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Project Report

THE ECONOMICALLY ATTRACTIVE POTENTIAL FOR ENERGY EFFICIENCY GAINS IN CANADA

MAY 1991

Prepared for

Efficiency and Alternative Energy Branch
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Toronto
May 14, 1991
MR/8966/ss

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FOREWORD

This document describes the findings of a study completed for the Efficiency and Alternative Energy Branch by Peat Marwick Stevenson and Kellogg Management Consultants in association with Marbek Resource Consultants Limited, Torrie Smith and Associates, and WATSRF at the University of Waterloo. The views expressed in the report are those of the authors, and do not necessarily reflect the position of Energy, Mines and Resources Canada (EMR).

The primary objective of the study was to estimate the economically attractive energy efficiency potential in Canada. For the purpose of this study, energy efficiency potential is a precisely defined term specified on pages 3 and 4 of the attached report. To estimate the potential, the authors adopted a case study approach in which a number of areas of energy use were analysed in depth. The results of these studies and general estimates of potential for the remaining end use areas were aggregated to obtain an overall estimate of the potential for energy efficiency in Canada. The list of case studies prepared for this project is presented on page 12 of the attached report. The ten case studies, arranged into eight separate appendices, are available on request.

As the authors point out in the report, estimating energy efficiency potential is a complex task, frequently constrained by a paucity of good quality data. In some areas, it is difficult to establish an analytical framework that effectively separates energy efficiency potential from industrial processes or lifestyle changes. It is important that the reader understand these caveats, and ensure they are given appropriate weight in interpreting study results. Nonetheless, EMR believes the study offers a useful reference point from which future work in this area can evolve.

In an effort to gain a better appreciation of the concept of energy efficiency potential, the Efficiency and Alternative Energy Branch and the Energy Policy Branch of EMR Canada hosted a *Workshop on the Potential for Energy Efficiency in Canada* on April 16, 1991 for the benefit of senior federal government policy advisors. The objective of the workshop was twofold: to introduce the audience to some of the current thinking on the subject of energy efficiency potential and to present the findings of a preliminary version of the Peat Marwick study. The workshop was organized for EMR by The Conference Board of Canada, who provided Rapporteur's notes on the day's proceedings. These notes are also available on request.

Efficiency and Alternative
Energy Branch, EMR Canada

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Executive Summary

A. Introduction

Despite significant gains in energy efficiency since the early 1970's, there appears to be a considerable further untapped, cost-effective potential for energy efficiency gains in Canada. This study is intended to provide estimates of the economically attractive potential for such energy efficiency gains.

The objectives of this study are as follows:

- To estimate the remaining economically attractive energy savings potential in the Canadian economy from improved energy efficiency.
- To estimate the net environmental benefits (expressed in terms of reductions in emissions) of realizing the economical potential.
- To identify some of the key market barriers impeding the commercialization of economically attractive energy efficient technologies.

To the extent possible, the study results are disaggregated by region, sector and fuel type, and are presented in five year intervals to 2020.

The following definitions are useful in understanding the study results:

- The **economically attractive potential** for energy efficiency gains refers to energy savings which can be achieved at a favourable social benefit-cost ratio, i.e., at a cost below the social opportunity cost of the energy saved.
- The base case against which economically attractive energy efficiency gains are defined is the **frozen efficiency scenario**. Conceptually, this scenario assumes that all future investment is put in place at the same energy intensities as the actual investment put in place in the base year (1988).
- The **market case** scenario is a forecast of the levels of energy use which are likely to actually occur, given an outlook for economic growth and energy prices, and without any changes in government policy intervention.

B. Approach

The level and type of disaggregation required for this study have led us to use an end-use orientation to the energy efficiency analysis, rather than the econometric approach embodied in the InterFuel Substitution Demand ("IFSD") model used by Energy, Mines and Resources Canada ("EMR").

The study approach focuses on case studies of a number of "loci of analysis". Loci of analysis are clusters of energy efficiency opportunity areas, defined in a multi-dimensional matrix with axes of sector/end use/technology.

Case studies were undertaken of the ten loci of analysis described in Exhibit A, **below**.

Exhibit A
Loci of Analysis Selected as Case Studies

Sector	Locus	Case Study Appendix
Residential	New Single Family Space Heating	#1
	Retrofit Single Family Space Heating	#1
	Appliances Including Lighting	#2
Commercial	New Office and Retail	#3
	Retrofit Office and Retail	#3
Transportation	Light Vehicles	#4
Industrial	Chemical Industries	#5
	Forest Industries	#6
	Iron & Steel Industries	#7
	Drivepower	#8

A case study was conducted for each of the ten loci described above. Essentially, a case study involved four basic components:

- Collection of detailed historical energy use data for the locus of analysis.
- Review of all available published reports of relevance.
- Where feasible, analysis of cost and performance data to determine potential.
- A series of discussions with those knowledgeable in the field.

For reporting purposes, some case studies have been grouped; eight separate case study appendices have been produced.

Since the case study approach is selective, it is also necessary to have a comprehensive framework to ensure that the required global estimates of energy efficiency potential reflect 100% of the projected energy baseline.

We have used the SERF model to move to this baseline, as follows:

- Case studies of the potential for energy efficiency gains were undertaken for the ten loci of analysis described above.

- As the next step, preliminary "sector roll-ups" were developed, estimating the aggregate energy efficiency potential in each of the four basic energy sectors. (These estimates are for the year 2020.)

- The four sector roll-ups and their underlying case studies have been incorporated into the SERF format. Judgements have been made by sector as to the appropriate way of "moving to" 2020 levels of potential, and estimates of economically attractive potential have been made for five-year intervals from 1995 to 2020.

C. Economic potential in the case studies

Below we summarize the estimates of economic potential developed in the ten case study loci of analysis. First, however, we summarize some of the major assumptions and caveats which affect the interpretation of study results.

1. Major assumptions and their impact on results

a) Frozen efficiency scenarios

The frozen efficiency scenarios have been made consistent with the Energy Mines and Resources ("EMR")/Environment Canada ("EC") Reference Case of July, 1990, in two aspects:

- Base year (1988) energy use has been made consistent.

- Economic/demographic projections have been made consistent.

To develop the frozen efficiency scenario, marginal energy intensities were frozen at 1988 levels. In practice, it is not possible to implement the marginal frozen efficiency perspective in the three industry sub-sectors which were studied, and average frozen efficiencies were used. The use of average rather than marginal frozen efficiency tends to overstate the magnitude of economic potential.

b) Economically attractive scenarios

Once a frozen efficiency scenario had been developed for a locus of analysis, the case study focused on identifying and evaluating individual energy efficiency technologies. The following guidelines were employed:

- We sought to restrict ourselves to those energy efficiency technologies which can increase energy efficiency without any adjustment in the actual service levels provided to energy users. This is a narrower definition that is sometimes used in studies of energy conservation potential.

- Generally speaking, only currently available technologies were considered (there are exceptions to this in the light vehicles case study).

- Although we explored circumstances in which prices of technology might be expected to decline over time, in practice we have assumed constant real prices for virtually all technologies over the analysis period. Both this and the prior guideline can be viewed as conservative with respect to the ultimate level of potential.

- In the residential appliance and light vehicle case studies, it was necessary to assume that potential efficiency measures are adopted on a North American scale, because of the nature of these industries. There are clearly limits on the realization of this potential, which can be achieved by purely Canadian policy initiatives.

c) Energy prices and discount rates used

As estimates of social opportunity costs, the study uses the energy price projections from the EMR/EC Reference Case. The price projections represent market prices, rather than true social opportunity costs for the energy forms analyzed. In evaluating the energy efficiency technologies, a 7% real discount rate was used. The discount rate represents a social rate, rather than those rates actually used by businesses and consumers to make energy efficiency decisions in Canada. Because we have not yet developed or reviewed up-to-date estimates of true social opportunity costs for various energy forms in Canada, we do not know what the impacts of using such assumptions would be on the results.

The sensitivity of results to higher energy prices was considered in some of the case studies. However, data limitations did not permit us to extend these sensitivity analyses to the aggregate results.

Although in principle the assessment of economically attractive technology depends on the year in which the technology is assumed to be implemented, we have focused our analysis on energy prices in the year 2020. The energy price projections used are unchanged after the year 2000, and are relatively stable for many energy types in the 1990's.

2. Case study results

a) How the case studies worked out

Our methodology was designed around an "ideal" case study, in which:

- The bulk of the energy efficiency potential is in the form of "pure" energy conservation measures, which can be identified and costed.

- There is a good deal of available information which permits the identification and costing of such measures.

In fact, only the residential appliance and light vehicle case studies fell into this broad category. The residential space heating, and new and retrofit office and retail case studies, relied extensively on detailed databases in the files of the consultants, in many cases arising from earlier or concurrent studies.

The case study process was not satisfactory for the forest products and iron and steel, and to a lesser extent, chemical industry case studies. This reflects both weaknesses in the case study methodology as applied to these industrial subsectors, as well as unavailability of relevant data. In particular:

- We found little information of relevance to the study.
- The concept of the frozen efficiency scenario was clearly less valid than for other sectors.
- There was inadequate population data to permit results to be scaled up.

As a consequence, the results for the industrial sector are the weakest of those developed in this study.

b) Summary of case study results

Exhibit B, **overleaf**, summarizes the key case study results.

The results are presented in terms of the magnitude of economic potential for energy efficiency savings in the year 2020, in relation to the frozen efficiency scenario appropriate to each case study. For two of the industry sub-sectors, the case studies did not develop quantitative estimates of potential. The drive power case study estimated drive power savings potential in the three industry subsectors which were case studied, and the range of results presented in the table are for these three sub-sectors.

Exhibit B
Summary of Case Studies
2020 Economically Attractive Potential for Energy Efficiency

Locus	Potential: PJ/Year	Potential: As % of Frozen Efficiency Energy Use
New and Retrofit Single Family Space Heating	321	44%
Residential Appliances	51	11%
New and Retrofit Office and Retail	212	36%
Light Vehicles	645	44%
Chemical Industries	210	37%
Forest Industries	NA	NA
Iron & Steel Industries	NA	NA
Drivepower	25,000 GWh	20% (15% - 21%)

NA = No estimate made in this case study

D. Aggregating economic potential

The SERF model was used to develop estimates of aggregate economically attractive energy efficiency improvements, at five year intervals to the year 2020. SERF "frozen efficiency" and "economic potential" cases were developed, based on the case studies and sector roll-ups. It was necessary to make assumptions as to the phase in of the intensity improvements determined in the case studies and sector roll ups. The following assumptions were made:

- All building retrofit potential would be available by 1995
- New residential and commercial potential would be available as the new buildings are constructed
- There are explicit stock replacement models in the appliance and transportation sectors of SERF, and the phase-in potential was tied directly to stock replacement.
- Potential in the industrial sector primarily represents replacement, rather than retrofit. In the absence of models of stock replacement, it was assumed that the potential year 2020 intensities would be phased in on a linear basis, over the period to 2005.

The concept of economically attractive potential used in the study is based on purely economic calculations. We have not considered how rapidly this potential might be realized under various scenarios. The practical constraints on implementation can be viewed as barriers to the achievement of potential.

1. Barriers

A continued barrier to the achievement of economically attractive levels of energy efficiency is the so called private-social gap. Historically, this has comprised two elements:

- There have been gaps between the private and social costs of energy. This gap does not exist in the current study, because we have used projections of actual market prices as proxies for social opportunity costs.
- Typically, decision makers in both the private and public sectors use more stringent decision making criteria than those implicit in the net present value decision making criterion, with a social discount rate in real terms of 7%, which was used to calculate economic attractiveness.

Other sector-specific barriers identified in the study include the following:

- In international industries such as passenger vehicles and appliances, products are designed and manufactured to meet the needs of a market which is much broader than the Canadian market. This limits the ability of Canadian consumers and governments to achieve economically attractive levels of potential in Canada alone.
- The magnitude of economically achievable potential in many cases dwarfs the capability of existing infrastructure. For example, there are limited numbers of trained construction trades to implement energy saving measures in residential housing. These constraints limit the rate at which potential could in fact be captured, particularly in the near term.
- In the residential and, more particularly, the commercial sectors, the structure of the development, ownership, and operation of buildings provides a pervasive environment of split incentives. These are barriers not only to the achievement of the "social optimum" efficiency, but even to the achievement of the optimal level of energy efficiency, when viewed from the private financial perspective of the ultimate owners or tenants.
- There is still to some extent an uneven playing field for energy efficiency measures, in which there is no agreement as to the true social or even avoided costs of conventional fuels. There is some distance to go before public utilities provide a set of such signals consistent with the social cost of energy supply in Canada.

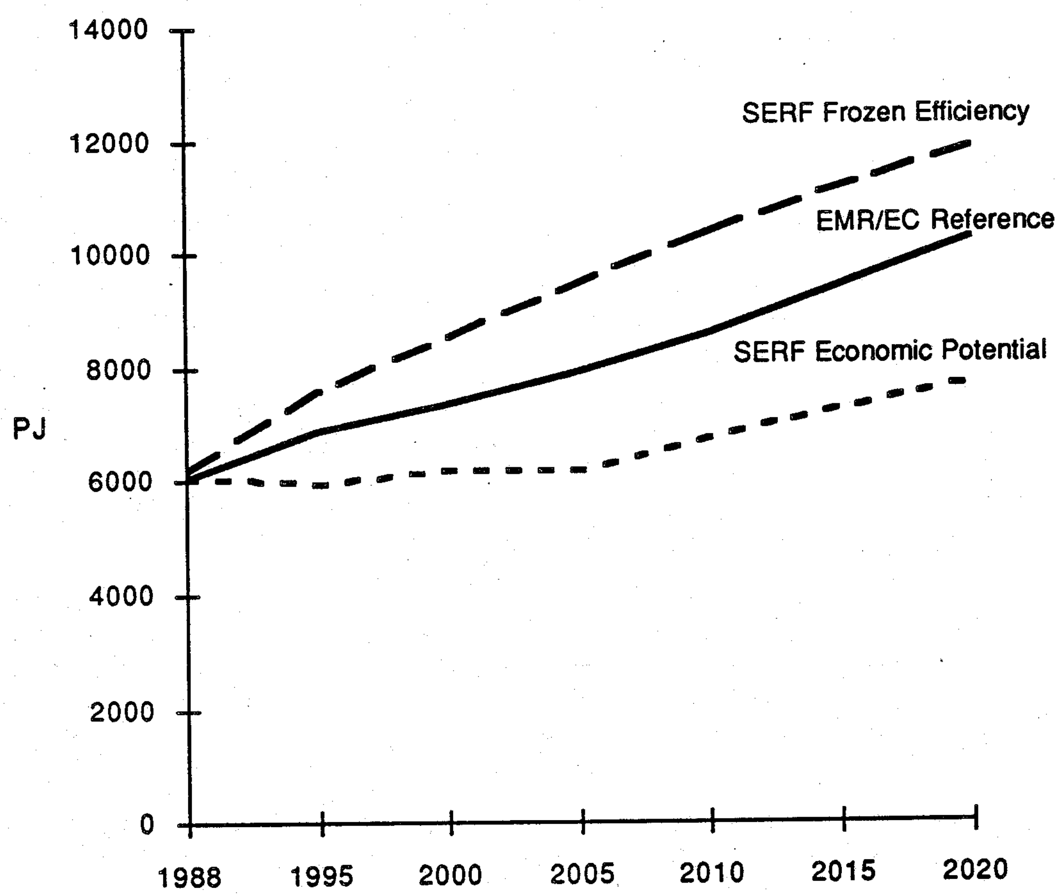
2. Aggregate results

Exhibit C, **overleaf**, provides the aggregate results in graphical form. The three lines on Exhibit C represent, for the period to 2020:

- The SERF frozen efficiency case

- The SERF economically attractive efficiency potential case, and
- The EMR/EC Reference Case of July 1990, which can be considered the "market case".

Exhibit C
Secondary Energy Use — 1988-2020
Comparison of SERF Frozen Efficiency and Economic Potential Cases and EMR/EC Reference Case (excluding biomass)

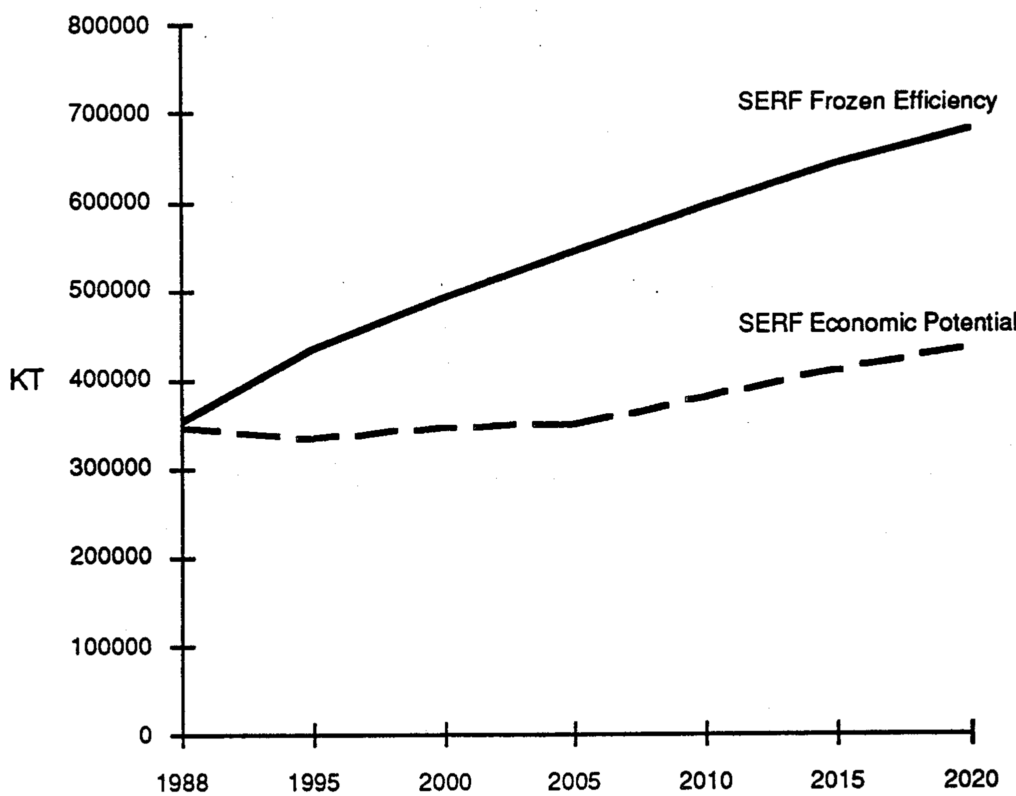


The difference between the frozen efficiency and economic potential cases is the estimated magnitude of economically attractive potential for energy efficiency. The market case, although derived through a different approach than that used in this study, lies between the other two cases in aggregate. Conceptually, the gap between the market case and the economically attractive potential case can be considered the magnitude of the area within which policy might conceivably operate.

E. Environmental impacts

We translated the estimates of economically achievable potential, expressed in secondary energy terms, into associated estimates of reductions in environment emissions. Emissions are estimated by converting the economically attractive energy efficiency demand potential, expressed in primary energy terms, into reductions in environmental emissions, using a series of emissions coefficients provided by EMR. Thus, it was necessary to make a number of assumptions to convert from secondary to primary energy. The most important of these, from the perspective of aggregate results, was the assumption that the fuel shares of electrical generation are frozen at 1988 shares, by region, over the projection period. This probably understates the environmental benefits of efficiency improvements. Exhibit D, **below**, summarizes the impact of achieving conservation potential to 2020. Note that, apart from the adjustment for electricity noted above, Exhibit D reflects CO_2 emissions associated with energy demand - the energy supply industries are excluded from the analyses.

Exhibit D
Carbon Dioxide Emissions — 1988-2020
Comparison of SERF Frozen Efficiency and Economic Potential Cases, and EMR/EC Reference Case



F. Lessons learned

The thrust of this study was to draw on available information on a number of industry sectors, end uses, and energy efficiency technologies, to develop a comprehensive estimate of energy efficiency potential in Canada. The following observations represent some of the major "lessons learned" in this exercise:

- The focus provided by the case study of particular loci of analysis was a key element of the study. In a number of sectors, the approach was very successful. However, it was difficult to apply the case study concept across the board. In particular, in the industrial sector, a more detailed focus, and perhaps a different set of questions, is necessary.

- The conduct of the study required us to compare results from the econometric modelling of energy demand, embodied in the EMR/EC Reference case, with the more disaggregated end use focus of the SERF model. Contrasting these two approaches yields a number of insights into energy efficiency issues.

- The concept of energy efficiency potential applied to the economy as a whole, is not straightforward. Its practical application requires a number of arbitrary analytical assumptions, such as freezing industry output mix, fuel shares, etc. Also it requires specific assumptions as to the appropriate definition of energy efficiency, such as the social benefit/cost perspective implicit in this study. The specific definition used clearly influences the results, and must be selected with care.

- Not surprisingly, the study was most effective in areas for which data of appropriate quality were most readily available. Because there is no adequate database of end use information in the public domain, data availability tended to be best in those areas in which members of the consulting team had done prior work. Without better and more comprehensive data, other researchers exploring this issue will be forced to "reinvent the wheel" to an inappropriate extent.

- For the above reasons, it is necessary to interpret the results of the study with care. This is not because the results are neither interesting nor relevant. It is instead because, in order to derive the results, a number of specific assumptions had to be made. It is necessary to understand both these assumptions, and the specific question which is being addressed in this study, before the results can be understood.

I

Introduction

In this chapter, we discuss the background to the study, its objectives, and some definitions.

A. Background

The Canadian economy has achieved significant energy efficiency gains since the first OPEC shock in 1973. Despite these significant gains in energy efficiency, there appears to be a considerable further untapped, cost-effective potential for such gains. Over the years, a number of studies have focused on estimating the technical potential for further cost-effective energy efficiency improvements. This study is intended to move from estimates of technical potential, to estimates of economically attractive potential.

B. Study objectives

The objectives of the study evolved significantly during the course of the work. The study objectives are as follows:

- **Economically attractive potential for energy efficiency gains**

  To estimate the remaining economically attractive energy savings potential in the Canadian economy from improved energy efficiency.

- **Environmental benefits**

  To estimate the net environmental benefits (expressed in terms of reductions in emissions) of realizing the economically attractive potential.

- **Barriers**

  To identify some of the key market barriers impeding the commercialization of economically attractive energy efficient technologies.

The study results should be disaggregated, to the extent possible, by region, sector, and fuel type, and should be presented in five-year intervals to 2020.

C. Various scenarios of energy use

1. Economically attractive scenario

The term economically attractive is used in a specific sense in this study. **Economically attractive** potential for energy efficiency gains refers to energy savings that can be achieved at a favorable social benefit-cost ratio, i.e., energy which can be conserved at a cost below the social opportunity cost for that energy. The way in which economically attractive potential is determined is discussed in Chapter II.

2. Frozen efficiency scenario

In order to define the potential for energy efficiency gains, a base case or status quo scenario must be defined. In this study, the base case against which economically attractive potential is defined is the **frozen efficiency** scenario. Conceptually, this scenario assumes that all future investment is put in place at the same energy intensities as the actual investment put in place in the base year, which is 1988. For example, for passenger vehicles, the frozen efficiency scenario assumes that all new vehicles have the same fuel efficiency as the average new car in 1988. Thus, under the frozen efficiency scenario, energy intensities will change over time as old stock is replaced, and overall energy use will change to reflect both these changing intensities and changing levels of economic activity. In practice, it is not always possible to implement this "frozen marginal efficiency" approach, and in some cases we have used an assumption of "frozen average efficiency".

3. Market case

Some of the economically attractive potential for energy efficiency gains may not be financially attractive to individual energy users, and may not be implemented. A number of other barriers to such investment exist, so that market forces will not in themselves cause all of the economically attractive potential to be implemented.

The **"market case"** scenario is a forecast of the levels of energy use which are likely to actually occur, given an outlook for economic growth and energy prices, but without any change in government policy intervention.

II

Overview Of Approach

In this chapter, we focus on five basic elements of our overall approach:

- The definition of economically attractive potential for energy efficiency gains.
- End-use modelling of the potential for energy efficiency gains.
- The use of case studies to focus end-use analysis.
- The use of the SERF (Socio-Economic Research Framework) model to develop a comprehensive estimate of potential.
- The determination of environmental effects.

A. Economically attractive potential for energy efficiency gains

For the purposes of this study, economically attractive potential for energy efficiency gains is a precisely defined term. It is the potential energy savings which can be achieved at a favorable social benefit-cost ratio, i.e., energy which can be saved at a cost below the social opportunity cost of obtaining that energy.

Conceptually, economically attractive potential is determined in the following manner:

- Possible energy efficiency measures are identified, and the actual capital cost of implementing these alternatives is estimated. (Conceptually, operating costs are also considered, although this is rarely done in practice.)
- The annual stream of physical energy savings, over the expected useful life of the efficiency investment, is determined.
- The supply price of saved energy is determined, as the price of energy saved which sets the net present value of the energy savings less the capital investment in the efficiency measure to zero, using a social discount rate.

- If the supply price is at or below the social opportunity cost of the saved energy, the associated potential for energy efficiency improvement is economically attractive.

The Steering Committee has provided the basis of social opportunity costs and social discount rates for this study.

- Social opportunity costs of energy are defined as energy price projections presented in the Energy Mines and Resources Canada ("EMR")/Environment Canada ("EC") Reference Case of July, 1990. These are summarized in Exhibit II-1, **overleaf.**

- The social discount rate, in real terms, is 7%.

It should be noted that the energy prices specified in the EMR/EC Reference Case as the social opportunity costs for this analysis are actually forecasts of market prices. Conceptually, they may differ from "true" social opportunity costs, defined from a benefit/cost analysis perspective, for reasons such as the following:

- They reflect average rather than marginal costs of energy generation.

