other industries in that the product generally cannot profitably be transported over large distances. Therefore, production has to be located in close proximity to the market, which means that for cement producers, the notion of pollution havens does not apply. Instead, the Cement Sustainability Initiative offers an opportunity to examine the possibility of a detectable pollution halo effect, not least within the restructuring process presently underway in Chinese cement production.

Acknowledgement

This work was supported by the Swedish International Development Co-operation Agency (Sida) under contract SWE-2001-244.

Notes

Note 1. Lafarge, who in their own calculations include displacement of fossil fuels through substitution by waste-derived fuels, state a total carbon dioxide reduction commitment of 15 %. According to WWF's more conservative method of carbon accounting, however, this corresponds to a reduction of 10 %.
Note 2. The figure for Spain refers to 1997.

References

Battelle (2002) Toward a Sustainable Cement Industry. Summary Report [online] (Geneva: World Business Council for Sustainable Development) [cited 8 August 2002], available at www.wbcsdcement.org.

Hendriks, C.A., E. Worrell, L. Price, N. Martin, and L. Ozawa Meida (1999) 'Greenhouse Gases from Cement Production' in The reduction of greenhouse gas emissions from the cement industry, Report number PH3/7 (Cheltenham, UK: IEA Greenhouse Gas R&D Programme).

Humphreys, K., M. Mahasenan (2002) Toward a Sustainable Cement Industry. Substudy 8: Climate Change [online] (Geneva: World Business Council for Sustainable Development) [cited 8 August 2002], available at www.wbcsdcement.org.

Lafarge (2001) Building a Sustainable World (Paris: Lafarge).

Marland, G., T.A. Boden, and R.J. Andres (2001) Trends: A Compendium of Data on Global Change [online] (Oak Ridge, Tenn.: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy) [cited 8 August 2002], available at http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm.

Nicholls, M. (2002) 'Setting sustainability in stone?', Environmental Finance (May 2002): 20-21.

Nordqvist, J., and L.J. Nilsson (2001) 'Prospects for Industrial Technology Transfer in Chinese Cement Industry' in 2001 ACEEE Summer Study on Energy Efficiency in Industry, Proceedings Vol. 2: Increasing Productivity through Energy Efficiency (Washington, D.C.: American Council for an Energy-Efficient Economy): 223-236.

Organisation for Economic Co-operation and Development (OECD) (2002) China in the World Economy. The Domestic Policy Challenges (Paris: OECD).

Rauscher, M. (1999) 'Environmental policy in open economies' in Handbook of Environmental and Resource Economics, ed. J.C.J.M. van den Bergh (Cheltenham: Edward Elgar): 395-403.

Soule, M.H., J.S. Logan, and T.A. Stewart (2002) Toward a Sustainable Cement Industry: Trends, Challenges, and Opportunities in China's Cement Industry [online] (Geneva: World Business Council for Sustainable Development) [cited 8 August 2002], available at www.wbcsdcement.org.

Sprigg, G., and H. Klee (2002) 'Sustainable development', International Cement Review (April 2002): 67-70.

Stigson, B. (2001) The business case for sustainable development [online] (Bergamo: Italcementi) [cited 8 August 2002], available at www.italcementigroup.com/newsite/stigson.htm.

United Nations (UN) (2001) Statistical Yearbook. Forty-fifth issue (New York, NY: UN).

Vanderborght, B., and U. Brodmann (2001) The Cement CO_2 Protocol: CO_2 Emissions Monitoring and Reporting Protocol for the Cement Industry. Guide to the Protocol, Version 1.6 [online] (Geneva: World Business Council for Sustainable Development) [cited 8 August 2002], available at www.wbcsdcement.org/pdf/co2-protocol.pdf.

World Business Council for Sustainable Development (WBCSD) (2002a) 'Cement industry embarks upon road to sustainability', International Cement & Lime Journal (issue 1, 2002): 54-56.

——— (2002b) The cement sustainability initiative – our agenda for action [online] (Geneva: WBCSD) [cited 8 August 2002], available at www.wbcsdcement.org.

ZKG International (2002) 'High grade cement challenges in China', ZKG International (No. 9/2002, Vol. 55): 21-26.

III. Decision Making Behaviour

Opportunities and barriers to energy efficiency implementation in the Italian industrial sector: an open matter

Norma Anglani[1]†, Davide Mariani‡, Giovanni Petrecca†‡
† Department of Electrical Engineering, University of Pavia (I)
‡ CSE Group Ltd, Pavia (I)

Abstract
The study has been sponsored by the Ministry of Environment through FIRE (Italian Federation promoting the rational use of energy) to support actions helping to comply to the latest energy efficiency decrees (promulgated by the Ministry of Manufacturing Activities on April 24th, 2001). The paper aims to illustrate the preliminary results from an ongoing study which approaches energy efficiency issues with respect to the Italian situation; a case study in a specific industrial sector is also reported.

The authors aim to evaluate how much energy is usually exploited to compress air, which the savings potential and how increasing the pace of supporting actions could help to decrease the cost of the avoided emissions. The next step is to establish if there is any potential for business in such field. The surveys have pointed out that roughly 30% of electricity is used for this purpose in the sector of EPS (expanded polystyrene) production: compressed air is mainly employed in the pneumatic pistons of the presses and in the pre-expanders, as well as in the tank loading and shaking off of the block-molding machines, but also improper use of compressed air is often encountered. Energy saving potentials (in the production, handling, delivery and use of compressed air) have been assessed and results projected on the overall Italian market, relaying on data, which have been taken both from trade association and from statistical publications. Opportunities but also barriers for energy savings in the compressed air service are going to be reported, comparing the preliminary results to updated international outcomes on the matter, in order to give a solid technical background to energy efficiency forthcoming policies, which should take advantage by bottom-up approaches.

1. Introduction

A report has been recently published with the support of the European Commission, under the Save program: it deals with the results of a market assessment of potential savings and possible policy actions in the use of compressed air in several Member states. The final remarks strike on the high profitability of the energy efficiency measures, whose payback times can often be less than 36 months [6].

The considerations seem to support the first results achieved by this study, which has been mainly focused onto few Italian industrial sectors: the plastic transformation, the food and kindred and the mechanics [1][2][3]. In this paper the case study "compressed air in the EPS

[1] Lead author: dr. Norma Anglani ,Department of Electrical Engineering, University of Pavia. Via ferrata, 1 27100 Pavia (I); Tel ++39 0382 505253, fax: ++39 0382 422 276; Email: NAnglani@unipv.it

(expanded polystyrene) manufacturing" will be discussed, because of the high potential unveiled since the very first surveys. Besides, from an engineering point of view the overall efficiency of such systems, which deal with the overall chain of air delivery (compression, handling, distribution and delivery), is usually very low and around 10-15%.

The idea has also been drawn by an analysis of the Italian market data, which is one of the most important world market for air compressors, according to AFISAC[1], that still has room for a further growth [6], likely because of the characterization of the Italian industry, made up of a plethora of SMEs.

Currently, a first awareness campaign has started, sponsored by FIRE (Italian Federation, promoting the rational use of energy) and lead by the University of Pavia.

The aim is to identify real opportunities and business in the compressed air generation, distribution and delivery chain, according to what recommended in the decrees April 24th, 2001 (also known as energy efficiency decrees [8]), which set targets and schedules for suppliers to increase energy efficiency (both electrical and thermal) at the final end-user.

The authors intend to show how important is backing these studies on compressed air, because a strong technical background can give a better idea of hidden potentials and how they can be boosted through targeted actions. In fact, in the light of the above decrees, whose guidelines are currently under the review of the Authority for energy and natural gas (AEEG), FIRE is trying to understand both how to promote the creation of ESCOs, specializing in the delivery of some services and to overcome certain issues, specific to the sectors under exams.

The final results of this first study on the matter are expected by February 2003.

2. A short background on the study

Compressed air production for industrial use can represent a very important item in energy consumption and costs.

The study on the potentials for energy savings had its kick-off in 1998 with a laboratory simulation of the efficiency of the chain for an industrial process, whose compressors had been operated according to different controlling logics [5]. The results showed a very low overall efficiency of the system in various configurations.

Following that, the next experience consisted in the evaluation of the overall potential, not only related with the control of a set of compressors, but also considering how to optimize the use of air in a real firm manufacturing EPS [3].

The further collaboration with AFISAC gave the chance to set several measuring campaigns on different industrial sites, whose preliminary results have been presented in 2002 [1].

The study, sponsored by FIRE, was born from the results of the above work and has been organized in various stages, in order to comply to specific needs of the Ministry of the Environment. The final aim is to help to define business areas and energy saving potentials, according to what stated by the current legislation and possibly make them available to specific Trade Unions.

In this paper phase 1 and 2 will be discussed. Phase 3 will mostly involve a consulting company in the energy business since more than 20 years, through the access to its client database, in order to cross-checking the benchmarking indexes.

[1] The association of manufacturers and dealers of compressed air systems

During phase 1 the University of Pavia, along with a collaborative manufacture, has carried out several measuring surveys which have given a broader idea on a feasible business in the compressed air sector, through onsite visits and interviews.

The agreement with the companies has been achieved through a free of charge survey of the firm, on condition to remain anonymous. The results have been presented at a sector exhibition and on a specialist journal.

This experience, supported by the results achieved in the past surveys, along with the final remarks deriving from [3] has caused a sort of chain-effect by making the various companies, running the EPS business, aware of this chance and eventually by involving the trade association (AIPE) which has agreed to help contacting potential interested parties.

FIRE support is showing to be promising because of the access to the energy managers database. More than 900 letters have been sent lately, after a first screening has been done. In order to better focus this survey has been decided to choose companies either because the percentage of energy used by compressors is somehow relevant, if compared to the overall consumption, or because the amount of energy for compressing air is relevant in absolute value.

We expect to have a 10% positive answer, feedback or expression of interest; although this number seems not too high, this would be the biggest campaign, involving the assessment on compressed air consumption in Italy. Other surveys are reported in [9].

In order to further skim off the demand for being included in the survey, a questionnaire has been organized. This questionnaire, reported in Tab. 1, can be easily filled up by the energy manager or the production manager and send it back by fax.

Table 1.Draft questionnaire for a company installing up to CN compressors .

COMPANY NAME	
COMPRESSORS MANUFACTURER AND MODEL C1/C2/C3/C4 .../CN	
LUBRIFICATION/OIL FREE	
INSTALLATION YEAR C1/C2/C3/C4 .../CN	
POWER C1/C2/C3/C4 .../CN	
OPERATING PRESSURE C1/C2/C3/C4 .../CN	
FREE AIR DELIVERY C1/C2/C3/C4 .../CN	
NUMBER OF DISTRIBUTION LINES (IF MORE THAN 1)	
MAIN PIPES DIAMETER	
TANKS (NUMBER AND CAPACITY)	
AIR HANDLING UNITS (Y/N)	
MANUFACTURING CODE	
SHIFT PER DAY	
HOURS/SHIFT	
WORKING DAYS PER WEEK	
WORKING WEEKS PER YEAR	
PRODUCTION (CONGRUENT UNIT)	
ELECTRICITY (kWh/y)	
AVERAGE POWER OF THE FIRM (kW)	
AVERAGE E. COST (EUR/kWh)	
COGENERAZIONE (Y/N)	
HOW WERE YOU AWARE OF THIS SURVEY?	
QUESTIONNAIRE FILLED BY	
Function	
TEL	
FAX	
EMAIL	

3. The case study in the manufacturing of plastics

Despite of having the industrial sector achieved good results on improving the energy use over the last decades, there is still room for effectively acting "at home" (see definition in paragraph 4): compressing air is still an hot topic, considering the high economic value of the savings (being 8 times more expensive than other sources).

The information, taken from the questionnaire of Tab. 1 will be stored in a database. Selecting criteria, which are going to define the eligibility, will identify those companies whose consumption for compressing air is either a relevant percentage of the overall electric consumption or somewhat remarkable in absolute terms (i.e. more than 1 GWh/y). When the assessed consumption is an important percentage over the total, then it is very likely that this feature is a repetitive one for the sector under exam. This turned to be particularly outstanding for companies manufacturing EPS.

Relying on the preliminary gathered information, the authors are hopeful that the final results will help to pursue the objective of the study and will also give the boost to get extra funding to go through the undertaken activity.

The voluntary participations of companies as well as manufacturers, who will provide the measuring and recording equipment, is expected because both parties can count on a good chance to get something from this situation: either a free of charge feasibility study or an extra chance to get in touch with potential clients.

The detailed survey goes on by collecting further data on energy costs, equipment consumption, load factors, annual average running hours of the plant, production cycle, annual throughput, unit labor and possibly the turnover.

A case study for companies in the EPS production business follows below.

In order to work with reliable data, several surveys have been scheduled in a couple of the firms which have at first volunteered. Statistical data and data from the Trade Association have also been used for the national overall assessment of savings.

Along with the above information, the flow of raw material (through various process stages) has been studied in order to associate different energy input to each stage and assess several specific indexes for each transformation (electricity, thermal energy: fuel and steam, compressed air, CO_2 emissions).

A measuring campaign is next organized. The current measuring equipment is able to record the value of the piping line pressure and how the system (usually more than one compressor) is operating: load/unload/off cycle. Input data are: the compressors technical data (free air delivery and rated power) as well as the overall line capacity (including tanks).

In Tab. 2 the information coming from the measuring campaign are reported.

Table 2.Information from the measuring equipment (on Kn compressors).

compressor	*kW rated (A)*	*Free air delivery m^3/min (B)*	*Pressure (Pa) (C)*	*kW load (D)*	*kW unload (E)*	*Time on (s) (F)*	*Time off (s) (G)*	*Time load (s) (H)*
Type	*input*	*Input*	*output*	*measured*[1]	*measured*[3]	*output*	*output*	*Output*
K1								
K2								
...								
Kn								

The measuring campaign lasts for one week and gives enough information to assess the weekly energy EN_W, used by the compressors:

$$EN_W = \sum_{i=1}^{Kn} D_i * H_i + E_i * (F_i - H_i) \quad (kWh) \qquad (1)$$

it is worthy to say that in the next future we are going to improve the measuring campaign by adding watt-meters and programming software to gather and collect more electrical information such as the current value and the phase displacement, useful for a precise assessment of unload consumption, which sometimes tend to play an unusually important role.

[1] only at the measuring equipment installation

The value of compressed air over the week has also been assessed in order to obtain some benchmarking indexes.

The manufacturers themselves agree that data on free air delivery are the weakest link of the measurement procedures, because they rely on an alleged information.

At this stage information such as specific compressed air consumption per tons of throughput is easy calculated as: $EN_T = EN_W / t_W$ (t_W and t_Y are the weekly and annual throughput) and the annual consumption EN_Y for compressing air is equal to $EN_Y = EN_T * t_Y$

Other interesting indexes are $AC_{\%} = \frac{EN_Y}{Annual_energy_consumption}$, the percentage of compressors consumption over the total energy consumption and the weight of compressed air cost over the total production $C_{AC} = \frac{c * EN_Y}{t_Y}$, where c (€/kWh) is the average cost of electricity. Other interesting indexes are Q_W/t_W and graphing EN_T over it for every recorded day.

The surveys and the modeling have pointed out that roughly 30% of electricity is used for this purpose: compressed air is mainly employed in the pneumatic pistons of the presses and in the pre-expanders, as well as in the tank loading and shaking off of the block-molding machines, but also improper use of compressed air has often been encountered.

By analyzing how air is averagely used in these firms, an underestimated 25% of potentials is assessed on a National level, considering quite unlikely the chance of a simultaneous upgrade of every systems that could be improved.

A new accounting system has been set up in order to take under control the indexes and it will be used by on of the 2 companies to check the achievable results of some of the proposed interventions. We expect to confirm our preliminary results in less than six months.

For the other company, despite of the profitability of the investment, the management has decided not to proceed with the proposed measures, because at first they had to comply with environmental regulations, whose delay would have made the firm shut down.

In Tab. 3 a summary of the proposed measures and improvements are listed for such sector.

One of the major issue to face while deriving the compressors consumption for the entire sector occurs when analyzing what we called “secondary” data: for instance, companies manufacturing the same output (EPS along with cardboard) may have been differently classified, according to statistical code of the manufacturing activity, because the code only identifies the main production.

Besides, electric national consumption is published every year, but not with the same sub-code detail given by other national statistics, thus an extra effort has to be done to extrapolate the real consumption of the sector under exam.

In [3] a detailed analysis has been carried on a possible calculation methodology. According to the national productions of EPS, electrical statistics, labor units and overall compressors sales an estimate of energy consumption and savings has been proposed and compared with [6] and [9].

Table 3.List of all the possible measures and improvements which can be undertaken.

POSSIBLE MEASURES TO IMPROVE ENERGY CONSUMPTION FOR COMPRESSORS IN THE CASE STUDY FIRM	
Measures	**Savings**
THE FIRM IN THE OVERALL (1)	
decrease in mass losses	12-15%
setting up a rigorous maintenence procedure	3-5%
Advanced compressors' control	10-15%
IN THE MOLDING AND SHEETS DEPARTMENT (2)	
Doubling the distribution network, according to 2 levels of pressure	15-25%
avoiding imporper use of air (i.e. in the vacuum creation)	10%
Advanced control on final use (3)	5-10%
(1): % on the overall compressed air consumption	
(2): % on the share used in the department	
(3): depending on the final user	

4. A comment on the preliminary results

According to statistics, Italy is one of the major countries, after USA, Germany and UK, in the sale of compressors [6], also because the structure of the Italian industry is made of a plethora of SMEs. This feature is proven to be true also for the EPS sector with 130 companies operating in the country. In fact, if we look at the overall estimates for consumption a modest 22 GWh/y seems to be used by compressors. Assuming that 50% of energy savings measures will be implemented by year 2010, roughly 2,7 GWh/y could be saved by using electricity in a more conscientious way. According to various strategies, Fig.1 reports the cost of saved tCO2, assuming different penetration factors (15%, 20%-30% and 35%) for the first year and realizing the overall investments by the year 2010 (savings are accounted over 10 years, through 2012). Besides, the same factors have been used to assess the cost of CO2, assuming that the investments could be realized within the third year.

Costs can vary from 50 to 80 €/t CO2, which is an outstanding value for "at home[1]" measures.

The value of such result lies in the proposed assumption, which has intentionally underestimated the real potential, but also in the knowledge that there is still room for improvements in all the other industrial sectors, left behind at this stage.

Payback times below 36 months, on an average, were found in our survey as well as in [6]; an overall investment of 720 kEUR can save 6 to 7 kt CO2 through 2010 and more than 1500 tCO2/y from 2010 onward.

In order to propose good policy actions tailored to a given sector, a thoroughly understanding of processes and issues needs to be gained, yet. The proposed study aims to support these requirements.

If the aim is to cover the matter as much broadly as possible the estimation of the potential and barriers to the implementation to energy efficiency measures has to be considered carefully, depending on the features of the national market.

