SOFTLINKING QUEST AND CIMS:
COMMUNICATING ENERGY-ECONOMY ISSUES THROUGH THE USE OF SIMULATION MODELS

by

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ABSTRACT

This research project demonstrates how a technologically-detailed simulation model (Canadian Integrated Modelling System) can be used to provide parameter estimates for a more general, but pedagogically useful, regional sustainability computer model (Georgia Basin QUEST). QUEST is a computer game in which the user undertakes various actions in an attempt to sustainably develop the Georgia Basin region of British Columbia. An external review committee suggested the QUEST enhance its ability to represent economic feedbacks and technological evolution.

In response, scenarios were developed in CIMS to reflect the world view, action, and policy choices available to the QUEST user. CIMS is a technologically explicit and behaviourally realistic simulation model which is considerably more complex than the QUEST energy model in terms of its representation of individual technologies, economic feedbacks and energy consumption forecasts. The CIMS scenarios included an information campaign, a \$75 tax per tonne of carbon dioxide equivalent emissions (CO_2e), a \$225 tax per tonne of CO_2e and a regulation requiring that the lowest-CO_2 emitting technology be utilized for all energy services. Each of these policy types were modelled under two different World Views (sets of assumptions) regarding how consumers respond to the financial and non-financial attributes of technologies. The outputs of CIMS (fuel consumption, CO_2 emissions, costs and market penetration rates of technologies) were converted to coefficients per unit of growth and summarized in matrices which are accessed by QUEST as it calculates its own scenario outputs. Thus, micro-economic feedbacks were incorporated into QUEST improving its economic realism. Linking the detail and complexity of CIMS with the visual appeal and game-like nature of QUEST creates a powerful communications tool with the ability to educate the public and assist policy makers regarding sustainable futures for the Georgia Basin.

Acknowledgements

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To: Micheal, for your support and patience.

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1. Introduction

Regional sustainability depends upon an energy system that is cost-effective and minimizes negative social and environmental impacts. Yet government policies designed to influence energy demand and supply often encounter resistance from broad segments of the general public. Increasingly, computer models are being used in public consultation processes to aid laypeople in understanding the complex scientific, economic and social interactions that influence the ability of regions to sustain healthy economies, communities and natural environments.[1] In order to be effective in influencing and communicating to the public, the computer models must strike a balance between being understandable and transparent to the layperson, while still containing sufficient detail and realism to gain credibility. The objective of this study is to show how a detailed micro-economic, technology simulation model can provide parameter values to improve the realism of a more general, but pedagogically valuable, model while maintaining its public appeal. Combining the strengths of both modelling approaches yields a provocative communications tool that empowers the public constituency with a comprehensive understanding of the energy system, the policy tools that influence it and its role in developing a sustainable region.

QUEST is a game-like computer model designed by the Sustainable Development Research Institute (SDRI) at the University of British Columbia to engage the general public in exploring the wide-range of potential futures in the Georgia Basin region of British Columbia (Figure 1.1) and the policy alternatives available to achieve them. QUEST can be classified as an integrated assessment model. Integrated assessment has been described as "an interdisciplinary process of combining, interpreting and communicating knowledge from diverse scientific disciplines. The aim is to describe the entire cause-effect chain of a problem so that it can be evaluated from a synoptic

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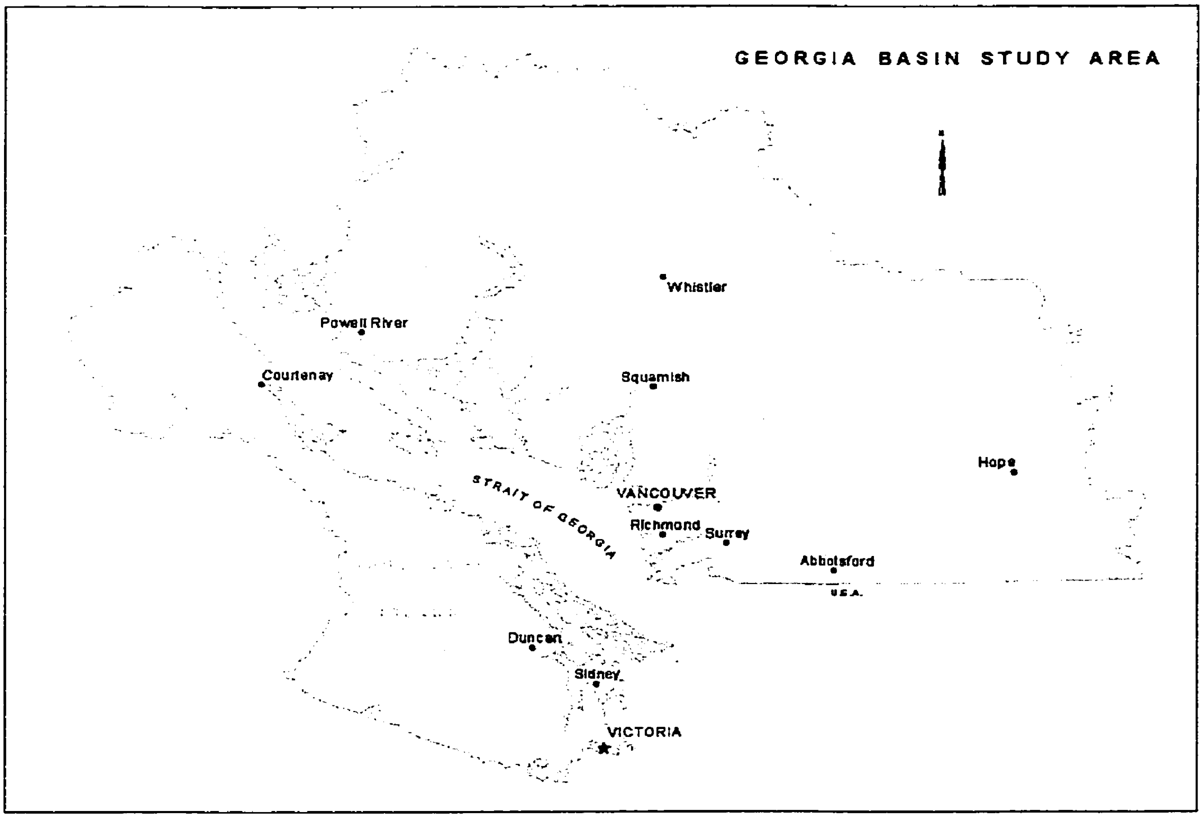
[1] Examples of the use of Integrated Assessment models for engaging the public in thinking about alternative forms of development include the Urban Lifestyles, Sustainability, and Integrated Environmental Assessment project (ULYSSES), the Climate, Energy and Alpine Regions project (CLEAR) and the Integrated Visions for Sustainable Europe project (VISIONS) (Robinson and Herbert, 2000).

perspective" (van Asselt et al., 1996; Dowlatabadi, 1995). QUEST seeks to address the problem of how the Georgia Basin can develop into a sustainable region. Sustainable development is commonly defined as "a form of development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). To describe the entire cause-effect chain of the factors that influence sustainable development, QUEST models all sectors of the economy and their economic, social and environmental impacts. The user-interface is designed like a video game. The use of interactive newspaper headlines, and colourful charts and maps to display scenario outputs creates a very appealing tool for public consultation. A challenge for the QUEST model is to achieve realism and credibility when representing the complex web of interactions among such a wide range of economic sectors and the social and ecological systems with which they interact. This is particularly difficult when dealing with the impacts of energy supply and consumption, as energy is integral to nearly all sectors of the economy.

Figure 1-1. Georgia Basin Study Area.



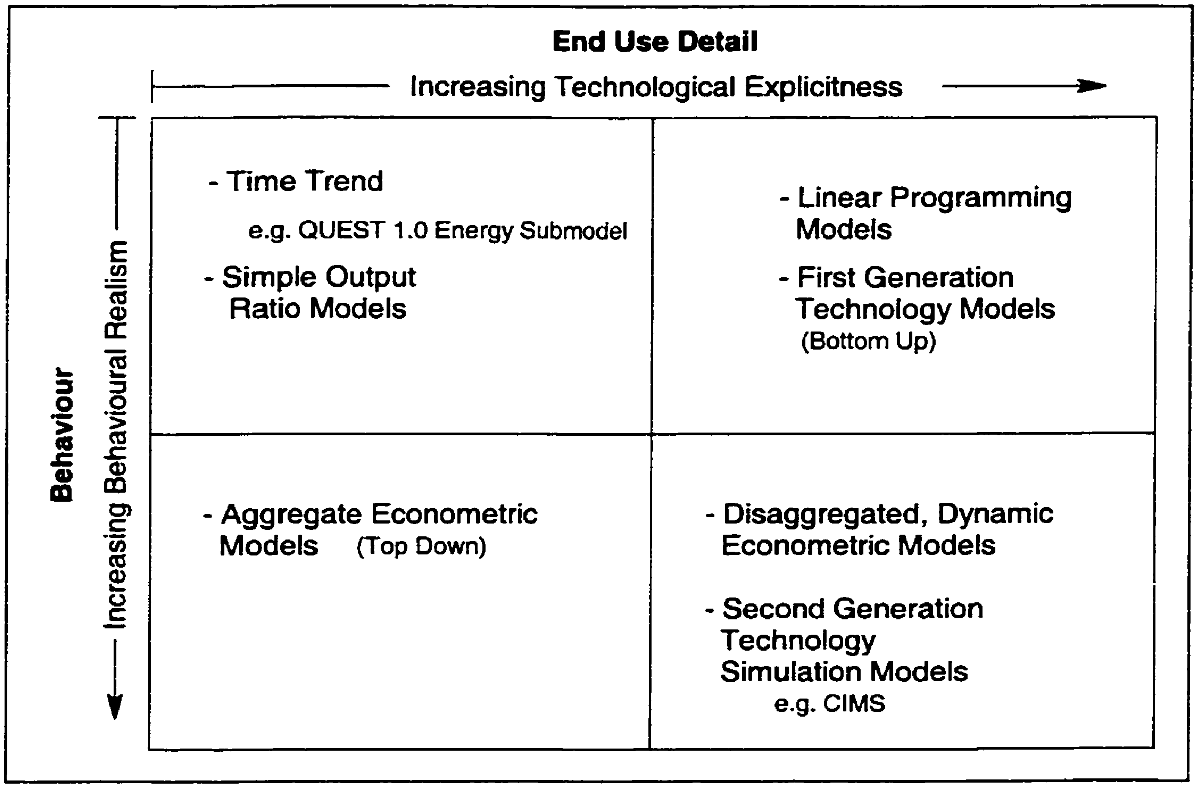
In response to an external evaluation of a previous version of QUEST (QUEST 1.0), SDRI highlighted improving the ability of QUEST 2.0 to represent economic feedbacks as a key objective during a recent re-design endeavour. A key economic feedback is the relationship between energy prices, policy costs and sustainability. The previous energy component of QUEST 1.0 lacked sufficient detail in four key areas which will be enhanced in QUEST 2.0 through this project. The areas are:

1) technological evolution;
2) the economic responses of firms and consumers to changes in energy costs and technology options;
3) the differential impacts of alternative policy types; and
4) the indirect impacts of changes in the energy system on the broader economy.

Representing these four factors is a challenge for a wide variety of energy and economic models. Several approaches in energy modelling have been developed to attempt to address some of these weaknesses. As energy modelling has advanced, the focus has been on two dimensions: 1) increasing technological explicitness and 2) enhancing behavioural realism. Figure 1.2 compares a variety of types of energy models with respect to their ability to represent individual energy-using technologies and how consumers respond to the attributes of these technologies in the market place.

The energy submodel in QUEST 1.0 is a simple time trend model. It does not contain information on individual technologies nor simulate how consumers respond to the costs of energy services when purchasing energy-using technologies. Instead, exogenous assumptions are made by the QUEST user about the rates of energy efficiency change under different scenarios in order to forecast future energy consumption. Clearly, this simple type of energy model is not sufficient to address the desire to include economic feedbacks and technological detail in QUEST 2.0.

Figure 1-2. Comparison of model types used to analyze energy demand with respect to ability to portray energy end-uses and consumer behaviour.



- Time Trend e.g. QUEST 1.0 Energy Submodel - Simple Output Ratio Models	- Linear Programming Models - First Generation Technology Models (Bottom Up)
- Aggregate Econometric Models (Top Down)	- Disaggregated, Dynamic Econometric Models - Second Generation Technology Simulation Models e.g. CIMS

*Figure derived from Nyboer, 1997.

In order to improve the energy component in QUEST 2.0, the QUEST research team has several options. The team could develop a more advanced energy component within QUEST by improving along each of the two dimensions in Figure 1.2. Alternatively, QUEST could either hardlink or softlink to a more detailed energy-economy model, which would then provide energy forecasts for the QUEST scenarios. Hardlinking involves physically connecting two or more models. Softlinking involves generating outputs from one model to serve as inputs to another model without physically connecting the two. Developing a QUEST energy-economy energy model is impractical given the time and resources required to develop and maintain a technology database alone. Hardlinking, while feasible, was quickly determined to be too computationally taxing. All of QUEST's calculations must occur in less than 30 seconds in order to maintain the user's interest and most advanced energy-economy models take much longer to run. Softlinking was therefore determined to be the preferred route by which to improve the QUEST 2.0 approach to energy-economy modelling.

The full spectrum of energy model types shown in Figure. 1.2 was explored in order to select the best model to softlink with QUEST. Aggregate econometric models, commonly known as top-down models, forecast energy consumption based on statistically-derived relationships between energy consumption, economic activity and fuel prices from historical data. This approach is behaviourally realistic in that it incorporates data on how consumers actually behaved in the marketplace of the past. However, detailed technological information is usually not included and the use of historical data limits the ability of these models to explore the potential for emerging technologies to alter energy consumption patterns from those seen in the past. The intent with QUEST is to explore all potential futures and thus this constraint to past technologies in top-down models is too constrictive.

In contrast to the top-down approach, bottom-up models (linear programming, first generation technology models) are technologically detailed. Bottom-up models incorporate information on the fuel consumption, energy efficiency and costs of individual technologies that provide energy services. The adoption of these technologies into the market is then simulated, typically by minimizing the cost of achieving the desired services. Because emerging technologies can be included, bottom-up models provide a better representation of future possibilities for changing energy consumption patterns. Unfortunately, bottom-up models are often criticized for focussing exclusively on the financial characteristics of technologies and ignoring other attributes that are known to influence consumer behaviour (e.g. product preferences, perceived risk). By highlighting what is technologically possible and overlooking consumer resistance to adopting the cheapest technology possible for providing a given energy service, bottom-up models tend to conclude that it is cheap or even profitable to reduce energy consumption. To be credible, QUEST must provide a portrayal of consumer purchasing behaviour that “rings true” with its users. The lack of behavioural realism in bottom-up models precludes their use for this application.

To overcome these challenges, the trend in energy modelling has been to develop hybrid approaches that combine the technological detail of bottom-up models with the behavioural realism of top-down models. Econometric models have moved towards greater disaggregation in representing the end-uses of technologies. Second generation technology simulation models have improved ways of simulating consumer behaviour with detailed technology databases. A hybrid model has the potential to enhance significantly QUEST's energy submodel through softlinking.

The Canadian Integrated Modelling System (CIMS) is a hybrid model that covers each province of Canada. Its submodels for British Columbia encompass the Georgia Basin. CIMS is composed of a set of integrated energy and economic simulation models developed by the Energy and Materials Research Group (EMRG) at Simon Fraser University. The energy component of CIMS is a second-generation technology simulation model. CIMS can contribute to enhancing all four of the aforementioned key areas for improvement.

CIMS can provide a detailed picture of technology evolution in response to various economic conditions. CIMS tracks stocks of individual technologies, their costs, their energy consumption and their associated emissions over time as they enter the market place. CIMS is behaviourally realistic in reflecting the process by which these technologies are adopted because it simulates the responses of consumers and firms to changes in both financial and non-financial attributes of technologies. By portraying how consumers actually behave, CIMS provides more credible forecasts of the likely response to various policies designed to alter energy consumption. Additionally, CIMS models the energy supply and demand sectors in an integrated manner, allowing fuel price feedbacks to occur. As a result, CIMS provides information on both the fuel switching and increased energy efficiency responses of consumers to changes in energy costs. A variety of policies can be simulated explicitly in CIMS allowing the QUEST user to differentiate between the effectiveness and costs of various policy alternatives. Finally, CIMS contains an optional macro-economic model which is available to simulate the indirect effects of the micro-economic responses of firms and consumers on the broader economy.

When activated, this feature of CIMS provides information on feedbacks on the level of overall economic activity and changes in the structure of the economy.

Given that CIMS can provide both a qualitative description of technology futures and a credible portrayal of demand and supply-side responses to policies designed to influence energy consumption, softlinking QUEST and CIMS was selected for enhancing QUEST 2.0's energy-economic scenarios. The softlinking approach combines the detail and complexity available from CIMS with the visual appeal and communicative strengths of QUEST.

1.1 Research Objectives

The purpose of this project is to utilize CIMS to enhance the realism of the QUEST 2.0 energy submodel such that it presents a comprehensive representation of the ecological, technological, economic and social impacts of policies designed to influence the evolution of the energy system. The specific research objectives are the following:

1) To endogenize micro-economic feedbacks to different energy policies in QUEST.
2) To increase the interest of the QUEST scenarios for users by incorporating detailed information on the technologies adopted under different economic conditions.
3) To differentiate between the impacts of different policy types in terms of fuel consumption, emissions, technologies, and particularly costs and who pays them.
4) To incorporate energy supply systems into QUEST 2.0.

Although not directly accomplished by this project, a theme throughout is how this research can be extended to macro-economic feedbacks in subsequent revisions of the QUEST model.

This report explains how CIMS was used to inform parameter estimates and provide outputs for QUEST 2.0. Section 2 provides background on key energy issues that

QUEST must communicate. Section 3 assesses each stage of the QUEST game to highlight specific areas for improving its representation of energy-economy issues. Section 4 outlines the general methodological approach and describes how CIMS functions. Section 5 presents the data inputs. The results of the softlinking exercise are reported and discussed in Section 6 followed by conclusions and suggestions for future research in Section 7.

2. Background

In attempting to realistically and thoroughly address all of the factors that influence the sustainability of the Georgia Basin region, there is a hazard of overwhelming the QUEST user with too much detail. The first step in re-designing the energy model for QUEST 2.0 was therefore to target the key issues which are critical to understanding the role of the energy system in achieving sustainability. In essence there are four key questions regarding the energy system that QUEST should answer for the user.

1) Why is the current energy system unsustainable?
2) What policy tools can be employed to move towards a more sustainable energy system?
3) What feedbacks may influence the evolution of the energy-economy system?
4) How does uncertainty affect our ability to assess energy futures?

The QUEST 2.0 energy-economy model must address these questions using the most up-to-date, and credible scientific information available.

2.1 *Why is the current energy system unsustainable?*

Most scientists concur that the energy consumption patterns of industrialized countries are unsustainable because they are dependent on the combustion of a finite supply of fossil fuels that release greenhouse gases (GHGs) and contribute to global warming (IPCC, 1996). Greenhouse gases, such as carbon dioxide, methane and nitrous oxide, occur naturally in the atmosphere, trapping heat from the sun and maintaining global temperatures in a range suitable for human existence. However, "human activities (primarily the burning of fossil fuels and changes in land use and land cover) are increasing the atmospheric concentrations of greenhouse gases, which alter radiative balances and tend to warm the atmosphere" (IPCC, 1997). Based on a range of scenarios, the IPCC projects that in the absence of climate policies, the mean annual global surface temperature will increase by 1.4-5.8° C and that globally averaged sea levels will rise by 0.09 to 0.88m relative to 1990 by 2100 (IPCC, 2000).

According to the Canada Country Study on climate change impacts and adaptation (EC, 1997), the potential consequences of accelerated climate change in British Columbia include physical impacts (increased frequency of flooding, more landslides, rising sea levels, glacier reduction and disappearance) and impacts on natural ecosystems (increased fish and waterfowl die back, forest transformations due to fire, pests and disease, extinction of rare species and migratory bird impacts). Economic and lifestyle impacts are also predicted, such as loss of coastal infrastructure, fisheries declines, energy disruptions and human health risks (EC, 1997).

Clearly the negative by-products of the current energy system have unsustainable impacts. QUEST must have the ability to forecast the levels of greenhouse gas emissions that result from energy consumption in order to indicate whether the scenario is sustainable from a climate change perspective.

2.2 Policy tools and their impacts

Given the potentially devastating costs of global warming, international efforts are underway to develop policies to limit emissions of greenhouse gases. In 1997, the Kyoto Protocol to the United Nations Framework Convention on Climate Change was negotiated and Canada committed to reduce greenhouse gas emissions to 6% below 1990 levels between the years 2008 and 2012. Although the exact nature of the international policy package and Canada's domestic strategy to decrease greenhouse gas emissions remain unknown, there are three basic classes of policy mechanisms that may be employed. These are market-based instruments, information / moral suasions campaigns, and regulatory measures. Because these policy tools have different levels of cost-effectiveness, political acceptability, and allocate the costs and benefits differently among distinct segments of society, there has been lively debate over which of these mechanisms is appropriate.

Market-based Mechanisms

Market-based policies alter the prices of fuels and / or technologies such that emissions-intensive goods and services have higher market prices and / or lower profits to the producer. This sends a price signal through the market that encourages direct responses by consumers and producers to switch away from polluting energy sources, invest in energy efficient technologies, or change their consumption / production mix. Market-based instruments are often preferred by industry because they are cost-effective, meaning that they achieve a targeted level of emissions reductions at a minimal overall cost. Carbon taxes, where charges are added to each fossil fuel in proportion to their carbon content (and thus emissions of CO_2), are one example of a market-based instrument. The magnitude of the price increase required to achieve a specific target level of greenhouse gas emissions is estimated by government and the tax level is set accordingly. Polluters who can reduce their emissions for a lower cost than paying the tax will do so. Polluters for whom it is more expensive to abate will prefer to pay the tax. In this manner, carbon taxes implicitly equalize the marginal costs of abatement among polluters (Baranzani et al., 2000).

In the Georgia Basin, any form of additional taxation tends to be politically unfavourable; thus tradable emissions permits are increasingly proposed as a market-based alternative to carbon taxes. In a tradable permit system, the administrative body will initially issue a set number of GHG emissions permits, which firms and households can then trade amongst themselves in a competitive market. This option is less likely to encounter resistance primarily because it allows firms to purchase emissions permits at known prices in advance of major projects, an approach similar to commodity hedging instruments that are a familiar tool in industry. Carbon taxes and tradable permit systems may differ in terms of their effectiveness in limiting absolute emission levels. Under a carbon tax scheme, there is not a firm upper limit on the total quantity of emissions allowed; consumers can emit as many GHG's as they are willing to pay for. In contrast, the tradable permit system is more likely to achieve a specified emissions target because it caps the overall level of emissions.

Other market-based instruments include feebates (which assess fees on inefficient technologies while providing rebates for purchases of high fuel efficiency or low GHG emission technologies) and subsidies to encourage investment in energy efficient technologies. The BC Climate Change Business Plan states that "BC favours a market-based approach to GHG reduction that ensures cost-effective emission reductions and continued competitiveness in world markets"(MELP, 2000). Therefore, it is important that QUEST have the capability to model explicitly the impacts of this policy type.

Information

Information or moral suasion campaigns are another policy tool commonly employed by governments and other agencies to discourage consumer behaviour that is not in the public interest (e.g. drunk driving and smoking). This type of policy is also applied in the energy sector. For example, in the industrial sector, the *Industrial Energy Innovators Initiative* is a voluntary, company-based program, which encourages companies to become more energy efficient (NRC, 2001). Companies can publicly report their voluntary efforts to reduce GHG emissions via the Voluntary Challenge and Registry (VCR Inc, 2000.). Information and moral suasion campaigns are politically popular because consumer and industry response is voluntary; however, the willingness of firms to adopt technologies and practices which decrease emissions may be limited to actions which have a net financial benefit or at least a low cost. Thus, the effectiveness of information campaigns for meeting strict emissions reductions is questionable.

Regulation

Regulatory policies impose limits on the use of technologies or fuels in order to reduce GHG emissions. For example, Canada's *Energy Efficiency Act* regulates the minimum energy performance levels for energy-using products and enables energy labelling of specific products (NRCan, 1999). Minimum levels of energy efficiency are specified for household appliances, water heaters, heating and air conditioning systems, and various lighting products and motors. Regulations regarding use of High Occupancy Vehicle lanes on highways encourage carpooling and subsequently reduce fuel consumption per person kilometre travelled. Regulatory approaches are often economically inefficient in that they impose the same restrictions on all firms regardless of cost. Regulation is considered effective in reaching the specified energy efficiency level or emissions reduction because most firms will comply with legislated standards.

QUEST must differentiate between the impacts of the three policy types in terms of their cost-effectiveness, ability to reduce total GHG emissions, political feasibility and their allocation of benefits and costs so that the user can fairly evaluate different policy alternatives.

Policy Feedbacks

Policies designed to influence energy consumption and supply patterns have far-reaching effects because energy is an integral input to almost every sector of the economy. Potential feedbacks within and between different sectors of the economy must be considered because they may unexpectedly influence the overall system's response to greenhouse gas reduction policies. Policies that alter the cost of energy services will have direct impacts on the future decision-making of firms and households (micro-economic feedbacks) as well as indirect impacts on the broader economy (macro-economic feedbacks). At the micro-economic level, different policy instruments can incur very different financial costs for firms and households in the short and long run. Each of these instruments engenders its own unique set of responses from firms and households, which feeds back upon the relative mix of technologies, research and development leading to new technologies, and the way in which technologies are used (lifestyle).

At the macro-economic level, different policies, and the subsequent evolution of technology and service demands of society, can feed back differently upon both the structural evolution and the overall level of activity in the economy. For instance, a carbon tax may cause a decline in fossil-fuel intensive industries relative to less energy-intensive industries in the service sector creating a shift in the overall importance of the sectors in terms of their contribution to the total economy (structural shift). Also, if certain sectors discover opportunities for investment in energy efficient technologies that provide energy cost savings, they may increase their competitiveness and stimulate growth in overall economic activity.

Technology Evolution

In addition to economic feedback effects, it is also important for the QUEST user to be aware of the potential impact of emerging technologies on the ability to achieve regional sustainability. Energy-efficient or low emission technologies, such as electric hybrid vehicles, have the potential to decrease overall energy consumption and GHG emissions while providing the same energy services as more emission-intensive vehicles types. Alternative fuel technologies, like hydrogen fuel cells, could revolutionize energy use in the residential, commercial and transportation sector. Technologies are even being developed to retrieve GHG emissions from fuels prior to combustion and to sequester them such that they are not released to the atmosphere. The rate at which technological innovations that decrease the GHG emissions associated with energy services are developed is a critical factor in determining the overall ability of the region to meet energy service demands in a sustainable manner.

2.3 Uncertainty in Integrated Assessment

In attempting to represent the entire realm of interacting factors that influence sustainability, QUEST necessarily makes broad assumptions about processes and relationships both within and between ecological, economic and social systems. The interplay of so many factors encompasses a great deal of uncertainty when attempting to simulate the future of the energy system alone. Even if it were possible to validate the energy submodel in isolation, this would not ensure the reliability of its interactions with other QUEST submodels. QUEST must acknowledge the existence of uncertainty without invalidating the entire approach.

In energy models, there is often uncertainty with regards to three primary factors that determine energy consumption:

- the level of economic activity,
- price-related factors and
- price-independent factors.

Uncertainty in forecasts of overall levels of economic activity has the largest impact on the level of energy services and therefore on the energy requirements and GHG emissions of a scenario. Uncertainty regarding how easily firms and consumers substitute different fuels for one another and / or substitute capital for energy (by purchasing more expensive, fuel-efficient technology stocks) in response to relative price changes also has important consequences. Manne and Richels (1994) found that the degree of substitutability between capital and energy was the second most important determinant of CO_2 emissions and the cost of reducing them, after economic activity levels. Trends that influence the demand for energy can also be a function of time rather than relative prices. Uncertainty also exists with respect to the direction and magnitude of such trends. The approach used in QUEST to address the existence of uncertainty is to allow the user to explore a variety of scenarios based on different modelling assumptions or perspectives.

The following section reviews QUEST 1.0's ability to address the three critical uncertainties in energy modelling. Alternatives and recommendations for improving QUEST 2.0, either through softlinking with CIMS or other mechanisms, are discussed. Many of these recommendations are implemented directly by this research project and require some basic modifications to the QUEST 2.0 interface which are outlined in Section 3. Other suggestions put forth in this section, particularly those related to macro-economic feedbacks, are presented only as possible directions for future research.

3. Methodology: Modifying QUEST

The four stages of the QUEST game provide a conceptual framework for understanding the modelling mechanisms.[2] Figure 3.1 shows the 4 stages of the QUEST game. In Stages 1 and 2, the user makes decisions that determine key model inputs. In the *Invent-a-Future* stage, the user specifies (1) the growth scenario they would like to explore and (2) key model inputs that influence the reaction of the model to the user's selection of actions in the subsequent *Choose Policies* stage. During the *Choose Policies* stage, the user selects various actions that they would like to see implemented and chooses the policy types that they would use to instigate the actions. In Stages 3 and 4, the QUEST model calculates and displays various outputs of interest to the user. In the *View Consequences* stage, the user examines the impact of their policies over a decade by observing trends in various indicators. The user then repeats the selection and review of policy choices each subsequent decade, over a 40 year period. Finally, the user examines the cumulative impact of the policy actions over the full forty-year scenario in the *Review Scenario* stage.

Stage 1: Invent-a-Future

Set Economic and Population Growth Forecast

In the Goals and Targets section of the *Invent-a-Future* stage, the QUEST user selects the population trend[3] and economic growth trend that they would like to explore

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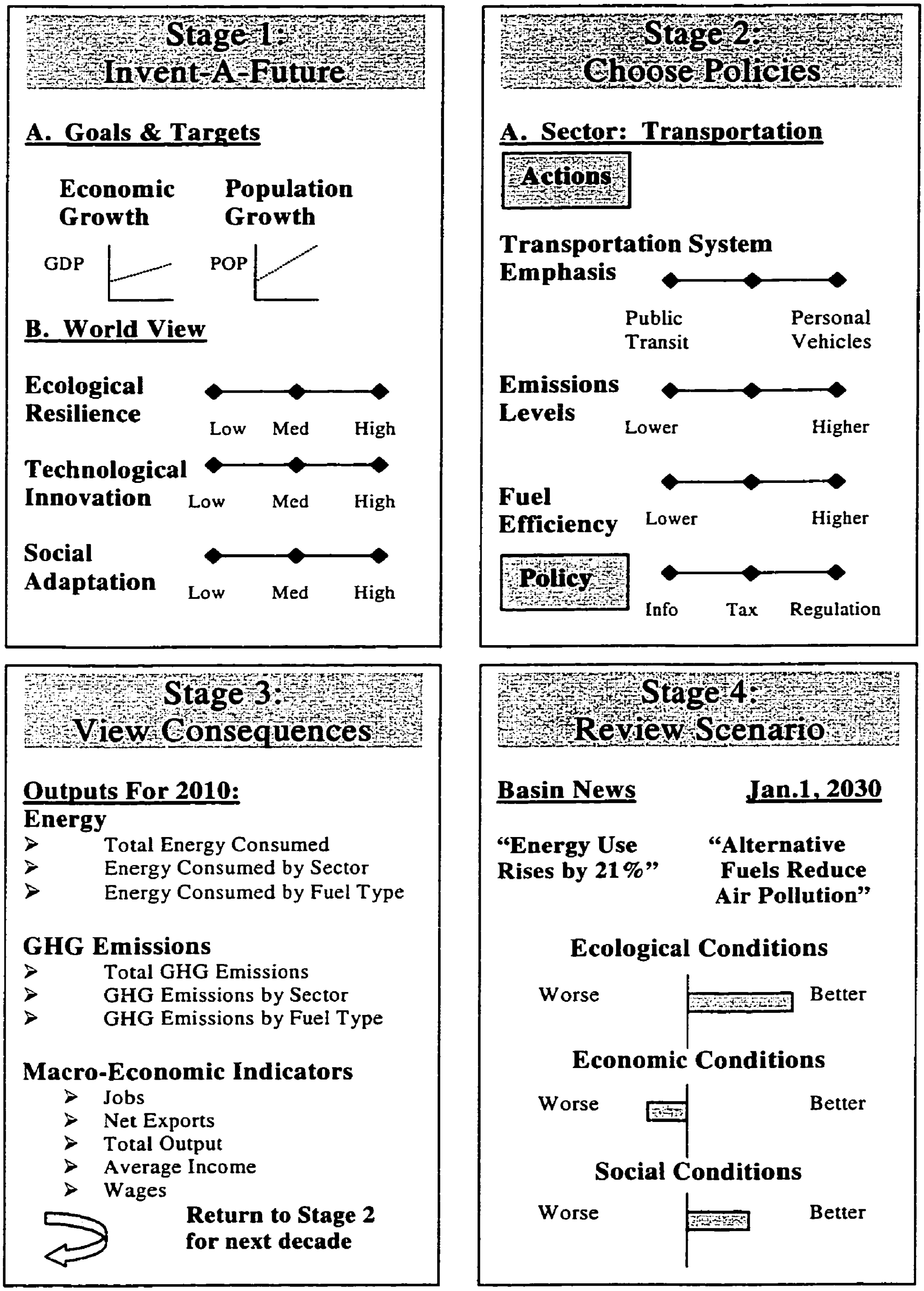
[2] For additional reading on the QUEST model see the publication "Lower Fraser Basin QUEST Model Structure" (EST/SDRI, 2001). In order to give the user the feeling of playing a video game, there are many "bells and whistles" added to the basic QUEST model. Only those details relevant to the functioning of the model are discussed in this section.

[3] The migration rate is adjusted in the demographic submodel to achieve the desired population level. Birth and death rates are assumed constant.

Figure 3-1. Stages of the QUEST game.



from among the wide range of possibilities provided.[4] There are no feedbacks (negative or positive) on the level of population or economic growth in the QUEST scenario in response to the user's subsequent policy selections. In the real world, the implementation of policies to influence the cost of energy services may feedback on both the population in the Georgia Basin and overall economic activity. An example is the migration of people and businesses to regions with lower taxes. While these feedbacks are important, the QUEST research team wants the user to face the consequences of a set level of population and economic activity and thus feedbacks on these variables are not incorporated in QUEST 2.0. Allowing the QUEST user to explore a variety of economic activity levels enables them to determine the impact of uncertainty in this critical variable for energy forecasting.

Along with a growth scenario, most energy models require fuel price forecasts to realistically forecast the level of energy demand and to determine the energy costs associated with meeting the demand for energy services. Fuel price forecasts are notably missing from the *Invent-a-Future stage* of QUEST 1.0. This precludes modelling the micro-economic responses of individuals and firms to changes in the relative costs of different fuels under market-based policies. In QUEST 2.0, fuel prices will be incorporated in order to represent (1) the impacts of market-based policies on the relative prices of fuels and (2) the fuel-switching and energy-efficiency purchasing responses of consumers to changes in the costs of energy services.

Select World View

In the second part of Stage 1, the QUEST user specifies their world view settings (Fig. 3.1). A *world view* is a belief regarding the structure of reality and an accompanying vision of the relationship between people and environment (van Asselt et al., 1996). The individuals who play QUEST may hold fundamentally different views regarding how the world works that influence how they believe change can be

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[4] QUEST assumes that population and economic growth are not linked and allows the user to explore whichever combinations they prefer.

accomplished. In order to explore these different beliefs and to acknowledge uncertainty, QUEST provides *multiple model routes* for the user to explore. A *model route* is "a chain of perspective-dependent interpretations of the crucial uncertainties in an integrated assessment model" (van Asselt et al., 1996). A *perspective* is defined by an individual's *world view* and *management style.* Management style refers to the policy types that the individual prefers or believes are effective. The availability of several world views forces the user to question their confidence that their own perspective is correct and to consider the potential consequences of being wrong.[5] The ability to portray different beliefs regarding the three aforementioned critical uncertainties in energy modelling must be maintained in QUEST 2.0.

In this stage, the user specifies their world view beliefs regarding three key uncertainties:

1) Level of Ecological resilience -how fragile are our ecosystems?
2) Rate of Technological innovation -how rapidly will new technologies be developed?
3) Degree of Social adaptability -how willing are individuals to change their behaviour?

Each world view choice is represented by a slider, which the user sets at low, medium or high in accordance with their answers to these three questions. In QUEST 1.0, the user's settings for each world view slider determine the numerical ranges of a set of model variables that specify the allowable rate of change in response to actions in the *Choose Policies* stage (Fig. 3.2). Thus, the user's value-based assumptions are translated into numeric parameters, which provide a consistent representation within the model of how the user believes the world functions (EST/SDRI, 2001). For example, if the user believes that the rate of technological innovation will be low and later implements a policy to increase fuel efficiency, the increase in fuel efficiency will be much smaller than if they had selected the world view belief of rapid technological innovation. Using this approach, the world view settings simply scale model parameters up or down in a linear

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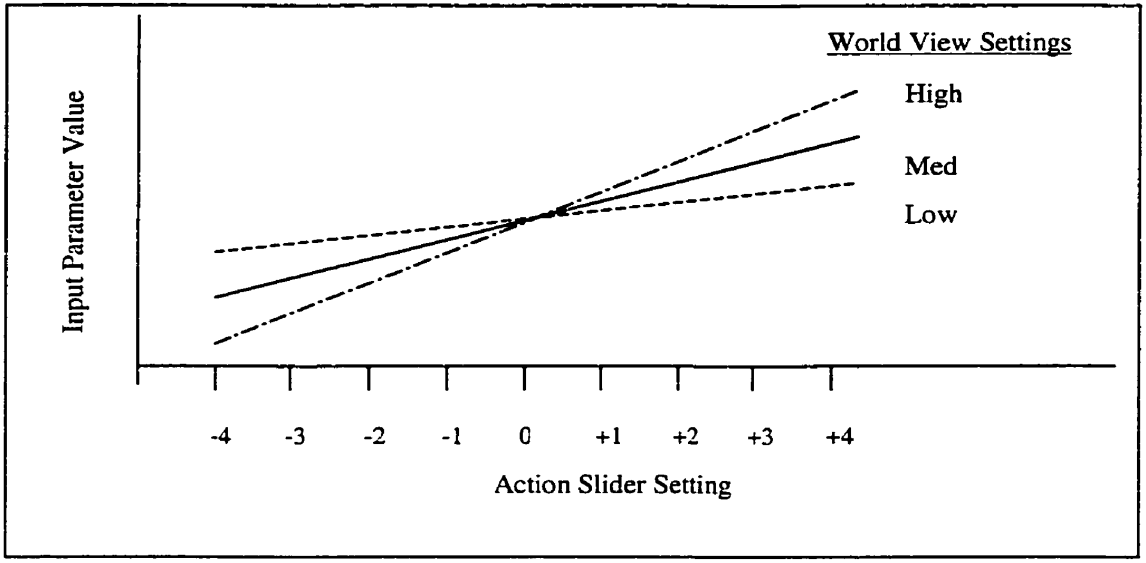
[5] While this approach is useful for highlighting that there is uncertainty regarding which is the "correct" world view, it should be pointed out that the model's representation of each individual world view is highly subjective and masks a great deal of uncertainty.

manner with no explicit relationship to processes functioning in the real world to stimulate such changes.

In QUEST 2.0, the world view approach will be enhanced such that (1) each world view slider reflects a real world process (how the world works) and (2) different beliefs regarding these processes can be defined and simulated. Translating conceptual ideas, such as the world views, into quantitative model parameters inevitably involves subjective decisions on the part of the modeller. I will outline my definition of the Technological Innovation and Social Adaptation sliders to clarify how I conducted this process.[6]

Figure 3-2. Effect of World View Sliders on the parameter values associated with Action slider settings.



In subjectively defining the Social Adaptation and Technological Innovation sliders I must first acknowledge that there is a degree of overlap between these concepts. Technological innovation does not occur in isolation from society. A highly adaptable society may be more willing to change its purchasing behaviour and take risks on innovative and unproven technologies. This could stimulate learning and additional technological developments. Such a society may be more willing to fund research and

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[6] The Ecological Resilience world view slider is not discussed further because it deals with the magnitude of the ecological consequences that occur as a result of energy consumption and related GHG emissions.

development. Likewise, technological breakthroughs can facilitate behavioural changes in society. For instance, new communications technologies (fax machines, internet) make it easier for people to work at home.

While acknowledging the synergies between Technological Innovation and Social Adaptation, it is necessary to isolate them in order to represent them distinctly in numeric terms in the model. As discussed previously, energy modellers often think of economic activity levels, relative prices, and price-independent trends, as the three determinants of future energy demand. Following discussions with the QUEST modelling team, it was decided to define the Social Adaptation slider as representing different views regarding how consumers respond to energy costs and to define the Technological Innovation slider as representing different views regarding rates of price-independent technological evolution. This approach reflects common distinctions in energy modelling and thus allows quantitative parameters to be determined from the literature or other models. Each world view slider and supporting literature for its settings in QUEST 2.0 are reviewed below.

Social Adaptation

World views regarding social adaptability affect energy consumption on several levels. Firstly, how consumers weigh future benefits against current costs has important implications for energy consumption. For instance, do consumers prefer to avoid immediate costs even if it means that they relinquish the potential for future benefits? If so, then consumers are less likely to purchase energy efficient technologies or alternative fuel technologies, which have higher upfront costs but provide energy cost savings in the future. Social adaptability may also relate to consumers' willingness to alter their preferences for specific technology attributes. For instance, if consumers were highly adaptive to the threat of climate change, and thus willing to live in apartments, rather than large stand-alone houses, the demand for energy for space heating would decline. Social adaptability may also be reflected in how cities and regions are allowed to develop. For example, mixed-use neighbourhoods where people can live, work and shop within walking distance decrease the demand for vehicle travel. QUEST users can already directly control urban planning decisions and some key user preferences (see Table 3.1) that relate to energy consumption; therefore, I have developed the Social Adaptation slider to represent different perspectives regarding the process by which consumers respond to costs when purchasing energy-using technologies.

Uncertainty regarding how consumers make technology-acquisition decisions is critical to a central debate in the current energy-economic literature. The debate centers on whether there is an "energy efficiency" gap between actual levels of energy use and the optimal level of energy use (Jaffe & Stavins, 1994). The definition of what is optimal energy use depends on which perspective one takes. Economically optimal energy use would maximize the value of goods and services consumed by society over time. To the extent that negative environmental externalities compromise that value, they would be considered suboptimal. While the economically optimum level of energy use is a concern for public policy, from a strict financial cost point of view, the optimum level of energy use minimizes the financial costs that consumers face in achieving their desired level of energy services.

There is evidence of technologies where the energy cost savings exceed the initial investment costs (Koomey & Sanstad, 1994). This suggests that it is financially profitable to undertake energy efficiency investments that may also yield societal benefits, such as reduced risk of climate change. This possibility has obvious appeal. Yet despite their apparent profitability, many of these technologies have shown only gradual market penetration or none at all. If these investments are so cost-effective, why do consumers not undertake them as a matter of economic self-interest?

Empirical research shows that consumers utilize high implicit discount rates when purchasing energy-efficient equipment. (Hausman, 1979; Ruderman et. al., 1987; see Jaffe & Stavins, 1994) Consumers who exhibit high discount rates weight present consumption with more importance than future consumption and are therefore biased against purchasing energy efficient technologies, which are typically initially more expensive than inefficient alternatives. Such consumers prefer to save money immediately on the upfront capital costs of the technology, rather than wait to save money by spending less on energy bills in the future. The magnitude of the "energy-gap" is determined by the extent to which the revealed discount rates implicit in consumer purchases diverge from other information about their time preferences that suggest much lower discount rates. In other words, discount rates that are too high prevent consumers from minimizing their financial costs over time and thus prevent consumers from reaching the financially efficient level of energy use.

Do consumers discount energy-using technologies correctly? While there are many nuances to the debate, two opposing perspectives, which I will call the Economic Efficiency world view and the Average Consumer world view, are outlined here to highlight the differences in the underlying beliefs. These two perspectives are later modelled in CIMS and serve as different settings for the Social Adaptation world view slider in QUEST 2.0.[7]

Economic Efficiency World View

On one side of the issue, researchers argue that market barriers and / or market failures cause consumers to utilize discount rates that are too high and hinder them from purchasing the economically efficient level of energy efficient technologies. Market barriers may include: lack of information regarding the cost saving attributes of the technology, transaction costs (gathering, assessing and applying information on the characteristics and performance of energy-using equipment) and lack of access to capital. Additionally, energy-efficient technologies may not be purchased at the economically optimal level if the individual who must purchase the technology is not the person who will benefit from the energy cost savings (Jaffe & Stavins, 1994; Howarth & Andersson, Sanstad & Howarth, 1994) (e.g. a renter would save on their electricity bill while the building owner would pay the extra cost of a more energy-efficient refrigerator). De Canio (1998) suggests that organizational and institutional factors (size of firm, type of

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[7] As a result, the Social Adaptation world view slider in QUEST 2.0 has two rather than three settings.

institution, type of facility, equipment provider) also act as barriers and influence the decision-making of firms almost as strongly as economic forces. Proponents of this world view believe that if such barriers were removed, consumers would utilize a lower discount rate, purchase more energy-efficient technologies and minimize their financial costs over time. I define this as equivalent to a more highly adaptable society.

Average Consumer World View

In contrast to the Economic Efficiency perspective, many economists are doubtful that there is a large abundance of unexploited opportunity for economic benefits through energy efficient technologies (Sutherland, 1994; Nichols, 1994). They argue that the high discount rates used by consumers are consistent with the real costs and risks they face rather than the result of market barriers. These costs may include transaction costs, risks of technology failure, loss of preferred technology attributes, and loss of option value (Nichols, 1994). The transaction costs involved with purchasing energy-efficient technologies may be higher as consumers must search out information related to energy-efficiency, availability and how the technology fits within their home or lifestyle. Proponents also argue that one should consider not just the capital cost, but also the "expected" cost given the probability that the technology will fail. Given that the most energy-efficient technologies are usually new to the market, consumers are unfamiliar with their performance and may expect a higher failure rate, increasing the perceived cost of the technology. Consumers may also perceive differences in the quality of service provided by the technology. They may, for example, find that electric-hybrid vehicles lack the horsepower of gas-powered vehicles or that compact fluorescent lighting has a different hue than incandescent lights. Finally, there is evidence that competitive markets require a higher rate of return for capital-intensive investments than for energy-intensive technologies because capital-intensive investments represent irreversible, sunk costs which decrease the flexibility of the consumer or firm to respond to changing conditions in the future (loss of option value) (Metcalf, 1994).

These costs are more difficult to quantify than the measurable financial costs (capital costs, energy expenditures and operating and maintenance) typically accounted for in the simple financial calculations that often support claims regarding the cost-effectiveness of energy-efficient technologies. Proponents of this world view believe that high discount rates are justifiable when they account for the real uncertainty that consumers face. I equate this belief with the low setting of the Social Adaptability world view slider as such consumers are less likely to change their purchasing behaviour.

One's perspective regarding how consumers respond to costs when making technology purchases has a drastic impact on the model's portrayal of the evolution of technology stocks and thus on fuel consumption and levels of greenhouse gas emissions. In energy models, the responsiveness of firms and consumers to relative costs is embodied in the explicit or implicit values that the model adopts for the ease of substitutability between capital (technology stocks) and different forms of energy over time. These values are called the long-run capital for energy elasticity of substitution (K for E elasticity) and inter-fuel elasticity of substitution respectively. The term elasticity of substitution refers to how much a change in the relative prices of inputs changes their relative demands. Different modelling approaches utilize significantly different estimates for these parameters (Bataille, 1998).

In bottom-up models, the implicit value of K for E elasticity of substitution is typically high (strong substitutability). In other words, a small increase in the relative price of energy will stimulate a larger increase in the demand for technology stocks with greater energy efficiency. This implies that it is relatively cheap to reduce energy consumption and its negative environmental impacts. This is expected, as bottom-up models emphasize what is technologically possible.

In top-down models, the K for E elasticity of substitution is usually lower (mild substitutability) indicating that it is more expensive to reduce GHG emissions. Top-down models reflect the tendency of consumers to respond more to perceived costs (including transaction costs, real and perceived risks and preferences) than simply financial costs. Thus, top-down models reflect the resistance of the market to switching to the least expensive technology or fuel for achieving a given energy service. However, top-down models are unable to detect emerging technologies and changing preferences and, therefore, their estimates of elasticities of substitution are conservative.

Bataille (1998) utilized the hybrid CIMS Energy Demand Model to estimate long-run capital for energy elasticity of substitution and inter-fuel elastcity of substitution values. He concluded that the aggregate Canadian capital for energy elasticity value was 0.24, falling roughly between estimates from top-down and bottom-up sources. Bataille reached other important conclusions that strongly support the use of hybrid models for estimating the costs of GHG reduction actions and for informing policy development. To summarize, Bataille found that:

- K for E elasticities vary widely for different sectors of the economy;
- K for E elasticities vary by province;
- Inter-fuel elasticities exceed those for capital and energy by two to three times; and
- K for E elasticities are sensitive to the discount rate applied by purchasers.

These results suggest that the use of a single aggregate parameter for K for E elasticities is inappropriate given the heterogeneous abilities of different sectors to substitute between energy forms or away from energy to technological stocks with increased fuel efficiency. Disaggregated analysis is best able to reflect this varying flexibility. Given that inter-fuel substitution elasticities exceed capital for energy elasticities by two to three times, fuel switching is a more likely response to changes in energy price than increased purchases of energy efficient technologies. The ability to integrate the supply and demand sectors is thus increasingly important in order to incorporate fuel price feedbacks. Finally, the sensitivity of K for E elasticities to the discount rates applied by purchasers indicates that different world views regarding the appropriate discount rate influence one's belief about the substitutability of different energy forms and technology stocks. Based on the pulp and paper sector, Bataille's results show that higher discount rates result in lower K for E elasticities while lower discount rates result in higher K for E elasticities (increased substitutability).

Technological Innovation

In my interpretation, the Technological Innovation world view slider represents the user's beliefs about trends in technological evolution that occur regardless of price effects. Price-independent technological evolution refers to broad trends in technology evolution that are a function of time rather than direct price effects. The evolution of technology towards higher or lower energy intensity is a function of numerous factors that are not easily distinguished. If these factors act consistently over time, they can have a significant impact on the future demand for energy and should be incorporated into the QUEST 2.0 energy model.

Energy modellers utilize the term "autonomous energy efficiency index" (AEEI) to describe the effect of technological evolution (with prices held constant) on the demand for energy. AEEI measures the price-independent determinants of energy use and is generally interpreted as measuring the trend in technological energy efficiency. Again, different types of energy models produce varying estimates of the value of the AEEI parameters. Top-down models employ a time-trend variable to account for the price independent technological changes that affect energy demand. Top-down models produce lower estimates of AEEI than bottom-up models if the parameter is estimated from a period of relatively low public and research concern for energy scarcity, meaning that the technological innovation was not focussed on energy. Bottom-up models incorporate detailed information on all potential energy-using technologies and simulate their penetration into the market over time. Demand for additional technology stocks is a function of retirement of old technology stocks and increases in economic activity. Technologies compete for new market share based on their annualized life-cycle costs. Bottom-up models can yield high estimates of AEEI if they include emerging technologies. Hybrid models combine the technological detail of bottom-up models with adjustments for behavioural realism. They thus combine features of both approaches and should tend to yield AEEI estimates that fall between those from top-down and bottom-up models (Luciuk, 1999).