- They may reflect the market values, rather than the social values, of inputs required to generate or produce energy. In particular, all energy taxes and royalties are included in these prices.

- They do not reflect any external environmental costs associated with energy use.

The Steering Committee directed that economically attractive energy efficiency potential also be considered using two sensitivity analyses, with energy social opportunity costs 20 and 40% higher than the base case numbers. This direction is intended in part to reflect possible gaps between the EMR/EC Reference Case energy price projections, and "true" social opportunity costs. It has been possible to conduct such sensitivity analyses for some specific case studies, but we have made no global estimates of the sensitivity of our estimates of economically attractive potential. More specifically, the impact of higher prices is discussed for the residential and industrial sectors.

B. End-use modelling of energy efficiency potential

The InterFuel Substitution Demand ("IFSD") framework, which has traditionally been used at EMR to assess energy demand, has at its core a large-scale econometrically-based model of the Canadian energy economy. Demand is essentially driven by underlying economic activity levels, and responds to differential energy prices. The model has been estimated on a rich base of economic and energy data, and is able to draw on a range of historical experience, including a variety of economic circumstances and associated energy costs and availability.

Exhibit II-1
Summary of Energy Price Projections

	1990 Prices	1995	2000	2010	2020
		(INDEX 1990 = 100)			
Electricity (¢/kwh)					
► residential	5.41	93	97	103	96
► commercial	6.57	92	95	102	96
► industrial	3.77	93	96	101	94
Heavy Fuel Oil (¢/L)					
► commercial	12.8	121	144	144	144
► manufacturing	12.8	121	145	145	145
Regular Leaded Gasoline (¢/L)	56.1	104	110	109	109
Natural Gas ($/GJ)					
► residential	5.24	112	127	128	127
► commercial	4.49	115	132	133	133
► industrial	3.15	118	141	143	143

Source: EMR/EC Reference Case, July 1990

The level and type of disaggregation required for this study have led us to take an end-use orientation to the energy efficiency analysis, rather then the econometric approach embodied in IFSD. The end use technique for analyzing energy demand developed in response to the need for analytical tools that would allow a more detailed analysis of the factors that determine the demand for fuels and electricity than is afforded by traditional econometric forecasting tools such as IFSD.

The application of the technique to energy efficiency potential is simple in its basic structure. Starting with a baseline description of the level of activity and its energy intensity, one then applies engineering performance and cost information for a particular energy efficiency measure. The application of the technique, however, grows in complexity with the scope of the analysis.

At one end of the scale are studies which focus very narrowly on the application of a particular technology. These are studies which have taken a particular technology for improving energy efficiency and have analyzed its technical, economic and financial potential in some depth. They typically include a review of the actual market penetrations achieved, and an analysis of the reasons such market penetrations have fallen short of the economic or financial potential. Examples in this category include Marbek's reviews of commercial lighting, electric motors and residential appliances. [1]

There have been a number of studies which have analyzed potential for energy efficiency improvements for an entire sector or subsector across a number of technologies and end uses. Examples here would include the Marbek/Engineering Interface study of the commercial buildings sector, the Acres study of the potential in the Canadian industrial sector.[2]

There have also been a number of end use type studies which have focused on the conservation potential for a particular fuel, most notably for electricity. Examples here include the Marbek/Torrie Smith Associates electricity conservation supply curves for Ontario, the ESSA/Marbek/WATSRF analysis for the Canadian Electrical Association of

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1a *Marbek Resource Consultants Ltd., "Energy Efficient Fluorescent Lighting in Canadian Office Building: Technologies,Market Factors and Penetration Rates", prepared for Energy, Mines and Resources Canada. July 1986.*

1b. *Marbek Resource Consultants Ltd., "Energy Efficient Motors in Canada: Technologies, Market Factors and Penetration Rates", prepared for Energy, Mines and Resources Canada. November 1987.*

1c. *Marbek Resource Consultants Ltd., "Appliance Efficiency Information Base," prepared for the Ontario Ministry of Energy. May 1987.*

2a. *Engineering Interface Limited and Marbek Resource Consultants Limited, "Commercial/Institutional Buildings: Electrical Energy Technology Study," prepared for Ontario Ministry of Energy. February 1988.*

2b. *Acres Consulting Services Limited, "A Study of the Potential for Energy Conservation in Canadian Industry", prepared for Energy, Mines, and Resources Canada. December 1979.*

the impact of emerging technologies on the future demand for electricity, and Marbek's work for Ontario Hydro in identifying and analyzing components of the second generation of demand management programs for the commercial sector.[1]

Finally, there have been a few efforts to construct comprehensive estimates of the potential for energy efficiency improvements across the full range of end uses, sectors, fuels and technologies. Some of the earliest work of this type was done within the Department of Energy, Mines and Resources in the late 1970's. In 1983, Friends of the Earth published such a comprehensive assessment for the year 2025, under a contract with EMR and other federal departments. The results of this broad brush analysis were updated by Torrie Smith and Associates during the recent Energy Options exercise, and most recently, DPA has completed such a comprehensive assessment as part of a study to identify opportunities for reducing carbon emissions. [2]

C. Focusing end-use analysis using case studies

The comprehensive end-use based analyses of energy efficiency and conservation potential which have been done to-date have necessarily been broad brush. In particular, they lack the focus on specific industry/end-user/technology combinations which is necessary to get beyond simple estimates of theoretical energy efficiency potential. The nature of the problem is made clear, when it is realized that the requirements for this study specify a highly disaggregated analysis of energy efficiency, which ideally identifies the potential by fuel, by region, by end-use, by technology, and by application. This defines a multi-dimensional matrix of several thousand cells.

The approach used in this study attempts to directly address the competing requirements for a comprehensive assessment of economic potential, and the need to go into some depth on the regulatory, institutional, and behaviour factors relevant to particular end-uses and sectors. The study approach focuses on case studies of a number of "loci of analysis". These cover the majority of meaningful opportunities for energy efficiency improvements,

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1a. *Marbek Resource Consultants Ltd., "Electricity Conservation Supply Curves for Ontario", prepared for the Ontario Ministry of Energy. August 1987.*

1b. *Environmental and Social Systems Analysts Ltd. et al, "Engineering Technologies Impacting on Electricity Needs to the Year 2020", prepared for the Canadian Electrical Association. September 1988.*

1c. *Marbek Resource Consultants Ltd., "Second Generation Energy Management Programs for the Commercial Sector: A Planning and Research Framework; Volume II", prepared for Ontario Hydro. February 1989.*

2a. *Torrie, Ralph D. and Brooks, David B., "2025: Soft Energy Futures for Canada—1988 Update", prepared for Energy, Mines and Resources. February 1988.*

2b. *The DPA Group Inc., "Study on the Reduction of Energy-Related Greenhouse Gas Emissions", prepared for the Ontario Ministry of Energy and various federal departments. March 1989.*

while still being sufficiently limited in number to permit a meaningful focus of analysis on each particular locus. The case study process, and its application, are described in more detail in Chapter III.

D. Using the SERF model to develop a comprehensive estimate of potential

Since the case study approach is in its nature selective, it is also necessary to have a comprehensive framework to ensure that the required global estimates of energy efficiency potential reflect 100% of the projected energy baseline.

An analysis of this type must operate on a projection of activity to the year 2020 which represents a plausible future Canadian society and which generates an energy baseline which represents a "pre-conservation," frozen efficiency scenario.

The study team have used the facilities at the Waterloo Simulation Research Facility ("WATSRF"), which houses and operates the Canadian Socio-Economic Research Framework model ("SERF"). The SERF model has been calibrated to the historical time series energy data in the Canadian energy balances (Statistics Canada Quarterly Report on Energy Supply and Demand).

1. The frozen efficiency scenario with SERF

We have specified baseline assumptions, based on EMR/EC data, with respect to level and mix of economic activity, and with respect to trends in fuel market shares. These have been used by WATSRF to produce a variation on one of the existing SERF projections, to yield a detailed and comprehensive energy baseline for the year 2020, calibrated to the activity projections underlying the EMR/EC Reference Case of July, 1990. This baseline has been used by our team of analysts to construct a "frozen efficiency" scenario, as a reference point for the detailed analysis of the potential for energy efficiency gains. The frozen efficiency scenario has been defined so as to correspond to the assumptions underlying the EMR/EC Reference Case, in two areas:

- Consistency of base year energy use.
- Level and mix of economic activity over the period to 2020, e.g., population growth, GDP growth, etc.

The SERF model and its role in this study are described in greater detail in Chapter IV.

2. Moving from case studies to SERF

The SERF model has been used in the following way:

- Case studies of the potential for energy efficiency gains have been undertaken, for ten key elements of the Canadian economy. The case studies have sought to develop a frozen efficiency scenario, an economically attractive case, and an estimate of economically attractive potential. SERF data and analysis was used to help develop activity level projections and estimates of base year energy use in some case studies. In most cases, this estimate has been broken down by region, fuel type, and end use, for the year 2020.

- As the next step, preliminary "sector roll-ups" were developed, estimating the aggregate energy efficiency potential in each of the four basic energy-using sectors (residential, commercial, industrial, and transportation). These roll-ups are based on the case study results, and attempt to generalize them, drawing on other easily available information, to make overall estimates of economically attractive potential in each of the four sectors. These estimates are for the year 2020, and are, for the most part, disaggregated by region, fuel type, and end-use. The four roll-ups are described in Chapters V - VIII. The base year energy data on the rollups comes from a range of sources, and are not always consistent with the IFSD and/or SERF frameworks.

- These four sector roll-ups, and their underlying case studies, have been incorporated into the SERF format as percent changes in intensity. Estimates have been made by sector as to the appropriate way of "ramping up" to 2020 levels of potential, and estimates of economically attractive potential have been made at five-year intervals from 1995 to 2020. These results are provided in Chapter IX. SERF does not provide information on end-use, and in many cases, does not provide a regional disaggregation. However, it has the advantage of an extremely comprehensive and internally consistent set of economic and energy relationships, which form the basis of its annual projections.

Ultimately, it is the SERF roll-ups, reported in Chapter IX, that form the basis of aggregate estimates of economically attractive potential for energy efficiency gains, and of the environmental implications of achieving this potential. The SERF rollups at the sector level are meant to be consistent with the sector rollups in Chapters V - VIII, but do not always provide identical results for the year 2020.

E. Determining the environmental effects

One objective in this study is to estimate the environmental benefits of realizing the economically attractive potential for energy efficiency gains.

The environmental benefits estimated in this study are in the form of reduced emissions from the end use of natural gas, coal, petroleum fuels and electricity. In the case of electricity savings, the environmental impact depends on the sources of power in a particular region or province. This task requires that the potential energy savings identified in the global energy analysis (disaggregated by fuel) be partitioned by region, and that emission coefficients associated with the and use of these fuels be applied to the savings. As noted above, adjustments have been made to convert secondary electricity to the appropriate primary fuels. Apart from this, the analysis is demand-oriented, and excludes the environmental impact of the energy supply sector.

EMR has provided a list of pollutants, as well as appropriate coefficients for emissions per unit of end-use energy associated with each energy form.

The results of these analyses are described in Chapter X of this report.

III

The Case Study Process

The application of the case study approach to loci of analysis is the key to our approach, and constitutes the key research task of the engagement.

In this chapter, we describe the case study process, including the following topics:

- Selection of loci of analysis.
- Definition of the case study.
- Approach to case study research.
- What we learned from conducting the case studies.

A. Selecting loci of analysis

Loci of analysis are clusters of energy efficiency opportunity areas, defined in a multi-dimensional matrix with axes of sector/end-use/technology.

The factors which helped determine the appropriateness of various loci of analyses included the following:

1. Magnitude of energy used

There could be only a limited number of loci, and together they must account for most of the energy used in the baseline.

2. Savings potential

The set of loci was chosen to represent as much of the total savings potential as possible, so that each cluster selected for analysis represented significant energy savings potential.

3. Data constraints

Data availability and quality are always a constraint in energy end-use analyses. Sectors in which data are so poor that it was unlikely the useful results would be determined were avoided.

4. Program activity interface

The energy analyses should be structured so that they map meaningfully on to possible program options. The Steering Committee provided some indication of preferences, based on this criterion.

In the actual selection process, two quite different perspectives were taken. Separate comprehensive sets of loci of analysis were defined according to:

- Sector and end-use within sector, and
- Technology

The final selection of case studies combine elements of both approaches, e.g., electric drive power in a number of industries was selected as a technology area, while a number of industry sub-sectors were also selected as case study areas. The results of these two perspectives were integrated in the final analyses.

The process of selecting loci of analysis was iterative. The consultants suggested potential loci, based on the criteria described above. These were reviewed and amended in discussions with the Steering Committee, until a common consensus was determined.

The ten loci of analysis which were selected as case studies are summarized in Exhibit III-1, **below**. Separate case studies of each locus of analysis have been prepared, and are provided as appendices. The individual case studies are summarized very briefly in the sector rollups in Chapters V - VIII. Exhibit III-1 also provides the appendix number for each case study. For single family residential and office and retail, the new and retrofit case studies have been combined, so that there are eight volumes of case studies associated with this report.

Exhibit III-1
Loci of Analysis Selected as Case Studies

Sector	Locus	Case Study Appendix
Residential	New Single Family Space Heating	#1
	Retrofit Single Family Space Heating	#1
	Appliances Including Lighting	#2
Commercial	New Office and Retail	#3
	Retrofit Office and Retail	#3
Transportation	Light Vehicles	#4
Industrial	Chemical Industries	#5
	Forest Industries	#6
	Iron & Steel Industries	#7
	Drivepower	#8

B. What is a case study

Essentially, a case study involved four basic components:

- Collection of detailed historical energy use data for the locus of analysis.
- Review of all available published reports of relevance.
- Where it was feasible, analysis of cost and performance data to determine potential.
- A series of discussions with those knowledgeable in the field, with a particular emphasis on obtaining their views regarding future trends, and the nature and application of particular barriers.

Exhibit III-2, **overleaf**, summarizes the conceptual structure of an "ideal" case study. It became clear, particularly in the industrial sectors, that available information base did not support this type of analysis. As a consequence, some case studies are more qualitative, with a focus on factors which are likely to influence energy intensities in the future. The structures of individual case study write-ups vary to some extent by case study, reflecting this circumstance. This issue is discussed in more detail at the end of this chapter.

C. Estimating energy efficiency potential in the case studies

In the following paragraphs, we discuss in more detail the conceptual framework for defining the potential for energy efficiency gains in the case studies.

1. Frozen efficiency scenarios

The following are the key elements of the Frozen Efficiency scenarios:

- Base Year (1988) energy use, by sector and sub-sector, is defined to be consistent with the EMR/EC Reference Case.[1]

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1 *In fact, EMR's Vision 2020 document, produced in late 1989, was the basis of the reconciliation. Subsequently, EMR revised its long range forecasts. In order to maintain consistency, we revised our results to reflect the EMR/EC Reference Case of July, 1990. Since no additional resources were made available for this task, we restricted our adjustments to those which were easily achievable. In practice, we have closely matched the assumptions underlying the July, 1990 outlook.*

Exhibit III-2
Ideal Procedure for Each Case Study

End-Use Definition:

1. Define locus of analysis in terms of market segment and/or end-use.
2. Determine baseline (1988) energy end-use by province and fuel for the locus of analysis.
3. Determine "frozen efficiency" energy end-use in 2020 by fuel and province for locus of analysis from baseline SERF run or other source.

Technical Potential:

4. Identify candidate best available energy efficiency technologies and measures applicable to locus of analysis, which are expected to be market ready before 2020.
5. Determine the energy reduction (%) associated with each technology over current standard practice.
6. Determine the lifecycle costs associated with implementing each measure or technology. Where appropriate, document both hard (easily estimated) and soft (less easily estimated) costs. Calculate annualized cost at social discount rates.
7. Determine the energy savings (by fuel and province) associated with full implementation of each technology by applying reduction factors determined in Step 5 to frozen efficiency estimates from Step 3.
8. Determine the unit price of each measure form Steps 6 and 7 and construct a conservation supply curve.
9. Iterate through Steps 7 and 8 to account for interactions between low cost and higher cost measures (low cost measures assumed implemented before higher cost measures).

Economic Potential

10. Compare supply curves with a range of fuel prices and identify measures and technologies that are economically attractive over the period 1988-2020.
11. Identify non-price barriers to implementing those measures and technologies identified as attractive in Step 10.
12. Conduct interviews with technology suppliers and users to gather information on these barriers, including ways to remove or minimize the barriers.
13. Estimate and discuss the sensitivity of changes in costs, discount rate, economic structure, fuel prices and fuel shares on the results of the analysis.
14. Estimate the overall savings over the period 1988 to 2020 by fuel and province from full implementation of attractive measures and technologies in Step 10.
15. Prepare a report on the locus of analysis, including all analytical results, interview results, discussion, and conclusions.

- The economic outlook embodied in the IFSD projections, which can be viewed as a set of demographic assumptions and projections of levels of economic activity, form the basis of the Frozen Efficiency scenario.

- Ideally, marginal energy intensities were frozen at the 1988 levels. In other words, the Frozen Efficiency scenario assumes that energy efficiencies (or intensities) remain at those levels embodied in capital assets put in place in 1988. This concept can be defined as a **marginal frozen efficiency**, as opposed to **average frozen efficiency**, which maintains average energy intensities within loci of analysis at their 1988 levels. In practice, it was possible to implement the marginal frozen efficiency perspective only in some sectors, particularly single family residential; commercial; appliances; the light vehicle sector; and to a lesser extent, industrial drive power. For the industrial subsectors, it was necessary to employ an average frozen efficiency assumption. This assumption was necessary because insufficient information was available on differences between average and marginal efficiencies in the existing stock, as well as the nature and pattern of stock replacement.

- In order to make the frozen efficiency scenario approach implementable, it was also necessary to "freeze" other aspects of the economic and energy using structure of the economy. In particular:

    - The use of frozen efficiency scenarios for loci of analysis in effect freezes output mix within these loci.

    - It was assumed that, within loci of analysis, relative fuel shares would also be frozen. While this assumption may not be realistic in light of the projected shifts in relative energy prices which underlie the study, it was a practical necessity. In some cases, the frozen fuel share assumption was implemented at a more disaggregated level than the case study as a whole.

2. Economically attractive scenarios

As Exhibit III-2 illustrates, once a frozen efficiency scenario has been developed for a locus of analysis, the focus of the case study is on identifying and evaluating individual energy efficiency technologies, to determine those which can supply savings at supply prices which are lower than the social opportunity costs of the energy saved. A number of guidelines were developed in order to implement this procedure. The study team developed some clarity at the conceptual level in defining the criteria for identifying economically attractive technological changes. However, it was often difficult to implement these criteria precisely in the individual case studies, due to lack of sufficiently detailed information. In some cases, this reflected an inability to disaggregate the results of other studies.

The following guidelines underlay the choice and evaluation of technologies:

- We sought to restrict ourselves to those energy efficiency technologies which could reduce energy intensities or increase energy efficiency, without any adjustment in the actual service levels provided to energy users. We excluded technologies which might be expected to reduce comfort or convenience, e.g., lifestyle changes, enforced modal shifts in the transportation sector, changes in urban design, etc. Although in practice it is often difficult to determine whether changes in service levels are implicit in various forms of conservation technologies, our intent was to restrict ourselves to those which did not imply changes in service levels.

- In the case studies, we sought to determine circumstances in which prices of technology might be expected to change, and particularly decline in real terms, over the timeframe of the analysis. In such a circumstance, an energy efficiency technology which might not be economically attractive in 1990 might become attractive in later years, as it became cheaper to implement. While we explored this possibility during a number of the case studies, in practice we did not identify technologies in which it appeared to be feasible to quantify such relationships (apart from some aspects of the drivepower case study). Thus, the quantitative analysis of potential assumes constant real prices of technology over the analysis period.

- One implication of the prior point is that we restricted ourselves to considering energy efficiency measures and technologies which are currently available. There is one exception to the above rule. In the light vehicle case study, we examined technologies that are expected to be developed over the next decade.

- In principle, the assessment of economically attractive technologies yields different results, depending on the year in which the technology is assumed to be implemented. Because of projections of changing energy prices, the value of energy efficiency improvements achieved by a given technology varies over time. In practice, we did not explore fully this dimension of potential. This reflects two considerations:

  - The baseline energy prices are relatively stable for many energy types, although there are increases in some energy prices to the year 2000.

  - Energy prices do not change in real terms past the year 2000.

  Consequently, the case studies have focussed on assessing the potential in the year 2020, assuming energy prices in that year. Phase-in assumptions were used in the SERF roll-up of aggregate results, to develop estimates of potential in the intervening years.

- In order to obtain meaningful results for some loci of analysis, it is necessary to assume that potential efficiency measures are adopted on a scale which exceeds the size of the Canadian market. For example, in both the appliance and light vehicle case studies, product design is international in scope, and the cost of implementing many design changes associated with energy efficiency improvements would be prohibitive if undertaken for the Canadian market alone. Thus, we have costed such measures on the assumption that they are implemented for, at a minimum, the North American market. This appears to be the most realistic assumption, although it also highlights barriers to the achievement of economically attractive potential in the sectors, as a result of Canadian policy measures alone.

D. What we learned from conducting the case studies

The approach to our work was designed with a clear view of the role of the case study, and of the structure of a typical case study. Although these assumptions were not necessarily explicit at the time of study design, the implicit assumptions underlying the case study structure outlined in Exhibit II-2 include the following:

- A locus of analysis covers an area in which the bulk of energy efficiency potential is in the form of "pure" energy efficiency measures, which can be identified and costed.
- There is a good deal of available information, either in existing literature or through discussion with knowledgeable industry members, which permits the identification and costing of such measures.
- Data are available to permit the results to be scaled up to the locus of analyses, e.g., an industry sub-sector.

In fact, this "idealized" case study became the exception, rather than the rule. In retrospect, it is clear that the case studies fell into three broad categories.

1. The "ideal" case study

Perhaps only the residential appliance case study is an example of the ideal case study, as it was anticipated. To a lesser extent, the light vehicle case study also falls in this category, although existing studies did not permit a calculation of true economically attractive potential, which had to be inferred.

2. Those studies which relied on extensive, in-house data available to the consultants

Several of the case studies were ultimately conducted as very detailed aggregations of end-use data, which relied extensively on detailed information in the files of the consultants, in many cases, arising from earlier or concurrent studies. The new and retrofit office and retail case studies (and associated roll-ups) are perhaps the clearest example of this, as they provide a level of depth and detail well beyond that conceived in the original case study design. The wealth of data available both to Marbek and within the SERF model permitted a similar approach to the residential space heating case studies, although they have much in common with the "ideal" model described above. The industrial drive power case study was able to draw upon detailed, mill-level data on existing industrial motor stock, which had been developed by Marbek in previous studies.

3. Case studies for which existing data were inadequate

The third category of case studies were of loci of analysis for which the basic assumptions underlying the case study process were not fulfilled. This is true for the pulp and paper and iron and steel, and to a lesser extent, chemical case studies. For these industrial sectors:

- There was very little information available in existing studies, or in the files of the consultants, addressing issues of relevance to the study. Those studies which were available tended to focus on technological potential, with inadequate information to provide costing, and with inadequate population data to permit any scaling-up of results to the population as a whole.

- The concept of the "frozen efficiency" scenario, with its assumptions of frozen output mix and frozen fuel share, was clearly less valid than for other sectors.

- Not only was population data inadequate, but there was little available information to determine to what extent "theoretical" energy efficiency potential has already been implemented within the industry.

IV

Establishing A Common Framework

As noted in Chapter II, the energy analysis in this study is based on an end use approach, focused on a number of specific case studies, and rolled up to provide economy-wide numbers using the SERF model. This is distinct from the framework within which EMR does its own energy demand forecasting, which is an econometrically-based approach, known as the IFSD model.

In order that the results of this study are interpretable within the context of EMR's work, it was necessary to establish a common framework for the work, and, in particular, to ensure that the frozen efficiency scenario used in this study can be compared to and interpreted in the context of the existing EMR/EC Reference Case projections of energy price and demand in the Canadian economy, produced with the IFSD model.

In this chapter, we:

- describe and compare the IFSD and SERF models, and the associated frameworks within which they operate.
- Provide an overview of the adjustments made to the SERF model, in order to reconcile it to the July, 1990 EMR/EC Reference Case.
- Describe the frozen efficiency scenario.

A. SERF and IFSD compared

From the perspective of this study, there are some relevant differences between SERF and IFSD. Both are essentially fed by external assumptions with respect to demographics and economic activity levels. The core of IFSD is an econometrically estimated behavioural model of energy demand. SERF, on the other hand, is essentially an extremely detailed set of physical accounting relationships. All behavioural assumptions are provided exogenously to SERF, but the basic structural and technological relationships are defined explicitly and in great detail. Thus, the approach of the two models to energy issues is quite distinct. Essentially, IFSD focuses on trends in energy demand, mediated by changes in relative prices, but with very little insight into the technology and capital investment decisions whereby decisions regarding energy demand are actually implemented. SERF, on the other hand, permits a detailed exploration of these technological decisions at the end-use level, but, inside the model, provides no insight into the nature of price effects.

B. Overview of adjustments and reconciliation

The primary purposes of the adjustment and reconciliation of SERF to the EMR/EC Reference Case projections, were two-fold:

- To ensure that both models had a common view of 1988 energy use, by fuel type and sector, and
- To ensure that the two models shared common views with respect to demographic and economic activity over the period from 1988 to 2020.