[1] Differently to "abroad" implementations, allowed by the Kyoto's flexible mechanisms

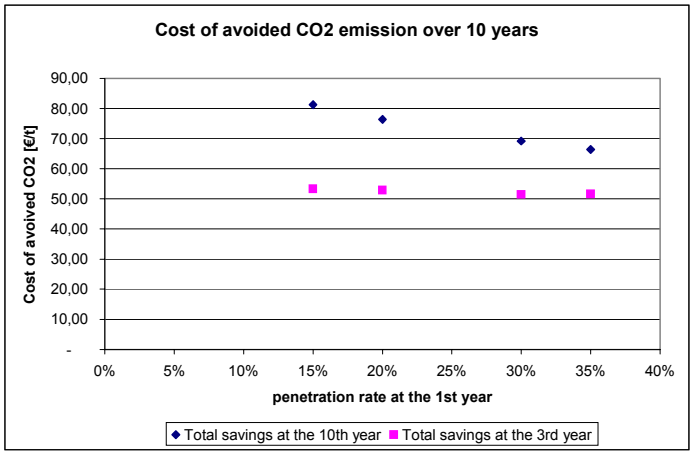


Fig. 1: Cost of saved tCO2 in different scenarios

Barriers are mainly due to difficult access to capital and to compliance to several environmental laws, which can direct to more urgent investments.

The main lesson learnt is that the management of such kind of services can be an outstanding element for improving competition in several industrial sectors, especially where a technical specialized management in energy issues does not exist in the company.

Compressed air is often seen like an item to focus the attention onto, only when the system undergoes through critical times and the emergency has to be managed as soon as possible.

In these cases, the commonest action is to upgrade the supply through an upgrade of the machines (in number and/or power); rarely it is felt the need to give a look at the demand, trying to optimize it. This attitude comes from the habit of considering compressed air as well as other energies, neglecting that the variables of these systems are more numerous and interconnected than for the other services. The factors, affecting the overall efficiency, are multifold and they all need to be considered (pressure losses, mass losses, line operating pressure, improper use of air, disorganized development, lack of study in the system configuration …)

Trade associations can play a very important role in spreading amongst members the knowledge for these potentials, helping researchers and policy makers to understand how to achieve the best economy of scale. The better the understanding of the production cycle and various production philosophies, the better the characterization of issues is, in order to promote only feasible solutions. This should also help to identify a "package of actions" with a real energy saving content.

5. Lessons learnt from a policy making perspective

The new energy efficiency decrees ask the suppliers of energy services to realize improvements on the final end-users, giving targets and schedules. After a first step, when targets have been set, the identification of "action areas" (i.e. compressed air production) has to follow, by looking at those investments with a good energy saving potential as well as short payback times.

Even alleged-niche sectors can provide interesting information to consider, while modeling energy policies and making everyone more aware of hidden potentials.

Fostering the "outsourcing" of this service, through ESCOs for instance, as well as what is proposed in [6] seems to be a good tool for pursuing certain results, but a detailed National analysis, where to identify the best organizational aspects has to follow to focus on business opportunities. If this step is missing, the hurdles to overcome financing problems are left behind, and this can nullify the efforts done, since SMEs are often characterized by a difficult access to money for energy efficiency investments. This turned to be the major barrier to energy efficiency implementations, along with the priority given to more direct interventions on the production.

A policy, promoting the delivery of the service as well as what happens with electricity (where one pays for power as well as for energy) could boost the improvements in this field.

From our experience the bottom-up approach seems to be very performing and able to find out hidden potentials.

The Italian situation, because of the highly fragmentized demand coming from the SMEs, needs to be carefully analyzed. It can occur to deal with companies whose compressors' size and power are less than 50 kW: below this size, outsourcing has to prove to be convenient. Upon these conditions, which can represent a good share of the sector under exam, it seems to be more convenient for these services to grow and spread if industrial districts are involved in the projects.

6. Conclusions

This ongoing study has been sponsored by the Ministry of the Environmental, through FIRE, to understand which real opportunities for business exist in the compressed air field, according to what is required by the two new decrees. The compressed air service has been investigated for one industrial sector in particular. A detailed knowledge of the sector under exam is felt to be a "must" if addressed actions need to be studied, thus modeling the demand side seems to give a greater help than just dealing with the supply side.

From these preliminary results, the authors believe that a policy supporting feasibility studies and investments could play an important role to knock down the barriers to action, but also education and knowledge have to be fostered inside the industrial sector, possibly at a SMEs level by working with trade associations.

A good start could be represented by the realization of a National benchmarking indexes register (could the EMAS certification be a good sink?), both helping each company to fill the gap with competitors and creating a fertile background for ESCOs to grow and spread, also by focusing on such kind of service. Compressors manufacturers as well as dealers seem to be the most likely target for this awareness campaign for business.

7. References

[1] Anglani, N. 2002. Risparmio energetico, modalità di utilizzo e gestione dell'aria compressa nell'industria. – I Quaderni dell'Aria Compressa. Anno VII. N.3. Marzo. pag. 32-36.

[2] Anglani, N. Mariani, D. Petrecca, G. 2002. Uso razionale dell'energia: quale ruolo per l'aria compressa? Introduzione ad uno studio di dettaglio. Ricicla energia, workshop FIRE, Rimini, November 7th.

[3] Barbieri, G. 2001. Possibilità di risparmio energetico nella generazione di aria compressa nel settore industriale della produzione della plastica. Tesi di Laurea Dipartimento Ingegneria Elettrica, Università degli Studi di Pavia.

[4] .

[5] Pondrano, P. Anglani, N. Petrecca, G. 2001. 14. Simulation, Planning and Control of a central compressed air plant for a more efficient energy use. 6th Annual International conference on Industrial Engineering theory, applications and practice, November 18-20, San Francisco (USA).
[6] Radgen, P. Blaustein, E. 2001. Compressed Air systems in the European Union: energy, emissions, savings potential and policy actions. LOG_X Verlag GmbH. Stuttgart.
[7] Office of industrial technologies (USDOE). Compressed air challenge Sourcebook. www.oit.doe.gov/bestpractices/compressed_air/
http://www.compressedairchallenge.org/content/library/sourcebook/index.htm
[8] MICA. 2001. Decreto 24 Aprile 2001: Individuazione degli obiettivi quantitativi per l'incremento dell'efficienza energetica negli usi finali ai sensi dell'art. 9, comma 1, del decreto legislativo 16 marzo 1999, n.79.
http://www.fire-italia.it/primopiano/decreti.asp#decreti
[9] Spanò, A. 2002. Risparmio energetico nel settore dell'aria compressa. Oleodinamica pneumatica. Tecniche Nuove. Milano. Febbraio. Pag. 60-67.

Modelling Industrial Technology Evolution: Capturing Behaviour in a Bottom Up Model

John Nyboer,[1] Mark Jaccard, Nic Rivers, Matt Horne, Margo Dennis

Energy and Materials Research Group (EMRG)
School of Resource and Environmental Management
Simon Fraser University

Abstract

In an assessment of the analyses EMRG completed for the National Climate Change Process in Canada, a committee established to assess how Canada might meet its Kyoto commitments, EMRG's researchers began to review simulation outcomes by critically looking at the actions of the model's technology choice algorithms. Currently the model uses three parameters to assess technology choice, the discount rate, *r*, a set of intangible costs, *i*, and a parameter meant to measure market homogeneity, *v*. The parameters are subject to a number of conditions and, in fact, some degree of overlap (e.g., some notion of intangibles can be captured in the discount rate). Also, data that confirm the parameters are scarce and we have not devised simple method to estimate uncertainties in the outcomes. So, we sought a more empirical assessment of choice – discreet choice analysis / modelling.

Discrete choice analysis / modelling is a well-developed avenue of consumer research used extensively in transportation, residential, and recreation applications to predict individual and market behaviour in response to observable attributes. As such, it may provide an effective means of addressing these shortcomings. Three main strengths of discrete choice models (DCM) make them an ideal candidate for representing the competition for technologies in CIMS in a way that neatly avoids the current shortcomings.

1) They are empirically derived from actual or hypothetical consumer behaviour.
2) They are compatible with micro-economic theory (random utility models).
3) Their formulation is consistent with the way actual decisions are made in the marketplace at a disaggregate level.
4) One can easily vary parameters to estimate degrees of uncertainty around a parameter, and its impact on technology choice (a crucial criterion in decision making).

We will present some critique and analysis of various modelling approaches in general (top down, bottom up, hybrids), and highlight this more recent work in order to assess evolution of technologies in industrial (and other) sectors.

[1] Author can be reached at jnyboer@sfu.ca

1 Introduction

We have, on many occasions, seen divergent cost estimates in analyses focused on reducing greenhouse gases (GHGs). Even when cost modellers follow the same assumptions about the business-as-usual evolution of the domestic energy-economy system, and of external factors such as the price of internationally traded energy, cost estimates will still vary significantly. This may be because analysts use different definitions of cost. Alternatively, they make different assumptions about key uncertain parameters. We explain the definitions issue first in order to show why the solution to this challenge leads to the second issue which is the focus of this paper: improving estimates of parameters related to purchasing behaviour of firms and households and assessing the uncertainty associated with key assumptions.

Analysts and interest group advocates alike hold competing views of the costs of GHG emission reduction. Bottom-up studies focus on the financial costs (using a social discount rate) of technologies that compete to provide the same energy service. Because low-GHG technologies are available with similar or even lower life cycle costs than today's dominant technologies, simple benefit cost analysis shows GHG reduction to be low cost. But these studies usually assume that technologies are perfect substitutes for providing a given service like lighting or mobility. In reality, technologies can differ dramatically in the eyes of consumers, and their willingness to pay for one may be much higher than for its competitor: (1) new technologies are perceived to be riskier, (2) technologies with longer paybacks are perceived to be riskier, (3) some technologies are perceived to provide a better service (cars over transit, incandescent lights over compact fluorescents), and (4) financial costs are not everywhere the same. The compensation (subsidy) or penalty (charge) required to get a firm or household to switch to the low-GHG technology is considered by economists to be a reflection of the welfare cost (financial plus extra value) of GHG reduction, something that is ignored by conventional bottom-up studies.

Top-down studies, in contrast, use real-world market data to estimate the relationship between relative prices and relative demand for the energy, capital and other inputs used by firms and consumers in production and consumption processes. Thus, real-world data on the readiness of firms and households to use less energy when its price rises provides an indication of the full welfare costs of switching to low-GHG technologies. These studies usually show GHG reduction to be high cost. But these models, based on historical, aggregated data, are of little use to policy analysts trying to assess the impact and cost of a package of policies, some of which are technology-specific, and all of which seek to influence the long-run evolution of technology costs and even consumer preferences. The cross-price elasticity between ethanol and gasoline might change dramatically when ethanol is widely available and ethanol fueled vehicles are well known. A typical top-down approach ignores this potential dynamic between policy and long-run welfare costs of GHG reduction.

Motivated by this cost definition problem, researchers have built hybrid models that explicitly model technological evolution and include a realistic behavioural representation of firms and households. In Canada, the federal government is adopting the NEMS model of the US government, and the national climate change process has used both Energy 2020 and CIMS; all three can be generally classified as hybrid models.[1] But even using such models, we see that the future cost of GHG emission reduction is highly uncertain, and should provide some estimate of this uncertainty. Yet most studies provide only single point cost estimates for a

[1] MARKAL is excluded from this list because it is an optimization model.

given target and no information on the uncertainty associated with such estimates. Meanwhile, advocates and even independent researchers challenge each other's cost estimates without an understanding of the relative contribution of uncertainty and differing cost definitions to their divergent cost estimates. Policy analysts and decision makers don't know whom to believe, making agreement on target setting and implementation all the more difficult to achieve. This brings us to the focus of this paper.

> ***Even if hybrid modellers used common assumptions about business-as-usual conditions and external factors, and applied a consistent definition of costs, they might still estimate dramatically different GHG reduction costs if they have different assumptions about key uncertain parameters. We cannot get rid of this uncertainty. But we can try to understand it better.***

We identify two major sources of uncertainty. The first relates to technological evolution and the second to preference change.

1) A wide body of research shows that technological evolution is to some extent endogenous to the political-economic system. Heavy subsidies to windmill production enabled developers of that technology to achieve economies of scale in production and economies of learning in design, installation and operation such that the cost of electricity from windmills in favourable sites has fallen from about 15 ¢/kWh 20 years ago to 5 ¢/kWh today. Twenty years ago, many experts were predicting that policies to cause widespread commercialization would drive down the price of windmill-generated electricity, but their estimates covered a fairly wide range (perhaps 3¢ / kWh - 9¢ / kWh). Today, we have great uncertainty about the effect of subsidies and other programs that foster the capture and storage of CO_2. We know these policy efforts will reduce the cost, but we are uncertain to what level by 20 years from now. Fortunately, a considerable amount of physics, engineering and industrial research in recent years has improved our understanding of the shape of these declining cost curves (learning curves) and our ability to predict their trend for technologies with different types of properties.

2) The second major source of uncertainty relates to the technology-specific preferences of consumers and businesses. Research shows that while preferences are in many ways beyond control of the political-economic system, they can be influenced somewhat by the slate of technologies that are made available to them. Launched in 1990, California's vehicle emissions standards required automobile manufacturers to design, produce and market low emission vehicles by the end of the decade. Because of this policy, the hybrid gasoline-electric vehicle is now a viable option to which some consumers turn and that some manufacturers aggressively market in terms of its fuel savings and environmental friendliness. However, while the market share of hybrid vehicles is guaranteed by California's emission standard policy, there was and remains considerable uncertainty of the compensation (hence the size of subsidy) that additional consumers would require in order to adopt this technology.

> ***In essence, it would be very useful for decision makers to have a better sense of the potential for consumers to adopt low-GHG technologies and of the uncertainty associated with how these preferences affect the estimation of GHG emission reduction costs.***

In this regard, the Office of Energy Efficiency of Natural Resources Canada is currently supporting research on the decision making characteristics of businesses and consumers in order to better predict, and assess the uncertainty of, their decision making concerning the acquisition, retrofit and use of technologies. This research is critical for designing and implementing programs to improve energy efficiency and thus reduce GHG emissions. It is

equally critical for improving our understanding of the future uncertainties associated with costing GHG emissions reduction. In decision making research, the usual empirical techniques involve discrete choice analysis: asking respondents to make trade-offs between choice attributes, or seeing how they made such trade-offs in past decisions.

However, discrete choice research is of only partial use to policy makers if it cannot be effectively incorporated into the integrated technology-explicit simulation models (NEMS, Energy 2020, CIMS) that governments use to assess the costs of achieving an environmental target such as a future reduction of GHG emissions. Because the total system costs of any shift in technology market share (from x% to x+10%) depends on many attributes elsewhere in the system, an integrated model provides the only means of assessing all critical interactive effects. The cost-effectiveness of an appliance efficiency program cannot be estimated independently of the price of electricity, which in turn depends on efficiency and fuel switching efforts in the electricity sector and any other programs or policies that change electricity demand and supply. Likewise, the GHG reductions, and GHG reduction costs, of the appliance efficiency program are unknown except through simulating the entire system.

> ***A critical issue, therefore, is the transfer of information from discrete choice research into integrated, technology-explicit models. This can both improve the behavioural parameters of such models and provide information about the uncertainty associated with these parameter values.***

2 CIMS and its Current Set of Parameters.

Aside from a number of hard controls regulating technology penetration,[1] CIMS uses a declining capital cost curve for new or upcoming technologies and three parameters to determine the market share of newly purchased (or retrofit) technologies that provide similar services, the discount rate, *r*, a set of intangible costs, *i*, and a parameter meant to measure market homogeneity, *v*. Presently within CIMS, market shares of competing technologies are estimated at each competition node based on their life cycle cost according to the following formula:

$$MS_j = \frac{\left[DCC_j * (1+i_j) * \frac{r}{1-(1+r)^{-n}} + MC_j + EC_j \right]^{-v}}{\sum_{k=1}^{K} \left\{ \left[DCC_k * (1+i_k) * \frac{r}{1-(1+r)^{-n}} + MC_k + EC_k \right]^{-v} \right\}} \qquad \textit{(Equation 2.1)}$$

where MS = market share, DCC =declining capital cost (declines only for new technologies, otherwise just CC = capital cost), MC = maintenance and operation cost and EC = energy cost. The main part of the formula (the part inside the square brackets) is, in essence, simply the life cycle cost of the technology. In this formulation, the inverse power function acts to distribute the penetration of that particular technology *j* relative to all other technologies *k* in a

[1] Hard controls limit penetration of technologies directly, i.e., consumer behaviour is not absolute in determining penetration rate. For example, one can limit the maximum, minimum or even the rate of penetration of technologies exogenously in the competition for service provision. Technologies can be designated as "No longer available", retired early or competed such that it obtains all of the market based on some attribute it posses (e.g., most efficient, cheapest, lowest emissions, etc., a "winner-take-all" function).

way resembling a "normal" distribution. Note that, in this formulation, we assume the intangible cost to be some fraction or ratio of the capital cost. In an alternative formulation, we assume this "cost" to be independent of the capital cost. The equation would then be:

$$MS_j = \frac{\left[DCC_j * \frac{r}{1-(1+r)^{-n}} + MC_j + EC_j + i_j \right]^{-v}}{\sum_{k=1}^{K} \left\{ \left[DCC_k * \frac{r}{1-(1+r)^{-n}} + MC_k + EC_k + i_k \right]^{-v} \right\}} \qquad \textit{(Equation 2.2)}$$

In fact, we can utilize any combination of these relationships to reflect any number of intangible associations.[1] Thus, the formula can become very complex and reflect a number of different values to the consumer.

The discount rate has been estimated through a combination of literature reviews, expert opinion, and guesswork. The *v* and *i* parameters, however, cannot be measured directly. Instead, they are chosen so that the resulting market shares are similar to our expectations and external forecasts. The current process is subject to three shortcomings that limit CIMS's flexibility to analyze various policy options, and combinations of technology characteristics and make it difficult to assess uncertainty. We stress that these are shortcomings of the process used to assign parameter values, and they are not necessarily a product of CIMS' algorithms, some regression or other analysis.

1. The behavioural parameters have not been simultaneously estimated from empirical evidence (e.g., by multiple regression), so it is not clear if the current values result in a realistic portrayal of behaviour, especially over a wide range of attribute levels.
2. Because the parameters have not been empirically estimated, there is no way of knowing and portraying the uncertainty associated with each parameter.
3. No method exists to directly manipulate non-cost attributes or their importance in the decision process (because they are accounted for in combination using *v*, *i*, and *r*).

We are currently testing the use of discrete choice models (DCM) and analysing its potential to provide some solution to these issues. Discrete choice modelling is a well-developed avenue of consumer research that has been used extensively in transportation, residential, and recreation applications to predict individual and market behaviour in response to observable attributes, and as such it may provide an effective means of addressing these shortcomings. Three main strengths of DCMs make them an ideal candidate for representing the competition in CIMS in a way that neatly avoids the current shortcomings.

1. They are empirically derived from actual or hypothetical consumer behavior.
2. They are compatible with micro-economic theory (random utility models).
3. Their formulation is consistent with the way actual decisions are made in the marketplace at a disaggregate level.