Despite uncertainty regarding the rate of price-independent technological evolution, estimates of AEEI from these three model types provide an indication of the range and general magnitude of the effect of price-independent factors on the evolution of technology stocks, and thus energy demand over time. Each Technological Innovation world view setting in QUEST 2.0 will be represented by an appropriate AEEI values from among the range in the literature

To review, at the end of Stage 1: *Invent-a-Future*, users have set the level of economic activity they wish to explore. They have also expressed their world views regarding how consumers make technology acquisition decisions and how price-independent trends will impact energy demand. This allows the modeller to customize the quantitative functions of QUEST to reflect how users believe the world works. In Stage 2: *Choose Policies*, the World View settings act either to enhance or detract from the effectiveness of users' choices (see Figure 3.2).

Stage 2: Choose Policies

In the *Choose Policies* stage of the QUEST game, users (1) implement actions that they believe contribute to a desirable future in the region and (2) specify the policy type they would use to achieve the action for one decade at a time (Fig. 3.1). The following definitions are applied:

1. *Action*: change in equipment acquisition, equipment use rates, lifestyle choices, or resource management that changes the consequences of the scenario from what they otherwise would be.

2. *Policy*: effort by government to realize an action (outcome).

3. *Measure*: The application of a policy for the purpose of achieving one or more actions (Policy + Action = Measure). In the real world measures can have varying degrees of success in achieving the desired outcome.

Action Sliders

Potential actions are represented by sliders in QUEST that the user can move to one of three settings. The centre position is the default and maintains the existing "business-as-usual" trend in the associated indicator. Moving the slider away from the centre position increases or decreases the numerical value of a related model parameter, providing a direct input to the submodel's calculations. The range of the numerical values is constrained as described above by the user's world view settings; however, all values are based on academic literature, input from more complex sector-specific models or expert opinion if no empirical or model data is available. A total of 31 action sliders are available to the QUEST user including urban planning, technological, lifestyle and environmental protection decisions (EST/SDRI, 2001). For example, the user may determine that a desirable action in the transportation sector is that average vehicle occupancy should increase over the next decade. If the user specified that Social Adaptation was high, this would increase average vehicle occupancy from 1 occupant to 1.5 occupants over the next decade. If the user specified Social Adaptation was low, average vehicle occupancy would only increase to 1.25 occupants. Table 3.1 shows the energy-related action sliders in QUEST 1.0.

For the three primary sectors, transportation, residential and industry, the focus of the actions that directly impact the calculations of the Energy Use submodel (shown in bold text) is on energy efficiency. While energy efficiency is an important mechanism by which to achieve the objective of lowering greenhouse gas emissions and local air pollutants[8] to sustainable levels, it is not an end in itself. It is possible to have a future

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[8] Greenhouse gas emissions include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride, perfluorocarbons and hydrofluorocarbons (EC, 1999). This report covers CO_2, CH_4 and N_2O. Local air pollutants include nitrous oxides, sulphur dioxide, ground level ozone, fine particulates, volatile organic compounds and mercury. They are controlled by the same slider but are modelled in the Air Quality submodel of QUEST.

with very low levels of energy efficiency yet with greatly reduced emissions through fuel switching to cleaner fuels or through technologies that recapture these emissions from the atmosphere. In QUEST 2.0, these action sliders will be altered to focus on GHG and air-polluting emissions, rather than energy efficiency, as they are more appropriate indicators of the sustainability of the energy system.

Table 3-1. Action sliders in QUEST 1.0 prior to re-design.

Transportation Actions	**Residential Actions**	**Industry Actions**
Transportation priorities	Housing density	**Energy efficiency**
Vehicle occupancy	**Energy efficiency**	Pollution control
Fuel efficiency	**Fuel mix**	R&D spending
Emissions levels		Structural change
Agriculture Actions[9]	**Lifestyle Actions**	**Labour Actions**
Agricultural methods	Diet	Workweek length
Agricultural intensity	Energy & Water Use	
	Shopping	**Commercial Actions**
	Waste Generation	Energy Efficiency

*Actions in bold font influence a direct input into the Energy Use Model's calculations. Other actions are indirectly incorporated through growth factors developed in other submodels (see Section 3.2).

Two sliders in Table 3.1 specify actions that may be contrary to the user's decisions elsewhere in the model. The fuel mix slider in the residential sector allows the user to determine the mix of electricity and natural gas used in household end-uses. The user's selected action for this slider could be contrary to their decision for the emissions actions slider recommended above depending on whether the fuel mix used to create electricity releases more or less emissions than direct combustion of natural gas in residential end-uses. In QUEST 2.0, the mix of electricity and natural gas consumption in the residential sector is reported during the *View Consequences* stage as a consequence of

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[9] CIMS does not model the agricultural sector individually. Emissions from this sector are incorporated in the transportation and chemical models (i.e. fertilizer manufacturing).

the user's action selections in the rest of the model rather than an outcome that they can directly control.

Similarly, the structural change slider is used to allocate the total gross domestic product (GDP) of the Georgia Basin between service sectors and industrial sectors regardless of the user's actions elsewhere in the model which impact upon the relative rate of economic growth in these sectors. For example, if the user implements extensive measures to control emissions, industrial sectors may be impacted more than the service sectors because they are relatively more fossil-fuel intensive. The industrial sector would therefore be expected to shrink relative to the service sector; however, the user could set the structural change slider to increase the relative size of the industrial sector. This would require a subsidy from the government that is not accounted for in the QUEST 1.0 model, allowing the user to implement "costless" actions in the model. Ideally, this internally inconsistent approach would be replaced with endogenously determined outcomes for structural change in QUEST 2.0.

Although indirect impacts such as structural change are beyond the scope of this softlinking exercise, I will briefly highlight how CIMS could be utilized for this purpose. CIMS provides the option to model macro-economic feedbacks on the demand levels for energy services in response to changes in the costs of providing those services. Firstly, CIMS calculates changes in the costs of key energy services. If the cost of providing an energy service has increased by more than a set threshold, the demand for that energy service in the subsequent 5-year simulation period will be decreased from the initial forecasted demand for the service. The magnitude of the decrease can either be specified directly by the user or based on energy service demand elasticity values from the literature. Elasticity values specify the percentage change in demand for energy service that occurs in response to a percentage increase in the cost of that energy service. This feature of CIMS allows the model to simulate structural change in the economy as different sectors will face different costs and exhibit varying responses. In future research, the structural change responses of CIMS to different policies could be used to inform the structural change slider of QUEST. For the purposes of this research project, the macro-economic feedback in CIMS was disabled. This is consistent with the lack of feedbacks on both population and GDP growth in QUEST (see Stage 1).

In QUEST 1.0, the available actions (Table 3.1) did not provide the user with the ability to undertake actions that affect the supply sectors that provide energy (electricity production, natural gas extraction and processing, petroleum extraction and refining). These sectors account for roughly 8% of the total emissions in BC (EC, 1999) and future electricity production may or may not be emission intensive (hydro versus natural gas). Therefore, it is important to include actions directed at these sectors in QUEST 2.0. Furthermore, the demand and supply sectors will be modelled in an integrated fashion to reflect common economic feedbacks. If demand for electricity rises, the supply sector may respond by adding new production facilities. This may cause the cost of producing electricity to increase and this cost increase will be passed on to consumers. Consumers may react to higher costs by decreasing their demand for electricity. Similarly, policies which influence the cost of production for supply sectors will eventually impact consumers who demand their products. The CIMS iteration between the supply and demand sectors was activated in order to create a realistic depiction of technology evolution in response to changing fuel prices.

Table 3.2 shows a set of action sliders that will provide an enhanced representation of the energy sector in QUEST 2.0. The sliders focus on emissions rather than efficiency and include energy supply sector actions.

Table 3-2. Recommended action sliders for revised QUEST 2.0.

Transportation Actions	**Residential Actions**	**Industry Actions**
Transportation priorities	Housing density	**Emissions Levels**
Vehicle occupancy	**Emissions Levels**	R&D spending
Emissions Levels		
Lifestyle Actions	**Labour Actions**	**Energy Supply Actions**
Diet	Workweek length	**Emissions Levels**
Energy & Water Use		
Shopping		**Commercial Actions**
Waste Generation		**Emissions Levels**

*Actions in bold font influence a direct input into the Energy Use Model's calculations. Other actions are indirectly incorporated through growth factors developed in other submodels (see Section 3.2).

Policy Type Selection

As defined in Section 2.2, three policy types are available in QUEST to encourage actions: market-based, information or regulatory instruments. In QUEST 1.0, the action selected by the user is fully achieved regardless of the policy type selected.[10] In other words, all policies are assumed to be equally effective (100%) at achieving the desired outcome. In the real world, policies have different levels of success in achieving outcomes as well as different costs for different sectors. Since an objective of the re-design of QUEST is to incorporate more detailed micro-economic cost estimates for the actions taken by the user, as well as more detailed information on technological evolution, it is important to explicitly represent the different impacts of the policy types available to the user. At the conclusion of the *Choose Policies* stage, the user has specified all of the inputs that QUEST requires to determine the level of energy consumption and corresponding GHG emissions for this decade of their scenario.

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[10] Although it does not impact the model's calculations, the choice of policy types can stimulate discussion when the game is used in a group setting. The user's choices of policies throughout the scenario is tabulated and compared to the style of governance that the user states that they prefer in the *Invent-a-Future* stage. This provides a "cognitive dissonance meter" measuring the distinction between how the user believes they would govern and how they actually implement actions.

Stage 3: View Consequences

Once the user has specified their actions for the decade, QUEST runs a series of integrated submodels customized to reflect the user's scenario inputs. The consequences (outputs) are then presented in a virtual newspaper containing headlines, graphs and maps that convey the significant impacts of the user's choices. The user then iterates through the process of selecting actions and viewing consequences for three additional decades.

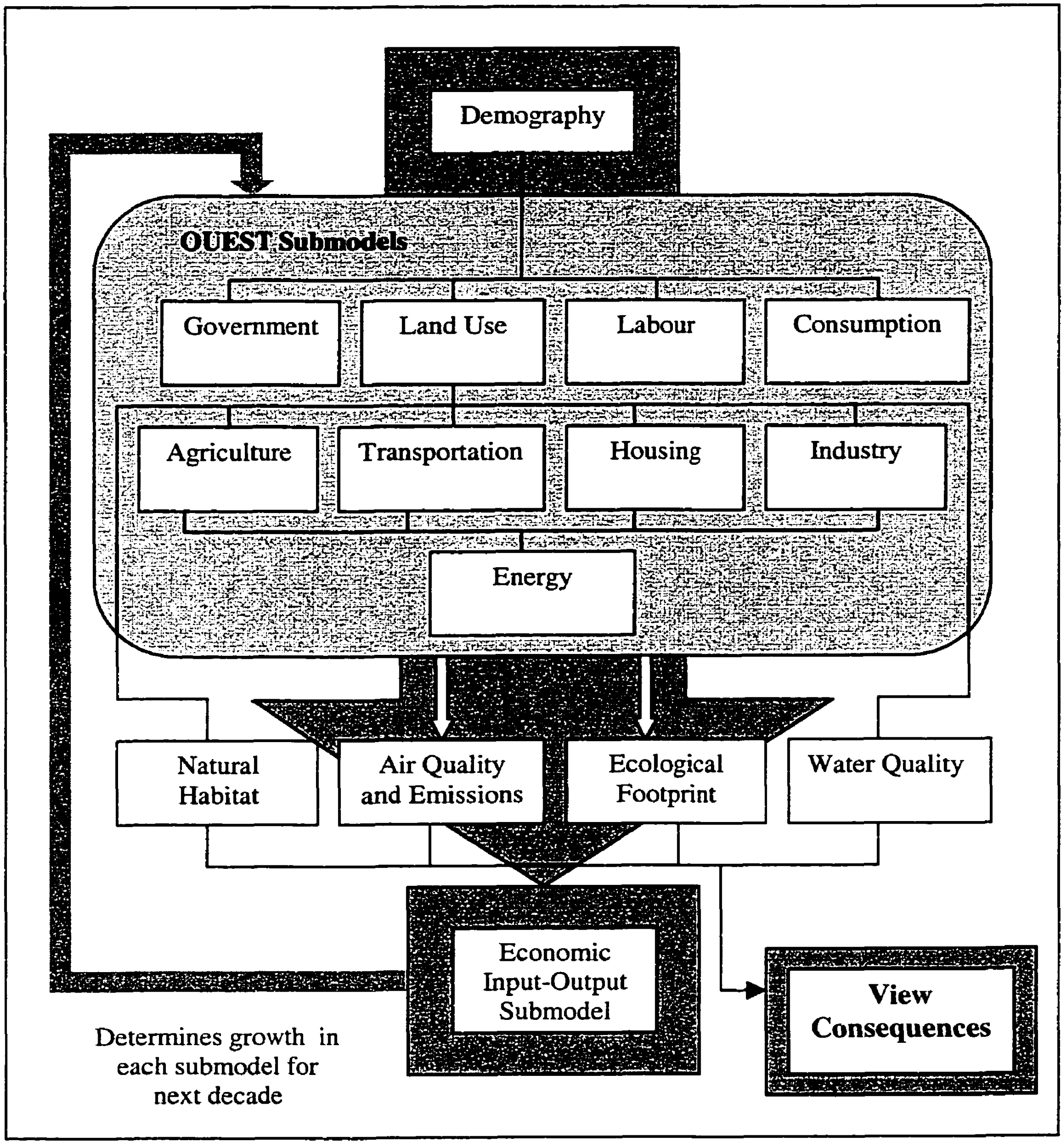
A detailed look at the QUEST Energy and Economic submodels is required in order to evaluate the methods used to calculate outputs related to energy and the economy and also to clarify precisely where CIMS can provide parameters to enhance QUEST. The Energy and Economic submodels are encompassed within the broader QUEST modelling framework. QUEST 1.0 model includes 15 different submodels (Fig. 3.3). The submodels function in a linear sequence; however, the submodels are highly interconnected both directly and indirectly (EST/SDRI, 2001). Direct interaction is when a parameter calculated in one submodel is used in another submodel's calculations. Indirect interaction occurs when the initiating submodel passes data to an intermediate model which subsequently affects another submodel directly. Each submodel requires input parameters from those above it in the hierarchy for its calculations.

QUEST Energy Use Submodel

The Energy submodel is near the bottom of Figure 3.3 indicating that it receives inputs from many other submodels. The Energy submodel calculates the energy consumption resulting from the actions implemented in the submodels above it. The outputs of the submodel are displayed in the *View Consequences* stage and include:

- Total energy use by sector (industry, transportation, commercial & residential)
- Total energy use by fuel type (coal, petroleum, biomass, natural gas, & electricity)
- Total energy use (economy-wide)

Figure 3-3. QUEST Submodel dependency structure.



*Derived from QUEST model documentation (EST/SDRI, 2001).

In QUEST 1.0, energy use is calculated based on the energy consumption in the previous decade multiplied by adjustment factors for economic growth, population growth, direct action slider settings and indirect adjustments resulting from actions in other submodels above energy use in the modelling hierarchy. The equations are as follows:

Eq'n 1: Industry

$$E_{SFt} = \sum_{c=1}^{c=6} E_{cFt}$$

$$E_{cFt} = E_{cF(t-1)} X (G_{GDP})_c XSld_{IEE}$$

Eq'n 2: Transportation

$$E_{SFt} = E_{SF(t-1)} X (G_{GDP})_s XSld_{TFE} XG_{km}$$

Eq'n 3: Residential

$$E_{SFt} = E_{SF(t-1)} XG_{POP} XSld_{HEE} XG_{hfoot} XSld_{HFM}$$

Eq'n 4: Commercial

$$E_{SFt} = E_{SF(t-1)} XG_{GDP} XSld_{IEE}$$

Eq'n 5: Total Energy Use

$$E_{TOTAL} = (E_{IND} + E_{TRAN} + E_{RES} + E_{COM}$$

where:

E = Energy use (GJ)

c = Industrial subsectors (1 = mining, 2 = manufacturing, 3 = construction, 4 = government, 5 = forestry, or 6 = agriculture)

S = Major economic sector (industrial, residential, transportation, or commercial)
F = fuel type (coal, petroleum, biomass, natural gas, or electricity)
t = decade
G_{GDP} = GDP by industrial sector, from Economic submodel
G_{POP} = Population growth factor = pop_n / pop_{n-1}, from Demographics submodel
G_{km} = Transportation growth factor = km_n / km_{n-1}, from Transportation submodel
G_{hfoot} = Housing footprint growth factor[11]

Sld_{IEE} = Industrial Energy Efficiency slider setting
Sld_{TFE} = Transportation Energy Efficiency slider setting
Sld_{HEE} = Household Energy Efficiency slider setting
Sld_{HFM} = Household Fuel Mix slider setting

The numerical value of each slider parameter (Sld) is dependent on the user's world view settings (which constrains the range of the value) and which of the three settings the user selected on that particular action slider in the *Choose Policies* stage. Over the four decades of policy choices, the user can move each of the four energy related policy sliders (Sld) to nine possible levels (baseline plus four decades in either direction, see Fig. 3.2). Each setting corresponds to a different multiplier value used in the calculation of energy demand. In QUEST 1.0 the numerical values of the Slider parameters are the same for a given world view and action setting, regardless of the policy type selected. These multipliers represent exogenous assumptions about changes in energy demand over time (time trend model).

In QUEST 2.0, these exogenously determined slider values are replaced with values endogenously calculated in CIMS based on its micro-economic responses. Because policy types can be modelled explicitly in CIMS, softlinking allows the parameter values associated with different action slider settings to vary in accordance with the policy type selected by the user. The QUEST user is therefore able to

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[11] This growth factor refers to the cumulative impact of a number of household consumption-related sliders in the model (shopping, proximity of food production, etc). This growth factor is intended to modify the energy consumption of the Residential sector to reflect changes in the embodied energy of many household products caused by the user's decisions. For instance, if the user decides that more food will be produced locally, less energy is required to transport it and this decrease is attributed to the residential sector.

differentiate between the outcomes of various policy types.

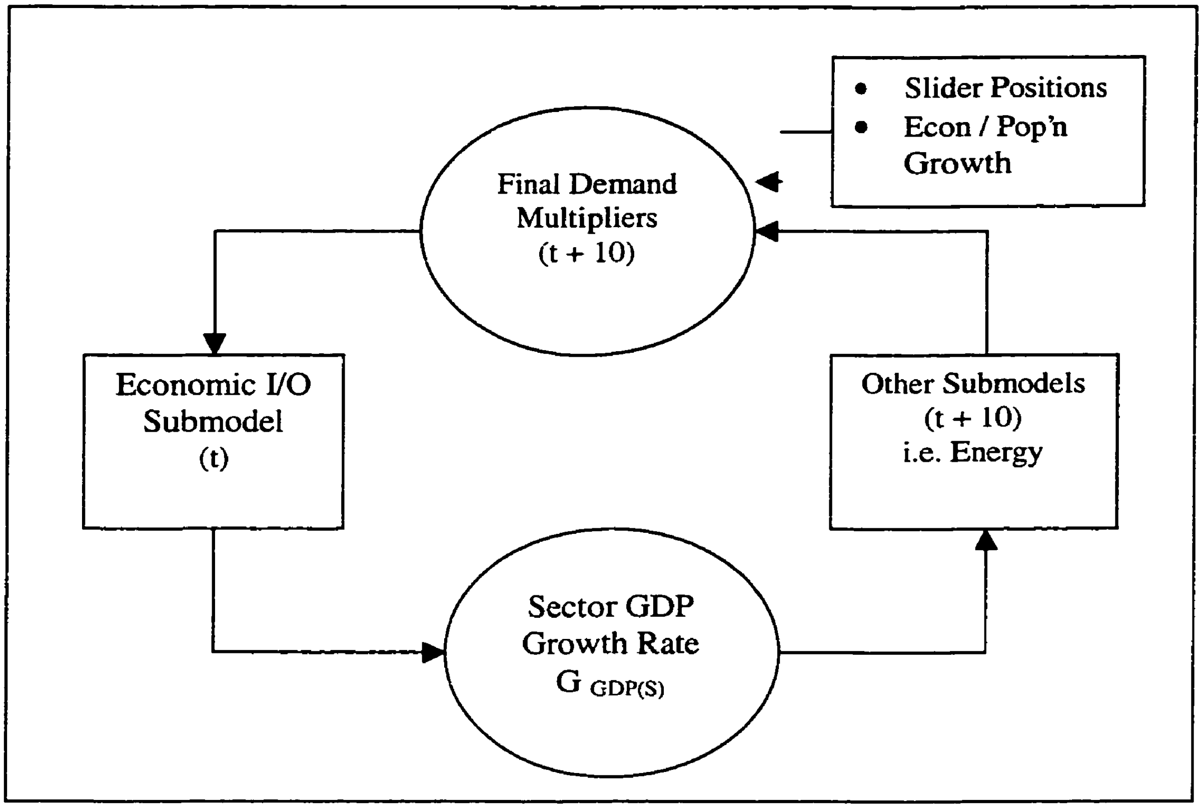
QUEST Economic Input-Output Submodel

The QUEST Economic Input-Output submodel calculates the change in sectoral GDP as a result of the user's choices. Because the GHG emissions and macro-economic indicators listed in Figure 3.1 are derived based on sectoral GDP, the Economic Input-Output submodel must run before these outputs can be calculated. I discuss these outputs following a description of the Economic Input-Output submodel.

As highlighted by its unique position in Fig. 3.3, the Economic Input-Output submodel in QUEST is a highly interconnected submodel that provides direct inputs to many submodels and indirectly affects all submodels via the various interactions. QUEST utilizes an input-output model to link sectors of the economy. The linkages are coefficients based on detailed study of the economy in the base year. A key weakness of this approach is that these coefficients remain static over time. Essentially, the input-output submodel in QUEST scales the demand level for commodities up or down depending on the user's inputs but then allocates demand for that commodity among the sectors that produce the commodity according to the proportion of total final demand provided by each sector in the base year. As a result, this method does not capture structural evolution of the economy.

The interaction between the Economic Input-Output submodel and the Energy submodel is depicted in Figure 3.4. The basis of the Economic Input-Output submodel is the 1990 provincial final demand matrix of commodities by economic sector (EST/SDRI, 2001). Each decade, the final demand measures in this table are scaled by specific Final Demand Multipliers to yield a user-modified final demand matrix for the following decade. There are three sources of Final Demand Multipliers. The population and economic growth multipliers are constants specified by the user's growth scenario selection in the *Invent-a-Future* stage.[12] Other Final Demand Multipliers are the result of calculations within specific submodels. For instance, the transportation submodel calculates a fuel demand per capita multiplier based on inputs to the transportation submodel. Finally, Final Demand Multipliers may be directly related to an action slider setting. The last two categories of Final Demand Multipliers are re-calculated each decade based on the user's choices in the *Choose Policies* stage.

Figure 3-4. Relationship between the Economic Input-Output submodel and other QUEST submodels.



The Economic Input-Output submodel scales the provincial final demand for commodities into the equivalent value of gross domestic product (GDP) for the Georgia Basin (GB) through a series of conversion calculations shown in Figure 3.5. Following modification of the coefficients in the provincial final demand matrix by the Final Demand Multipliers (Step 1), the coefficients are then multiplied by the 'D' matrix (Step

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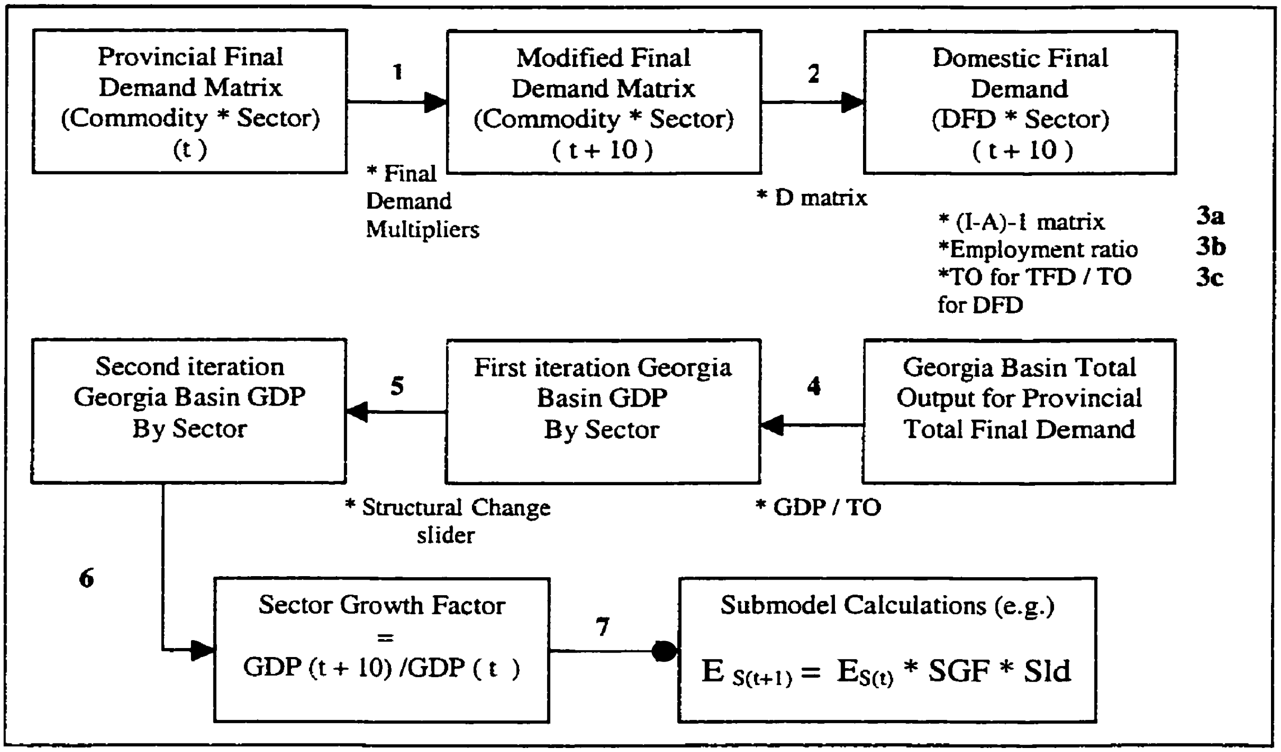
[12] The population growth multiplier is the ratio of total population in the second decade divided by total population in the first decade. The economic growth multiplier is the ratio of GDP in the second decade (as determined by converting the user-modified Final Demand Matrix) divided by GDP in the first decade.

2). The D matrix coefficients specify the percentage of total commodity output that comes from each economic sector in input-output tables. For example, 99.99% of the total amount of grain produced is from the agricultural sector and 0.01% is from the manufacturing sector. The D matrix is derived from information provided in the provincial Make matrix for the base year and the allocation of final demand to different sectors is static throughout the forty year QUEST scenario. Multiplication of the Final Demand Matrix by the 'D' matrix allocates the final demand for commodities among sectors of the economy according to these base year ratios.

Several calculations occur in Step 3 of Figure 3.5. Firstly, multiplication of domestic final demand by sector by the $(I-A)^{-1}$ matrix determines the total output (TO) from each sector required to meet domestic final demand (DFD). The $(I-A)^{-1}$ matrix contains the direct as well as indirect requirements of each industry needed to produce one dollar's worth of output. The remainder of the conversion calculations in Step 3 are based on ratios developed from the 1990 base year data and are necessary to convert total output into GDP. The employment ratio is simply the ratio of employment in the Georgia Basin to employment in the province in 1990. This scales the provincial data down to the level of the Georgia Basin. In Step 3c, the total output for each sector in the Georgia Basin is multiplied by the ratio of total output for total final demand over total output for domestic final demand. Total Final Demand differs from Domestic final demand in that it includes the demand for exports. Therefore, Step 3c increases the amount of output required from the economic sectors in the Georgia Basin in order to meet exports as well as domestic needs. In Step 4, total output is converted to GDP based on the 1990 ratio yielding the desired GDP by sector at the level of the Georgia Basin. In Step 5, the user's setting for the structural change slider is used to re-allocate GDP among industrial and service sectors. Again, endogenization of this step to reflect the expected impacts of the user's other actions in the model is desirable in future model refinements.

Figure 3-5. Series of Conversion Calculations to scale provincial demand for commodities to the level of the Georgia Basin and convert to GDP by sector.



Once GDP by sector is determined for the upcoming decade, GDP Sector Growth Factors (SGF) are calculated for each major economic sector (and industrial sub sector) in Step 6 as follows:

Eq'n 6: $$G_{GDP(s)} = \frac{GDP_{S(t+1)}}{GDP_{S(t)}}$$

where:

$G_{GDP(S)}$ = growth rate of sector GDP
S = Major economic sector (industrial, residential, transportation, or commercial)
t = decade

In the final step, the Economic Input-Output submodel passes the sector GDP growth factors to the other submodels to serve as inputs to the calculations of individual submodels' outputs for the next decade (see Equations 1-4 above). Once GDP for each Georgia Basin sector (GDP_S) has been determined for a decade, QUEST 1.0 calculates GHG and air pollutant emissions and various macro-economic indicators of the health of the economy.

Emissions

QUEST reports on emissions of greenhouse gases (CO_2, CH_4, N_2O and CFC's) and several sources of local air pollution (CO, NO_x, SO_x, and VOCs) by economic sector each decade. All emissions are based on the following equation:

Eq'n 7: $$Emission(tonnes) = GDP_t * \frac{emission(tonnes)}{GDP_{1990}} * Sld_{IPC}$$

where:

GDP_t = Total GDP for Georgia Basin in decade 't'

Sld $_{IPC}$ = Industrial Pollution control slider setting

This approach constrains emissions to rise at the same rate as GDP, countered by a user-specified adjustment for the Industrial Pollution control slider. Again, the numerical value of the Industrial Pollution control slider is the same for a given World View and action setting, regardless of the policy type selected. In reality, the ratio of emissions to growth in output changes over time, in response to efficiency improvements and fuel switching. Also, emissions of greenhouse gases such as CO_2, CH_4, and N_2O are proportional to the amount of fuel combusted and calculations for these gases would be more accurate if linked to the fuel consumption reported by the Energy Submodel. In QUEST 2.0, GHG emissions will be calculated by multiplying the amount of each fuel consumed (GJ) by the appropriate GHG emissions factor (tonnes GHG / GJ fuel).

Macro-economic Indicators

Based on the $GDP_{(s)}$, QUEST also reports on 5 indicators of the strength of the broader economy: jobs, total wages, total output, net exports, and average income. The formulas are:

Eq'n 8: $$Jobs_S = GDP_{S(t)} * \frac{employment_{1990}}{GDP_{1990}} * Sld_{LP} * Sld_{SC}$$

Eq'n 9: $$Wages = GDP_{S(t)} * \frac{labor\_income_{1990}}{GDP_{1990}}$$

Eq'n 10: $$TotalOutput_{GB} = GDP_{S(t)} * \frac{TotalOutput_{GB(1990)}}{GDP_{1990}}$$

Eq'n 11: $$NetExports_{S(t)} = TotalOutput_{GB} - TotalOutput_{forDFD}$$

Eq'n 12: $$AverageIncome = \frac{Wages_{S(t)}}{Jobs_{S(t)}}$$

where:

Sld_{LP} = Labour Productivity slider setting
Sld_{SC} = Structural Change slider setting
Total Output_{GB} = Total output from Georgia Basin including output for exports
$\text{Total Output}_{\text{for DFD}}$ = Total output for domestic final demand

The QUEST economic model was not developed in a general equilibrium framework and thus does not achieve closure between investment, production, consumption and the government's budgetary flow. Therefore, there is no endogenous alteration of the economy's structure. The coefficients in the D and $(I-A)^{-1}$ matrices are fixed at base year levels as are the various other ratios used to allocate demand to sectors of the Georgia Basin (see Fig. 3.5). Additionally, the user directly controls the allocation of GDP between industrial and service sectors. As a result, there is no endogenous recognition and equilibration of the links between the above macro-economic indicators and the consequences of the user's actions on the availability of capital and energy. Introducing endogenized structural change in QUEST would allow the calculations of the macro-economic indicators in Equations 8 through 12 to reflect the limited availability of capital, energy and labour, but that is not an objective for this study.

Costs

In QUEST 1.0, the energy and economic submodel outputs did not include estimates of the financial costs of greenhouse gas reduction actions. Estimates of the costs of actions should be provided in the *View Consequences* stage of QUEST 2.0 for two key purposes. Firstly, estimates of the costs of actions are certain to interest QUEST users. A limited pool of capital is available with which to accomplish the many desires of society and explicitly portraying the costs of the user's energy-related actions makes the required tradeoffs more apparent. Secondly, changes in the costs of energy services can impact various sectors of the economy differently leading to structural change in the economy. Therefore, estimates of the costs of actions for particular sectors serve as a logical starting point for endogenizing the effects of the structural change slider.

While it sounds like a relatively simple matter to tabulate the costs of an action, there is a range of opinions regarding what constitutes the appropriate estimate of costs. I will define three different methods for calculating costs and outline how each could be applied to QUEST 2.0. The three types of cost estimates are techno-economic costs, perceived private costs and expected resource costs.

Typically there are several technologies that have the ability to provide a particular energy service. Policies may be aimed at influencing consumers to switch from one technology to another. **Techno-economic costs** estimate the benefits or costs of an action by determining the net financial flows of the energy savings minus the equipment investment costs. This approach considers differences in the capital costs, operating, maintenance and energy costs between the technology mix existing prior to the action and afterwards and tends to yield relatively optimistic results regarding the net benefits of investments in energy efficiency. Proponents of the Economic Efficiency world view often utilize this type of cost estimate when arguing for the economic benefits of investing in energy efficient technologies. In seeking to portray the economic costs of the user's actions, QUEST may wish to utilize techno-economic costs because they represent the minimum cost estimates for the strict technological requirements of the scenario. They can be calculated with a relatively high degree of certainty as all of the components are tangible and are more easily supported by engineering evidence and market data.

However, although two technologies provide the same energy service, there may be differences in the quality of service, the associated risk of technology failure or unreliability, and the time required to obtain information regarding the technology. Furthermore, consumers have heterogeneous tastes and are not all likely to prefer the same technology attributes. When consumers have preferences for particular technology attributes, they may be willing to pay a premium, in excess of the market price, to secure the additional benefits that the particular technology provides. This premium is called *consumers' surplus*. When a policy limits the choice of technologies for consumers, the loss of consumers' surplus represents a perceived cost to consumers. For example, switching from a personal vehicle to public transit may entail loss of comfort, privacy or feelings of independence or freedom. Proponents of the Average Consumer world view are likely to argue that changes in consumers' surplus and financial cost, rather than just changes in financial cost, is the appropriate measure of benefits to consumers (Sutherland, 1996). **Perceived private costs** therefore include changes in consumers'surplus in addition to the techno-economic costs of the action. While techno-economic costs reflect fiscal net returns of an action, consumers' surplus reflects the perceived impact of the action on consumers. The magnitude of the perceived private costs is therefore useful as an indication of the level of public resistance that may be expected in response to policies designed to alter technology acquisition or use behaviour.

Both techno-economic and perceived private costs, measure the direct costs of actions on consumers and firms. These direct costs stimulate second-order effects (indirect effects) on the broader economy including changes in the structure of the economy, overall economic activity levels and many of the macro-economic indicators discussed in the previous section (e.g. levels of employment, exports /imports and wages). Estimates of these indirect effects are typically obtained from macro-economic models, integrated models that include micro-economic and macro-economic components. In order to determine these indirect costs, macro-economic models require estimates of the expected flows of capital that the action will stimulate. Techno-economic costs underestimate the actual expected flows of capital because they exclude real risks associated with new technologies (i.e. technology failure, unreliability). New technologies have a higher expectation of failure than proven technologies. Conversely, estimates of perceived private costs overestimate the expected flows of capital because they include intangible costs that are experienced by consumers but are not materialized as actual flows of money. A third cost estimate is therefore required. **Expected resource costs** are estimated as techno-economic costs plus the additional costs of premature technology replacement or repair weighted by probability of occurrence. The addition of expected resource cost estimates to QUEST enables future research to progress with endogenization of structural change and other macro-economic feedbacks if desired. This may be accomplished within QUEST itself or through continued collaboration with CIMS or another model with macro-economic modelling capabilities.

Stage 4: Review Scenario

At the end of four iterations between Stages 2 and 3, a summary of the entire 40-year scenario is displayed. The user then has the option of saving this scenario and replaying it with a different World Views or policy choices.

As a review, Table 3.3 summarizes the improvements that will be made in QUEST 2.0. Softlinking with CIMS allows some of these goals to be achieved. Those beyond the scope of this project are indicated.

Table 3-3. Summary of Enhancements for QUEST 2.0.

QUEST Stage	**Decisions**
Stage 1: Invent-a-Future	
A. Goals & Targets	Maintain the deterministic approach, no feedbacks
	Incorporate Fuel Prices
B. World Views	
Social Adaptation	Define quantitatively based on the Average Consumer and Economic Efficiency World Views
Technological Innovation	Define quantitatively using AEEI
Stage 2: Choose Policies	
Actions	Re-name efficiency sliders to focus on emissions
	Remove residential fuel-mix slider. Allow the emissions slider to indirectly control fuel mix.
	Replace user-controlled structural change with endogenous estimates*
	Add energy supply sectors in integrated system.
Policy	Model policy types and their outcomes explicitly.
Stage 3: View Consequences	
Energy	Link energy consumption changes to policy type
Emissions	Link emissions to fuel use rather than GDP
Economic	Report the techno-economic, perceived private and expected resource costs of actions
	Link the macro-economic indicators to the consequences of user's actions rather than the structural change slider*

*Represents a decision that is beyond the scope of this project but may be implemented by the QUEST modelling team in the future.

4. Methodology: Simulations with CIMS

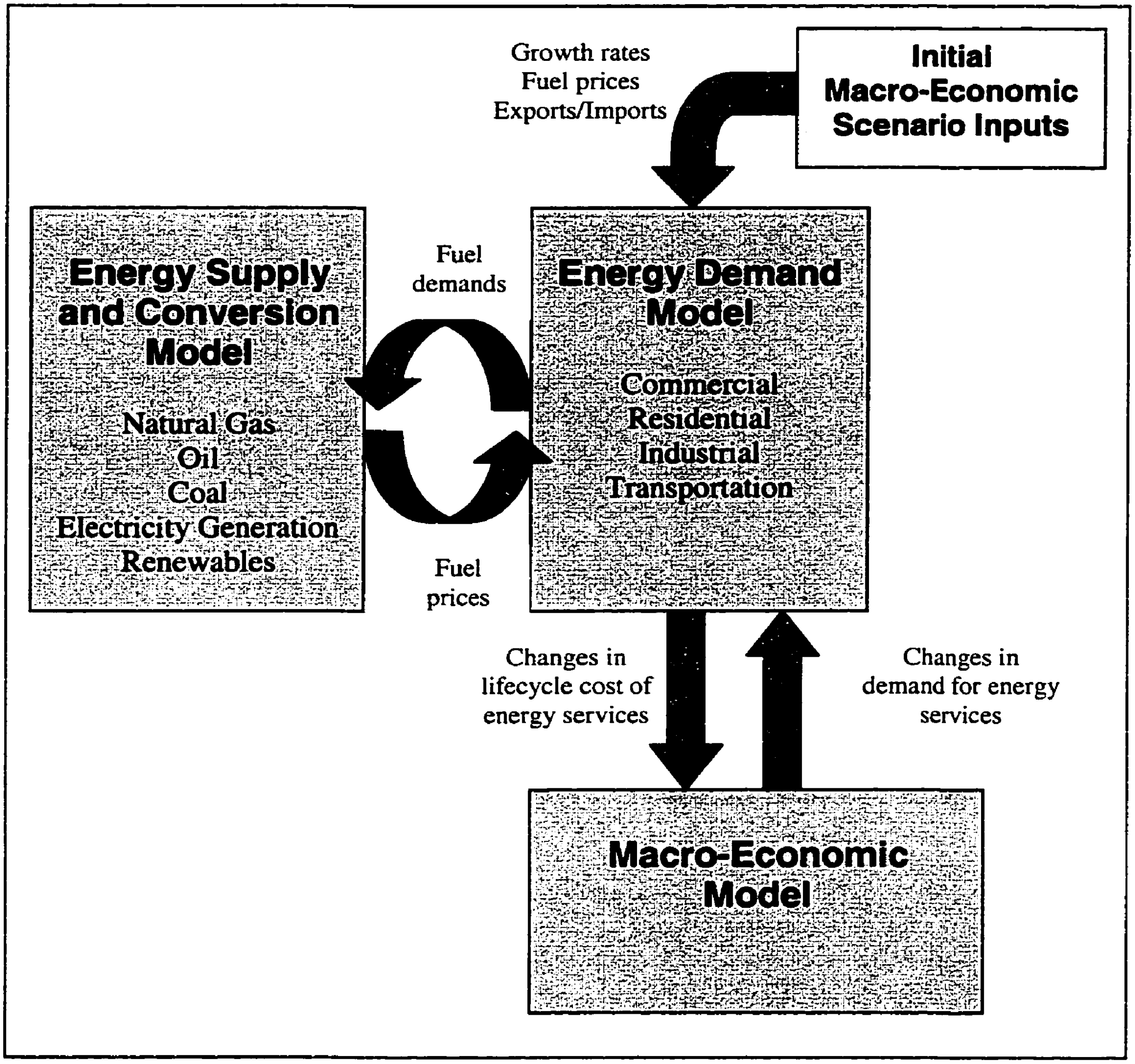
4.1 Generalized Methodology

A set of model runs were simulated in CIMS which reflect the energy policy choices available to the QUEST user and the two different Social Adaptation world view settings regarding how consumers respond to financial costs of technologies (see Section 3). The energy consumption, CO_2 equivalent emissions, and costs associated with these CIMS runs were converted to coefficients per unit of economic growth and summarized in a series of matrices. The coefficients in these matrices serve as parameter inputs for a spreadsheet model within QUEST that calculates the energy consumption, GHG emissions and costs of the user's scenarios. Parameter estimates for the Technological Innovation world view settings were defined based on the energy-economic literature and act as multipliers on the results from CIMS. The market penetration rates of technologies are reported for the scenarios modelled in CIMS to provide the desired information on technological evolution (Appendix E).

4.2 Energy-Economic Modelling in CIMS

Figure 4.1 shows the three primary components of CIMS. CIMS begins with an exogenous macro-economic scenario forecast that determines an initial fuel price forecast and specifies the demand for energy services over the scenario period. The Energy Demand Model determines the energy required to meet a forecasted demand for *energy services* in the residential, commercial, transportation and industrial sectors. Energy services are technological applications that consumers desire which require energy (e.g., vehicle kilometres of travel, lighting, space heating). The Energy Supply and Conversion Model determines which technologies will be used by the supply sectors to provide the energy required. The link between the Energy Demand Model and the Energy Supply and Conversion Model represents the relationship between the quantity of energy demand from the energy-demanding sectors, the cost of production for the supply and conversion sectors and the subsequent impact on the market price of energy. CIMS iterates between the Energy Demand and Supply components until price-equilibrium is achieved. The macro-economic feedback loop then represents the feedback effect of changes in the costs of energy services on the demand for these services and thus on the structure of the economy and overall economic growth.

Figure 4-1. Canadian Integrated Modelling System.



Macro-Economic Scenario Inputs

An exogenous forecast of the anticipated demand for energy services (preferably in physical units[13]) is required to initiate a simulation in CIMS. Forecasts of the demand for energy services are typically based on a macro-economic scenario including forecasts of population growth, industrial throughput and economic growth. Examples of driving variables used to forecast demand for energy services include area of floor space for the commercial sector, housing starts for the residential sector, and changes in throughput in the mining sector. From these variables it is possible to determine the demand for key energy services, such as lighting, heating or vehicle kilometres of travel. The growth of the four primary economic sectors (residential, commercial, industrial, transportation) relative to one another and the relative growth between industrial subsectors form the structural change assumption on which the simulation is based. Fuel price forecasts for the period of the scenario are also required as an input for the initial simulation of the Energy Demand Model. The Energy Supply and Conversion Model requires an estimate of the expected exports and imports of energy.

CIMS Energy Demand Model Structure

The Energy Demand Model of CIMS includes stand-alone models for the residential, commercial, industrial and transportation sectors.[14] The industrial sector is very detailed including 9 different subsectors. Energy Demand models exist for each province in Canada; therefore, results are available at the provincial and national levels. QUEST focuses on the Georgia Basin region of British Columbia; thus, only the CIMS models for this province were utilized.

Flow models are used to depict the structure and flows of energy for each industry

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[13] It is sometimes necessary to derive physical units from economic measures of growth such as GDP or Gross Output.

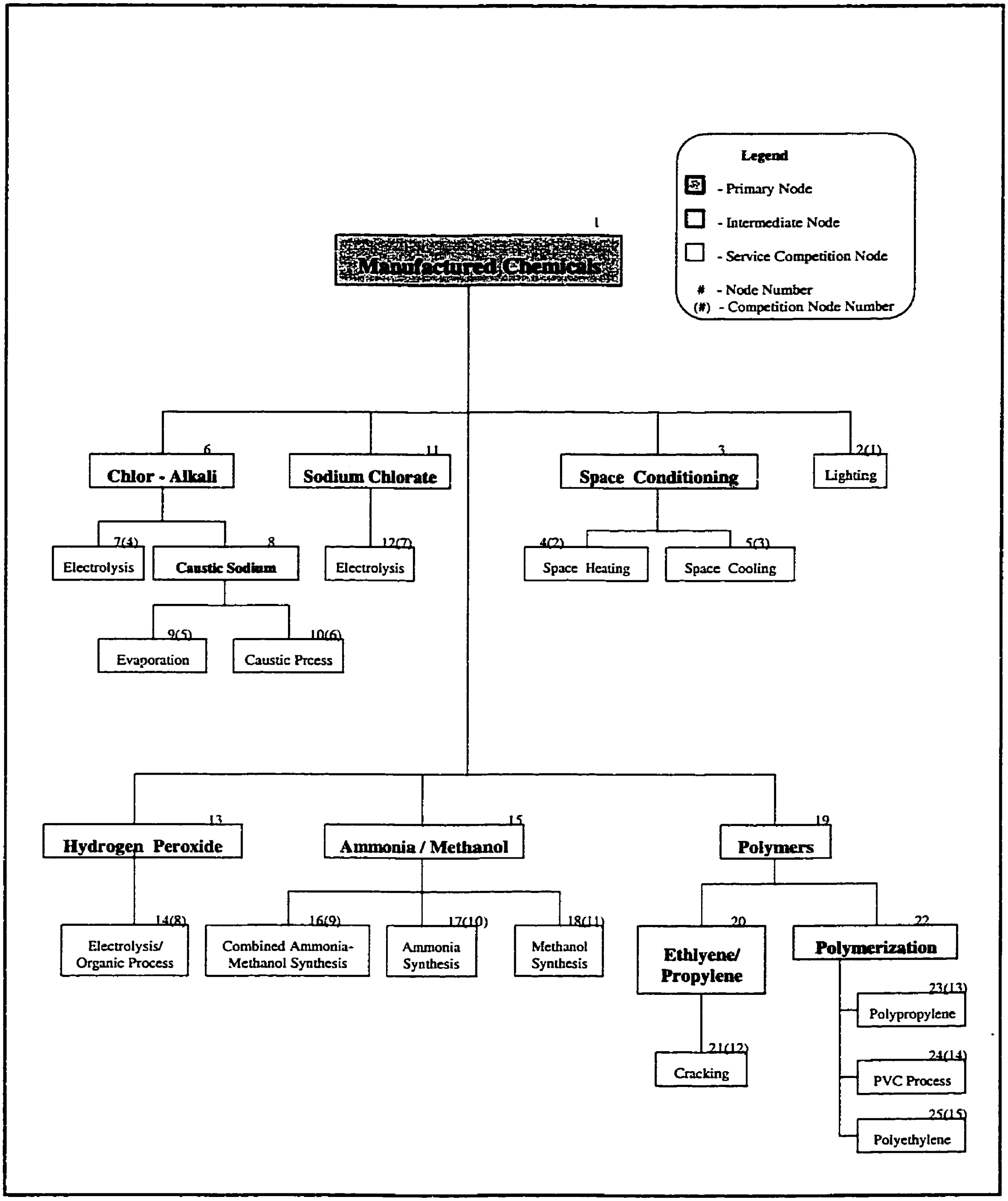
[14] The residential, commercial and industrial modules were previously operated in isolation as the Intra-Sectoral Technology Use Model (ISTUM). They have since been integrated into the CIMS framework. The transportation module is a new addition. For additional information on the modelling approach see Nyboer (1997).

represented by a demand model (Fig. 4.2 & Appendix A). The primary node of the flow model represents the key driving variable for overall energy service demand (e.g. demand for manufactured chemicals, houses or tonnes of mined ore). In order to meet this primary demand, demand is allocated to secondary nodes that represent services or products upon which the primary node depends. For example, the demand for manufactured chemicals is split among secondary nodes for chlor-alkali, sodium chlorate, hydrogen peroxide, ammonia / methanol and polymers in proportion to the amount of output required to meet demand in each of these categories. The level of output required at each node determines the amount of energy services, such as evaporation, electrolysis and cracking, which must be generated. The demand for these services is allocated down to individual technologies (e.g. evaporators, electrolysis cells) that are able to provide them. The base year allocation of energy demand from primary nodes down to specific technologies is based on real-world energy consumption data and knowledge of the technology mix used by the industry. Throughout the scenario period, the allocation ratios change over time in response to changes in the economy. For most primary and some secondary nodes changes to the allocation ratios over the scenario period are pre-determined based on the macro-economic forecast of structural and substructural change provided (or feedback from the macro feedback loop if it is activated). For most secondary and tertiary nodes, the model endogenously determines allocation ratios as a function of technology lifecycle cost. This process is described in the following section.

4.3 Modelling Sequence of the CIMS Energy Demand Model

The CIMS Energy Demand model simulates the evolution of technology stocks in five-year increments for the simulation period. There are five basic steps to this simulation: input growth scenario, retirement, retrofit, acquire new technology stocks, and calculate fuel use, emissions and cost outputs. Each of these steps is described in more detail below.

Figure 4-2. Energy Flow Model of the Chemical Products Industry.



Input Growth Scenario

A forecast of growth in demand for energy services is provided to the Energy Demand model. Individual technologies are explicitly represented in the Energy Demand module in terms of the quantity of energy service they can provide and their fuel requirements per unit of service output. Other technology attributes represented in the model include capital costs, operating and maintenance costs, lifespan, efficiency and emissions. The Energy Demand model determines the stock of each technology required to meet demand for energy services via a technology competition process.