1. Base year energy comparisons

Although both models are ultimately calibrated to Statistics Canada Catalogue 57-003 (Quarterly Report on Energy Supply—Demand in Canada), their 1988 energy base year data differed, primarily for two reasons:

- For IFSD, 1988 is a base year[1]; for SERF, 1981 is the base year, and 1988 is a "forecast" year. Thus, it is necessary to ensure that SERF "forecasts" 1988 base year data, and to revise these forecasts as other adjustments are made to the 1988 data (e.g., revising estimates of vehicle stock)
- There are a number of other differences in sectoral definitions in the two models. Where possible, these have been dealt with by reformatting SERF results in the IFSD framework (or occasionally vice versa), e.g., moving electricity used for pipeline fuel, and electricity used in road transport and urban transport, to the commercial sector. Others cannot really be dealt with within the existing model frameworks. For example, SERF includes wood as an energy source for residential heating, but excludes wood as an energy source in the industrial sector. IFSD makes the opposite assumptions.

The reconciliation of the SERF 1988 base year data, in the frozen efficiency scenario, and the IFSD 1988 data, from the EMR/EC Reference Case, is summarized in Exhibit IV-1, **overleaf**.

- As Exhibit IV-1 illustrates, the standardization of base year energy assumptions is quite close. Excluding wood, the biggest percentage discrepancy is in the transportation sector, where SERF shows approximately 6% greater base year energy use than does IFSD.

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1 *The IFSD database had not been updated for 1988 at the time those reconciliations were made. However, the IFSD data for 1988 had been "tuned" to actual data.*

Exhibit IV-1
Overall Comparison of SERF Frozen Efficiency and EMR/EC Reference Case—Base Year (1988) Energy Use (PJ)

Sector		Coal and Coke	Elec.	Nat. Gas	Wood and Steam	Fuel Oil	Gasoline	Trans. Diesel	Av. Fuel	LPG's	Total	Total Excl. Wood
Residential	SERF	3	466	557	39	196	0	0	0	36	1,298	1,259
	EMR/EC	3	447	535	0	203	0	0	0	36	1,224	1,224
Commercial	SERF	0	351	365	0	112	0	0	0	27	855	855
	EMR/EC	1	357*	362	0	112	0	0	0	16	847	847
Industrial	SERF	224	708	730	0	323	0	0	0	8	1,993	1,993
	EMR/EC	230	710	700	459	325	0	0	0	13	2,438	2,012
Transportation	SERF	0	2	1	0	56	1,287	496	186	29	2,057	2,057
	EMR/EC	0	0	3	0	55	1,180	482	186	25	1,930	1,930
Total	SERF	227	1,527	1,654	39	687	1,287	496	186	100	6,203	6,164
	EMR/EC	233	1,514	1,600	459	692	1,180	482	186	90	6,439	6,013

Totals may not add due to rounding.

* Includes street lighting

Source: SERF and IFSD databases

- ► There are discrepancies between gasoline and diesel, in the transportation sector.
- ► There are some differences in sectoral allocation of LPGs, which are a relatively minor energy source.

These comparisons are shown in graphical form in Exhibit IV-2, **overleaf.**

2. Activity levels

IFSD drives its basic demographic and economic growth assumptions from the Informetrica model of the Canadian economy. Recognizing that there are differences in sectoral definitions between SERF and IFSD, we have attempted to match the demographic and economic activity level assumptions in the two models. Comparisons between the two models are only possible at the level of disaggregation of IFSD. Exhibits IV-3, **below,** and IV-4, **overleaf,** summarize these results.

Exhibit IV-3
Comparison of Economic Growth Assumptions—
EMR/EC Reference Case Assumptions of Economic Growth
(million 1981 $)

	1988	2020	2020/1988
Agriculture	9.23	17.55	1.90
Iron and Steel	1.53	3.17	2.07
Industrial	132.8	274.8	2.07
Commercial and Public Administration	208.1	385.7	1.85
Total	397.4	783.4	1.97

Source: Inter Fuel Substitution Demand Model Database.

In considering these exhibits, it is useful to consider the following:

- ► IFSD is denominated in 1981 constant dollars, while SERF is denominated in 1971 constant dollars.
- ► IFSD requires explicit assumptions about agriculture, iron and steel, industrial, commercial and total real domestic product. EMR obtains these assumptions from the most recent macroeconomic projection of Informetrica Limited. Since Informetrica projections only extend to 2005, EMR must extrapolate the required variables through 2020 to meet its needs.

Exhibit IV-2
Comparison of SERF Frozen Efficiency and EMR/EC Reference Case Sectoral Energy Use in 1988 (excluding biomass)

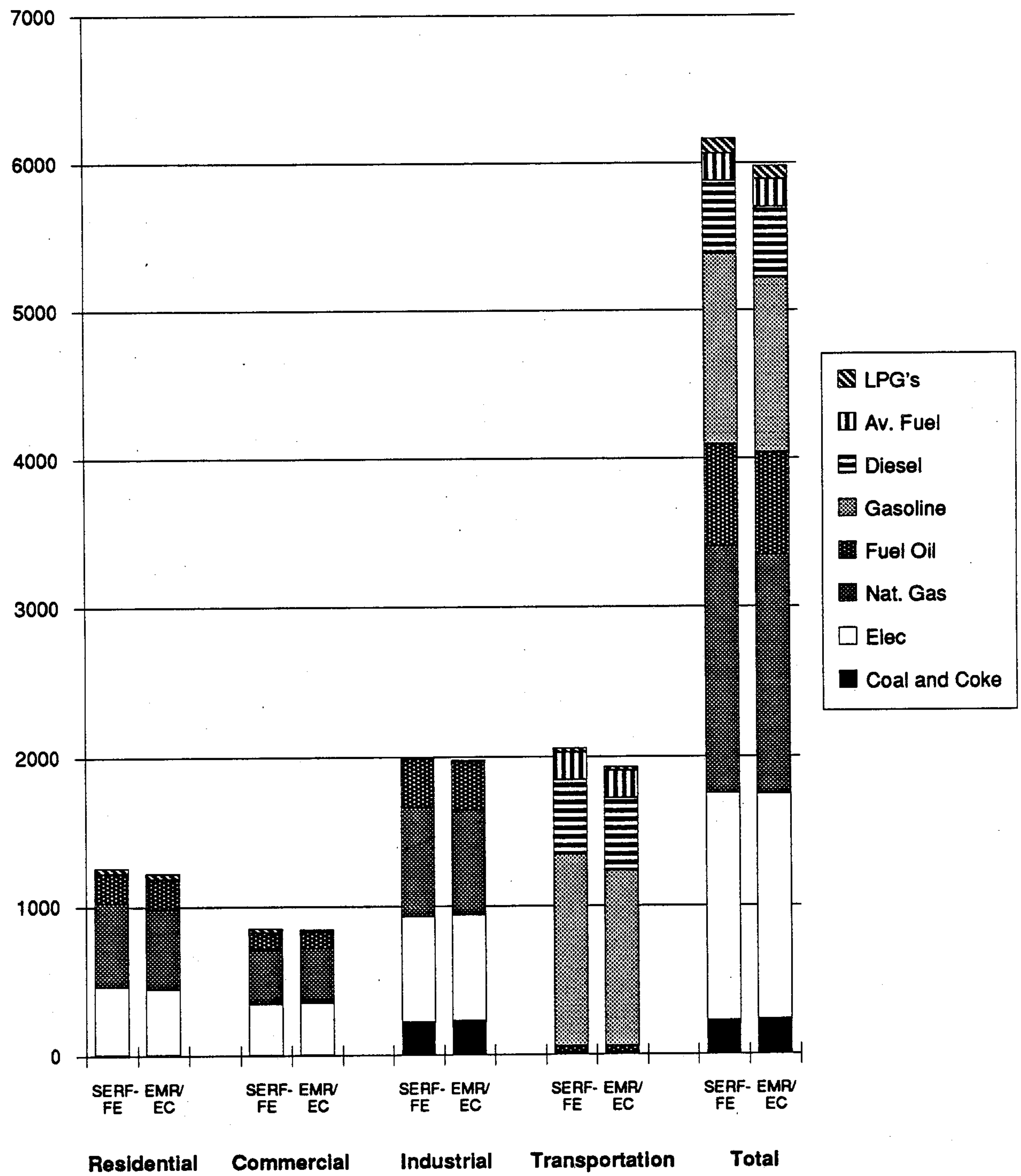

Exhibit IV-4
SERF Frozen Efficiency Projections of Economic Growth (million 1971$)

	SERF 1988	SERF 2020	SERF 2020/1988	IFSD 2020/1988	SERF ratio/ IFSD ratio
Mining	3,308	4,807	1.45	N/A	N/A
Forestry	8,170	13,814	1.69	N/A	N/A
Agriculture	6,762	12,578	1.86	1.90	0.98
Fisheries	337	182	0.54	N/A	N/A
Prim. Industries	18,577	31,382	1.69	N/A	N/A
P&P & Primwoodi	12,673	22,063	1.74	N/A	N/A
Chemproc	8,269	18,919	2.29	N/A	N/A
Ironsteel	4,396	8,650	1.97	2.07	0.95
Other Mfg	92,464	190,720	2.06	N/A	N/A
Subtotal Prim & Sec	136,379	271,735	1.99	2.07	0.96
Communications	421	1,167	2.77	N/A	N/A
Education	15,755	24,735	1.57	N/A	N/A
Health	918	1,431	1.56	N/A	N/A
Other Services*	8,858	15,841	1.79	N/A	N/A
Subtotal Commercial	25,952	43,174	1.88	1.85	1.02
TOTAL	162,331	314,909	1.94	1.97	0.98

* merchandising, personal services, office buildings

Source: SERF model database

SERF requires highly detailed projections of real domestic product to 2020. We have used the Informetrica projection of real domestic product underlying the EMR/EC Reference Case through 2005, and have linearly extrapolated the required RDP's through 2020 to meet the input requirements of SERF.

- The sectoral definitions themselves are quite different in the two models. For this reason, the basic approach used has been to take growth factors, based on IFSD (i.e., the ratio of 1981 dollar output in the year 2020 divided by similar output in 1988), and to apply these growth ratios to the SERF base year activity levels.

The application of such ratios is not always straightforward, because the complex input/output structural relationships implicit in SERF mean that a change in the output of any industry affects the outputs of other industries.

The results are visible in Exhibit IV-4, which compares the non-transportation growth rate factors ultimately embodied in the SERF frozen efficiency projections, with similar growth factors from IFSD (derived from Exhibit IV-3).

Standardization of the two sets of activity projections for the transportation sector proceeded somewhat differently. The transportation sector in SERF is structured around "distance travelled" activity variables. Growth in number of kilometers traveled by various modes is typically built up as a combination of a stock of transportation infrastructure, and a distance travelled per unit of stock variable. Transportation in IFSD is described in terms of RDP.

SERF distance travel activity variables were adjusted so that their growth, over the period 1988 to 2020, was the same as the growth rates by mode in IFSD. As is illustrated by Exhibit IV-5, **below**, the matching in growth rates was exact, although it is difficult to determine whether the implications for energy use have also been matched, because of the different measures used.

Exhibit IV-5
Comparison of Growth Factors in Transportation

	IFSD 2020/1988	SERF 2020/1988	SERF Ratio/IFSD Ratio
Road	2.14	2.16	1.01
Rail	2.14	2.13	1.00
Urban Transit	2.17	2.16	1.00
Marine	2.35	2.36	1.00
Air	2.09	2.09	1.00
Total without Marine	2.13	2.15	1.01

C. The frozen efficiency scenario in SERF

The frozen efficiency scenario in SERF was built up from a SERF run which had been standardized with IFSD with respect to base year energy use, and demography/activity levels as described above. Ideally, the frozen efficiency scenario is defined in terms of "marginal frozen efficiency", i.e., new investment is brought on-stream over the study period to 2020, embodying energy intensities characteristic of the 1988 base year.

In some cases, it was possible to implement this true "marginal" concept, and in other cases, an "average" definition was required. In particular:

- SERF has detailed vintage stock data with respect to most of the transportation sector, the residential housing sector, and the residential appliance sector. In these cases, true "marginal" frozen efficiency was applied.

- In the industrial and commercial sectors, no capital stock data are available in SERF. For the industrial sector, average frozen efficiency concepts (energy intensity per dollar of RDP) were applied. For the commercial sector, a different approach was used. The commercial sector roll-up, which was done independently of SERF and is reported in Chapter VI, uses vintage stock data, and has applied a true "marginal" frozen efficiency approach. The SERF commercial sector energy use in the frozen efficiency scenario was calibrated to the results of this rollup analysis, thus incorporating the effects of a marginal frozen efficiency calculation in the SERF projection.

These distinctions should be remembered when considering sectoral results. Generally speaking, a true "marginal" frozen efficiency baseline will show lower energy use in the future than an "average" frozen efficiency scenario. As a consequence, the scope for additional, economically attractive energy efficiency potential is more limited under a "marginal" frozen efficiency scenario. Stated differently, some of the identified potential in the industrial sector reflects the replacement of older, less efficient stock with new stock having the energy use characteristics of 1988 investment.

Exhibit IV-6, **overleaf**, summarizes the frozen efficiency scenario under SERF, and compares it to IFSD results in 2020. Particularly after adjusting for their different treatments of wood energy, the SERF frozen efficiency run and IFSD projections of energy use are relatively similar, with IFSD showing marginally less energy use in 2020, in all sectors (excluding biomass), but particularly in transportation. This may reflect the treatment of transportation in IFSD, in which some "exogenous" fuel efficiency improvements are assumed, i.e, a modified end-use approach is used.

Exhibit IV-6

COMPARISON OF SERF "FROZEN EFFICIENCY", AND EMR/EC REFERENCE CASE PROJECTIONS OF ENERGY USE IN 2020 (PJ) (excluding biomass)

Sector		Coal & Coke	Elec	Nat. Gas	Fuel Oil	Wood and Steam	Gasoline	Trans. Diesel	Av. Fuel	LPG'S	Total	1988 Total	2020/1988
Residential	SERF	6	732	731	187	0	0	0	0	104	1,759	1,298	1.36
	EMR/EC	2	748	709	138	0	0	0	0	44	1,641	1,224	1.34
Commercial	SERF	0	750	701	206	0	0	0	0	55	1,711	855	2.00
	EMR/EC	1	759 *	595	194	0	0	0	0	29	1,578	847	1.86
Industrial	SERF	439	1,362	1,424	605	0	0	0	0	17	3,847	1,993	1.93
	EMR/EC	353	1,606	1,342	499	64	0	0	0	20	3,884	2,012	1.93
Transportation	SERF	0	5	3	187	0	2,681	1,167	375	121	4,539	2,057	2.21
	EMR/EC	0	0	15	85	0	1,809	890	314	44	3,157	1,930	1.64
Total	SERF	445	2,849	2,858	1,184	0	2,681	1,167	375	297	11,857	6,203	1.91
	EMR/EC	356	3,113	2,661	915	0	1,809	890	314	137	10,259	6,013	1.71

Totals may not add due to rounding

* Includes street lighting

V

Economically Attractive Potential In The Residential Sector

A. Introduction

This section summarizes the results of two residential case studies on space and water heating in single family homes (detached, double and row), and electrical appliances in all residential homes. It also provides an estimate of potential savings in space and water heating in multifamily (apartment) homes, and a consolidated estimate of savings for the whole residential sector. It excludes the agricultural sector, and so total energy use is less than for the SERF and IFSD results.

B. The residential sector

Exhibit V-1, **below**, presents an estimate of the number of households in Canada in 1988 by region and type. Single and attached (double and row) housing is often referred to as "Single Family Housing", and the number of homes and households are synonymous. Apartment housing consists of low-rise (walk-up) and high-rise, and one household represents a single unit and not the number of buildings.

Exhibit V-1
Canadian Residential Housing Stock in 1988

Region	Atlantic	Quebec	Ontario	Prairies	BC	Canada
Single	556,724	1,112,740	1,994,100	1,064,561	688,020	5,416,150
Attached	45,579	113,286	390,885	153,853	87,024	790,627
Subtotal, Single Family	602,303	1,226,026	2,384,985	1,218,414	775,044	6,206,772
Apartments	177,225	1,339,470	1,149,230	458,785	396,524	3,521,230
Total	779,528	2,565,500	3,534,220	1,677,199	1,171,568	9,728,006

Source: Informetrica, 1990

Exhibit V-2, **below**, shows regional variations in new housing by type.

Exhibit V-2
New Housing by Type (1988)

Region	Single	Double	Row	Apartment	Total
Atlantic	10,347	1,024	366	2,067	13,804
Quebec	8,980	2,809	1,718	31,717	65,224
Ontario	58,072	2,552	10,168	17,935	88,727
Prairies	16,027	843	1,049	3,255	21,174
BC	15,785	883	3,382	7,553	27,603
Canada	129,211	8,111	16,683	62,527	216,532

Source: Canada Mortgage and Housing Corporation

1. Single family homes

Single family homes normally are of woodframe construction, and consist of self contained housing units which are either detached (single), semi-detached (double or duplex), or joined to other housing units (row or triplex etc.). Each unit has its own space and water heating system and its own appliances. New construction for all three types is covered by the same residential building code (with some minor variations). Most new single family homes are being built today with 2x6 wall construction with insulation levels equivalent to the 1983 NRC Recommended Measures for energy conservation, except in southern Ontario and British Columbia.

2. Apartments

Apartment buildings normally use concrete construction similar to commercial buildings, and space and water heating systems are often shared between individual units in each building, although each unit may be separately metered for heat and hot water, and have its own thermostat. Each unit will usually have its own set of electrical appliances, unless the building has its own laundry room. New construction is usually subject to different building codes than for single family homes.

3. Expected growth 1988 to 2020

The EMR/EC Reference Case assumes a growth in the total number of households of 1.3% per year over the next 30 years. Exhibit V-3, **overleaf**, provides an estimate of the number of households in 2020 by region and housing type, based on the assumptions underlying the EMR/EC Reference Case.

Exhibit V-3
Estimated Canadian Residential Housing Stock in 2020

Region	Atlantic	Quebec	Ontario	Prairies	BC	Canada
Single	695,933	1,584,840	2,808,850	1,504,373	1,002,039	7,596,035
Attached	58,284	146,096	709,648	332,068	149,208	1,395,304
Subtotal	754,217	1,730,936	3,518,498	1,836,441	1,151,247	8,991,339
Apartments	254,852	1,864,880	2,074,030	860,350	821,691	5,875,803
Total	1,009,069	3,595,816	5,592,528	2,696,791	1,972,938	14,867,142

Source: Informetrica, 1990

C. Energy use in the residential sector

Energy use in the residential sector may be conveniently divided into three main end-uses:

- Space heating.
- Water heating.
- Appliances including lighting and space cooling.

Exhibit V-4, **overleaf**, provides a breakdown of 1988 energy use in the residential sector by region, household type and end-use, based on estimates, made in the two case studies, of energy use by appliances and single family space and water heating.

Space and water heating energy use in apartments was estimated as follows, assuming average intensities for a typical apartment unit as shown, and an average apartment unit size of $65m^2$:

	Intensity Kwh/ft²yr	Intensity MJ/m²yr	Energy Use MJ/unit yr
Water Heating	7.5	290	19,000
Space Heating	10.0	385	25,000

Fuel shares for apartments were assumed to be the same as for single family homes in each region.

The figures in Exhibit V-4 are lower than Statistics Canada 1988 residential energy use by about 70 PJ and IFSD 1988 energy use in the residential sector by about 140 PJ.

Exhibit V-4

1988 RESIDENTIAL ENERGY USE (PJ)

	Space Heating				Water Heating				Appliances		Total Energy			
	Elec	Gas	Oil	Total	Elec	Gas	Oil	Total	Elec	Gas	Elec	Gas	Oil	Total
SINGLE FAMILY HOMES														
Atlantic	13.0	0.6	28.1	41.7	9.3	0.0	4.7	14.0	13.1	0.0	35.4	0.6	32.8	68.8
Quebec	56.4	9.3	29.7	95.4	22.2	1.3	3.1	26.6	43.0	0.3	121.6	10.9	32.8	165.3
Ontario	32.8	157.2	48.3	238.3	23.8	38.6	1.1	63.5	61.7	2.1	118.3	197.9	49.4	365.6
Prairies	12.7	146.5	7.0	166.2	5.7	30.4	0.2	36.3	29.9	1.2	48.3	178.1	7.2	233.6
BC	10.1	30.6	7.3	48.0	7.6	12.4	0.7	20.7	20.1	0.4	37.8	43.4	8.0	89.2
Canada	125.0	344.2	120.4	589.6	68.6	82.7	9.8	161.1	167.8	4.0	361.4	430.9	130.2	922.5
APARTMENTS														
Atlantic	1.4	0.1	3.0	4.4	2.2	0.0	1.1	3.4	*	*	3.6	0.1	4.1	7.8
Quebec	19.8	3.3	10.4	33.5	21.2	1.2	3.0	25.4	*	*	41.0	4.5	13.4	58.9
Ontario	4.0	19.0	5.8	28.7	8.2	13.3	0.4	21.8	*	*	12.1	32.2	6.2	50.6
Prairies	0.9	10.1	0.5	11.5	1.4	7.3	0.0	8.7	*	*	2.2	17.4	0.5	20.2
BC	2.1	6.3	1.5	9.9	2.8	4.5	0.3	7.5	*	*	4.9	10.8	1.8	17.4
Canada	28.1	38.7	21.2	88.0	35.8	26.3	4.8	66.9	*	*	63.9	65.0	26.0	154.9
ALL HOUSING														
Atlantic	14.4	0.7	31.1	46.1	11.5	0.0	5.8	17.4	13.1	0.0	39.0	0.7	36.9	76.6
Quebec	76.2	12.6	40.1	128.9	43.4	2.5	6.1	52.0	43.0	0.3	162.6	15.4	46.2	224.2
Ontario	36.8	176.2	54.1	267.0	32.0	51.9	1.5	85.3	61.7	2.1	130.4	230.1	55.6	416.2
Prairies	13.6	156.6	7.5	177.7	7.1	37.7	0.2	45.0	29.9	1.2	50.5	195.5	7.7	253.8
BC	12.2	36.9	8.8	57.9	10.4	16.9	1.0	28.2	20.1	0.4	42.7	54.2	9.8	106.6
												0.0		
Canada	153.1	382.9	141.6	677.6	104.4	109.0	14.6	228.0	167.8	4.0	425.3	495.9	156.2	1077.4

Sources: See relevant case studies

* included in single family homes

1. Space heating

Space heating is normally met by gas, oil or wood using forced air or hydronic heat distribution systems, or by electricity using baseboard heaters or central forced air or hydronic resistance or heat pump systems. Space heating accounts for over 80% of oil and gas use and 36% of electricity use. Apartments commonly have central heating systems serving all units (except baseboard electric), while single family homes have separate systems for each unit. Some single family households supplement their primary heating source with wood, electric baseboard, and propane.

2. Water heating

Water heating needs are normally met by electricity or gas in a stand-alone unit, but in some cases are met by oil in a combined water/space heating system. Water heating accounts for about 21% of residential energy use. Many apartments, particularly those with hydronic heat distribution systems, also have combined space and water systems. Water heating requirements are determined by shower, bath, dishwasher and clothes washer use. Energy use for hot water heating usually includes the hot water used by clothes washers and dishwashers, but not the mechanical power needed for agitators, pumps etc., which is considered appliance energy use.

3. Appliances

Appliances may be assumed to use electricity only and include the major "white" appliances (refrigerators, freezers, dryers, ranges, washers (non hot water), and dishwashers (non hot water)), small appliances such as mixers and microwave ovens, lighting, TV and other entertainment equipment, power tools, and space cooling (room or central air conditioners). These appliances account for about 39% of electricity use and 16% of total residential energy use. Each single family or apartment household unit has its own set of appliances, except in some apartment buildings with central laundry facilities.

Exhibit V-5, **overleaf**, shows an estimated breakdown of 1988 appliance electricity, gas and oil use by each type of appliance (including water heaters in single family homes).

Exhibit V-5
Appliance Energy Use in 1988 (TJ)

Region		Atlantic	Quebec	Ontario	Prairies	BC	Canada
Refrigerators		4,254	14,774	21,882	10,286	7,060	58,255
Freezers		1,820	3,892	7,100	3,994	2,356	19,162
Washer		461	1,456	1,740	886	583	5,126
Dryers	- Elec.	2,272	7,944	9,158	4,709	3,283	27,367
	- Gas	32	76	903	719	76	1,806
Ranges	- Elec.	1,961	6,693	8,862	4,291	3,096	24,903
	- Gas	0	241	1,242	438	290	2,211
Water Heaters*							
	- Elec.	9,317	22,176	23,761	5,682	7,616	68,551
	- Gas	0	1,343	38,577	30,417	12,371	82,708
	- Oil	4,695	3,065	1,076	196	685	9,716
Dishwashers		124	669	823	488	369	2,473
A/C		58	685	2,566	680	171	4,160
Lighting		2,180	6,958	9,622	4,568	3,298	26,626
Total		27,176	69,972	127,311	68,354	41,252	333,064
Subtotal							
	- Elec.	22,449	65,247	85,514	35,583	27,830	236,623
	- Gas	32	1,660	40,722	31,574	12,737	86,725
	- Oil	4,695	3,065	1,076	196	685	9,716

* Single family homes only

Source: Appliance Case Study

D. Economically attractive potential for energy efficiency gains

The potential for energy efficiency gains in the residential sector is defined as the savings that are economically attractive over the period 1990 to 2020 when compared to the supply prices of conventional fuels over this period. This potential is the maximum savings achievable, assuming that all energy efficiency measures below the supply price of conventional fuels are fully utilized, and that the time period is long enough for all existing stock to turn over and be replaced by energy efficient technologies.