3 Overview of Discrete Choice Models

In general, the market shares in a DCM are evaluated based on the relative utilities of each competing technology, with the utility of technology j, U_j, being defined as:

[1] In this case, we are assuming that there is some intangible benefit or cost to the technology itself (e.g., you prefer one particular car, boiler, electric motor or lightbulb over another). However, we can also model an O&M intangible as well, as in taking bike or walking over a car or a bus.

$$U_j = V_j + \varepsilon_j \qquad \textit{(Equation 3.1)}$$

where V_j is the observed utility and ε_j is the unobserved utility. The unobserved utility is a random variable, and it accounts for the fact that an external observer can never fully understand all of the factors that influence an individual's decision-making process. Observed utility represents the factors in the decision that can be explained and measured, and it is composed of a vector of observable technology attributes, X_j, and a corresponding vector of weighting parameters, β_j. The weighting parameters can be different for each alternative (values of transit time being different for cars and buses for example), which results in the general form of the observed utility. Equation 3.3 is an example of a possible function for the observed utility of car j:

$$V_j = \beta_j * X_j \qquad \textit{(Equation 3.2)}$$

$$V_j = \beta_1 * CC_j + \beta_2 * MC_j + \beta_3 * EC_j + \beta_4 * TT_j + \beta_5 \qquad \textit{(Equation 3.3)}$$

where CC_j is the capital cost of the car, MC_j is the maintenance cost, EC_j is the energy cost, and TT_j is the travel time. β_1, β_2, β_3, and β_4 are the weighting coefficients for each attribute, and β_5 is a technology specific constant that would account for systematic differences specific to the car that were not accounted for in the four other attributes. Both variables and weighting coefficients can also be subscripted to reflect various segments of the population (income groups for example), but they have been omitted for simplicity.

By definition, the unobserved component of utility can never be empirically estimated by the researcher, so it is modeled as a random variable, resulting in probabilistic market shares, namely:

$$MS_i = \text{Prob}(U_i > U_j) = \text{Prob}(V_i - V_j > \varepsilon_i - \varepsilon_j), \text{ for all } j \neq i \qquad \textit{(Equation 3.4)}$$

When the unobserved components, ε_j are each assumed to follow type 1 extreme value distributions[1], integrating the probability function in Equation 3.4 over all values of ε_j results in a multi-nomial logit (MNL) model, which has the following market share equation:

$$MS_i = \frac{e^{V_i}}{\sum_{j=1}^{J} e^{V_j}} \qquad \textit{(Equation 3.5)}$$

The remainder of this report will focus on the MNL model, but many other members of the DCM family exist, and the issues discussed hereafter are relevant to any of them. These alternative formulations are obtained by changing or relaxing the assumptions on the distribution of the unobserved component of utility, and the relationships between each alternative's utility.

In order to obtain data for these parameters, we are currently beginning some survey analyses based on "discrete choice" questions; providing respondents with a number of tradeoff questions to assess the degree to which they would prefer one option over another.

---

[1] The extreme value type 1 (EV1) distribution is similar in shape to a Weibull distribution, and is used in discrete choice models because parameters can be estimated using straightforward analytical techniques. Other distributions require more complex simulation routines to estimate the model.

4 Improving the Behavioural Component of CIMS, Description of Options

Analysts and policy makers relying on CIMS (or other hybrid models) will clearly benefit if CIMS is made increasingly behaviourally realistic through the incorporation of empirical data. Discussions have led to two clear options for the future of CIMS: 1) embedding a DCM within CIMS, and 2) revising the current parameters in CIMS, and estimating them to mimic a DCM. Both options are based on the belief that a discrete choice model will be able to provide a realistic representation of reality, and as such will serve as a solid foundation in an attempt to portray reality and our uncertainty surrounding that portrayal. Both options will involve considerable research (through surveys or literature reviews) to develop the discrete choice models needed.

The option of embedding a DCM within CIMS would involve replacing the current technology competition algorithm with the market share calculation for a discrete choice model (Equation 2.2 with 3.5). Although the market share equation is generic, the utility formulation would likely be unique for each competition node. Because of the number of nodes in CIMS, it would not be possible to develop unique DCM's for all CIMS competition nodes easily.

The second option of revising the current parameters in CIMS proposes to use the results of the discreet choice modelling to determine the value of the parameters in CIMS. The r and i parameters would be calculated from the discrete choice model using valuation techniques, and the v parameter would be solved to equate the market shares at a base case scenario. In fact, a number of estimates for i could be obtained, but for ease of analysis, they will be rolled into a single value for i, as shown in Equation 2.1 and 2.2.

Under this option, the non-cost information used to construct the DCM would remain external to CIMS, and sets of v, i and r could be estimated from the model to simulate various policy scenarios. When there is a need to change the i values (e.g., to reflect decreased travel times for transit) during the course of a simulation, this would necessitate redefining the i, and v values.

5 Representation of Uncertainty

CIMS currently produces output deterministicly, meaning that it produces the same point estimate for the amount of emissions that would be reduced for a given scenario every time that scenario is run. However, due to the complexity of the decisions being represented within the model, there is uncertainty in the output of CIMS that is not currently accounted for. In order to avoid promoting a false sense of confidence in modellers and policy makers, and in order for CIMS to be easily compared to other models, it should be possible to explicitly represent uncertainty. There are two primary sources of data uncertainty within CIMS: 1) uncertainty in the behavioural parameters that the model uses in the competition algorithm and 2) uncertainty in the characteristics and costs of technologies represented in the model. This section focuses on the first of these two uncertainties, but a similar solution (sampling from probability distributions) could be used to deal with both. Two steps are required to generate a meaningful estimate of the uncertainty due to behavioural parameters in the output of CIMS: 1) represent the uncertainty in the competition algorithm parameters and 2) propagate the uncertainty in these parameters through the model.

5.1 CIMS with current parameters

With each node in CIMS based on a DCM whose parameters are uncertain, that uncertainty should be carried through to the three parameters in CIMS[1]. Using numerical methods is one way to transfer the uncertainty from the DCM parameters to the CIMS parameters. The probability distribution on the DCM parameters would be sampled from and for each sample, the corresponding CIMS parameters would be found as defined in Section 4.2. This process would generate probability distributions for each CIMS parameter. Alternatively, it might be possible to transfer the uncertainty in an analytical fashion by using probability distribution algebra (note that this solution involves integration, which ultimately ends up as a numerical solution for a computer). With probability distributions assigned to the CIMS parameters, the propagation of uncertainty through the model could proceed similar to the way described below.

5.2 Uncertainty in β parameters

If a utility-based formulation is used to represent consumer decision making in CIMS, the key uncertain parameters are the various β_j coefficients in the utility functions. These parameters will be estimated using empirical data so that they represent real market decisions as closely as possible. However, they are still only estimates of the utility placed by consumers on different attributes of alternatives and are measured imperfectly, and therefore have uncertainty associated with them.

Typically, the β parameters are chosen as those that generate the maximum likelihood of the model given the data, however, this ignores the fact that other β*'s* are possible with significant likelihood. A Bayesian approach would recognize that there is a distribution of β parameters possible for each utility function with probabilities assigned using the likelihood function. However, it would be incorrect to generate independent β parameter distributions for each β_j in the utility function. The likelihood function is generated for combinations of β parameters, so any point on the likelihood function represents the likelihood of a combination of the β parameters – in other words, a joint probability distribution across all the different β parameters at that point.

5.3 Propagation of uncertainty

If we represent the β parameters by joint probability distributions, then a range of market shares are possible for each technology within a node. These different market shares in each node will interact with each other to produce a range of possible outputs. Because of the complex model dynamics in CIMS, it is not possible to analytically determine what the distribution of outputs will be given the joint probability distributions. Nor is it possible to simply generate 'best case' and 'worst case' scenarios by picking appropriate values of each β_j, since it is not obvious which values one would select for each parameter in our non-linear model. The most obvious method for generating a probability distribution of outputs in CIMS, given uncertain input parameters, will be to use some form of sampling. Various sampling strategies are available, differing primarily in the way that samples are drawn from the probability distributions. Monte Carlo sampling draws the values randomly from probability distributions, while Latin hypercube sampling is a stratified sampling technique that samples only once from each of m equiprobable strata.

For example, CIMS will be run m times. In each run, a sample will be drawn from each joint probability distribution of β parameters to generate a scenario. The selected β parameters will determine market shares of technologies as usual and the model will be run for the desired

[1] Under this formulation, we would effectively be basing the parameters of a model (CIMS) on the output of another model (DCM) which could magnify the uncertainty present in the model.

number of years. Since the model is run *m* times, *m* outputs (in this case the amount of carbon dioxide emissions reduced) will be generated, and they can be combined to produce a probability density function for outputs, which would be a useful measure of uncertainty. In addition to the distribution of the output, the sampling process will also allow us to determine the contribution to the variance in output that each input is responsible for. This information can guide further research by identifying the input parameters that are the have the largest influence on overall output.

The drawback of sampling to determine uncertainty in the output parameters is that performing multiple runs can consume large amounts of computer time[1]. If computer time was found to be an issue in generating uncertainty, users could be given the option of whether or not to conduct an uncertainty analysis, so that for a run when uncertainty was not an issue, just the best estimates for the β parameters could be used.

6 Further Issues for Discussion

Some issues that are clearly relevant to the ongoing comparison of the two options have been identified, but have not yet been comprehensively analyzed. These issues include: 1) the flexibility to accommodate alternative DCM formulation such as mixed logit, nested logit, or multinomial probit, 2) the ability to represent socio-economic information of individual decision makers, which would require the introduction of new variables to CIMS, and 3) potential problems involved when nested levels of CIMS follow different decision rules (this only occurs if one were to substitute a DCM model for the current choice algorithm in the set of CIMS nodes simulated).

7 Conclusions

This document has outlined the need for an empirically estimated technology competition algorithm in CIMS. We propose to satisfy this need by using discrete choice models to understand the attributes that lead decision makers to select certain technologies over others. Discrete choice models are a leading paradigm for individual choice and market behaviour modeling, and we propose two main avenues for integrating them into CIMS:

1. Maintaining the current parameters in CIMS, but estimating the values of the parameters using discrete choice models.
2. Replacing the current new stock competition algorithm in CIMS with empirically estimated discrete choice models at each competition node in CIMS.
3.

In either case, the empirical nature of DCMs allows the analyst to evaluate uncertainty associated with the model outcomes to a much greater extent than has historically been possible. This estimation of uncertainty is bound to be helpful to decision makers and policy analysts.

[1] The amount of samples required depends on the degree of confidence we want to be able to place on our results, and the sampling strategy followed.

IV. Modeling

Economic Analysis on Energy Conservation Policies in Korea
A CGE Modeling Approach

Jaekyu Lim[1]

Korea Energy Economics Institute, Korea

Abstract

This study investigates impacts of energy saving policies on the national economy in Korea. As energy saving policies, the R&D investment, government loan program, energy taxation, and the energy efficiency standard program are examined. These policies applied on specific sector cause changes of energy consumption patterns of the specific sector and also the other sectors. In addition to the impacts on energy consumption, such policies can change energy prices, output, employment, consumer price levels, and resources allocation in the economy. In this context, the analysis on the impacts of energy saving policies needs to consider such interactions between economic sectors. Thus, this study employs a computable general equilibrium (CGE) model to analyze and compare the impacts of various energy saving policies.

As a result of analysis, the R&D investment policy in energy sector is found to be the most effective policy option. It is projected to increase real GNP and real GDP as well as to decrease the energy consumption. Accordingly, it is considered as one of so-called no-regret policies, appropriate to the energy intensive and transportation sectors. The government loan program is also found to raise real GNP with the reduction of energy consumption, although it may have a negative impact on trade balance. And, it is observed to be suitable for the transportation and household sectors.

On the one hand, the energy taxation policy is found to be cost-effective since the marginal cost of energy conservation is much lower than about 80,000 won per ton of oil equivalent. It is recommended, however, that an additional energy tax should be imposed with care, given the existing high level of energy tax. The impacts on energy efficiency standards on transportation, household, and commercial sectors are found to vary depending on the movements of prices of relevant energy using equipment and appliances. This study also recommends for efficiency standard schemes to be implemented only when they incur no significant price changes of relevant energy using equipment and appliances.

[1] E-mail: jklim@keei.re.kr

KEEI

INEDIS / EETA Workshop on Policy Modeling for Industrial Energy Use
jointly organized by KEEI, KREA and LBNL
7th-8th November 2002, Seoul, Korea

Economic Analysis on Energy Conservation Policies in Korea : A CGE Modeling Approach

Jaekyu Lim
Korea Energy Economics Institute (KEEI)

KEEI

Contents

- Energy conservation policies in Korea
- Model : KORTEM
- The reference case
- Policy scenarios
- Impacts of energy saving policies
- Conclusion and policy implications

KEEI

Energy Conservation Policies in Korea(1)

- Energy taxation and charge scheme
  - charges on oil and natural gas
  - transportation tax, special consumption tax, education tax, etc
  - under process of restructuring of energy tax system
- Financial support and incentives
  - tax deduction on energy saving facility investment
  - incentives on district heating, ESCO, VA, etc
- Energy technology R&D
  - energy saving, alternative energy and clean energy technology development
  - "ten-year national plan for energy technology development (1997-2006)" : 21 technology targets

KEEI

Energy Conservation Policies in Korea(2)

- Command and control
  - energy efficiency standards & labeling program
  - certification of high efficiency energy-using appliance program
  - energy saving office equipment & home electronic program
  - fuel economy rating / labeling program (motor vehicle)
  - fuel economy target scheme

KEEI

Model : KORTEM (1)

- One-country, dynamic, multi-sector model
  - Johansen style model : percentage change form
- 103 commodities and Industries
  - 19 energies and 10 margins (4 transport margins)
- 3 types of primary factors: labor, capital, land
  - labor divided to 9 different occupations
- Nested production and consumption structure
- Inter-fuel and energy-capital substitution
- Detailed treatment of the government sector
  - tax revenue recycling

KEEI

Model : KORTEM (2)

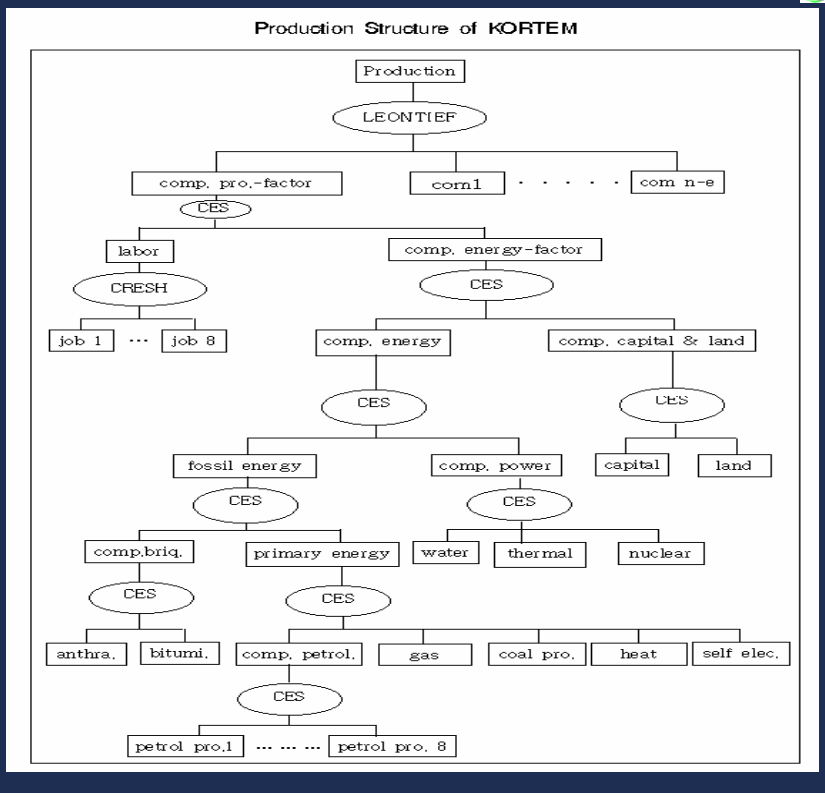
- Static Components
  - producers' demands for produced inputs and primary factors
  - producers' supplies of commodities
  - demands for inputs to capital formation
  - household, export and government demands
  - the relationship of basic values to production costs and to purchasers' prices
  - market clearing conditions for commodities and primary factors
  - numerous macroeconomic variables and price indices

KEEI

Model : KORTEM (3)

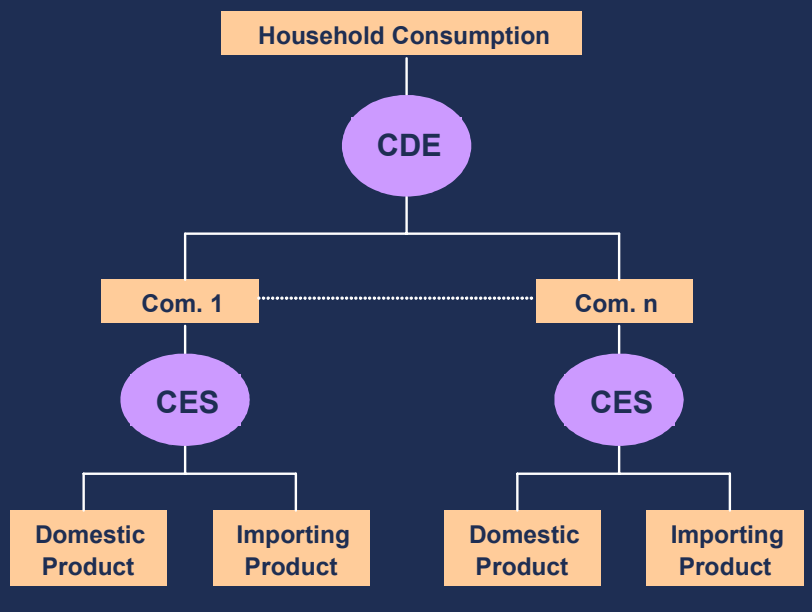
- Dynamic components
  - capital accumulation : initial stock, depreciation rate and investment.
  - population accumulation : demographic module
  - debt accumulation : national saving and investment
- Various energy conservation policy analysis
  - taxation, financial support, command and control, etc

KEEI



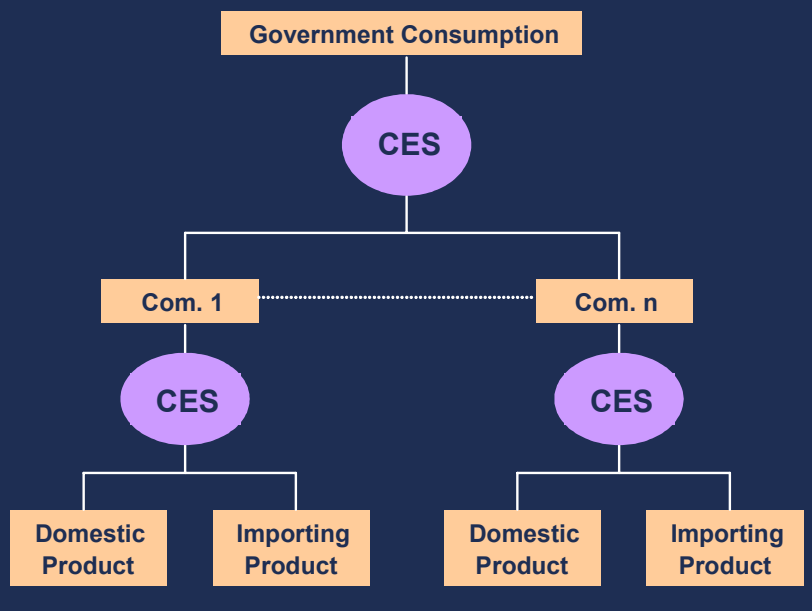
KEEI

Household Consumption



KEEI

Government Consumption



KEEI

The Reference Case (1)

- Economy and energy consumption

	2000	2005	2010	AAGR(%)	
				2000~2005	2005~2010
Real GDP (Trillion Won)	442.4	579.6	732.3	5.55	4.79
Population (Million)	47.2	49.2	50.8	0.84	0.64
Energy Consumption (MTOE)	148.0	190.2	239.4	5.14	4.71
Energy Intensity (MTOE/TW)	0.335	0.328	0.327	-0.38	-0.08