Retirement

In each future simulation period, a portion of the base-year technology stock is retired as a function of age.[15] If the remaining technology stocks are insufficient to meet the demand for energy services, investment occurs to acquire additional technology stocks to meet the unsatisfied demand for energy services.

Retrofit

Following retirement, retrofit possibilities compete to upgrade the remaining technology stocks if the retrofit function is activated. This competition is controlled by the same parameters described in the following sections but excludes the capital costs of the existing technology stocks as these are sunk costs paid when the technology was initially purchased.

Technology Acquisition

Prospective technologies compete for a share of new investment primarily on the basis of their annualized life-cycle cost (LCC) for providing the desired energy service; however, CIMS is also behaviourally realistic and includes parameters to represent non-

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[15] Following normal retirement, if excess stock exists beyond what is required to meet forecasted growth in demand for energy services, an additional portion of stock is permanently retired.

financial factors known to influence consumers' purchasing decisions. The procedure by which the model acquires new technology stocks is set up to reflect as realistically as possible all of the decision-making criteria used by consumers. The annualized LCC estimates in CIMS are thus based on perceived private costs. CIMS relies on extensive industry consultation and market research to estimate consumer preferences. For existing technologies, data on actual consumer behaviour often exists and is referred to as 'revealed preference data'. For emerging technologies, firms and consumers must be surveyed to determine their likely preferences - referred to as 'stated preferences'. Because individuals' preferences differ, the technology competition is simulated probabilistically with financial costs as one of several factors that determine market share.

Five key model parameters influence how CIMS allocates new market share among competing technologies: (1) discount rates, (2) declining capital costs, (3) intangible cost adjustments, (4) cost variance, and (5) maximum / minimum market share constraint parameters. CIMS is typically operated in a deterministic manner (using the best-guess estimates for the values of these parameters to generate the most realistic forecasts of energy use possible) but the numerical values of these parameters can be varied to reflect different perspectives regarding how consumers make technology acquisition decisions. This allows CIMS to be used as an "if-then" tool to test different parameter values, especially where these values are highly uncertain as in the case of the world views. The function of each parameter is described here.

Discount Rates

Discounting is a technique that allows costs and benefits occurring at different points in time to be compared in terms of their present value. Because CIMS compares costs occurring at different points in time (i.e. life cycle costs), discount rates are applied in order to compare costs at a single point in time. The magnitude of the discount rate determines the relative preference that an individual shows for consumption in the present as opposed to consumption in the future. A high discount rate implies that the consumer prefers technologies with a lower initial capital cost to those that promise future financial savings due to energy efficiency. The most energy efficient technologies tend to have relatively higher capital costs; therefore, high discount rates "penalize" the future benefits promised by these technologies to account for the greater risk of technological failure, higher transaction costs, and loss of option value associated with new and unproven technologies. Because the CIMS competition is based on perceived private costs, high discount rates (20-50%) are used in order to represent these factors in consumer decision-making. The technology-specific discount rates are determined by surveying firms for the criteria they use when making investment decisions (Nyboer, 1997).

Declining Capital Costs

Emerging technologies often have high capital costs that decline over time due to economies of scale as production increases and induced learning. Asymptotic functions in CIMS cause the capital cost of new technologies to decline over time as a function of increasing market share. This influences the capital cost portion of the LCC calculation and increases the competitiveness of technologies as they become more common in the marketplace.

Intangible Cost Adjustments

When making purchases, consumers often exhibit preferences for certain technology attributes (qualities) that are unrelated to solely financial considerations. In CIMS, additional capital costs are added to technologies that lack preferred attributes in order to reflect the perceived costs that consumers associate with their use. The value of the intangible costs can be adjusted over time to reflect changing preferences among consumers. For example, consumer preference for personal vehicles may decline as road congestion increases.

Cost Variability and Market Share Allocation

The annualized LCC values represent a point estimate of average perceived private cost; however, individual consumers face different costs due to variability in fuel prices, distribution and installation costs, available information and personal preferences.

Due to this cost variability in the real world, a single technology rarely gains 100% of new market share. For this reason, the allocation of market share to technologies in the CIMS Energy Demand Model is probabilistic. The portion of the new market share that the "winning" technology receives is dependent on the size of the cost difference between it and the next preferred technology (Fig. 4.3). A logistic curve is used to represent how the variability in LCC affects the allocation of market share.

The user can adjust the cost variance parameter to change the slope of the logistic curve using an inverse power function. To derive the market share of a technology from the inverse power function in CIMS the equation is:

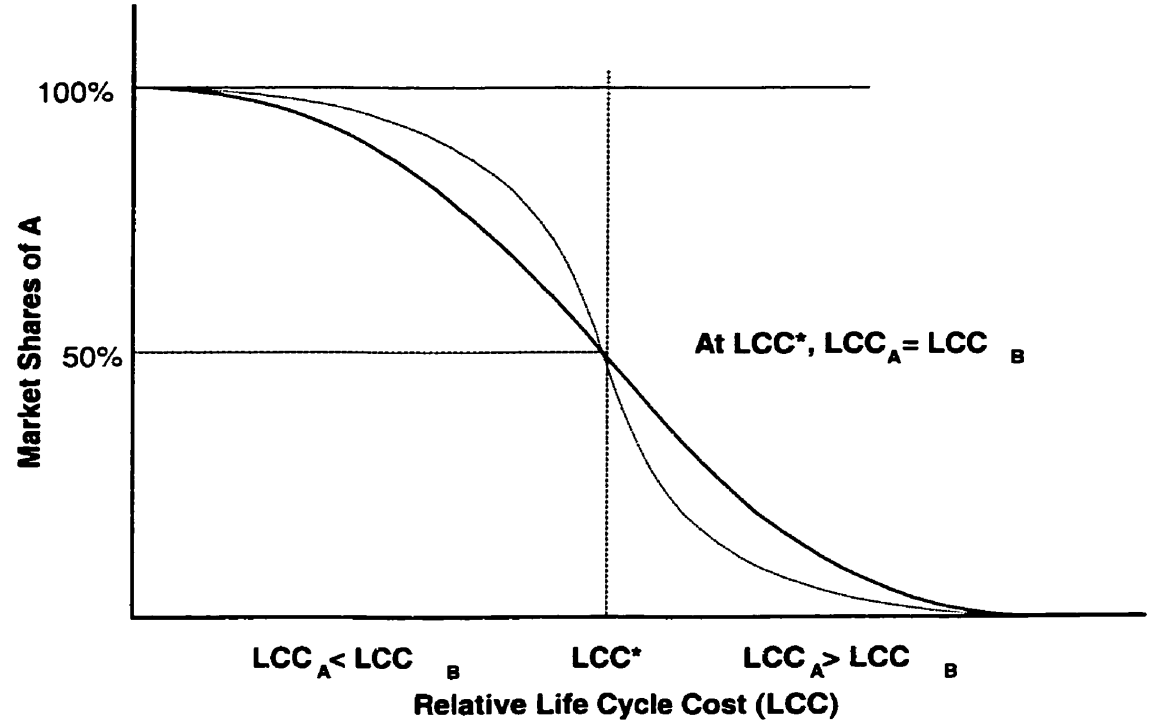
Eq'n 13: $$MS_k = LCC_k^{-n} \Big/ \sum_{k=1}^{v} LCC_k^{-n}$$

where:

MS_k = market share of technology k
LCC_k = annual life cycle cost of technology k
n = cost variance parameter
v = total number of technologies in a competition node.

When the value of a technology's cost variance parameter (n) is increased (variance is lower), the slope of the logistic curve is steeper and the cheapest technology gains a larger portion of market share. Decreasing the value of the cost variance parameter (increasing variance) decreases the slope of the logistic curve and the cheapest technology gains relatively less market share. Changing the value of the cost variance parameter is useful for reflecting how the relative perceived costs of technologies that perform the same energy service impact the market penetration of technologies.

Figure 4-3. Market Share Allocation in CIMS.



Maximum and Minimum Market Share

Occasionally in CIMS, the market penetration levels of specific technologies are constrained by specifying maximum and minimum market shares. These constraints can represent the existence of government regulations which limit technology use, or a lack of availability of the technology or fuel sources in different locations (e.g. access to natural gas is restricted to the extension of the grid). Different regulatory policies can be simulated using this feature of CIMS.

In CIMS, these five parameters determine the results of the technology competition and thus the pattern of technology evolution throughout the simulation period. Varying these parameter values in an internally consistent manner can simulate different world views regarding how consumers respond to financial costs.

Outputs of the Energy Demand Model

After each five-year simulation period of the Energy Demand Model, these outputs are calculated:

- Energy consumption by fuel type
- GHG Emissions (CO_2, CH_4 and N_2O)
- Costs
- Technology stocks

The demand for each fuel type (electricity, natural gas, oil and coal) serves as an input to the Energy Supply and Conversion Models.

Energy consumption by fuel type is calculated for each technology by multiplying the total stock of the technology by the energy required per unit of stock output (GJ / unit stock output). Energy consumption per unit stock is available in the CIMS technology database and is based on the fuel type required and the efficiency of the technology. Energy consumption by fuel type is then summed across all technologies.

Emissions of CO_2, CH_4 and N_2O are calculated for each technology by multiplying the energy consumption by fuel type for the technology by the corresponding emission coefficient of each fuel (tonnes emissions / GJ).[16] CH_4 and N_2O emissions are converted into CO_2 equivalents based on their relative greenhouse gas warming potentials. Total CO_2 equivalent emissions are then summed across all technologies.[17]

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[16] For this project, CIMS was also set up to calculate emissions of nitrous oxides (NO_x). Unlike CO_2 emissions, NO_x emissions are not proportional to the volume of fuel combusted but depend heavily on the operating conditions (e.g. temperature) of the technology. Therefore, the NO_x emissions estimates were deemed unreliable and are not reported here. Researchers are currently enhancing the ability of CIMS to model NO_x and other criteria air contaminants.

[17] CO_2 equivalent emissions are determined by converting the global warming potentials of CH_4 and N_2O into the equivalent amounts of CO_2. CH_4 and N_2O have global warming potentials of 21 and 310 times that of CO_2 respectively (EC, 1999).

In some instances, greenhouse gas emissions are not released from fuel combustion but rather result from a chemical reaction within the industrial process. These emissions are called *process emissions*. For example, CO_2 is released during the smelting of aluminium due to the reduction of Al_2O_3 and the oxidation of carbon anodes. As a result of this chemical reaction, approximately 1.6 tonnes of CO_2 are released for every tonne of aluminium without any associated fuel combustion (Nyboer & D'Abate, 2000). CIMS accounts for process emissions.

In CIMS, costs can be reported as the total cost of the scenario or the incremental cost of implementing a policy option above the costs of the business-as-usual (BAU) scenario. As discussed in Section 2, researchers hold different views regarding what constitutes the appropriate measure of policy costs. CIMS tabulates techno-economic, perceived private and expected resource cost estimates so that the QUEST user can determine for themselves which definition of costs they prefer. The three costing methodologies are described in the following sections.

Techno-Economic Costs

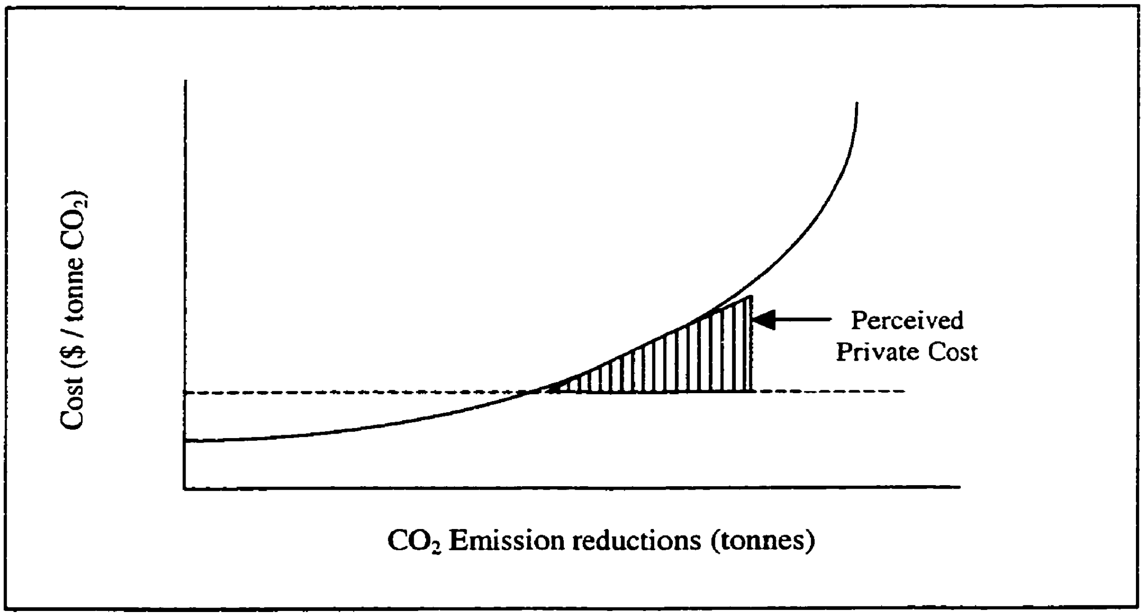
The techno-economic costs of the scenario are the sum of the capital costs, operating and maintenance costs and energy costs (excluding taxes) of all of the technology stocks. Energy costs are based on the amount of energy consumed per unit output by the technology multiplied by a fuel price forecast (or the modified fuel prices determined by the Energy Supply and Conversion Model). Because taxes are transfers between government and consumers, they are not included in the techno-economic costs. A social discount rate is used to discount techno-economic costs to the base year.

In CIMS, techno-economic costs include a *demand correction* to account for any loss of revenue experienced by the electricity sector in scenarios where the demand for electricity declines as the result of implementing a policy option. Unless lost revenue from sales decline is accounted for, the Electricity sector would otherwise show a financial benefit. The demand correction for the electricity sector is estimated by multiplying the difference in the amounts of electricity generation between the policy and the BAU by the average cost of electricity production in the BAU scenario.

Perceived Private Costs

Under certain conditions, CIMS can also be utilized to approximate perceived private costs. Perceived private costs include all techno-economic costs plus the additional costs of risk, transaction costs and loss of option value. Taxes are included in perceived private costs while infrastructure and administration costs are excluded.[18] The CIMS method of estimating perceived private costs requires the development of a cost curve. A cost curve is a plot of the emissions reduction achieved with a policy (relative to the BAU) against the perceived private cost per unit emission reduction (Fig. 4.4). Cost curves are created by conducting multiple CIMS runs at different tax levels for CO_2 emissions and determining the emissions reductions achieved at each tax level. If one assumes that consumers purchase energy efficient technologies and implement fuel switching up until the point where they perceive it to be less costly to simply pay the tax, the area under the cost curve then approximates the perceived private costs of the policy.

Figure 4-4. Example of Cost Curve Methodology for Determining Perceived Private Costs.



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[18] The taxes paid by the electricity sector are assumed to be passed on to the demand sectors and are added to the estimates of perceived private costs.

Expected Resource Costs

Techno-economic and perceived private costs represent two extremes of the spectrum of costs. Many proponents of techno-economic costs would be willing to accept that there are real risks associated with new technologies that create a real expectation of additional costs. Expected resource costs therefore include the techno-economic costs plus the "expected" costs associated with the probability of technology failure and loss of option value. It is extremely difficult to determine what is a “real” resource cost. In past research, a crude rule-of-thumb assumption has been made that 75% of the difference between the total perceived private welfare costs and the total techno-economic costs represents expected resource costs. This portion of the difference between the perceived private costs and the techno-economic is added to techno-economic costs to yield a rough estimate of the expected resource costs. Expected resource costs may also include government resource costs such as infrastructure, personnel and communications.

All of the outputs described in this section can be displayed in the *View Consequences* stage of QUEST. In CIMS, these Energy Demand Model outputs are not considered final until convergence is achieved between the Energy Demand Model and the Energy Supply and Conversion Model because changes in demand levels or the cost of production in the supply sectors may cause fuel prices to change from the original fuel price forecast.

4.4 Iteration with the Energy Supply and Conversion Models

CIMS simulates the process by which market equilibrium is reached through an iterative modelling sequence. The Energy Demand Model first calculates demand levels for fossil fuels and electricity based on the initial fuel price forecast. Then, the response of the supply sectors to this level of demand is simulated.[19] The supply sector adds or removes technology stocks in order to generate sufficient supply. As the supply sector

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[19] Demand for exports/imports of fossil fuels and electricity can be specified as an exogenous input.

alters its technology mix and output level, its cost of production may change resulting in adjustmnts to the initial fuel price forecast.[20]

The user sets a threshold for the amount of electricity or fossil fuel price change that can occur in a 5 year simulation period before the Energy Demand Model must be re-run with the altered prices. This threshold is typically set at a default value of 5%. In other words, CIMS assumes that a 5% change in electricity and fossil fuel prices is "tolerated" by the Energy Demand Model with no changes to the technology or fuel mix determined in the first iteration. If any fuel price change exceeds this threshold, the Energy Demand Model re-runs automatically for the same simulation period using the adjusted fuel prices. The iteration procedure continues until all fuel prices have converged below the pre-set threshold. The "converged" electricity and fossil fuel prices are used by the Energy Demand Model in the next 5-year simulation period, replacing the initial fuel price forecast. Once the Energy Supply and Convergence Model and the Energy Demand Model have achieved convergence, the final outputs are reported for the five-year simulation period.

The ability of CIMS to model the economy as an integrated unit provides a powerful and realistic policy exploration tool. It allows the development of policy-specific parameter values for the QUEST Energy submodel that incorporate micro-economic feedbacks to changes in fuel costs.

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[20] In this version of CIMS, changes in the cost of natural gas, oil and coal production do not affect the price of these commodities. This is due to the complexity of simultaneously adjusting prices for both resource availability and the cost of production. The supply curves are based on national demand levels including exports. The prices of these fossil fuels are found endogenously in a national market.

5. Data Inputs for Softlinking

5.1 Simulating Social Adaptation in CIMS

Key parameter values were varied in CIMS to allow the model to simulate Economic Efficiency and Average Consumer settings regarding how consumers respond to costs for the Social Adaptation world view slider in QUEST. For the Average Consumer setting, discounts rates were set at 35% and 50% in the industrial sector for process and auxiliary technologies respectively. Discount rates of 20%-35% were used in the residential and commercial sectors. The cost variances were set such that the lowest LCC technology gains 80% of new market share when its LCC is 10% lower than the next most expensive technology. These discount rates and cost variance parameters are based on market reports and interviews with industry and sector experts (Nyboer, 1997).

For the Economic Efficiency setting, the criteria for technology acquisition decisions were set to reflect decisions based almost exclusively on pure financial costs. Discount rates for all technologies were reduced to 10%. The cost variance parameter was increased such that the technology with the lowest lifecycle cost wins over 90% of new market share given a 10% difference in cost between it and the next most expensive technology.[21] Baseline runs (also called business-as-usual, BAU) were conducted for each world view setting with no policies being applied.

5.2 Simulating Technological Innovation

In order to determine rates of price-independent technological evolution, a literature search was conducted to identify estimates for the autonomous energy efficiency index. Results from top-down modelled revealed AEEI values ranging from 0-1.0 (Manne & Richels, 1994), 0.34 (Hogan & Jorgenson, 1992) to 0.3 (Grubler & Nakicenovic, 1997). Bottom-up values for AEEI were 1.5-3.0 (Williams, 1990) and 0.76

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[21] Additionally in the Economic Efficiency world, the retrofit option in CIMS was activated for the residential and commercial sectors to allow the model an even greater ability to respond to changes in the costs of fuels. This was a subjective decision meant to reflect the life-cycle cost approach attitude of the Economically Efficient consumer.

(Nystrom, 1997). An estimate from the Canadian Integrated Modelling System (CIMS), a hybrid model, for the aggregate Canadian economy was 0.7, although sector-specific estimates varied widely (Luciuk, 1999).

For each setting of the Technological Innovation World View slider, an appropriate estimate of the percentage change of energy use over time (with the price of energy and other inputs held constant) is applied as a multiplier in the energy demand and emissions calculations as a crude representation of the impact of technological innovation on the demand for energy. The low settings of the Technological Innovation world view slider is associated with a multiplier of .998 (low degree of autonomous energy efficiency improvements) on the energy, and emissions calculations in the QUEST 2.0 Energy submodel spreadsheet. The medium and high settings of these world view sliders are represented by multipliers which reduce energy consumption and emissions by 0.69% and 2.5% respectively from the values calculated using the coefficients in Section 6.10.

5.3 Simulating Policies in CIMS

Four policy options were modelled against each world view baseline. In order to model policies explicitly in CIMS, the QUEST policy types had to be clearly defined in terms of their type and aggressiveness. The policies modelled in CIMS are examples of the three basic policy types described in Section 2.2. Table 5.1 summarizes the policy runs.

Table 5-1. Policy Options Modelled in CIMS.

Policy Option	Average Consumer	Economic Efficiency
Business-as-Usual	No change from BAU	No change from BAU
Info Campaign	\$40 /tonne price of CO_2	\$40 /tonne price of CO_2
Low Tax	\$75/tonne CO_2	\$75/tonne CO_2
High Tax	\$225/tonne CO_2	\$225/tonne CO_2
Regulation	Least-CO_2 technology	Least-CO_2 technology

The market-based mechanism is a carbon tax. The tax is implemented beginning in the year 2001 and continues until 2030. Two levels of aggressiveness were simulated. The Low Tax policy option is a $75 / tonne tax on CO_2 equivalent emissions. The High Tax policy option is a $225 / tonne tax on CO_2 equivalent emissions. The information campaign was subjectively defined as policy that yields a $40 / tonne implicit price on carbon emissions. The regulatory policy is a strict government rule that the technology that omits the least CO_2 be adopted at each competition node.

Some sector-specific modifications were necessary to make the Regulatory policy option more realistic. For instance, some industrial technologies do not generate direct CO_2 emissions but depend on steam from boilers or cogenerators that do generate CO_2 emissions. In such cases, the regulation was set to force adoption of the technology with the lowest steam requirement. In the commercial sector, the regulatory policy option was modified to account for the large percentage of electricity consuming technologies. In CIMS, the winner-take-all function for lowest CO_2 on competition nodes at which all technologies consume electricity will allocate equal market shares to each technology, regardless of its electric efficiency. This results in large increases in electricity consumption, which is obviously not the objective of the regulation. Therefore, minimum market shares of 25% were set for the most efficient refrigerators, plug loads, and for solar water heating applications (based on natural gas). The competition was hard-wired such that no natural gas technologies were allowed to compete for heating, ventilation, and air conditioning services based on the assumption that on average in British Columbia electricity has lower emissions than natural gas due to the high percentage of hydro-electric resources.[22] Also, a generic shell type was modelled for all HVAC systems and one efficiency level each is modelled for natural gas and electricity HVAC systems. As a result, there is considerable untapped potential in the commercial sector for reductions in electricity and natural gas demand through building shell improvements that decrease the demand for space heating and through increased technological efficiency.

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[22] Future modelling should explore the different strategy required if incremental investment in electricity generation uses natural gas.

In the transportation sector, the regulatory policy option mandates that hydrogen fuel cell vehicles replace gasoline powered vehicles at the rate of vehicle retirement (15 year lifespan) starting in the year 2005, such that by the year the 2020 hydrogen fuel cell vehicles win 100% of new market share for personal vehicles. The winner-take-all for lowest CO_2 function is not used for the transportation sector as this method allocates market share equally between electric and fuel cell vehicles. In reality, it is likely that society will select one or the other of the two technologies due to the large infrastructure investments required for this type of fuel switching. For the purposes of this demonstration, the fuel cell future was selected.

The transportation model is very sensitive to the capital costs of vehicles and their fuel consumption. The capital costs for all vehicle types except the electric hybrid and the fuel cell are from Murphy (2000). These costs represent categories of vehicles. The electric hybrid cost is set at the current subsidized cost that is perceived by customers in the market (Table 5.2). The actual cost of producing electric hybrid vehicles is roughly $50,000 at present. The transportation model will therefore slightly underestimate the full costs to society because it excludes the subsidy. The intangible cost factors applied in the model are a percentage of the capital costs of the technologies (Murphy, 2000).

Table 5-2. Transportation model assumptions.

Vehicle Type	Fuel Efficiency (GJ / km)	Capital Cost ($)	Intangible Cost (% of cap cost)	Declining Cap Cost	Lowest Achievable Cost
Ultra Efficiency, Gas	0.0017	17,367	40	0.95	676,445
Low Efficiency, Gas	0.0052	24,517	-15	1.00	-343,238
High Efficiency, Propane	0.0022	26,111	80	0.96	2,030,391
High Efficiency, 'Diesel	0.0032	25,821	39	1.00	1,032,840
Electric	0.0013	54,607	63	0.60	2,096,909
Electric Hybrid	0.00263	30,900	26	0.57	475,551
Fuel Cell	0.0035	125,679	0	0.24	30,163

Declining capital cost functions were applied to new vehicles such that capital costs decline as a function of market share. The declining capital cost values shown in

Table 5.2 show the percentage of the original capital cost that is used in the LCC calculation when the technology has achieved 50% of new market share. This is the lowest capital cost achievable in the model as the DCC function is set here to asymptote at 50% of market share. The capital cost of the fuel cell vehicles was set such that with the full effect of the declining capital cost function, the capital cost applied in the model would be $7,000 greater than the Ultra Efficient gasoline vehicle. This is based on estimates provided to the Transportation Issue Table of the National Climate Change Process (LEL, 1999). Because fuel cell vehicles only penetrate in the Regulatory policy option in which technology costs do not influence market penetration, the intangible cost parameter has no effect and was eliminated to make cost calculations more straightforward.

5.4 Macro-Economic Scenario Inputs

Both world view baselines and all policy options are based on the same forecast of energy service demand and fuel prices. For each scenario, the energy service demands are fixed at these levels; however, the technologies and energy required to provide these services vary according to the decision-making criteria specified by the QUEST user and the policy option applied. The CIMS runs were conducted based on the energy service growth forecast in physical units shown for British Columbia in Table 5.3. These physical measures were derived by EMRG from a set of macro-economic assumptions in Canada's Emissions Outlook: An Update (AMG, 1999, see Table 5.4).[23] CIMS generally uses physical measures of growth because they are more closely linked to changes in energy services. However, because macro-economic forecasters often provide economic growth in terms of value, the CIMS user must convert the value units into units of physical service. Sometimes this works well, but in other cases substructural changes and changes in product quality can result in the physical and value measures changing at different rates. The user must be careful to anticipate such possibilities.

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[23] Note that GDP is presented net of inflation.

Table 5-3. Physical Growth Forecast of Energy Service Demand for British Columbia.

Sector	Units	1995	2000	2010	2020	2030
Industrial						
Chemical Products	10^6 tonnes	1.2	1.2	1.5	1.9	2.3
Coal Mining	10^6 tonnes	24.4	25.3	28.1	32.7	38.1
Industrial Minerals	10^6 tonnes	2.0	2.0	2.3	2.6	3.1
Metals	10^6 tonnes	0.6	0.6	1.0	1.4	2.0
Mining	10^6 tonnes	0.6	0.6	0.7	0.8	0.9
Pulp & Paper	10^6 tonnes	2.5	2.4	2.5	2.6	2.7
Other Manufacturing	GDP ($1986 billions)	5.8	6.7	8.0	9.7	11.4
Commercial	10^6 m2 floor space	65.8	73.5	90.7	101.6	113.0
Residential	10^6 households	1.5	1.7	1.6	1.9	2.4
Transportation	10^9 (km travelled)	811.6	698.5	803.1	911.9	1,038.4
Electricity Supply	PJ	216.9	248.2	283.3	324.9	324.9

Table 5-4. Macro-economic assumptions associated with physical growth forecast for British Columbia.

Sector	1995	2000	2010	2020	2030
GDP $1986 billions					
Commercial & Public Admin	38.0	41.7	51.9	62.3	72.6
Total Industrial	16.3	16.5	20.2	24.7	28.8
Total Economy	70.0	77.3	96.9	116.8	136.6
Industrial Gross Output $1986 billions					
Pulp & Paper	8.4	7.7	9.4	11.1	12.9
Chemical	0.4	0.4	0.5	0.7	0.8
Iron & Steel	0.00	0.00	0.00	0.01	0.01
Smelting & Refining	1.2	1.0	1.4	1.9	2.3
Mining	4.2	5.1	5.8	6.5	7.2
Other Manufacturing	13.7	16.4	20.7	26.2	31.0
Construction	12.3	11.2	13.8	17.2	20.2
Forestry	3.5	3.1	3.8	4.5	5.2
Cement	0.1	0.1	0.2	0.2	0.2
Petroleum Refining	1.6	1.5	1.7	1.9	2.1
Total Industrial G.O.	45.4	46.5	57.2	70.2	81.9
Population '000,000					
Individuals	3.9	4.1	4.5	4.9	5.3

*The macroeconomic forecast provided only extended from 1995 to 2020 therefore the values for 2030 are extrapolated.

Forecasted British Columbia fuel prices from the CEOU (AMG, 1999) are listed in Table 5.5. Electricity price is subsequently determined endogenously by CIMS depending on the level of demand from the energy demand sectors and changes to the cost of production (see Section 4.4).

Table 5-5. Fuel price forecast in $/GJ for British Columbia.

Fuel	Sector	1995	2000	2010	2020	2030
Natural Gas	Industry	1.9	1.6	1.7	1.7	1.7
	Residential	4.9	5.6	5.8	5.8	5.8
	Commercial	4.7	5.3	5.5	5.5	5.5
	Transportation	15.0	15.6	15.3	15.2	15.2
Electricity	Industry	10.5	10.5	10.5	10.1	10.1
	Residential	19.5	19.5	19.5	18.8	18.8
	Commercial	14.1	14.1	14.2	13.9	13.9
Dist Oil	Industry	10.3	11.3	10.9	10.8	10.8
	Residential	10.1	10.0	9.6	9.6	9.6
	Commercial	10.1	9.4	9.0	9.0	9.0
Liquid Petroleum Gas	Commercial	11.2	11.0	10.5	10.4	10.4
Petroleum Coke	Industry	2.5	2.5	2.4	2.3	2.3
LS & HS Residual	Industry	3.6	3.7	3.3	3.3	3.3
Coke & Coal	Industry	2.5	2.5	2.4	2.3	2.3
Methanol	Transportation	33.8	35.4	34.5	34.3	34.3
Ethanol	Transportation	25.6	26.8	26.1	25.9	25.9
Diesel	Transportation	13.7	14.5	14.1	14.0	14.0
Gasoline	Transportation	17.1	17.8	17.4	17.3	17.3
Propane	Transportation	11.2	11.0	10.5	10.4	10.4
Hydrogen	Transportation	52.8	55.2	53.8	53.5	53.5

5.5 Consistency of Modelling Scope and Timing

Because the scope of this project is the Georgia Basin region, the CIMS results now generated at the provincial level had to be converted to coefficients per unit of GDP. The results are then scaled to the level of the Georgia Basin by multiplying these coefficients by Georgia Basin GDP in QUEST's calculation of outputs (see Section 3). The provincial CIMS also includes some sectors of British Columbia's economy that do not have a significant presence in the Georgia Basin. Table 5.6 compares the sectors available in CIMS with those found in the Georgia Basin. Only energy demand sectors that have a significant presence in the Georgia Basin are included in the calculations of outputs used to derive the coefficients.[24] The Industrial category in Section 6 therefore includes chemical products, other manufacturing, industrial minerals and pulp and paper. A fuller description of the CIMS industrial subsector models is available from the flow models in Appendix A.

Table 5-6. Comparison of CIMS sectors with Georgia Basin.

CIMS Demand Sectors	**Georgia Basin Demand Sectors**
Residential	X
Commercial	X
Transportation	X
Industrial	X
Chemical Products	X
Coal Mining	
Industrial Minerals	X
Iron & Steel	
Metal Mining	
Non-Metal Mining	
Other Manufacturing	X
Paper	X
CIMS Supply Models	**Georgia Basin**
Electricity	X
Natural Gas Extraction	
Petroleum Refining	

The provincial scale of the current CIMS data affects the treatment of electricity. Most electricity generation is located outside of the Georgia Basin region. Because demand for electricity, and thus electricity price, are determined at the provincial level, this sector was treated differently than the demand sectors. In order to model electricity demand at the provincial level, CIMS was run including all of the sectors in British Columbia. Thus, electricity price changes from the Energy Supply and Conversion Model are generated based on total provincial demand. The electricity results presented in Section 6 therefore include electricity demand from sectors outside of the Georgia Basin but were adjusted afterward to reflect the share of electricity demand that comes only from the Georgia Basin. Petroleum refining and natural gas extraction are primarily

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[24] Some coal mining is present on Vancouver Island however its energy consumption was not large enough to merit inclusion.

located outside the Georgia Basin and emissions from these supply sectors are excluded from this analysis.

Scenarios in CIMS and QUEST also cover slightly different time periods. QUEST scenarios extend to 2040 while CIMS scenarios run from 1995 to 2030. CIMS results must be extrapolated to provide results to QUEST for 2040.

Other discrepancies between the two models arise because the softlinking approach places practical limits on the number of QUEST choices that can be explicitly represented in CIMS. QUEST provides the user with an immense amount and frequency of choices. For instance, QUEST allows the user to maintain the BAU, increase or decrease each action slider every decade and also to alter the policy type every decade. Additionally, the QUEST user can apply policies to some sectors and not others. This results in a large number of possible parameter combinations and it would be onerous to model each one in CIMS. The following simplifications were made in CIMS for this research: (1) only one policy type was applied over the scenario period (2) one level of aggressiveness was applied over the entire scenario[25] and (3) policies were applied to all sectors of the economy, which was modelled as an integrated system.

5.6 Calculation of Coefficients

The variety of choices in QUEST includes different growth and structural change scenarios. The CIMS runs were all based on a single growth and structural change scenario (Table 5.3). In order for the results demonstrated in this paper to be extrapolated to the full range of scenarios available in QUEST, coefficients of CIMS outputs per unit of economic growth were developed for each world view baseline and policy option using

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[25] The QUEST modelling option to increase emissions was not simulated in CIMS. QUEST is re-structuring their action to sliders to reflect real trade-offs that consumers make. For example, while an individual is unlikely to decide to increase GHG emissions, they may decide that they would prefer a larger vehicle with increased storage space and safety over a very fuel-efficient vehicle. When these action sliders are fully defined, CIMS will be able to model these choices explicitly. In the meantime, the user has the choice to maintain the BAU or decrease emissions only.

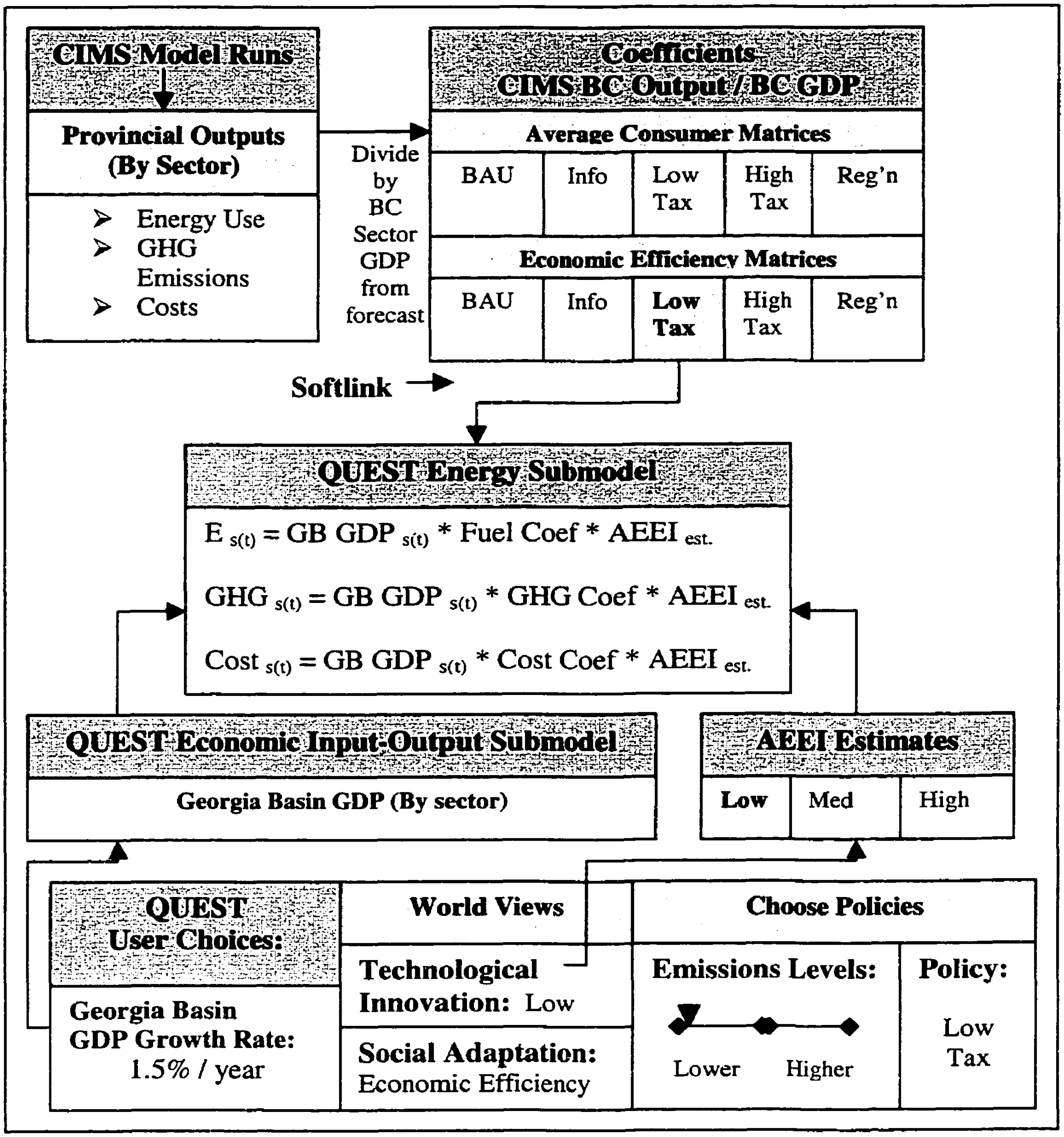
the economic measures of growth in Table 5.4 as the denominator (Fig. 5.1). In QUEST, the calculation of fuel consumption and the mechanism for modelling structural change are linked to changes in GDP (see Fig. 3.5). Therefore, coefficients of CIMS output per unit GDP allow the QUEST user's other structural change and economic growth scenario choices to adjust energy consumption, GHG emissions and costs accordingly. The CIMS coefficient values encompass the world view, action and policy type, selected by the user in a single value. They also reflect the micro-economic feedbacks in the CIMS model. The coefficients are summarized in a series of matrices (by world view / policy type / sector / and decade) and embedded in the Energy submodel within QUEST. The Energy submodel is a simple spreadsheet model. Once the user has selected a model route (World View, Georgia Basin growth scenario and various actions), the spreadsheet accesses the corresponding matrix and inserts the correct coefficient into the equation for fuel use, emissions or costs. For example, the fuel consumption coefficient replaces the last two terms of Equations 1 through 4 in Section 3.

The macro-economic forecast in Table 5.4 does not specifically provide GDP for each of the sectors in the Georgia Basin. Table 5.7 outlines which measure in Table 5.4 was used as the denominator (growth measure) in the coefficients for each sector in QUEST. Care must be taken in QUEST to multiply these coefficients by the same measure of growth as the denominator.

Table 5-7. Comparison of CIMS sectors with Georgia Basin.

QUEST Sectors	Coefficient Denominator
Residential	Total Economy GDP
Commercial	Commercial & Public Admin GDP
Transportation	Industrial GDP
Industrial	
Chemical Products	Chemical GDP
Industrial Minerals	Cement GDP
Other Manufacturing	Other Manufacturing GDP
Pulp & Paper	Pulp & Paper GDP
Electricity	Total Economy GDP

Figure 5-1. Softlinking Data Inputs to QUEST Energy Submodel.



Because no GDP values were provided specifically for the electricity and residential sectors, the total economy GDP was used as the denominator. Since the demand for electricity generation is a function of the energy services required by all of the demand sectors this is a reasonable assumption. To derive GDP for the industrial subsectors from Table 5.4, each sector's percentage of total industrial gross output was multiplied by Total Industrial GDP.[26] For the transportation sector, the industrial GDP was more closely correlated with the physical increase in VKT modelled in CIMS; therefore, this value was used as the denominator. Alternatively, the assumption could be made that growth in physical output is equivalent to growth in GDP and QUEST could simply utilize the coefficients based on physical units in the denominator in its equations for calculation energy consumption. Coefficients based on economic growth are presented in Appendix F-G.

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[26] Ideally, each industrial sector's percentage of GDP would be utilized instead of Gross Output but these data were not available. Gross Output is the sum of all goods and services produced by a sector in a year. It does not eliminate intermediate goods or by-products and thus there may be some double-counting. GDP is the value of the goods and services and eliminates the possibility of double-counting.

6. Results and Discussion

This chapter presents a comparison of the emissions, fuel consumption, market penetration of technologies and costs of the different policy options for each sector by the year 2030. The year 2030 was selected because it is the final year of the CIMS simulations and represents the full extent of the actions available to the user.[27] The results are shown for the province of BC but include only the sectors present in the Georgia Basin. In Section 6.10, these results are converted to coefficients that are used to scale the results to the Georgia Basin region.

6.1 *Integrated Results for Total Economy*

The CO_2 emissions for the total economy follow the predicted pattern with emissions from the Average Consumer world exceeding those of the Economic Efficiency world for all policy options (Fig. 6.1).[28] Emissions in each world decline as the cost of emitting CO_2 increases. The Regulatory policy option achieves the largest reductions, cutting CO_2 emissions by more than 50%.

Table 6.1 shows the consumption of major fuels in the economy under each policy option. Reduced consumption of fossil fuels (refined petroleum products (RPP) and natural gas) is responsible for the emissions reductions in Figure 6.1. Electricity consumption increases as the cost of CO_2 emissions increases because the electricity generation sector is also shifting towards energy sources with very low levels of greenhouse gas emissions, primarily hydroelectric. In the Regulatory scenario, which requires that the least-CO_2 technology be utilized, electricity consumption increases by 53% and 114% in the Average Consumer and Economic Efficiency worlds respectively.

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[27] Results will be presented to 2040 in QUEST; however, these must be extrapolated in the QUEST Energy Submodel from the results presented here as CIMS simulations extend only to 2030. Results for 2000, 2010 and 2020 are shown in the appendices.

[28] All emissions are presented as CO_2 equivalents including CH_4 and N_2O emissions. Emissions in the Regulatory policy option are equal for the Average Consumer and Economic Efficiency worlds because regulatory compliance is assumed.

Figure 6-1. Comparison of annual CO2 emissions from the Total Economy under different policy options in 2030.

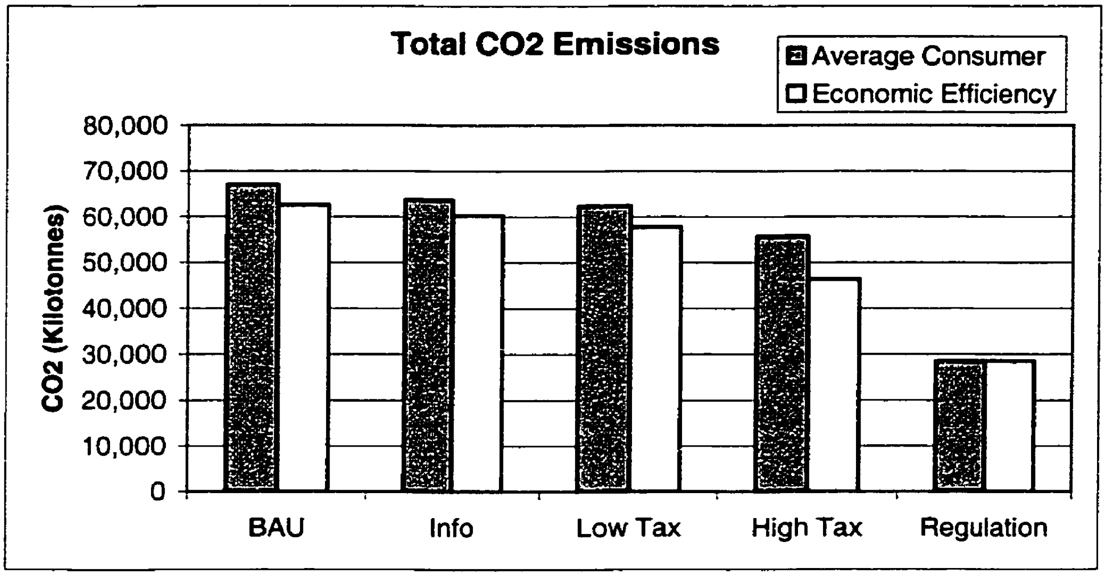

Table 6-1. Comparison of Total End-Use Energy Consumption of Major Fuels (PJ) in 2030 under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
RPP	552 47%	531 46%	526 46%	511 46%	515 45%	500 45%	491 46%	468 49%	295 40%
Nat Gas	367 31%	349 30%	335 29%	245 22%	429 38%	401 36%	366 34%	191 20%	43 6%
Elec	265 22%	274 24%	283 25%	346 31%	189 17%	201 18%	216 20%	303 31%	406 55%
Total	**1,183** 100%	**1,154** 100%	**1,145** 100%	**1,102** 100%	**1,133** 100%	**1,103** 100%	**1,072** 100%	**962** 100%	**744** 100%

Table 6.2 shows the contribution of each primary sector of the economy to overall emissions in the Georgia Basin. The transportation sector is responsible for over half of total greenhouse gas emissions in each policy option and composes an increasing percentage of total emissions as tax levels on CO_2 are increased, which means that reductions are more cost-effective in other sectors.

Table 6-2. Contribution of each primary sector to Total Economy CO_2 emissions in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Commercial	5.9%	5.9%	5.6%	4.5%	7.5%	7.1%	6.5%	3.0%	1.5%
Industry	18.1%	17.7%	17.8%	16.1%	18.0%	18.4%	19.0%	17.2%	12.9%
Residential	9.1%	8.5%	7.8%	6.0%	11.4%	10.6%	9.0%	4.8%	6.7%
Transportation	58.9%	59.9%	60.8%	66.5%	60.0%	60.6%	62.0%	73.8%	76.7%
Electricity	8.0%	8.0%	8.0%	6.9%	3.2%	3.4%	3.4%	1.3%	2.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The percentage of total emission reductions achieved by each sector is shown in Table 6.3 for each policy option. The sources of the emissions reductions are dependent on the Social Adaptation world view setting and the specific policy option selected. The following sections take a closer look at the GHG emissions and fuel consumption in each sector of the economy.

Table 6-3. Contribution of each primary sector to Total Economy emission reductions.

	Average Consumer			Economic Efficiency			
	Info	L.Tax	H.Tax	Info	L.Tax	H.Tax	Reg'n
Commercial	6.7%	9.5%	12.8%	19.5%	20.0%	20.5%	9.1%
Industry	26.5%	22.4%	27.7%	8.1%	5.7%	20.4%	21.9%
Residential	20.2%	25.9%	24.3%	31.3%	38.9%	30.1%	10.9%
Transportation	39.3%	33.7%	21.6%	43.1%	35.5%	20.6%	45.8%
Electricity	7.3%	8.6%	13.6%	-1.9%	0.0%	8.4%	12.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

*Regulatory reductions are calculated relative to Average Consumer BAU here.

6.2 Transportation Sector

The transportation sector plays a pivotal role in reducing overall CO_2 emissions (Table 6.3) although its relative share of emission reductions declines as the CO_2 tax increases. Transportation sector emissions follow a predictable pattern and are consistent with what one expects given the assumptions for the world views (Fig. 6.2). The Average Consumer world emissions are greater than in the Economic Efficiency world for all policy options. Under both world views, the transportation CO_2 emissions decrease as the tax on CO_2 emissions is increased. Table 6.4 shows that the emission reductions achieved in the market-based policy options are due to improvements in the fuel efficiency of gasoline vehicles as no fuel switching is apparent. Gasoline remains the predominant fuel type in all of these policy options. In the Regulatory policy option, drastic CO_2 emission reductions of 45% and 42% from the Average Consumer and Economic Efficiency baselines respectively are achieved through switching to hydrogen fuel cell vehicles.

Figure 6-2. Comparison of CO2 emissions from the Transportation sector under different policy options in 2030.

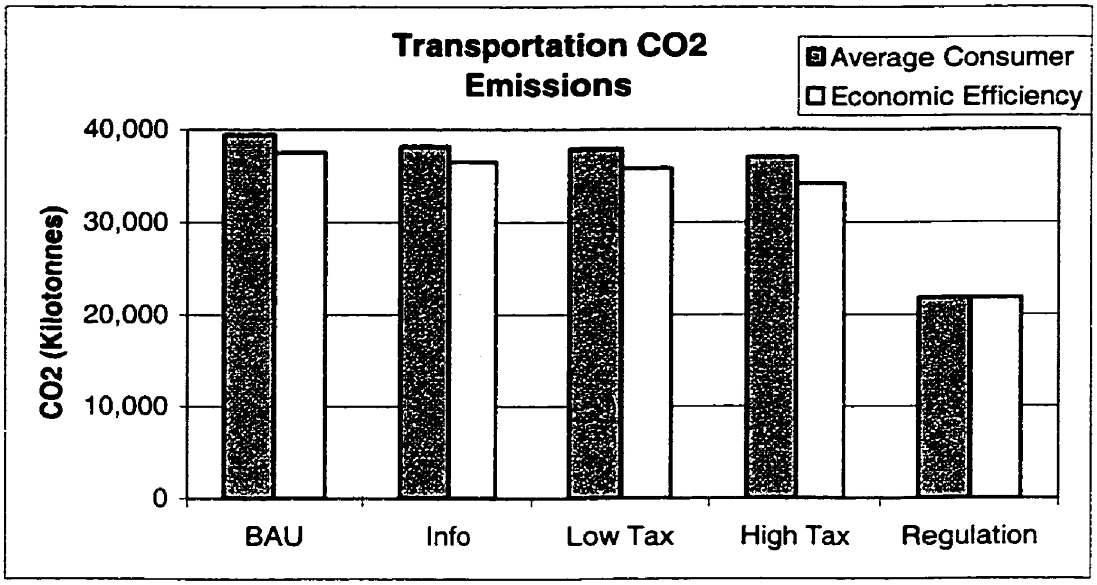

Table 6-4. Fuel consumption (PJ) in the Transportation sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
RPP	540.3 99.6%	522.4 99.6%	518.7 99.6%	506.2 99.6%	513.7 99.7%	499.4 99.7%	489.6 99.7%	466.8 99.7%	293.9 99.5%
Nat Gas	1.1 0.2%	0.8 0.2%	0.9 0.2%	1.0 0.2%	0.4 0.1%	0.4 0.1%	0.4 0.1%	0.4 0.1%	0.4 0.1%
Elec	1.1 0.2%	1.1 0.2%	1.1 0.2%	1.1 0.2%	1.1 0.2%	1.1 0.2%	1.1 0.2%	1.1 0.2%	1.1 0.4%
Total	542.4 100.0%	524.3 100.0%	520.6 100.0%	508.2 100.0%	515.2 100.0%	500.9 100.0%	491.1 100.0%	468.3 100.0%	295.4 100.0%

These transportation sector results are based on a version of the CIMS transportation model that relies heavily on exogenous assumptions regarding mode splits and technology shares.[29] The technology competitions occurring endogenously in the model are purchases of new cars and trucks (Murphy, 2000). The percentage of total kilometres traveled by alternative modes (buses, cycling, walking, personal vehicles, freight, airplane or marine), and the allocation of new market share among other technologies at each competition node over time are set exogenously. The magnitude of gasoline consumption in the Regulatory policy option (294 GJ), where gasoline-fuelled cars and trucks are eliminated from the market, is indicative of the proportion of CO_2 emissions which are essentially unresponsive to policy-induced price change in the transportation model (primarily from freight, air, rail and marine). This portion represents 54.4% and 57.2% of the total gasoline consumption of the Average Consumer and Economic Efficiency baselines respectively. The transportation sector results for the non-regulatory policy options therefore underestimate the full technical potential of the sector for emissions reductions.