The two case studies carried out under this project estimated the economically attractive potential that exists in residential appliances and in space heating of single family homes. Water heaters were defined as appliances in single family homes but not in apartments. The next three subsections summarize the economic potential estimated in the two case studies and provide a brief analysis of potential in the remaining residential end-uses, space and water heating in apartments.

1. Economically attractive savings potential in appliances and water heating

The economic savings potential from the use of more energy efficient appliances and water heaters was derived by estimating the annualized "supply" price of several new appliance technologies that are currently in use or about to be commercialized, and comparing them with regional supply prices of gas and electricity. Full details of the analysis may be found in the case study report, but the key findings are given below.

Six residential appliances, hot water heating and lighting were included in the analysis. The following types of energy efficient upgrades were studied:

Refrigerators

- improved insulation, more efficient fans and compressors, adaptive defrost, improved evaporator, two-compressor system

Freezers

- improved insulation and compressor efficiency

Dryers

- improved insulation, better controls, exhaust air heat recovery

Ranges

- better insulation, bi-radiant oven

Dishwashers

- more efficient motor, improved fill control and food filters

Clothes Washers

- more efficient motor, higher spin speed, front loading, thermostatic valves

Water Heaters

- lower standby losses and improved (combustion) efficiency

Lighting

- compact fluorescent lamps, higher efficiency incandescent lamps

The analysis showed that at the EMR/EC Reference Case supply prices for electricity and gas, the following technologies were economically attractive:

Refrigerators

- improved evaporator, door foam insulation, and a 5.05 EER compressor

Freezers

- door foam insulation and 5.05 EER compressor plus evacuated panels in Ontario only

Dryers

- temperature and moisture sensors

Ranges

- better door insulation

Clothes Washers

- front loading in Ontario and Atlantic regions and only if water heated electrically

Dishwashers

- improved food filter

Water Heaters

- increased insulation (lower standby losses) in electric water heaters, and improved combustion efficiency in gas water heaters

Lighting

- replacement of high usage incandescent lamps with compact fluorescent lamps.

The results of the analysis are shown in Exhibit V-6, **overleaf**. The changes in appliance technology would reduce 2020 appliance and water heater electricity use by 14%, and gas use by 1.7%. These percentages are equivalent to reductions of 48.8 PJ of electricity and 2.2 PJ of gas. (These values equal the figures shown for appliance energy savings, plus the savings for water heating in single-family homes.)

In our analysis, energy used by applicances in the form of hot water has been included in the energy used by water heaters. The listed energy consumption for clothes washers and dishwashers therefore includes only the electrical energy used by motors, controls, and heating elements within the appliance. In Exhibit V-6, therefore, no savings are shown for clothes washers and dishwashers since the economically attractive efficiency improvements reduce only hot water use, and have no impact on the direct consumption of electricity by these appliances.

Efficiency improvements to room air-conditioners were not examined. The economically attractive savings potential for air conditioners is arbitrarily set at zero in our analysis.

2. Economically attractive savings potential in single family space heating

The economic savings potential from the upgrading of building envelopes and heating systems in single family housing was derived by estimating the annualized "supply" price of various envelope upgrade and heating system measures in each region, and comparing them with regional supply prices of conventional fuels. Full details of the analysis may be found in a separate case study, but the key findings are given below.

Envelope upgrades were defined as either retrofitting existing stock from one level of insulation and air tightness to another, or the building of new stock to various levels of insulation or air tightness up to super energy efficient (SEEH) levels. Five insulation levels or "thermal archetypes" for existing housing were defined:

- uninsulated
- minor insulation
- standard (2x4 construction)
- improved (2x6 or 2x4 + sheathing), and
- SEEH.

Thermal archetypes for new housing were defined as:

- "1978 Measures"
- "1983 Measures", and
- SEEH.

Exhibit V-6
Frozen Efficiency Energy Use and Economically Attractive Savings Potential in Appliances and Water Heaters in 2020 (TJ)

Region		Atlantic	Quebec	Ontario	Prairies	BC	Canada
Frozen Efficiency							
Refrigerators		4,601	17,842	29,721	14,192	9,870	76,226
Freezers		1,728	4,124	8,461	4,835	2,890	22,037
Washer		614	2,167	2,913	1,506	1,005	8,205
Dryers	- Elec.	3,029	11,824	15,330	8,007	5,657	43,847
	- Gas	43	113	1,512	1,223	131	3,021
Ranges	- Elec.	2,614	9,962	14,834	7,297	5,335	40,041
	- Gas	0	358	2,079	744	500	3,682
Water Heaters*							
	- Elec.	11,667	31,308	35,054	8,563	11,312	97,905
	- Gas	0	1,896	56,911	45,846	18,376	123,029
Dishwashers		166	995	1,378	830	635	4,004
A/C		78	1,019	4,295	1,157	294	6,843
Lighting		2,906	10,356	16,106	7,767	5,682	42,817
Total		27,445	91,965	188,593	101,966	61,687	471,657
Subtotal							
- Elec.		27,403	89,597	128,091	54,153	42,681	341,925
- Gas		43	2,368	60,502	47,814	19,006	129,732
Economically Attractive Savings Potential							
Refrigerators		860	2,919	5,556	2,322	1,615	13,271
Freezers		223	532	3,524	623	372	5,274
Washer		0	0	0	0	0	0
Dryers	- Elec.	193	755	978	511	361	2,798
	- Gas	0	0	0	0	0	0
Ranges	- Elec.	102	389	579	0	208	1,278
	- Gas	0	0	0	0	0	0
Water Heaters*							
	- Elec.	1,021	367	3,940	113	154	4,594
	- Gas	0	520	699	703	295	2,216
Dishwashers		0	0	0	0	0	0
A/C		0	0	0	0	0	0
Lighting		1,464	5,217	8,114	3,913	2,862	21,569
Total		3,864	10,697	22,390	8,183	5,868	51,001
Subtotal							
- Elec.		3,864	10,178	21,691	7,480	5,573	48,785
- Gas		0	520	699	703	295	2,216

* Single family homes only

Heating system upgrades analyzed included replacing conventional gas and oil furnaces with mid or high efficiency units, and the use of air and ground source heat pumps as alternatives to electric resistance heating.

The following space heating measures were found to be economically attractive; allowing for the fact that heating system upgrades are less cost-effective after an envelope upgrade has been applied:

a) **Envelope Upgrades**

All Regions:

- Retrofit all uninsulated homes to Improved Efficiency levels.
- Retrofit all electrically heated homes with minor insulation to Improved Efficiency levels.
- Build all new oil and electrically heated homes to 1983 Measures levels.

Regional Variations:

Prairies/Ontario	- Retrofit oil heated homes with minor insulation to Improved Efficiency levels.
	- Build new gas heated homes to 1978 Measures levels.
British Columbia	- Build new gas heated homes to 1978 Measures levels
Quebec	- Retrofit gas heated homes with minor insulation to Standard levels.
	- Build new gas heated homes to 1983 Measures levels

This means that it is economically attractive for all existing Canadian housing to be upgraded to Standard levels or above, except in B.C. Since most new housing is already being built to 1983 Measures or is gas heated, there are few opportunities for economic savings in new housing.

b) **Window upgrades**

It is economically attractive to use triple glazed low-e glass with argon fill in all new housing and window replacements.

c) Heating Systems

It is economically attractive to upgrade from standard to mid-efficiency gas and oil furnaces in "standard" homes or those with minor insulation. Heat pumps are not economically attractive at current electricity prices.

The results of the analysis of savings in single family space heating are shown in Exhibit V-7, below. The economically attractive measures would reduce 2020 energy use by 321 PJ/year or 43.5%.

Exhibit V-7
Frozen Efficiency Energy Use and Economically Attractive Savings Potential in Single Family Space Heating in 2020 (PJ)

	Electricity	Gas	Oil	Total
Frozen Efficiency				
Atlantic	17.8	0.7	28.9	47.4
Quebec	75.2	9.6	31.0	115.8
Ontario	46.7	202.9	51.5	301.2
Prairies	16.0	186.3	8.3	210.5
BC	14.5	38.2	10.0	62.7
Canada	170.2	437.7	129.7	737.6
Economically Attractive Savings Potential				
Atlantic	10.4	0.3	13.2	24.0
Quebec	37.1	3.7	11.3	52.2
Ontario	29.9	79.7	22.5	132.1
Prairies	9.7	17.0	5.1	31.7
BC	9.6	24.3	5.9	39.8
Canada	95.3	170.9	55.0	321.2

3. Economically attractive savings potential in apartment space and water heating

a) Cost effective energy saving technologies

As with commercial and institutional buildings, it is possible to build new apartment buildings with very low space and water heating requirements. By using high quality windows and a well sealed envelope, and by efficiently recovering and distributing waste heat from lighting and air conditioning within the building using heat pumps, very low heating requirements can be achieved.

A recent pilot survey of new apartment buildings[1] indicated that most are still being built with conventional double glazed windows, R20 wall insulation, R30 roof insulation , and no special features to recover heat or use heating fuel more efficiently. A large proportion of new buildings surveyed were electrically heated.

It would be conservative, therefore, to assume that the same degree of savings could be achieved in new apartment buildings as in new commercial office buildings[2], i.e., about 15 to 30% relative to new apartments being built in 1988 (and 50% less than an average existing building), by using energy-efficient gas or oil boilers, heat pumps and improved windows.

The economic savings potential in existing apartments is more difficult to analyze. There are few studies that have estimated the relative costs of apartment retrofit, and most of these are for electrically heated apartments only. While a large percentage of new apartment buildings are electrically heated, most older apartments use oil or gas.

The greatest savings potential in existing apartment buildings appears to be through reducing air infiltration by upgrading windows and the outside skin of the building. Savings of 15% appear to be possible at unit cost of 0.6¢/kWh[3], well below the supply price of all fuels. Similar conclusions were obtained in an analysis of a multi-residential seal-up program for electrically heated apartment buildings in Ontario.[4]

Upgrading of an apartments' heating system can also result in significant savings (10% or more) at a reasonable cost.[5]

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1 *Profile of New Multi-Unit Residential Sector (Pilot-Phase), Marbek Resource Consultants for Ontario Research Foundation and Energy, Mines and Resources Canada, March 31, 1988.*

2 *See Commercial Sector Case Study.*

3 *Electricity Conservation Supply Curves for Ontario, Marbek Resource Consultants for Ontario Ministry of Energy, August 1987.*

4 *Second Generation Energy Management Programs for the Commercial Sector, Marbek Resource Consultants for Ontario Hydro, Report PTA-89-22.*

5 *Energy Conservation Building Operations Demonstration for Forty Multiple Unit Residential Buildings, Engineering Interface Limited for Ontario Ministry of Municipal Affairs and Housing, January 1984.*

Hot water use in apartments can be cost effectively reduced by about 20% by introducing a low flow shower head[1], and more efficient dishwashers and clothes washers.[2]

b) Potential savings in energy use in 2020

To obtain an estimate of economic savings potential for apartment space and water heating, the following assumptions were made:

- Water heating in all apartment buildings can be reduced by 20%.
- Space heating in all existing apartment buildings can be reduced by 23% through envelope upgrades and heating system improvements.
- Space heating in all new apartment buildings is half that in existing buildings.

Exhibit V-8, **below**, shows the application of these assumptions to all Canadian apartment space and water heating in 2020.

Exhibit V-8
Economically Attractive Energy Savings Potential in Canadian Apartments in 2020 (PJ)

	Electricity	Gas	Oil	Total
Frozen Efficiency				
Space Heat	46.9	64.6	35.4	146.8
Water Heat	59.7	43.9	8.0	111.6
Total	**106.6**	**108.5**	**43.4**	**258.5**
Economically Attractive Savings Potential				
Space Heat	15.9	21.8	12.0	49.6
Water Heat	11.9	8.8	1.6	22.3
Total	**27.8**	**30.6**	**13.6**	**72.0**

4. Summary of economically attractive potential

Exhibit V-9, **overleaf**, provides a summary of the economic savings potential in the whole residential sector in 2020, based on the results of the case studies and the above analysis of apartment savings potential. This shows an overall savings potential of 444 PJ, or 29.5%, when compared against a frozen efficiency forecast.

1 *Second Generation Energy Management Programs for the Commercial Sector, op.cit.*

2 *Electricity Conservation Supply Curves for Ontario, op.cit*

Exhibit V-9

2020 CANADIAN RESIDENTIAL ENERGY SAVINGS POTENTIAL (PJ)

	Space Heating				Water Heating				Appliances		Total Energy			
	Elec	Gas	Oil	Total	Elec	Gas	Oil	Total	Elec	Gas	Elec	Gas	Oil	Total
SINGLE FAMILY HOMES														
Frozen Efficiency	170.2	437.7	129.7	737.6	124.1	123.0	15.1	262.2	240.4	6.7	534.7	567.4	144.8	1246.9
Economic Potential	74.9	266.8	74.7	416.4	118.6	120.8	15.1	254.5	196.9	6.7	390.4	387.6	89.8	867.8
Savings	95.3	170.9	55.0	321.2	5.5	2.2	0.0	7.7	43.5	0.0	144.3	173.1	55.0	372.4
APARTMENTS														
Frozen Efficiency	46.9	64.6	35.4	146.9	59.7	43.9	8.0	111.6	*	*	106.6	108.5	43.4	258.5
Economic Potential	31.0	42.7	23.4	97.1	47.8	35.1	6.4	89.3	*	*	78.8	77.8	29.8	186.4
Savings	15.9	21.9	12.0	49.8	11.9	8.8	1.6	22.3	*	*	27.8	30.7	13.6	72.1
ALL HOUSING														
Frozen Efficiency	217.1	502.3	165.1	884.5	183.8	166.9	23.1	373.8	240.4	6.7	641.3	675.9	188.2	1505.4
Economic Potential	105.9	309.5	98.1	513.5	166.4	155.9	21.5	343.8	196.9	6.7	469.2	465.4	119.6	1054.2
Savings	111.2	192.8	67.0	371.0	17.4	11.0	1.6	30.0	43.5	0.0	172.1	203.8	68.6	444.5

* included in single family homes

E. Sensitivity to energy prices

The sensitivity of the economic potential to increases in the supply prices of conventional fuels was briefly analyzed in each of the two case studies. The results of this sensitivity analysis are given below.

1. Appliances and water heating

The only appliances significantly affected by increases in supply prices are freezers, dishwashers, refrigerators and gas water heaters. At both a 20% and 40% increase in electricity prices, evacuated wall panels become economically attractive in freezers. Efficient motors become economically attractive in dishwashers. There is a small increase in the economic potential of refrigerators because thicker door insulation becomes economically attractive at higher electricity prices. Submerged combustion gas water heaters become economically attractive in Ontario at both a 20% and 40% gas price increase.

2. Space heating

The economic savings potential in space heating is significantly affected by increased supply prices, particularly a 40% increase. A 20% increase would make it economically attractive to upgrade all uninsulated oil and electrically heated homes to the SEEH level. A 40% increase would make the following additional measures cost-effective.

- Upgrade all homes with minor insulation to Improved Efficiency levels.
- Build all new electrically heated homes to SEEH levels instead of only to 1983 Measures levels.
- Use mid-efficiency furnaces in all gas heated homes.

VI

Economically Attractive Potential In The Commercial Sector

A. Introduction

This chapter describes an estimate of the total potential for energy efficiency gains in the commercial and institutional buildings sector over the 1988-2020 period. It is based on the analysis done in the case studies of office and retail buildings. This "roll-up" of the commercial sector energy efficiency potential was achieved by combining estimates of floor areas in different building types with corresponding estimates of end use energy intensities for those building types and the potential for savings in those end uses. The roll-up calculation was done using a model of commercial and institutional building energy use that allows for disaggregation by building type, vintage, fuel, and end use.

Total commercial and institutional energy use as reported by Statistics Canada contains some energy use that is not associated with buildings, such as for street lighting, water works, and sewage treatment plants, but these non-building uses represent less than two percent of the sector's energy use. Furthermore, most of the energy use in this sector is the result of the lighting and conditioning of the space inside buildings. While this energy use varies among building types (retail stores use much more lighting than elementary schools and warehouses require less space conditioning than offices, etc.), commercial-sector energy end use modelling typically assumes that it is valid to generalize about energy end use intensities within particular building types.

In this analysis of the energy efficiency potential in the commercial sector, we:

- First develop a profile of floor area by building type for 1988 and for 2020, as described in the next section.
- Then estimate the end use intensities by building type for the base year stock in 1988, as well as for typical new stock in 1988.
- Combine these intensities with the floor area data and assumptions about fuel shares and secondary/tertiary efficiencies for space and water heating to create a profile of commercial energy use in 1988.

- Use this base year calibration to develop a frozen efficiency scenario of future commercial energy use.
- Develop an estimate of the "economically attractive potential", by assuming the effect on commercial energy demand of implementing those energy efficiency measures that were included in the case study analysis and that were determined to be cost effective against projected fuel and electricity prices.

The final section contains a discussion of the analysis of the results.

B. Commercial and institutional building floor area profiles

Activity in this sector can be represented by the amount of floor area of each building type. A summary of our floor area estimates is presented in Exhibit VI-1, **below**, for both the base year (1988) and for 2020, the end point year of the energy analysis. The 2020 floor area is further disaggregated into two vintages -- the surviving 1988 stock and new stock built between 1988 and 2020.

Exhibit VI-1
Commercial And Institutional Buildings Floor Area In 1988 And Projections For 2020

(Millions of Square Metres)

Building Type	Floor Area In 1988	Floor Area In 2020		
		1988 Stock	1988-2020 Stock	Total Stock
Education	71.5	60.8	52.9	113.7
Health	17.0	14.5	13.8	28.2
Religious	11.2	9.5	12.2	21.7
Other Institutions	33.8	28.7	36.8	65.6
Offices	83.0	70.6	161.9	232.4
Retail	59.0	50.2	58.4	108.6
Hotels/Restaurants	20.3	17.3	22.1	39.4
Recreation	13.7	11.6	14.9	26.6
Warehouse	58.5	49.7	70.2	119.9
Total Sector Floor Area	**368.0**	**312.8**	**443.2**	**756.0**

Source: Torrie Smith Associates database

The first task in creating such a profile is to specify the floor areas in the base year, by building type. There is no authoritative source for such information; primary information about building floor area by building type is not systematically collected and compiled in Canada. For the two most important sectors -- offices and retail stores -- we have used the floor area estimates developed in the case studies done for these building types as part of this project. For the other building types, we have adopted the current estimates of building floor area for 1988 by extrapolating to national totals (by population or subsector output) from a combination of province-specific estimates from utility, government and private sources.

For some building types, separate estimates have been made at the next level of disaggregation. Specifically, educational floor area is comprised of elementary and secondary schools, colleges and universities; offices are subdivided into large and small offices buildings; retail buildings are subdivided into food stores and large and small non-food stores; and hotels/restaurants are subdivided into hotels, motels, and restaurants.

The result is a total of 368 million square metres of building floor area, with 75% of the total floor area in the four largest building types—offices, educational, stores and warehouses.

To develop the profile of floor area by building type in 2020, the base year floor areas are simply projected forward according to the rate of growth of output. The implicit assumption in using this technique is that the ratio of output to floor area will remain constant over time. Increases in labour productivity in the commercial sector would tend to lower the floor area/output ratio, but the effect cannot be simulated by simply substituting employment for output as a driver of floor area growth. Labour productivity is being achieved partly due to a proliferation of office equipment which itself requires space, thus moderating the decline in floor area/output ratios that would otherwise be expected with productivity gains. Nevertheless, escalating floor area at the same rate as output will result in energy forecasts which err on the high side.

The output growth rates used to escalate floor area are taken from the SERF simulation of the economic growth rate underlying the IFSD energy projections. To be consistent with the office and retail subsector case studies, the floor area growth for these subsectors is taken directly from the case studies, which are in turn based on the SERF simulation. For the sector as a whole, output (and therefore floor area) increases to 2.05 times its 1988 level by 2020. Education and health care floor area grow considerably slower (to 1.59 and 1.69, respectively, of 1988 levels), and office space grows much faster (to 2.80 of 1988 levels by 2020).

Finally, the floor area for 2020 has been divided into new and old stock by assuming that old stock disappears at a rate of 0.5% per year over the course of the study period. This results, by the year 2020, in about 15% of the original 1988 base year stock being replaced by new stock.

C. Energy use in commercial and institutional buildings

Energy use by fuel and by end use for each building type is generated "from the bottom up" by combining information about fuel shares and end use intensities by building type with the floor area profiles described above. The end uses modelled in this analysis include space heating, water heating, lighting, cooling, ventilation and equipment. Tertiary end use intensities by building type for the average stock in 1988 are shown in Exhibit VI-2, below.

Exhibit VI-2
Energy End Use Intensities in Commercial Buildings in 1988

(MJ per Square Metre)

	Lighting	Cooling	Ventilation	Equipment	Space Heat	Water Heat
Elementary School	137	50	97	21	828	40
Secondary School	186	50	122	32	828	40
Colleges	234	50	176	49	768	79
Universities	234	50	176	55	768	79
Health	400	132	300	150	1,000	300
Religious	186	22	103	0	547	90
Other Institutions	180	130	200	0	700	80
Small Office	255	120	150	175	725	23
Large Office	455	120	190	200	600	23
Small Retail	450	200	250	180	600	40
Large Retail	450	200	250	180	600	40
Food Retail	550	350	1,325	180	550	45
Motel	300	470	100	150	540	160
Hotel	350	470	300	150	700	160
Restaurant	490	470	200	1,500	700	420
Recreation	300	24	500	0	668	85
Warehouses	250	28	200	0	432	0

Source: Torrie Smith Associates database

Lighting is the single largest use of electricity in most building types, and is large enough to have significant effects on building heating and cooling loads. Fluorescent lighting accounts for most commercial and institutional building lighting. Lighting intensity in the base year stock (2-3 W per square foot) is now generally regarded to be unnecessarily high for most applications, and is usually obtained using standard 40W fluorescent bulbs in two- or four-bulb luminaries with conventional core ballasts. While the technical and economic potential for both lower lighting levels and more efficient technology has been well established, the base year stock energy end use intensities for lighting reflect very little market penetration of these new technologies.

Cooling energy refers to the electricity used to run central and unitary air conditioning equipment (but does not include the fans that move the air). Large buildings typically employ central cooling systems that are integrated with the building's HVAC design, and which use refrigerant compressors to produce chilled water which in turn cools building air. Over 90% of these systems employ centrifugal compressors, with the remainder being comprised of screw and reciprocating type compressors. We have modelled cooling energy as an exclusively electric end use, although there are some systems based on gas-fired compressors. In the simple model used for this roll-up calculation, the low saturation of space cooling in some building types (e.g., educational buildings, warehouses) has been modelled as a lower energy intensity in the base year stock.

The **ventilation** end use refers to the fan motors that are used in building HVAC systems to provide clean air and distribute conditioned air throughout the building space. In Exhibit VI-2, the refrigeration motor loads of supermarkets have also been included in this end use category, simply to avoid creating a refrigeration end use category throughout the model that is only of significance in food retail stores.

The **equipment** end use refers to all the other myriad uses of electricity in commercial and institutional buildings. This consists primarily of the so-called "plug-in" load, but also includes service motors for elevators and other electrically-powered building systems which are not part of the lighting or HVAC systems. The intensity of the plug-in load has been increasing rapidly in some building types, due to the proliferation of modern information processing technologies in the service sector, and this trend is reflected in the relatively high equipment end use intensities for office and retail buildings shown in Exhibit VI-2. Also, cooking energy for restaurants has been included in this end use category, rather than create a new end use category for cooking that would only be of relevance for restaurants. Implicit in this treatment of restaurant cooking energy is the assumption that it is all electric, although gas cooking is significant in this subsector.

Space heating is the single largest energy end use in most commercial building types, although it is not as dominant as for residential buildings where surface to volume ratios are much higher. Natural gas is the preferred heating fuel for commercial buildings; on a national basis, fully two thirds of commercial building space is gas heated. Oil and electricity account for 18% and 14%, respectively, of the commercial space heating market (on a floor area basis) in 1988. Heating systems vary according to the size and type of building. Gas, oil and electric boiler systems are all used in large buildings, but gas-fired boilers have been the overwhelming favorite for large buildings, where gas is available. For smaller buildings, boiler-based heating systems (still most often with constant volume air flowthrough) are still prevalent, but there is also significant use of gas-fired rooftop units and electric heating systems.

Water heating is a relatively insignificant end use for most commercial building types, with hospitals and restaurants being the obvious exceptions. Although not covered in the case studies, intensities for water heating have been included in Exhibit VI-2 for completeness.

The end use intensities summarized in Exhibit VI-2 are combined with the floor areas in Exhibit VI-1 and fuel market share and secondary/tertiary efficiencies to produce the profile of commercial sector energy use by building type and fuels for 1988 shown in Exhibit VI-3. This basic calibration of the sector then becomes the starting point for projecting a "pre-conservation" or "frozen efficiency" baseline for future years.

The total of 830 PJ commercial energy shown in Exhibit VI-3, **overleaf**, is somewhat below the 855 PJ reported by Statistics Canada and used as the base in the IFSD model. While some of the difference could be accounted for by non-building energy use that is not captured by the end use model, the agreement is well within the error bands that would be expected, given the quality of the end use data.

In attempting to build a "bottom-up" end-use profile of commercial energy use in Canada, it is usually the case that an end use model of building energy use employing reasonable estimates of end use intensities, fuel shares and efficiencies fails to account for all of the reported commercial oil and gas use equipment in the national energy balance. There has never been a definitive explanation for this calibration problem; it is usually assumed that either some industrial oil and gas use is being reported as commercial, or that there are some large anomalous uses of oil and gas in the sector which are not captured in average building energy use statistics. Another possibility is that the actual annual average secondary/tertiary energy ratio of oil and gas heated buildings is lower than the 65% - 70% commonly assumed.