	2000	2005	2010	AAGR(%)	
				2000~2005	2005~2010
Coal	19.8	21.3	22.3	1.45	0.95
Oil	105.5	142.1	185.9	6.13	5.52
Electricity	15.2	17.1	18.8	2.26	2.01
Gas	6.7	8.8	11.1	5.64	4.91
Heat	0.6	0.8	1.1	5.56	4.67

KEEI

The Reference Case (2)

- Industry production

	2000~2005	2005~2010
Agriculture, fishery	1.75	1.41
Mining	2.16	1.30
Food, beverage	2.84	2.39
Textile, apparel, leather	1.05	0.84
Wood and paper products	2.92	2.27
Coal products	1.04	0.41
Petroleum products	6.72	6.13
Chemicals, rubber, plastic	2.52	1.97
Non-metallic products	3.70	2.71
Primary metal products	1.75	0.85
Fabricated metal products	2.86	2.09
Machinery and equipment	2.83	1.93
Electronic and electric equipment	7.79	6.02
Other manufactured products	3.06	2.58
Construction	4.68	3.81
Trade and hotel	4.68	4.11
Service	4.87	4.26
Transportation	5.05	5.43

KEEI

Policy Scenarios (1)

- Energy tax
  - target : reduction of total final energy consumption by 5%, 10%, 15% relative to the reference case in 2010
  - endogenous optimal tax rate on final energy source
  - tax exemption on agriculture and fishery
  - tax revenue recycling by income tax reduction
- Financial incentives
  - target : reduction of total final energy consumption by 5%, 10%, 15% relative to the reference case in 2010
  - difficult to apply on the model => indirect application
  - import charge on oil and gas => investment of energy intensive industries => expected substitution between capital and energy

KEEI

Policy Scenarios (2)

- R&D investment
  - target : reduction of total final energy consumption by 5%, 10%, 15% relative to the reference case in 2010
  - import charge on oil and gas => R&D of energy intensive industries => expected substitution between R&D and composite of energy (modification of model)
- Energy efficiency standards
  - target : reduction of electricity consumption in household and commercial sectors by 5%, 10%, 15% relative to the reference case in 2010
  - stronger standards on energy using appliances in household and commercial sectors
  - different assumption on price change of electronic and electric appliances

KEEI

Policy Scenarios (3)

- Fuel economy on motor vehicle
  - target : reduction of consumption of gasoline, diesel and LPG in transportation sector by 5%, 10%, 15% relative to the reference case in 2010
  - stronger fuel economy on motor vehicles
  - different assumption on price change of motor vehicle

KEEI

Impacts of Energy Saving Policies (1)

- Economy and energy consumption (10% target)

	Tax	F. I.	R&D	E. E.	F. E.
Real GNP	- 0.07	0.46	1.91	0.42	- 0.20
Real GDP	- 0.04	- 1.19	1.80	0.34	- 0.17
Energy Consumption	- 10.00	- 6.12	- 5.38	3.14	- 1.64
Energy Intensity	- 9.43	- 4.99	- 7.06	2.79	- 1.47

	Tax	F. I.	R&D	E. E.	F. E.
Energy Intensive Ind.	- 13.14	3.00	- 0.01	4.56	- 0.65
Other Industries	- 9.17	- 9.71	- 6.35	2.60	- 0.12
Transportation	- 5.83	- 11.94	- 13.67	11.02	- 6.36
Commercial & Public	- 11.15	- 14.65	- 10.32	- 11.14	- 0.29
Household	- 10.20	- 10.65	- 6.50	- 0.78	- 0.06

Note: 1) E. E. shows the result for the case of 7.5% increase of price of household electronic and electric appliances
2) F. E. shows the result for the case of 7.5% increase of price of motor vehicles

KEEI

Impacts of Energy Saving Policies (2)

- R&D investment : expansion of economic activity and energy saving => 'no regret policy'
  - effective for transportation and commercial sectors
- financial incentive : increase of real GNP with energy saving, but trade account deficit causing decrease of real GDP
  - effective for transport, commercial and household sectors
- energy tax : effective but economic cost
  - important role of tax revenue recycling
  - careful implementation, give the existing high level of energy tax
- other policies : depends on the movements of prices of energy using equipments and appliances
  - no significant price change of relevant appliances required

KEEI

Impacts of Energy Saving Policies (3)

- Industry production

	Tax	F. I.	R&D	E. E.	F. E.
Agriculture, fishery	- 0.07	0.01	0.33	1.27	- 0.05
Mining	- 0.40	0.87	3.72	- 0.77	- 0.14
Food, beverage	- 0.18	- 0.21	0.96	2.19	- 0.11
Textile, apparel, leather	- 0.29	- 0.35	0.95	5.33	0.26
Wood and paper products	- 0.43	5.59	2.28	3.14	- 0.04
Coal products	- 4.47	0.50	4.91	9.15	- 0.73
Petroleum products	- 6.04	- 9.94	- 9.70	4.95	- 2.30
Chemicals, rubber, plastic	- 0.97	4.35	14.72	3.90	0.08
Non-metallic products	- 0.02	1.62	4.51	- 3.91	0.20
Primary metal products	- 1.28	- 0.22	3.73	6.59	- 0.26
Fabricated metal products	- 0.57	0.96	1.82	0.81	- 0.07
Machinery and equipment	- 0.33	- 0.53	1.85	1.92	0.19
Electro. & elec. equip.	1.52	2.39	3.10	- 13.14	0.90
Other manufactured prod.	- 0.57	12.87	1.62	1.60	- 0.59
Construction	- 0.56	0.28	1.57	- 2.41	- 0.12
Trade and hotel	- 0.45	0.62	- 0.78	3.71	- 0.09
Service	- 0.29	0.33	- 0.12	1.33	0.01
Transportation	- 0.70	0.21	- 0.13	1.12	0.29

KEEI

Impacts of Energy Saving Policies (4)

- energy tax : widespread reduction of industry output
  - significant in energy and energy intensive industries
  - resource reallocation to non-energy intensive industries
- financial incentive : mixed movement of industry output
  - general increase in non-energy intensive industries, especially investment goods producing industries
  - incentive effect on wood, chemicals, and other manufac.
  - petroleum product and primary metal products : caused by increase of prices of oil and gas
- R&D investment : widespread increase of industry output, with R&D investment on energy intensive industries
  - reduction of petroleum product caused by oil price change
  - resource allocation to energy intensive industries

KEEI

Impacts of Energy Saving Policies (5)

- energy efficiency standard for household and commercial appliances
  - mixed impacts on industrial output
  - significant reduction of electronic and electric appliances
  - different impacts for assumption on price change of household and commercial appliances
- fuel economy on motor vehicle
  - mixed impacts on industrial output
  - general increase of production of durable consumer goods with increase of price of motor vehicle
  - smaller extent of production change with assumed lower change of price of motor vehicle
  - significant decrease of production of petroleum products

KEEI

Conclusion & Policy Implications (1)

- Different impacts on economy
  - R&D investment : no-regret policy
  - no strict improvement of trade account with energy saving policies
    - potential deterioration of trade account with energy efficiency standard, fuel economy and financial incentive policies
- Different impacts on energy consumption
  - energy saving with R&D investment and financial incentive policies
  - possible energy saving with energy efficiency standard and fuel economy schemes with strict price control of energy using appliances and motor vehicles

KEEI

Conclusion & Policy Implications (2)

- Careful consideration on implementation of command and control and energy taxation
  - energy efficiency standard and fuel economy
  - complementary policies and measures for efficient energy saving without significant economic costs
- High priority on R&D investment and financial incentive schemes as energy saving policies
  - potential non-regret policies
  - higher priority on R&D investment

Modeling Policies in the Clean Energy Futures Study

Ernst Worrell[1] and Lynn Price
Lawrence Berkeley National Laboratory

Abstract
Scenarios for a Clean Energy Future (CEF) studied the role that efficient clean energy technologies can play in meeting the economic and environmental challenges for our future energy supply. The study describes a portfolio of policies that would motivate energy users and businesses to invest in innovative energy efficient technologies. On the basis of the portfolios, two policy scenarios have been developed, i.e. a moderate scenario and an advanced scenario. We focus on the industrial part of the CEF-study. The studied policies include a wide scope of activities, which are organized under the umbrella of voluntary industrial sector agreements. The policies for the policy scenarios have been modeled using the National Energy Modeling System (CEF-NEMS). Under the reference scenario industrial energy use would grow to 43.3 EJ in 2020, compared to 36.7 EJ in 1997, with an average improvement of the energy intensity by 1.1% per year. In the Moderate scenario the annual improvement is about 1.5%/year, leading to primary energy use of 40.0 EJ in 2020, resulting in 10% lower CO_2 emissions by 2020 compared to the reference scenario. In the Advanced scenario the annual improvement increases to 1.8% per year, leading to primary energy use of 36.1 EJ in 2020, and 29% lower CO_2 emissions. We report on the policies, modeling assumptions and results for industry.

Introduction

The industrial sector is extremely diverse and includes agriculture, mining, construction, energy-intensive industries, and non-energy-intensive manufacturing. In 1997, the industrial sector consumed 37 EJ (Exajoule, 10^{18} J)of primary energy, accounting for 37% of the primary energy consumed in the U.S. that year. Energy-intensive industries are still the largest energy users, although the share of light industries has grown over the past few years. Carbon dioxide emissions from industrial energy use and process emissions from cement manufacture were 494 MtC, accounting for 33% of total U.S. CO_2 emissions in 1997. Some industries also emit process emissions, which have partially been accounted for (e.g. cement and chemical industry) or excluded (e.g. limestone use in the steel industry) in this study.

Various bottom-up studies have found cost-effective potentials for energy efficiency improvement in the industrial sector (Interlaboratory Working Group, 1997; Energy Innovations, 1997). Many studies identified energy efficiency improvement opportunities. Innovative industrial technologies aim to not only reduce energy use, but also to improve productivity, reduce capital costs, reduce operation costs, improve reliability as well as reduce emissions and improve working conditions. Hence, many of the technologies discussed below will reduce the production cost of industries, and increase competitiveness in a globalizing economy.

[1] Corresponding author. E-mail: Eworrell@lbl.gov

We present scenarios for future industrial energy use, based on different assumptions for U.S. energy policies, using the results of the *Scenarios for a Clean Energy Future* (CEF) study (IWG, 2000). Following a 1997 study, *Scenarios of U.S. Carbon Reductions,* the U.S. Department of Energy (US DOE) commissioned an Interlaboratory Working Group to examine the potential for public policies and programs to foster efficient and clean energy technology solutions to these energy-related challenges. The earlier report (Interlaboratory Working Group, 1997) identified a portfolio of technologies that could reduce carbon emissions in the United States to their 1990 levels by the year 2010. The CEF study identifies specific policies and programs that could motivate businesses to purchase the technologies making up its scenarios. A scenario is a way to understand the implications of a possible future through modeling assumptions that reflect this future. By definition, considerable uncertainties exist in all scenario analyses and this is also true for the industrial sector where ever-changing dynamics drive decision-making. Uncertainties in the assumptions affect the final results of the scenarios. However, as it is not always possible to quantitatively estimate the uncertainties and for reasons of presentation we only present point estimates.

We analyze two policy-driven scenarios using the CEF-NEMS model. The CEF-NEMS model does not allow direct modeling of demand side policies in the industrial sector. Hence, extensive changes were made to the model inputs to reflect the actions due to new policies in the policy scenarios, as outlined in the methodology section. The projected changes in inputs are based on analyses by industry, government and academic sources.

Methodology

For the analysis we used an adapted version of the U.S. Energy Information Administration's National Energy Modeling System (NEMS), which is used for EIA's energy forecasting. In NEMS energy use can be modeled at the energy service demand, or process stage, level, while for other sectors no equipment is explicitly modeled nor are there any engineering links between process stages, and technology is represented parametrically. The CEF-NEMS Industrial Module contains no explicit equipment characterizations, but the parameters can be calculated based on assumptions of technology performance and penetration. These estimates are an exogenous input to the model. For the CEF policy scenarios, new inputs were developed for the CEF-NEMS model.

Business-As-Usual Scenario. In the CEF –study we adopted the economic scenarios as used by the EIA for the AEO99 as the business-as-usual scenario. We adopt the energy consumption data of the AEO99 reference case for the business-as-usual scenario for all industrial sub-sectors except for paper, cement, steel, and aluminum, the first three of which we analyzed in detail. For the paper, cement, and steel sectors, our estimates of physical energy intensities by process differed from those in used in the AEO99. We also changed the retirement rates for all sub-sectors to reflect actual lifetimes of installed equipment, based on detailed assessments of equipment ages and future developments in these sectors. Although NEMS does not treat equipment lifetime endogenously, it is possible to define the retirement rate for process equipment. Retirement rates for industrial technologies in the AEO99 scenario seem to be low, when compared to other sources (BEA, 1993; Jaccard & Willis, 1996), or assessments of technical and economic lifetimes of technologies. The modifications to the AOE99 reference case result in slightly lower CEF-NEMS business-as-usual energy consumption values compared to AEO99 (approximately 2% lower by 2020).

Policy Scenarios. We analyze two policy implementation scenarios – a moderate scenario based on establishment of voluntary agreements with industry that set moderate annual energy efficiency improvement commitments and an advanced scenario setting higher voluntary energy efficiency improvement commitments. The two policy scenarios assume

successful implementation of a portfolio of policy measures to improve energy efficiency. Our analysis begins with an assessment of policies and programs applicable to the industrial sector. We use voluntary industrial sector agreements between industry and government as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions. These voluntary industrial sector agreements are supported by a comprehensive package of policies and programs designed to encourage implementation of energy-efficient technologies and practices.

The NEMS-model does not allow the direct modeling of policies. In NEMS even the effects increased energy prices have to be modeled exogenously, except for some secondary feedback effects. Hence, except for a carbon cap and trade system in the advanced scenario, we had to estimate the potential impact on energy intensity and technology assumptions in the model for each scenario. Based on policy evaluations (ex-ante and ex-post) and different (international) studies, we have estimated the effect of policy implementation on industrial technology choice and energy use. The effects of the different policies have been combined to model the impact of the policy portfolio. This has led to a series of bottom-up assumptions on energy intensities in each modeled industrial sector, which are reported in the appendices of the study (IWG, 2000).

After running the model the total effect on energy use (i.e. the difference between the baseline scenario and policy scenario, accounting for changes in the power supply sector) has been evaluated top-down, through a cross-check on the basis of policy-evaluations. The found energy savings in each of the policy scenarios were explained on the basis of these evaluations. Since voluntary industrial sector agreements are the umbrella under which a number of policies and programs contribute to decisions to implement energy-efficient technologies and measures, it is often difficult to allocate specific actions to specific policies or programs. Estimates are made to allocate the overall synergetic effects of actions taken due the supporting policies and measures. The energy savings resulting from the carbon cap and trade system were estimated by running the model with and without the permit-costs.

The investments made to achieve the energy savings were based on supply-curves for energy efficiently improvement in three sectors modeled in detail (see below). The costs of administering and implementing the policy programs were estimated on the average cost of five policy evaluations. These evaluations (not necessarily in the industrial sector alone) resulted in an estimated program cost expressed in $/GJ-saved. Multiplying this cost factor with the achieved savings resulted in the total program costs.

Actions Addressed Within CEF-NEMS. We determined where and how the energy savings might be achieved in terms of modeling parameters and modeled these changes in CEF-NEMS, on an aggregation level appropriate for the CEF-NEMS model. Some policies may affect only one modeling parameter. For example, research and development is most likely to affect the energy efficiency improvement and availability of new equipment. On the other hand, a carbon trading system will affect the price of energy and will likely influence all parameters of the model.

For *existing equipment* in the paper, cement, and steel sectors, modifications were made based on calculations made outside of CEF-NEMS. For the other sectors, we relied on recent analyses of the energy efficiency improvement potentials in these sectors or used the AEO99 HiTech Case inputs. The rate of adoption of *new energy-efficient technologies* and measures for new equipment is characterized in NEMS using TPCs. The TPCs were modified in the moderate and advanced scenarios in all sectors based on recent analyses of the energy efficiency improvement potentials (e.g. Worrell et al, 1999; Martin et al., 1999; Martin et al, 2000). Product labeling programs and pollution prevention programs will reduce primary

resources inputs in the paper, glass, cement, steel, and aluminum subsectors as these industries move toward increased use of recycled materials. Material inputs in CEF-NEMS have been adjusted in the moderate and advanced scenarios to reflect such a shift, based on recent studies (e.g. Barnett, 1998; McLaren, 1997; PCA, 1997; Plunker, 1997) and technical limitations. Expanded Steam Challenge, state programs, Clean Air programs and SIPs, and OIT R&D programs will all contribute to improved *boiler efficiency*. Boilers in AEO99 are modeled with a set or fixed efficiency of around 80% for boilers using fossil fuels and 74% for by-product boilers. In reality boiler efficiency can vary widely, e.g. between 65% and 85% for coal boilers (CIBO, 1997). Also, in NEMS, boilers are not retired, so the efficiency gains from new boilers are not captured in the model. Based on the assumptions in the BAU-scenario, and assessments of boiler efficiency improvements (CIBO, 1997; Einstein et al., 2001) we have determined improvement rates for the policy scenarios, reflecting the retirement of older boilers as well as the potential impact of the policy measures. Various programs will lead to improvements in *industrial building energy efficiency*. The NEMS model does not account for energy use in buildings in the agriculture, mining, or construction industries, but does include building energy use in all of the remaining industries. For these industries, we adopt the energy savings potential for the moderate and advanced scenarios identified in this study for commercial buildings.

Actions Addressed Outside CEF-NEMS. Various actions due to policies were modeled outside of CEF-NEMS, although some results were fed into the CEF-NEMS model. We assessed the potential impacts of policies on retrofitting existing technologies in the paper, cement, and steel industry, and two related cross-cutting opportunities, i.e. cogeneration (or combined heat and power, CHP) and motor systems. In the paper, cement, and steel *industrial sub-sectors* we assessed the technologies available to *retrofit* existing plants. In total, over one hundred technologies were characterized with respect to potential energy savings, costs, and potential degree of implementation. *Combined Heat and Power Production* (CHP) is modeled separately to model the interaction with the power sector, effects of policy initiatives, and the replacement of retired industrial boilers. The model allows the use of CHP for new steam generation capacity, due to growth of steam demand in the sectors. The NEMS model does not retire old boilers. Hence, brownfield applications of CHP cannot be modeled inside the model, but are modeled outside the model. As growth in steam demand in most sectors is slow in the policy scenarios, implementation of CHP in the model itself is very limited. The CHP analysis was performed using Resource Dynamics Corporation's DISPERSE model[1]. The results were compared with results of studies using other utility models, i.e. the IPM model run for US EPA. DISPERSE is a model that compares on-site power generation with the grid on the basis of costs. DISPERSE estimates the achievable economic potential for CHP. The model not only determines whether on-site generation is more cost effective, but also which technology and size appears to be the most economic. As a result, double counting of market potential for a variety of competing technologies is avoided. It was not possible to fully integrate the DISPERSE results into CEF-NEMS[2]. Hence we were unable to assess the integrated impact on electricity generation and fuel mix.

Barriers and Policies

Industrial sector policies and programs are designed to address a number of barriers to investment in energy efficiency and greenhouse gas emissions reduction options including

[1] Distributed Power Economic Rationale Selection (DISPERSE) model.