In contrast, the Regulatory policy option may overestimate the potential emission reductions of switching to hydrogen fuel cell vehicles because it does not account for CO_2 emissions potentially associated with the production of hydrogen fuel. The amount of CO_2 emitted during production is dependent on the hydrogen source. Hydrogen can currently be derived from gasoline, methanol, natural gas or electrolysis, in some cases on board the vehicle and in others in production plants. The associated greenhouse gas emissions are highly dependent on the fuel source and method of conversion (Jensen & Ross, 2000).

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[29] The transportation sector has since been revised to endogenously model mode switching (personal vehicles, transit, biking and walking), choices between High Occupancy vehicles and Single Occupancy vehicles and to separate the freight component of transportation from the personal transportation sector. See working paper " Costing Greenhouse Gas Abatement in Canadian Transportation: Probing the Uncertainties" (Murphy & Jaccard, 2001).

The market penetration of various vehicle categories in Table 6.5 further explains the CO_2 emission results. In the Info policy option of the Average Consumer world, low efficiency gasoline vehicles lose market share to electric hybrid vehicles. As the cost of CO_2 emissions is increased further in the Low Tax and High Tax policy options, an ultra efficient gasoline vehicle also gains increased market share at the expense of traditional low efficiency vehicles.

Table 6-5. Allocation of new market share among personal transportation technologies under different policy options in 2030 (% new market share).

Technology	Efficiency	Average Consumer				Economic Efficiency				
		BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Auto, New										
Gas	Ultra	32	29	31	39	74	81	86	95	0
Gas	Low	20	16	14	10	25	19	14	4	0
Propane	High	0	0	0	0	0	0	0	0	0
Diesel	High	1	1	1	1	0	0	0	0	0
Electric		0	0	0	0	0	0	0	0	0
Elec Hybrid		47	54	54	50	0	0	0	0	0
Fuel Cell		0	0	0	0	0	0	0	0	100
Truck New										
Gas	Ultra	51	32	33	39	75	81	85	94	0
Gas	Low	31	17	16	11	25	19	15	6	0
Propane	High	0	0	0	0	0	0	0	0	0
Diesel	High	1	1	1	1	0	0	0	0	0
Electric		0	0	0	0	0	0	0	0	0
Elec Hybrid		16	50	50	49	0	0	0	0	0
Fuel Cell		0	0	0	0	0	0	0	0	100

Under the Economic Efficiency world view, the ultra efficient gasoline vehicle dominates the market, receiving 95% of new market share under the High Tax policy option. The exclusion of the electric hybrid from the Economic Efficiency world is explained by detailed comparison of the fuel efficiency, costs and declining capital costs parameters assumed for electric hybrid and ultra efficient cars (Table 5.2).

In the Average Consumer world, electric hybrids initially have slightly lower capital costs (approx. $22,192) than the ultra efficient class of vehicles (above $23,098). Incorporating energy costs (at a $40 cost for CO_2) into the LCC calculation does not alter their relative costs. As the tax on CO_2 increases to $75 / tonne CO_2, energy costs gain increasing importance in the LCC calculation and the ultra efficiency gas vehicle class (which is more fuel efficient on average than the hybrid) gains market share. In the Economic Efficiency world, the fuel cost savings associated with the ultra efficient gasoline vehicle weigh even more heavily in the LCC algorithm due to the low discount rate and thus it gains market share at the exclusion of the electric hybrid.

In CIMS, modelling a regulatory future based on electric vehicles would result in the same emission estimates as Figure 6.2. The indirect emissions associated with increased electricity generation for electric vehicles must be weighed against the CO_2 emissions associated with hydrogen production for fuel cells before determining which strategy is more appropriate to a sustainable future in the Georgia Basin. A key question is whether growth in demand for electricity will be met with natural gas-fired generation or if some of the province's renewable potential will dominate – large hydro, small hydro, biomass.

6.3 Total Industrial Sector

The aggregate industrial CO_2 emissions follow the predicted pattern with the Economic Efficiency world showing lower emissions than the Average Consumer world and emissions in both worlds declining as the tax on CO_2 emissions increases (Fig. 6.3). The Info and Low Tax policy options yield modest emissions reductions compared to the High Tax and Regulatory policy options. The industrial sector is able to generate emissions reductions of approximately 26% under the High Taxes and up to 70% under the Regulatory policy option.

Table 6.6 shows the contribution of each Georgia Basin industry subsector to aggregate industrial sector emissions. Other Manufacturing subsector is responsible for the largest percentage of total CO_2 emissions in the baseline, Info and Low Tax scenarios. Under the High Tax policy options, the Pulp and Paper subsector composes the largest percentage. Both the Chemicals and Industrial Minerals subsectors compose a much larger proportion of the total emissions in the Regulatory option compared to the market-based options indicating that the technological potential of these sectors for reducing emissions is relatively small compared to Pulp and Paper and Other Manufacturing.

Figure 6-3. Comparison of CO2 emissions from the Aggregate Industrial sector under different policy options in 2030.

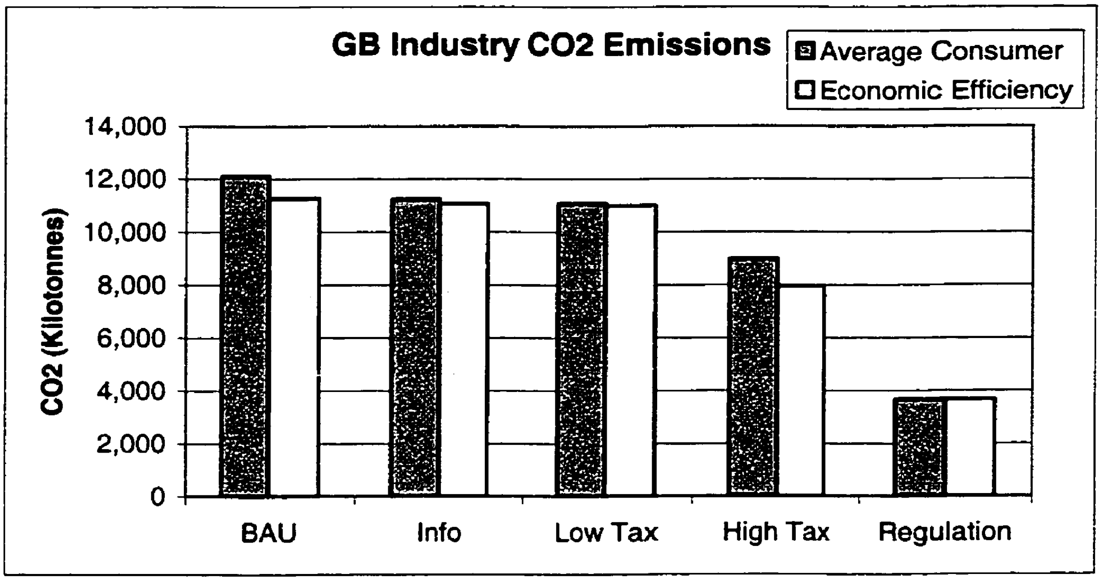


Table 6-6. Contribution of each primary sector to Aggregate Industrial CO_2 emissions in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
Chemicals	5.8%	6.1%	6.2%	7.4%	6.0%	6.0%	6.0%	8.1%	17.3%
Ind. Minerals	21.2%	20.8%	20.7%	25.2%	20.3%	20.3%	20.4%	28.1%	48.2%
Oth. Man.	44.8%	43.2%	43.2%	33.1%	42.8%	43.3%	43.3%	27.3%	14.5%
Pulp & Paper	28.3%	29.9%	29.9%	34.3%	31.0%	30.4%	30.3%	36.5%	19.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

*Regulatory percentages are calculated relative to the Average Consumer BAU.

The relative contribution of each subsector to total industrial emission reductions is shown in Table 6.7. In the Average Consumer world, Other Manufacturing is consistently responsible for over 60% of the reductions. In the Economic Efficiency world, Pulp and Paper is responsible for approximately 60% of emission reductions in the Info and Low Tax policy options but drops to 17.7% in the High Tax policy option where Other Manufacturing yields 80% of total reductions.

Table 6-7. Contribution of each industrial subsector to Aggregate Industrial emission reductions.

	Average Consumer			Economic Efficiency			
	Info	L. Tax	H. Tax	Info	L. Tax	H. Tax	Reg'n
Chemicals	1.0%	1.3%	0.9%	3.8%	4.1%	0.8%	0.7%
Ind. Minerals	26.5%	26.7%	9.9%	18.6%	15.0%	1.5%	9.5%
Oth. Man.	65.1%	61.3%	78.4%	14.1%	21.8%	80.0%	58.0%
Pulp & Paper	7.3%	10.7%	10.8%	63.4%	59.1%	17.7%	31.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

*Regulatory percentages are calculated relative to the Average Consumer BAU.

Other Manufacturing

Table 6.6 shows that Other Manufacturing produces the largest proportion of greenhouse gas emissions from among the industrial subsectors located in the Georgia Basin for all policy options except the High Tax and Regulatory scenarios. In the Average Consumer world, this sector is responsible for the majority of the emissions reductions as tax levels are increased (Table 6.7). In the Economic Efficiency world, Other Manufacturing tends to contribute less to overall emission reductions with the exception of the High Tax scenario where it is responsible for 80% of total industrial sector reductions.

Figure 6.4 shows the emissions associated with this sector under the various policy options. The Economic Efficiency World has lower overall emissions than the Average World for all policy options (Fig. 6.4). CO_2 emissions decrease under both world views as the tax on CO_2 increases but the declines are moderate for the Info and Low Tax policy options. Substantial emissions reductions are only achieved under the High Tax and Regulation policy options.

The High Tax policy options show large CO_2 reductions because of strong fuel switching from natural gas to electricity (Table 6.8). Electricity doubles and nearly triples its market share in the Average Consumer and Economic Efficiency High Tax policy options respectively. This drastic increase occurs because at a cost of $225 / tonne CO_2 emissions it becomes economic to use electricity for direct process heating applications (Appendix E). New building shells, with HVAC systems heated by only electricity also increase market share (Appendix E). In the Regulatory policy option, these electricity-based technologies penetrate to an even greater extent.

Figure 6-4. Comparison of CO2 emissions from the Other Manufacturing sector under different policy options in 2030.

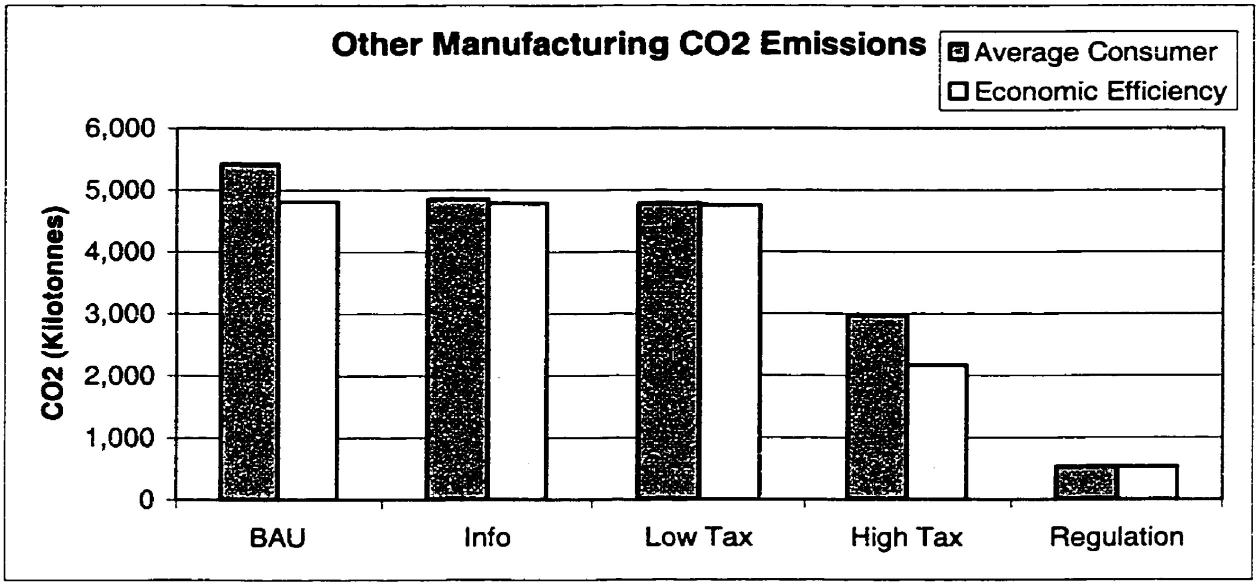


Table 6-8. Fuel consumption (PJ) in the Other Manufacturing subsector under different policy options in 2030.

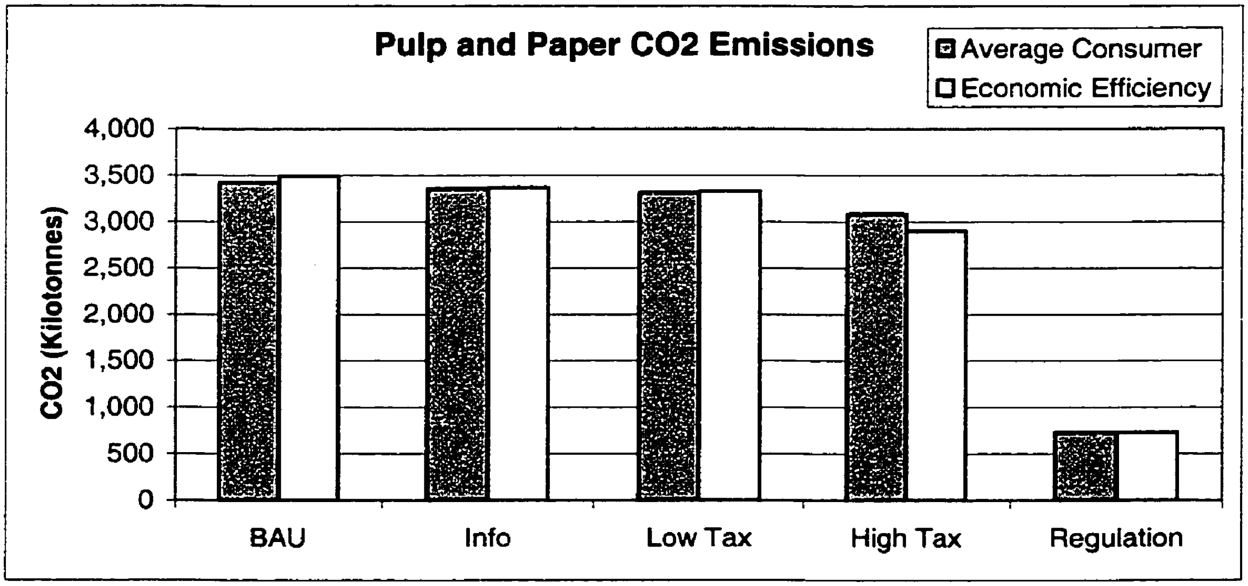
	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Elec	27.0 18.0%	27.1 17.9%	27.8 18.4%	57.0 39.1%	26.5 17.4%	26.4 17.5%	26.4 17.5%	68.9 48.6%	100.6 71.9%
Nat Gas	101.2 67.5%	92.0 60.7%	91.6 60.6%	56.7 38.9%	96.8 63.7%	96.2 63.6%	95.6 63.4%	42.3 29.8%	8.7 6.2%
Oil	5.8 3.9%	3.7 2.4%	3.0 2.0%	1.4 0.9%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Coal	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Pet Coke	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Biomass	15.9 10.6%	28.7 19.0%	28.9 19.1%	30.5 21.0%	28.7 18.9%	28.7 18.9%	28.7 19.0%	30.5 21.5%	30.5 21.8%
Total	150.0 100.0%	151.6 100.0%	151.2 100.0%	145.6 100.0%	152.0 100.0%	151.4 100.0%	150.7 100.0%	141.7 100.0%	139.9 100.0%

Pulp and Paper

The Pulp and Paper subsector is the second largest industrial producer of greenhouse gas emissions in the Georgia Basin, constituting approximately 30% of the industrial sector emissions (Table 6.6). In the Average Consumer world, this sector provides only a minimal contribution to emission reductions (Table 6.7). In the Info and Low Tax scenarios of the Economic Efficiency world, the Pulp and Paper subsector provides over 59% of industrial sector emission reductions indicating that it is a cost-effective source of emission reductions relative to other sectors.

CO_2 emissions from the Pulp and Paper subsector follow a counterintuitive pattern (Fig. 6.5) in that the CO_2 emissions in the Economic Efficiency world are actually greater than those of the Average Consumer world for the BAU, Info and Low Tax policy options. Under the assumptions of the Economic Efficiency world, one expects a greater market penetration of fuel-efficient or alternative fuel technologies and thus lower emissions (see Section 3).

Figure 6-5. Comparison of CO2 emissions from the Pulp and Paper sector under different policy options in 2030.



The energy consumption by fuel type for the different policy options (Table 6.9) explains this pattern of emission reductions. Emissions are greater in the Economic Efficiency world when the consumption of natural gas exceeds that in the Average Consumer world policy options (e.g. BAU, Info, Low Tax). Combustion of natural gas directly releases 0.487 tonnes of CO_2 / GJ whereas the end-uses of electricity create no direct emissions. Of course, the increased demand for electricity may result in indirect emissions through increased fuel use in the electricity supply sectors, but we currently do not attribute indirect emissions to the demand sectors. Indirect emissions are reported in Section 6.6. The trend towards increased use of electricity at higher levels of CO_2 taxes and in the Regulatory policy option (Table 6.9) thus yields the direct emission reductions observed in Figure 6.5. Lower natural gas consumption due to fuel switching to electricity and biomass in the Economic Efficiency world under the High Tax policy option results in lower emissions than the same policy option in the Average Consumer world. Under the Regulatory policy option, fuel switching to biomass (particularly for hog fuel boilers and cogenerators, see Appendix E) from natural gas yields large emission reductions.

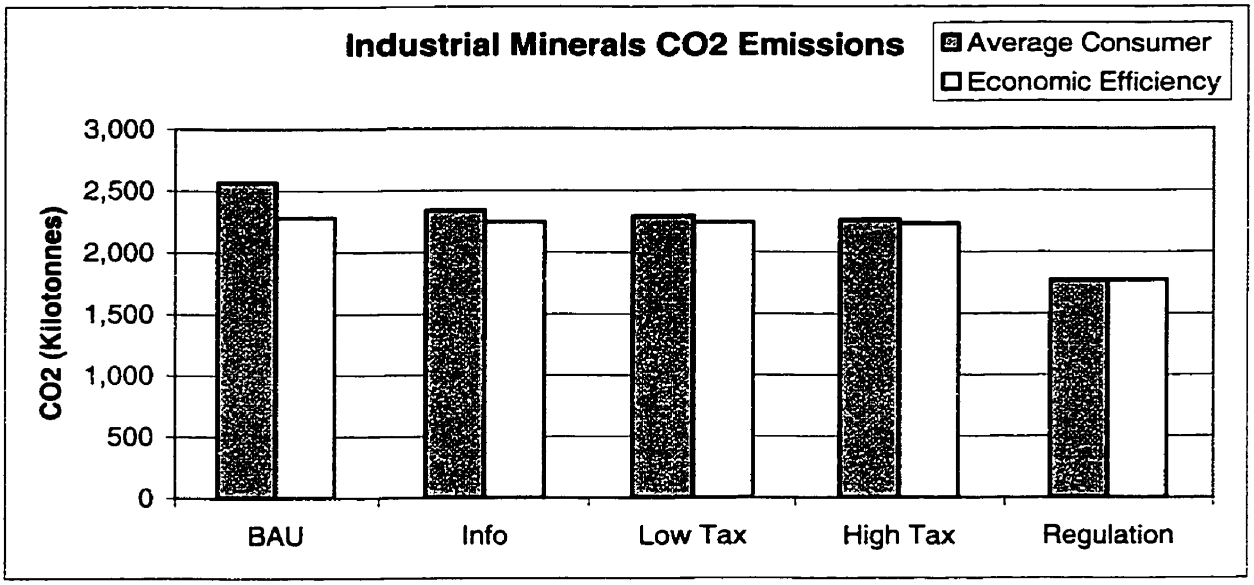
Table 6-9. Fuel consumption (PJ) in the Pulp and Paper sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
Elec	56.4 33.4%	56.3 33.6%	56.4 33.9%	58.1 35.7%	39.5 25.2%	40.8 26.1%	40.6 26.1%	43.6 28.3%	44.9 26.5%
Nat Gas	63.2 37.4%	62.7 37.4%	62.0 37.3%	58.0 35.6%	68.2 43.6%	65.6 42.0%	64.7 41.6%	55.7 36.1%	6.8 4.0%
Oil	2.5 1.5%	2.0 1.2%	1.8 1.1%	1.4 0.9%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Coal	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Pet Coke	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Biomass	46.7 27.7%	46.4 27.7%	46.2 27.8%	45.4 27.9%	48.9 31.2%	49.8 31.9%	50.3 32.3%	54.9 35.6%	117.7 69.4%
Total	168.6 100.0%	167.3 100.0%	166.4 100.0%	162.9 100.0%	156.5 100.0%	156.3 100.0%	155.7 100.0%	154.2 100.0%	169.4 100.0%

Industrial Minerals

The Industrial Minerals sector is typically responsible for approximately 20% of the aggregate industrial sector CO_2 emissions with the exception of the Regulatory policy where it jumps to 48% (Table 6.6). In this sector, CO_2 emissions are lower in the Economic Efficiency world than in the Average Consumer world in all cases (Fig. 6.6). The relatively large decline in emissions between the Average Consumer BAU and the Info policy option is due to a strong decline in coal and petroleum coke consumption from 56.5% to 12.3% of total energy consumption (Table 6.10). These high carbon content fuels are replaced with natural gas, which has a lower CO_2 coefficient. Due to this large drop in emissions in the Info scenario, the Industrial Minerals sector is responsible for 26.5% of aggregate industrial emissions reductions for this policy option in the Average Consumer World (Table 6.7).

Figure 6-6. Comparison of CO2 emissions from the Industrial Minerals sector under different policy options in 2030.



The Economic Efficiency world has consistently lower CO_2 emissions because consumption of coal and petroleum coke is near zero in the Economic Efficiency BAU and is eliminated in the remainder of its policy options. Although natural gas consumption decreases slightly from 11.86 PJ in the Economic Efficiency Info policy option to 11.58 PJ in the High Tax policy option, the emissions declines in Figure 6.6 are primarily due to specific energy efficiency improvements (Appendix E). For instance, fuel-efficient natural gas lime kilns with preheating increase from 63% of new market share in the Economic Efficiency BAU to 83% under the High Tax policy option. Economic opportunities for CO_2 emission reductions appear to be limited once natural gas consumption approaches 80% of total fuel consumption as evidenced by the minimal declines in CO_2 emissions gained with taxes over $40 / tonne CO_2.

Unlike the Other Manufacturing and Pulp and Paper, the Industrial Minerals subsector does not show a large technological potential to reduce its emissions in the Regulatory policy option. The ability of the Industrial Minerals sector to reduce emissions is constrained because production of cement, a key product, results in process emissions in direct proportion to output (CIEEDAC, 2000). CO_2 emissions from fuel combustion decline moderately due to a drop in natural gas consumption and a corresponding increase in waste fuel, which has a CO_2 emissions coefficient of zero. Table 5 in Appendix E shows that burners fueled by hazardous waste and residue derived fuels each gain 50% of new market share. One should also note that there is an availability limit on these fuels.

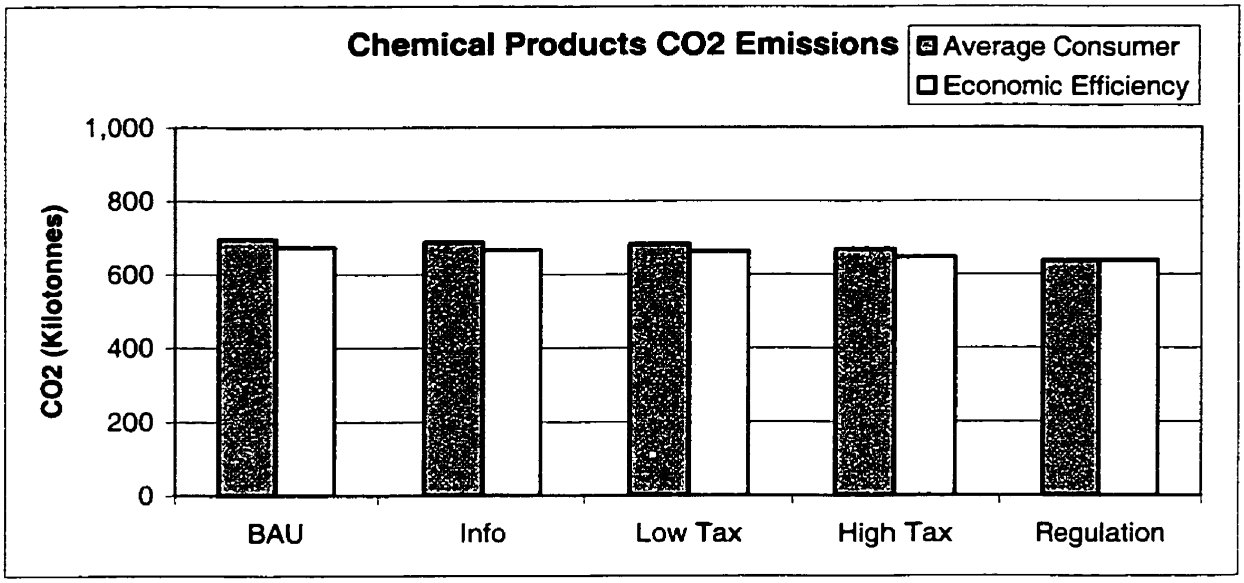
Table 6-10. Fuel consumption (PJ) in the Industrial Minerals sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Elec	1.9 12.7%	1.9 12.6%	1.9 12.7%	1.9 12.8%	1.8 12.3%	1.8 12.4%	1.8 12.4%	1.8 12.5%	1.9 17.0%
Nat Gas	3.6 24.1%	10.2 67.1%	11.3 74.7%	11.6 78.3%	11.4 76.8%	11.9 81.2%	11.8 81.2%	11.6 81.1%	2.4 21.6%
Oil	0.0 0.3%	0.3 1.8%	0.3 1.8%	0.2 1.5%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Coal	3.5 23.3%	0.9 5.8%	0.3 2.3%	0.1 0.6%	0.2 1.5%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Pet Coke	5.0 33.2%	1.0 6.5%	0.4 2.4%	0.1 0.6%	0.5 3.1%	0.0 0.0%	0.0 0.0%	0.0 0.0%	0.0 0.0%
Waste Fuel	0.9 6.3%	0.9 6.2%	0.9 6.2%	0.9 6.2%	0.9 6.3%	0.9 6.3%	0.9 6.3%	0.9 6.3%	6.7 61.4%
Total	15.1 100.0%	15.2 100.0%	15.1 100.0%	14.8 100.0%	14.8 100.0%	14.6 100.0%	14.5 100.0%	14.3 100.0%	10.9 100.0%

Chemical Products

The Chemical Products subsector produces less than 8% of industrial emissions under the majority of policy options. Only under the Regulatory option is it responsible for a substantial portion of industrial aggregate emissions (Table 6.6). The emissions from the Chemicals subsector follow the expected pattern but the emissions reductions are very small (Fig. 6.7).

Figure 6-7. Comparison of CO2 emissions from the Chemical Products sector under different policy options in 2030.



No dramatic changes in fuel consumption occur under any of the policy options (Table 6.11). The split between electricity and natural gas is nearly even in both World Views with the Average Consumer World biased slightly towards electricity and the Economic Efficiency World slightly towards natural gas. Emission reductions are achieved in the Average Consumer world through declines in the consumption of oil and coal in conjunction with energy efficiency improvements. Despite greater consumption of natural gas, the CO_2 emissions in the Economic Efficiency world BAU, Info and Low Tax policy options are lower than the Average Consumer world because oil and coal consumption are eliminated.

Appendix E shows the new market penetration of high efficiency technologies in the Chemical Products sector. In all cases, as the tax on CO_2 emissions increases, penetration of high efficiency technologies is greater. The Economic Efficiency World shows greater market penetration by energy efficient technologies than the Average Consumer World. In particular, improvements in electrolysis, evaporators and boilers contribute to declining emissions.

Table 6-11. Fuel consumption (PJ) in the Chemical Products sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Elec	14.8	14.8	14.7	14.6	13.1	12.9	12.8	12.6	10.8
	51.4%	51.5%	51.5%	51.8%	48.6%	48.6%	48.4%	48.6%	45.2%
Nat Gas	13.5	13.6	13.6	13.4	13.8	13.7	13.6	13.3	13.1
	46.8%	47.4%	47.5%	47.5%	51.4%	51.4%	51.6%	51.4%	54.8%
Oil	0.4	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0
	1.5%	1.1%	0.9%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%
Coal	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	28.8	28.7	28.6	28.2	26.9	26.6	26.4	25.9	23.9
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

6.4 Residential Sector

Among the energy demand sectors, the residential sector is responsible for 6-11% of total economy emissions under various policy options (Table 6.2). Despite its small contribution to overall emissions, the residential sector is responsible for between 20-39% of total emissions reductions in the majority of the policy options (Table 6.3). In the Regulatory policy option, its only contributes 11% of total reductions.

Figure 6.8 shows that Residential sector emissions follow the same counterintuitive pattern as the Pulp and Paper subsector in that emissions from the Economic Efficiency world are higher than those from the Average Consumer world for the BAU, Info and Low Tax policy options. Again, where the Economic Efficiency world CO_2 emissions are higher, natural gas is the predominant fuel, constituting over two-thirds of energy consumption in the Economic Efficiency world as opposed to roughly half of the energy consumed in the Average Consumer world. Under the High Tax scenario, the Average Consumer World emissions exceed the Economic Efficiency world as expected because natural gas consumption is greater.

The Regulatory policy option is the most effective for lowering CO_2 emissions. The Regulatory emissions are 58% and 55% lower than the Average Consumer and Economic Efficiency baseline emissions respectively. This occurs because of fuel switching towards electricity and wood. Wood is assigned a CO_2 coefficient of zero because growing trees is assumed to recapture from the atmosphere all of the CO_2 emitted from combustion of wood (Environment Canada, 1998). Indirect CO_2 emissions associated with the increased demand for electricity from the residential sector are reported in Section 6.6.

Figure 6-8. Comparison of annual CO2 emissions from the Residential sector under different policy options in 2030.

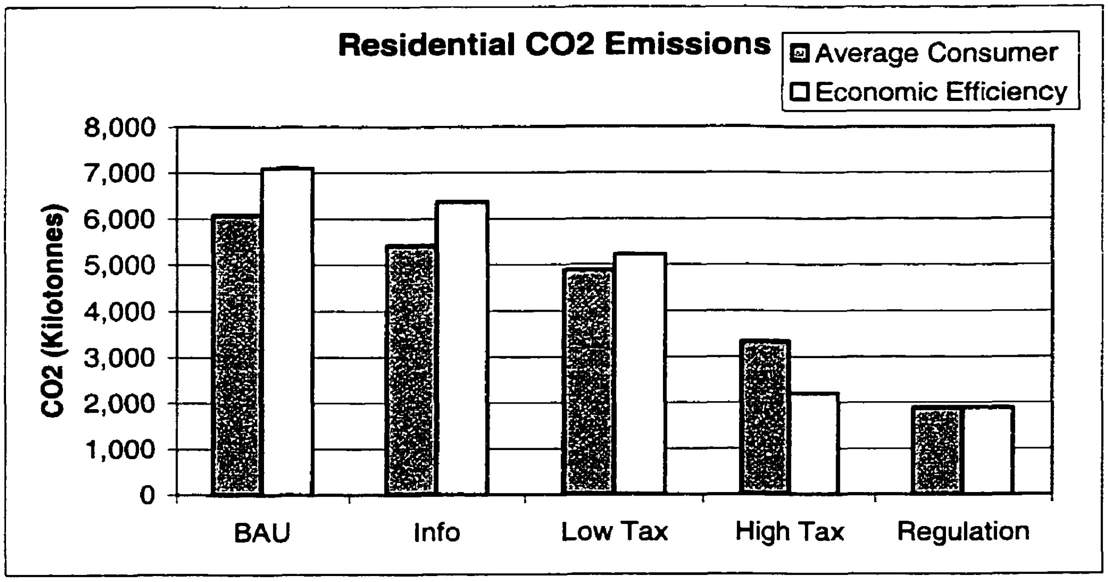


Table 6-12. Fuel consumption (PJ) in the Residential Sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Elec	83.1 41%	90.0 46%	96.0 50%	114.6 64%	38.2 21%	43.2 25%	52.0 33%	63.5 59%	121.6 74%
Nat Gas	104.2 51%	93.7 47%	84.3 44%	53.9 30%	142.2 78%	126.9 73%	103.5 65%	40.4 38%	3.3 2%
RPP	2.4 1.2%	2.0 1.0%	1.7 0.9%	1.1 0.6%	0.6 0.3%	0.6 0.4%	0.6 0.4%	0.6 0.6%	0.6 0.4%
Wood	13.7 7%	11.7 6%	10.8 6%	10.3 6%	2.2 1%	2.3 1%	2.3 1%	3.2 3%	38.4 23%
Total	203.4 100%	197.4 100%	192.8 100%	180.1 100%	183.2 100%	173.0 100%	158.4 100%	107.7 100%	163.9 100%

Improvements in energy efficiency also contribute to the decline in Residential emissions as the CO_2 tax rate is increased. The percentages of new market share gained by various technologies in the residential sector are shown in Appendix E. In the Economic Efficiency world, there is typically greater penetration of more fuel-efficient technologies, such as improved shells for apartments and row housing, and high efficiency natural gas for space heating in new homes. The retrofit option in the Economic Efficiency world resulted in a substantial amount of conversion to high efficiency natural gas space heating systems in existing houses.

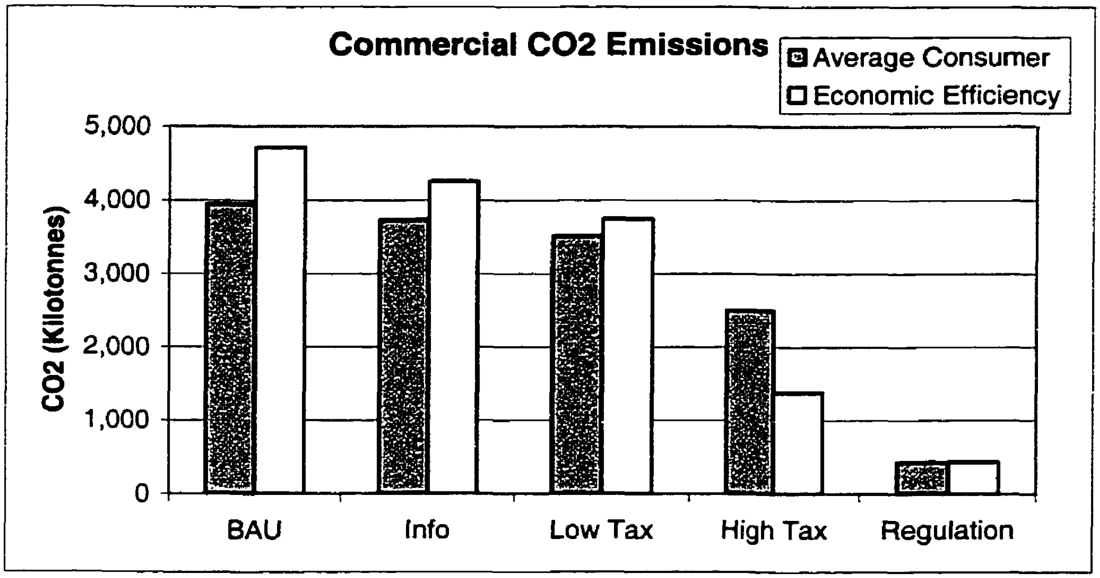
6.5 Commercial Sector

The Commercial sector is responsible for less than 7% of total CO_2 emissions (Table 6.2). In the Average Consumer world, it contributes only a small percentage to total emissions reductions; however, in the Economic Efficiency world, this sector is responsible for roughly 20% of total emissions reductions (Table 6.3). The Commercial emissions (Fig. 6.9) follow the same counterintuitive pattern as the Residential and Pulp and Paper sectors in that:

- Greater consumption of natural gas in the Economic Efficiency World than in the Average Consumer World leads to higher CO_2 emissions under the BAU, Info, and Low Tax scenarios (Table 6.13).

- Commercial CO_2 emissions decrease due to fuel switching to electricity and increased energy efficiency as the CO_2 tax rate increases.
- Greater consumption of natural gas in the Average Consumer world than in the Economic Efficiency world under the High Tax policy option results in higher CO_2 emissions.
- The lowest CO_2 emissions are achieved with the Regulatory policy option due to fuel switching to electricity.

Figure 6-9. Comparison of annual CO2 emissions from the Commercial sector under different policy options in 2030.



Appendix E shows the percentage of new market investment won by various technologies in the commercial sector under the scenarios in the year 2030. For most space heating applications there is a trend towards electric heaters as the tax on CO_2 is increased. By forcing the penetration of energy efficient electric technologies and solar heating (see Section 5.3), the regulation run achieves large emission reduction with a relatively small increase in electricity consumption.

The Residential and Commercial sector results highlight the importance of considering fuel-switching responses to changes in relative fuel costs when designing policies to reduce GHG emissions. Regulatory approaches that focus solely on promoting technologies with the lowest CO_2 per unit output are not ideal for demand sectors due to the tendency to increase demand for electricity. In its current configuration, the winner-take-all function for lowest-CO_2 technologies in CIMS attributes equal market shares to all electrical technologies regardless of their electrical efficiency because these technologies all share the same low CO_2 coefficients. Although efforts were made to account for this by specifying minimum market shares for the highest efficiency electrical technologies, electricity consumption is higher in the Regulatory scenarios than the High Tax options, particularly for the Residential sector. In this modelling framework, responsibility for the resulting indirect emissions falls upon the electricity generation sector rather than the sector from which the electricity demand originated. In the future, adjusting the winner-take-all function to minimize both the electrical consumption and CO_2 emissions per unit of output of the technology mix would provide a better representation of the emission reductions possible through strict regulatory measures. Cogeneration technologies, which meet both commercial space heating and electricity generation needs, would penetrate in such scenarios and yield reductions in economy-wide emissions and electricity consumption.

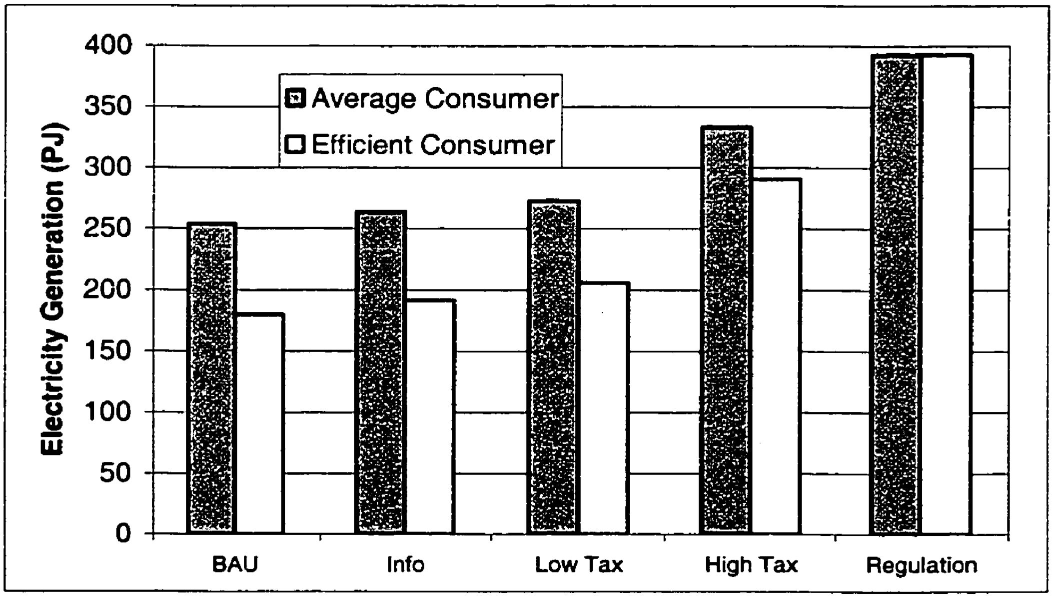
Table 6-13. Fuel consumption (PJ) in the Commercial sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Elec	80.3 49.6%	82.9 51.9%	85.6 54.1%	98.3 65.5%	69.2 41.6%	74.8 46.0%	81.0 51.1%	111.3 79.5%	124.9 93.0%
Nat Gas	80.4 49.7%	75.9 47.4%	71.4 45.1%	50.6 33.7%	96.1 57.7%	86.7 53.3%	76.2 48.1%	27.5 19.7%	8.2 6.1%
RPP	0.4 0.2%	0.4 0.2%	0.4 0.2%	0.4 0.3%	0.4 0.2%	0.4 0.2%	0.4 0.2%	0.4 0.3%	0.4 0.3%
LPG	0.8 0.5%	0.8 0.5%	0.8 0.5%	0.8 0.5%	0.8 0.5%	0.8 0.5%	0.8 0.5%	0.8 0.6%	0.8 0.6%
Total	161.8 100.0%	160.0 100.0%	158.2 100.0%	150.0 100.0%	166.5 100.0%	162.6 100.0%	158.3 100.0%	140.0 100.0%	134.3 100.0%

6.6 Electricity Sector

Many of the energy demand sectors achieve substantial emission reductions through fuel switching to electricity and away from carbon-intensive fuels. A primary benefit of utilizing the integrated CIMS supply and demand models is the ability to model the impacts of this increased demand for electricity on the electricity supply sector and its subsequent CO_2 emissions. Figure 6.10 compares the total electricity generated in order to meet the needs of the demand sectors under various policy options. As the cost of CO_2 emissions is increased, fuel switching to electricity greatly increases the amount of electricity that the supply sector must generate. Under the Regulatory policy option, electricity generation increases by 47% and 94% from the Average Consumer and Economic Efficiency baselines respectively. The Economic Efficiency world demands less electricity overall than the Average Consumer world for two reasons. Firstly, the Residential, Commercial, and Pulp and Paper sectors improve their economic efficiency by switching to more use of natural gas. This lowers the overall demand for electricity. Secondly, increased penetration of high efficiency electricity-consuming technologies in the Economic Efficiency world provides the same services while using less electricity.

Figure 6-10. Electricity Generation (PJ) under different policy options in 2030.



By requiring increased production of electricity from the electricity supply sector, each demand sector is indirectly responsible for a portion of any increased emissions from the electricity generation sector. Table 6.14 shows how electricity demand changes in each demand sectors as the cost of CO_2 emissions changes. For many sectors, electricity demand remains relatively constant (e.g., Transportation, Industrial Minerals, Pulp and Paper, and Chemicals). Significant increases in electricity demand occur in the Other Manufacturing, Residential and Commercial sectors. Table 6.15 shows the magnitude of changes in electricity demand in these three sectors and calculates their percentage contribution to total increased demand for electricity.

Table 6-14. Electricity Demand (PJ) from Demand Sectors under various policy options.[30]

	Average Consumer				Economic Efficiency				
	BAU	**Info**	**L.Tax**	**H.Tax**	**BAU**	**Info**	**L.Tax**	**H.Tax**	**Reg'n**
Transportation	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Industry	100.1	100.1	100.8	131.6	80.8	82.0	81.5	126.9	158.2
Oth. Man	27.0	27.1	27.8	57.0	26.5	26.4	26.4	68.9	100.6
Pulp & Paper	56.4	56.3	56.4	58.1	39.5	40.8	40.6	43.6	44.9
Ind. Min.	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.9
Chemicals	14.8	14.8	14.7	14.6	13.1	12.9	12.8	12.6	10.8
Residential	83.1	90.0	96.0	114.6	38.2	43.2	52.0	63.5	121.6
Commercial	80.3	82.9	85.6	98.3	69.2	74.8	81.0	111.3	124.9
Total	**264.5**	**274.2**	**283.5**	**345.6**	**189.3**	**201.1**	**215.6**	**302.8**	**405.8**

Table 6-15. Change in Electricity Consumption relative to Baseline (PJ) and percentage contribution to total change in electricity demand.

	Average Consumer			Economic Efficiency			
	Info	**L.Tax**	**H.Tax**	**Info**	**L.Tax**	**H.Tax**	**Reg'n**
Oth. Man	0.1 1.5%	0.8 4.0%	30.0 37.0%	-0.1 -0.4%	-0.1 -0.4%	42.4 37.4%	73.6 52.1%
Residential	6.9 71.9%	12.9 68.0%	31.6 38.9%	5.0 42.8%	13.8 52.6%	25.3 22.3%	38.5 27.3%
Commercial	2.7 27.7%	5.4 28.3%	18.0 22.2%	5.6 47.3%	11.7 44.7%	42.1 37.1%	44.6 31.6%
Sum	**9.8** 101.1%	**19.0** 100.3%	**79.6** 98.1%	**10.5** 89.7%	**25.4** 96.9%	**109.9** 96.8%	**156.8** 111.0%
Total Change	**9.7**	**19.0**	**81.1**	**11.7**	**26.2**	**113.5**	**141.3**

*Change in electricity demand for Regulatory policy option is calculated relative to Average Consumer baseline here.

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[30] Discrepancies between levels of electricity generated and that demanded are due to exogenous estimation of the electricity required for the natural gas, coal mining and petroleum refining sectors.

Table 6.15 provides a rough indication of the indirect emissions for which these three demand sectors may be considered responsible. Indirect emissions are estimated for these sectors by multiplying the net change in electricity demand (PJ) by the average emissions per PJ of electricity generation from each policy option. The emissions coefficients and indirect emissions attributed to these sectors are reported in Table 6.16.

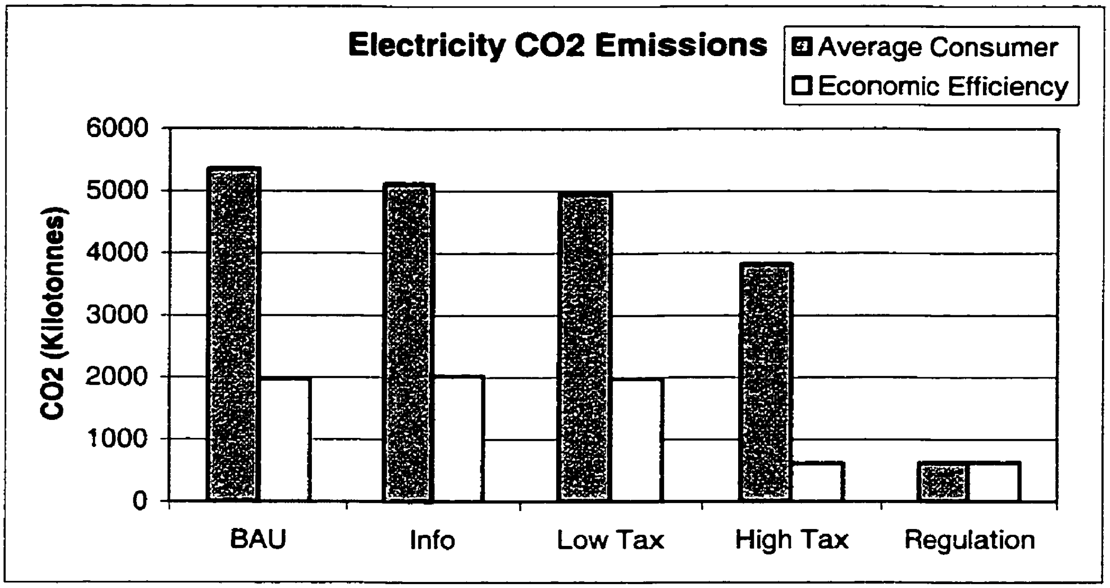
Table 6-16. Indirect emissions attributed to the Other Manufacturing, Residential and Commercial sectors based on average emissions per PJ of electricity.

	Average Consumer			Economic Efficiency			
	Info	L.Tax	H.Tax	Info	L.Tax	H.Tax	Reg'n
Ave. ktonnes CO2 / PJ electricity generated	19.4	18.2	11.5	10.5	9.6	2.1	1.6
Indirect Emisisons (kt)							
Other Manufacturing	2.9	13.9	344.5	-0.6	-1.0	89.6	117.7
Residential	134.9	234.5	362.5	52.9	132.5	53.5	61.6
Commercial	51.9	97.5	206.8	58.6	112.4	88.9	71.3
Total	**189.7**	**346.0**	**913.9**	**110.9**	**243.9**	**232.0**	**250.6**

In both worlds, the average emissions of the electricity supply sector per PJ of electricity produced decline as the tax on CO_2 causes the supply sector itself to switch to less carbon-intense fuels, in particular hydro-electricity and renewable energy sources (Table 6.17). The average emissions per PJ of electricity are much lower in the Economic Efficiency world than in the Average Consumer world. This yields smaller indirect emissions for the Economic Efficiency demand sectors. The indirect emissions increase as the tax level of CO_2 increases because these demand sectors relied heavily on switching to electricity to reduce their direct emissions and associated costs.

Not surprisingly, the direct CO_2 emissions from the electricity supply sector show a drastic contrast between the Average Consumer and the Economic Efficiency worlds. For all policy options, the Economic Efficiency world shows substantially lower CO_2 emissions (Fig. 6.11) as a combined result of lower demand and fuel switching. CO_2 emissions are lower in the Economic Efficiency world because reduced demand for electricity due to efficiency improvements in the demand sectors allows for large reductions in fossil fuel consumption by the electricity generation sector (Table 6.17). Natural gas consumption is roughly one-third of levels in the Average Consumer World and refined petroleum products are eliminated from the fuel mix. In both the Average Consumer and Economic Efficiency worlds, emissions decline as the cost of CO_2 increases due to fuel switching away from natural gas to hydro-electricity, wind generation and geothermal heat pumps (Table 7, App. E). The Average Consumer world meets a small portion new demand with combined cycle natural gas turbines but its market share declines as the tax rate increases.