In any event, the calibration in Exhibit VI-3 has been achieved by setting oil and gas secondary/tertiary efficiencies to 45% and 50%, respectively. This results in a calibration that is in reasonably good agreement with reported commercial energy use and which does not require a technique that upsets the electricity calibration, in which confidence levels are higher. By holding the secondary/tertiary ratios for oil and gas buildings at these levels in all the scenario analysis (therefore showing heating system improvement as part of the tertiary energy reduction in fuel heated buildings), the problem of unallocated energy in the commercial sector is tied to the fuels shares for oil and gas.

As Exhibit VI-3 shows, offices, retail buildings, educational buildings, warehouses and hotels and restaurants together account for over 75% of the sector's, energy use. Gas and electricity provide about equal shares of total secondary energy (43%) with the balance being provided by petroleum fuels. On an end use basis, space heating accounts for over half the secondary commercial energy use, with lighting, motors and equipment accounting for most of the rest.

Exhibit VI-3
Commercial Sector Energy Use by Fuel and End-Use in 1988 (PJ)

	Lighting (Elec.)	Cooling (Elec.)	Ventilation (Elec.)	Equipment (Elec.)	Space Heat (Elec.)	Space Heat (Oil)	Space Heat (Gas)	Space Heat (Total)	Water Heat (Elec.)	Water Heat (Oil)	Water Heat (Gas)	Water Heat (Total)	TOTALS
Education	16,095.0	3,600.7	8,936.0	2,341.7	8,115.2	23,186.4	78,833.8	110,135.4	513.2	1,466.3	4,985.5	6,965.0	148,073.8
Health	6,800.0	2,237.5	5,100.0	3,400.0	2,380.0	6,800.0	23,120.0	32,300.0	714.0	2,040.0	6,936.0	9,690.0	59,527.5
Religious	2,086.1	246.5	1,151.0	560.0	857.3	2,449.5	8,328.2	11,635.0	141.1	403.2	1,370.9	1,915.2	17,593.8
Other Institutions	8,450.0	4,394.0	6,760.0	5,070.0	3,312.4	9,464.0	32,177.6	44,954.0	378.6	1,081.6	3,677.4	5,137.6	74,765.6
Offices	31,125.0	9,960.0	14,442.0	15,770.0	7,553.0	21,580.0	73,372.0	102,505.0	267.3	763.6	2,596.2	3,627.1	177,429.1
Stores	28,009.0	13,979.0	30,342.5	10,623.6	4,856.2	13,874.8	47,174.3	65,905.3	340.7	973.3	3,309.3	4,623.3	153,482.7
Hotels/Rest.	8,609.0	9,534.3	4,780.0	23,560.0	1,966.9	5,619.8	19,107.4	26,694.1	881.7	2,519.2	8,565.3	11,966.2	85,143.6
Recreation	4,110.0	328.7	6,843.2	1,370.0	1,281.7	3,662.1	12,451.2	17,395.0	163.0	465.8	1,583.7	2,212.5	32,259.4
Warehouse	14,625.0	1,637.4	11,700.0	5,850.0	3,535.2	10,100.6	34,342.1	47,977.9	0.0	0.0	0.0	0.0	81,790.3
TOTALS	119,909.1	45,918.1	90,054.7	68,545.3	33,857.9	96,737.2	328,906.6	459,501.7	3,399.6	9,713.0	33,024.3	46,136.9	830,065.8

Source: Based on Exhibits VI-1 and VI-2

D. Economically attractive potential for energy efficiency gains

1. Establishing the frozen efficiency baseline

To estimate the potential for energy efficiency improvements to the year 2020, one must first have a "pre-conservation" baseline against which to measure the savings. In the end use modelling technique, this involves combining the floor area projection (Exhibit VI-1) with end use intensities characteristic of the base year. This means freezing the energy intensity of the base year stock at its base year level and assuming that all new stock is put in place with the energy intensities characteristic of typical new stock in the base year. The result, even in this "frozen efficiency" scenario, will be some improvement in the average efficiency of the sector if the new stock is more efficient than average stock in the base year.

Based on the work done for the office and retail building case studies, it is assumed in this study that new commercial energy technologies were more efficient than average technologies in 1988 for some end uses. Specifically, space heating in new commercial buildings is assumed to require 33% less energy than the average existing building in 1988, and lighting and motor intensities are assumed to be 15% lower than in the base stock. Equipment and water heating intensities are assumed to be the same as for the base stock; cooling intensity actually increases due to the preponderance of space cooling systems in new commercial buildings of all sizes.

The frozen efficiency scenario is summarized in Exhibit VI-4, **overleaf**.

In our Frozen Efficiency Scenario, fuel market shares are kept at their average base year values, but new stock end-use intensities are set at the values discussed above. We have explored other variations of the "Frozen Efficiency Scenario", and these are discussed in Section E (Discussion and Interpretation of Results).

2. Economically attractive potential for energy efficiency gains

The final stage in this exercise is to "roll-up" the results from the case study analyses of economically attractive potential in office and retail buildings to other commercial building types.

The most dramatic potential for efficiency improvements is in lighting. Both the base year and new stock energy intensities drop to about 33% of their 1988 levels as the result of advanced lighting technologies. These technologies are described in some detail in the technology profiles that form part of the case studies. Optical reflectors, electronic ballasts, high efficiency fluorescent lamps, occupancy sensors, and daylight dimming controls are all cost effective in at least some applications.

Exhibit VI-4
Commercial Sector Frozen Efficiency Energy Use by Fuel and End-Use in 2020 (TJ)

	Lighting (Elec.)	Cooling (Elec.)	Ventilation (Elec.)	Equipment (Elec.)	Space Heat (Elec.)	Space Heat (Oil)	Space Heat (Gas)	Space Heat (Total)	Water Heat (Elec.)	Water Heat (Oil)	Water Heat (Gas)	Water Heat (Total)	TOTALS
Education	21,555.5	8,389.7	13,216.3	3,723.4	10,921.5	31,204.3	106,094.5	148,220.3	816.0	2,331.5	7,927.0	11,074.5	206,179.7
Health	10,461.8	5,526.7	7,846.4	4,955.5	3,314.6	9,470.4	32,199.2	44,984.2	1,127.4	3,221.2	10,951.9	15,300.5	89,075.1
Religious	3,706.0	746.9	2,044.8	476.0	1,354.8	3,870.9	13,161.1	18,386.8	273.8	782.2	2,659.5	3,715.5	29,076.0
Other Institutions	12,814.9	13,313.8	12,009.1	4,309.5	5,234.6	14,956.0	50,850.3	71,040.9	734.4	2,098.3	7,134.2	9,966.9	123,455.1
Offices	78,045.9	44,073.0	36,213.3	44,156.0	16,288.0	46,537.3	158,226.7	221,052.0	748.3	2,138.1	7,269.5	10,155.9	433,696.1
Stores	47,377.2	25,721.4	51,324.3	19,547.4	8,334.4	23,812.6	80,962.9	113,109.9	626.8	1,790.9	6,089.1	8,506.8	265,587.0
Hotels/Rest.	15,293.9	18,061.3	8,491.7	34,978.2	3,531.0	10,088.5	34,301.0	47,920.5	1,639.4	4,684.0	15,925.5	22,248.9	146,994.5
Recreation	7,301.4	1,026.0	12,156.9	1,164.5	2,025.5	5,787.2	19,676.6	27,489.3	316.3	903.7	3,072.4	4,292.4	53,430.5
Warehouse	27,348.8	5,603.8	21,879.0	4,972.5	5,847.2	16,706.4	56,801.8	79,355.4	0.0	0.0	0.0	0.0	139,159.5
TOTALS	223,905.4	122,462.6	165,181.8	118,283.0	56,851.6	162,433.6	552,274.1	771,559.3	6,282.4	17,949.9	61,029.1	85,261.4	1,486,653.5

The other gains that are assumed in the base year stock are a 15% reduction in the energy intensity of motor load and a drop in cooling intensity of nearly 50%. Equipment, space and water heating energy intensities are all held constant at their base year levels.

In new buildings, the gains can be somewhat greater. In addition to the lighting, motor and cooling intensity improvements assumed for all buildings, the equipment energy intensity in new buildings drops by 15% and space heating intensities drop by 33%.

Rolling up these intensity improvements to the entire sector yields the results shown in Exhibit VI-5, **overleaf**. Total commercial energy use is 30% lower in the economically attractive scenario than in frozen efficiency forecast. Two thirds of the savings are in the form of electricity, as compared with electricity's 47% share of secondary energy in the pre-conservation projection and 38% share after conservation. Electricity savings predominate because of the high levels of efficiency that can be achieved in advanced lighting systems and the gains that can be made in ventilation motor drive through efficient building and HVAC design and high efficiency fan motors.

E. Discussion and interpretation of results

1. Discussion

All the energy projections in Exhibits VI-4 and VI-5 are based on floor area escalating at the same rate as output. If employment were used instead (arguably a more appropriate surrogate for floor area requirements), the projected energy demands would be at least another 10% lower by 2020.

The plug-in load remains subject to a high degree of uncertainty. The proliferation of information processing technologies in all types of commercial buildings, and especially in offices, raises the prospect of increasing energy intensities for this end use category. On the other hand, the technical and economic potential for efficiency gains for this type of equipment is very large. The marginal cost associated with these improvements will be very small; indeed, the power requirements of lap top computers are already ten times less than equivalent desktop models. One recent analysis of projected office equipment electricity use in the United States[1] started with the Electric Power Research Institute's projection of 124 TW.h of added electricity use for electronic office equipment in U.S. buildings from 1982 to the mid-1990's and concluded that even with high saturation levels, the trend toward the current state-of-the-art would bring the level down to 115 TW.h (a savings of 7% in absolute terms).

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1 *Les Forford, Ari Rabl, Jeffrey Harris, and Jacques Roturier, "Electric Office Equipment: The Impact of Market Trends and Technology on End-Use Demand for Electricity," in Electricity, Thomas B. Johansson, ed., op. cit.*

Exhibit VI-5
Commercial Sector Economic Potential Energy Use by Fuel and End-Use in 2020 (TJ)

	Lighting (Elec.)	Cooling (Elec.)	Ventilation (Elec.)	Equipment (Elec.)	Space Heat (Elec.)	Space Heat (Oil)	Space Heat (Gas)	Space Heat (Total)	Water Heat (Elec.)	Water Heat (Oil)	Water Heat (Gas)	Water Heat (Total)	TOTALS
Education	6,189.2	4,194.9	9,435.3	3,515.4	9,412.7	26,893.3	91,437.3	127,743.3	626.1	1,788.9	6,082.4	8,497.4	159,575.5
Health	3,499.2	2,763.4	5,545.8	3,985.1	2,830.3	8,086.5	27,494.0	38,410.8	867.2	2,477.6	8,423.8	11,768.6	65,972.9
Religious	1,242.3	373.5	1,396.8	0.0	1,120.0	3,200.1	10,880.3	15,200.4	196.9	562.5	1,912.4	2,671.8	20,884.8
Other Institutions	3,620.3	6,656.9	8,203.6	0.0	4,327.4	12,364.1	42,038.0	58,729.5	528.1	1,508.8	5,130.0	7,166.9	84,377.2
Offices	26,271.1	22,036.5	23,121.3	40,465.8	12,587.5	35,964.4	122,279.0	170,830.9	487.7	1,393.6	4,738.1	6,619.4	289,345.0
Stores	15,870.2	12,860.7	35,455.1	18,285.3	6,756.9	19,305.5	65,638.6	91,701.0	458.2	1,309.1	4,451.0	6,218.3	180,390.6
Hotels/Rest.	5,126.7	9,030.7	5,800.7	32,619.9	2,833.8	8,096.7	27,528.6	38,459.1	1,194.4	3,412.7	11,603.0	16,210.1	107,247.2
Recreation	2,447.5	513.0	8,304.5	0.0	1,674.5	4,784.3	16,266.7	22,725.5	227.4	649.8	2,209.3	3,086.5	37,077.0
Warehouse	9,174.3	2,801.9	14,778.3	0.0	4,781.4	13,661.1	46,447.7	64,890.2	0.0	0.0	0.0	0.0	91,644.7
TOTALS	73,440.8	61,231.5	112,041.4	98,871.5	46,324.5	132,356.0	450,010.2	628,690.7	4,586.0	13,103.0	44,550.0	62,239.0	1,036,514.9

The same analysis concluded that technical improvements in hardware and operating systems, based on technology already available, could reduce consumption by an additional factor of five, to about 20-25 TW.h, or 16% of the base projection.

2. Variants on the frozen efficiency scenario

The Frozen Efficiency Scenario which we have used for this analysis is in accordance with the conventions established for this study (frozen average fuel market shares, frozen marginal efficiencies). The results will be somewhat different if efficiencies are frozen at their average base year levels (rather than freezing marginal efficiencies), or if new stock is assumed to exhibit the marginal fuel market shares characteristic of new buildings in 1988. In particular, the shift toward electric heat that is taking place in some parts of the country can have the effect of bringing space heating energy intensities down over time, even with frozen tertiary space heating intensities.

To illustrate the effect of these different assumptions on the "frozen efficiency" scenario, several variations were computed and are shown in Exhibit VI-6, **below**.

Exhibit VI-6
Commercial Sector Energy Use in 2020 (PJ) By Fuel
Frozen Efficiency Variations

	Frozen Efficiency Variations		
	Case A	Case B	Case C
Gas	728	613	577
Electricity	735	693	729
Oil	214	180	140
LPG and Other			
Total	1,677	1,487	1,447

Case B is the "frozen average market share, frozen marginal efficiency" case which we have used in this study. In Case A, efficiencies and fuel market shares are frozen at their average base year levels. With floor area escalated at the same rate as output, this scenario yields results which are closest to an "econometrically frozen" efficiency, i.e., the ratio of energy used to output does not change over time. Comparing Case A and Case B illustrates that the fairly modest improvements in the efficiency of new stock assumed in Case B can have relatively large impacts on total demand in the long run.

In Case C, the fuel market shares in new stock are assumed to be different from the market shares in the average base year stock. Where tertiary space heat (and water heat) floor area shares in the average base year stock are 14% oil, 68% gas, and 18%

electricity, in the new stock they are assumed to be 10% oil, 60% gas and 30% electricity. The shift to electricity results in yet a lower version of the "frozen efficiency" scenario.

Perhaps more clearly than other parts of the study, these results illustrate the arbitrariness associated with a specific definition of "frozen efficiency" and the relatively large changes which can be obtained from various definitions of this concept, over a 30-year study timeframe.

VII

Economically Attractive Potential In The Transportation Sector

A. Introduction

This chapter summarizes the results of the case study on light vehicles (cars and light trucks). It also provides an estimate of potential energy savings in the remainder of the transportation sector.

The transportation sector consists of the following sub-sectors:

- Light Vehicles
- Road Transport and Urban Transport
- Airlines
- Railways
- Marine Transportation
- Pipelines.

Each of these sub-sectors is discussed below.

B. Historical energy use

Exhibit VII-1, **overleaf**, shows energy use in the Canadian transportation sector in 1988. Gasoline sold through retail pumps accounts for the majority (57%) of energy consumption in this sector. This energy is consumed primarily by automobiles and light trucks, and therefore has been attributed to light vehicles.

Exhibit VII-1
1988 TRANSPORTATION SECTOR ENERGY USE (PJ)

Subsector	Fuel	REGION Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
Railways	-Diesel	4.9	9.3	25.0	33.6	12.5	85.3
Airlines	-Turbo	11.6	34.1	53.5	25.9	27.3	154.1
Marine	-Diesel	16.4	5.8	6.1	0.0	13.3	41.7
	-Fuel Oil	12.4	18.9	10.5	0.0	15.7	57.5
Pipelines	-Natural Gas	0.0	0.6	41.1	66.2	14.2	122.1
Truck & Bus	-Gasoline	2.9	7.1	11.0	12.8	6.9	41.1
	-NGL's	0.2	1.6	12.2	9.1	5.1	28.3
	-Diesel	16.1	61.1	85.0	62.8	32.3	258.9
Light Vehicles	-Gasoline	90.8	224.2	405.5	202.0	109.9	1,034.9
TOTAL		155.3	362.6	649.9	412.4	237.2	1,823.7

Source: Statistics Canada 57-0003

Road transport and urban transport together account for the next largest component of energy use, at 11% of total consumption. In Exhibit VII-1, we have added the retail pump sales of diesel fuel to the Statistics Canada category for road transport and urban transport, as most purchases of diesel fuel at the retail pump are by truck operators. The combined energy-use category has been labelled "Truck and Bus."

The airline sector also accounts for a significant portion of transportation energy use, at 8% of the total.

C. The frozen efficiency scenario in 2020

1. Activity levels

The following table shows the assumed growth in real output for each non-case study sector, represented by the ratio of sector RDP in 2020 to sector RDP in 1988. The data are based on Exhibit IV-5:

Rail	2.14
Air	2.09
Marine	2.35
Pipelines	2.13[1]
Truck and Bus	2.155[2]

Some specific factors relevant to activity levels in the case study sector (light vehicles), and the road and rail sectors are discussed below.

a) Light vehicles

Based on a range of considerations, we project a 73% increase in total distance driven by light passenger vehicles between 1988 and 2020. We have assumed that the distance driven per vehicle remains constant over this period, so that the total distance driven increases in proportion to the increase in the number of vehicles. The following factors enter into this decision.

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1 *Equal to ratio of RDP's for total transportation sector without marine subsector.*

2 *Equal to the average of the ratios for road transport and urban transport (2.14 and 2.17 respectively).*

Between 1984 and 1988, the Fuel Consumption Survey by Statistics Canada reported a 7% increase in the average distance driven annually per automobile.[1] IFSD projects a 73% increase in the number of passenger vehicles in service between 1988 and 2020. This will increase the number of vehicles per thousand people from 393 to 531. It could be argued that the increase in the rate of vehicle ownership will result in a drop in the distance driven per vehicle: as vehicle ownership increases, each vehicle has to serve the transportation needs of fewer people. According to this hypothesis, recent trends towards increased vehicle use would not then continue.

The demand for transportation, and hence, the total distance driven by light vehicles, will also depend on the pattern of urban development. For example, low density urban 'sprawl', by increasing trip distances, can increase the number of kilometres driven. Low-density development also makes the provision of efficient public transit services more difficult.

a) Rail, road, and urban transport

Between 1977 and 1987, truck transportation's share of economic output in the transportation sector rose from 22 to 29%. At the same time, rail's share of output decreased from 20 to 18%.[2] This is consistent with long-term historical trends towards more energy-intensive modes of transport. Shifts from rail to road transport are hastened by industry's adoption of Just-In-Time delivery schedules, which favour smaller but more frequent shipments.

While the dollar output of the truck transport industry has grown faster than GDP, growth in the total number of truck vehicle-kilometres has about matched overall economic growth over the period 1973-1989. The resulting decrease in vehicle-kilometres per dollar of output is due to more efficient scheduling and management systems.[3]

Between 1988 and 2020, we have assumed that vehicle-kilometres for the truck transportation sector wil grow at the same rate as sector RDP.

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1 *Fuel Consumption Survey. Statistics Canada 53-226.*

The average distance driven per personal-use passenger car increased from 16,280 km in 1984 to 17,380 km in 1988. Personal use automobiles (as opposed to trucks and vans, and cars used primarily for commercial purposes) accounted for approximately half of the gasoline sold through retail outlets in that year, as reported in Statistics Canada 53-218.

2 *Statistics Canada 53-222, 1987. Special study: "An Analysis of the Transportation Sector's Contribution to Canada's Gross Domestic Product, With Special Emphasis on the For-Hire Trucking Industry, 1977-1987." pp. 181-189.*

3 *Marbek Resource Consultants, "Energy Demand in Canada, 1973-1987, A Retrospective Analysis, Volume I", March 1989, p. B.26.*

2. Energy intensity

For all sectors other than light vehicles, energy use in 2020 under the Frozen Efficiency Scenario was projected by assuming that energy intensities remain at 1988 levels, where the intensity is defined as the physical energy used per dollar of real output. The result is shown in Exhibit VII-2, **overleaf.**

In the light vehicle case study, energy consumption of light vehicles (which is assumed to be represented by retail-pump gasoline sales) was projected assuming that the current light vehicle fleet, which includes older, less efficient vehicles, is replaced by a fleet whose average fuel efficiency equals that of the new vehicle fleet in 1988. In the SERF model, the weighted average fuel consumption of the total gasoline-powered vehicle fleet in 1988 is estimated as 12.72 L/100km. The equivalent figure for the new vehicle fleet is 10.46 L/100km, or 17.8% less. For the frozen efficiency scenario, we have therefore assumed that the fuel consumption of light vehicles will drop by 17.8% as older vehicles are eventually phased out of the vehicle stock.

D. The economically attractive scenario

For the light vehicle sector, energy use under the economically attractive scenario is estimated assuming that, by 2020, all vehicles have the same rated fuel efficiency as projected for the new vehicle fleet in 2010. In our year-by-year projections, the fuel efficiency of new vehicles remains constant after 2010.

For sectors other than light vehicles, we based estimates of the economically attractive scenario on our assessment of what is likely to happen. We believe that this will roughly correspond to an economically attractive level of efficiency. The other transportation modes are operated as commercial enterprises. The vehicles used by these modes are operated more intensively than personal-use automobiles, so that fuel cost is a larger component of operating expenses, and therefore has more influence on purchase decisions. This is particularly true of the airline sector.

Since vehicle purchase decisions are fundamental to a transportation firm's operating strategy, they can be expected to be subject to relatively detailed scrutiny. Because of this scrutiny, we believe that the transportation sector will be relatively less prone to the sorts of market failures (such as information barriers) that can lead firms to under-invest in energy efficiency. As profit-maximizing entities, businesses in the transportation sector should optimize their operating efficiency within market prices for fuel and the firm's cost of capital. The commercial transportation sector has substantial incentive to move naturally in the direction of its cost-effective level of energy efficiency.

To the extent that the cost of capital perceived by business is greater than its actual social cost, the improvement in energy efficiency obtained will be less than the economically attractive scenario optimum. We have not made adjustments for this

Exhibit VII-2
Frozen Efficiency Energy Use in Transportation in 2020 (PJ)

		REGION					
Subsector	**Fuel**	**Atlantic**	**Quebec**	**Ontario**	**Prairies**	**B.C.**	**Canada**
Railways	-Diesel	10.4	19.8	53.5	71.9	26.8	182.5
Airlines	-Turbo	24.3	71.2	111.9	54.1	57.0	322.0
Marine	-Diesel	38.6	13.6	14.3	0.1	31.3	97.9
	-Fuel Oil	29.1	44.3	24.7	0.0	37.0	135.1
Pipelines	-Natural Gas	0.0	1.1	99.4	128.7	26.5	260.0
Truck & Bus	-Gasoline	6.3	15.3	23.7	27.7	14.8	88.6
	-NGL's	0.5	3.5	26.4	19.6	10.9	60.9
	-Diesel	34.7	131.6	183.2	135.3	69.5	554.3
Light Vehicles	-Gasoline	114.4	279.9	594.3	318.1	171.4	1,469.7
TOTAL		258.2	580.5	1,131.4	755.4	445.2	3,171.0

discrepancy, however, since we did not have a basis for estimating the impact of higher private-sector discount rates. Our economically attractive scenario may therefore under-estimate the cost-effective level of energy conservation.

Various assumptions have been made about the potential reduction in energy consumption in the commercial transportation sectors. These assumptions are outlined in more detail below.

1. Automobiles, and light trucks and vans

The light vehicle case study projects a 44% decrease between 1988 and 2010 in the weighted-average fuel consumption rating of the new vehicle fleet and uses this as a proxy for the economically attractive scenario.

The projection of a 44% decrease in new vehicle fuel consumption reflects assessments by Energy and Environmental Analysis (EEA) of what will be technically possible, given the successful development of at least one "high-risk" technology. The EEA reports do not explicitly evaluate the cost-effectiveness of their long-term forecasts. An EEA analysis of potential short-term improvements, however, suggests that the projected increases in fuel economy will be cost-effective under this study's Canadian energy price scenarios, using the study's real discount rate of 7% over the full vehicle life. This point is discussed in more detail in the case study.

In addition to average rated fuel economy, actual energy use in 2020 by light vehicles will depend on the discrepancy between rated and actual fuel consumption, the number of vehicles in service, and the distance driven by each. Fuel consumption ratings under-estimate the fuel consumed in actual use, since they reflect "ideal" test conditions. Increases in urban traffic congestion, or an increase in the proportion of urban versus highway driving, could increase the discrepancy between rated and actual fuel consumption, and thereby offset some of the projected improvement in rated economy.

2. Road transport and urban transport

A 1988 study of energy use in the transportation sector assumed, for an optimistic scenario, that the fuel consumption of new heavy trucks would be reduced by about 30% by 2010.[1] The use of composite materials to reduce weight, reduced aerodynamic drag, electronic control of the powertrain, and, perhaps most importantly, introduction of an adiabatic diesel engine, are the technologies that could

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1 *Cheng, H.C. "Potential Reductions in U.S. CO2 Emissions in 1995 and 2010 By Technology Improvements in Electricity Generation and Transportation Sectors". Brookhaven National Laboratory, report prepared for U.S. Dept. of Energy, No. DE88 010662, April 1988.*

permit this reduction in fuel consumption. Significant doubts exist, however, about the acceptability of the adiabatic diesel engine, one of the key technologies for reducing fuel consumption. Diesel engines and, in particular, adiabatic diesel engines, have very serious problems with NOx emissions, which may not be resolved. Accordingly, for our energy use projections we have adopted the pessimistic scenario from the Cheng study, and assumed a 17.5% reduction in fuel consumption by 2020.

The economically attractive reduction in truck fuel consumption is proportionately much less than that for light trucks and cars. This is consistent with the fact that heavy trucks have fixed load carrying requirements that limit the technical potential for improvements in their efficiency.