[2] Within the timeframe of this study it proved to be impossible to model the cogeneration results into CEF-NEMS model at the industrial sub-sector level. Future work is needed to balance the boiler representation used in DISPERSE-model with steam demand in CEF-NEMS and to integrate the DISPERSE-results in the integrated CEF-NEMS scenarios to estimate impact on power sector energy demand and fuel-mix, as well as second order effects, due to changes in fuel mix and energy demand.

willingness to invest, information and transaction costs, profitability barriers, lack of skilled personnel, and other market barriers.

Voluntary sector agreements between government and industry are used as the key policy mechanism to reduce the barriers, while accounting for the characteristics of technologies, plant-specific conditions, and industrial sector business practices. Policies and measures supporting these voluntary sector agreements should account for the diversity of the industrial sector while at the same time being flexible and comprehensive, offering a mix of policy instruments, giving the right incentives to the decision maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures. Industry is extremely diverse, and even within one sub-sector large variations in the characteristics may be found. Various instruments that support the voluntary sector agreements, both at the federal level and state level, are put in place in the policy scenarios to reach the very diverse stakeholders.

Voluntary agreements (VAs) are "agreements between government and industry to facilitate voluntary actions with desirable social outcomes, which are encouraged by the government, to be undertaken by the participants, based on the participants' self-interest" (Story, 1996). A VA can be formulated in various ways; two common methods are those based on specified energy efficiency improvement targets and those based on specific energy use or carbon emissions reduction commitments. In this study, the VAs are defined as a commitment for an industrial partner or association to achieve a specified energy efficiency improvement potential over a defined period. The level of commitment, and hence specified goal, varies with the moderate and advanced scenario. The number and degree of supporting measures also varies with the two scenarios, where we expect the increased industrial commitment to be met with a similar increased support effort by the federal and state government. The effectiveness of VAs is still difficult to assess, due to the wide variety and as many are still underway. We estimate the effect on the basis of various efforts undertaken. VAs in Japan and Germany are examples of self-commitments, without specific support measures provided by the government. Industries promised to improve energy efficiency by 0.6% to 1.5% per year in those countries (IEA, 1997a). The VAs in The Netherlands have set an efficiency improvement goal of 2% per year (IEA, 1997b). Industries participating in the voluntary agreements in The Netherlands receive support by the government, in the form of subsidies for demonstration projects and other programs. The VAs were attractive to industry, as they allowed the development of a comprehensive approach, provided stability to the policy field, and were an alternative to future energy taxation (Van Ginkel & De Jong, 1995), or regulation through environmental permitting. For more details on VAs, see Worrell & Price (2001). Evaluation of voluntary industrial sector agreements in The Netherlands showed that the agreements helped industries to focus attention on energy efficiency and find low-cost options within commonly used investment criteria. Experience with industrial sector VAs exists in the U.S. for the abatement of CFC and non-CO_2 GHG emissions. For example, eleven of twelve primary aluminum smelting industries in the U.S. have signed the Voluntary Aluminum Industrial Partnership (VAIP) with EPA to reduce perfluorocarbon (PFC) emissions from the electrolysis process by almost 40% by the year 2000. Similar programs exist with the other industries.

Table 1 outlines the various policies and programs. These include expansion of a number of existing programs as well as establishment of new programs. The effects of increased program efforts are difficult to assess. Cost-effectiveness may improve due the increased volume, but may also be less effective as programs reach smaller energy users or lead to implementation of less-effective measures. The interaction of various measures deployed simultaneously is difficult to estimate ex-ante, or even ex-poste (Blok, 1993). It is also often

more difficult to assess the impacts of individual programs than the estimated impact of a set of policies.

Table 1. Policies and Programs for Reducing Energy Use and Greenhouse Gas Emissions from the Industrial Sector Under the Moderate and Advanced Scenarios.

Policy/Program	Moderate Scenario	Advanced Scenario
Voluntary Industrial Sector Agreements		
Voluntary Industrial Sector Agreements	Voluntary programs to reduce GHG emissions in energy-intensive and GHG-intensive industries.	Voluntary programs to reduce GHG emissions (CO2 and non-CO2) in all industries, including benchmarking.
Voluntary Programs		
Expanded Challenge programs Motor and Compressed Air Challenge	Increased effort to assist in motor system.	Increased promotion of motor system efficiency and use of adjustable-speed drives by offering greater financial incentives.
Steam Challenge	Outreach, training, and development of assessment tools is increased.	Expanded to include outreach to smaller boiler users and automated monitoring and controls.
CHP Challenge	Financial incentives, utility programs promoting CHP, and removal of barriers.	Program expands to include increased outreach, dissemination, and clearing-house activities
Expanded ENERGY STAR Buildings and Green Lights	Best practices management tools and benchmarking information. Floorspace covered by program increases by 50%.	Floorspace covered by program increases by 100%.
Expanded ENERGY STAR and Climate Wise program	Increased and program expansion.	Program expanded to include light industries, agriculture, construction, and mining.
Expanded Pollution Prevention Programs	Expanded effort leads to increased recycling in the steel, aluminum, paper, and glass industries.	Number of partners grows to 1600 by 2020 (from 700 in 1997).
Information Programs		
Expanded Assessment Programs	Number of industrial assessment centers increases. Expanded to include business schools. Added emphasis on follow-up.	Number of industrial assessment centers increases. Comprehensive energy plans for each audited facility added.
Product Labeling and Procurement	Development of labels for two products.	Labeling expanded to other products (e.g. glass bottles). Marketing of labels. Government procurement policies include labeled products.
Investment Enabling Programs		
Expanded State Programs State Industrial Energy Efficiency Programs	Current state level programs are expanded. Participation grows to 30 states.	Programs expanded to include all 50 states.
Clean Air Partnership Fund	Expanded use of integrated approaches for complying with	GHG emissions reduction projects given higher priority.

	CAA.	
Expanded ESCO/utility programs Standard performance contracting (line charge)	Expansion of line charges to 30 states and increased efforts to target small industrial customers.	Expansion of line charges to 50 states and further increased efforts to target small industrial customers.
Financial incentives Tax incentives for energy managers	Provides tax rebates of 50% of the salary of an energy manager to medium and large industries.	Tax rebates provided to 10,000 medium and large energy using-industries by 2020.
Tax rebates for specific industrial technologies	Increased rebates focus on implementation of advanced technologies.	Increased rebates focus on implementation of advanced technologies.
Investment tax credit for CHP systems	Tax credit extended from 2003 to 2020.	Tax credit extended from 2003 to 2020.
Regulations		
Motors Standards and Certification	Mandates upgrade of all motors to EPACT standards by 2020. Promote national motor repair standard.	Extends standards to all motor systems. Mandates national motor repair standard.
State Implementation Plans/Clean Air Partnership Fund	Identifies control measures and regulations to adopt and enforce the control strategies.	Identifies control measures and regulations to adopt and enforce the control strategies.
Research & Development Programs		
Expanded Demonstration Programs	Demonstration programs expanded.	Extent of demonstration programs further expanded in all sectors and incorporated into state demonstration programs.
Expanded R&D programs Industries of the Future	Increased R&D efforts in all industries currently in program.	Increased R&D efforts and expansion to a number of smaller "other manufacturing" industries.
Other OIT R&D programs	Program R&D efforts increased in all areas related to improving industrial sector energy efficiency.	Industrial sector energy efficiency R&D efforts further increased.
Domestic Carbon Dioxide Emissions Trading System	N/A	

Scenario Results

Generally, a number of cross-cutting technologies can achieve large improvements, e.g. preventative maintenance, pollution prevention and waste recycling, process control and management, steam distribution system upgrades, improved energy recovery, cogeneration (CHP), and drive system improvements. However, a large share of the efficiency improvements is achieved by retiring old process equipment and replacing it with state-of-the-art equipment (Steinmeyer, 1997). This emphasizes the need for flexibility in achieving energy efficiency improvement targets, as provided by the voluntary industrial agreements.

Energy savings are found in all industrial sub-sectors. Production growth is lower in most energy-intensive industries than the less energy-intensive manufacturing industries. Hence,

most of the growth in energy use and emissions can be found in the light industries. Energy efficiency improvements in the policy scenarios appear high, as the improvements in the baseline scenario are almost zero in the light industries. While light industries would consume almost half of the energy by 2020 in the reference scenario, almost 50% of the total energy savings in the advanced scenario are also found in these industries.

The characteristics of decision makers vary widely. Hence, there is no "silver bullet" policy; instead, an integrated policy accounting for the characteristics of technologies and target groups is needed. Acknowledging the differences between individual industries (even within one economic sector) is essential to develop an integrated policy. Policies and measures accounting for the diversity of industry, offer a mix of policy instruments, give the right incentives to the decision maker at the firm level, and provide flexibility needed to implement industrial energy efficiency measures.

In the **reference scenario** industrial energy use grows from 36.7 EJ in 1997 to 43.3 EJ in 2020, which is almost equal to that of the AEO99 (44.4 EJ), see Figure 1. Energy use in the reference scenario shows a slight growth of 0.7%/year, while industrial output grows by almost 1.9%/year. Hence, the aggregate industrial energy intensity decreases by about 1.1%/year, or 23% over the scenario period. The intensity change in the AEO99 scenario is due to inter-sector structural change (almost three-fourths of the change), i.e. a shift to less energy intensive industries, and energy efficiency improvement (about one fourth). Carbon dioxide emissions from the industrial sector in the reference scenario increase by nearly 0.7%/year to 578 MtC. The growth in the reference scenario can be found in other manufacturing industries (e.g. metals based durables, other manufacturing) and the non-manufacturing industries. Energy use in the energy intensive industries grows slightly, or is even reduced, due to slower economic growth in these sectors, resulting in the inter-sector structural change of the economy. By 2020, energy intensive industries still consume 51% of total industrial energy use, down from 55% in 1997. The industrial fuel-mix changes slightly towards less carbon-intensive fuels.

In the **moderate scenario** industrial energy use grows from 36.7 EJ in 1997 to 40.0 EJ in 2020, equivalent to a growth of 0.4%/year (excluding CHP). Total industrial energy use in 2020 under the moderate scenario is about 8% lower than the reference scenario. In the moderate scenario overall industry energy intensity falls by 1.5%/year. Annual carbon emissions are increasing to approximately 521 MtC, or a reduction of 10%. The changes in carbon intensity are larger due to the shift towards lower carbon fuels and intra-sectoral structure changes. Under the policies in the moderate scenario the light non-energy intensive industries will remain the largest contributors to future growth in energy demand. The high growth in the reference scenario is offset by efficiency improvements (approximately 0.4%/year) in those industries under the moderate scenario. The overall fuel-mix in industry is changing more rapidly to low carbon fuels, when compared to the reference scenario. By 2020 natural gas will provide almost a third of the primary energy needs of the total industry. Energy service costs, including annual fuel costs, annualized incremental technology cost of energy efficiency improvement, and annual program costs to promote energy efficiency, decrease by approximately 9% by 2010 and 10% by 2020, relative to the reference scenario (see Table 3).

In the **advanced scenario** a stronger push to improve energy efficiency will result in an active policy for energy efficiency improvement and GHG emission reduction. In the advanced scenario industrial energy use remains stable, decreasing from 36.7 EJ in 1997 to approximately 36.1 EJ in 2020 (excluding CHP). Total industrial energy use in 2020 under the advanced scenario is 16.5% lower than the reference scenario. Under the conditions in the advanced scenario overall industry energy intensity falls by 1.8% per year (see Table 2), of

which 1.0% per year due to energy efficiency improvement. This compares well to the experiences in other countries that VAs can potentially contribute an efficiency improvement of 0.4% to 1.3% per year. Carbon emissions are actually decreasing to approximately 409 MtC, or a reduction of 29% relative to the reference scenario, especially due to de-carbonization in the power sector. While increased CHP in industry is expected to impact the observed shift to natural gas, the CHP results have not yet been integrated in the current fuel-mix shift. Annual energy service costs in the advanced scenario are reduced by 8% in 2010 and by 12% by 2020, translating to cost savings of approximately $\$8*10^9$ and $14 billion respectively. The savings are significantly higher in 2020 than in 2010, due to the larger investments in energy R&D in the advanced scenario, which results in greater energy savings on the long term.

Cogeneration

The results of the CHP calculations could not be integrated in the CEF-NEMS framework. Instead, we estimate the potential impact using the DISPERSE model. These estimates include both traditional and non-traditional applications of CHP, and is limited to industrial sector applications (hence, it excludes distributed CHP or district heating). In the *BAU scenario*, 8.8 GW of new CHP is projected, based on a continuation of current market penetration trends. Several technical and market barriers stand in the way of further use of CHP, as evidenced by the fact that over 80 percent of the potential capacity is projected as untapped. Most potential for CHP can be found in the paper, chemical, food and the non-energy-intensive manufacturing sectors. In the *moderate scenario*, the projected additional CHP-capacity grows to approximately 14 GW by 2010 and 40 GW by 2020. The net impact in 2020 is an energy saving of 0.53 EJ and a reduction in carbon dioxide emissions of 9.7 MtC. In the *advanced scenario*, the projected level of new CHP reaches approximately 29 GW by 2010 and 76 GW by 2020. The net impact in 2020 is an energy savings of 2.5 EJ and a reduction in carbon dioxide emissions of 39.7 MtC.

Figure 1. Scenario results for primary industrial energy use in U.S. industry.

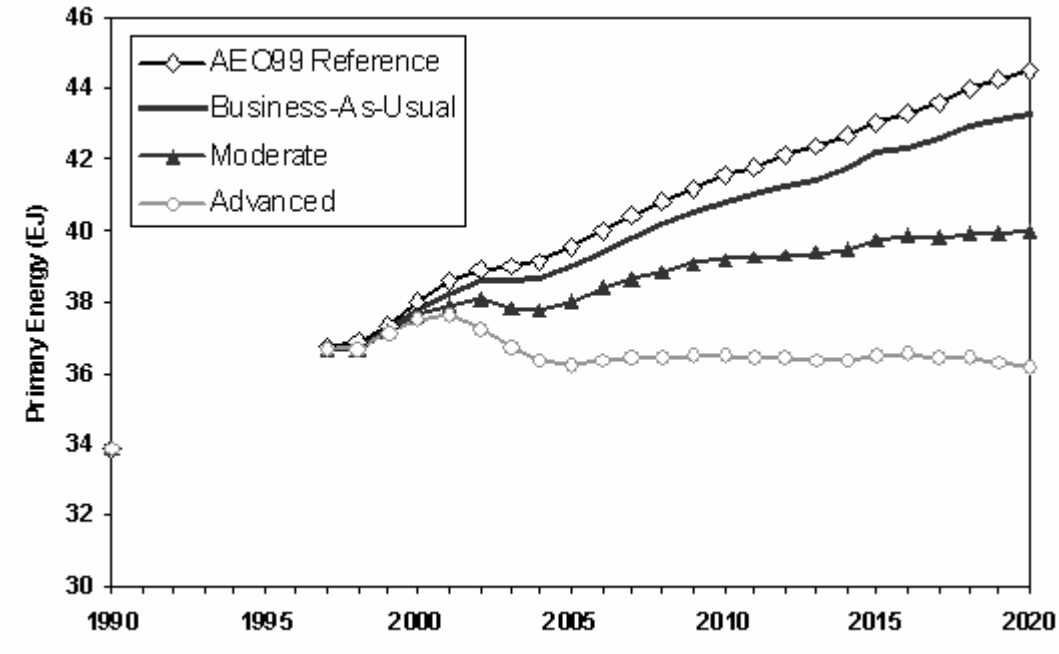


Table 2 Primary Energy Intensity Development in CEF-NEMS Scenarios.

Economic Intensities (MJ/$-output (1987-$) on a primary energy basis							
Scenario		**Business-as-Usual**		**Moderate**		**Advanced**	
Sector	1997	2010	2020	2010	2020	2010	2020
Refining	24.9	28.2	26.7	27.6	25.0	25.4	20.4
Food	4.5	4.1	3.9	4.0	3.8	3.7	3.5
Pulp & Paper	29.5	25.0	23.3	24.4	22.6	22.3	21.8
Bulk Chemicals	34.0	30.5	29.1	29.0	26.7	25.8	23.3
Glass	13.8	12.1	11.2	12.1	11.1	10.4	9.5
Cement	103.1	94.3	89.2	91.9	83.9	82.9	71.3
Iron & Steel	31.8	25.3	23.1	24.6	21.7	21.7	19.6
Aluminum	24.6	20.3	18.3	19.5	17.5	17.1	15.5
Agriculture	5.5	5.3	5.2	5.1	4.7	4.9	4.2
Construction	5.4	5.2	5.0	4.9	4.5	4.7	4.3
Mining	22.6	23.3	23.6	21.9	21.3	21.4	20.3
Metal Durables	2.1	1.9	1.7	1.8	1.6	1.6	1.4
Other Manufacturing	5.8	5.4	5.1	5.2	4.6	4.9	4.1
Total	9.2	7.8	7.1	7.5	6.5	7.0	5.9
Physical Intensities (GJ/tonne) on a primary energy basis							
Pulp & paper	39.4	33.0	30.7	32.3	29.8	29.5	28.7
Glass	20.0	17.7	16.4	17.7	16.3	15.2	14.1
Cement	5.5	5.4	4.7	4.8	4.4	4.3	3.7
Iron & Steel	23.5	21.2	16.9	18.0	16.6	15.9	14.3
Aluminum	145.7	123.0	108.3	115.3	101.7	101.1	91.9

Bulk chemicals excludes feedstocks. The increased contribution of CHP is excluded in this analysis

Table 3. Annual Total Costs of Energy Services by Scenario in the Industrial Sector (10^9 1997$/year)

		2010					*2020*				
	1997 B$/y	*BAU* B$/y	*Moderate* B$/yr	*Moderate* %	*Advanced* B$/yr	*Advanced* %	*BAU* B$/yr	*Moderate* B$/yr	*Moderate* %	*Advanced* B$/yr	*Advanced* %
Total - Industry											
Annual fuel cost	105	109	96	-12%	93	-15%	115	95	-17%	87	-24%
Annualized incremental technology cost of energy efficiency	0	0	2.7	N/A	5.8	N/A	0	6.0	N/A	10.4	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	2.2	N/A	0	2.1	N/A	3.9	N/A
Annual total cost of energy services	105	109	100	-9%	101	-8%	115	104	-10%	101	-12%

•

Notes:

(1) BAU = Business-As-Usual scenario

(2) Buildings in the industrial sector are not included in these results.

(3) % (change) is relative to the BAU scenario in that year.

(4) Energy service costs include cost of purchased fuels and electricity (minus any carbon permit trading fee Transfer payments), and the annualized costs of incremental efficiency improvements.

(5) The results exclude the increased role of industrial CHP.

Future Analysis

This study highlights issues for future research related to modeling and policies. The available resources limited a quantitative analysis of the uncertainties in scenarios. Future analysis aims not only at areas that need further analysis, but also at assessing the uncertainties in the scenarios. The analysis needs to include improved tools to model policy impacts, improved modeling of CHP and steam system representation, and a better understanding of retirement rates due to its important effect on energy use.

Detailed evaluations of industrial energy efficiency policies are rare (Martin et al., 1998; US DOE, 1996). Analysis of the effects and effectiveness of industrial energy policies is needed. Industrial technology development is often aimed at improving productivity rather than improving energy efficiency**,** and research is needed to better quantify other benefits of energy efficiency measures. Other topics for future research include the role of business cycles, improved understanding of technology diffusion, and the role of integrating other non-CO_2 GHGs in the assessment of **e**mission reduction strategies for industry.