Figure 6-11. Comparison of annual CO2 emissions from the Electricity Supply sector under different policy options in 2030.



The Regulatory policy option is particularly interesting in this sector as it shows the lowest overall CO_2 emissions despite having the highest electricity generation level among all other policy options. Using the winner-take-all function for the lowest CO_2 electricity generation technologies forces the sector to produce electricity using more hydro, wind, biomass and geothermal heat pumps, all of which have CO_2 emission coefficients of zero. For the Regulatory policy option, the majority of electricity is generated from hydro resources; however, biomass increases by a factor of four and wind generation by a factor of five, as well.

Emissions under the Economic Efficiency High Tax policy option are almost identical to the Regulatory policy option yet the demand for electricity is substantially lower (Fig. 6.11). This indicates that the High Tax policy option is likely more cost-effective than the Regulatory option. The Regulatory policy option while appealing from an emissions viewpoint may require the addition of more supply technologies, likely large-scale dams or natural gas turbines. The potential economic impacts on fisheries, land use and emissions are not accounted for in this study and could be substantial.

Table 6-17. Fuel consumption (PJ) in the Electricity Supply sector under different policy options in 2030.

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Hydro	205.2 65.1%	217.7 67.4%	228.6 69.2%	297.8 79.1%	161.6 80.0%	172.6 80.6%	187.0 82.2%	281.2 95.7%	372.5 96.6%
Nat Gas	109.6 34.8%	104.9 32.5%	101.8 30.8%	78.6 20.9%	40.5 20.0%	41.4 19.4%	40.5 17.8%	12.6 4.3%	12.9 3.3%
RPP	0.13 0.04%	0.06 0.02%	0.03 0.01%	0.00 0.00%	0.00 0.00%	0.00 0.00%	0.00 0.00%	0.00 0.00%	0.00 0.00%
Wood	0.05 0.02%	0.03 0.01%	0.03 0.01%	0.03 0.01%	0.00 0.00%	0.00 0.00%	0.00 0.00%	0.01 0.00%	0.04 0.01%
Wind	0.05 0.02%	0.05 0.01%	0.05 0.01%	0.07 0.02%	0.00 0.00%	0.01 0.00%	0.01 0.00%	0.03 0.01%	0.13 0.03%
Energy Consumed	**315.0** 100.0%	**322.8** 100.0%	**330.5** 100.0%	**376.5** 100.0%	**202.1** 100.0%	**214.1** 100.0%	**227.6** 100.0%	**293.8** 100.0%	**385.5** 100.0%

The wide-scale fuel switching to electricity, particularly under the High Tax policy option, indicates that it is often less costly for the electricity sector to reduce its emissions than it is for the demand sectors to invest in energy efficient technologies to achieve similar reductions. The next section addresses the critical issue of costs, and who pays them, in more detail.

6.7 Techno-Economic Costs

The policy costs reported are incremental to the costs that would have been incurred in the baselines for each world view including all expenditures / benefits. Table

6.18 shows the net techno-economic costs incurred by each sector for the various policy options from 2000-2030.

Table 6-18. Net financial impact of policy options ($ 1995 millions).

	Average Consumer			Efficient Consumer			
	Info	L.Tax	H.Tax	Info	L.Tax	H.Tax	Reg'n
Industry	**-173**	**-285**	**816**	**-149**	**56**	**2,706**	**6,707**
Chemicals	-7	-16	22	-26	-2	128	218
Industrial Minerals	-19	-24	-21	-6	-2	20	-65
Other Manufacturing	-50	-52	881	-50	31	1,776	5,603
Pulp & Paper	-98	-193	-65	-67	29	783	951
Residential	**641**	**1,160**	**3,968**	**126**	**668**	**2,913**	**7,738**
Commercial	**538**	**704**	**1,998**	**-36**	**451**	**3,036**	**5,315**
Transportation	**-1,958**	**-2,890**	**-6,059**	**-2,176**	**-3,712**	**-7,355**	**45,126**
Total	**-952**	**-1,310**	**723**	**-2,235**	**-2,538**	**1,299**	**64,885**
Elec w/out Revenue gain	803	1,478	3,981	859	1,547	5,976	6,240
Elec w/ Revenue gain	32	83	3,414	701	879	4,705	6,240

For both world views, the Information and Low Tax policies result in financial savings to the economy as a whole ranging from $952 million to $2.6 billion. The High Tax policy option results in financial costs of $723 million and $1.3 billion for the Average Consumer and Economic Efficiency world views respectively. A rough calculation based on provincial GDP in 1999 of 1.2 billion reveals that these costs are approximately .02-.03% of annual provincial GDP. The Regulatory scenario has a much higher cost of $64.9 billion, primarily due to the high costs incurred by the transportation sector in switching to hydrogen fuel cell vehicles. This represents approximately 1.8% of annual provincial GDP if spread evenly over the thirty year period.

Different sectors of the economy face very different financial consequences. The residential and commercial sectors experience substantial net increases in financial costs ranging from $126 million to $4.0 billion. The industrial sector experiences net financial benefits when the cost of CO_2 is lower but a net cost under the High Tax and Regulatory scenarios. In contrast, the transportation sector experiences large financial savings ranging from $1.9 billion to $7.4 billion in response to the market-based policy options. These large transportation savings counter the costs in the other sectors and have a dominant influence on the net effect to the total economy. The electricity sector results are not included in the total because all costs are assumed to be passed on to the demand sectors. The magnitude of costs experienced by the electricity supply sector is therefore indicative of the degree of electricity price increase experienced by the demand sectors.

In the Average Consumer world, the electricity supply sector experiences net financial costs ranging from $803 million to $3.9 billion under various policy options. The increased total costs are due to increased capital expenditures on energy efficiency and fuel switching and occur despite substantial savings on energy costs (Appendix D). Despite lower levels of generation, the Economic Efficiency world faces even greater increases in capital expenditure for electricity generation because of higher investment in more expensive renewable technologies, particularly under the High Tax policy option. The rising costs experienced by the electricity sector are offset to a degree by the increasing revenues resulting from higher demand for electricity (Table 6.18). The Economic Efficiency world is unable to offset its costs to the same extent as the Average Consumer world because of lower overall demand.

Both increased cost of production and direct CO_2 taxation costs faced by the electricity sector are passed on to the demand sectors in the price of electricity; however, it is assumed that revenue gains are not passed on. Table 6.19 shows how electricity prices rise both with and without the tax component. When making technology acquisition decisions, the demand sectors perceive electricity price to include both factors. However, electricity taxes are not included in the estimates of techno-economic energy costs for the demand sectors because they are considered transfers. The impact of rising electricity prices has a significant impact on the techno-economic costs experienced by the demand sectors.

Table 6-19. Electricity prices under various policy options ($/GJ).

	Average Consumer				Economic Efficiency				
	BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Perceived Cost	10.1	11.0	11.6	13.8	9.4	10.0	10.7	12.7	13.7
Cost excluding tax	10.1	10.2	10.3	11.2	9.4	9.6	10.3	12.3	13.7

In the residential and commercial sectors, despite increased investment in energy efficient technologies relative to the baselines, expenditures on energy are also higher due to the rising cost of electricity (see Appendix D). Both sectors relied heavily on fuel switching to electricity to reduce their direct emissions. Despite the increasing cost of electricity, the residential and commercial sectors found it economically efficient to switch to electricity rather than other technological options.

The industrial sector experiences a net financial benefit when the cost of CO_2 emissions is low but a net cost under the High Tax and Regulatory options. Financial benefits accrued when the additional capital expenditures on energy efficient technologies are more than compensated by the energy savings achieved (see Appendix D). In the Average Consumer world, all industrial subsectors experience energy savings of sufficient magnitude to compensate for increased capital expenditure in the Info and Low Tax policy options. Under the High Tax and Regulatory policy options, energy costs in the Other Manufacturing subsector rise by $856 million and $5.5 billion relative to baseline levels due to high levels of electricity consumption (Appendix D). This is expected as the Other Manufacturing sector is responsible for over 60% of emission reductions in the industrial sector. As a result, the aggregate industrial sector to show a net financial cost for these policy options. In the Economic Efficiency world, all industrial subsectors experience costs under the High Tax option; however, Other Manufacturing and Pulp and Paper experience the largest increases and together pay 95% of total costs to industry.

The transportation sector is unique in that it is the only sector in which capital expenditures decline in addition to declining energy expenditures for the market-based policies. While lower capital costs may appear at odds with the greater penetration of high efficiency vehicles, it is in fact a function of the modelling assumptions. Ultra efficient and electric hybrid vehicles are classified into categories of vehicles that are more likely to include smaller vehicles, like a GEO Metro. These small vehicles are typically in a lower price bracket than larger vehicles, such as suburban utility vehicles. As a result, capital expenditures decline relative to the reference scenario. Under the Regulatory policy option, the transportation sector experiences a very large net cost as consumers are forced to adopt hydrogen fuel cell vehicles which are assumed to be relatively expensive in CIMS. Additionally, energy costs increase under the Regulatory scenario because hydrogen fuel is roughly three times more expensive than gasoline. Over time, the techno-economic cost of fuel cell vehicles would likely drop with increasing commercialization and technological developments.

The transportation results highlight the importance of considering consumer preferences when determining the costs of a policy. The techno-economic cost estimates for the transportation suggest that, with a relatively small tax signal, the sector can achieve significant greenhouse gas emissions while accruing financial beneftis so large that they compensate the financial costs of all other sectors combined. This result should be interpreted with caution. Smaller and more fuel efficient vehicles are available on the market today yet many consumers routinely pay a premium for large, inefficient vehicles. Clearly, consumers have preferences for the attributes of these technologies and they are willing to pay for them. Perceived private costs measure the cost that consumers experience when they must sacrifice their preferences due to policy implementation. In Table 6.2, the transportation was noted as composing an ever-increasing percentage of total emissions as the cost of CO_2 emissions increased. Assuming that the estimates of intangible costs for transportation technologies are appropriate (Table 5.2), this indicates that when perceived costs are considered, sectors other than transportation provide CO_2 reductions more cost-effectively.

6.8 Perceived Private Costs

Table 6.20 shows the perceived private costs calculated using the cost curve methodology (including the net change in electricity costs faced by the demand sectors).

Because the cost curve methodology requires multiplication by the tax rate, no estimates of perceived private costs could be provided for the Regulatory policy option.

Unlike the financial cost estimates, the perceived private cost results suggest that it is quite costly to reduce CO_2 emissions. The perceived cost estimates range from $1.4 billion to $23 billion dollars. Costs for the transportation sector are underestimated here because cost changes from the Petroleum Refining sector were not endogenized in the version of CIMS utilized.[31] Continued effort goes into developing perceived private cost estimates that accurately reflect the preferences of consumers for various technology attributes. The estimates in Table 6.20 should be viewed only as indicative of the general magnitude of these intangible costs.

Table 6-20. Perceived Private Costs of Market-based Policy Options from 1995 to 2030 ($1995 millions).

	Average Consumer			**Economic Efficiency**		
	Info	**L.Tax**	**H.Tax**	**Info**	**L.Tax**	**H.Tax**
Industry	**894**	**1,584**	**5,964**	**514**	**964**	**6,413**
Pulp & Paper	494	897	2,549	295	550	1,988
Other Manufacturing	267	452	2,818	145	277	4,018
Industrial Minerals	39	63	132	12	22	66
Chemicals	94	171	465	62	115	340
Residential	**674**	**1,350**	**5,209**	**301**	**776**	**7,081**
Commercial	**693**	**1,326**	**4,622**	**484**	**1,027**	**6,661**
Transportation	**114**	**290**	**1,880**	**146**	**439**	**3,148**
Total	**2,374**	**4,550**	**17,675**	**1,444**	**3,206**	**23,303**

6.9 Expected Resource Costs

Although it is difficult to determine reliable estimates of the additional costs faced by consumers due to risk, one can safely assume that this value falls somewhere between perceived private costs (which include both risk and preferences) and techno-economic costs (risk-free financial costs). The expected resource costs reported in Table 6.21

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[31] EMRG is working towards endogenization of cost of production increases for the Petroleum refining, Natural gas extraction and Coal mining sectors. For the time being, supply curves are utilized to determine market price of fuels under different demand levels.

include an illustrative risk adjustment of 75% of the difference between perceived private costs and techno-economic costs. The expected resource cost estimates range from .01 - .5% of annual GDP assuming the costs are spread equally over the 30 year period based on a 1999 provincial GDP of 1.2 billion.

Table 6-21. Incremental Expected Resource Costs of different policy options relative to respective World View baseline costs ($1995 millions).

Sector	**Average Consumer**			**Economic Efficiency**		
	Info	**L. Tax**	**H. Tax**	**Info**	**L. Tax**	**H. Tax**
Industry	626.5	1,116.4	4,677.3	340.9	729.6	5,478.9
Pulp & Paper	345.7	624.3	1,895.8	202.7	417.7	1,684.8
Other Manufacturing	187.6	326.4	2,333.4	94.3	213.8	3,456.1
Industrial Minerals	24.3	41.2	93.7	7.5	15.9	54.4
Chemicals	69.0	124.5	354.5	36.4	82.2	283.7
Residential	666.0	1,302.3	4,898.6	245.1	736.8	6,026.6
Commercial	654.0	1,170.5	3,966.0	353.8	883.1	5,755.0
Transportation	-404.2	-504.7	-104.4	-434.8	-598.5	522.0
Total	**1,542.3**	**3,084.5**	**13,437.5**	**505.1**	**1,751.1**	**17,782.5**

6.10 Coefficients

This section presents the fuel, CO_2 and techno-economic cost coefficients which allow the extension of the results in Sections 6.1 through 6.7 to the wide range of economic growth scenarios available in QUEST. Table 6.22 summarizes the coefficients of fuel consumption per unit of economic output for the scenarios. Table 6.23 summarizes the emissions coefficients per unit of output. It is possible to derive the CO_2 emissions directly from fuel combustion levels; however, CIMS also accounts for some process emissions that are not incorporated into combustion emissions factors. The factors in Table 6.23 should be utilized to include both combustion-related and process emissions when determining the total emissions for each scenario. Finally, Table 6.24 shows the coefficients of techno-economic policy costs per unit of output.

Table 6-22. Coefficients of Fuel Consumption per unit economic output for different policy options in 2030.

SECTOR	Average Consumer				Economic Efficiency				
	BAU	Info	Low Tax	High Tax	BAU	Info	Low Tax	High Tax	Reg'n
Chemicals	**GJ/$1986 billion Chem GDP**				**GJ/$1986 billion Chem GDP**				
Electricity (GB)	50.0	49.8	49.7	49.3	44.0	43.6	43.0	42.4	36.4
Natural Gas	45.5	45.9	45.9	45.3	46.6	46.1	45.9	44.8	44.1
RPP	1.5	1.0	0.9	0.6	0.0	0.0	0.0	0.0	0.0
Coal	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Ind. Minerals	**GJ/$1986 billion Ind Min GDP**				**GJ/$1986 billion Ind Min GDP**				
Electricity (GB)	25.3	25.2	25.1	24.9	23.9	23.8	23.7	23.5	24.4
Natural Gas	47.8	133.6	147.9	152.4	150.0	155.9	154.6	152.2	30.9
RPP	0.6	3.6	3.5	2.9	0.0	0.0	0.0	0.1	0.0
Coal	46.3	11.6	4.5	1.1	2.9	0.1	0.0	0.0	0.0
Petroleum Coke	65.9	12.9	4.7	1.1	6.1	0.1	0.0	0.0	0.0
Waste Fuels	12.5	12.4	12.3	12.1	12.3	12.1	12.0	11.8	88.0
Oth. Manufacturing	**GJ/$1986 billion Oth Man GDP**				**GJ/$1986 billion Oth Man GDP**				
Electricity (GB)	2.5	2.5	2.5	5.2	2.4	2.4	2.4	6.3	9.2
Natural Gas	9.3	8.4	8.4	5.2	8.9	8.8	8.8	3.9	0.8
RPP	0.5	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.0
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood/ Hog Fuel	1.5	2.6	2.6	2.8	2.6	2.6	2.6	2.8	2.8
Pulp & Paper	**GJ/$1986 billion P&P GDP**				**GJ/$1986 billion P&P GDP**				
Electricity (GB)	12.5	12.4	12.5	12.8	8.7	9.0	9.0	9.6	9.9
Natural Gas	14.0	13.8	13.7	12.8	15.1	14.5	14.3	12.3	1.5
RPP	0.5	0.4	0.4	0.3	0.0	0.0	0.0	0.0	0.0
Wood/ Hog Fuel	10.3	10.3	10.2	10.0	10.8	11.0	11.1	12.1	26.0
Commercial	**GJ/$1986 billion Comm GDP**				**GJ/$1986 billion Comm GDP**				
Electricity	1.1	1.1	1.2	1.4	1.0	1.0	1.1	1.5	1.7
Natural Gas	1.1	1.0	1.0	0.7	1.3	1.2	1.0	0.4	0.1
RPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residential	**GJ/$1986 billion Total GDP**				**GJ/$1986 billion Total GDP**				
Electricity	0.6	0.7	0.7	0.8	0.3	0.3	0.4	0.5	0.9
Natural Gas	0.8	0.7	0.6	0.4	1.0	0.9	0.8	0.3	0.0
RPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.3
Transportation	**GJ/$1986 billion Ind GDP**				**GJ/$1986 billion Ind GDP**				
RPP	18.7	18.1	18.0	17.6	17.8	17.3	17.0	16.2	10.2
Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity (GB)	**GJ/$1986 billion Total GDP**				**GJ/$1986 billion Total GDP**				
Hydro	1.5	1.6	1.7	2.2	1.2	1.3	1.4	2.1	2.7
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas	0.8	0.8	0.7	0.6	0.3	0.3	0.3	0.1	0.1
RPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The coefficient tables are embedded in the QUEST 2.0 Energy submodel (Fig. 5.1). Once the user's model route has been specified (world view settings, actions and policy types), the corresponding coefficient is located in each of these tables. The coefficient is then multiplied by the Georgia Basin GDP value calculated by the QUEST Economic Input-Output submodel (Fig. 3.5) for the sector corresponding to that in the coefficient's denominator. The resulting energy, CO_2, costs and market penetration information are reported in the *View Consequences* stage of QUEST 2.0. Thus, the micro-economic feedbacks in CIMS model are endogenized within the QUEST 2.0 Energy submodel.

Table 6-23. Coefficients of CO2 emissions per unit economic output under different policy options in 2030.

SECTOR	Units (tonnes CO2/$1986 million of...)	Average Consumer				Economic Efficiency				
		BAU	Info	L.Tax	H.Tax	BAU	Info	L.Tax	H.Tax	Reg'n
Industry										
Chemicals	Chem GDP	2,350	2,319	2,304	2,255	2,271	2,247	2,233	2,182	2,148
Ind. Minerals	Ind Min GDP	33,798	30,763	30,166	29,744	29,998	29,528	29,459	29,340	23,306
Oth. Manufact.	Oth Man GDP	497	445	439	272	441	439	436	199	49
Pulp & Paper	P&P GDP	756	742	732	681	771	744	735	641	162
Commercial	Comm GDP	54	51	48	34	65	59	52	19	6
Residential	Total GDP	45	40	36	24	52	47	38	16	14
Transportation	Industrial GDP	1,369	1,324	1,315	1,284	1,302	1,267	1,242	1,186	757
Electricity (GB)	Total GDP	39	37	36	28	14	15	14	4	5

Table 6-24. Coefficients of techno-economic policy costs per unit of economic output under different policy options in 2030.

	Units ($1995 million per $1986 million of...)	Average Consumer			Economic Efficiency			
		Info	L.Tax	H.Tax	Info	L.Tax	H.Tax	Reg'n
Industry								
Chemicals	Chem GDP	-0.02	-0.05	0.07	-0.09	-0.01	0.43	0.74
Industrial Minerals	Ind Min GDP	-0.25	-0.32	-0.28	-0.08	-0.03	0.26	-0.85
Other Manufacturing	Oth Man GDP	0.00	0.00	0.08	0.00	0.00	0.16	0.51
Pulp & Paper	P&P GDP	-0.02	-0.04	-0.01	-0.01	0.01	0.17	0.21
Residential	**Comm GDP**	**0.00**	**0.01**	**0.03**	**0.00**	**0.00**	**0.02**	**0.06**
Commercial	**Total GDP**	**0.01**	**0.01**	**0.03**	**0.00**	**0.01**	**0.04**	**0.07**
Transportation	**Industrial GDP**	**-0.07**	**-0.10**	**-0.21**	**-0.08**	**-0.13**	**-0.26**	**1.57**
Elec w/out Revenue gain	Total GDP	0.01	0.01	0.03	0.01	0.01	0.04	0.05
Elec w/ Revenue gain	Total GDP	0.00	0.00	0.03	0.01	0.01	0.03	0.05

7. Summary and Future Research Recommendations

7.1 Summary

The primary research objective for this project was to endogenize micro-economic feedbacks in the QUEST 2.0 model. This was accomplished by modelling numerous scenarios in CIMS that reflect the world view, action and policy choices of the QUEST user. The results of these CIMS runs were converted to coefficients which endogenized micro-economic feedbacks within the QUEST model when softlinked into QUEST's Energy submodel.

Additional research objectives were also accomplished including incorporation of the electricity supply sector, differentiation between the outcomes of market-based, information and regulatory policies and increasing the range of indicators available for the QUEST user to evaluate other aspects of the scenario. In particular, the addition of cost feedbacks is a first for QUEST and greatly enhances the user's ability to examine the economic sustainability of various energy systems. The incorporation of more detailed information on the technologies used to achieve energy services in different scenarios allows QUEST to develop richer qualitative scenario descriptions which link the real-world technology choices of individuals to their ecological consequences. Finally, by portraying different world views regarding how consumers and firms respond to financial costs, this project highlights how uncertainty regarding technology decision making influences energy consumption. This encourages QUEST users to consider the implications of different world views on the appropriate policy mechanisms for encouraging sustainability.

While this softlinking approach worked well for accomplishing the research objectives, it does not account for constraints on the availability of fuel supplies such as wood waste, hazardous wastes or hydro sources. The QUEST interface will use text boxes to point out to the user scenarios where such constraints may exist. Also, the addition of new supply source may require tradeoffs with other QUEST submodels. For example, if the QUEST Energy submodel forecasts the need for additional hydro-electric dams this may affect the land use and fisheries submodels. The CIMS runs forecast the increased supply but do not currently comment on tradeoffs that may be required.

This softlinking approach utilized discrete runs of CIMS and directly linked these runs to slider choices in CIMS. Another option would have been to create a 'response surface' by running CIMS over a set of prices for CO_2 (or other changes) and then determining an algorithm that would reflect the response of CIMS to changing inputs. A supply constraint function could be added to such an algorithm. While this would provide a more elegant approach to CO_2 and fuel consumption forecasting, it would not provide detailed information on the penetration rates of specific technologies which is a key benefit of the discrete modelling approach. Discrete runs also provide maximum flexibility to address key issues that the QUEST team wants to highlight. For example, the market shares of hydrogen fuel cell vehicles can be exogenously constrained for a portion of the transportation service demand while endogenous competition can occur for the remaining service demand. Softlinking the outputs of discrete runs allows for such combinations of QUEST slider settings to be represented explicitly.

7.2 Future Research

There are several areas in which the softlinking of CIMS and QUEST could be improved. Several of the policy choices available in QUEST involve changes in spatial patterns of development. Examples include addressing urban sprawl by nodal development in which certain areas serve as hubs of economic activity and are linked by transportation infrastructure or intense densification of the Vancouver core. These choices have far-reaching implications for the types of transportation required, the ability to achieve the population density necessary for public transit to be successful, the size and type of housing and the potential for alternative heating systems (e.g. district heating and combined heat and power). Attempts to plan spatial patterns of development in order to minimize the energy requirements of regions are commonly referred to as Community Energy Management. Clearly, these broad policy choices have important consequences for forecasting energy consumption because they can alter the relationship between population, economic activity and the demand for energy services, especially demand for transportation and space heating. Additional clarification from the QUEST land use, housing and transportation sectors regarding the impacts of such broad development pattern changes on the demand for energy services in the Georgia Basin would enable CIMS to more accurately portray the resulting energy consumption and emissions.

Additionally, the climate change model of QUEST has recently been expanded to provide information on the impacts of climate change in the Georgia Basin. Many of the impacts have implications for the demand for energy services. For example, increasing temperatures in the region could influence the demand for air conditioning. Altered precipitation levels will impact river flows and thus the availability of hydro-electricity in the province. Additional work is required to identify linkages between energy supply and demand and the impacts of climate change.

QUEST is also expanding to incorporate global scenarios developed by the Tellus Institute (Gallopin et al., 1997). These global scenarios range from continuation of current trends to favourable social transformation to sustainable futures to undesirable social breakdown scenarios. The implications of the global scenario on the population, economy, ability to export and import energy, and fuel prices in the Georgia Basin are not well-defined at present but will have immense implications for the energy system.

There are many other opportunities for softlinking CIMS and QUEST. CIMS is developing its ability to model criteria air contaminants. These would serve as a useful input to the air quality submodel of QUEST which models the interactions of these pollutants in the atmosphere and their impacts on human health. CIMS is also expanding to incorporate materials modelling into its framework. This would provide QUEST with the ability to explore policies aimed at reducing solid wastes, water use and various toxins. Additionally, utilizing the macro-economic model of CIMS to generate structural change feedbacks for QUEST would be a useful next step for developing the ability of QUEST to represent the broader, indirect implications of measures to reduce GHGs.

Appendix A: Flow Models

The figures below illustrate the energy flow models for industries and sectors in CIMS (ISTUM). ISTUM is a simulation model that requires inputs based on technology- or process-specific data. The flow models focus on energy consumption and not material flow. Accordingly, the nodes in the ISTUM model are process stages in which energy consumption can be distinctly estimated. Sometimes the energy requirements in a low energy-consuming step in the process are included with the energy requirement of the next more energy intensive step. In other cases, the energy requirements are not significant enough to have any measurable impact on the accuracy of the final result and therefore are included elsewhere or left out of the analysis.

The flow models were constructed based on the following procedure:

- Review and analyse the process / service flow models related to the industry / sector – What happens in the industry from the start point to the finished product? What are the set of services required to provide a m^2 of livable or commercial space?
- Determine from the flow model where energy is used and what sorts of technologies are required to complete the process / provide the service.
- Evaluate the importance of the various processes / services and energy demands in terms of energy demand and unique process / service technologies. If energy demand is high and competition exists between technologies to provide the required service, the process / service should be represented as a node in ISTUM's energy flow model.
- Design and develop a flow model that captures the crucial energy and technology actions in that industry.

There are three levels of nodes in the flow models:

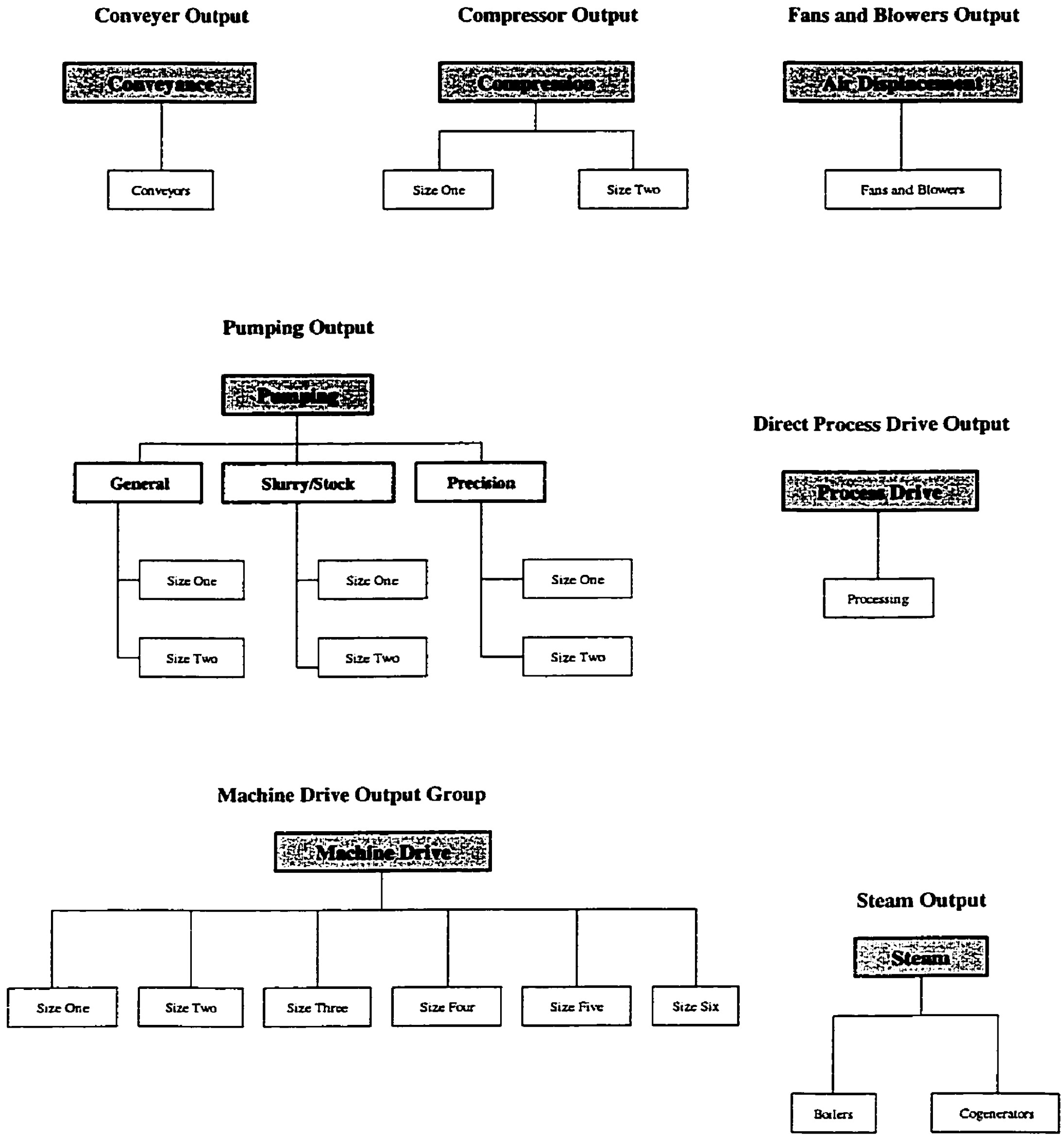
- Primary node – usually the product (or service demanded), steel, metals, paper, cement, houses, commercial space (m^2)
- Secondary node – specific process or service requirements required to permit the production of intermediate products needed to produce the final product or service (smelting nodes, drying nodes in paper)
- Competition node – points at which technologies compete to provide a specific action in the development of the intermediate or final product.

The flow models show the full range of processes that can be modelled in CIMS. Other Manufacturing contains all industries otherwise not included in the sectors that have their own specific models.

Auxiliary Nodes

Most of the sectors / industries require auxiliary services like heating, steam and pumping. Figure 1 provides a general schematic of the provision of these services.

Figure 1. Energy Flow Model of the Auxiliary Systems



Conveyer Output

Compressor Output

Fans and Blowers Output

Pumping Output

Direct Process Drive Output

Machine Drive Output Group

Steam Output

Industrial Minerals

This model currently covers cement and lime only.

Figure 2: Energy Flow Model of the Industrial Minerals Industry

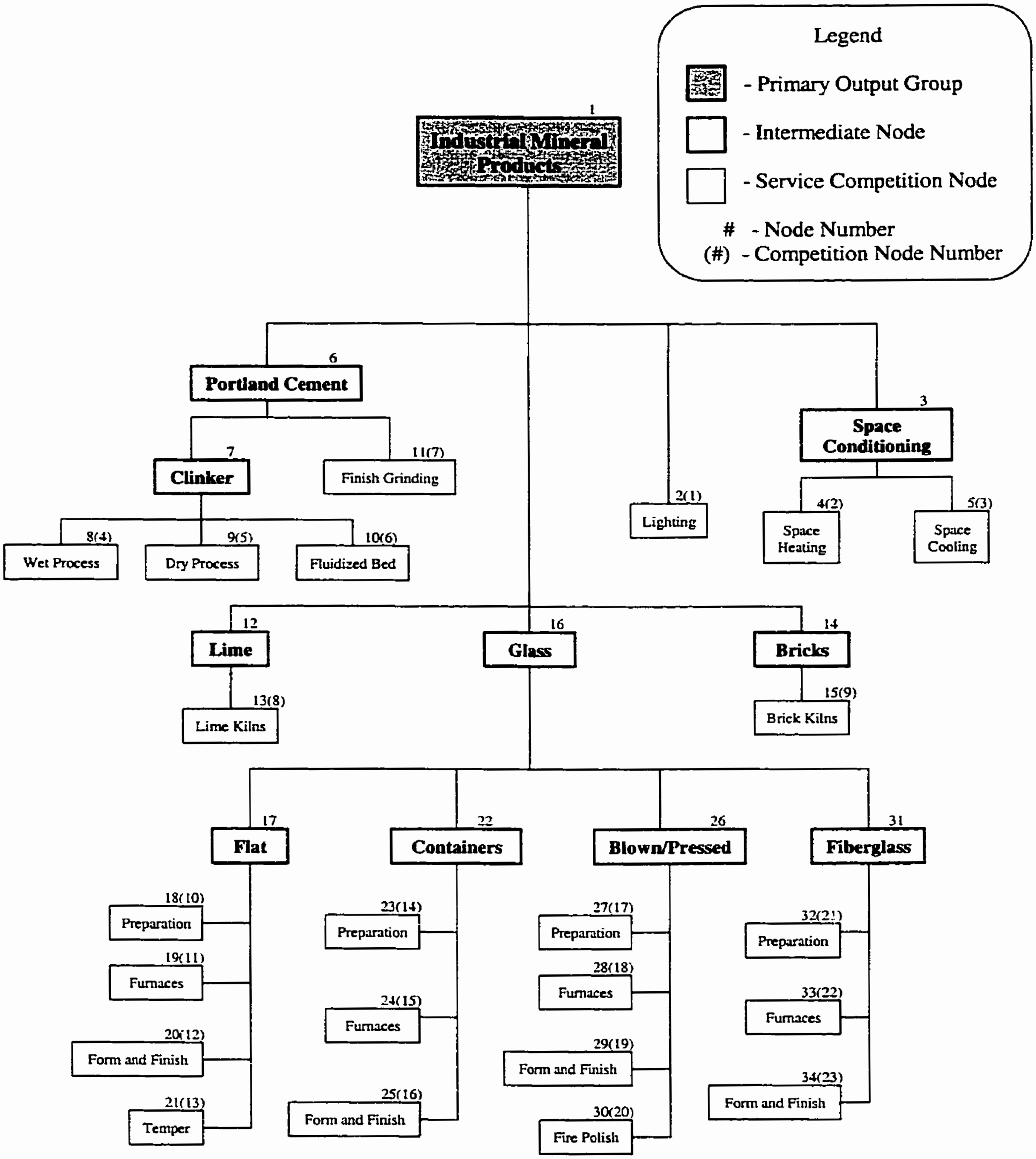
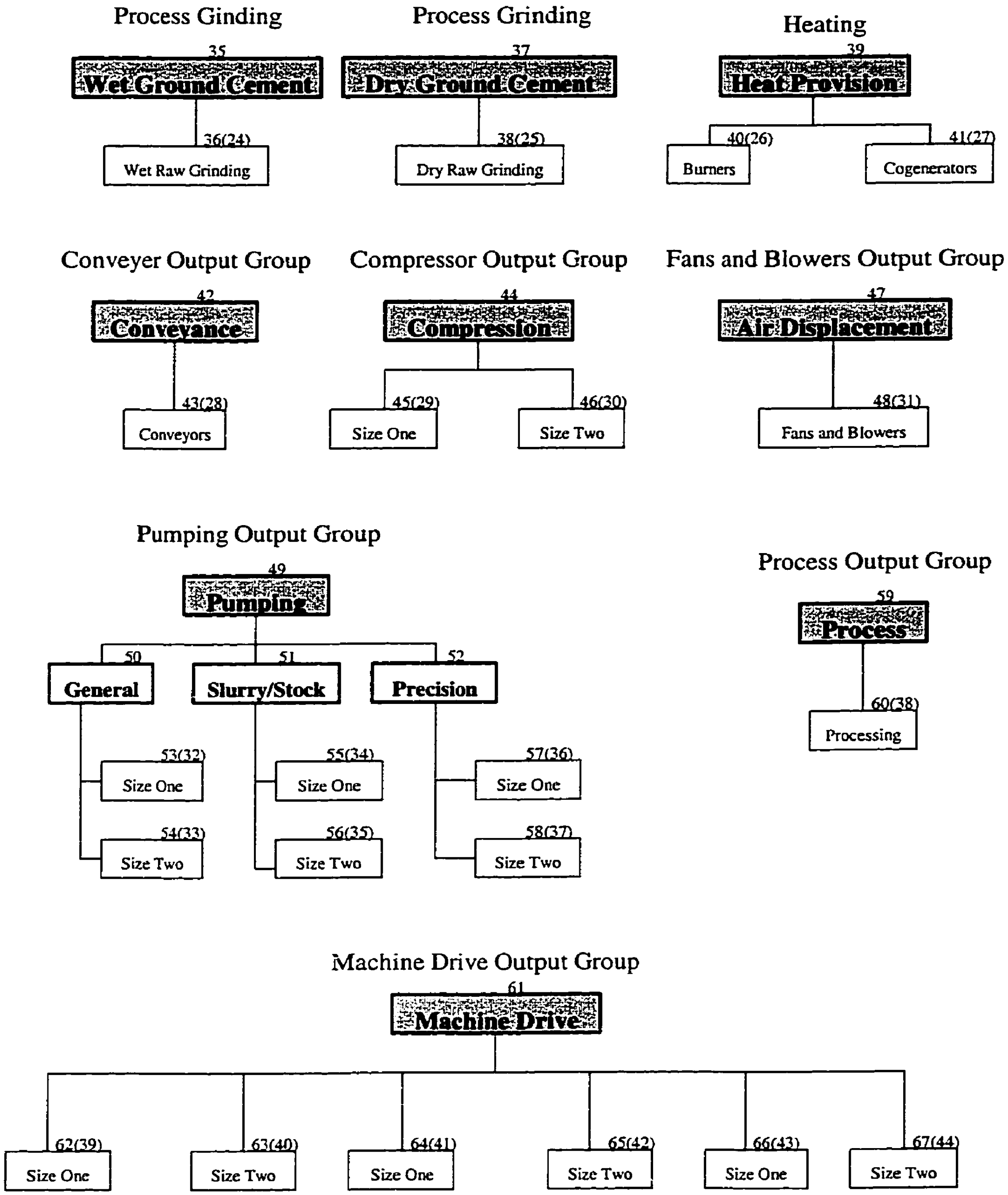


Figure 2: Energy Flow Model of the Industrial Minerals Industry cont'd



Chemical Products

Figure 3: Energy Flow Model of the Chemical Products Industry

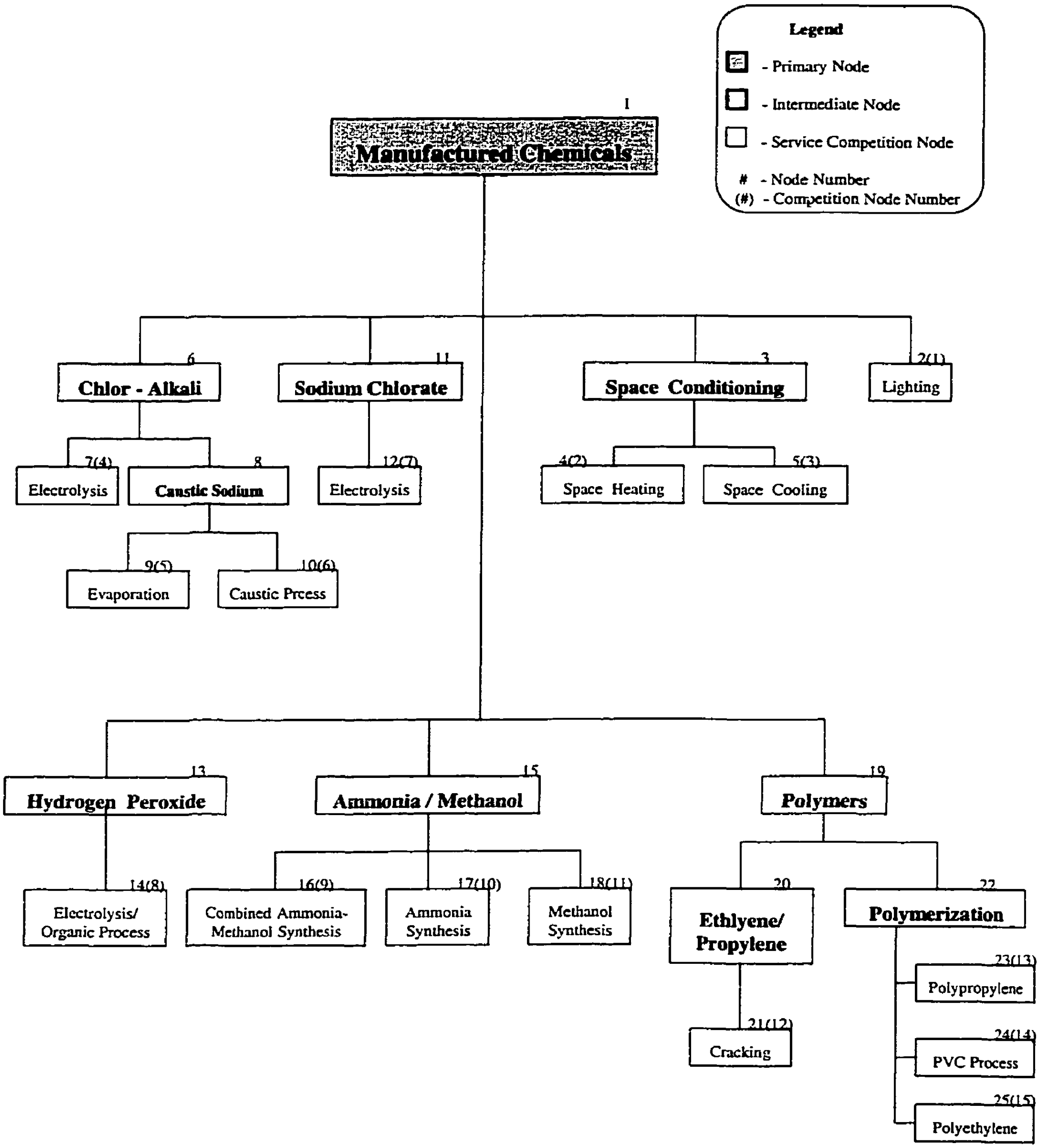
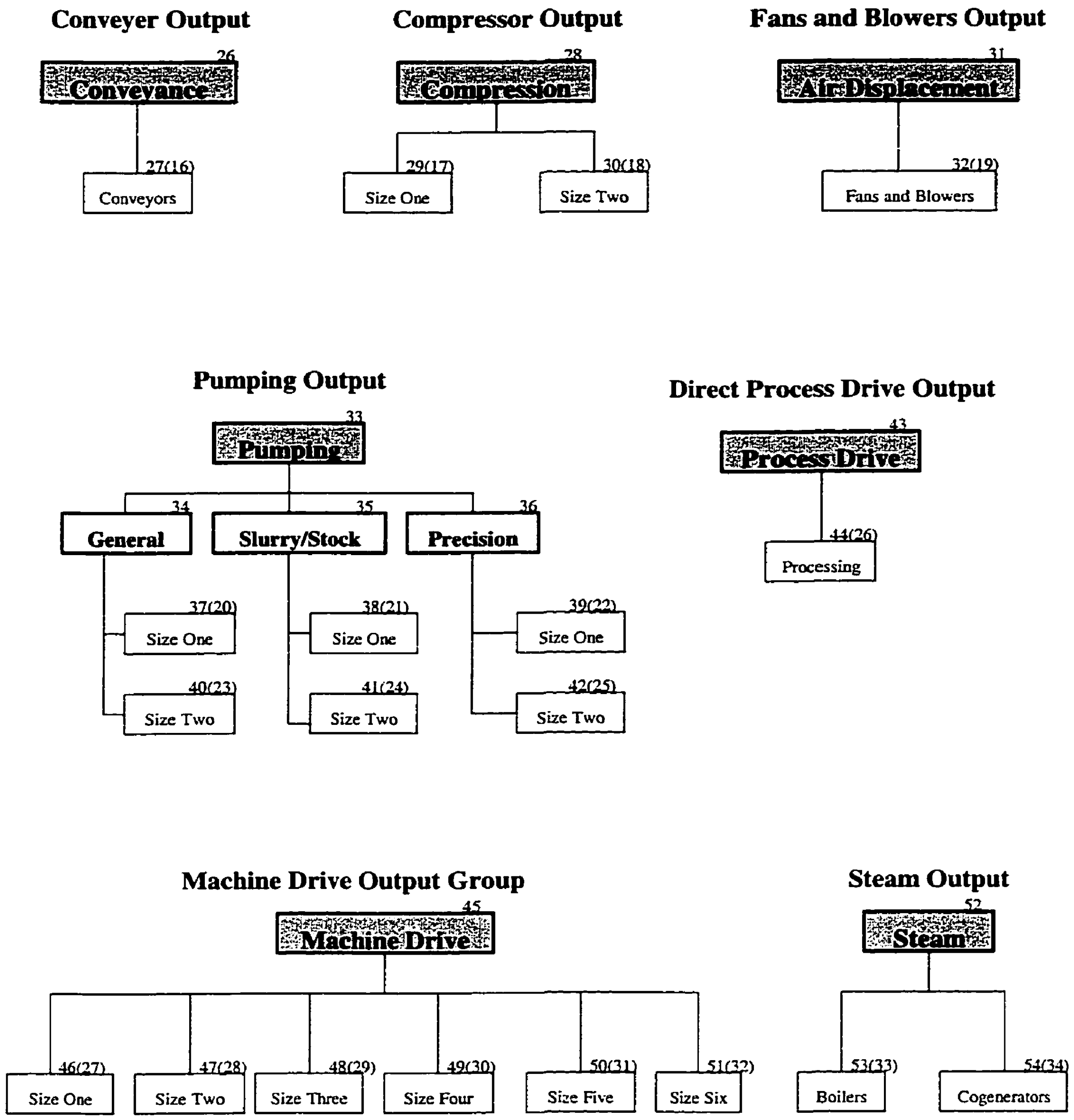


Figure 3: Energy Flow Model of the Chemical Products Industry, Cont'd



Conveyer Output

Compressor Output

Fans and Blowers Output

Pumping Output

Direct Process Drive Output

Machine Drive Output Group

Steam Output

Commercial

Figure 4: Energy Flow Model for the Commercial Sector

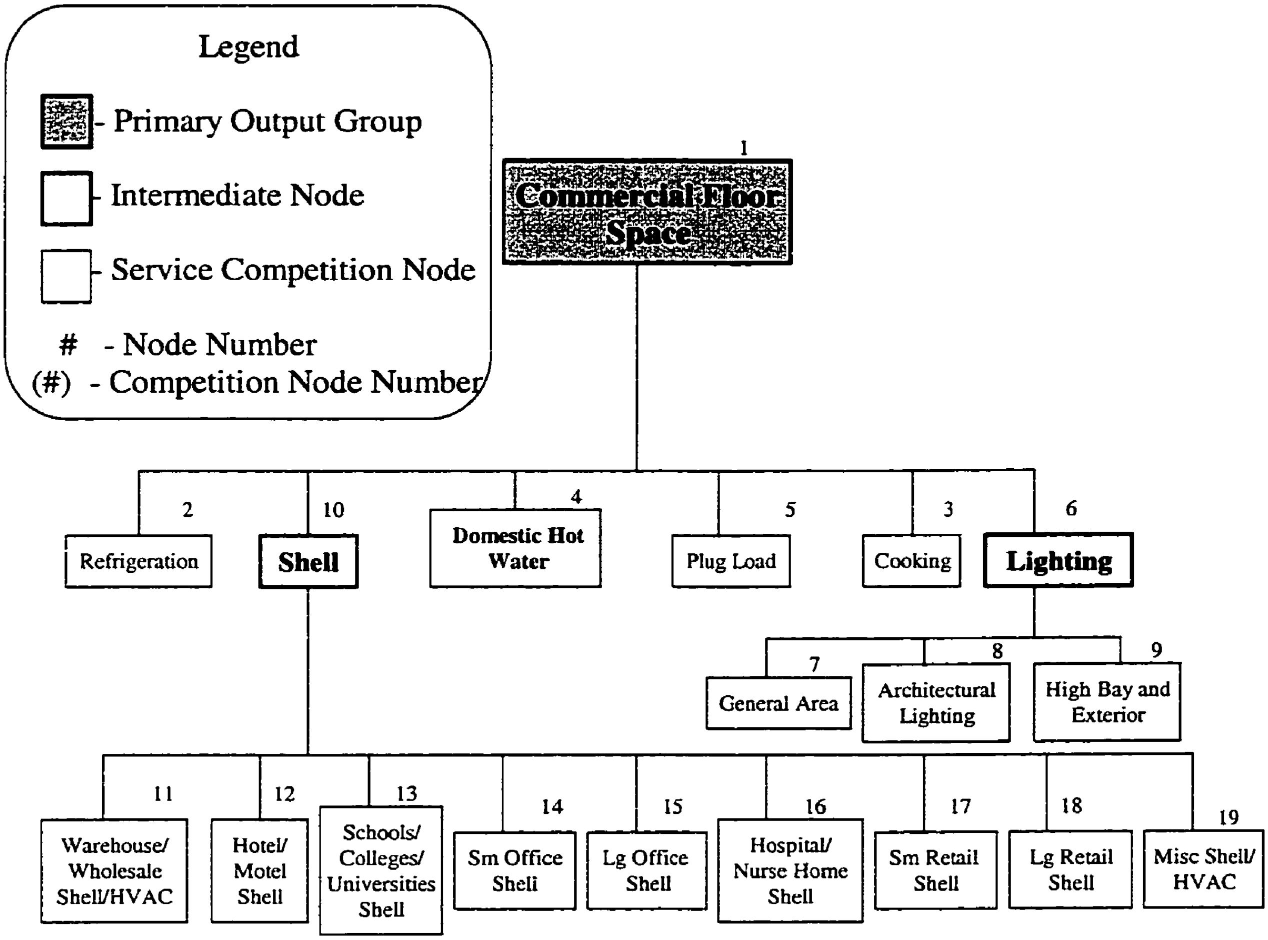
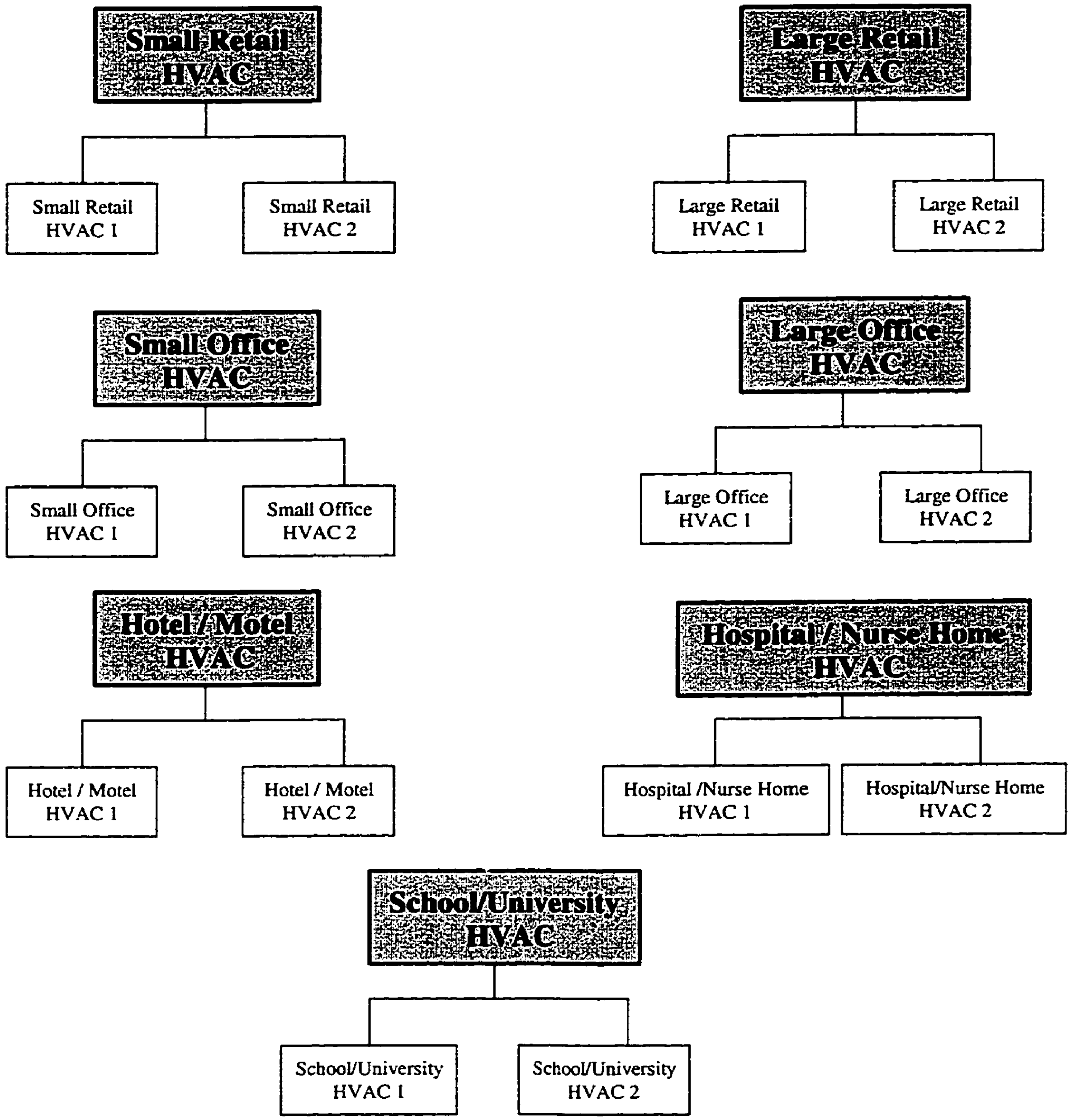