Energy use captured in the Statistics Canada sector "Road Transport and Urban Transport" includes energy consumption by municipal transit authorities and inter-city bus companies. Most of their energy is consumed by passenger buses in the form of diesel fuel. We have assumed the same percentage reduction in energy consumption by urban transport as for heavy trucks. This seems reasonable given that passenger buses and heavy trucks both have high load carrying requirements, and rely on large diesel engines. The amount of fuel consumed by buses is less than 10% of the amount consumed by trucks.

3. Airlines

Jet aircraft, which carry the bulk of passenger traffic, are a maturing technology. Today's generation of aircraft is not significantly faster than the first generation of jets introduced in the 1950's. Replacement of aircraft is therefore driven by economics and operating efficiencies, rather than by changes in functional characteristics or passenger appeal. As a result, aircraft are staying in service for much longer periods of time than before the advent of the jet era.

Large increases in aircraft prices and current fuel prices mean that the cost of ownership (amortized capital and financing costs) can represent over half of the direct operating cost of a new aircraft.

Newer generations of aircraft typically offer lower fuel, maintenance, and staffing costs (flight crews of two can replace flight crews of three), which must be balanced against the higher capital and insurance costs of new aircraft. Fuel remains a large component of airline operating costs, however, and airlines will be extremely sensitive to any increases in fuel price.

Increases in fuel price would speed the replacement of older, less efficient, aircraft. A Boeing 757, for example, uses 43% less fuel per seat-mile than the 727 that it replaces.[1] The rate of development of new technologies could also change dramatically depending on expectations of fuel prices.

In the current era of relatively low energy prices, aircraft manufacturers are placing less stress on being at the leading edge of technology, and more emphasis on economic efficiencies. Manufacturers offer "families" of aircraft that have a high degree of parts commonality, and where, in many cases, new models are based on old designs. Such derivative products can offer customers significant savings in the cost of parts, training and maintenance, and in the purchase price.

a) Possible technologies

Changes in technology are likely to be evolutionary, rather than revolutionary, and investments in technology may be oriented more towards reducing manufacturing costs than achieving design breakthroughs[2]. Several new technologies could be developed to improve the fuel consumption of aircraft. These are described below.

Unducted Fan Engines - Unducted fan (UDF) engines, which could be used on short- and medium-range aircraft, would reduce fuel consumption by 30% to 40% over today's generation of aircraft. The savings in fuel consumption have to be balanced against higher expected maintenance costs, and the need to amortize the development costs of this major new technology.

Because of the recent outlook for fuel prices, both Boeing and McDonnell Douglas have abandoned plans to develop airplanes incorporating UDF engines. Aircraft manufacturers believe that fuel prices of at least $CDN 0.30 a litre, and possibly even as high as $CDN 0.45 a litre, would be required to make an advanced propfan economically viable.[3] Under the EMR/EC Reference Case, fuel prices in 1990 are only about $0.22 per litre, and real prices remain under $0.30 until 2020 (in 1990 dollars).

Ducted Ultra-High-Bypass Engines - Forecasters do not envision the use of UDF engines on long-range aircraft because of speed limitations, and the fact that they are more suited to small aircraft. For long-range aircraft, ducted Ultra-High-Bypass engines could reduce fuel consumption by 20% to 30% over today's engine technology. This estimate reflects improved propulsion efficiency because of the ducted fan design, as well as improved thermal efficiency because of higher turbine temperatures.

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1 *Williams, J.P. "Is There Life Until 30?", Airline Business, July 1989, p. 57.*

2 *O'Lone, R.G. "Commercial Airframe Makers Take Conservative Approach", Aviation Week and Space Technology, March 20, 1990, p.199.*

3 *French, Trevor, "Fanning The Flames", Airline Business, April 1988, p. 55.*

Aerodynamic Changes - There is also a potential for improvements in aircraft aerodynamic efficiency through laminar-flow control on wings and engine cowlings. By combining advances in aerodynamic and engine efficiency, an overall improvement of 30% to 50% in aircraft fuel consumption may be technically possible over the next 50 years.[1]

Introduction of a second generation of supersonic passenger aircraft could offset the improvements in aircraft fuel efficiency outlined above. The Concorde, which represents the first generation of such aircraft, has a seat-mile fuel consumption about three times as high as long-haul subsonic transports built at the same time.[2] While radical improvements in fuel efficiency would be required to make development of a new supersonic aircraft economic, it is unlikely that such improvements would ever fully offset the fuel burn penalty of high-speed flight. Supersonic, or even hypersonic, high-speed transports have been proposed for use on long-haul flights, such as those across the Pacific.

b) Economically attractive intensities

For our economically attractive scenario, we have projected a 30% reduction in energy consumption per real dollar of output for the airline sector by 2020. This assumes that aircraft manufacturers will delay the development of radical new fuel-saving technologies because of the stable outlook for fuel prices. While UDF engines will probably have been introduced by that date, their impact on average fleet fuel consumption will be dampened by the continued increase in aircraft useful life, and the resulting slow fleet turnover. Much of the 30% reduction in fuel use will therefore have been achieved by the replacement of older jet aircraft by newer models, already introduced and flying, that dramatically reduce fuel efficiency. In this sense, the attributed conservation potential really reflects a deficiency in the definition of frozen efficiency in this sector.

4. Rail and marine transport

For the economically attractive scenario, we have projected a 20% decrease in energy consumption per real dollar of output for the rail and marine sectors by 2020. This estimate is not based on an assessment of the relevant technologies, but rather on the assumption that economically attractive in fuel efficiency will be proportionately less in these sectors than for the auto and air modes. Rail and marine traffic are inherently less energy-intensive than competing modes of transport, and fuel costs therefore have less of an impact on operating economics than other factors, such as the capital costs of new equipment.

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1 *Schmitt, D. "Airline Aircraft-II", Air World, Vol. 40, No. 3, 1988, p. 27.*

2 *Mikkelson, D.C., and G.M. Reck, "Aircraft Engines-III", Air World, Vol. 40, No. 3, 1988, p. 25.*

5. Pipelines

As for the rail and marine sectors, we arbitrarily assumed a 20% decrease in energy consumption per real dollar of output under the economically attractive scenario by 2020.

E. Summary of potential

Exhibit VII-3, **overleaf**, summarizes the Economically Attractive Scenario, and the economic savings potential. In aggregate, savings potential represents about 32% of energy use in the Frozen Efficiency Scenario (presented in Exhibit VII-2).

Exhibit VII-3
Economically Attractive Potential Scenario (EA Case) and Savings in Transportation Sector in 2020 (PJ)

Subsector—Fuel		REGION					
		Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
Railways—Diesel	• EA Case	8.3	15.9	42.8	57.4	21.4	145.9
	• Savings	2.1	4.0	10.7	14.4	5.4	36.6
Airlines—Turbo	• EA Case	17.0	49.8	78.3	37.9	39.9	223.0
	• Savings	7.3	21.4	33.6	16.2	17.1	99.0
Marine—Diesel	• EA Case	30.9	10.9	11.5	0.0	25.0	78.3
	• Savings	7.7	2.7	2.9	0.0	6.3	19.6
Marine—Fuel Oil	• EA Case	23.3	35.5	19.7	0.0	29.6	108.0
	• Savings	5.8	8.9	4.9	0.0	7.4	27.0
Pipelines—Natural Gas	• EA Case	0.0	0.9	79.5	103.0	21.2	204.6
	• Savings	0.0	0.2	19.9	25.7	5.3	55.4
Truck & Bus—Gasoline	• EA Case	5.2	12.6	19.5	22.8	12.2	72.4
	• Savings	1.1	2.7	4.1	4.9	2.6	16.2
Truck & Bus—NGL's	• EA Case	0.4	2.9	21.8	16.1	9.0	50.2
	• Savings	0.1	0.6	4.6	3.4	1.9	10.7
Truck & Bus—Diesel	• EA Case	28.6	108.5	151.1	111.6	57.3	457.2
	• Savings	6.1	23.1	32.1	23.7	12.2	97.1
Light Vehicles—Gasoline	• EA Case	63.8	156.1	331.5	177.4	95.6	824.4
	• Savings	50.6	123.8	262.8	140.6	75.8	645.2
TOTAL	• EA Case	177.5	393.2	755.7	526.4	311.3	2,164.1
	• Savings	80.8	187.3	375.6	229.0	133.9	1,006.9

Over 60% of the economically attractive potential for energy conservation in the transportation sector is found in light vehicles. Road transport and urban transport, and the aviation sector, represent the next most important sources of economic potential in the transportation sector.

F. Discussion of results

It should be noted that if a reduction in fuel consumption is achieved through successful introduction of an adiabatic diesel engine, then the composition of fuel consumed in the light vehicle sector would change dramatically. Diesel fuel would replace a large fraction of the gasoline sold. However, we have not reflected this shift because of our "frozen fuel share" methodology.

In the light vehicle case study, we analyzed technologies that are not currently available, but that are expected to enter production on at least a few models over the next decade. As in any situation in which forecasts are made of future developments, there is some uncertainty over the projected costs and savings of particular technologies. Problems in manufacturing or performance could well jeopardize some of the technical potential for efficiency improvements.

Our estimates of the technical potential for efficiency improvements are based on forecasts of future fuel efficiency levels made by Energy and Environmental Analysis (EEA). We assume that EEA forecasts of what will be technically possible also represent what is economically attractive (from a social cost perspective). This assumption is based on our analysis of other EEA forecasts for a " maximum technology" case which in the short-term are also economically attractive in a social cost framework, and using Canadian energy prices. For the longer term, however, our assumption that equates the economically attractive and technically possible may not be valid. The large improvements in fuel efficiency forecast for light vehicles relative to other transportation sectors raise this concern.

The light vehicle case study projects fuel efficiency improvements to 2010 by linearly extrapolating improvements forecast by EEA to 2005. Linear extrapolation is justified on the grounds that EEA assumes that the penetration of a set of fuel saving technologies in the new vehicle fleet will linearly increase between 2001 and 2010. The particular technologies may, however, be introduced first in the vehicles for which they provide the largest benefit. The annual fleetwide reduction in fuel consumption may therefore be greater in the early years of market penetration than in the latter.

While the factors above suggest that fuel efficiency forecasts for light vehicles may be optimistic, a conservative note is introduced by the fact that no gains in new vehicle fuel efficiency are assumed between 2010 and 2020.

VIII

Economically Attractive Potential In The Industrial Sector

A. Introduction

This chapter provides an estimate of the energy efficiency potential in the Canadian industrial sector in 2020. The approach taken differs from that used for the residential (Chapter V), and transportation (Chapter VII) sectors. Instead of summarizing the results of the case studies and estimating the energy efficiency potential in the remaining segments of the sector, the industrial sector is analyzed as a whole, with estimates of potential being allocated to each major industrial end-use. The industrial case studies are used as examples of potential rather than building blocks for total potential.

The reasons that this approach has been taken in the industrial sector are as follows:

- In this sector, aggregate energy use is highly dependent on the changes in the structure of the industrial economy. To analyze energy efficiency potential, it is necessary to separate energy changes that might occur as a result of structural (or process) changes, from those associated with energy efficiency investments. Such an analysis requires a detailed focus on individual industry segments. Our basic case study approach did not allow a sufficiently-detailed focus.

- In those segments which were case studied, our ability to develop realistic estimates of economic potential was limited by a severe lack of data. In part for the reasons noted above, it is difficult to focus on aggregate potential. In addition, unlike other sectors that were analyzed in this study, we found very little existing literature, and had relatively little information in our own files, to permit us to address these issues. Information has not been available which would permit the translation of technical potential into economically achievable potential.

The consequence is that the estimates of economic potential in the industrial sector are the weakest of those provided in this report. At the level of depth appropriate for this study, it has been difficult to isolate and quantify opportunities for energy efficiency gains in any more than a broad approach. The results of this chapter should be read with these qualifications in mind.

This chapter therefore covers the following topics.

- An overview of the Canadian industrial sector.
- A review of energy use in the industrial sector, including three perspectives — retrospective, an estimate of current (1988) energy by fuel and end-use, and a general look at possible future trends.
- A review of generic energy efficiency measures and technologies applicable to the industrial sector.
- Summaries of the four industrial case studies.
- An approximate estimate of economically attractive potential in the industrial sector.

B. The industrial sector

The Canadian industrial sector includes all mining, manufacturing, construction, logging and fishing activities. Manufacturing is normally sub-divided into the following major sub-sectors:

- Paper and Allied.
- Primary Metals.
- Non-metallic Mineral Products (cement etc.).
- Chemicals and Chemical Products.
- Food and Beverage.
- Other Manufacturing.

Exhibit VIII-1, **overleaf**, shows the changes in Real Gross Domestic Product in mining and each of the manufacturing sub-sectors between 1973 and 1987.

Exhibit VIII-1
Changes in Industrial GDP between 1973 and 1987 (Index 1973 = 100)

	1980	1987
Food and Beverage	106	113
Paper and Allied	100	110
Primary Metals	88	110
Non-metallic Minerals	91	106
Chemicals	125	165
Other Manufacturing	119	156
Total Manufacturing	111	138
Mining	76	84
Manufacturing and Mining	99	121

Source: Statistics Canada

C. Energy use in the industrial sector

1. A retrospective look at industrial energy use

The following review of industrial sector energy use is based on a recent report for EMR looking at energy demand over the past 15 years[1].

Industrial energy use accounted for 40% of total energy use in Canada in 1987. The majority of this energy was used in manufacturing and mining. Industrial energy use has grown at an average rate of about 1% per annum since 1973 in manufacturing while energy use in mining has dropped slightly over the same period. Expressed in term of energy intensity, however, energy use per GDP output has decreased in all sub-sectors except chemicals and mining.

Exhibit VIII-2, **overleaf**, provides a comparison of energy intensities between 1973 and 1987 in each sub-sector. The decline in intensity reflects a improvement in energy efficiency within industry. The small average reduction of 5% between 1973 and 1987 should, however, be compared with an improvement of 30% in IEA

1 Energy Demand in Canada, 1973-1987: A Retrospective Analysis. *Marbek Resource Consultants for Energy Mines and Resources Canada, March 1989.*

countries over a shorter period (1973 to 1985)[1]. Canadian industry still is the most intensive of all IEA countries.

Exhibit VIII-2
Trends in Industrial Energy Intensity between 1973 and 1987 (MJ/1981 $ GDP)

	1973	1987
Food and Beverage	13.8	11.4
Paper and Allied	56.7	51.0
Primary Metals	67.2	60.1
Non-metallic Minerals	58.7	47.9
Chemicals	53.3	59.3
Other Manufacturing	8.2	7.9
Total Manufacturing	25.4	21.3
Mining	6.2	7.0
Manufacturing and Mining	19.1	18.1

Source: Statistics Canada

There has been some shift in fuel shares over the past 15 years. Oil share has dropped from 34% in 1973 to 13% in 1987, while natural gas and electricity shares have risen to 47% and 29% respectively. These fuel shares have remained fairly constant in most industries since 1984.

2. Industrial energy use in 1988

Consistent industrial energy use statistics are difficult to derive because of the many different sectoral and sub-sectoral definitions used by various agencies. Exhibit VIII-3, **overleaf**, provides an estimate of industrial energy use in 1988 by industry sub-sector, fuel and end-use. The sources used to derive this breakdown were as follows:

- Statistics Canada Quarterly Report on Energy Supply-Demand. Catalogue 57-003, 1988.
- The Industrial Sector Database prepared as part of Energy Demand in Canada, 1973-1987: A Retrospective Analysis.

1 *Trends in Energy Intensities in Industrial Balances, International Energy Agency, IEA/SLT/EC, Paris February 1988.*

Exhibit VIII-3

1988 INDUSTRIAL ENERGY USE (TJ)

SUB-SECTOR	ELEC DRIVES	ELEC PROCESS	ELEC TOTAL	GAS STEAM	GAS DIRECT	GAS TOTAL	OIL STEAM	OIL DIRECT	OIL TOTAL	COAL	OTHER	TOTAL
PAPER AND ALLIED	181,925	9,575	191,500	60,550	25,950	86,500	57,050	24,450	81,500	3,000	396,500	759,000
CHEMICALS	33,500	16,500	50,000	149,100	63,900	213,000	7,700	3,300	11,000	3,000	0	277,000
IRON AND STEEL	21,655	13,845	35,500	9,750	55,250	65,000	2,325	13,175	15,500	169,500	0	285,500
OTHER METALS/MINERALS	101,250	33,750	135,000	6,600	37,400	44,000	3,225	18,275	21,500	43,000	0	243,500
FOOD AND BEVERAGE	12,750	4,250	17,000	48,000	12,000	60,000	8,000	2,000	10,000	0	0	87,000
OTHER MANUFACTURING	81,375	27,125	108,500	260,000	65,000	325,000	32,000	8,000	40,000	4,000	0	477,500
SUBTOTAL	432,455	105,045	537,500	534,000	259,500	793,500	110,300	69,200	179,500	222,500	396,500	2,129,500
MINING	76,500	25,500	102,000	11,025	62,475	73,500	13,425	76,075	89,500	2,500	0	267,500
TOTAL	508,955	130,545	639,500	545,025	321,975	867,000	123,725	145,275	269,000	225,000	396,500	2,397,000

Notes: 1. All amounts except Chemicals and Food/Beverage from Catalog 57-003
2. Chemicals and Food/Beverage developed from various sources
3. Other Manufacturing is 57-003 Other Manufacturing minus Food and Beverage
4. Other Metals and Minerals is 57-003 Smelting/Refining plus Cement
5. Drivepower fractions from provincial utilities
6. Steam/direct heat fractions from Industrial Energy Efficiency Technology Development Strategic Planning Options
7. Other includes steam, wood waste and spent pulping liquor

- Industrial Energy Efficiency Technology Development Strategy Planning Options, a recent report prepared for EMR's Energy Efficiency Division[1].
- Estimates of electricity use by various industries in several provinces provided by electrical utilities.
- SERF algorithms used to estimate industrial end-use.

Full information for 1988 was not available. 1988 Statistics Canada information was used as a base, with more detailed breakdowns being based on earlier years. Several of the major manufacturing sub-sectors were redefined to allow separate values to be used for major industries such as iron and steel (normally part of primary metals). In other cases, definitions were revised to improve consistency. For example, synthetic resins are included in chemicals instead of in other manufacturing. Finally some small sub-sectors that have very different end-use breakdowns, such as petroleum refining, have been separated out from manufacturing.

The energy end-uses used in the industrial sector breakdown are as follows:

- Electric drivepower, including motors and the equipment they drive, such as compressors, fans, pumps etc.
- Other electricity - mostly process electricity (e.g., electrolytic) and lighting.
- Steam raised by oil and gas.
- Direct heat met by oil and gas.
- Coal used for direct heat and steam.

Hydrocarbon feedstocks are not included.

3. Frozen efficiency scenario in the industrial sector

The pattern and size of energy use in the industrial sector depends very much on the structure of the economy, the national and international demand for goods, and Canada's position in the world market. Industries such as the pulp and paper and iron and steel industries will also be particularly affected in the future by process change, increasing use of recycled product, and world wide changes in the demand for various types of product. The shape of industrial energy demand in Canada will also depend on whether primary resource or secondary manufacturing becomes the dominant part of the Canadian economy, and also on the size of Canada's exports.

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1 *Industrial Energy Efficiency Technology Strategic Planning Options, Kentek, William G. Matthews Association and ROBBERT Associates for Energy Mines and Resources Canada, March 1990*

Estimating industrial energy use in 2020 under any set of criteria such as frozen efficiency or economic potential is therefore a hazardous and difficult exercise. The only way it can be carried out simply is to assume that the economy will grow at a certain rate but that economic structure, process technologies, export levels, and the relative importance of each sub-sector remains as it was in some base year, e.g. 1988. The only comfort in this approach is that over the last 15 years there have been no dramatic changes in industrial economic structure, and, apart from during the recession of the early 1980s, energy use has increased and intensity decreased at relatively smooth rates in many industries.

The projection of industrial activity underlying the EMR/EC Reference Case assumes increases in RDP of between 1.2% and 2.3% per year across the industrial sector over the next 30 years. Exhibit VIII-4, **overleaf**, shows the energy consumption that would occur in 2020 assuming industry specific growth rates, and assuming that energy intensities remain as they are in 1988 i.e., a frozen efficiency scenario. This is clearly an "average" frozen efficiency scenario, rather than a marginal scenario as is found in some other sectors.

D. Industrial energy efficiency measures

Many of the energy efficiency measures and technologies that can be applied to the industrial sector are generic, in that they can be used in most industries. They can increase the efficiency of drivepower, lighting, steam production and direct heating. The technologies reviewed in this section are as follows:

- Efficient drivepower, including energy efficient motors, variable frequency drives and efficient driven equipment (fans, bearings, pumps, compressors etc).
- Efficient lighting.
- Improved combustion efficiency in raising steam and providing direct heat.
- Heat recovery and heat pumping, including the use of Pinch Technology to identify optimum heat exchange.
- Cogeneration within industries to reduce purchased electricity.
- Electroheat technologies such as microwave drying.

Exhibit VIII-4

2020 INDUSTRIAL ENERGY USE (TJ) - FROZEN EFFICIENCY

SUB-SECTOR	ELEC DRIVES	ELEC PROCESS	ELEC TOTAL	GAS STEAM	GAS DIRECT	GAS TOTAL	OIL STEAM	OIL DIRECT	OIL TOTAL	COAL	OTHER	TOTAL
PAPER AND ALLIED	353,766	18,619	372,385	117,744	50,462	168,205	110,938	47,545	158,483	5,834	771,022	1,475,929
CHEMICALS	69,353	34,159	103,512	308,672	132,288	440,961	15,941	6,832	22,773	6,211	0	573,456
IRON AND STEEL	43,450	27,779	71,229	19,563	110,856	130,419	4,665	26,435	31,100	340,094	0	572,842
OTHER METALS/MINERALS	153,073	51,024	204,097	9,978	56,542	66,520	4,876	27,629	32,504	65,009	0	368,130
FOOD AND BEVERAGE	25,582	8,527	34,110	96,310	24,077	120,387	16,052	4,013	20,065	0	0	174,561
OTHER MANUFACTURING	163,275	54,425	217,700	521,677	130,419	652,097	64,206	16,052	80,258	8,026	0	958,081
SUBTOTAL	808,498	194,534	1,003,033	1,073,944	504,645	1,578,590	216,677	128,505	345,182	425,172	771,022	4,122,999
MINING	112,057	37,352	149,409	16,149	91,513	107,662	19,665	111,434	131,099	3,662	0	391,832
TOTAL	920,555	231,886	1,152,442	1,090,094	596,158	1,686,252	236,342	239,939	476,281	428,834	771,022	4,514,831

Notes: 1. Assumes average annual growth rates as follows:

Paper and Allied	2.1%
Chemicals	2.3%
Iron and Steel	2.2%
Other Metals/Minerals	1.3%
Food and Beverage	2.2%
Other Manufacturing	2.2%
Mining	1.2%

1. Drivepower

Motive electricity accounts for about 75% of industrial electricity consumption. This varies from a high of 95% in the pulp and paper industry to 60% in iron and steel (see Drivepower Case Study). Drivepower efficiency can be increased in several ways.

- By replacing standard motors with high efficiency motors.
- By replacing existing DC drives with solid state drives.
- By adding variable frequency drives (VFDs) to fixed speed motors.
- By improving the efficiency of pumps, fans and compressors.
- By reducing motor and equipment oversizing.
- By reducing friction in bearings etc.

More detailed descriptions of each of these technologies may be found in the technology profiles of the Drivepower Case Study or in Industrial Energy Efficiency Technology Developing Strategic Planning Options[1]. Exhibit VIII-5, **below,** provides estimates of the unit efficiency improvements that can be expected from each measure.

Exhibit VIII-5
Typical Drivepower Efficiency Measures

Measures	Equipment Efficiency Improvement
1 HP HE AC Motors	13%
100 HP HE AC Motors	4%
350 HP HE AC Motors	2%
VFDs for fixed speed AC Motors:	
► compressors	20-25%
► variable load pumps & fans	30-50%
► normal load pumps & fans	20-35%
Solid state DC drives	50%
HE pumps	3-10%
Reduced motor oversizing	15%
Reduced friction	20%

1 *Industrial Energy Efficiency Technology Development Strategic Planning Options, op.cit.*

All of the above measures are expected to be economically attractive by the year 2020, and in the three major industries of pulp and paper, chemicals, and iron and steel could reduce drivepower electricity by an average of 20% (see Drivepower Case Study).

2. Efficient lighting

Lighting is the second highest electricity end-use in industry after drivepower and accounts for close to 20% of electricity use[1]. Lighting efficiency improvements applicable in the commercial and institutional sectors, such as HE fluorescent lamps, electronic ballasts, reflectors, compact fluorescent, and HID lighting, are all suitable for deployment in industrial buildings and plants. Given that industrial lighting tends to have a higher utilization than commercial lighting, all technologies that are economically attractive in commercial buildings will also be attractive in industry. It may be assumed therefore that the 65-70% economic savings potential identified for the commercial sector (see Commercial Sector Case Studies) would also be applicable in industrial lighting.

3. Improved combustion efficiency

The combustion efficiency of boilers and hot air furnaces used in industry has improved steadily over recent years, and efficiency in the 75-80% range is common. There is still room for improvement, however, and several combustion technologies such as impulse burners, recuperative burners, regenerative burners, and low temperature oxygen fired units could bring efficiencies to greater than 90%. More information on some of these technologies is provided in the Chemicals and Iron and Steel Case Studies. It is difficult to obtain cost data on many of these new combustion technologies, but some are already in use and it may be assumed that most will economically attractive by 2020.