Acknowledgements. This work was supported by the Assistant Secretary of Energy Efficiency and Renewable Energy of the U.S. Department of Energy. The authors wish to acknowledge the help of Paul Lemar (RDC) and Marilyn Brown (ORNL) for the analysis of cogeneration and Philip Jallouk (ORNL) for help with the assessment of motor efficiency programs. Furthermore, Norma Anglani, Dan Einstein, Marta Khrushch, Bryan Lehman, Nathan Martin, Laura Van Wie McGrory (LBNL). Dian Phylipsen (Utrecht University), in alphabetical order, have helped with the technical analysis in this chapter. We thank Ken Friedman (DOE), Skip Laitner (EPA), and Neal Elliott (ACEEE) for the discussions on equipment lifetimes. We thank all reviewers of the report and members of the review committee for their help, as well as many others, for sharing their insights in the preparation of this study.

References

Barnett, D.F. 1998. Is the Blast Furnace Dead ? *Proceedings Steel Survival Strategies XIII*, New York City, NY, June 23-24, 1998.

Blok, K. 1993. The Development of Industrial CHP in The Netherlands. *Energy Policy* **21**: 158-175.

Bureau of Economic Analysis. 1993. *Fixed Reproducible Tangible Wealth in the United States, 1925-89.* U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis: Washington, DC.

CIBO. 1997. *CIBO Energy Efficiency Handbook.* Council of Industrial Boiler Owners, Burke, VA, November 1997

Einstein, D., E. Worrell and M. Khrushch. 1999. Steam Systems in Industry– Energy Use and Energy Efficiency Improvement Potentials. *Proceedings 2001 ACEEE Summer Study on Energy Efficiency in Industry*, Washington, DC.

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

IEA. 1997a. *Voluntary Actions for Energy-Related CO_2 Abatement.* International Energy Agency, Paris, France.

IEA. 1997b. *Energy Efficiency Initiatives*. (Volume 1 and 2), International Energy Agency, Paris.

Interlaboratory Working Group. 1997. *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond*. Lawrence Berkeley National Laboratory, Berkeley, CA and Oak Ridge National Laboratory, Oak Ridge, TN.

Interlaboratory Working Group. 2000. *Scenarios for a Clean Energy Future*. Lawrence Berkeley National Laboratory, Berkeley, CA and Oak Ridge National Laboratory, Oak Ridge, TN (LBNL-44029 and ORNL/CON-476).

Jaccard, M. and Willis Enterprises Associates. 1996. *Energy Conservation Potential in Six Canadian Industries.* Natural Resources Canada, Ottawa, Canada.

Martin, N., E. Worrell, A. Sandoval, J-W. Bode, and D. Phylipsen (eds.), 1998. *Industrial Energy Efficiency Policies: Understanding Success and Failure*, Proceedings of a workshop held in Utrecht, The Netherlands, June 11-12, 1998," Berkeley, CA: Lawrence Berkeley National Laboratory. (LBNL-42368).

Martin, N., E. Worrell and L.K. Price. 1999. *Energy Efficiency Options for the U.S. Cement Industry*. Berkeley, CA: Lawrence Berkeley National Laboratory. (LBNL-44182).

Martin, N., N. Anglani, M. Khrushch, D. Einstein, M. Khrushch, E. Worrell, and L.K. Price. 2000. *Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry.* Lawrence Berkeley National Laboratory: Berkeley, CA (LBNL-46141).

McLaren, H. (ed.). 1997. *1998 North American Pulp & Paper Factbook.* Miller Freeman, Inc., San Francisco, CA.

Plunkert, P.A. 1997. Aluminum, in: *Minerals Information 1997*, USGS, Washington, DC.

Portland Cement Association (PCA). 1997. *Blended Cement Potential Study*. Skokie, IL: Portland Cement Association.

Steinmeyer, 1997. Patterns of Energy Use in the Chemical Industry, in *Proceedings of the 1997 ACEEE Summer Study on Energy Efficiency in Industry*. Washington, DC: ACEEE.

Story, M. 1996. *Demand Side Efficiency: Voluntary Agreements with Industry, Policy and Measures for Common Action*. Paris: Organization for Economic Cooperation and Development.

U. S. Department of Energy. 1996. *Policies and Measures for Reducing Energy related Greenhouse Gas Emissions, Lessons from Recent Literature*. Washington, DC: Office of Policy and International Affairs, U.S. Department of Energy.

Van Ginkel, R.M., and A.G. De Jong. 1995. "Saving Energy Can Save The Environment," *AISE Spring Convention*, Salt Lake City, UT, May 1995.

Worrell, E., Martin, N., and Price, L. 1999. *Energy Efficiency and Carbon Emissions Reduction Opportunities in the U.S. Iron and Steel Sector*. Berkeley, CA: Lawrence Berkeley National Laboratory.

Worrell, E. and Price, L. 2001. Barriers and Opportunities, A Review of Selected Successful Energy-Efficiency Programs, *Proc. 23rd Industrial Energy Technology Conference*, Dallas, TX, May 1-4, 2001.

Energy Efficiency Modeling and Soft Policy Simulation: the Case of Electric Arc Furnaces in the United States

Gijs Biermans[1]

Ecofys, The Netherlands

1. Introduction

A well-known economist joke tells us the story of an economics professor and a student who were strolling through the campus. 'Look,' the student cried out, 'there's a $100 bill on the path!' 'No, you are mistaken,' the wiser head replied, 'that cannot be. If there had really been a $100 bill, someone would already have picked it up.'

In the field of energy conservation there are many free bills lying on the sidewalk. For example, in our research of the EAF-steel sector, many energy saving measures had a payback time of less than a year (Worrell et al. 1999). However, investors tend to be remarkably slow in picking up these bills. Either because they do not know in which street to look, or which stone to lift, or because they believe the profit from picking up these bills to small to bother looking for them. And sometimes investors are simply not aware that free bills exist at all. This leaves policy makers with the opportunity to draw attention to the existence of free bills. They should inform investors that free bills exist and should equip them with the appropriate roadmaps to find them.

In traditional energy modeling (general equilibrium models, dynamical optimization models and input-output models), based on the neo-classical economics' concept of rational behavior, free bills are considered non-existent (Koch et al. 2000). General equilibrium models and input output models assume a certain relation between economic activity and energy consumption based on an autonomous efficiency indicator. Those models can adequately model some policies, such as energy taxation and subsidies, but they disregard investment barriers and are incapable in simulating *soft policies*. However, in the modeling exercises used in this paper, substantial and profitable energy saving potentials (free bills) were encountered, which remained un-exploited by investors. This indicates not only that there are free bills (i.e. profitable not exploited energy reduction capital), but also that there are investment barriers. Dynamical optimization models (Koch et al. 2000) are also famous for their neglect of investment barriers; they assume profitability to be the main driver behind adoption. In my opinion, however, investment barriers are equally important as profitability for an accurate explanation of investment behavior. Moreover, a large share of today's energy saving policies is aimed more at tackling investment barriers than at improving the profitability of energy saving measures. Such policies, for example voluntary agreements, cannot be modeled using such old models that ignore investment barriers. Hence, a new generation of energy models needs to be developed.

2. Context

Between January and August 2002, Ecofys (Utrecht, The Netherlands) carried out an energy modeling exercise aimed at modeling Specific Energy Consumption (SEC) of the steel sector

[1] E-mail: Gbiermans@lbl.gov

in several regions. The approach taken was based on energy efficiency improvements by retrofitting technologies and measures. The technology data on energy savings were aggregated into five technology blocks. These technology blocks penetrate a sector because of a certain type of investment behavior. The advantage of using this general retrofit approach was that the model could be applied to different countries; the disadvantage that the model had serious flaws and high uncertainties. Its main weaknesses were:

1. Energy saving through stock turnover was not included; only energy saving through retrofit was addressed;
2. The parameters used to describe investment behavior had a high uncertainty;
3. The parameters used to describe energy efficiency improvements had a high uncertainty
4. It was infeasible to calibrate components of the model separately; only the dependent variable (that is, specific energy consumption) could be calibrated;
5. Intra-sectoral dynamics were not accounted for;
6. The assumed policy effect was not based on empirical data or literature study;
7.

To tackle the first four problems, a case study was performed at the Lawrence Berkeley National Laboratory, Berkeley (CA), USA. The present paper will discuss this case study which resulted in the development of a model simulating the Specific Energy Consumption (SEC) of Electric Arc Furnaces (EAFs) in the US. The EAF-steel sector, which is a sub-sector of the steel industry, was selected, because there is detailed data of this process (IS&M, 1990-2002), which enables us to tackle the first four of the problems described above. After developing the EAF-technology model, we intend to:

- To apply the EAF-technology model to other sub-sectors of the steel industry;
- To model intra-sectoral dependencies (tackling problem 5);
- To accurately include the effect of soft policies[1] by thoroughly analyzing policy evaluations at the sectoral level (tackling problem 6).
- To develop an (aggregated) steel technology model - as in the earlier Ecofys model - but which (i) includes a stock turnover approach and (ii) parameters based on bottom-up research and calibration, and which has been (iii) corrected for intra-sectoral dynamics.

Having taken these four steps, we aim to create a model that will be applicable across sectors and countries. In doing so, the greatest challenge will be to strike the right balance between the amount of technological and economic detail included in the model, and its applicability to other sectors and countries.

3. The EAF-steel sector in the US

Electric arc furnaces (EAFs) produce steel, predominantly out of scrap. They are also referred to sometimes as minimills. The steel they produce is often called secondary steel and is measured in tons of liquid steel (tls). In the model's base year, 1994, the US produced 36 Mtons of secondary steel. Between 1990-2002, the annual increase in production was 3.2%. In 1994, the EAF-steel sector in the US (excluding casting, hot and cold rolling and finishing) consumed 6 PJ of fuel and 62 PJ of electricity, resulting in a specific fuel consumption of 0.17 GJ/tls and a specific electricity consumption of 1.77 GJ/tls. Given a conversion efficiency of 32.5%, this results in primary Specific Energy Consumption (SEC) of 5.6 GJ/tls. In 2002, the specific electricity consumption was 15% lower than in 1990, indicating an annual decrease of 1.3%. (Worrell et al., 1999). Between 1994 and 2002 there were few new government policies on energy reduction. Therefore the figures above could be used as calibration of our base case scenario. The detailed energy consumption and capacity figures of the IS&M EAF-

[1] I use the term *soft policy* here to differentiate between policies that affect the profitability of measures (hard policies) and policies that are intended to reduce investment barriers (soft policies). Examples of soft policies are voluntary agreements, investment enabling and benchmarking.

roundups (at the level of the firm) enabled us to develop a comprehensive model, based on empirical data.

4. Original Goals of the EAF-Technology Model and Its Achievements So Far

The first goal of the EAF-technology model is to model accurately the specific energy consumption of the EAF-steel sector (excluding casting and finishing) in the coming 25 years, whilst accounting for the policy effects of a wide range of energy saving policies (such as voluntary agreements, benchmarking, investment enabling, etc). A second goal of the model is to test the new investment and policy simulation approach used, in order to determine whether this approach can also be applied to other sector technology models. As pointed out in the previous section, during the period 1990 – 2002, the SEC of the EAF-steel sector in the US decreased by 1.3% per annum. In this period, there were no government policies aimed at decreasing the SEC, which gives rise to the question what would have been the scenario if such policies had existed. By how much would the SEC have decreased had the US had voluntary agreements, investment subsidies or comprehensive benchmarking? By how much will the SEC decrease if the US government adopts such soft policies now? By how much will the SEC of the steel sector as a whole, or of the US industry as a whole, decrease if soft policies are adopted?

At the time of writing, the EAF-technology model has been constructed and our original goals have partly been met. The model we constructed can accurately model specific energy use for the coming 25 years. We succeeded, moreover, at creating a framework in which the policy effect (of a soft policy) can easily be included, although it is not yet possible to quantify such an effect. This is one of the challenges remaining, and hence the quantitative conclusions drawn here are indicative rather than conclusive.

5. The Structure of the Model: Retrofit and Stock Turnover Approach

The model discerns two possible ways of decreasing the SEC, through *retrofit of energy-saving technologies* or through *stock turnover,* meaning that old stock is replaced by newer, more efficient, stock. Although both processes are dependent on investment behavior and policy measures in a similar way, the model uses different parameters for each. The retrofit of energy-saving technologies refers to a process in which existing capacity is upgraded by implementing energy-saving technologies or measures. Stock turnover can lead to a decrease in SEC, because the depreciation of old stock tends to be accompanied by a higher SEC than that of new stock entering the fleet. The SEC can also decrease because of the growth of stock by the entry of more efficient stock. In the EAF-steel sector 60% of the decrease in SEC is accounted for by stock turnover, 40% by the retrofitting of technologies within the existing stock.

6. Retrofit

The model identifies the following individual retrofit technologies (Worrel et al., 1999; de Beer et al., 2000; IISI, 1998):

- Improved process control (neural network)
- Flue-gas monitoring and control
- Transformer efficiency - UHP transformers
- Bottom stirring / stirring gas injection
- Foamy slag practice
- Oxy-fuel burners
- Eccentric bottom tapping (EBT) on existing furnace
- Scrap preheating, post combustion (FUCHS & CONSTEEL)

Together, these technologies have an energy saving potential of 1.00 GJ/tls, which is 18% of primary energy consumption (assuming a conversion efficiency of 33%). The financial rewards from energy saving are dependent on the electricity and/or fuel price and, hence, on energy taxation and subsidies. These policies will be referred to as *hard policies*

Apart from saving energy, a new technology can also lead to an increase in productivity or to a reduction of maintenance costs, its so-called non-energy benefits. In the EAF-steel sector, non-energy benefits are 140% greater than energy benefits, a fact which is often ignored in traditional energy modeling.

Adopting an energy-saving technology requires an initial investment. In our model, the size of this initial investment for purchasing capital goods depends on a learning curve parameter. This learning curve parameter indicates the percentage reduction of initial investment costs resulting from a doubling of the penetration rate.

Using the energy-saving benefits, the non-energyg benefits, and the initial investment costs, the payback time can easily be calculated. This is the main indicator of an investment's profitability.
An investor will base his decision to adopt a retrofit energy-saving measure on this payback time[1]. To describe the relation between payback time and investment, a concept from the Ecofys pilot model was used: the Gaussian curve, as depicted in Figure 1. The shape of this curve is determined by two parameters: the Auto Zero Invest (AZI) and the Average Payback Criterion (APC). The parameter Auto Zero Invest (AZI) indicates what percentage of firms will invest in an energy-saving measure with a hypothetical payback time of zero years. In Figure 1, this is the intercept with the y-axis. The parameter Average Payback Criterion (APC) is an indicator of the internal payback time that firms use, and is the standard deviation of the Gaussian curve.

Auto Zero Invest (AZI)
Not all firms will adopt an investment with zero payback time, leaving some free bills on the sidewalk. This is due to the existence of investment barriers (see our discussion of investment behavior). As Woodruff (Woodruff et al., 1996)) points out, only 55% of companies that were recommended energy-saving measures with a negligible payback time chose to implement them. This implies that only 55% of all available energy-saving measures with a payback time of approximately zero years will be implemented. Woodruff also finds that only 80% of firms are well informed about the technologies used by other firms, and that only 70% of firms have knowledge of technologies not currently used by other firms (de Groot et al., 2001). This results in an Auto Zero Invest of 41.25% (=55%*75%).

Average Payback Criterion (APC)
Several studies pay attention to the payback criteria (Velthuijsen, 1995; Gillissen et al., 1994; Woodruff et al., 1996; Koot et al., 1984; Gruber et al., 1995). In the present study, three surveys are used to determine the Average Payback Criterion (gruber, Gillissen and Koot). A correction is made for the discrepancy between the reported and the actual payback criterion.

[1] Although Woodruff's analysis points out that initial investment is the most important criterion for investment decisions (Woodruff et al., 1996: p53) in the same report the manufacturers (roundtable participants) claim that payback time analysis is the most commonly used investment evaluation technique (p48). The relatively low dependency of payback time on the investment decision is probably due to the fact that most recommended energy-saving measures possess a payback time of less than 2 years and require a relatively small initial investment. Obviously, it will be hard to measure any payback dependency if one compares payback measures, with such low payback times, because the payback time will not be a restricting factor in that case. However, in our model we deal with substantial investment which a wider range of payback times. These technology measures and stock alternatives are more likely to be dependent on payback times. Also in the study of Velthuijsen of energy conservation in Czech and Slovak republics, the payback time seems the most important criterion (Velthuijsen, 1995: p211).

Figure 2, shows the average of the three modified surveys and the Gaussian curve, which best fits this investment behavior. The best fit is obtained when the APC is set at 4 years.

To describe retrofit investment behavior, a right-handed Gaussian curve was used, with a standard deviation of 4.0 years (=Average Payback Criterion) and an y-axis interception of 41% (=Auto Zero Invest). These numbers are based on the assumption that there are no energy saving policies. In addition to describing initial investment behavior, it also needs to be determined how often an investor considers a retrofit upgrading. This decision is mainly influenced by the fact that, in most cases, a furnace needs to be taken out of production to implement retrofit measures. The transaction time of collecting information on retrofit possibilities also influence the frequency of retrofit upgrades. Unfortunately, reliable information on the value of this variable was not readily available. This value has therefore been determined by calibrating the specific electricity consumption with the empirical data of the IS&M EAF-roundups. This gave a value of once every 8 years, meaning that an EAF investor considers retrofitting after every 8 years of operation.