Figure 4. Energy Flow Model for the Commercial Sector cont'd



Iron and Steel

Figure 5: Energy Flow Model of the Iron and Steel Industry

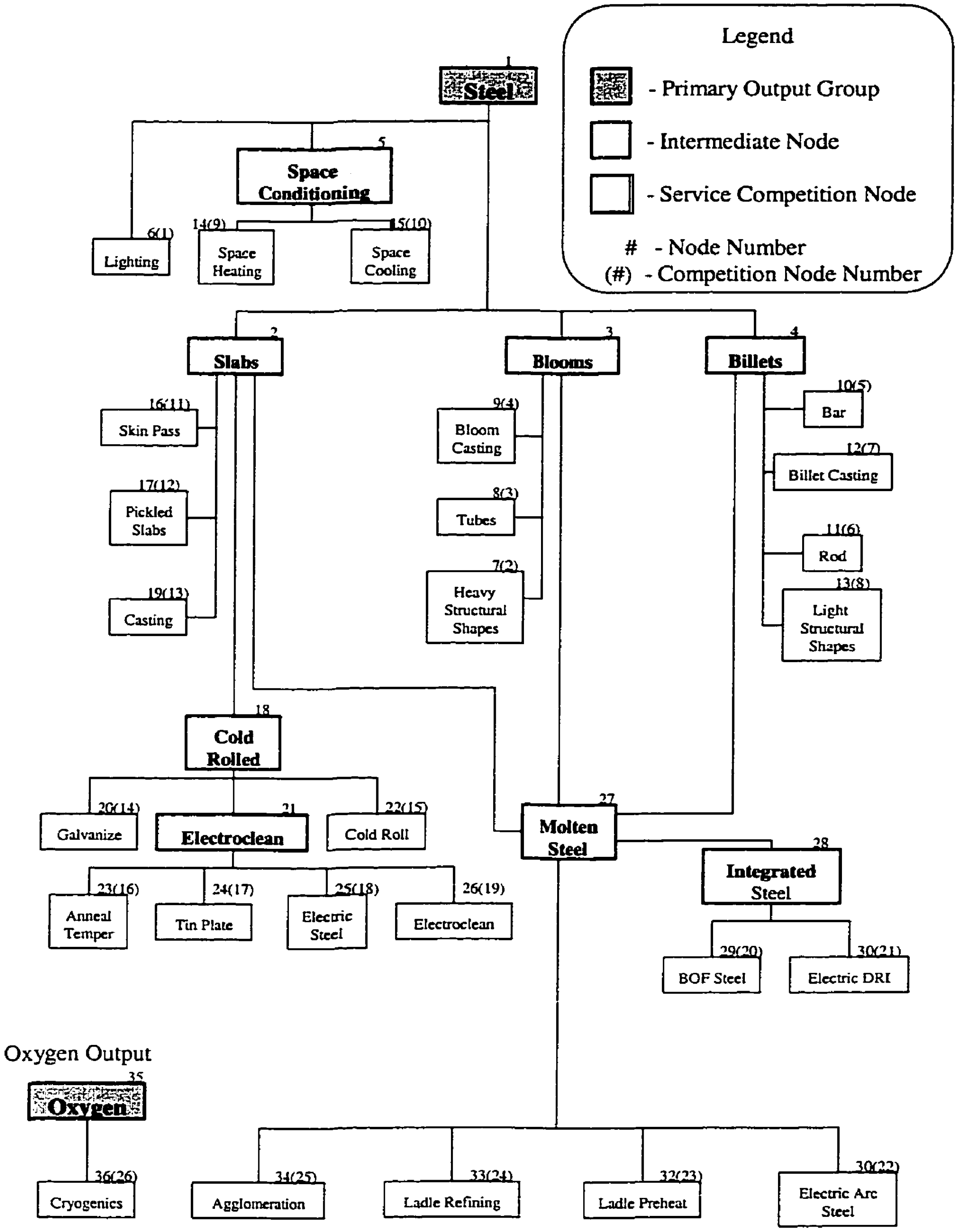
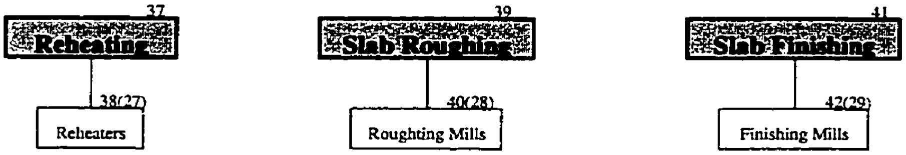
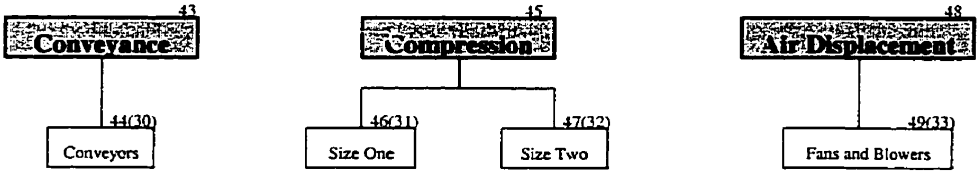


Figure 5: Energy Flow Model of the Iron and Steel Industry, cont'd

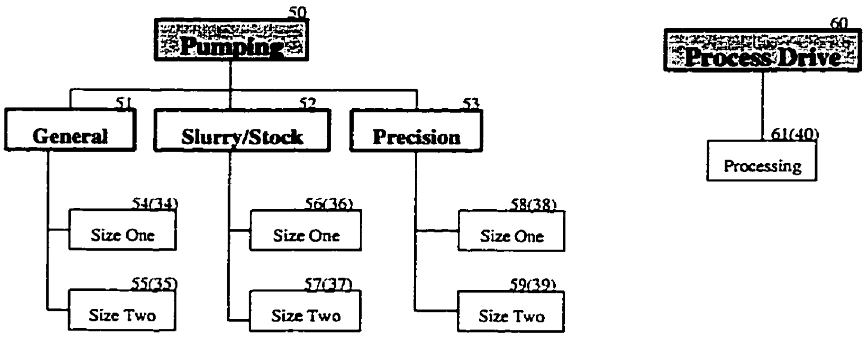
Reheating Output — Slab Roughing Output — Slab Finishing Output



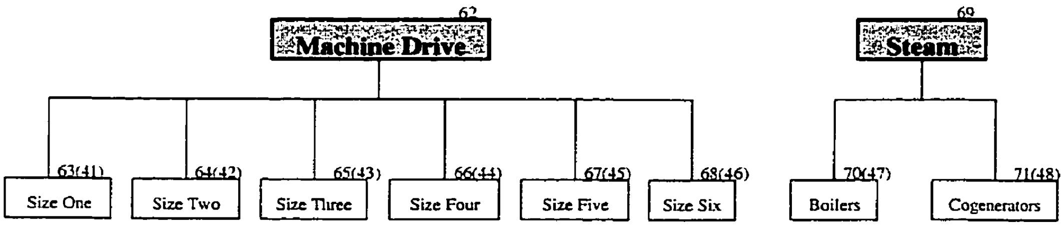
Conveyer Output — Compressor Output — Fans and Blowers Output



Pumping Output — Direct Process Drive Output



Machine Drive Output Group — Steam Output



Metal Smelting

The metal smelting model includes only those metals that are present in the region. The British Columbia metal smelting model includes aluminium, copper, lead and zinc.

Figure 6: Flow Model of the Metal Smelting and Refining Industry

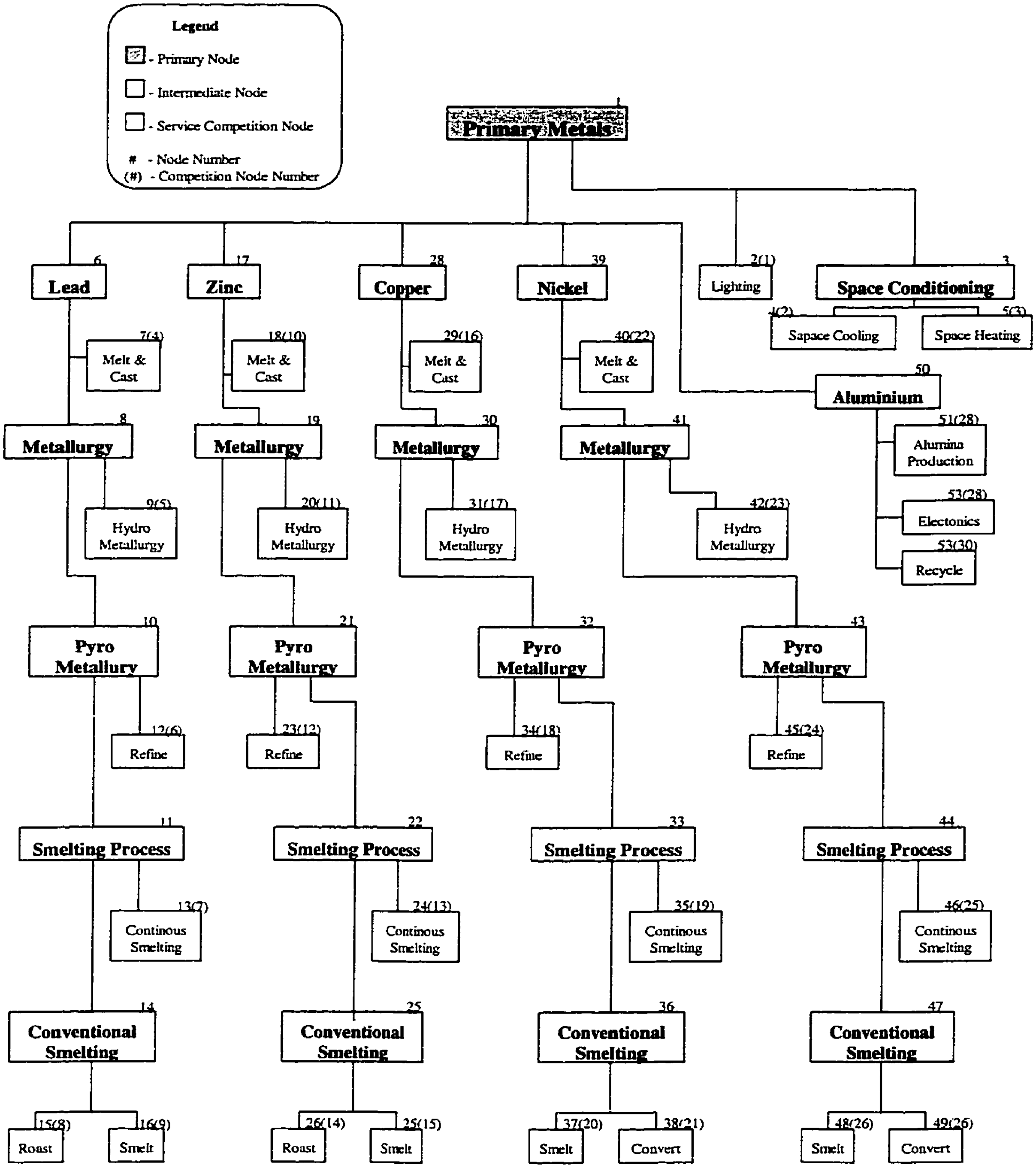
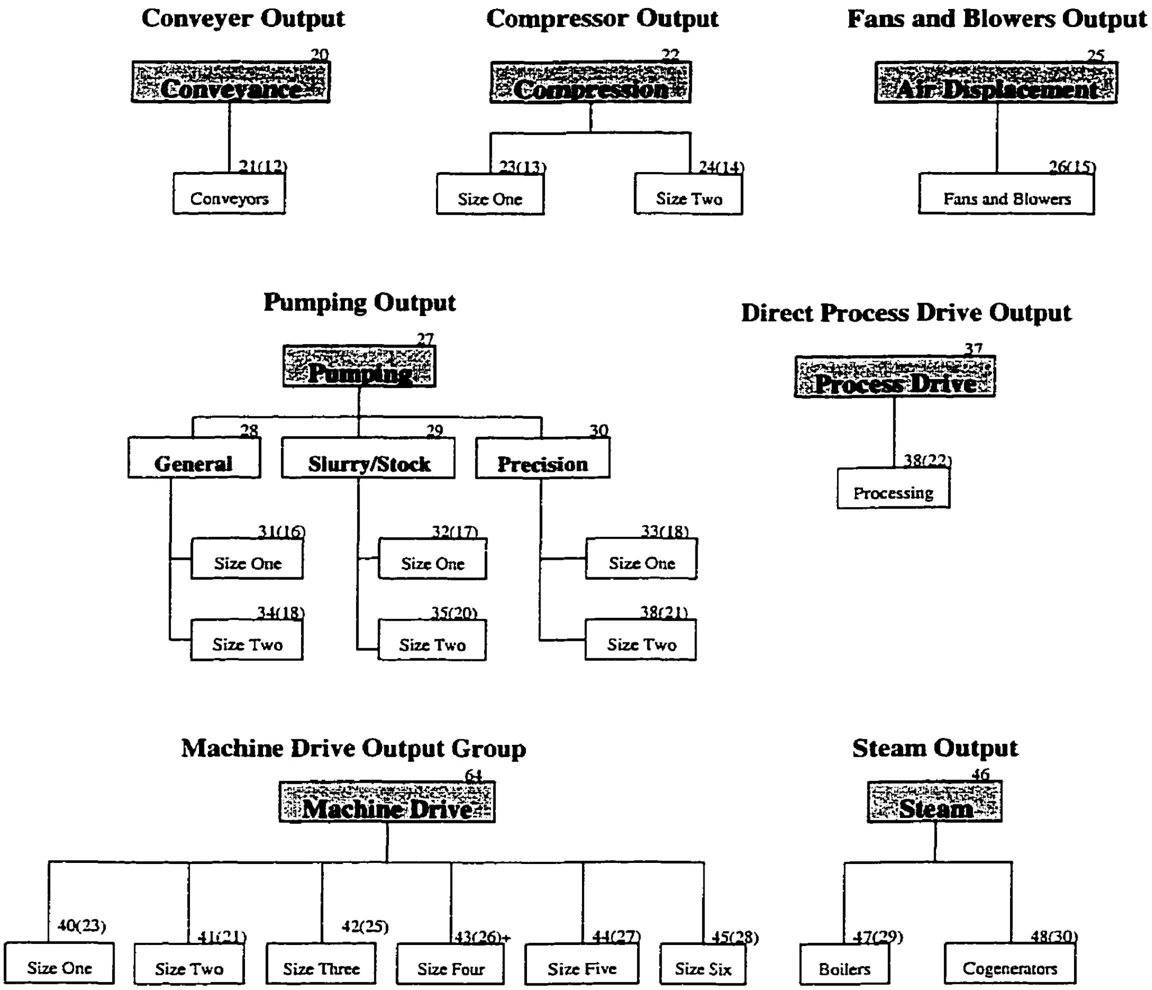


Figure 6: Flow Model of the Metal Smelting and Refining Industry cont'd.


Conveyer Output

Compressor Output

Fans and Blowers Output

Pumping Output

Direct Process Drive Output

Machine Drive Output Group

Steam Output

Mining

British Columbia has both Metal Underground and Metal Open Pit mining.

Figure 7: Energy Flow Model of the Mining Industry

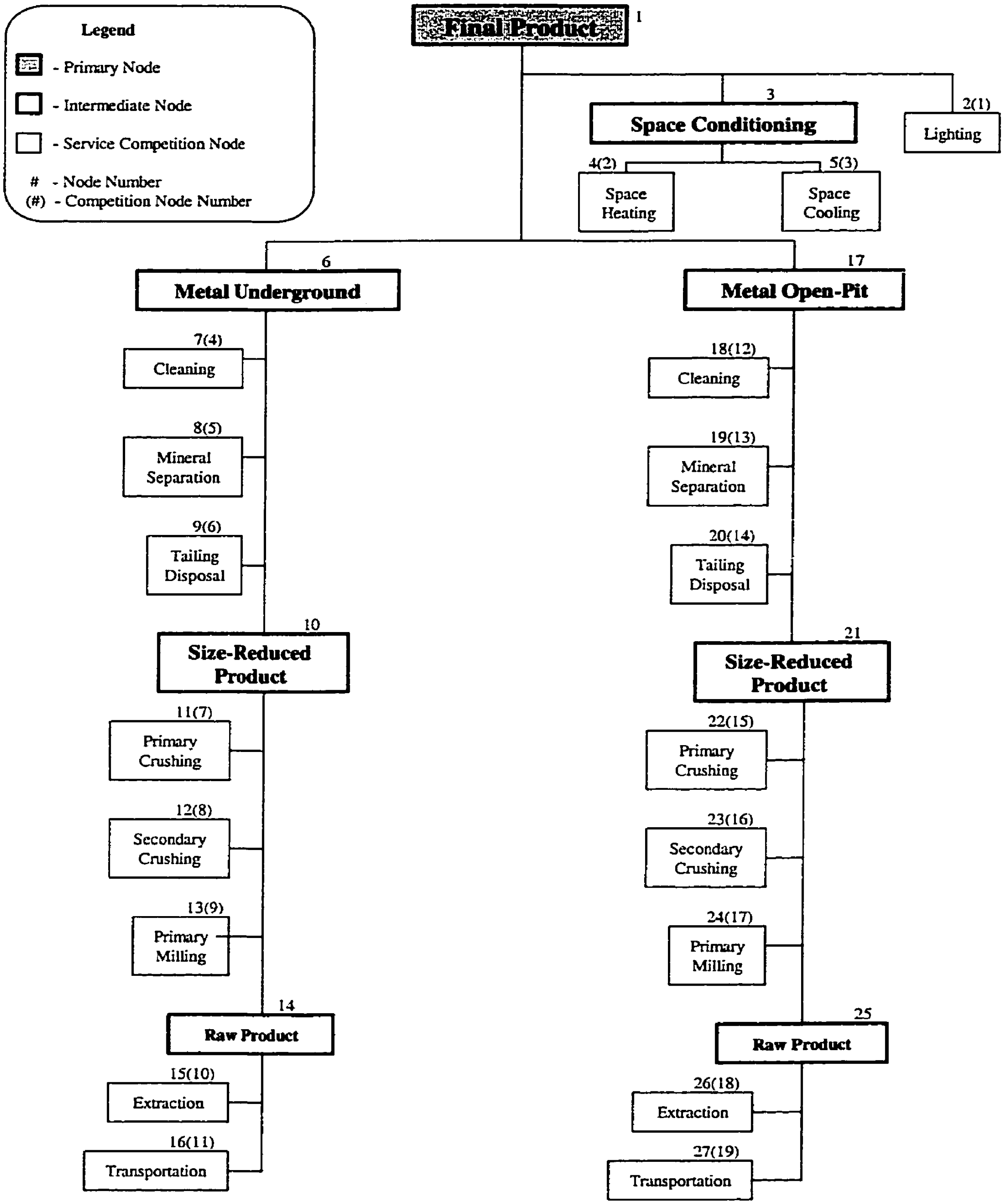
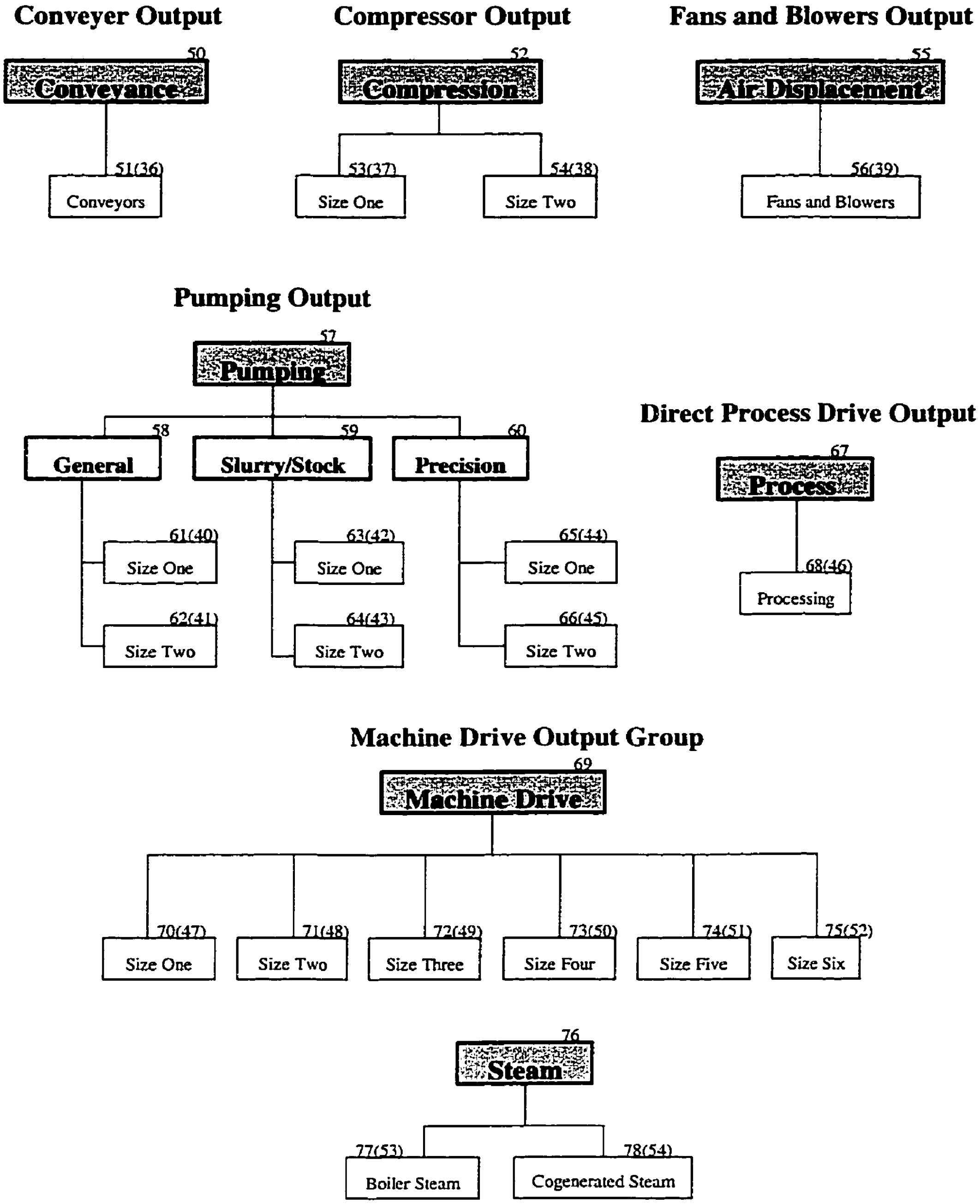


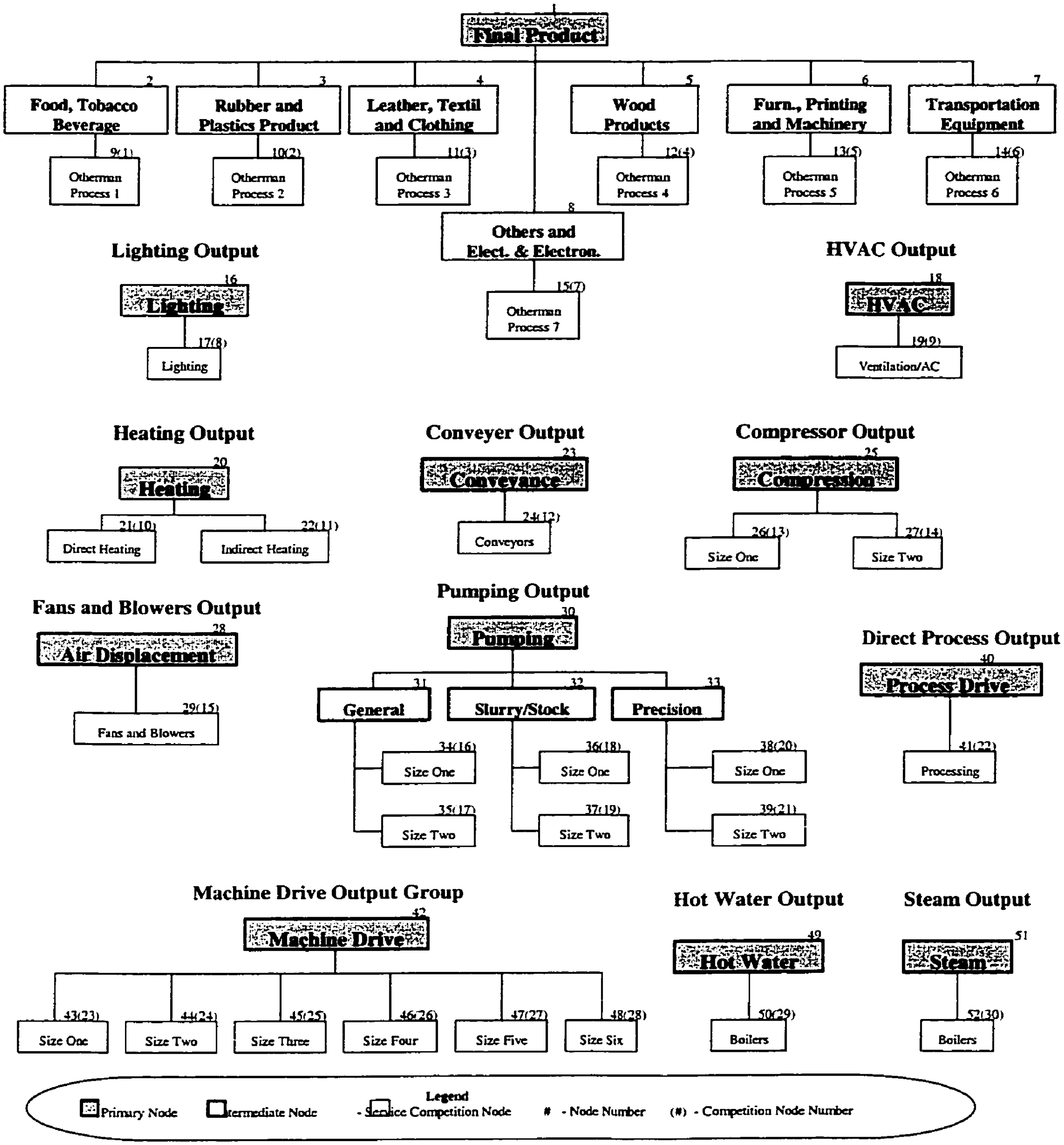
Figure 7: Energy Flow Model Mining Industry, cont'd



Other Manufacturing

All remaining industry not represented in one of the sector specific models defined here are aggregated into one of seven basic sub-categories loosely based on the quantity and type of energy they demand, as well as the expected rate of growth. Each region contains processes 1-7 as defined in the flow model.

Figure 8: Energy Flow Model of the Other Manufacturing



Pulp and Paper

The paper industry is highly variant from one region to another, but all models look the same, with various nodes turned off as defined by products and processes specific to that region.

Figure 9: Energy Flow Model of the Pulp and Paper Industry

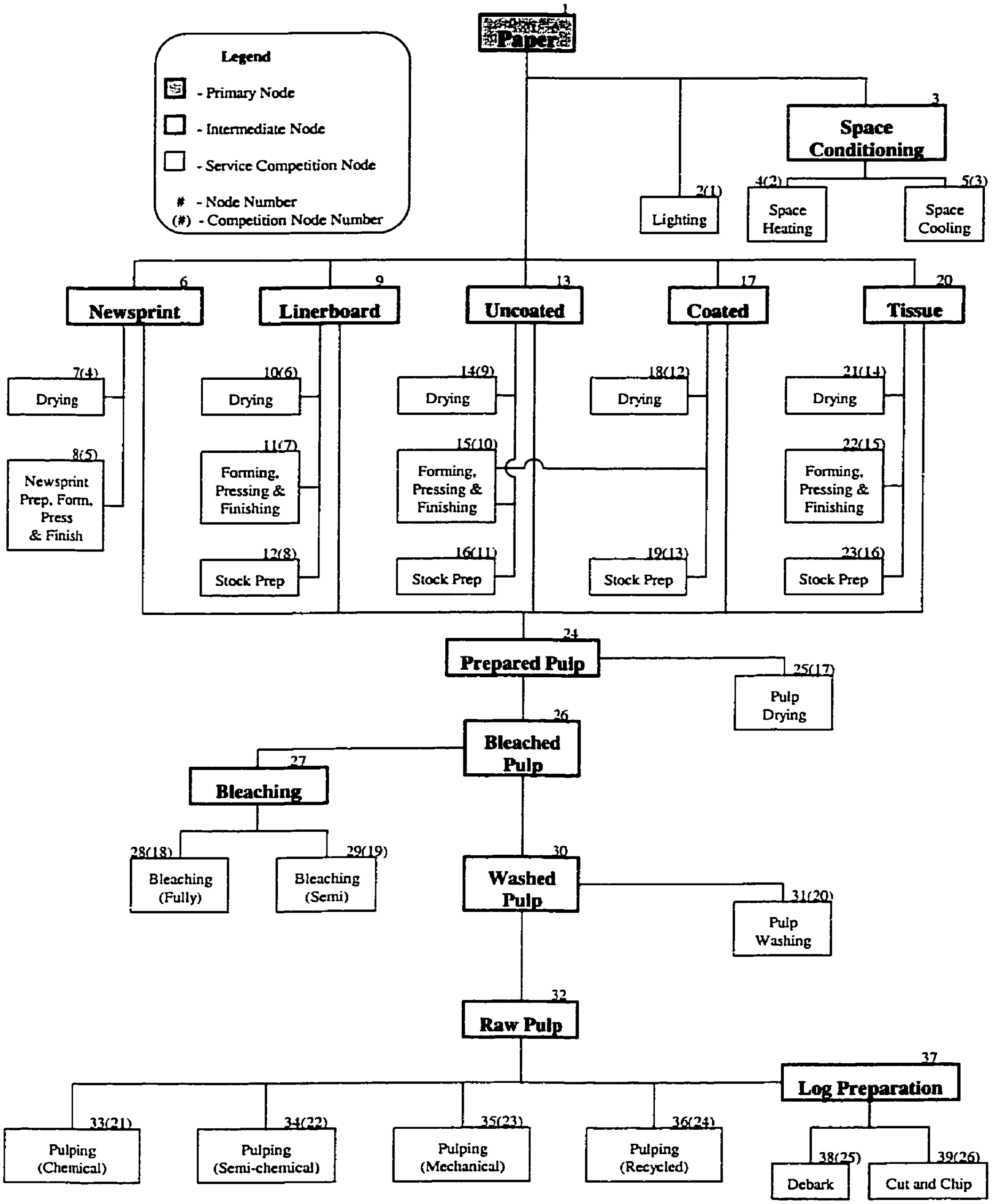
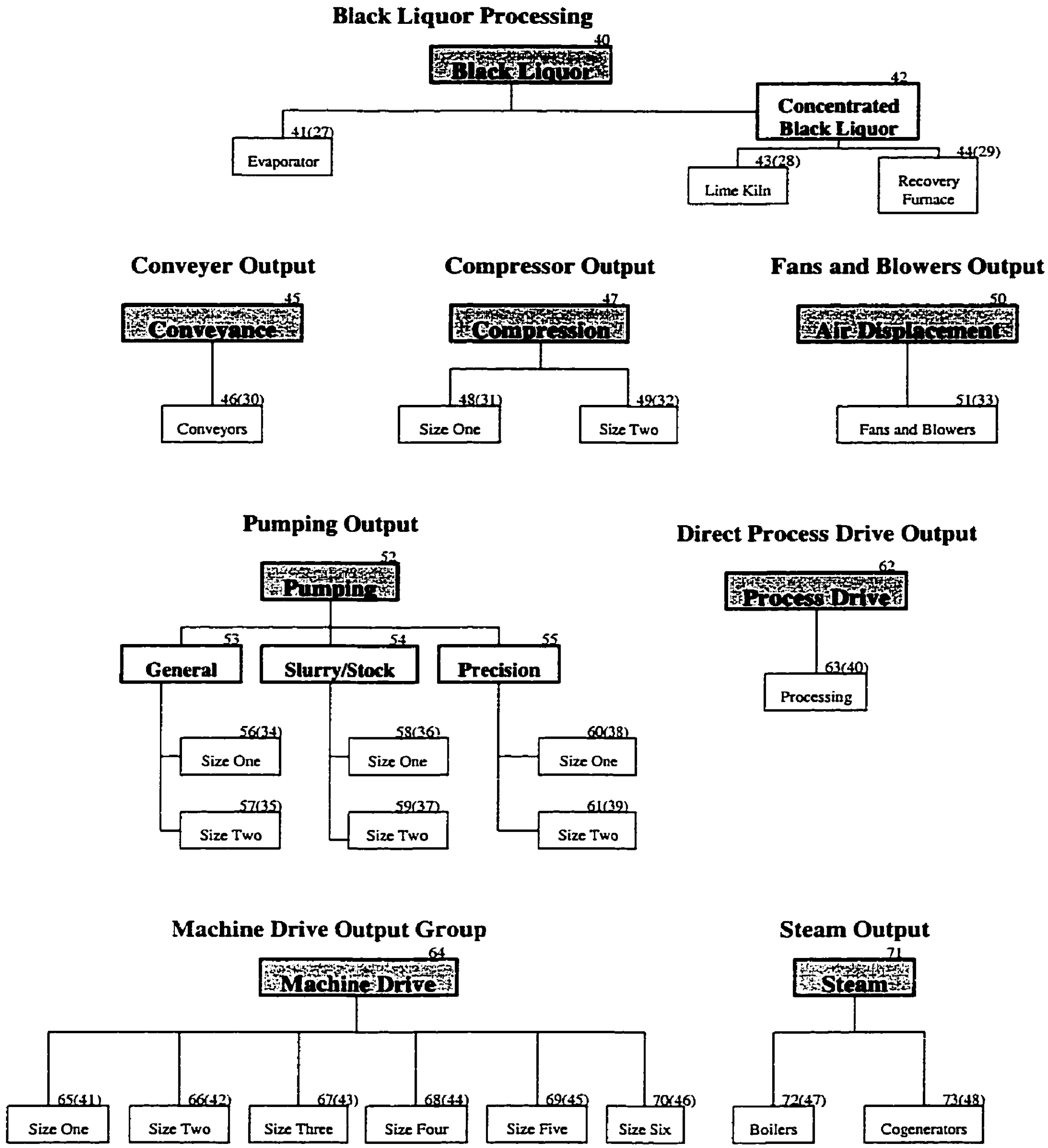


Figure 9: Energy Flow Model of the Pulp and Paper Industry, cont'd



Petroleum Refining
All production is tied to production of gasoline. If the market share ratio between gasoline and other RPPs change over time, the magnitude of the links from gasoline to the other nodes changes as well. The natural gas, once part of this model, has been turned off and in now modelled separately.

Figure 10. Flow Model of Petroleum Refining Industry

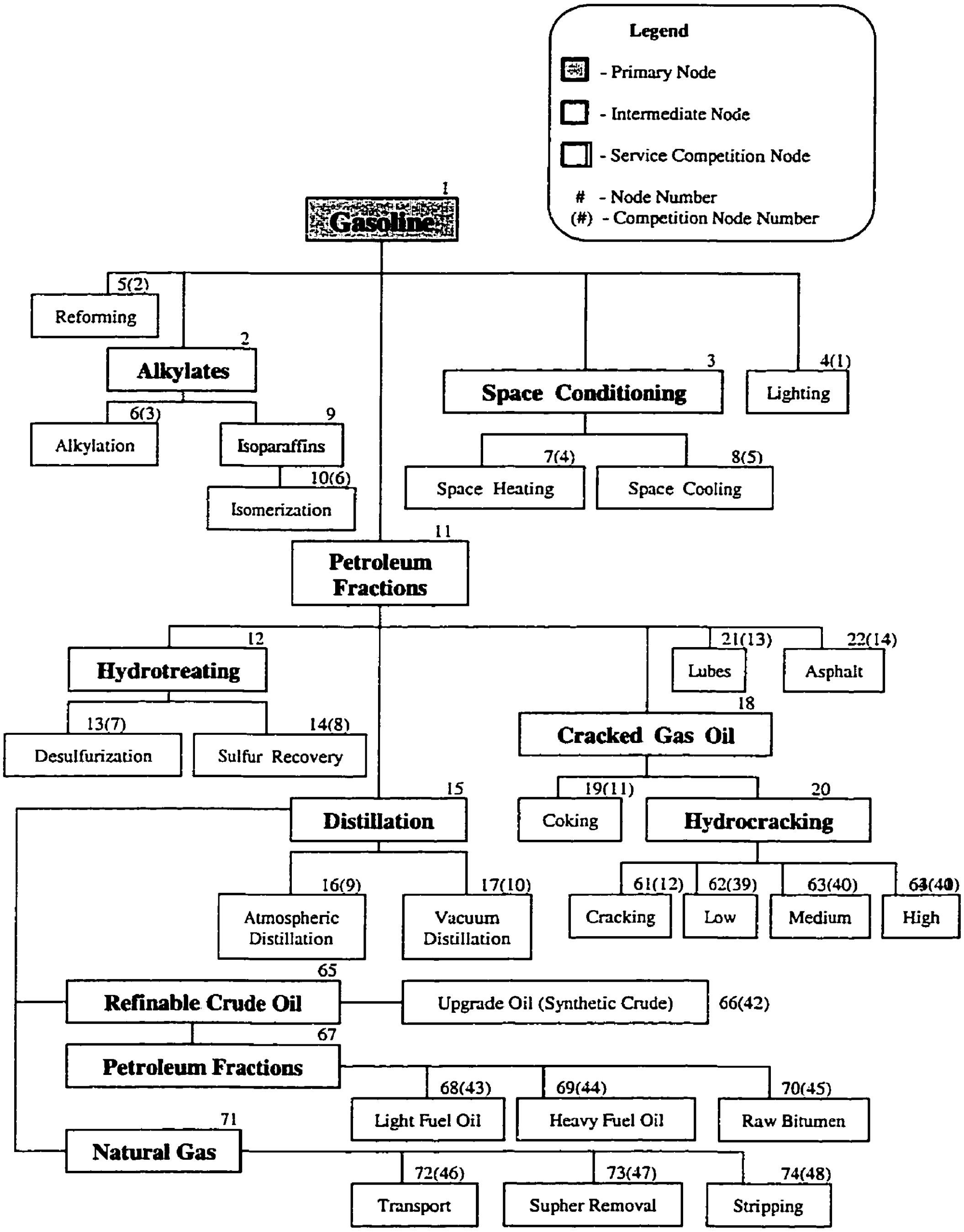
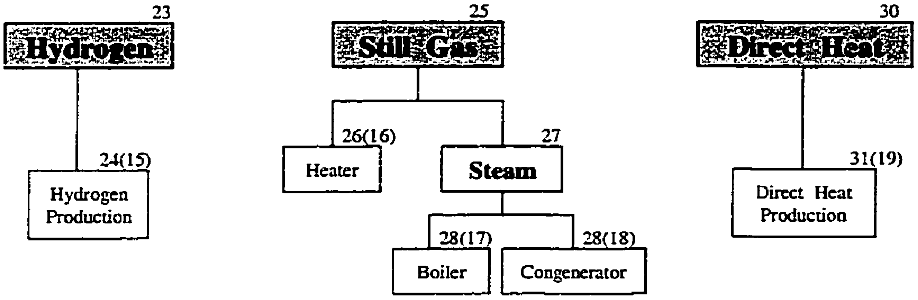
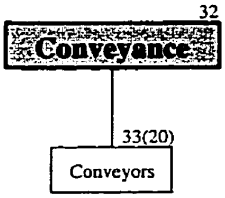


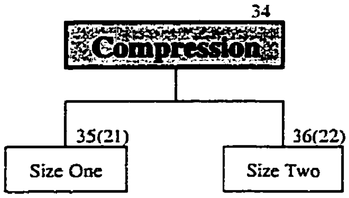
Figure 10. Flow Model of Petroleum Refining Industry cont'd



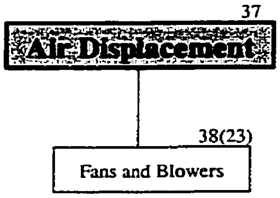
Conveyer Output



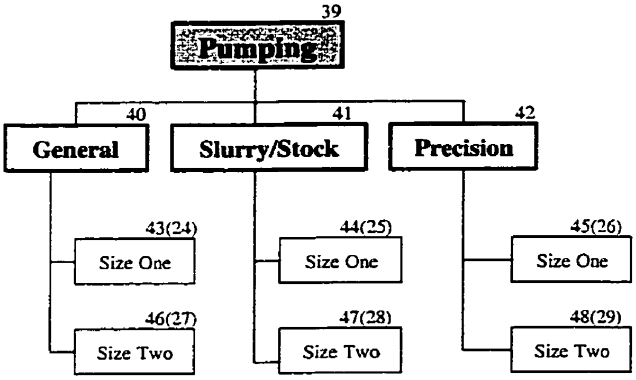
Compressor Output



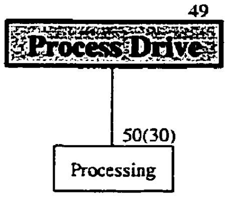
Fans and Blowers Output



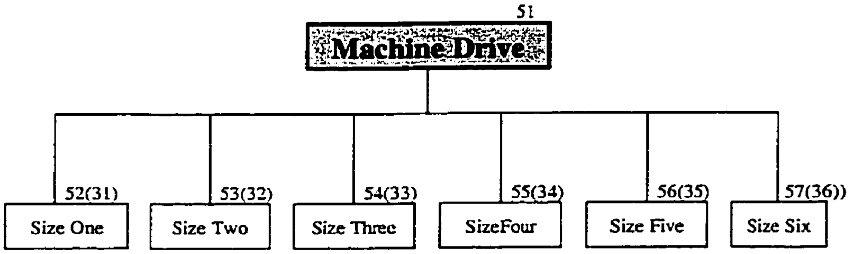
Pumping Output



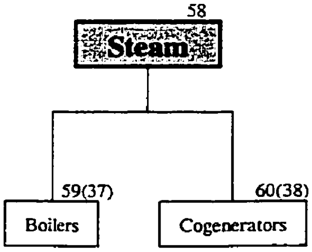
Direct Process Drive Output



Machine Drive Output Group

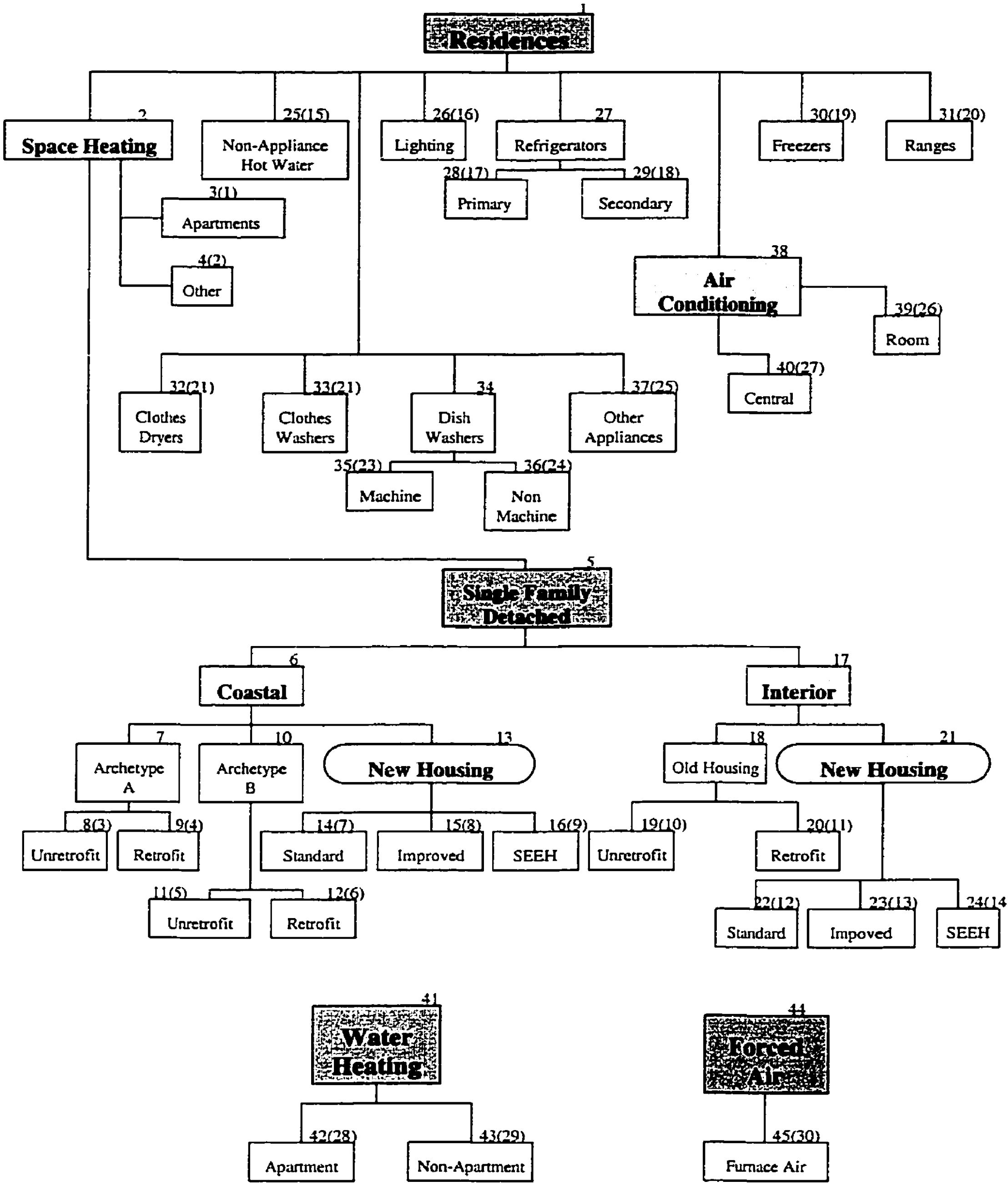


Steam Output



Residential

Figure 11: Energy Flow Model for the Residential Sector



Coal Mining

Coal mining is a variation of the mining flow model.