Industrial studies have shown that combustion losses might be reduced by 50% by using these new technologies and the recovery of waste heat through condensing recuperators. This would be equivalent to a decrease of about 20% in fuel consumption by boilers and direct fired furnaces.

4. Heat recovery and heat pumping

In many industries there are opportunities to recover waste heat from one process stream, or from stock gases, and use it to heat other streams. In some cases simple heat exchangers can be used, while in others it may be cost-effective to extract heat from low temperature streams using heat pumps, or upgrade low temperature steam using vapour recompressors.

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1 *Ibid.*

A recent innovation has been the development of Pinch Technology—a computerized optimization process for selecting the most economically attractive location and size of heat recovery and heat pumping equipment at a given fuel price. The economic degree of heat pumping also depends on the relative prices of electricity and fuels, since a heat pump or vapour recompressor replaces heating fuel with a combination of waste heat and electricity.

More information on pinch technology and heat pumps may be found in the Chemicals Case Study. Pinch technology, in effect, identifies the maximum economic savings at a given price. Typical savings at current industrial energy prices range between 20% and 40% of purchased fuel. If one third of these savings were accomplished using heat pumps with an average COP of 3 then there would be a corresponding increase in electricity use equivalent to about 10% of the fuel used.

5. Cogeneration

Cogeneration by an industrial user effectively reduces the amount of purchased electricity, but replaces this electricity with additional gas or oil. Efficiency is improved, but the economic attractiveness of the technology is dependent on the industry price differential between electricity and fuel. In Canada the industrial electricity to gas price ratio is about 3:1. Most utilities still, however, have buy-back rates which are lower than retail electric rates. This effectively limits the amount of cogeneration to a level where the amount of electricity produced is equal to the electricity demand of the plant (or industrial complex).

The Chemicals and Pulp and Paper Case Studies contain more information about cogeneration, and show that it is economically attractive at current electricity to gas ratios. The Chemicals Case Study also shows that in some chemical processes, all electricity requirements could be met by cogeneration. In others, plant process heat loads limit the contribution to about 50% of the electrical requirements after other energy efficiency measures had been met.

6. Electroheat technologies

Electroheat technologies may be defined as those which use electricity to meet a process unit operation or process need, instead of using electric resistances gas or oil heating, while using a reduced amount of energy. Examples include microwave drying, impulse drying, ultrasonic drying, UV radiation, lasers, and reverse osmosis. Most of these applications are very sub-sector and process specific, but they can often reduce the energy demand in the specific unit operations by 50% or more.

E. Energy efficiency potential in 2020

In the following paragraphs, we develop estimates of energy conservation potential in 2020. In so doing, we summarize the results of four industrial sector case studies which were undertaken. These are:

- The Forest Industry Case Study.
- The Iron and Steel Industry Case Study.
- The Chemicals Industry Case Study.
- The Drive Power Case Study, which looked at specific conservation potential for drive power in the three industries which were subject to the broader case studies. (This Case Study is not discussed separately, but the results are discussed within the context of each of the other three summaries.)

1. Potential for energy efficiency gains in the forest industry

The value of shipments by the Canadian forest industry in 1987 was almost $46 billion. Of this amount, the paper and allied sector accounted for half, the wood industry for one-third, and logging for roughly 15%.

The sector consumed about 759 PJ of energy in 1988. Fuel and electricity purchases are significant in all three subsectors, particularly so for pulp and paper. The paper and allied sector accounted for approximately three-quarters of the energy purchased by the forest industry in 1987, of which 94% was consumed in pulp and paper mills.

Self-produced energy forms such as wood wastes, self-generated hydro electricity, and pulping liquors accounted for 55% of the total energy used by the pulp and paper industry in 1988.

Assuming frozen 1987 intensities, the pulp and paper sector will consume approximately 1475 PJ of energy in 2020. Current industry projections of output mix suggest that there will be substantial shifts within the industry. These shifts in product mix will have implications for energy consumption by the industry. Energy intensities will also be influenced by major changes in technology. These potential shifts in both output and process, although not explicitly considered in the frozen efficiency scenario, can nonetheless have major implications for base line energy use over the study period. Their net impact on energy intensities is unclear.

The major areas for improved energy efficiency include:

- Plant modernization.
- Co-generation.
- Waste heat recovery.
- The use of recycled fibre.

Most of the major investments undertaken by the forest industry are not driven primarily by energy concerns. The economically efficient or socially optimal level of energy efficiency cannot be determined, given the existing information and the level of depth appropriate to this case study. Existing studies are fragmented, and tend to focus on one or a group of measures. Those studies which do provide financial analyses are typically not presented in sufficient detail to allow a transformation to the social perspective appropriate for this study.

Drivepower savings are estimated to be 21%.

2. Potential for energy efficiency gains in the iron and steel industry

The Canadian iron and steel industry, which is centred in Ontario and, to a lesser extent, Quebec, accounted for 3% of total manufacturing output in 1989.

This sector consumed 286 PJ of energy in 1988, with Ontario accounting for approximately 90%. Coal/coke is the major energy source, comprising approximately 59% of the total energy consumed.

Assuming no change in base year energy intensities, and using the EMR/EC Reference Case output growth assumptions, the frozen efficiency scenario for the industry results in consumption of 573 PJ in 2020.

The industry has undergone substantial change, and continued rapid change is expected. These changes are primarily linked to the need to make products more competitive, and to reduce costs. Moves towards structural reorganization and technical innovation are therefore largely a result of these stimuli, rather than energy conservation.

Many of the technology and process changes available to the industry in the future create the potential for energy efficiency gains. However, the nature and pace of capital investment will be determined primarily by the need to enhance operating efficiencies and quality.

The studies which we identified during the case study provide very little insight into the cost effectiveness of such investments, when viewed from an energy perspective.

Given this, it appears that the major areas of potential lie in developments of steel casting and direct rolling, as well as waste heat recovery and burner improvements.

At the level of research within the scope of this case study, we have identified virtually no literature which permits us to assess the economic level of energy efficiency potential within this industry sector, using the assumptions or parameters appropriate to this study. The clear exception to this is the drive power sector, which has been able to build on existing work. Even in this case, however, the drive power estimates require assumptions about the stability of technology and product mix which are clearly not going to be realized. Consequently, we have not attempted to make quantitative estimates of the economically attractive level of potential for this sector. The general results of case study, however, are consistent with the broad assumptions developed in this chapter.

Drivepower savings are estimated to be 15%.

3. Potential for energy efficiency gains in the chemicals industry

The following is a summary of the conclusions from the Chemical Industry Case Study.

The Canadian chemical industry consists of manufacturers of inorganic and organic chemicals, fertilizers, synthetic resins and chemical products. In 1988 the chemical industry consumed about 277 PJ of energy, of which 224 PJ were oil and gas. Energy use is dominated by several large chemical processes. Five of these processes—chlorine, ethylene, polyethylene, ammonia and methanol—account for 215 PJ or 78% of total energy use.

The largest energy end-use in the chemical industry is process heat, representing 85% of total energy use. It is used at several temperatures to raise steam and provide direct heat. Drivepower is the second largest end-use at 10%.

There is significant potential for improvements in energy efficiency in the chemical industry through the use of heat recovery, improved boiler combustion, efficient drivepower, and cogeneration, as well as through housekeeping measures such as pipe insulation and improved controls. Typical saving from economically attractive measures at projected EMR/EC Reference Case prices are estimated as follows:

Housekeeping measures:	10%
Drivepower efficiency:	18%
Heat recovery:	30-40%
Boiler upgrades:	25%
Cogeneration:	Up to a limit equivalent to plant process heat demand

New plants are expected to achieve the maximum potential savings.

Assuming that the chemical industry grows at a rate of 2.3% per year until 2020 (as per the Informetrica projections underlying the EMR/EC Reference Case, extrapolated to 2020), economic potential savings in 2020 are estimated to be 210 PJ, or 37%, through utilization of these above measures.

At higher supply prices it would become even more attractive to use cogeneration and heat recovery. The use of these technologies are also dependent, however, on the price ratio between electricity and fuels, as well as on the absolute price.

4. Economically attractive potential for energy efficiency gains in the industrial sector in 2020

To estimate the economically attractive potential in 2020, the following savings reduction factors were applied to each of the frozen efficiency energy end-use consumption figures in Exhibit VIII-4.

Efficient Drivepower:	Drivepower electricity reduced by 20%, except where industry specific savings were available from the case studies
Efficient Lighting:	Lighting electricity (80% of other electricity) reduced by 67%
Improved Combustion:	Steam and direct heat fuels reduced by 20%
Heat Recovery/Pumping:	Steam and direct heat reduced by 30%, and drivepower electricity increased by 10% of this reduction
Cogeneration:	Substitution of gas direct heat for 50% of electricity demand, at a gas efficiency of 83%

It was assumed that the energy efficiency measures would not be additive. The factors were applied in the order shown. The resulting 2020 economically attractive savings potential is shown in Exhibit VIII-6, **overleaf.**

Comparing Exhibits VIII-4 and VIII-6 shows that there is an overall reduction of about 1250 PJ, or 28% of total energy use, between the frozen efficiency and economically attractive potential scenarios in 2020. The largest reduction is in electricity (680 PJ or 59%), due to the large amount of cogeneration. Natural gas reduction is only 175 PJ, or 10%, again as a result of cogeneration.

Exhibit VIII-6

2020 INDUSTRIAL ENERGY USE (TJ) - ECONOMIC POTENTIAL SCENARIO

SUB-SECTOR	ELEC DRIVES	ELEC PROCESS	ELEC COGEN	ELEC TOTAL	GAS STEAM	GAS DIRECT	GAS COGEN	GAS TOTAL	OIL STEAM	OIL DIRECT	OIL TOTAL	COAL	OTHER	TOTAL
PAPER AND ALLIED	293,045	8,639	-150,842	150,842	65,937	28,259	181,011	275,206	62,125	26,625	88,750	3,267	771,022	1,289,087
CHEMICALS	75,258	15,850	-45,554	45,554	172,857	74,081	54,665	301,603	8,927	3,826	12,753	3,478	0	363,387
IRON AND STEEL	56,266	12,890	-34,578	34,578	10,955	62,080	41,493	114,528	2,612	14,804	17,416	190,452	0	356,974
OTHER METALS/MINERALS	127,686	23,675	-75,681	75,681	5,588	31,664	90,817	128,068	2,730	15,472	18,202	36,405	0	258,356
FOOD AND BEVERAGE	26,313	3,957	-15,135	15,135	53,933	13,483	18,162	85,579	8,989	2,247	11,236	0	0	111,950
OTHER MANUFACTURING	161,074	25,253	-93,164	93,164	292,139	73,035	111,796	476,970	35,956	8,989	44,945	4,494	0	619,573
SUBTOTAL	739,642	90,264	-414,953	414,953	601,409	282,601	497,943	1,381,954	121,339	71,963	193,302	238,097	771,022	2,999,327
MINING	98,855	17,331	-58,093	58,093	9,044	51,247	69,712	130,003	11,012	62,403	73,415	2,051	0	263,562
TOTAL	838,497	107,595	-473,046	473,046	610,452	333,849	567,655	1,511,956	132,352	134,366	266,717	240,147	771,022	3,262,889

Notes: 1. Chemicals savings as per case study. All others as follows:
2. Drivepower reduced by 21.5% (Paper and Allied), 14.9% (Iron and Steel). 20% all other
3. Drivepower increased by 10% of difference between gas, oil and coal frozen efficiency and conservation potential fuel (heat pumping)
4. 80% of Other Electricity reduced by 67% (lighting)
5. Total electricty reduced by 50% (cogeneration)
6. All gas, oil and coal reduced by 20% (combustion) and 30% (heat recovery)
7. Direct fired gas increased by 1.2 times total electricity (cogeneration)

F. Interpretation of results

1. Sensitivity to energy prices

The main impact of higher supply prices would be to make many of the heat recovery options more economically attractive. There would, however, be a limit to the attractiveness of electric heat pumps if the ratio between electricity and other fuels remains the same. At higher supply prices, it may become cost effective to consider advanced chemical heat pumps which use fuels other than electricity.

The economic attractiveness of drivepower options are relatively independent of supply price, since most motor, VFD and driven equipment options are already (or will be by 2020) economically attractive (see also Drivepower Case Study).

Cogeneration, like heat pumping, is dependent on the ratio of electricity to gas prices. At higher supply prices and a constant electricity/gas ratio it will become cost-effective to consider producing more electricity than is required by each plant. Industry could become a net producer of electricity.

IX

A SERF-Based Estimate Of The Economically Attractive Potential for Energy Efficiency Gains

In this chapter, we present the results of a SERF-based estimate of aggregate economically attractive energy efficiency improvements, at five-year intervals to the year 2020.

The economically attractive energy-use scenario was developed from the frozen efficiency scenario, described in Chapter IV. The assumptions with respect to economic potential, which have been described in Chapters V through VIII at the sector level, were implemented within the SERF framework as percentage changes in intensity. For a variety of reasons, the results in the year 2020 of the SERF rollup are not identical to the aggregation of the four sector rollups.

A. Phase-in of potential

In order to provide estimates of economically attractive energy efficiency potential in the intervening five-year intervals, it was necessary to make assumptions as to the phase-in of the intensity improvement drawn from Chapters V through VIII. The following assumptions were made:

- It was assumed that all building retrofit potential would be available by 1995.
- New residential and commercial potential would be available as the new buildings are constructed.
- There are explicit stock replacement models in the appliance and transportation sectors in SERF, and the phase-in potential was tied to stock replacement.
- Since potential in the industrial sector represents replacement, primarily rather than retrofit, and there are no good models of stock replacement, it was assumed that potential year 2020 intensities would be phased in on a linear basis, over the period to 2005. This is intended to proxy a form of stock replacement, without the ability to do so accurately.

The concept of economically attractive potential used in the study is based on purely economic calculations. We have not considered how rapidly this potential might be realized, under various scenarios. In other words, the concept of potential is defined independent of practical constraints on its implementation, such as the availability of skilled trades, etc. Nonetheless, such practical constraints are clearly of considerable importance in policy considerations.

B. Results

Exhibits IX-1 through IX-4, **overleaf**, portray in graphical form, the results of aggregate analysis. In each case, three cases are compared:

- The SERF Frozen Efficiency Case (abbreviated as SERF-FE).
- The SERF Economic Potential Case (abbreviated as SERF-EP).
- The EMR/EC Reference Case (abbreviated as EMR/EC).

The difference between the SERF Frozen Efficiency and economic potential cases reflects the magnitude of the economically attractive potential for energy efficiency improvements. The EMR/EC Reference Case can be viewed conceptually as the "market case", i.e., a projection of energy use under a similar set of assumptions about economic activity to the year 2020, but using a substantially different methodology. Because of the significantly different approaches used in this study and the EMR/EC Reference Case, considerable caution must be taken in making quantitative comparisons between them. With this proviso, the area between the SERF Frozen Efficiency and EMR/EC Reference Cases can conceptually be considered as that portion of economically attractive energy efficiency potential identified in this study, which might be expected to be achieved through market forces. The area between the EMR/EC Reference Case and the SERF Economic Potential case represents additional potential for economically attractive efficiency improvements, some of which might be achieved through additional policy actions by government.

The four exhibits show the following perspectives:

- Exhibit IX-1 shows the trends in the three scenarios over the study period.
- Exhibit IX-2 shows similar information in snapshot form for three time periods, with disaggregation by fuel type.
- Exhibit IX-3 shows, for the year 2000, a similar breakdown, by sector.
- Exhibit IX-4 provides a similar perspective for the year 2020.

Detailed quantitative results are provided in Exhibits B-1 through B-5, in the Statistical Annex (Appendix B).

Exhibit IX-1

Secondary Energy Use — 1988-2020
Comparison of SERF Frozen Efficiency and Economic Potential Cases and EMR/EC Reference Case

(excluding biomass)

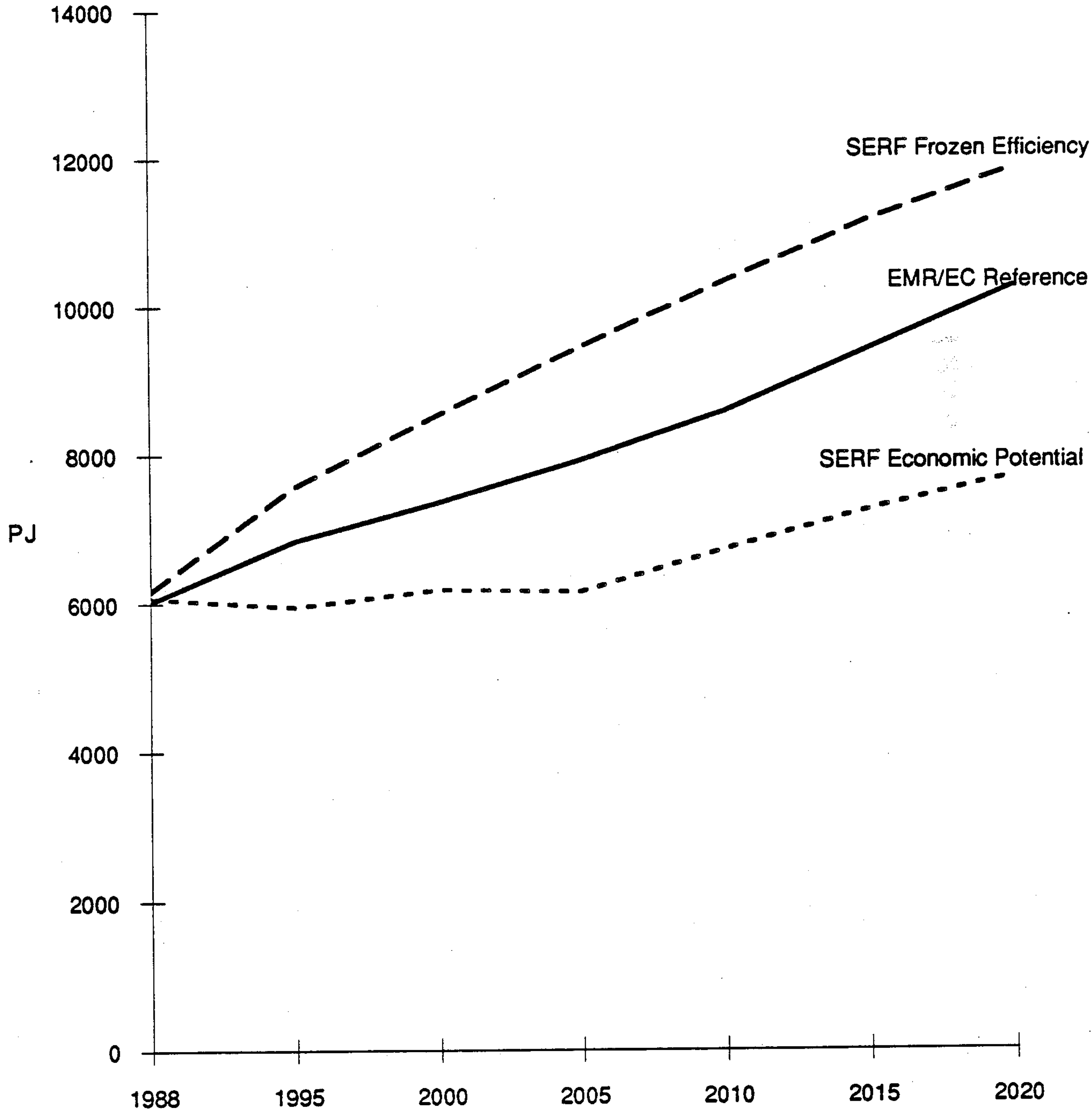


Exhibit IX-2

Secondary Energy Use — 1988-2020
Comparison of SERF Frozen Efficiency and Economic Potential Cases, and EMR/EC Reference Case

(excluding biomass)

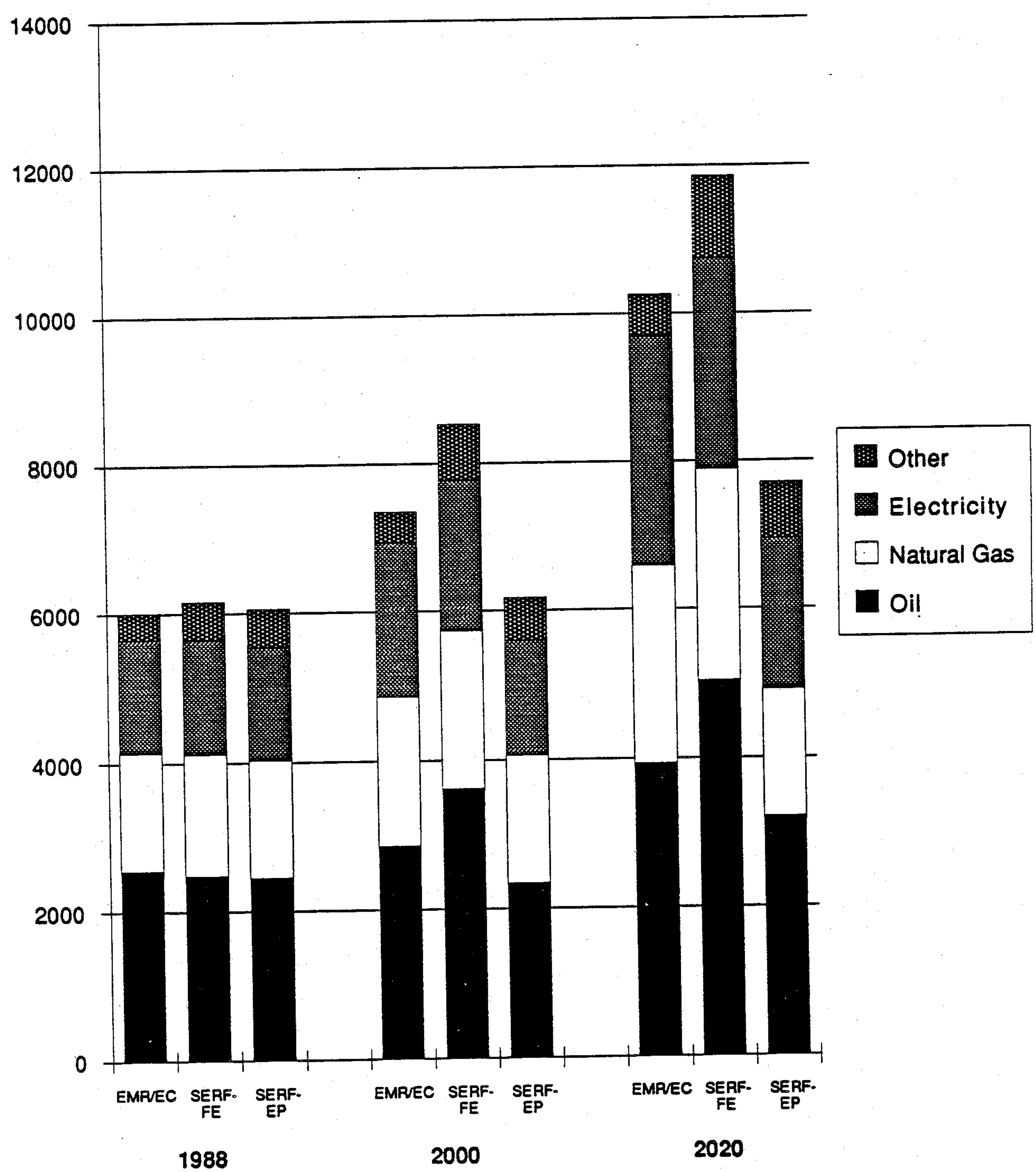


Exhibit IX-3
Comparison of SERF Frozen Efficiency and Economic Potential, and EMR/EC Reference Secondary Energy Use — 2000