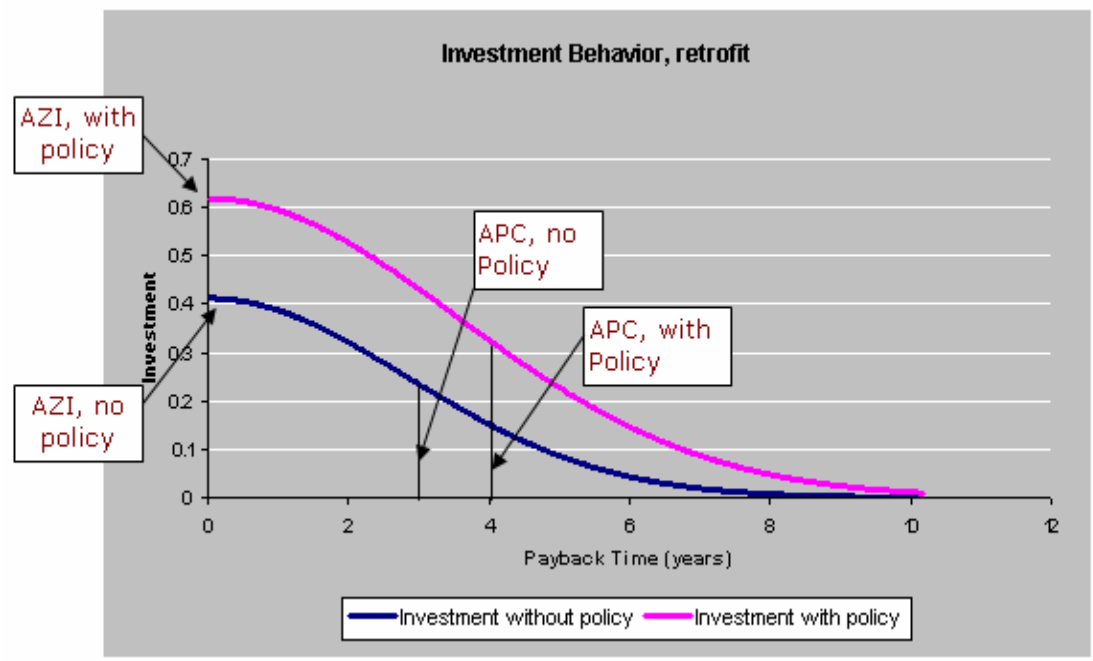


*Figure 1. Investment Behavior in Retrofit Measures. Investment behavior is dependent on the payback time of the energy-saving measure and can be influenced by policy measures. The curve is based on the formula: Invest (t) = frequency of retrofit rounds * AZI * $e^{-PBT(t)^2/APC^2}$, with PBT=Payback Time.*

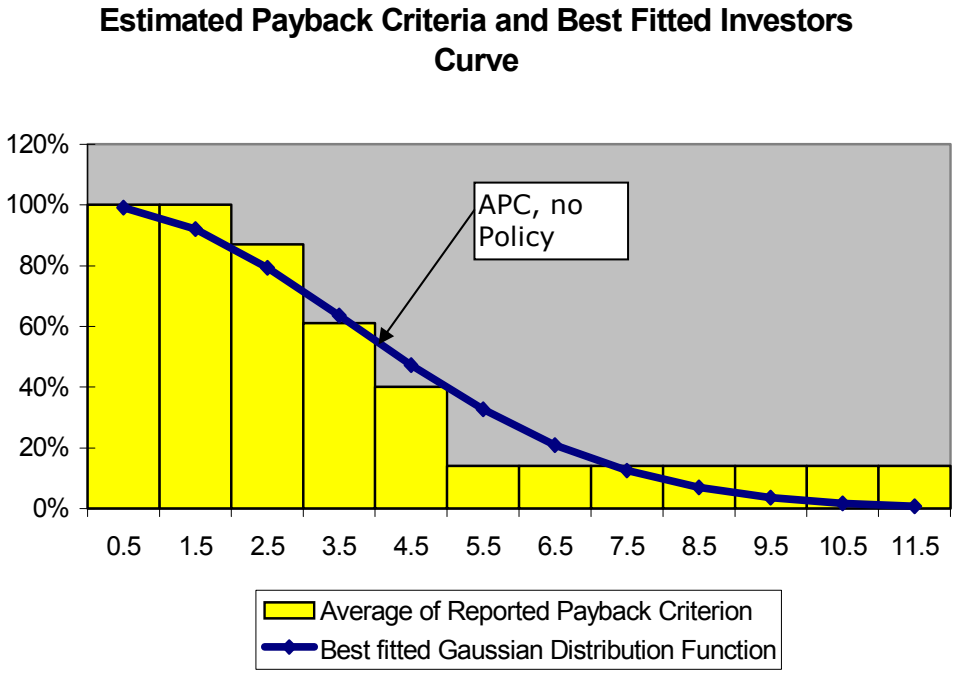


Figure 2: Payback Criteria and Best-Fitted[1] Gaussian Investor's Curve. The bars represent the investment criteria as reported by Gillissen et al., 1995; Koot et al., 1984; Gruber et al, 1995 and are corrected for the difference between reported and actual payback criterion.

7. Stock Turnover

The stock turnover approach models the SEC-decrease resulting from the replacement of old, inefficient, stock by newer, more efficient, stock. The capacity depreciating each year equals to 1 divided by the average lifetime of an EAF. According to the IS&M EAF-roundups, in the period 1990 - 2002, the average lifetime of an EAF was 28.7 years, meaning that each year 3.5% of the stock depreciates and is replaced by new stock (if total growth figures are not negative). The IS&M EAF-roundups also show that 71.4% of the aggregate stock growth (which is an exogenous variable in the model) is accounted for by capacity growth of the existing stock. This has strong implications for energy modeling, which tends to ascribe capacity growth to the entry of new stock in the fleet. Over the period 1990–2002, total capacity growth was 2.8 % per annum - 2.0% of this growth can be assigned to capacity growth of the existing stock, 0.8% to the entry of new stock. Since depreciated stock is usually replaced by new stock, the total amount of new stock entering the fleet is estimated to be 4.3% for the period 1990-2002. The average primary energy use of depreciating stock tends to be 7.8% higher than that of the average stock as a whole. New stock entering the fleet tends to have a primary SEC that is on average 10.7 % lower than the average SEC. In our model, these IS&M EAF-roundups are used to calibrate investment behavior of the stock turnover process.

The decision to purchase new stock depends on investment behavior. It is assumed that an investor can choose between three kinds of technology categories that characterize the new stock:

- Ecotech - technically proven technologies that are economically attractive in the base year (specific primary energy consumption of 5.35 GJ/tls)

[1] The investment curve is best fitted to the actual real data by the least-square method. For this the assumption is made that on average the payback criterion ">5 years" reflects a payback criterion of 10 years.

- Alltech – technically proven technologies that are not necessarily economically attractive in the base year (specific primary energy consumption of 4.23 GJ/tls)
- Advtech (Advanced Technologies) - technologies that have not yet been technically proven (specific primary energy consumption of 3.67 GJ/tls)[1]

Each of these three stock categories has a different retrofit potential. An investor's decision for a certain technology category will be based on its payback time and a policy effect. The relation between the investor's choice and the payback time is shown in Figure 3.

The investors-payback curve depicts the percentage of investors (y-axis) willing to invest in an energy-saving stock category with a certain payback time[2]. The investment curve has first been applied to the advtech category and then to the alltech category. This means that first it must be calculated which percentage of total investment will be invested in the advtech category, and then, which percentage of the remaining part will be invested in the alltech category. What is left over will be invested in the ecotech category.

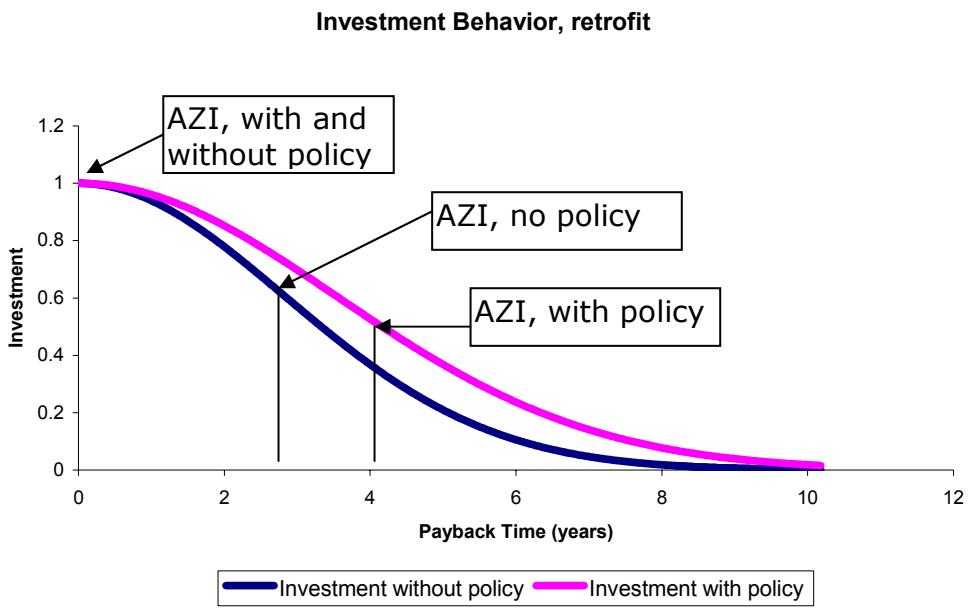


Figure 3. Investment Behavior Regarding New Stock. Investment behavior is dependent on the payback time of the stock category and can be influenced by policy measures.

As in the case of retrofit measures, this Gaussian relationship can be translated into two parameters, the Auto Zero Invest (AZI) and the Average Payback Criterion (APC). The parameter Auto Zero Invest (AZI) refers again to the intercept with the y-axis; the parameter Average Payback Criterion (APC) is again the standard deviation of this Gaussian curve.

In our model, the AZI is assumed to be 100%, indicating that, if an energy-saving technology category has a payback time of zero years, all investors will tend to choose it. This case differs from that of retrofit measures, in which case, zero-payback retrofit measures are not automatically adopted by all investors. This difference is due to the fact that, the decision to invest in new stock is so vital and large that lack of information on alternative investments is

[1] The ecotech and alltech categories are based on a study of the IISI (IISI, 1998). The advtech stock category is based on a study of LBNL and ACEEE (LBNL&ACEEE, 2000).

[2] The payback time for the advtech stock category equals the time that the extra investment in advtech (compared to the investment in alltech) is regained. The payback time for alltech stock category equals the time that the extra investment in alltech (compared to investment in ecotech) is regained.

negligible, that, compared to the total investment, information transaction costs are small, and that the investor takes the SEC as a criterion for his decision.

As in the case of retrofit investment, the APC was set at 4 years. The rationale behind this value is that the choice for an energy-saving technology alternative (that is, alltech or advtech) can be regarded as a measure with a certain payback time. This means that investing in ecotech is the base scenario, and that upgrading to alltech or advtech can be seen as "retrofit" measures. Consequently, investments in alltech or advtech are subject to the same payback criterion as normal retrofit measures. A second rationale for using the same average payback criterion for new stock investments and retrofit investments is the assumption that an investor, can choose between replacing his furnace by a new, and more efficient, furnace, and retrofitting his existing furnace to safeguard his competitiveness. His preference for either of these two options will mainly depend on their payback time.

The payback times of the alltech and advtech technology categories are exogenous to the model, which leads to a great deal of uncertainty. Fortunately, the model can be calibrated on empirical data from the IS&M roundups of the EAF-steel sector in the US. According to this data, new stock tends to be on average 10-11% more efficient than existing stock; depreciated stock is on average 7-8% less efficient than existing stock. Given these values the penetration rates of alltech and advtech in new stock can be deduced. Adding to this, the investment-payback relation, we can also deduce the payback times of alltech and advtech. It was found that alltech has an average payback time of 4.5 years, decreasing with 4% per annum. Advtech is estimated to have an average payback time of 8 years, decreasing with 4% per annum. We accounted for the dependency of the payback time on energy prices.

Having explained the crucial role of the investment curve in our model, the question remains how this investment curve is affected by policy measures.

8. Investment Behavior

In the previous section two investment curves were discussed: one curve for retrofit investment, and one curve for investments in new stock. Both curves can be explained by two parameters: the Auto Zero Invest (AZI) and the Average Payback Criterion (APC). Through calibration and literature study reliable values for these two parameters were found. The question remains, however, how both investment curves - and hence the AZI and APC - are affected by so-called soft policies. Since this question cannot yet be answered quantitatively, a summary will be provided of the factors influencing the APC and AZI. It will also be discussed how policy measures can affect those factors and, thus, the APC and AZI. In this way, the problem of (soft) policy simulation is reduced to the question how the APC and AZI are influenced by soft policy.

Factors Affecting Auto Zero Invest and the Average Payback Criterion

The AZI represents the percentage of investors investing in a hypothetical energy-saving measure with a payback time of zero years. Contrary to our expectations, this is not necessarily a 100%; some free bills are left on the sidewalk. This is due to the existence of investment barriers. On the basis of the source studies (Worrell and Price, 2001; Velthuijsen 1995; Woodruff et al., 1996), four main investment barriers can be identified:

1. The value of the payback time identified in the literature is not always applicable at the firm level. Firm-internal decision making processes may obstruct adoption (firm specific circumstances);
2. A technology is unknown or its benefits are too uncertain (information gap, information transaction costs);
3. An investor does not give priority or attention to energy reduction opportunities;
4. There is limited availability of capital and skilled labor (financial and labor barriers);

The first three of these barriers affect the AZI; the fourth barrier has an impact on the APC. In the absence of investment barriers, the Auto Zero Invest would be 100% and the actual APC would be the same as the reported APC. In reality, however, retrofit investment barriers reduce the Auto Zero Invest to 41.25% (Woodruff, 1996; de Groot, 2001) and increase the reported APC by 25%[1]. This creates a great opportunity for policymakers to reduce these investment barriers and to stimulate thereby the speed of diffusion of energy saving technologies.

In several countries, policies to reduce the investment barriers described above have already been taken. However, in the EAF-steel sector in the US they are virtually absent. Such policies can roughly be categorized into four groups (Worrell and Price, 2001):

1. Information dissemination (to increases the Auto Zero Invest)
2. Investment enabling (to increases the APC)
3. Regulations (to increases the AZI and the APC)
4. Demonstration (to increase the AZI)

Some policies address elements of more than one group. Voluntary agreements, for example, not only have an information dissemination effect, but are also backed up usually by a threat of regulations (combination of group 1 and 3). Benchmarking often leads to both information dissemination and demonstration (combination of group 1 and 4). The quantitative effects of different policies on the AZI and APC still need to be determined. This will be easier at the more aggregate level than at the level of the EAF-steel sector, because policy evaluations are normally carried out at a more aggregate level. In our future research, attention will be paid to determining the quantitative effect of policy measures. The quantitative effects presented in the remaining part of the paper are no more than tentative estimations and the conclusions based upon them are, therefore, only indicative.

9. Output With and Without a Policy Mix

To calculate output, a policy mix is assumed with the following quantitative effects on AZI and APC:

-The AZI of retrofit investments increases by 50%;
-The AZIof new stock investments remains 100%;
-The APC of retrofit and new stock investments increases by 25%;

Given this policy mix, an investor is 50% more likely to pick up free retrofit measures, and expands its payback criterion with 25 percent for non-free energy-saving measures and new stock investments.

Using these estimates, in the absence of any energy saving policies (business as usual), specific primary energy consumption would decrease by 1.23% per annum over the period 1994 – 2002. If policies would exist, it would decrease by 1.65% per annum (see Figure 4). Our 'business as usual' case gives results which are more or less equal to the historical average over the period 1990-2002 (1.3%, IS&M, 1990-2002). Since our calibration was carried out at a sub-divided level, and not at the level of the overall dependent variable (SEC), this result is an affirmation of our approach and of the reliability of our model. For the 'business as usual' scenario, the average SEC improvement over the period 1994-2020 is 1.06%; for the 'policy induced' scenario it is 1.22 % (see Figure 5). These estimates are lower than the figures for the period 1990 – 2002, which is due to the fact that the model only takes account of technologies existing today. To tackle this problem, the model could be expanded with indicators of future retrofit potential and future stock categories, but this would make it impossible to base the model entirely on hard facts.

[1] Expert Guess

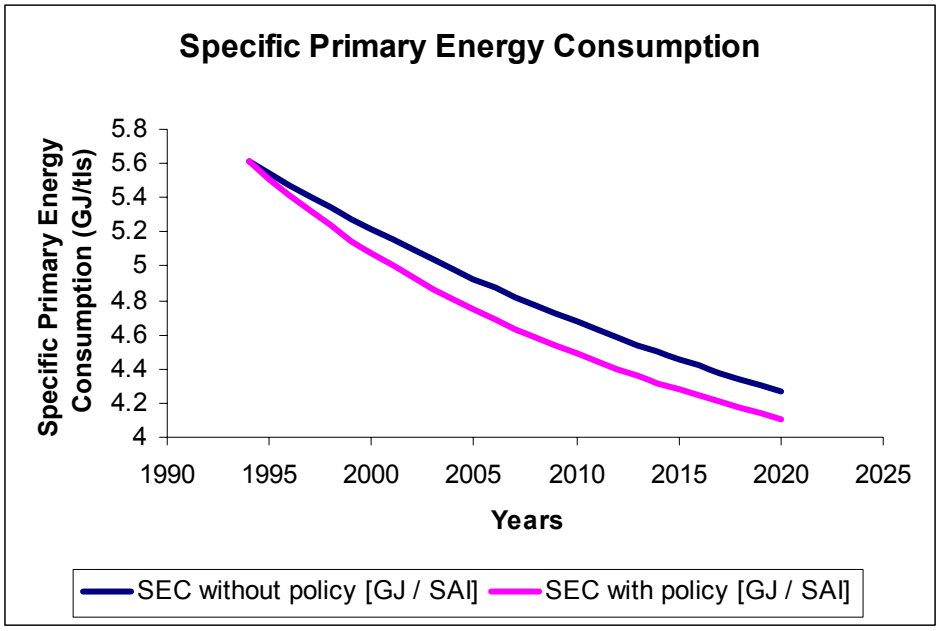


Figure 4. Specific Primary Energy Consumption for the 'Business as Usual' and 'Policy Induced' Scenarios

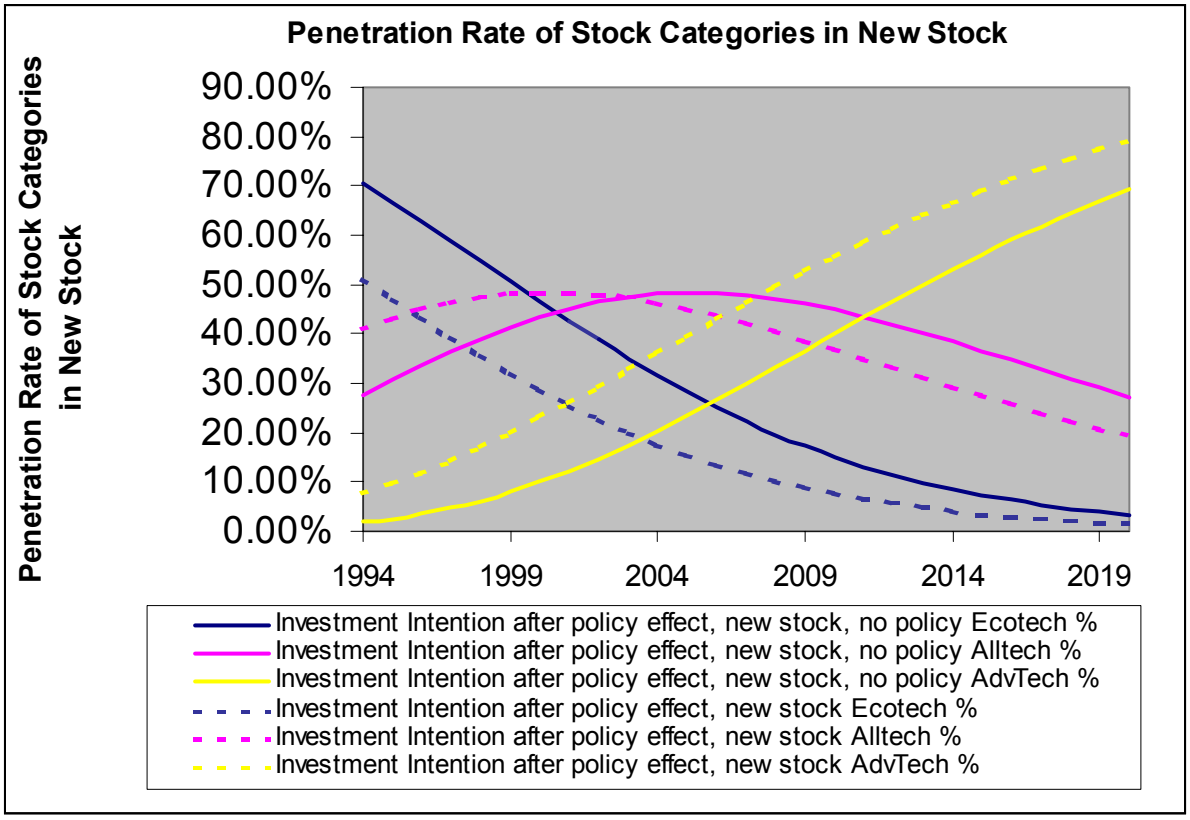


Figure 5. Penetration Rate of Stock Categories in New Stock for the 'Business as Usual' and 'Policy Induced' Scenarios

Figure 5 demonstrates the penetration rate of the three stock categories. It can be seen that in 2011 the advtech category will be the most common choice for the 'business as usual' scenario; for the 'policy induced' scenario this point will already be reached in 2006. In

general, it can be observed that in the 'policy induced' scenario, technologies penetrate approximately 5 years earlier than in the 'business as usual' scenario.