Figure 12: Energy Flow Model for the Coal Mining Industry

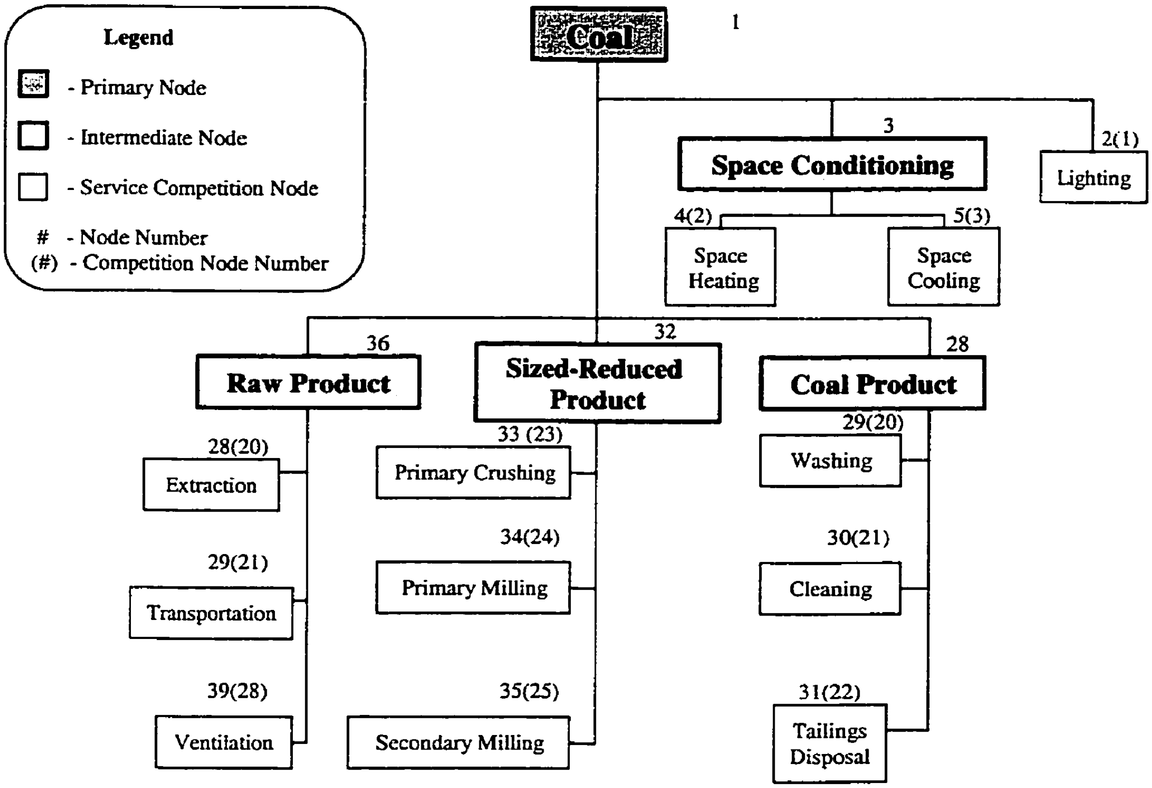
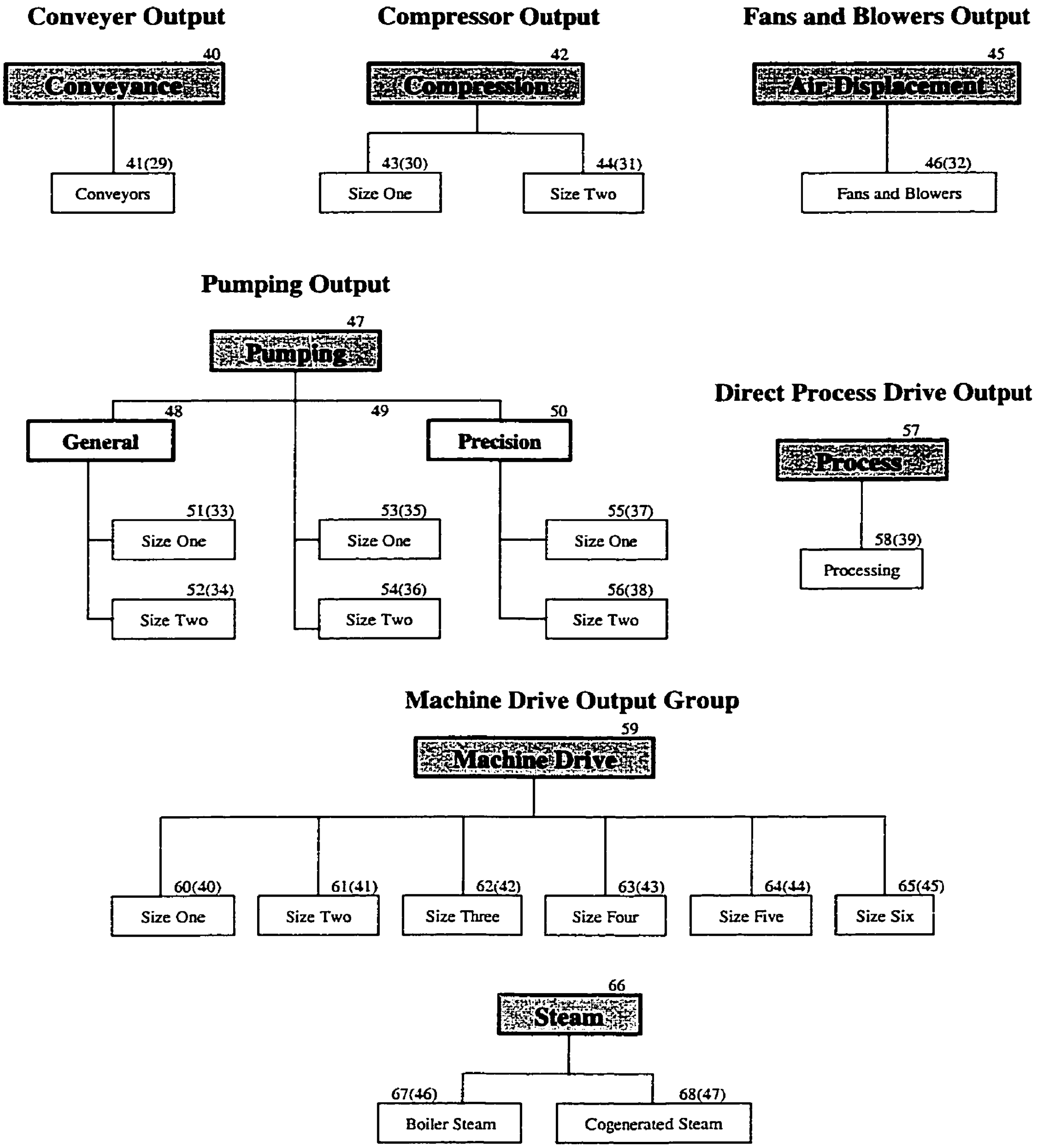


Figure 12: Energy Flow Model for the Coal Mining Industry cont'd



Natural Gas

This model was extracted from the petroleum refining model and improved to reflect potential for reduction of emissions

Figure 13: Energy Flow Model for the Natural Gas Extraction Industry

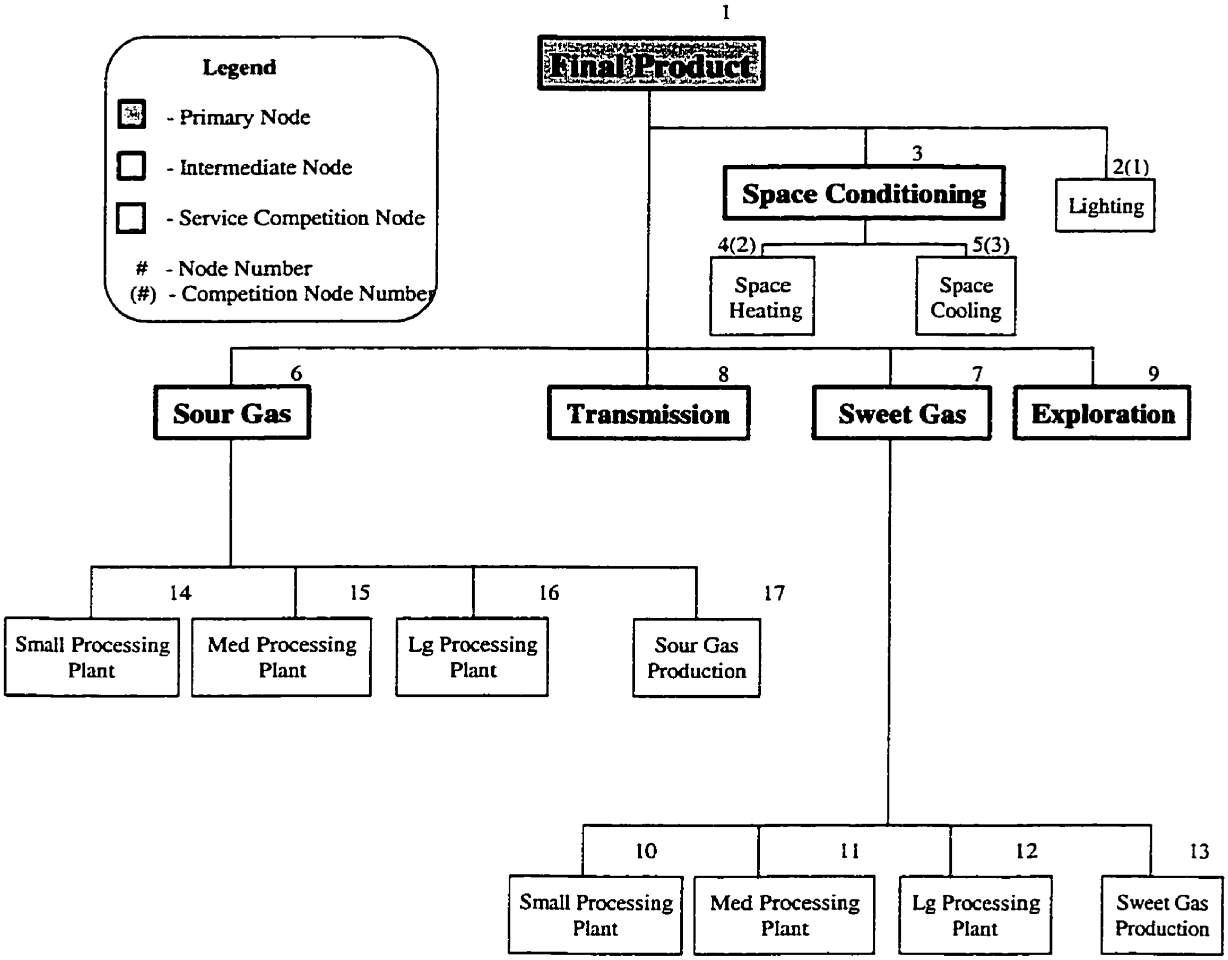


Figure 13. Energy Flow Model for the Natural Gas Extraction Industry cont'd

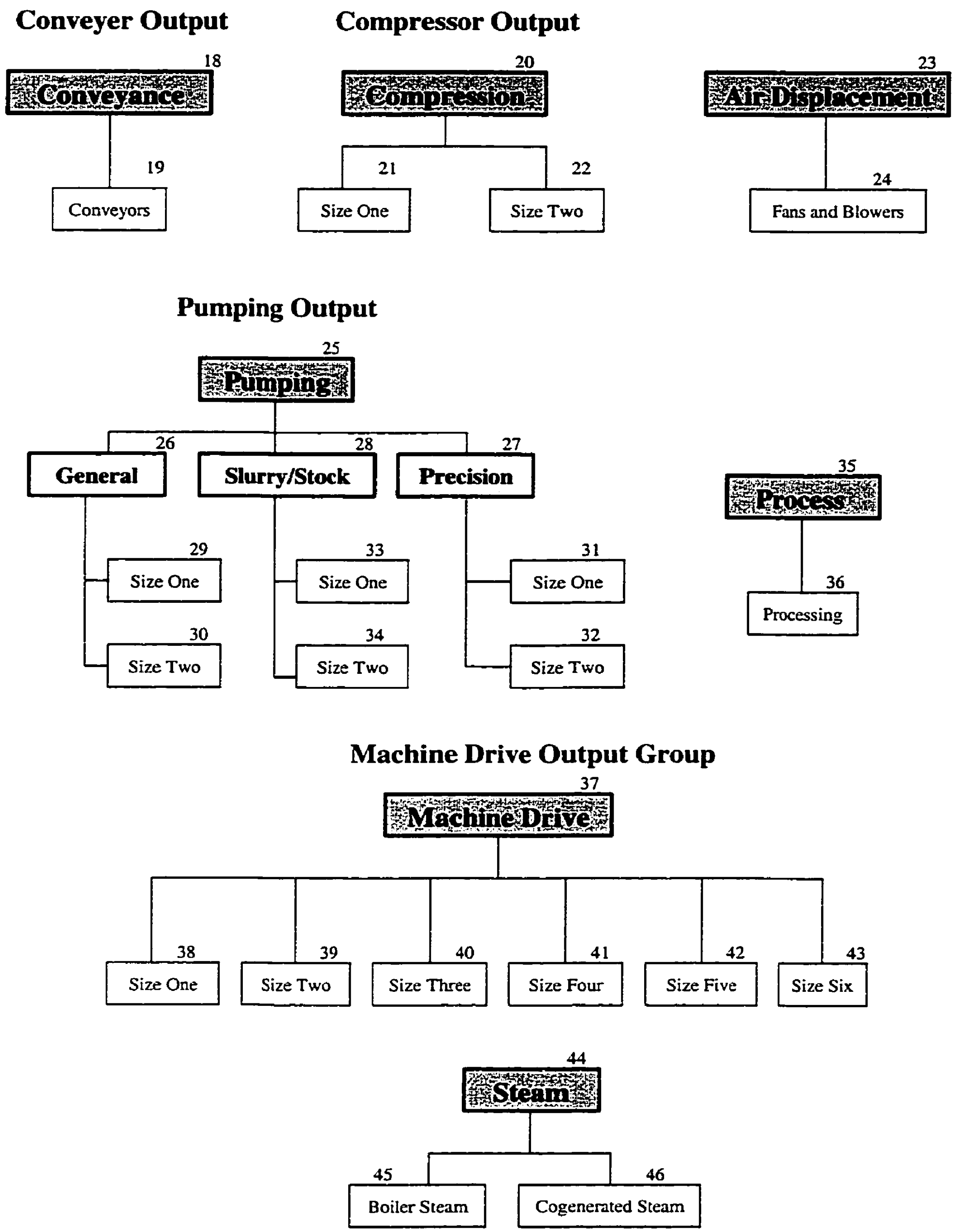


Figure 14. Flow Diagram of Transportation Industry

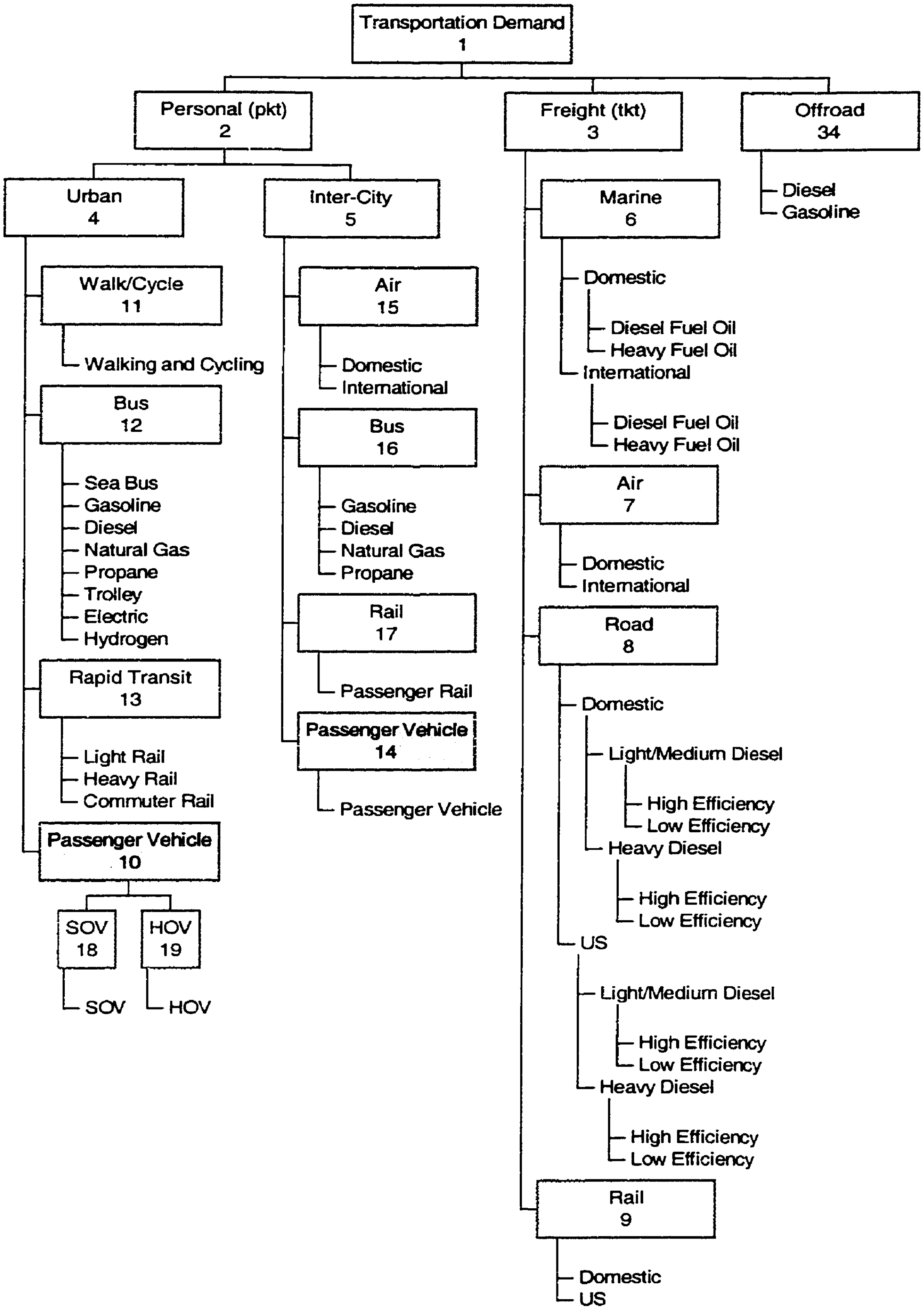
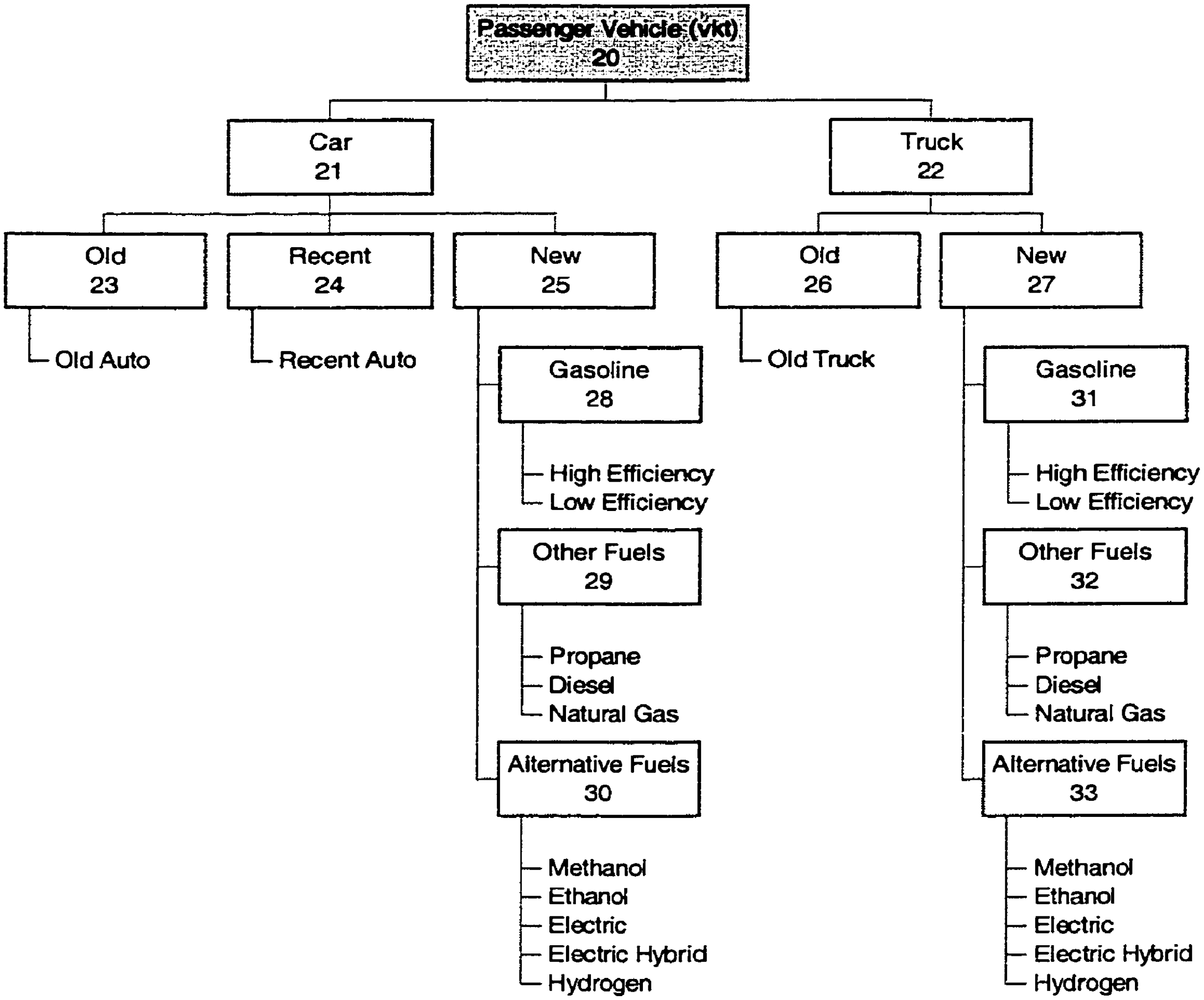


Figure 14. Flow Diagram of Transportation Industry cont'd



Appendix B: Energy Consumption.

Table 1. Energy consumption (PJ) by fuel type in the Average Consumer World, Business-as-Usual scenario.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	67.61	75.76	86.55	100.09
Natural Gas	110.54	132.03	156.56	181.51
RPP	11.48	8.83	7.81	8.79
Coal	3.12	2.89	3.13	3.60
Wood/ Hog Fuel	56.99	56.36	57.48	62.60
Petroleum Coke	0.54	2.79	4.28	5.02
Waste Fuels	0.70	0.75	0.83	0.95
Total	250.98	279.41	316.63	362.56
Electricity (BC)	102.27	119.39	142.77	174.14
% Elec GB	0.66	0.63	0.61	0.57
Commercial				
Electricity	52.16	62.56	71.47	80.28
Natural Gas	67.42	70.76	73.59	80.35
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	128.07	138.10	147.01	161.80
Residential				
Electricity	56.25	53.65	63.26	83.08
Natural Gas	84.21	72.72	80.36	104.24
RPP	5.61	2.73	2.36	2.36
LPG	0.00	0.00	0.00	0.00
Wood	7.63	9.58	10.12	13.71
Total	153.70	138.69	156.10	203.39
Transportation				
RPP	370.93	410.72	467.67	540.28
Natural Gas	3.02	1.40	0.95	1.07
Electricity	0.38	0.53	0.74	1.07
Total	374.33	412.64	469.35	542.41
Total End-Use Energy, Major Fuels				
Electricity	176.40	192.50	222.02	264.52
Natural Gas	265.19	276.91	311.46	367.17
RPP	393.85	425.07	478.47	551.81
Total	835.44	894.48	1011.94	1183.50
Electricity (GB)				
Hydro	138.85	168.51	201.84	205.15
Coal	0.00	0.00	0.00	0.00
Natural Gas	113.66	114.54	116.15	109.61
RPP	9.60	3.27	0.16	0.13
Wood	15.23	9.16	3.09	0.05
Wind	0.00	0.02	0.04	0.05
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	277.34	295.50	321.28	314.99
Electricity Generated	193.91	221.34	253.86	253.86

Table 2. Energy consumption (PJ) by fuel type in the Average Consumer World, Info Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	67.19	75.12	86.31	100.13
Natural Gas	108.53	129.50	153.74	178.41
RPP	11.25	7.81	5.92	6.20
Coal	2.93	1.41	0.82	0.92
Wood/ Hog Fuel	59.89	63.93	68.34	75.16
Petroleum Coke	0.26	0.57	0.81	0.98
Waste Fuels	0.70	0.74	0.82	0.94
Total	250.74	279.07	316.76	362.75
Electricity (BC)	102.16	118.99	142.74	174.31
% Elec GB	0.66	0.63	0.60	0.57
Comm / Inst				
Electricity	52.63	63.86	73.67	82.95
Natural Gas	66.62	68.52	69.87	75.86
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	127.74	137.16	145.49	159.98
Residential				
Electricity	57.59	56.55	68.14	90.03
Natural Gas	82.07	68.38	72.82	93.70
RPP	5.51	2.50	2.08	1.97
LPG	0.00	0.00	0.00	0.00
Wood	7.04	8.19	8.72	11.73
Total	152.21	135.62	151.75	197.44
Transportation				
RPP	368.48	404.45	454.52	522.39
Natural Gas	3.04	1.44	0.82	0.84
Electricity	0.38	0.53	0.74	1.06
Total	371.90	406.41	456.09	524.29
Total End-Use Energy, Major Fuels				
Electricity	177.79	196.05	228.85	274.18
Natural Gas	260.25	267.84	297.25	348.80
RPP	391.07	417.55	463.15	530.94
Total	829.12	881.44	989.25	1153.92
Electricity (GB)				
Hydro	139.99	173.30	211.58	217.69
Coal	0.00	0.00	0.00	0.00
Natural Gas	117.28	114.55	112.36	104.92
RPP	9.68	3.26	0.08	0.06
Wood	15.34	9.22	3.10	0.03
Wind	0.00	0.02	0.04	0.05
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	282.27	300.34	327.15	322.75
Electricity Generated	196.52	225.75	261.29	263.68

*Note: GB indicates Georgia Basin industries.

Table 3. Energy consumption (PJ) by fuel type in the Average Consumer World, Low Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	66.83	74.67	86.52	100.81
Natural Gas	108.41	129.64	153.88	178.45
RPP	11.18	7.47	5.27	5.29
Coal	2.90	1.14	0.38	0.37
Wood/ Hog Fuel	59.91	63.93	68.29	75.06
Petroleum Coke	0.23	0.26	0.30	0.36
Waste Fuels	0.70	0.74	0.82	0.93
Total	250.17	277.84	315.44	361.28
Electricity (BC)	101.78	118.57	143.11	175.29
% Elec GB	0.66	0.63	0.60	0.58
Comm / Inst				
Electricity	53.01	65.05	75.77	85.64
Natural Gas	65.98	66.48	66.34	71.37
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	127.47	136.32	144.06	158.18
Residential				
Electricity	58.09	58.79	72.13	95.98
Natural Gas	81.12	64.73	66.35	84.30
RPP	5.46	2.35	1.89	1.72
LPG	0.00	0.00	0.00	0.00
Wood	6.70	7.41	8.01	10.81
Total	151.36	133.28	148.38	192.80
Transportation				
RPP	366.47	399.70	450.18	518.66
Natural Gas	3.06	1.47	0.84	0.86
Electricity	0.38	0.53	0.74	1.07
Total	369.91	401.69	451.76	520.59
Total End-Use Energy, Major Fuels				
Electricity	178.31	199.03	235.16	283.49
Natural Gas	258.56	262.32	287.40	334.98
RPP	388.94	412.31	457.96	526.05
Total	825.82	873.67	980.52	1144.52
Electricity (GB)				
Hydro	140.99	177.44	219.72	228.58
Coal	0.00	0.00	0.00	0.00
Natural Gas	118.69	114.04	109.75	101.76
RPP	9.74	3.26	0.04	0.03
Wood	15.43	9.27	3.11	0.03
Wind	0.00	0.02	0.04	0.05
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	284.85	304.04	332.66	330.45
Electricity Generated	198.14	229.54	268.03	272.92

*Note: GB indicates Georgia Basin industries.

Table 4. Energy consumption (PJ) by fuel type in the Average Consumer World, High Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	70.30	82.61	105.00	131.63
Natural Gas	102.11	115.91	128.35	139.68
RPP	11.04	6.76	3.83	3.18
Coal	2.89	1.01	0.17	0.11
Wood/ Hog Fuel	60.16	64.77	69.29	75.92
Petroleum Coke	0.21	0.12	0.07	0.08
Waste Fuels	0.70	0.73	0.80	0.92
Total	247.40	271.91	307.52	351.51
Electricity (BC)	105.27	127.39	163.72	208.47
% Elec GB	0.67	0.65	0.64	0.63
Comm / Inst				
Electricity	55.31	71.18	86.03	98.28
Natural Gas	62.15	56.25	49.37	50.58
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	125.95	132.21	137.35	150.04
Residential				
Electricity	63.51	67.54	84.24	114.65
Natural Gas	71.38	49.16	45.75	53.91
RPP	5.25	1.94	1.47	1.14
LPG	0.00	0.00	0.00	0.00
Wood	6.25	6.44	7.38	10.35
Total	146.40	125.08	138.85	180.05
Transportation				
RPP	359.32	383.48	436.25	506.18
Natural Gas	3.12	1.58	0.93	0.96
Electricity	0.38	0.53	0.74	1.07
Total	362.82	385.59	437.92	508.21
Total End-Use Energy, Major Fuels				
Electricity	189.51	221.85	276.02	345.62
Natural Gas	238.75	222.90	224.41	245.13
RPP	381.44	394.98	442.18	510.88
Total	809.70	839.73	942.60	1101.63
Electricity (GB)				
Hydro	162.00	210.75	270.90	297.79
Coal	0.00	0.00	0.00	0.00
Natural Gas	103.16	95.33	87.56	78.61
RPP	10.06	3.35	0.00	0.00
Wood	15.95	9.58	3.21	0.03
Wind	0.02	0.04	0.06	0.07
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	291.18	319.06	361.74	376.50
Electricity Generated	213.88	256.00	310.76	333.46

*Note: GB indicates Georgia Basin industries.

Table 5. Energy consumption (PJ) by fuel type in the Economic Efficiency World, Business-as-Usual scenario.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	63.26	63.98	70.25	80.84
Natural Gas	109.80	134.88	162.96	190.21
RPP	10.62	5.12	1.20	0.03
Coal	2.88	1.02	0.22	0.22
Wood/ Hog Fuel	60.16	65.02	70.23	77.57
Petroleum Coke	0.21	0.22	0.31	0.47
Waste Fuels	0.70	0.74	0.82	0.93
Total	247.63	270.99	305.98	350.27
Electricity (BC)	97.54	106.05	123.56	151.28
% Elec GB	0.65	0.60	0.57	0.53
Comm / Inst				
Electricity	47.98	56.02	61.79	69.24
Natural Gas	66.59	77.59	87.48	96.13
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	123.06	138.40	151.22	166.54
Residential				
Electricity	40.82	27.32	28.93	38.18
Natural Gas	102.00	97.95	110.58	142.20
RPP	4.77	1.39	1.01	0.63
LPG	0.00	0.00	0.00	0.00
Wood	4.12	1.72	1.76	2.21
Total	151.71	128.38	142.28	183.21
Transportation				
RPP	366.92	394.36	442.90	513.66
Natural Gas	2.79	0.90	0.37	0.43
Electricity	0.38	0.52	0.74	1.06
Total	370.10	395.78	444.01	515.16
Total End-Use Energy, Major Fuels				
Electricity	152.45	147.85	161.70	189.33
Natural Gas	281.18	311.32	361.39	428.96
RPP	388.14	403.66	445.73	514.70
Total	821.78	862.83	968.83	1132.99
Electricity (GB)				
Hydro	128.13	144.47	168.34	161.58
Coal	0.00	0.00	0.00	0.00
Natural Gas	63.65	56.09	48.52	40.49
RPP	8.96	2.99	0.00	0.00
Wood	14.20	8.52	2.84	0.00
Wind	0.00	0.00	0.00	0.00
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	214.93	212.07	219.72	202.08
Electricity Generated	163.17	172.83	191.04	179.93

*Note: GB indicates Georgia Basin industries.

Table 6. Energy consumption (PJ) by fuel type in the Economic Efficiency World, Info Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	63.22	64.45	71.35	82.00
Natural Gas	109.41	133.51	160.66	187.39
RPP	10.62	5.12	1.20	0.03
Coal	2.88	0.95	0.08	0.01
Wood/ Hog Fuel	60.31	65.44	70.94	78.52
Petroleum Coke	0.21	0.07	0.00	0.01
Waste Fuels	0.70	0.73	0.80	0.92
Total	247.34	270.29	305.04	348.87
Electricity (BC)	97.52	106.56	124.87	152.56
% Elec GB	0.65	0.60	0.57	0.54
Comm / Inst				
Electricity	48.52	58.43	66.40	74.80
Natural Gas	65.62	73.42	79.62	86.67
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	122.64	136.63	147.98	162.64
Residential				
Electricity	40.56	29.00	33.78	43.20
Natural Gas	99.93	92.05	99.05	126.86
RPP	4.77	1.38	0.99	0.61
LPG	0.00	0.00	0.00	0.00
Wood	4.15	1.81	1.90	2.34
Total	149.42	124.23	135.73	173.02
Transportation				
RPP	362.09	384.13	431.26	499.40
Natural Gas	2.79	0.90	0.37	0.43
Electricity	0.38	0.52	0.74	1.06
Total	365.26	385.56	432.36	500.90
Total End-Use Energy, Major Fuels				
Electricity	152.69	152.41	172.27	201.06
Natural Gas	277.76	299.87	339.70	401.36
RPP	383.30	393.42	434.08	500.42
Total	813.75	845.70	946.05	1102.85
Electricity (GB)				
Hydro	130.15	149.94	178.71	172.61
Coal	0.00	0.00	0.00	0.00
Natural Gas	65.05	57.32	49.56	41.43
RPP	9.10	3.03	0.00	0.00
Wood	14.42	8.66	2.89	0.00
Wind	0.00	0.00	0.01	0.01
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	218.72	218.95	231.17	214.06
Electricity Generated	165.90	178.92	201.98	191.50

*Note: GB indicates Georgia Basin industries.

Table 7. Energy consumption (PJ) by fuel type in the Economic Efficiency World, Low Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	63.15	63.90	70.76	81.55
Natural Gas	109.15	132.82	159.41	185.68
RPP	10.62	5.12	1.20	0.03
Coal	2.88	0.95	0.08	0.00
Wood/ Hog Fuel	60.39	65.81	71.45	79.01
Petroleum Coke	0.21	0.07	0.00	0.00
Waste Fuels	0.69	0.73	0.80	0.91
Total	247.09	269.40	303.70	347.18
Electricity (BC)	97.43	105.98	124.34	152.39
% Elec GB	0.65	0.60	0.57	0.54
Comm / Inst				
Electricity	49.01	60.85	70.97	80.96
Natural Gas	64.59	69.18	71.78	76.21
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	122.09	134.82	144.70	158.34
Residential				
Electricity	40.45	30.59	38.06	51.99
Natural Gas	96.81	84.51	84.88	103.51
RPP	4.76	1.37	0.99	0.61
LPG	0.00	0.00	0.00	0.00
Wood	4.15	1.76	1.83	2.26
Total	146.17	118.24	125.76	158.37
Transportation				
RPP	358.48	376.79	423.22	489.60
Natural Gas	2.79	0.90	0.37	0.43
Electricity	0.38	0.52	0.74	1.06
Total	361.66	378.21	424.33	491.09
Total End-Use Energy, Major Fuels				
Electricity	153.00	155.87	180.53	215.56
Natural Gas	273.34	287.42	316.44	365.83
RPP	379.69	386.07	426.04	490.62
Total	806.02	829.35	923.00	1072.00
Electricity (GB)				
Hydro	133.15	155.60	188.47	187.04
Coal	0.00	0.00	0.00	0.00
Natural Gas	64.55	56.68	48.78	40.54
RPP	9.25	3.08	0.00	0.00
Wood	14.67	8.80	2.94	0.00
Wind	0.00	0.00	0.01	0.01
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	221.62	224.17	240.20	227.59
Electricity Generated	168.90	184.51	211.63	205.83

*Note: GB indicates Georgia Basin industries.

Table 8. Energy consumption (PJ) by fuel type in the Economic Efficiency World, High Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	68.44	78.77	98.82	126.86
Natural Gas	100.70	110.26	118.41	122.80
RPP	10.62	5.13	1.21	0.04
Coal	2.88	0.95	0.07	0.00
Wood/ Hog Fuel	60.73	67.82	76.09	85.46
Petroleum Coke	0.21	0.07	0.00	0.00
Waste Fuels	0.69	0.73	0.79	0.90
Total	244.26	263.73	295.40	336.06
Electricity (BC)	102.96	122.64	155.91	201.26
% Elec GB	0.66	0.64	0.63	0.63
Comm / Inst				
Electricity	54.01	78.47	98.71	111.35
Natural Gas	55.87	40.73	27.15	27.52
RPP	5.83	2.79	0.63	0.38
LPG	2.66	1.99	1.32	0.79
Total	118.37	123.98	127.81	140.04
Residential				
Electricity	44.41	38.57	47.60	63.50
Natural Gas	65.03	36.06	33.00	40.41
RPP	4.01	1.36	0.97	0.59
LPG	0.00	0.00	0.00	0.00
Wood	2.32	2.49	2.61	3.17
Total	115.77	78.48	84.19	107.68
Transportation				
RPP	349.12	358.87	404.61	466.82
Natural Gas	2.79	0.90	0.37	0.43
Electricity	0.38	0.52	0.74	1.06
Total	352.30	360.29	405.72	468.31
Total End-Use Energy, Major Fuels				
Electricity	167.24	196.33	245.87	302.78
Natural Gas	224.39	187.95	178.94	191.16
RPP	369.58	368.14	407.42	467.82
Total	761.21	752.42	832.23	961.77
Electricity (GB)				
Hydro	165.14	210.18	265.29	281.16
Coal	0.00	0.00	0.00	0.00
Natural Gas	37.75	29.36	20.97	12.59
RPP	9.87	3.29	0.00	0.00
Wood	15.64	9.39	3.14	0.01
Wind	0.00	0.01	0.02	0.03
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	228.41	252.24	289.42	293.78
Electricity Generated	191.70	229.81	279.14	290.82

*Note: GB indicates Georgia Basin industries.

Table 9. Energy consumption (PJ) by fuel type in the Regulatory Policy Option.

SECTOR	2000	2010	2020	2030
Industry				
Electricity (GB)	81.02	108.68	135.14	158.22
Natural Gas	82.23	51.56	33.15	31.01
RPP	10.61	5.11	1.18	0.00
Coal	2.88	0.95	0.07	0.00
Wood/ Hog Fuel	67.20	97.27	126.44	148.19
Petroleum Coke	0.21	0.07	0.00	0.00
Waste Fuels	1.26	3.91	5.70	6.69
Total	245.41	267.55	301.68	344.11
Electricity (BC)	117.60	159.05	203.56	247.06
% Elec GB	0.69	0.68	0.66	0.64
Comm / Inst				
Electricity	82.00	97.99	110.12	124.90
Natural Gas	19.57	12.99	10.56	8.16
RPP	2.01	0.88	0.63	0.38
LPG	2.67	2.02	1.37	0.84
Total	106.25	113.88	122.68	134.28
Residential				
Electricity	72.05	81.07	92.47	121.60
Natural Gas	48.05	7.75	5.48	3.29
RPP	2.62	1.34	0.96	0.58
LPG	0.00	0.00	0.00	0.00
Wood	14.98	27.25	27.78	38.42
Total	137.71	117.41	126.69	163.88
Transportation				
RPP	371.50	347.32	264.84	293.91
Natural Gas	2.79	0.90	0.37	0.43
Electricity	0.38	0.52	0.74	1.06
Total	374.67	348.74	265.94	295.40
Total End-Use Energy, Major Fuels				
Electricity	235.45	288.27	338.47	405.79
Natural Gas	152.65	73.19	49.56	42.89
RPP	386.74	354.66	267.60	294.86
Total	774.84	716.12	655.63	743.54
Electricity (GB)				
Hydro	205.88	278.06	342.36	372.48
Coal	0.00	0.00	0.00	0.00
Natural Gas	38.58	30.00	21.43	12.86
RPP	10.08	3.36	0.00	0.00
Wood	16.00	9.62	3.24	0.04
Wind	0.05	0.09	0.12	0.13
Nuclear	0.00	0.00	0.00	0.00
Electricity Fuel Use	270.59	321.13	367.15	385.51
Electricity Generated	253.17	315.07	369.92	392.83

*Note: GB indicates Georgia Basin industries.

Appendix C: CO_2 Equivalent Emissions

Table 1. CO_2 emissions (kilotonnes) in the Average Consumer World, Business-as-Usual Scenario.

SECTOR	2000	2010	2020	2030
Industry	7,825	8,976	10,437	12,111
Pulp & Paper	2,500	2,774	3,077	3,423
Other Manufacturing	3,190	3,810	4,588	5,421
Industrial Minerals	1,681	1,891	2,185	2,571
Chemicals	455	501	587	697
Residential Sector	4,977	4,325	4,702	6,083
Commercial Sector	3,741	3,673	3,645	3,950
Transportation Sector	27,261	30,083	34,192	39,467
Electricity Sector	6,265	5,846	5,690	5,360
Total -- All Sectors	50,069	52,903	58,666	66,971

Table 2. CO_2 emissions (kilotonnes) in the Average Consumer World, Info Policy Option.

SECTOR	2000	2010	2020	2030
Industry	7,680	8,489	9,708	11,241
Pulp & Paper	2,495	2,747	3,031	3,359
Other Manufacturing	3,068	3,482	4,110	4,855
Industrial Minerals	1,663	1,763	1,986	2,340
Chemicals	454	497	580	688
Residential Sector	4,830	4,011	4,229	5,422
Commercial Sector	3,702	3,564	3,463	3,731
Transportation Sector	27,088	29,637	33,246	38,175
Electricity Sector	6,447	5,842	5,493	5,120
Total -- All Sectors	49,746	51,544	56,138	63,689

Table 3. CO_2 emissions (kilotonnes) in the Average Consumer World, Low Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry	7,664	8,422	9,584	11,076
Pulp & Paper	2,493	2,731	2,997	3,312
Other Manufacturing	3,058	3,456	4,061	4,787
Industrial Minerals	1,659	1,740	1,949	2,295
Chemicals	454	496	577	683
Residential Sector	4,759	3,776	3,857	4,888
Commercial Sector	3,671	3,465	3,292	3,512
Transportation Sector	26,945	29,300	32,937	37,911
Electricity Sector	6,520	5,817	5,361	4,962
Total -- All Sectors	49,559	50,779	55,031	62,350

Table 4. CO_2 emissions (kilotonnes) in the Average Consumer World, High Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry	7,346	7,685	8,211	9,002
Pulp & Paper	2,470	2,644	2,831	3,085
Other Manufacturing	2,767	2,822	2,879	2,972
Industrial Minerals	1,655	1,723	1,924	2,263
Chemicals	454	496	577	683
Residential Sector	4,242	2,928	2,785	3,339
Commercial Sector	3,484	2,967	2,465	2,500
Transportation Sector	26,438	28,147	31,946	37,024
Electricity Sector	5,788	4,912	4,277	3,830
Total -- All Sectors	47,298	46,639	49,684	55,695

Table 5. CO_2 emissions (kilotonnes) in the Economic Efficiency World, Business-as-Usual Scenario.

SECTOR	2000	2010	2020	2030
Industry	7,688	8,495	9,725	11,272
Pulp & Paper	2,515	2,812	3,139	3,491
Other Manufacturing	3,062	3,459	4,075	4,816
Industrial Minerals	1,657	1,729	1,935	2,282
Chemicals	454	496	577	683
Residential Sector	5,568	4,977	5,567	7,105
Commercial Sector	3,700	4,006	4,321	4,718
Transportation Sector	26,963	28,887	32,391	37,530
Electricity Sector	3,780	2,972	2,373	1,973
Total -- All Sectors	47,700	49,337	54,377	62,598

Table 6. CO_2 emissions (kilotonnes) in the Economic Efficiency World, Info Policy Option.

SECTOR	2000	2010	2020	2030
Industry	7,670	8,415	9,583	11,087
Pulp & Paper	2,506	2,759	3,042	3,370
Other Manufacturing	3,056	3,446	4,054	4,789
Industrial Minerals	1,654	1,714	1,910	2,246
Chemicals	454	496	577	683
Residential Sector	5,469	4,693	5,012	6,365
Commercial Sector	3,653	3,802	3,939	4,258
Transportation Sector	26,618	28,157	31,559	36,512
Electricity Sector	3,859	3,035	2,424	2,019
Total -- All Sectors	47,269	48,102	52,517	60,241

Table 7. CO_2 emissions (kilotonnes) in the Economic Efficiency World, Low Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry	7,657	8,384	9,526	11,009
Pulp & Paper	2,501	2,745	3,013	3,329
Other Manufacturing	3,049	3,431	4,031	4,756
Industrial Minerals	1,653	1,711	1,906	2,241
Chemicals	454	496	577	683
Residential Sector	5,316	4,323	4,318	5,223
Commercial Sector	3,603	3,596	3,556	3,748
Transportation Sector	26,360	27,632	30,985	35,811
Electricity Sector	3,846	3,008	2,386	1,975
Total -- All Sectors	46,783	46,943	50,772	57,766

Table 8. CO_2 emissions (kilotonnes) in the Economic Efficiency World, High Tax Policy Option.

SECTOR	2000	2010	2020	2030
Industry	7,248	7,297	7,556	7,984
Pulp & Paper	2,488	2,620	2,723	2,903
Other Manufacturing	2,655	2,474	2,358	2,166
Industrial Minerals	1,651	1,707	1,899	2,232
Chemicals	454	496	577	683
Residential Sector	3,602	2,007	1,837	2,204
Commercial Sector	3,178	2,211	1,383	1,377
Transportation Sector	25,691	26,351	29,655	34,183
Electricity Sector	2,588	1,694	1,033	614
Total -- All Sectors	42,308	39,560	41,465	46,363

Table 9. CO_2 emissions (kilotonnes) in the Regulatory Policy Option.

SECTOR	2000	2010	2020	2030
Industry	6,371	4,537	3,571	3,721
Pulp & Paper	2,288	1,662	1,026	733
Other Manufacturing	2,010	935	473	532
Industrial Minerals	1,619	1,444	1,495	1,773
Chemicals	454	496	577	683
Residential Sector	3,362	1,801	1,606	1,900
Commercial Sector	1,127	718	575	434
Transportation Sector	27,290	25,526	19,667	21,828
Electricity Sector	2,645	1,732	1,056	628
Total -- All Sectors	40,795	34,314	26,476	28,510

Appendix D. Techno-Economic Policy Costs.

Table 1. Techno-Economic Policy Costs by sector for the Average Consumer World, Info Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	-173.4	21.9	3.4	-198.6	0
Pulp & Paper	-97.7	14.1	-1.9	-109.9	0
Other Manufacturing	-49.8	5.5	3.5	-58.7	0
Industrial Minerals	-19.2	1.1	-0.4	-19.9	0
Chemicals	-6.8	1.1	2.2	-10.1	0
Residential Sector	640.9	44.5	0.0	596.5	0
Commercial Sector	538.4	317.2	0.1	221.1	0
Transportation Sect	-1,957.5	-812.8	0.0	-1,144.7	0
Total -- All Sectors	-951.6	-429.3	3.5	-525.8	0
Electricity Sector	31.7	832.4	4.1	-33.2	-772

Table 2. Techno-Economic Policy Costs by sector for the Average Consumer World, Low Tax Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	-284.5	31.4	6.1	-322.1	0
Pulp & Paper	-193.0	19.0	-1.9	-210.1	0
Other Manufacturing	-51.9	8.5	5.1	-65.5	0
Industrial Minerals	-24.1	1.8	-0.6	-25.2	0
Chemicals	-15.6	2.1	3.5	-21.2	0
Residential Sector	1,160.2	79.0	-0.1	1,081.2	0
Commercial Sector	703.9	312.3	0.1	391.4	0
Transportation Sect	-2,889.8	-1,117.9	0.0	-1,771.8	0
Total -- All Sectors	-1,310.2	-695.2	6.2	-621.3	0
Electricity Sector	82.9	1,535.1	7.0	-64.4	-1,395

Table 3. Techno-Economic Policy Costs by sector for the Average Consumer World, High Tax Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	816.4	59.4	13.9	743.2	0
Pulp & Paper	-65.0	34.9	-2.7	-97.2	0
Other Manufacturing	881.0	14.9	9.5	856.6	0
Industrial Minerals	-21.2	4.0	-1.2	-23.9	0
Chemicals	21.6	5.6	8.3	7.7	0
Residential Sector	3,968.1	191.9	-0.6	3,776.9	0
Commercial Sector	1,997.6	288.5	0.3	1,708.8	0
Transportation Sect	-6,058.6	-2,086.3	-100.5	-3,871.8	0
Total -- All Sectors	723.5	-1,546.6	-87.0	2,357.1	0
Electricity Sector	3,414.2	4,438.1	18.6	-475.8	-567

Table 4. Techno-Economic Policy Costs by sector for the Economic Efficiency World, Info Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	-149.4	25.7	13.6	-188.7	0
Pulp & Paper	-66.5	14.4	3.3	-84.2	0
Other Manufacturing	-50.4	8.8	6.9	-66.1	0
Industrial Minerals	-6.4	1.7	-0.6	-7.5	0
Chemicals	-26.1	0.8	4.1	-30.9	0
Residential Sector	125.9	90.9	-0.4	35.4	0
Commercial Sector	-35.9	-22.8	-0.1	-13.0	0
Transportation Sect	-2,175.8	-682.7	0.0	-1,493.1	0
Total -- All Sectors	-2,235.2	-588.9	13.1	-1,659.4	0
Electricity Sector	700.9	847.0	4.8	6.7	-9,964

Table 5. Techno-Economic Policy Costs by sector for the Economic Efficiency World, Low Tax Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	55.9	35.3	23.7	-3.1	0
Pulp & Paper	28.5	7.4	3.7	17.4	0
Other Manufacturing	31.1	21.5	16.2	-6.6	0
Industrial Minerals	-2.0	3.0	-0.7	-4.4	0
Chemicals	-1.7	3.5	4.4	-9.6	0
Residential Sector	667.9	338.9	-0.7	329.7	0
Commercial Sector	450.5	-35.3	0.1	485.7	0
Transportation Sect	-3,712.4	-1,160.5	0.0	-2,551.8	0
Total -- All Sectors	-2,538.1	-821.6	23.0	-1,739.5	0
Electricity Sector	878.9	1,563.0	7.7	-24.2	-10,474

Table 6. Techno-Economic Policy Costs by sector for the Economic Efficiency World, High Tax Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	2,706.1	127.2	89.3	2,489.6	0
Pulp & Paper	782.5	55.5	35.5	691.5	0
Other Manufacturing	1,775.9	56.3	48.5	1,671.1	0
Industrial Minerals	20.0	6.7	-0.4	13.7	0
Chemicals	127.6	8.7	5.7	113.2	0
Residential Sector	2,912.6	2,237.0	-1.9	677.6	0
Commercial Sector	3,035.7	-132.7	-0.5	3,168.9	0
Transportation Sect	-7,355.3	-2,256.4	0.0	-5,098.9	0
Total -- All Sectors	1,299.2	-24.9	86.9	1,237.2	0
Electricity Sector	4,705.1	6,534.7	28.3	-587.4	-11,077

Table 7. Techno-Economic Policy Costs by sector for the Regulatory Policy Option ($1995 millions) from 2000-2030.

SECTOR	Total Cost	Breakdown of Cost			Demand Correction
		Investment	O/M	Energy	
Industry	6,707.2	447.9	183.0	6,076.3	0
Pulp & Paper	950.8	297.4	143.8	509.6	0
Other Manufacturing	5,603.0	42.1	24.5	5,536.4	0
Industrial Minerals	-64.7	2.4	-1.1	-66.0	0
Chemicals	218.0	106.0	15.8	96.3	0
Residential Sector	7,737.5	79.9	-3.3	7,660.9	0
Commercial Sector	5,314.7	-1,202.7	-14.8	6,532.1	0
Transportation Sect	45,125.8	14,050.2	-100.5	31,176.1	0
Total -- All Sectors	64,885.2	13,375.3	64.4	51,445.5	0
Electricity Sector	6,239.8	7,839.5	41.4	-1,641.1	0

Appendix E. Market penetration rates of technologies by sector under different policy options in 2030.

Table 1. Allocation of new market share (% share of new stock) for the Residential Sector under different policy options in 2030.