10. Discussion of the results

In the previous section it has been discussed how a policy mix can (potentially) have a significant positive effect on investment barriers, and thereby on energy efficiency. Other sources, which have not been discussed in this paper, show that the extra efficiency improvements caused by such a hypothetical policy mix are hard to achieve by energy taxation, if assumed that the investment curve does not change because of energy taxation.[1] Our model is fairly inelastic to energy price increases, at least compared to the effect of a reduction of energy barriers. This is due to the fact that many energy-saving measures are already profitable (Worrell et al., 1999), implying that an energy price increase will only make such measures "even more profitable". Since, before the taxation, the profitability of energy-saving measures was not the main restriction, such taxation will not have a large effect on investments in energy-saving measures. Removing investment barriers, in contrast, does seem to be effective. It can easily boost energy efficiency improvement from 1.2% to 1.6% per year, at least, if our assumptions about the effect of soft policies on the investment curve are realistic. Whether they are, will be the subject of our future research. However, the experience of a number of countries with voluntary agreements and other soft policies already seems to confirm our suggestion that they potentially have a large impact on energy efficiency (Phylipsen et al., *to be published*). Moreover, industries tend to be more positively predisposed towards soft policies, such as voluntary agreements and benchmarking, than towards hard policies, such as energy taxation.

11. Future Research

Three important fields of research, which can facilitate energy efficiency modeling and which can improve policy simulations, have so far been insufficiently addressed or have not yet been addressed at all: These fields are:

1. The translation of effects of soft policies into AZI and APC, or another manipulation of the investment curve;
2. Research on the learning curve of energy saving (both retrofit and new stock) technologies;
3. Transformation of the EAF-technology model into a technology model that is generally applicable to all (sub) sectors;

The first gap constitutes the largest weakness of the US EAF-technology model. So far, the policy mix has not been based on any empirical evidence. It was simply assumed that it would have a certain effect on the investment curve. The effect of individual policies and policy mixes on investment behavior should be given more attention. Many policy evaluations skip the step of determining the effect of policies on investment behavior and immediately address the effect of policies on energy efficiency improvement (NOVEM, 2001). Although our model can use such policy evaluations, it would be far better to have a policy evaluation investigating the direct effect of policies on investment behavior. Moreover, many policy evaluations are carried out at a more aggregate level than the level used in our study - the EAF-steel sector in the US. It is necessary, therefore, to transform our model into a technology model that is applicable to the entire steel sector, before determining the effect of soft policies. Finally, soft policies may have different effects in different countries, making it difficult to use the policy evaluation of one country to determine the policy effect in another country.

[1] However, one caveat should be made. Aside from the fact, that an energy price increase (for example through taxation) can make a measure more profitable, it can also trigger the attention from investors on energy efficiency and therewith change the investment curve. This effect is not accounted for in our analysis.

The assumed learning effect in our model is unfortunately not based on thorough research because it proved impossible to find sources describing learning effects for end-use technologies.
In the process of our research, it was decided to focus first on scrutinizing a well-documented sub-sector, before expanding the model to major sectors or the industry as a whole, in order to get a good insight into the dynamics of energy efficiency improvements. The next step will be to expand our case study to the entire steel sector and to other industrial sectors, which will enable us better to determine the effect of soft policies

12. Conclusions

In the EAF-steel sector in the US we encountered investors that tend to be remarkably slow in adopting energy saving technologies which are profitable. This phenomena can be explained by the existence of several investment barriers. Many qualitative studies acknowledge this fact, however, energy modeling lags behind in the recognition of investment barriers. Consequently, policies aimed at reducing investment barriers, the so called *soft policies*, cannot be modeled with the old class of models. In this perspective an energy simulation model is developed at the Lawrence Berkeley National Laboratory. Although, the scope of the model is very limited, the EAF-steel sector in the US, we were successful in including investment barriers into the model and in accurately predicting specific energy consumption for the coming 20 years. Moreover, we succeeded at creating a framework in which the effects of soft policy can easily be included, although it is not yet possible to quantify such an effect.

The approach used incorporates both a retrofit and stock turnover process. In both processes investment behavior plays a central role. Through literature study, calibration and empirical data from the EAF-steel sector we created a reliable business as usual scenario. However, the 'policy induced' scenario is still tentative and should be reassessed in the future. The quantification of the effect of soft policy on the investment curve is one of the major challenges remaining.

13. References

de Beer, J., J. Harnisch, M. Kerssemeeckers, 2000. *Greenhouse Gas Emissions from Iron and Steel Production*, Utrecht, the Netherlands: IEA Greenhouse Gas R&D Programme

de Groot, H.L.F., E. T. Verhoef and P. Nijkamp, 2001. "Energy saving by firms: decision-making, barriers and policies", *Energy Economics,* **23**, p717-740: Department of Spatial Economics and Tinbergen Institute, Free University of Amsterdam

Gillissen, M. and H. Opschoor, 1994. *Energy Conservation and Investment Behaviour: an Empirical Analysis of Influential Factors and Attitudes*, Amsterdam, The Netherlands: Ecological Economics Group, Department of Spatial Economics, University of Amsterdam.

Gruber, E. and M. Brand, 1991. "Promoting Energy Conservation in Small and Medium-Sized Companies", *Energy Policy*, **April**, p279-287.

International Iron and Steel Institute, 1998. *Energy Use in the Steel Industry*, Brussels, Belgium: IISI

IS&M, various years, "Annual EAF roundups", *Iron & Steelmaker*, **5**, over the years 1990-2002.

Koch, M, J. Harnisch, M. Patel and K. Blok, 2000. *Systematische Analyse der Eigenschaft von Energiemodellen im Hinblick auf ihre Eignung für möglichst praktische Politik-Beratung zur Fortentwicklung der Klimaschutzstrategie*, Cologne, Germany: Umweltbundesamt

Koot, L.W., M.H. Brascamp, G. Gerritse, G.J.A.M. Meijer, A.G. Melman and H.J. Munter, 1984. *Evaluatie van de werking en effectiviteit van de energietoeslag op de WIR-basispremie en de regeling geldelijke steun beperking energieverbruik in de non-profit sector*, Apeldoorn, The Netherlands: Netherlands Organization for Applied Scientific Research, TNO.

LBNL & ACEEE, 2000. *Emerging Energy-Efficient Industrial Technologies*, Berkeley.

Novem, 2002. *Meerjarenafspraken energie-efficiency. Resultaten 2001* (Long-term agreements energy efficiency. Results 2001), Novem, Utrecht.

Phylipsen, G.J.M., to be published. "The effectiveness of policies to reduce industrial greenhouse gas emissions", Utrecht, the Netherlands: Ecofys B.V.

Velthuijsen, J.W., 1995. *Determinants of Investment in Energy Conservation*, Amsterdam, The Netherlands: Foundation for Economic Research of the University of Amsterdam.

Woodruff, M.G., J.M. Roop, H.E. Seely, M.R. Muller, T.W. Jones and J. Dowd, 1996. *Analysis of Energy-Efficiency Investment Decisions by Small and Medium-Size Manufacturers*, Washington, DC: U.S. DOE

Worrell, E., N. Martin and L. Price, 1999. *Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector*, Lawrence Berkeley National Laboratory, Berkeley.

Worrell, E. and L. Price, 2001. "Policy scenarios for energy efficiency improvement in industry", *Energy Policy* **29**, pp.1223-1241.

Appendix A: Workshop Program

Thursday, November 7th, 2002

09:00 Welcome
Tai-Yoo Kim, President, Korea Resource Economics Association

09:05 Keynote address: Energy Sector Reform and Energy Conservation Policies in Korea
Sang-Gon LEE, President, Korea Energy Economics Institute

State of the Art in International Scenario Modeling and Challenges

09:45 APEC Energy Demand and Supply Outlook for 2020 and its Policy Implications
Yonghun Jung, Asia and Pacific Energy Research Centre, Japan

10:30 World Energy Outlook 2002: Using Bottom-Up Models in Global Energy Trend
Hiroyuki Kato, International Energy Agency, France

11:15 Towards Improved Policy Relevance in Engineering-Economic Analysis
Ernst Worrell, Stephan Ramesohl, and Gale Boyd

12:00 Lunch

Opportunity Assessment

13:30 Energy Efficiency Improvements in the Korean Manufacturing Sector
Hi-chun Park, Inha University, Korea

14:15 Energy Efficiency Benchmarking
Wolfgang Eichhammer, Fraunhofer Institute - ISI, Germany

15:00 – 15:20 Break

15:20 Assessing the Cost of GHG Abatement Policies: A Cost Curve Analysis
John Nyboer and Mark Jaccard, Simon Fraser University, Canada

16:05 Three big C's: Climate, Cement, and China
Joakim Nordqvist, Christopher Boyd, and Howard Klee

16:10 Discussion of the first day

Friday, November 8th, 2002

Decision Making Behaviour

09:00 Opportunities and Barriers to Energy Efficiency Implementation in the Italian Industrial Sector: An Open Matter
Norma Anglani et al., University of Pavia, Italy

09:45 Modelling Industrial Technology Evolution: Capturing Behaviour in a Bottom-Up Model
John Nyboer and Mark Jaccard, Simon Fraser University, Canada

10:30 – 10:45 Break

Modeling

10:45 Economic Analysis on Energy Conservation Policies in Korea: A CGE Modeling Approach
Jaekyu Lim, Korea Energy Economics Institute, Korea

11:30 Modeling Policies in the Clean Energy Futures Study
Ernst Worrell and Lynn Price, LBNL, USA

12:15 Lunch

14:00 Energy Efficiency Modeling and Policy Simulation
Gijs Biermans, Ecofys, The Netherlands

14:45 Discussion of the second day

15:15 – 15:35 Break

Wrap-up: Challenges and the Road Ahead

15:35 Guided discussion on promising ways to improve industrial energy modeling and ways to improve policy representation

- Needs
- Challenges
- Promising routes
- Setting a research agenda for industrial energy modeling

Appendix B: Attendees

Dr. Norma Anglani
Department of Electrical Engineering, University of Pavia
Via Ferrata 1
27100 Pavia, Italy
Tel. +39 0382 505 253, Fax +39 02 700 552 840
E-mail: NAnglani@unipv.it

Mr. Gijs Biermans
Environmental Energy Technologies Division, Lawrence Berkeley Laboratory (LBNL)
1 Cyclotron Road, MS: 90-4000
Berkeley, CA 94720, USA
Tel. +1-510-486 5916, Fax +1-510-486 6996
E-mail: GBiermans@lbl.gov, g.biermans@ecofys.nl

Mr. Byung-Ryeal Choi
Research Fellow, Korea Energy Economics Institute (KEEI)
665-1, Neson-Dong, Euiwang-Si
Kyunggi-Do, 437-713, Korea
Tel. +82-31-420-2284, Fax. +82-31-420-2110
E-mail: brchoi@keei.re.kr

Dr. Sang-Jin Choi
Senior Researcher, Korea Institute of Energy Research (KIER)
71-2, Jang-Dong, Yusung-Gu
Taejon 305-343, Korea
Tel. +82-42-860-3173, Fax +82-42-860-3135
E-mail: sjinchoi@kier.re.kr

Dr. Wolfgang Eichhammer
Fraunhofer Institute for Systems and Innovation Research
Breslauer Strasse 48
D-76139 Karlsruhe, Germany
Tel. +49 721 68 09-158, Fax +49 721 68 91 52
E-mail: ei@isi.fhg.de

Mr. K. T. Hwang
Supply Team 1, LG-Caltex Gas Co., Ltd.
14F ASEM Tower, 159-1, Samsung-dong, Gangnam-gu
Seoul 135-798, Korea
Tel. +82-2-3441-4289, Fax +82-2-6204-1408
E-mail: kth1697@lgcaltexgas.com

Mr. Jai-Mo Jeong
General Manager, Korea Western Power Co., Ltd.
167, Samsung-Dong, Kangnam-Ku
Seoul 135-791, Korea
Tel. +82-2-3456-7708, Fax +82-2-3456-7869
E-mail: jjmo@westernpower.co.kr

Dr. Yonghun Jung
Vice-president, APERC, Institute of Energy Economics, Japan
Shuwa Kamiyacho Building, 4-3-13 Toranomon
Minato-ku, Tokyo 105-0001, Japan
Tel. +831 5401 4551, Fax +831 5401 4555
E-mail: jung@aperc.ieej.or.jp

Dr. Hiroyuki Kato
Economic Analysis Division, International Energy Agency (IEA)
9, rue de la Federation
F-75739 Paris Cedex 15
Tel. +33 1 40 57 67 28, Fax +33 1 40 57 66 59
E-mail: Hiroyuki.Kato@iea.org

Mr. Dok-Han Kim
Chief Officer, Business Division, Korea Independent Energy Corp.
Hanwha Bldg., #1 Changgyo-Dong, Chung-Gu
Seoul 100-797, Korea
Tel. +82-2-729-2053, Fax +82-2-729-2244
E-mail: kdh@hanwha.co.kr

Mr. Ho-Kyong Kim
Principal, HK Energy Consulting
4-503 Asian Village Apt., Jamsil, Songpa-Ku
Seoul 138-797, Korea
Tel. +82-2-422-8555, Fax +82-2-422-8110
E-mail: hkkim39@hotmail.com

Dr. Jong-Wook Kim
Leader, Technology Assessment Research Team, KIER
71-2, Jang-Dong, Yusung-Gu
Taejon 305-343, Korea
Tel. +82-42-860-3170, Fax +82-42-860-3135
E-mail: jongwkim@kier.re.kr

Prof. Tai-Yoo Kim
Seoul National University
San 56-1, Shirim-Dong, Kwanak-Ku
Seoul 151-742, Korea
Tel. +82-2-880-7228
E-mail: tykim@snu.ac.kr

Dr. Wook Kim
Analyst, Utilities Sector, Research Center, Samsung Securities Co., Ltd.
13th Fl., Naewei Bldg., 6, 2-ga, Eulji-ro, Jung-gu
Seoul 100-192, Korea
Tel. +82-2-726-0737, Fax +82-2-726-0299
E-mail: wookkim@samsung.co.kr

Dr. Bom-Soon Lee
Senior Vice President & Director R&D Division, Training Center, Korea Gas Corporation
638-1, Il-Dong, Ansan-City
Kyunggi-Do 425-790, Korea
Tel. +82-31-406-2641, Fax +82-31-406-2643
E-mail: blee@kogas.or.kr

Mr. John W. Lee
President, ExxonMobil Gas Marketing, ExxonMobil Korea Inc.
Kang Nam P. O. Box 1900
Seoul 135-619, Korea
Tel. +82-2-6248-5111, Fax +82-2-6248-5120
E-mail: john.w.lee@exxonmobil.com

Dr. Sang-Gon LEE
President, KEEI
665-1, Neson-Dong, Euiwang-City
Kyunggi-Do, 437-713, Korea
Tel. +82-31-421-0681, Fax +82-31-421-0688
E-mail: sanglee@keei.re.kr

Mr. Seung-Hwan Lee
Secretary General, Korea Gas Union
131, Nonhyun-Dong Kangnam-Ku
Seoul 135-824, KOREA
Tel. +82-2-563-9657, Fax: +82-2-563-9658
E-mail: shlee@kgu.or.kr

Mr. Young Cheol Lee
President & CEO, Korea Western Power Co., Ltd.
167, Samsung-Dong, Kangnam-Ku
Seoul 135-791, Korea
Tel. +82-2-3456-7700, Fax +82-2-3456-7801
E-mail: leeych@iwest.co.kr

Dr. Jaekyu Lim
Research Fellow, KEEI
665-1, Neson-Dong, Euiwang-Si
Kyunggi-Do, 437-713, Korea
Tel. +82-31-420-2157, Fax. +82-31-420-2162
E-mail: jklim@keei.re.kr

Ms. Jae In Nam
Power & LNG Business Division, SK Corporation
99, Seorin-dong, Jongro-gu
Seoul 110-110, Korea
Tel. +82-2-2121-7694, Fax +82-2-2121-6045
E-mail: namjaein@skcorp.com

Mr. Joakim Nordqvist
Department of Environmental and Energy Systems Studies, Lund University
Gerdagatan 13
SE-223 62 Lund, Sweden
Tel. +46 46 222 38 48, Fax +46 46 222 86 44
E-mail: Joakim.Nordqvist@miljo.lth.se

Dr. John Nyboer
University Research Associate,
Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC)
Energy and Materials Research Group (EMRG)
School of Resource and Environmental Management, Simon Fraser University
Burnaby, BC. Canada V5A 1S6
Tel. +1-604-291-3068, Fax +1-604-291-5473
E-mail: jnyboer@sfu.ca

Prof. Hi-chun Park
Department of Economics, Inha University
253, Yonghyen-Dong, Nam-Ku
Incheon 402-751, Korea
Tel. +82-32-860 7781
E-mail: hi-chun.park@inha.ac.kr

Yang-Rae Park
Researcher, Kim & Chang
5F, Hannuri Bldg., 219, Naeja-Dong, Chongro-Ku
Seoul 110-053, Korea
Tel +82-2-3703-1326, Fax +82-2-3703-1495
E-mail: yrpark@kimchang.com

Young-Gu Park
Technology Analysis Team, Center for Climate Mitigation Projects, KEMCO
1157, Pungdukchun-2-dong, Yongin
Kyonggi-do 449-994, Korea
Tel. +82-31-2604-551, Fax +82-31-2604-559
E-mail: park09@kemco.or.kr

Mr. Wan-Shik Park
Vice President, Electric Business Division, Korea Independent Energy Corp.
Hanwha Bldg., #1 Changgyo-Dong, Chung-Gu
Seoul 100-797, Korea
Tel. +82-2-729-2090, Fax +82-2-729-2244
E-mail: Parkws@hanwha.co.kr

Dr. Ji-Chul Ryu
Senior Research Fellow, KEEI
665-1, Neson-Dong, Euiwang-City
Kyunggi-Do, 437-713, Korea
Tel. +82-31-420-2120, Fax +82-31-420-2164
E-mail: jcryu@keei.re.kr

Dr. Sang Yul Shim
Senior Research Fellow, KEEI
665-1, Neson-Dong, Euiwang-City
Kyunggi-Do, 437-713, Korea
Tel. +82-31-420-2277, Fax +82-31-420-2163
E-mail: srshim@keei.re.kr

Dr. Jeong-Shik Shin
Senior Advisor, Shin & Kim
ACE Tower, 4th Floor, 1-170, Soonhwa-Dong, Chung-Ku
Seoul 100-712, Korea
Tel. +82-2-316-4276, Fax +82-2-756-6226
E-mail: jsshin@shinkim.com

Dr. Ernst Worrell
Environmental Energy Technologies Division, LBNL
1 Cyclotron Road, MS: 90-4000
Berkeley, CA 94720, USA
Tel.: +1-510-486 6794, Fax +1-510-486 6996
E-mail: EWorrell@lbl.gov