Energy Service	Building Type	Tech-nology	Average Consumer				Economic Efficiency				
			BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Regn
Space Heating	**Appartments**	Oil	1	1	1	0	0	0	0	0	0
		NG	57	53	49	31	59	44	30	1	0
		NG2	23	24	24	21	37	40	35	3	0
		Elec	17	19	22	37	0	1	2	2	10
	Improved shells	NG2	1	1	2	3	3	8	18	27	0
		NG3 .	0	0	0	1	0	1	1	4	0
		Elec	2	2	3	7	1	6	14	63	90
	Other	Oil	1	1	1	0	0	0	0	0	0
		NG	49	45	40	22	47	28	12	0	0
		NG2	25	25	25	19	45	38	21	0	0
		Elec	22	26	29	46	0	1	1	0	10
	Improved shells	NG2	1	1	1	3	3	10	18	16	0
		NG3	0	0	0	1	0	2	4	4	0
		Elec	2	2	3	8	5	22	45	79	90
	Existing Houses										
	Pre-1960	NG2	94	92	91	80	100	100	100	98	0
		Elec	5	7	8	20	0	0	0	2	100
	Pre-1960 Retrofit	NG2	0	0	0	0	82	77	73	52	0
		NG3	0	0	0	0	15	18	22	35	0
		Elec	0	0	0	0	3	4	5	13	100
	1961-1999	Oil	3	3	2	1	0	0	0	0	0
		NG2	25	26	26	23	91	87	84	59	0
		Elec	72	71	72	76	9	13	15	41	100
	1961-1999 Retrofit	NG2	0	0	0	0	69	66	64	48	0
		NG3	0	0	0	0	1	1	1	2	0
		Elec	0	0	0	0	30	33	34	49	100
	New Houses										
	Standard	Oil	1	1	1	0	0	0	0	0	0
		NG2	72	67	62	39	83	74	66	31	0
		NG3	11	12	13	14	16	24	31	43	0
		Elec	15	18	22	43	0	0	1	17	96
	Improved Shell	NG2	1	1	1	2	0	1	1	3	0
		NG3	0	0	0	1	0	0	1	3	0
		Elec	0	0	1	2	0	0	0	2	4
Lighting											
		Incandescent	79	76	74	67	46	28	15	2	68
		Krypton	21	24	26	32	14	11	7	1	31
		Compact Fluorescent	0	0	0	1	39	61	78	97	1
Water Heating	**Appartments**										
		NG (0-1)	45	31	22	4	77	59	37	0	0
		NG2 (FE=.72	9	8	6	2	21	26	21	0	0
		Elec (0-1)	28	35	42	52	0	5	14	31	56
		Elec 2 (FE=.8	19	25	30	43	1	10	28	69	45

Numerical values following the codes for natural gas (NG) and electricity (Elec) indicate the efficiency level of the technology. More efficient technologies are indicated with higher numerical values.

Table 2. Allocation of new market share (% share of new stock) for the Commercial Sector under different policy options in 2030.

	Building	Fuel	Average Consumer				Efficient Consumer				
Energy Service	**Type**	**Type**	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Regn
Cooking Equipment	All types	NG	47	48	49	52	72	76	79	86	52
		Elec	53	52	51	48	28	24	21	14	48
Refrigerator	All types	Elec	100	100	100	100	100	100	100	100	75
Refrigerator, efficient		Elec	0	0	0	0	0	0	0	0	25
Water heating		Elec	44	44	44	45	38	38	39	42	33
		NG	56	56	56	55	62	62	61	58	42
		Solar	0	0	0	0	0	0	0	0	25
Plug Load		Elec	100	100	100	100	100	100	100	100	75
Plug Load efficient		Elec	0	0	0	0	0	0	0	0	25
Lighting	All types										
Halide Retrofit to GenII			18	16	15	11	0	0	0	0	12
Halide New Building*			18	18	18	18	1	1	1	1	18
GenII Upgrade to Halide			64	66	67	71	98	98	99	99	70
HVAC & New Shell	Warehouse	NG	72	71	71	69	89	88	86	77	0
		Elec	28	29	29	31	11	12	14	23	100
	Misc.	NG	72	71	71	68	89	87	86	75	0
		Elec	28	29	29	32	11	13	14	25	100
HVAC	Hotel	NG	77	71	65	38	94	81	63	4	0
		Elec	23	29	35	62	6	19	37	96	100
	Schools	NG	85	79	72	35	98	92	79	6	0
		Elec	15	21	28	65	2	8	21	94	100
	Offices	NG	81	76	71	46.5	97	91	81.5	12.5	0
		Elec	20	24	29	53.5	3	9	18.5	87.5	100
	Hospitals	NG	78	69	60	25	92	74	51	2	0
		Elec	22	31	40	75	8	26	49	98	100
	Retail	NG	75	70	64	40.5	92	78	60.5	8	0
		Elec	25	31	36	59.5	8.5	23	39.5	92	100

Table 3. Allocation of new market share (% share of new stock) for the Transportation Sector under different policy options in 2030.

Technology	Efficiency	Average Consumer				Economic Efficiency				
		BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
Auto, New		0	0	0	0	0	0	0	0	0
Gas	Ultra	32	29	31	39	74	81	86	95	0
Gas	Low	20	16	14	10	25	19	14	4	0
Propane	High	0	0	0	0	0	0	0	0	0
Diesel	High	1	1	1	1	0	0	0	0	0
Electric		0	0	0	0	0	0	0	0	0
Elec Hybrid		47	54	54	50	0	0	0	0	0
Fuel Cell		0	0	0	0	0	0	0	0	100
Truck New										
Gas	Ultra	51	32	33	39	75	81	85	94	0
Gas	Low	31	17	16	11	25	19	15	6	0
Propane	High	0	0	0	0	0	0	0	0	0
Diesel	High	1	1	1	1	0	0	0	0	0
Electric		0	0	0	0	0	0	0	0	0
Elec Hybrid		16	50	50	49	0	0	0	0	0
Fuel Cell		0	0	0	0	0	0	0	0	100

Table 4. Technology penetration rates (% share of market) for the Chemical Products Sector under different policy options in 2030.

Energy	Technology	Average Consumer				Economic Efficiency				
Service		BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
Process										
Electrolysis	Caustic Chlorine (Mercury Cell)	87	83	80	66	64	47	35	11	0
	Caustic Chlorine (Diaphragm)	1	2	2	4	1	1	1	2	10
	Caustic Chlorine (Membrane cell)	12	15	18	31	35	52	64	87	90
Electrolysis	Sodium Chlorate (Graphite electrode cell)	93	92	91	89	60	57	55	48	0
	Sodium Chlorate (Metal Anode cell)	1	1	1	2	10	11	12	14	16
	Sodium Chlorate (Bipolar membrane)	6	7	8	9	30	32	34	38	84
Evaporators	Evaporators I-II	45	41	39	31	50	43	41	36	0
	Evaporators II, computer control Group C	41	38	37	31	40	36	35	35	0
	Evaporators II, Large, vapor recomp (elec)	7	10	11	17	4	9	9	11	50
	Evaporators II, All	8	11	13	21	5	13	14	18	50
Boilers	Natural Gas @600 PSIG	43	34	30	24	29	21	19	16	0
	Nat Gas @600 PSIG w/heat recovery	24	26	26	26	29	28	27	25	0
	Nat Gas @600 PSIG w/regenerative burners	16	20	21	23	21	22	22	22	0
	Nat Gas @600 PSIG w/heat rec & regen burners	9	15	19	25	21	29	32	37	100
Auxiliary										
Pumps	Cent. pump syst w/VSD size 1-3	8	12	15	26	97	98	98	99	80
	Cent. pump syst w/VSD size 4-6	22	29	35	51	99	99	99	100	86
	Rotary pump w/VSD size 1-3	1	1	1	2	7	12	19	49	100
	Rotary pump w/VSD size 4-6	2	3	4	7	68	79	86	96	100
	Reciprocating pump syst. w/VSD size 1-3	0	0	1	1	3	5	9	29	100
	Reciprocating pump syst. w/VSD size 4-6	1	2	2	5	49	63	75	92	100
Fans	Backward inclined fan	0	0	0	1	24	30	36	52	58
	Radial fan	0	0	0	0	0	0	0	0	0
	Airfoil fan	0	0	0	0	0	0	0	0	0
	Vane axial/Tube axial fan	0	0	0	1	4	5	5	7	42
Compressors	Centrifugal compressor size 1-3	0	0	0	1	2	3	5	11	20
	Centrifugal compressor size 4-6	1	1	2	3	18	22	26	36	30
	Double acting reciprocating compressor size 1-3	0	0	0	0	0	1	1	2	7
	Double acting reciprocating compressor size 4-6	0	1	1	1	4	5	6	9	14
	Rotary compressor size 1-3	1	2	2	3	10	14	18	31	73
	Rotary compressor size 4-6	2	3	4	6	26	30	33	36	57
	Single acting reciprocating compressor size 1-3	0	0	0	0	0	0	0	0	0
	Single acting reciprocating compressor size 4-6	0	0	0	0	0	0	0	0	0
Conveyors	Belt conveyor	35	36	36	37	54	54	54	54	62
	Screw conveyor	20	21	21	23	28	28	29	30	38
	Apron conveyor	0	0	0	0	0	0	0	0	0
	Chain conveyor	0	0	0	0	0	0	0	0	0

The auxiliary technologies listed for the Chemical Products, Industrial minerals and Other Manufacturing sectors include only the highest efficiency levels. As the market penetration rates of these technologies increase, the market penetration of standard efficiency equipment declines accordingly.

Table 5. Technology penetration rates (% share of market) for the Industrial Minerals Sector under different policy options in 2030.

Type of		Average Consumer				Economic Efficiency				
Action	**Technology**	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
Process	Finishing ball mill w/high eff. separator	27	27	26	26	24	24	24	23	26
upgrades	Finish faller w/high eff. separator	13	13	13	14	13	14	15	18	14
	Rotary lime kiln preheat nat gas	56	38	31	22	32	21	19	17	0
	Rotary lime kiln preheat with internal nat gas	44	62	69	78	68	79	81	83	100
	Rotary lime kiln preheat coal	0	0	0	0	0	0	0	0	0
	Rotary lime kiln preheat internal coal	0	0	0	0	0	0	0	0	0
	Rotary lime kiln preheat residual oil	0	0	0	0	0	0	0	0	0
	Rotary lime kiln preheat w/internal residual oil	0	0	0	0	0	0	0	0	0
	Burner standard fired by natural gas	4	30	33	31	23	20	19	17	0
	Burner efficient fired by natural gas	4	41	50	57	62	72	73	75	0
	Burner efficient fired by oil	0	1	1	1	0	0	0	0	0
Alternative	Burner standard hazardous waste fuel	0	0	0	0	0	0	0	0	50
Fuels	Burner standard fired by residue derived fuel	8	8	8	8	8	8	8	8	50
Eff. kilns										
Rotary kilns	w/efficiency cooler	0	0	0	0	0	0	0	0	0
wet standar	w/slurrey press & high eff. cooler	0	0	0	0	0	0	0	0	0
	w/waste recovery cogen & high eff. cooler	0	0	0	0	0	0	0	0	0
Rotary kiln	standard process w/high eff. cooler	0	0	0	0	0	0	0	0	0
long dry	preheating w/eff. cooler	0	0	0	0	0	0	0	0	0
	preheating & precalcine w/eff. cooler	0	0	0	0	0	0	0	0	0
Rotary kiln	dry preheating process w/high eff. cooler	85	71	62	38	62	40	31	17	92
new	dry preheating & precalcine process w/eff. cool	15	29	37	57	38	57	62	59	8
More	Cent. pump syst w/VSD size 1-3	0	0	0	0	0	0	0	0	0
Efficient	Cent. pump syst w/VSD size 4-6	0	0	0	0	0	0	0	0	0
Auxiliary	Rotary pump w/VSD size 1-3	0	0	0	0	0	0	0	0	0
	Rotary pump w/VSD size 4-6	0	0	0	0	0	0	0	0	0
	Reciprocating pump syst. w/VSD size 1-3	0	0	0	0	0	0	0	0	0
	Reciprocating pump syst. w/VSD size 4-6	0	0	0	0	0	0	0	0	0
	Backward inclined fan	7	8	9	11	22	22	22	22	28
	Radial fan	5	5	6	7	7	7	7	6	18
	Airfoil fan	10	12	13	17	64	65	66	67	41
	Vane axial/Tube axial fan	4	4	5	5	2	2	2	2	13
	Centrifugal compressor size 1-3	15	16	17	19	33	35	36	40	22
	Centrifugal compressor size 4-6	22	23	24	26	47	48	49	52	30
	Double acting reciprocating compressor size 1-3	6	7	7	8	8	9	9	11	10
	Double acting reciprocating compressor size 4-6	11	11	12	13	13	14	14	15	15
	Rotary compressor size 1-3	34	34	34	34	40	39	37	33	40
	Rotary compressor size 4-6	27	27	27	27	28	26	25	23	32
	Single acting reciprocating compressor size 1-3	25	25	25	25	18	17	16	15	29
	Single acting reciprocating compressor size 4-6	20	20	20	19	12	11	11	10	23
	Belt conveyor	34	34	34	34	50	50	50	50	48
	Screw conveyor	23	24	24	24	29	29	30	30	35
	Apron conveyor	0	0	0	0	0	0	0	0	17
	Chain conveyor	0	0	0	0	0	0	0	0	50
Space	Space heating w/natural gas	87	84	80	55	100	100	99	54	93
heating	Space heating w/elec	13	16	20	45	0	0	1	46	7

Table 6. Allocation of new market share (% share of new stock) for the Other Manufacturing Sector under different policy options in 2030.

Type of		Average Consumer				Economic Efficiency				
Action	**Technology**	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Regn
HVAC /	HVAC system for large old shell	69	66	63	52	91	81	67	11	0
Shell System	HVAC system for large retrofit shell	12	13	14	18	5	10	18	52	0
	HVAC for large new shell (elec only)	5	6	6	9	1	2	4	12	60
	HVAC system for super efficiency shell	3	4	4	6	1	1	3	12	40
Direct Heat	Direct Heat, std. fueled by nat gas	44	37	36	21	40	35	33	12	0
	Direct Heat, efficient, fueled by nat gas	31	29	30	20	30	34	36	16	0
	Direct Heat, std. fueled by elec	0	0	1	15	0	0	0	18	36
	Direct Heat, efficient, fueled by elec	6	6	6	16	6	6	6	28	38
	Direct Heat, std. fueled by woodwaste	8	15	15	16	15	15	15	16	16
	Direct Heat, efficient, fueled by woodwas	5	9	9	10	9	9	9	10	10
More	Cent. pump syst w/VSD size 1-3	41	46	49	57	97	97	98	99	61
Efficient	Cent. pump syst w/VSD size 4-6	0	0	0	0	0	0	0	0	0
Auxiliary	Rotary pump w/VSD size 1-3	25	30	33	44	97	98	99	100	100
	Rotary pump w/VSD size 4-6	0	0	0	0	0	0	0	0	0
	Reciprocating pump syst. w/VSD size 1-3	20	24	26	36	95	97	98	99	100
	Reciprocating pump syst. w/VSD size 4-6	0	0	0	0	0	0	0	0	0
	Backward inclined fan	2	3	3	5	20	20	21	21	28
	Radial fan	1	2	2	3	6	7	7	6	18
	Airfoil fan	3	4	4	7	56	58	60	64	40
	Vane axial/Tube axial fan	1	1	2	2	2	2	2	2	14
	Centrifugal compressor size 1-3	5	6	7	9	22	24	26	31	18
	Centrifugal compressor size 4-6	11	12	13	16	39	41	43	46	26
Double acting	Reciprocating compressor sz. 1-3	2	2	3	4	5	5	6	8	7
Double acting	Reciprocating compressor sz. 4-6	5	6	6	8	10	11	12	13	13
	Rotary compressor size 1-3	15	17	18	21	44	44	43	40	42
	Rotary compressor size 4-6	17	18	19	21	32	31	30	27	35
Single acting	Reciprocating compressor size 1-3	12	13	14	16	22	21	20	19	33
Single acting	Reciprocating compressor size 4-6	13	13	14	16	15	14	13	12	26
	Belt conveyor	27	27	27	27	44	44	44	44	41
	Screw conveyor	18	19	19	19	26	26	26	27	29
	Apron conveyor	9	9	9	9	6	6	6	6	14
	Chain conveyor	10	10	10	11	10	10	10	10	16

Table 7. Allocation of new market share (% share of market) for the Electricity Generation Sector under different policy options in 2030.

	Average Consumer				Efficient Consumer				
Base	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Reg'n
Gas Fired Turbines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined Cycle Gas Greenfield New	10.9	6.4	4.0	0.6	0.1	0.0	0.0	0.0	0.0
Single Cycle Oil	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro Over Equipment	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Small Hydro Optimal	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0
Large Hydro	80.8	85.4	87.7	91.1	91.9	92.0	92.0	92.0	92.0
Small Hydro Lower Grade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Single Cycle Gas Turbine New	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large Hydro Base (Existing)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shoulder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Fired Turbines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined Cycle Gas Greenfield New	10.9	6.4	4.0	0.6	0.0	0.0	0.0	0.0	0.0
Single Cycle Oil	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro Over Equipment	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Small Hydro Optimal	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.2
Large Hydro	80.8	85.4	87.7	91.1	92.0	92.0	92.0	92.0	91.8
Small Hydro Lower Grade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Single Cycle Gas Turbine New	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large Hydro Base (Existing)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peak	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Fired Turbines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined Cycle Gas Greenfield New	10.9	6.3	4.0	0.6	0.0	0.0	0.0	0.0	0.0
Single Cycle Oil	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro Over Equipment	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Small Hydro Optimal	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.2
Large Hydro	80.8	85.4	87.8	91.1	92.0	92.0	92.0	92.0	91.8
Small Hydro Lower Grade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Single Cycle Gas Turbine New	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large Hydro Base (Existing)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Renewables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass Steam Power Plant	17.1	14.9	13.4	10.7	18.2	12.2	10.5	10.0	10.0
Small Biomass Producer	17.1	14.9	13.4	10.7	15.2	12.2	10.5	10.0	10.0
Microturbines run on Nat Gas	17.1	14.9	13.4	10.7	18.2	12.2	10.5	0.0	0.0
Solar PhotoVoltaic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Parabolic Trough Solar Power Plant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind Good Sites	36.8	42.0	45.3	51.4	45.5	58.5	62.9	73.4	60.7
Geothermal Heat Pump	11.4	13.0	14.0	15.9	3.0	4.9	5.4	6.5	18.7
Wind Marginal Sites	0.4	0.4	0.5	0.5	0.0	0.0	0.0	0.0	0.6
% Renewables of Total GWH	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note that the 'Renewables' category allocates the total new market share to renewables among the renewable technologies. Renewables constitute less than one percent of the market for new electricity in each policy option.

Table 8. Allocation of new market share (% share of new stock) in the Pulp & Paper sector cont.

		Average Consumer				Economic Efficiency			
Technology	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Regn
Boiler Hog Fuel @ 600 PSIG	44	44	44	45	44	45	45	45	98
Boiler Natural Gas @ 600 PSIG	55	55	55	54	56	55	55	55	0
Cogenerator, hog fuel @ 900 PSIG, steamturbine	0	0	0	0	0	0	0	0	94
Cogenerator, hog fuel @ 900 PSIG, steamturbine w/regnerative burners	6	6	6	6	6	6	6	6	6
Cogenerator, nat gas @ 900 PSIG, steamturbine	41	38	36	32	34	32	31	30	0
Cogenerator, nat gas @ 900 PSIG, steamturbine w/regnerative burners	12	16	18	21	22	23	24	25	0
KR BA RDH	38	39	39	40	52	51	50	48	41
TMP THER	32	33	33	35	50	51	53	57	34
Explosion pulping for hardwood pulps only	0	0	0	0	0	0	0	0	0
Diffusion Washer, high efficiency	26	26	26	26	26	26	26	26	26
Oxygen delignification >70% chlorine dioxide in 1st stage	4	4	4	5	1	1	1	1	4
Oxygen delignification >70% chlorine dioxide in 1st stage. Comp. Control Grp.A	4	4	4	5	1	1	1	2	4
Oxygen delignification with mini O2>70% chlorine dioxide in 2nd stage.	11	10	10	9	5	5	4	4	10
Oxygen delignification w/mini O2>70% chlorine dioxide in 2nd stage. Comp. control Grp.A	12	12	12	11	6	6	6	6	11
Efficient Linerboard disc refining and screening.	7	8	8	9	3	3	4	6	9
Efficient uncoated woodfree disc refining and screening.	10	11	11	13	8	9	11	18	13
Efficient coated woodfree disc refining and screening.	10	11	11	13	8	9	11	18	13
Efficient tissue paper disc refining and screening.	26	28	30	35	56	60	64	74	35
Space heating nat gas	72	63	55	23	86	58	33	1	84
Space heating elec	14	20	26	58	0	1	2	69	8
Space heating steam	14	17	19	19	14	41	65	30	8

Table 8. Allocation of new market share (% share of new stock) in the Pulp & Paper sector cont.

		Average Consumer				Economic Efficiency			
Technology	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Regn
Backward inclined fan	0	0	0	0	6	8	10	14	33
Radial fan	0	0	0	0	0	0	0	0	0
Airfoil fan	0	0	0	0	15	20	25	38	43
Vane axial/Tube axial fan	0	0	0	0	1	1	1	2	24
Centrifugal compressor size 1-3	0	0	0	1	2	3	5	11	20
Centrifugal compressor size 4-6	1	1	2	3	18	22	27	36	30
Double acting reciprocating compressor size 1-3	0	0	0	0	0	1	1	2	7
Double acting reciprocating compressor size 4-6	0	1	1	1	4	5	7	9	13
Rotary compressor size 1-3	1	1	2	3	11	14	19	31	73
Rotary compressor size 4-6	2	3	4	6	26	30	33	36	57
Single acting reciprocating compressor size 1-3	0	0	0	0	0	0	0	0	0
Single acting reciprocating compressor size 4-6	0	0	0	0	0	0	0	0	0
Belt conveyor	18	18	17	17	7	7	7	6	62
Screw conveyor	20	21	22	23	27	27	28	29	38
Apron conveyor	0	0	0	0	0	0	0	0	0
Chain conveyor	0	0	0	0	0	0	0	0	0
Efficient AC Induction motor 1-5HP	28	29	30	32	27	28	30	33	100
Efficient motor 6-25 HP	49	49	50	50	56	56	56	57	100
Efficient AC Induction motor 26-100HP	46	47	47	48	51	51	51	52	100
Efficient AC Induction motor 101-200HP	49	49	49	49	51	51	51	51	100
Efficient AC Induction motor 201-500HP	22	22	22	22	23	23	23	23	45
Efficient AC Induction motor >500HP	23	23	23	23	25	25	25	25	45

Table 8. Allocation of new market share (% share of new stock) in the Pulp & Paper sector for different policy options in 2030.

		Average Consumer				Economic Efficiency			
Technology	BAU	Info	L. Tax	H. Tax	BAU	Info	L. Tax	H. Tax	Regn
Boiler Hog Fuel @ 600 PSIG, with vibrating gate	0	0	0	0	0	0	0	0	0
Tomlins on recov. furnace, low odour configuration, retrofit to optimize operation, 5% more steam prod'n	0	0	0	0	0	0	0	0	0
Cogen Hog Fuel @ 600 PSIG, retrofit, non-condensing turbines	0	0	0	0	0	0	0	0	0
Tomlis on recov. furnace, blk liq. gasific'n, CC & Cogen	2	1	1	1	13	9	9	6	0
1200 PSIG, low odour config'n, high solids firing and computer control									
Conv. lime kiln w/nat gas & gasified wood	0	0	0	0	0	0	0	1	0
Conv. lime kiln w/oil& gasified wood waste	0	0	0	0	0	0	0	0	0
Lime Kiln w/lime kiln CO	0	0	0	0	0	0	0	90	100
Lime kiln w/oil & wood waste gasification	0	0	0	0	0	0	0	0	0
Conv. lime kiln w/nat gas, use lignin precipitate from recov. boilers, retrofit	47	45	42	26	75	69	65	53	44
Lime kiln w/flash dryers, use nat gas & lignin precip. from recov. boilers, retrofit	44	43	42	40	62	56	52	44	42
Paper dry Std. size II - high intensity drying	29	28	28	26	38	34	33	28	27
Linerboard dry steam- high intensity drying	0	0	0	0	0	0	0	0	0
Uncoated paper dry steam-high intensity drying	0	0	0	0	0	0	0	0	0
Uncoated paper nat gas. - high intensity drying	1	1	1	0	70	58	36	0	2
Uncoated paper dry resid. oil - high intensity drying	0	0	0	0	0	0	0	0	0
Coated paper dry steam- high intensity drying	0	0	0	0	0	0	0	0	0
Coated paper dry nat gas - high intensity drying	0	0	0	0	0	0	0	0	0
Coated paper dry resid. oil - high intensity dygin	0	0	0	0	0	0	0	0	0
Coated paper dry elec. -high intensity drying	8	11	14	26	97	98	99	99	80
Cent. pump syst w/VSD size 1-3	8	11	14	26	97	98	99	99	80
Cent. pump syst w/VSD size 4-6	21	28	34	51	99	99	100	100	86
Rotary pump w/VSD size 1-3	92	93	93	94	100	100	100	100	100
Rotary pump w/VSD size 4-6	2	3	4	7	69	80	87	96	100
Reciprocating pump syst. w/VSD size 1-3	0	0	1	1	3	5	9	30	100
Reciprocating pump syst. w/VSD size 4-6	1	2	2	4	50	64	76	93	100

Appendix F: Fuel Coefficients based on growth in economic units.

Table 1. Coefficients of fuel consumption per unit of economic output in the Average Consumer World, Business-as-Usual scenario.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ /				
Electricity (GB)	$1986 million	44,408	45,932	47,556	49,972
Natural Gas	Chem GDP	62,211	51,911	46,215	45,486
RPP		639	910	1,271	1,493
Coal		23	129	223	266
Industrial Minerals	GJ /				
Electricity (GB)	$1986 million	23,651	23,328	22,637	25,259
Natural Gas	Ind Min GDP	93,578	69,409	49,227	47,792
RPP		31,131	9,538	580	628
Coal		57,912	48,884	44,151	46,298
Petroleum Coke		11,400	51,630	62,881	65,937
Waste Fuels		14,829	13,821	12,142	12,467
Oth. Manufacturing	GJ /				
Electricity (GB)	$1986 million	2,674	2,586	2,480	2,474
Natural Gas	Oth Man GDP	9,910	9,715	9,325	9,279
RPP		738	541	495	535
Coal		63	30	8	0
Wood/ Hog Fuel		1,842	1,562	1,444	1,461
Pulp & Paper	GJ /				
Electricity (GB)	$1986 million	16,386	14,070	12,872	12,451
Natural Gas	Pulp & Paper GDP	14,535	14,237	14,233	13,951
RPP		2,075	1,257	737	546
Wood/ Hog Fuel		17,082	13,516	11,295	10,307
Commercial	GJ /				
Electricity	$1986 million	1,252	1,204	1,148	1,106
Natural Gas	Comm GDP	1,619	1,362	1,182	1,107
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ /				
Electricity	$1986 million	728	553	541	608
Natural Gas	Total GDP	1,090	750	688	763
RPP		73	28	20	17
Wood		99	99	87	100
Transportation	GJ /				
RPP	$1986 million	22,520	20,305	18,898	18,743
Natural Gas	Industrial GDP	183	69	38	37
Electricity		23	26	30	37
Electricity (GB)	GJ /				
Hydro	$1986 million	1,797	1,738	1,727	1,502
Coal	Total GDP	0	0	0	0
Natural Gas		1,471	1,182	994	803
RPP		124	34	1	1
Wood		197	94	26	0
Wind		0.0	0.2	0.4	0.4

Table 2. Coefficients of fuel consumption per unit of economic output in the Average Consumer World, Info Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ / $1986 million Chem GDP				
Electricity (GB)		44,322	45,749	47,379	49,797
Natural Gas		62,169	51,963	46,446	45,850
RPP		639	742	910	1,020
Coal		12	59	98	115
Industrial Minerals	GJ / $1986 million Ind Min GDP				
Electricity (GB)		23,616	23,270	22,577	25,192
Natural Gas		102,694	136,470	132,297	133,596
RPP		31,304	11,449	3,163	3,564
Coal		53,950	21,741	10,616	11,550
Petroleum Coke		5,487	10,483	11,909	12,943
Waste Fuels		14,787	13,751	12,055	12,354
Oth Manufacturing	GJ / $1986 million Oth Man GDP				
Electricity (GB)		2,677	2,593	2,491	2,488
Natural Gas		9,505	8,915	8,447	8,433
RPP		697	412	318	336
Coal		63	30	8	0
Wood/ Hog Fuel		2,342	2,615	2,635	2,635
Pulp & Paper	GJ / $1986 million P&P GDP				
Electricity (GB)		16,229	13,874	12,795	12,439
Natural Gas		14,502	14,139	14,126	13,840
RPP		2,075	1,214	650	433
Wood/ Hog Fuel		17,079	13,481	11,260	10,255
Commercial	GJ / $1986 million Comm GDP				
Electricity		1,264	1,229	1,183	1,143
Natural Gas		1,599	1,319	1,122	1,045
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ / $1986 million Total GDP				
Electricity		745	583	583	659
Natural Gas		1,062	705	623	686
RPP		71	26	18	14
LPG		0	0	0	0
Wood		91	84	75	86
Transportation	GJ / $1986 million Industrial GDP				
RPP		22,371	19,995	18,367	18,122
Natural Gas		185	71	33	29
Electricity		23	26	30	37
Electricity (GB)	GJ / $1986 million Total GDP				
Hydro		1,812	1,788	1,811	1,594
Coal		0	0	0	0
Natural Gas		1,518	1,182	962	768
RPP		125	34	1	0
Wood		199	95	27	0
Wind		0.0	0.2	0.3	0.3
Nuclear		0.0	0.0	0.0	0.0

Table 3. Coefficients of fuel consumption per unit of economic output in the Average Consumer World, Low Tax Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ / $1986 million Chem GDP				
Electricity (GB)		44,225	45,576	47,232	49,662
Natural Gas		62,140	51,915	46,421	45,856
RPP		637	679	781	854
Coal		9	42	69	80
Industrial Minerals	GJ / $1986 million Ind Min GDP				
Electricity (GB)		23,575	23,206	22,517	25,130
Natural Gas		103,359	146,261	145,364	147,950
RPP		31,331	11,500	3,172	3,507
Coal		53,377	16,808	4,173	4,478
Petroleum Coke		4,818	4,734	4,411	4,730
Waste Fuels		14,753	13,695	11,988	12,273
Oth Manufacturing	GJ / $1986 million Oth Man GDP				
Electricity (GB)		2,691	2,621	2,538	2,544
Natural Gas		9,487	8,897	8,417	8,395
RPP		686	375	266	277
Coal		63	30	8	0
Wood/ Hog Fuel		2,344	2,620	2,644	2,646
Pulp & Paper	GJ / $1986 million P&P GDP				
Electricity (GB)		16,075	13,688	12,750	12,462
Natural Gas		14,486	14,065	14,005	13,699
RPP		2,075	1,196	614	387
Wood/ Hog Fuel		17,085	13,470	11,227	10,205
Commercial	GJ / $1986 million Comm GDP				
Electricity		1,273	1,252	1,217	1,180
Natural Gas		1,584	1,280	1,065	983
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ / $1986 million Total GDP				
Electricity		752	606	617	703
Natural Gas		1,050	668	568	617
RPP		71	24	16	13
LPG		0	0	0	0
Wood		87	76	69	79
Transportation	GJ / $1986 million Industrial GDP				
RPP		22,249	19,761	18,191	17,993
Natural Gas		186	73	34	30
Electricity		23	26	30	37
Electricity (GB)	GJ / $1986 million Total GDP				
Hydro		1,825	1,830	1,881	1,674
Coal		0	0	0	0
Natural Gas		1,536	1,176	939	745
RPP		126	34	0	0
Wood		200	96	27	0
Wind		0.0	0.2	0.3	0.3
Nuclear		0.0	0.0	0.0	0.0

Table 4. Coefficients of fuel consumption per unit of economic output in the Average Consumer World, High Tax Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ /				
Electricity (GB)	$1986 million	43,928	44,976	46,796	49,334
Natural Gas	Chem GDP	62,015	51,520	45,870	45,270
RPP		631	583	597	621
Coal		6	24	38	44
Industrial Minerals	GJ /				
Electricity (GB)	$1986 million	23,465	22,999	22,323	24,939
Natural Gas	Ind Min GDP	102,656	149,138	149,542	152,356
RPP		31,349	11,257	2,741	2,906
Coal		53,088	14,408	1,074	1,119
Petroleum Coke		4,505	2,130	1,055	1,100
Waste Fuels		14,667	13,553	11,818	12,060
Oth Manufacturing	GJ /				
Electricity (GB)	$1986 million	3,378	3,855	4,500	5,223
Natural Gas	Oth Man GDP	8,491	7,226	5,963	5,198
RPP		661	296	145	126
Coal		63	31	9	1
Wood/ Hog Fuel		2,406	2,756	2,799	2,798
Pulp & Paper	GJ /				
Electricity (GB)	$1986 million	15,898	13,405	12,874	12,838
Natural Gas	P&P GDP	14,315	13,582	13,235	12,803
RPP		2,073	1,165	552	308
Wood/ Hog Fuel		17,045	13,423	11,115	10,029
Commercial	GJ /				
Electricity	$1986 million	1,328	1,370	1,381	1,354
Natural Gas	Comm GDP	1,492	1,083	793	697
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ /				
Electricity	$1986 million	822	697	721	840
Natural Gas	Total GDP	924	507	392	395
RPP		68	20	13	8
LPG		0	0	0	0
Wood		81	66	63	76
Transportation	GJ /				
RPP	$1986 million	21,815	18,959	17,628	17,560
Natural Gas	Industrial GDP	189	78	38	33
Electricity		23	26	30	37
Electricity (GB)	GJ /				
Hydro	$1986 million	2,097	2,174	2,319	2,181
Coal	Total GDP	0	0	0	0
Natural Gas		1,335	983	749	576
RPP		130	35	0	0
Wood		206	99	28	0
Wind		0.3	0.4	0.5	0.5
Nuclear		0.0	0.0	0.0	0.0

Table 5. Coefficients of fuel consumption per unit of economic output in the Economic Efficiency World, Business-as-Usual Scenario.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ / $1986 million Chem GDP				
Electricity (GB)		42,426	41,529	42,029	44,036
Natural Gas		62,240	52,369	47,086	46,625
RPP		560	259	67	1
Coal		0	3	6	7
Industrial Minerals	GJ / $1986 million Ind Min GDP				
Electricity (GB)		23,122	22,339	21,389	23,919
Natural Gas		104,022	150,004	148,850	149,973
RPP		31,086	9,091	2	2
Coal		53,017	14,878	2,159	2,892
Petroleum Coke		4,489	4,109	4,569	6,129
Waste Fuels		14,748	13,688	11,982	12,266
Oth Manufacturing	GJ / $1986 million Oth Man GDP				
Electricity (GB)		2,649	2,541	2,434	2,429
Natural Gas		9,621	9,218	8,845	8,873
RPP		608	172	8	2
Coal		63	30	8	0
Wood/ Hog Fuel		2,341	2,612	2,631	2,630
Pulp & Paper	GJ / $1986 million P&P GDP				
Electricity (GB)		14,952	10,898	9,182	8,717
Natural Gas		14,698	14,847	15,215	15,060
RPP		2,039	998	285	2
Wood/ Hog Fuel		17,183	13,815	11,752	10,798
Commercial	GJ / $1986 million Comm GDP				
Electricity		1,152	1,078	992	954
Natural Gas		1,599	1,494	1,405	1,324
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ / $1986 million Total GDP				
Electricity		528	282	248	280
Natural Gas		1,320	1,010	946	1,041
RPP		62	14	9	5
LPG		0	0	0	0
Wood		53	18	15	16
Transportation	GJ / $1986 million Industrial GDP				
RPP		22,277	19,497	17,897	17,820
Natural Gas		170	44	15	15
Electricity		23	26	30	37
Electricity (GB)	GJ / $1986 million Total GDP				
Hydro		1,658	1,490	1,441	1,183
Coal		0	0	0	0
Natural Gas		824	579	415	297
RPP		116	31	0	0
Wood		184	88	24	0
Wind		0.0	0.0	0.0	0.0
Nuclear		0.0	0.0	0.0	0.0

Table 6. Coefficients of fuel consumption per unit of economic output in the Economic Efficiency World, Info Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ / $1986 million Chem GDP				
Electricity (GB)		42,308	41,218	41,770	43,624
Natural Gas		62,151	52,023	46,614	46,131
RPP		560	259	68	2
Coal		0	0	1	1
Industrial Minerals	GJ / $1986 million Ind Min GDP				
Electricity (GB)		23,074	22,244	21,302	23,796
Natural Gas		102,857	151,652	152,799	155,865
RPP		31,087	9,097	9	11
Coal		52,978	13,587	58	67
Petroleum Coke		4,400	1,331	64	76
Waste Fuels		14,671	13,561	11,829	12,077
Oth Manufacturing	GJ / $1986 million Oth Man GDP				
Electricity (GB)		2,647	2,537	2,430	2,424
Natural Gas		9,599	9,181	8,800	8,822
RPP		609	172	8	2
Coal		63	30	8	0
Wood/ Hog Fuel		2,341	2,612	2,631	2,630
Pulp & Paper	GJ / $1986 million P&P GDP				
Electricity (GB)		14,947	11,066	9,491	9,014
Natural Gas		14,626	14,511	14,693	14,494
RPP		2,039	998	285	2
Wood/ Hog Fuel		17,238	13,943	11,935	11,008
Commercial	GJ / $1986 million Comm GDP				
Electricity		1,165	1,125	1,066	1,031
Natural Gas		1,576	1,413	1,279	1,194
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ / $1986 million Total GDP				
Electricity		525	299	289	316
Natural Gas		1,293	950	848	929
RPP		62	14	8	4
LPG		0	0	0	0
Wood		54	19	16	17
Transportation	GJ / $1986 million Industrial GDP				
RPP		21,983	18,991	17,427	17,325
Natural Gas		170	44	15	15
Electricity		23	26	30	37
Electricity (GB)	GJ / $1986 million Total GDP				
Hydro		1,684	1,547	1,530	1,264
Coal		0	0	0	0
Natural Gas		842	591	424	303
RPP		118	31	0	0
Wood		187	89	25	0
Wind		0.0	0.0	0.1	0.1
Nuclear		0.0	0.0	0.0	0.0

Table 7. Coefficients of fuel consumption per unit of economic output in the Economic Efficiency World, Low Tax Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ / $1986 million Chem GDP				
Electricity (GB)		42,153	40,785	41,205	43,037
Natural Gas		62,118	51,865	46,359	45,853
RPP		560	260	69	3
Coal		0	0	0	1
Industrial Minerals	GJ / $1986 million Ind Min GDP				
Electricity (GB)		23,017	22,123	21,172	23,666
Natural Gas		102,363	150,754	151,753	154,613
RPP		31,088	9,103	17	20
Coal		52,977	13,566	26	29
Petroleum Coke		4,398	1,301	20	23
Waste Fuels		14,640	13,507	11,762	11,991
Oth Manufacturing	GJ / $1986 million Oth Man GDP				
Electricity (GB)		2,645	2,533	2,426	2,419
Natural Gas		9,576	9,140	8,748	8,761
RPP		609	172	8	2
Coal		63	30	8	0
Wood/ Hog Fuel		2,341	2,612	2,631	2,630
Pulp & Paper	GJ / $1986 million P&P GDP				
Electricity (GB)		14,935	10,936	9,389	8,968
Natural Gas		14,587	14,418	14,532	14,301
RPP		2,039	998	285	3
Wood/ Hog Fuel		17,268	14,053	12,064	11,116
Commercial	GJ / $1986 million Comm GDP				
Electricity		1,177	1,171	1,140	1,115
Natural Gas		1,551	1,332	1,153	1,050
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ / $1986 million Total GDP				
Electricity		524	316	326	381
Natural Gas		1,253	872	726	758
RPP		62	14	8	4
LPG		0	0	0	0
Wood		54	18	16	17
Transportation	GJ / $1986 million Industrial GDP				
RPP		21,764	18,628	17,102	16,985
Natural Gas		170	44	15	15
Electricity		23	26	30	37
Electricity (GB)	GJ / $1986 million Total GDP				
Hydro		1,723	1,605	1,613	1,370
Coal		0	0	0	0
Natural Gas		835	585	418	297
RPP		120	32	0	0
Wood		190	91	25	0
Wind		0.0	0.0	0.1	0.1
Nuclear		0.0	0.0	0.0	0.0

Table 8. Coefficients of fuel consumption per unit of economic output in the Economic Efficiency World, HighTax Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ /				
Electricity (GB)	$1986 million	41,960	40,283	40,572	42,404
Natural Gas	Chem GDP	62,020	51,371	45,508	44,804
RPP		561	261	71	6
Coal		0	0	0	0
Industrial Minerals	GJ /				
Electricity (GB)	$1986 million	22,911	21,922	20,965	23,462
Natural Gas	Ind Min GDP	101,507	149,141	149,807	152,235
RPP		31,097	9,132	48	51
Coal		52,977	13,558	14	14
Petroleum Coke		4,397	1,290	5	5
Waste Fuels		14,586	13,417	11,646	11,838
Oth Manufacturing	GJ /				
Electricity (GB)	$1986 million	3,540	4,455	5,273	6,318
Natural Gas	Oth Man GDP	8,176	6,440	5,017	3,875
RPP		609	172	7	1
Coal		63	30	8	0
Wood/ Hog Fuel		2,406	2,756	2,799	2,798
Pulp & Paper	GJ /				
Electricity (GB)	$1986 million	14,982	11,218	9,884	9,626
Natural Gas	P&P GDP	14,489	13,618	12,947	12,294
RPP		2,039	1,000	287	5
Wood/ Hog Fuel		17,253	14,341	12,856	12,135
Commercial	GJ /				
Electricity	$1986 million	1,297	1,511	1,585	1,534
Natural Gas	Comm GDP	1,341	784	436	379
RPP		140	54	10	5
LPG		64	38	21	11
Residential	GJ /				
Electricity	$1986 million	575	398	407	465
Natural Gas	Total GDP	842	372	282	296
RPP		52	14	8	4
LPG		0	0	0	0
Wood		30	26	22	23
Transportation	GJ /				
RPP	$1986 million	21,196	17,742	16,350	16,194
Natural Gas	Industrial GDP	170	45	15	15
Electricity		23	26	30	37
Electricity (GB)	GJ /				
Hydro	$1986 million	2,137	2,168	2,271	2,059
Coal	Total GDP	0	0	0	0
Natural Gas		489	303	180	92
RPP		128	34	0	0
Wood		202	97	27	0
Wind		0.1	0.1	0.2	0.2
Nuclear		0.0	0.0	0.0	0.0

Table 9. Coefficients of fuel consumption per unit of economic output in the Regulatory Policy Option.

SECTOR	Units	2000	2010	2020	2030
Chemicals	GJ / $1986 million Chem GDP				
Electricity (GB)		40,995	36,947	35,558	36,417
Natural Gas		61,745	50,509	44,586	44,107
RPP		560	259	67	0
Coal		0	0	0	0
Industrial Minerals	GJ / $1986 million Ind Min GDP				
Electricity (GB)		23,284	22,634	21,844	24,388
Natural Gas		88,151	51,326	30,454	30,935
RPP		31,086	9,090	0	0
Coal		52,973	13,545	0	0
Petroleum Coke		4,397	1,286	0	0
Waste Fuels		26,524	72,235	83,731	87,970
Oth Manufacturing	GJ / $1986 million Oth Man GDP				
Electricity (GB)		5,700	8,543	9,231	9,224
Natural Gas		5,893	2,114	829	801
RPP		608	171	6	0
Coal		63	30	8	0
Wood/ Hog Fuel		2,406	2,756	2,799	2,798
Pulp & Paper	GJ / $1986 million P&P GDP				
Electricity (GB)		15,045	11,412	10,127	9,926
Natural Gas		12,812	7,110	3,162	1,511
RPP		2,039	997	283	0
Wood/ Hog Fuel		19,641	23,198	25,740	25,993
Commercial	GJ / $1986 million Comm GDP				
Electricity		1,969	1,886	1,768	1,721
Natural Gas		470	250	170	112
RPP		48	17	10	5
LPG		64	39	22	12
Residential	GJ / $1986 million Total GDP				
Electricity		932	836	791	890
Natural Gas		622	80	47	24
RPP		34	14	8	4
LPG		0	0	0	0
Wood		194	281	238	281
Transportation	GJ / $1986 million Industrial GDP				
RPP		22,555	17,171	10,702	10,196
Natural Gas		169	44	15	15
Electricity		23	26	30	37
Electricity (GB)	GJ / $1986 million Total GDP				
Hydro		2,665	2,868	2,930	2,728
Coal		0	0	0	0
Natural Gas		499	310	183	94
RPP		131	35	0	0
Wood		207	99	28	0
Wind		0.6	0.9	1.0	1.0
Nuclear		0.0	0.0	0.0	0.0

Appendix G: Emissions Coefficients based on growth in Economic output.

Table 1. Coefficients of CO_2 emissions per unit of economic output in the Average Consumer World, Business-as-Usual Scenario.

SECTOR	Units tonnes CO2/ $1986 million of...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,079	2,607	2,365	2,350
Industrial Minerals	Ind Min GDP	35,420	34,961	32,116	33,798
Other Manufacturing	Oth Man GDP	550	522	497	497
Pulp & Paper	P&P GDP	922	834	787	756
Commercial	Comm GDP	90	71	59	54
Residential	Total GDP	64	45	40	45
Transportation	Industrial GDP	1,655	1,487	1,382	1,369
Electricity (GB)	Total GDP	81	60	49	39

Table 2. Coefficients of CO_2 emissions per unit of economic output in the Average Consumer World, Info Policy Option.

SECTOR	Units tonnes CO2/ $1986 million of...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,076	2,591	2,338	2,319
Industrial Minerals	Ind Min GDP	35,041	32,586	29,196	30,763
Other Manufacturing	Oth Man GDP	529	477	445	445
Pulp & Paper	P&P GDP	921	826	776	742
Commercial	Comm GDP	89	69	56	51
Residential	Total GDP	63	41	36	40
Transportation	Industrial GDP	1,645	1,465	1,343	1,324
Electricity (GB)	Total GDP	83	60	47	37

Table 3. Coefficients of CO_2 emissions per unit of economic output in the Average Consumer World, Low Tax Policy Option.

SECTOR	Units tonnes CO2 / $1986 million of...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,075	2,583	2,325	2,304
Industrial Minerals	Ind Min GDP	34,970	32,163	28,655	30,166
Other Manufacturing	Oth Man GDP	527	473	440	439
Pulp & Paper	P&P GDP	920	821	767	732
Commercial	Comm GDP	88	67	53	48
Residential	Total GDP	62	39	33	36
Transportation	Industrial GDP	1,636	1,449	1,331	1,315
Electricity (GB)	Total GDP	84	60	46	36

Table 4. Coefficients of CO_2 emissions per unit of economic output in the Average Consumer World, High Tax Policy Option.

SECTOR	Units tonnes CO2 / $1986 million of...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,068	2,555	2,282	2,255
Industrial Minerals	Ind Min GDP	34,884	31,861	28,280	29,744
Other Manufacturing	Oth Man GDP	477	386	312	272
Pulp & Paper	P&P GDP	911	795	724	681
Commercial	Comm GDP	84	57	40	34
Residential	Total GDP	55	30	24	24
Transportation	Industrial GDP	1,605	1,392	1,291	1,284
Electricity (GB)	Total GDP	75	51	37	28

Table 5. Coefficients of CO_2 emissions per unit of economic output in the Economic Efficiency World, Business-as-Usual Scenario.

SECTOR	Units tonnes CO2 / $1986 million of...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,073	2,570	2,299	2,271
Industrial Minerals	Ind Min GDP	34,926	31,956	28,440	29,998
Other Manufacturing	Oth Man GDP	528	473	441	441
Pulp & Paper	P&P GDP	928	846	803	771
Commercial	Comm GDP	89	77	69	65
Residential	Total GDP	72	51	48	52
Transportation	Industrial GDP	1,637	1,428	1,309	1,302
Electricity (GB)	Total GDP	49	31	20	14

Table 6. Coefficients of CO_2 emissions per unit of economic output in the Economic Efficiency World, Info Policy Option.

SECTOR	Units tonnes CO2 / $1986 million of ...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,069	2,553	2,275	2,247
Industrial Minerals	Ind Min GDP	34,857	31,689	28,069	29,528
Other Manufacturing	Oth Man GDP	527	472	439	439
Pulp & Paper	P&P GDP	925	830	778	744
Commercial	Comm GDP	88	73	63	59
Residential	Total GDP	71	48	43	47
Transportation	Industrial GDP	1,616	1,392	1,275	1,267
Electricity (GB)	Total GDP	50	31	21	15

Table 7. Coefficients of CO_2 emissions per unit of economic output in the Economic Efficiency World, Low Tax Policy Option.

SECTOR	Units tonnes CO2 / $1986 million of ...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,067	2,545	2,263	2,233
Industrial Minerals	Ind Min GDP	34,832	31,640	28,011	29,459
Other Manufacturing	Oth Man GDP	525	470	436	436
Pulp & Paper	P&P GDP	923	826	771	735
Commercial	Comm GDP	87	69	57	52
Residential	Total GDP	69	45	37	38
Transportation	Industrial GDP	1,600	1,366	1,252	1,242
Electricity (GB)	Total GDP	50	31	20	14

Table 8. Coefficients of CO_2 emissions per unit of economic output in the Economic Efficiency World, High Tax Policy Option.

SECTOR	Units tonnes CO2 / $1986 million of ...	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,062	2,521	2,222	2,182
Industrial Minerals	Ind Min GDP	34,790	31,561	27,914	29,340
Other Manufacturing	Oth Man GDP	457	339	255	199
Pulp & Paper	P&P GDP	918	788	697	641
Commercial	Comm GDP	76	43	22	19
Residential	Total GDP	47	21	16	16
Transportation	Industrial GDP	1,560	1,303	1,198	1,186
Electricity (GB)	Total GDP	33	17	9	4

Table 9. Coefficients of CO_2 emissions per unit of economic output in the Regulatory Policy Option.

SECTOR	Units tonnes CO2 / $1986 million of	2000	2010	2020	2030
Industry					
Chemicals	Chem GDP	3,049	2,479	2,176	2,148
Industrial Minerals	Ind Min GDP	34,125	26,695	21,977	23,306
Other Manufacturing	Oth Man GDP	346	128	51	49
Pulp & Paper	P&P GDP	844	500	263	162
Commercial	Comm GDP	27	14	9	6
Residential	Total GDP	44	19	14	14
Transportation	Industrial GDP	1,657	1,262	795	757
Electricity (GB)	Total GDP	34	18	9	5

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