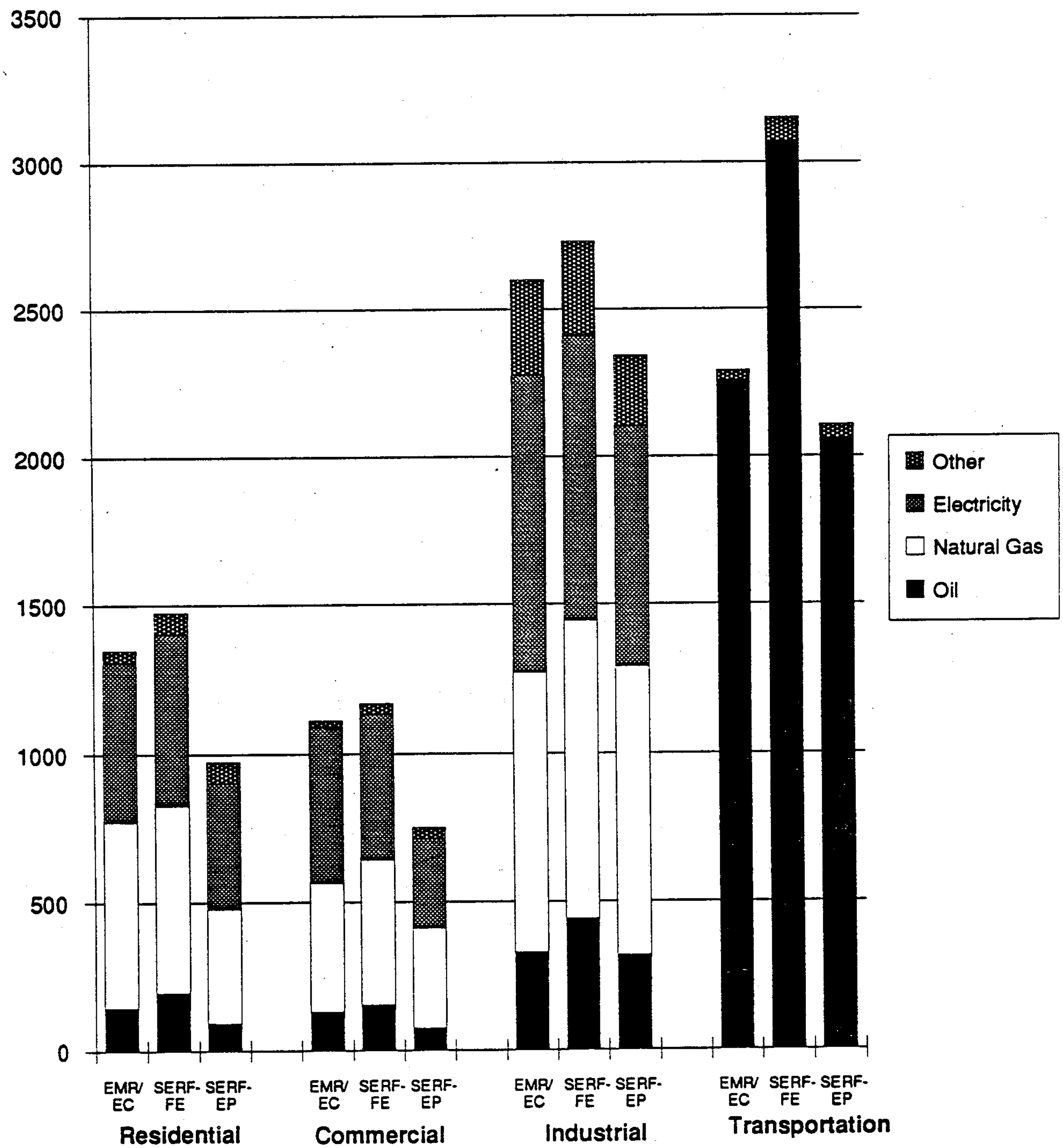
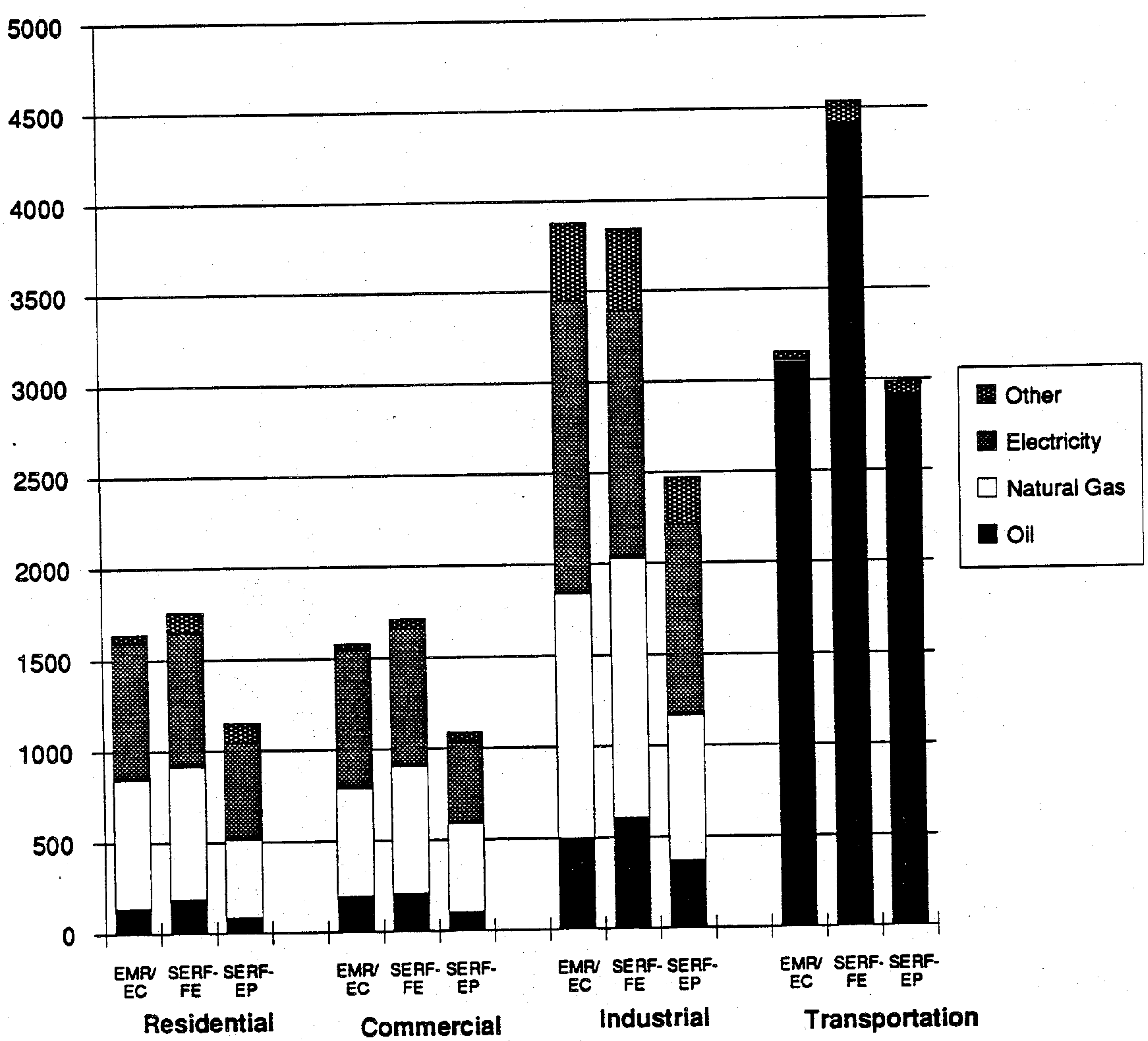


Exhibit IX-4
Comparison of SERF Frozen Efficiency and Economic Potential, and EMR/EC Reference Secondary Energy Use — 2020



C. Discussion of results

These results should be interpreted in the context of the major assumptions used in these derivations. A number of these assumptions are presented in the first four chapters of this report, and are summarized in the Executive Summary.

X

Impact On Environmental Emissions Of Achieving Economically Attractive Potential

In this chapter, we translate estimates of economically achievable potential into associated estimates of reductions in environmental emissions.

As a result of the SERF rollup, energy conservation potential (presented in Exhibit IX-1), is expressed in terms of secondary energy. Environmental emissions are estimated by converting the economically attractive conservation potential demand, expressed in primary energy terms, into reductions in environmental emissions, using a series of emissions coefficients provided by EMR.[1] In order to apply the emission coefficients, it is necessary to do the following:

- Provide a breakdown by region. While the SERF model does not provide regional results, we have been able to use the case studies, sector rollups, and other sources to apportion the efficiency potential to the regional level.

- Provide further disaggregation by fuel, e.g. within the fuel oil category, a distinction is required between heavy and light.

- To convert from secondary to primary energy, electricity must be allocated to various generation sources, by region, and fossil based electricity must be converted to its primary energy equivalents, by fuel. Note that, apart from this adjustment for electricity generation, we have not considered the emission impacts of the energy supply industries.

The process whereby this has been undertaken is described below.

A. Disaggregated primary energy equivalent potential for energy efficiency gains

The following paragraphs describe in more detail the process for converting from the results presented in Chapter IX (and provided in more detail in Exhibits B-1 through B-5 in

1 *Emission Factors for Greenhouse and Other Gases by Fuel Type: An Inventory. E.M.R., December 1990.*

Appendix B), to a format appropriate for determining the impacts on environmental emissions. Three forms of adjustment have been made.

1. Disaggregation by region

The SERF results are not disaggregated by region. However, for the most, part, the sector rollups in Chapters V through VIII, are regionally disaggregated. The results in Chapter IX have been disaggregated regionally, on the following basis:

a) Residential

Chapter V provides a regional breakdown of savings potential in single family homes, but not for apartments for 2020. Base year (1988) data for apartments were used to determine the regional breakdown in 2020.

b) Commercial

The regional breakdown provided in the commercial case study was used to disaggregate electricity and gas. For fuel oil, no reliable breakdown by region was available from the case study, and the residential breakdown by region for fuel oil was used as a proxy.

c) Transportation

The regional breakdown was available in Chapter VII.

d) Industrial

Statistics Canada 57-003 was used to allocate energy usage by fuel type and by region, using base year 1988 data.

2. Further disaggregation by fuel type

In order to implement the environmental emission coefficients provided by EMR, a further disaggregation of three fuel types was required:

- Fuel oil was disaggregated into light, heavy, and petroleum coke.
- Diesel was disaggregated into marine, rail, and road use categories in the transportation sector.
- Coal was disaggregated into bituminous, sub-bituminous, imported, lignite, coke, and other gas.

This disaggregation was done regionally, based on 1988 data from Statistics Canada 57-003. For the residential sector, it was assumed that all oil was light oil.

The results of these first two steps are provided in Exhibits B-6 through B-11, in Appendix B.

3. Converting electricity to primary energy

The major adjustment from secondary to primary energy is the conversion of electricity into various primary energy sources used, i.e. hydro, nuclear, and fossil fuels. Apart from this adjustment, the focus has been on the impacts of energy demand, and the energy supply industries are excluded from the analysis.

Electrical consumption was converted into region specific primary fuel shares, based on 1988 data from Statistics Canada (57-202 and 57-003). In keeping with the convention of constant fuel shares, it was assumed that conservation potential for electricity would be shared across fossil and non-fossil generation, in the proportion that these energy sources represented; in 1988 fossil fuels represented approximately 22%. The conversion to primary energy is based on fuel specific conversion efficiency based on the same Statistics Canada sources.

This conversion was made for each five-year interval to the year 2020. The results for the year 2020 are presented in Exhibits B-12 through B-16 in Appendix B.

B. Emission impacts

Exhibit X-1, **overleaf**, summarizes the results of transforming the primary energy conservation potential, discussed above, into emission impacts.

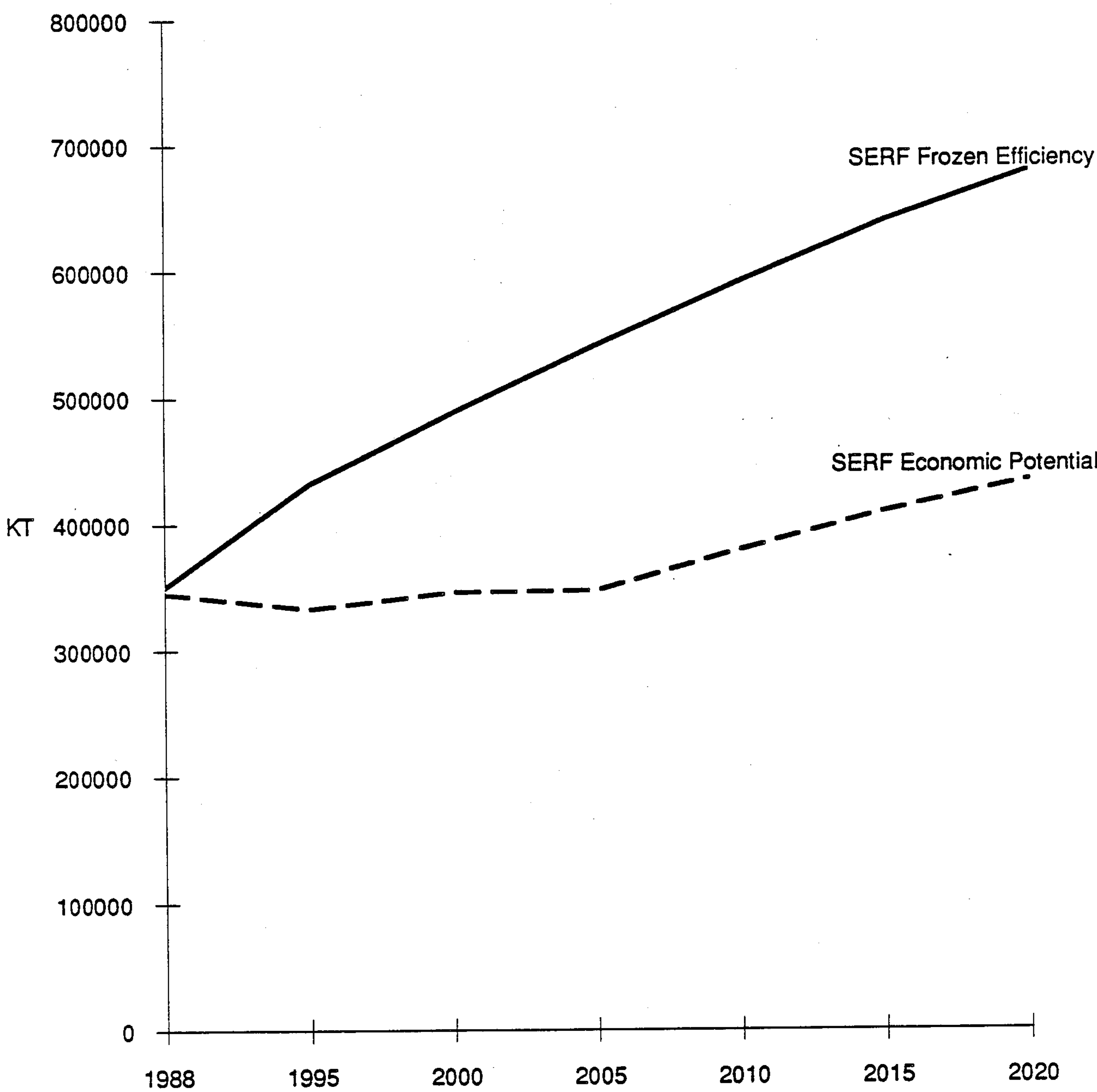
Exhibit X-1 provides results for carbon dioxide only. It is based on more detailed results, provided in Exhibits B-17 through B-21 in Appendix B.

C. Discussion of results

The estimates in this chapter represent a straightforward translation of the estimates of economically attractive potential into equivalent emissions. Thus, as is discussed in Chapter IX, they are subject to the constraints implicit in the estimates both of the level of economically attractive potential, as well as the specific method used to implement the concept of frozen efficiency. The assumptions of frozen fuel shares, both within the framework for generating estimates of economically attractive potential, and in the disaggregation of these estimates by electrical generation capacity, should also be considered. If, for example, an alternative view were taken—that efficiency potential would disproportionately reduce fossil fuel generation activity—the estimates of associated reductions in emissions would be increased accordingly.

Exhibit X-1

Carbon Dioxide Emissions — 1988-2020
Comparison of SERF Frozen Efficiency and Economic Potential Cases



XI

Barriers To Achieving Potential

One purpose of the case study process was to focus on barriers to achieving the economically attractive level of potential for energy efficiency. During the mid to late 1970s, and early 1980s, there was considerable discussion of and research into barriers to achieving socially optimal levels of energy conservation.

The focus of the barriers analysis in this study was not to redo or rethink these earlier analyses, but rather to seek to identify whether old barriers had lost their force, or new barriers had emerged in the intervening period.

A. The traditional view of barriers

Traditionally, the following categories of barriers have been identified as inhibiting socially effective investment in energy efficiency:

- The gap between private and social pricing, i.e., the difference between the prices, discount rates, and decision criteria appropriate for social benefit cost analysis, (which determine the socially optimal level of investment in energy efficiency), and the actual decision criteria and market signals faced by the decision makers who make these investments.
- Information barriers, i.e., insufficient information, which either makes investors unaware of opportunities for energy-related investments, or increases the perceived risks of these investments.
- Financing availability barriers, which prevent businesses from investing in capital projects.
- A concern that decision-makers evaluate energy efficiency investments using more stringent standards than other capital investments.

We comment more fully on these below, and make comments on possible new emerging barriers. Lastly, we make some sector-specific comments, based on the results of the case studies.

B. The private-social gap

1. The price gap

Many energy conservation programs in the 1970s were direct subsidies or incentives, intending to bridge the gap between the social valuation of energy conservation, and its private valuation. At that time, market prices were substantially below the estimated social opportunity cost of energy. Since decision makers in conservation investments were responding to private signals, they were not investing sufficiently, from the social perspective. Various forms of incentive were intended to frame the investment decision as though investors were facing the social opportunity cost of the energy being saved.

The gap between private prices faced by decision makers, and social opportunity costs for energy, have narrowed in recent years and, at times, may have even reversed signs.

In addition, at the direction of the Steering Committee, the energy prices used for estimating the social opportunity cost of energy saved through increased efficiency are in fact the current forecast of market prices. Therefore, using the definitions employed in this study, this private/social gap in energy prices essentially disappears, except to the extent that private decision makers may have different forecasts of future energy prices than are embodied in the EMR/EC Reference Case projections.

2. Other elements of the gap

However, there is a remaining private-social gap, which has to do with the bases for decision making. The definition of supply price which underlies this study is based on a net present value decision-making criterion, assuming social discount rates in real terms of 7%. It is clear that most private sector decision making, and most practical decision making in the public and not-for-profit sectors, is based on much more stringent evaluation criteria. Thus, there remains a substantial gap between the discount rates, pay back periods, and/or time horizons used by actual energy efficiency decision-makers, and those appropriate for social decision making.

These particular gaps are not specifically related to energy investments, although they also apply to energy efficiency investments.

3. Implications

Fundamentally, however, these gaps exist, and can generally be addressed by three methods:

- Various forms of subsidization, which place the private decision in a framework which leads to the same results as the social benefit/cost analyses.

- Where appropriate, the application of standards which impose higher efficiency requirements than the "market" would otherwise provide.

- In some cases, information programs, which essentially exhort investors to consider the public good and apply unique decision making criteria to energy efficiency investments.

C. Other types of barriers

A number of the other types of barriers described above are typical of technologies and types of investment in their early stages of development. It is generally agreed that, since energy became a concern in the early 1970s, information flows have increased, the technical and knowledge infrastructure has broadened, demonstration projects are generally in place, and the impact of these barriers has diminished over time.

On the other hand, it is clear that in the last few years, energy as an issue has fallen low on the list of priorities and concerns of most of those in a position to make energy efficiency investments, whether in the public or private sectors. It is not yet clear how much the events of recent months in the Middle East, and/or the increase in awareness of the energy/environment link, are raising energy's profile. The situation in which a number of major electrical generation utilities find themselves, has led to considerably increased emphasis on the conservation of electrical, and, to a lesser extent, natural gas energy. This is having a substantial impact on overall awareness of the issue.

D. Sector specific comments

There are a range of other barriers, identified in the case studies, which are particularly relevant to specific sectors or loci of analysis. We briefly outline some of these below.

1. International industries

Industries such as passenger vehicles and appliances are continental or even global in scope. Fundamentally, products are designed and manufactured to meet the needs of a market which is much broader than the Canadian market. Consequently, the energy-use characteristics of these goods are unlikely to be particularly sensitive to the Canadian environment. Reflecting this circumstance, in the appliance and light vehicle case studies, we assumed that all energy conservation measures would be adopted on a scale which is at least North American in size; this was intended to obtain realistic cost estimates. From the perspective of barriers, this assumption has a "flip side"; whatever impetus is provided to the adoption of economically attractive savings potential, it is unlikely to come from the Canadian market. While Canadian consumers and governments can make energy conservation choices from among the existing mix of products, it is not likely that either consumer purchasing power or government regulation will lead to the incorporation of energy efficiency standards which are not relevant to the broader markets within which such manufacturers operate.

2. Shortage of skilled trades

Our approach to the definition of economically achievable savings potential attempted to cost energy efficiency measures, in terms of design, materials and manufacturing costs required to incorporate them, marked up in an appropriate fashion to reflect distribution channel practices. Realistically, however, the magnitude of economically achievable efficiency potential in many cases dwarfs the capability of existing infrastructure. For example, there are limited numbers of trained construction and equipment trades to implement energy saving measures (1983 measures or EEH). From one perspective, this constraint means that we have underestimated the costs of implementing the efficiency measure. From a more practical perspective, however, it makes the point that, particularly in the retrofit areas where it is assumed that all potential currently exists, there are a number of constraints on people and other resources, which limit the rate at which potential could in fact be captured.

3. Split incentives

In the residential sector, and, more particularly in the commercial sector, the structure of the development, ownership and operation provides a pervasive environment of "split incentives." In the commercial sector, building developers focus on initial costs, at the expense of energy efficient building techniques and equipment. Under the net lease structure, heating and maintenance costs are passed on to the tenants, thus, further diluting the owners' incentive to invest in energy efficiency.

There may be similar split incentives at the level of single family residential homes, if homeowners do not believe that the resale market will capture the value of energy efficiency investments in the home, and therefore restrict themselves to investments with a shorter payback than their expected occupancy period.

It must be recognized that such split incentives are barriers not only to the achievement of the "social optimum" level of efficiency, but even to the achievement of the optimal level of energy efficiency, when viewed from the private financial perspective of the ultimate owners or tenants.

4. Mixed signals on the value of energy

There is still to some extent an "uneven playing field" for energy efficiency measures, in which there is no agreement as to the true social or even avoided costs of conventional fuels. Electrical utilities have historically been viewed as holding back on true avoided costs for either conserved or alternatively supplied energy. More recently, public policy-oriented Crown electric utilities have developed a desire to avoid some of the system expansion implications of growth in demand for energy (and particularly electricity) above the social optimum. However, it appears that there is still some distance to go before public utilities provide a set of both financial and other signals, which is consistent with the social cost of energy supply in Canada.

Appendix A

Background Information On The SERF Model

TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE 33, 311–323 (1988)

The Evolution of Socio-Economic Modeling in Canada

R. B. HOFFMAN and B. C. McINNIS

ABSTRACT

For the past 15 years the authors have been associated with a research program concerned with the development of structural economic models that had their origins in the input–output models of Leontief. This program has produced a set of conceptual tools embracing a new approach to socio-economic modeling which we term the "design approach." This approach draws on general systems theory and control theory in application to large social systems. Also emerging from this program as its test prototype is a particular set of models designed for society wide resource analysis and a set of software tools within which design approach models can be designed, implemented, and operated. The design approach provides a new method of assessing technologies in regard to their overall socio-economic resource impact. The objective of this paper is to describe the unique institutional setting and the particular issues which provided the setting and the motivation for embarking on a large scale modeling program. The paper is organized chronologically, describing first of all the evolution of the program approach, the software tools, the Socio-Economic Resource Framework (SERF), which is the prototype set of models that have been implemented, and some results obtained from it.

Origins

The structural model program had its origins in the Statistics Canada program of compiling input–output tables. With the completion of the first commodity-by-industry input–output table for Canada for the reference year 1961, a unit was established in Statistics Canada to implement models based on the input–output tables and to provide access to them on a client service basis. In 1973, this unit became the Structural Analysis Division, a research staff consisting of, on average, ten researchers with support staff.

The first generation of models developed by the Structural Analysis Division consisted of comparative static input–output models. To the national input–output model [9] was added a price propagation model, an interprovincial input-output model, and an energy component of the national input-output model. These models were used to perform comparative static and partial impact analyses: for example, the impact on employment and income of a major project or an export sale, the impact of oil price change on the consumer price index, the calculation of the energy embodied in a bill of final demand.

Two issues emerged during the decade of the 1970s which stimulated the development of time-structured input–output models: The energy supply shock originating from the OPEC Nations, and the industrial strategy debate in which the further fabrication of raw materials and the concurrent development of the manufacturing base were seen as the means of maintaining full employment in Canada.

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The Long Term Simulation Model (LTSM) developed in the period 1974–1976 was the response to these issues [5, 10]. The LTSM linked a population model to a final demand model which transformed the components of gross national expenditure by category of expenditure into demand for commodities in a top-down fashion. Final demand by commodity was passed to an input–output model which calculated industry activity levels. Import share coefficients were modifiable in order to assure an international trade balance on current account. Labor supply was calculated in the population model and labor requirements in the input–output model. Subsequently, a detailed residential energy model and a domestic appliance model were implemented both as stand-alone models and as submodels within the LTSM [5, 6].

From the experience of using the LTSM to support a series of studies, a number of provocative or counterintuitive results were indicated, which stimulated further model development work in order to substantiate them. For example:

- Employment was found to be insensitive to both the level and composition of foreign trade. This result countered the industrial strategy hypothesis that the model was intended to substantiate.
- The supply of labour tended to exceed requirements for labor in increasing amounts until at least the turn of the century. Four factors could be identified which led to this result: the passage of the baby boom cohort through prime labor force ages, increased female participation in the labor force, saturation in the demand for consumer durables, and the accumulation of increases in labor productivity.
- The growth and age structure of the population, taking its dynamics from the high birth rates of 1950–1965 followed by a steep decline to below replacement, in conjunction with stock/flow modeling of housing, indicated that the number of new houses required to maintain the stock at an appropriate level would halve by the year 2000.
- Future rates of growth of domestic energy demand were found to be significantly lower than those observed in the decades of the fifties, sixties, and early seventies. Furthermore, energy requirements were found not to be proportional to GNP.

The energy analysis work led to several conclusions with respect to the analysis of natural resources. Resource questions are clearly dynamic, involving the interaction of population, economic growth, and lifestyle change with the structure of production in general, and the resource-supplying sectors in particular. Over the longer term, it is the problem of transition from one resource base to another, or from one technological regime to another, and the time available for such transitions, which are paramount. Renewable resource questions are also dynamic, but hinge more on the issue of sustainable yield than the cycle of exploration, development, exploitation, and transition.

The experience of linking the stock/flow models of housing and appliances to demographic variables led to the conclusion that the interactions among stocks with different life profiles provides interesting insights into system dynamics.

National accounting and in particular input–output accounting make use of accounting identities in each time period. These identities equate the supply and disposition of each commodity and the inputs and outputs of each sector, and as such, they provide coherence to economic information. However, economic information has not been subject to stock/flow accounting over time. Once the accounting is in place to keep track of the vintages of stocks over time, it may then be interesting associate operating or use characteristics with vintages. It became clear that the representation of composition by means of the

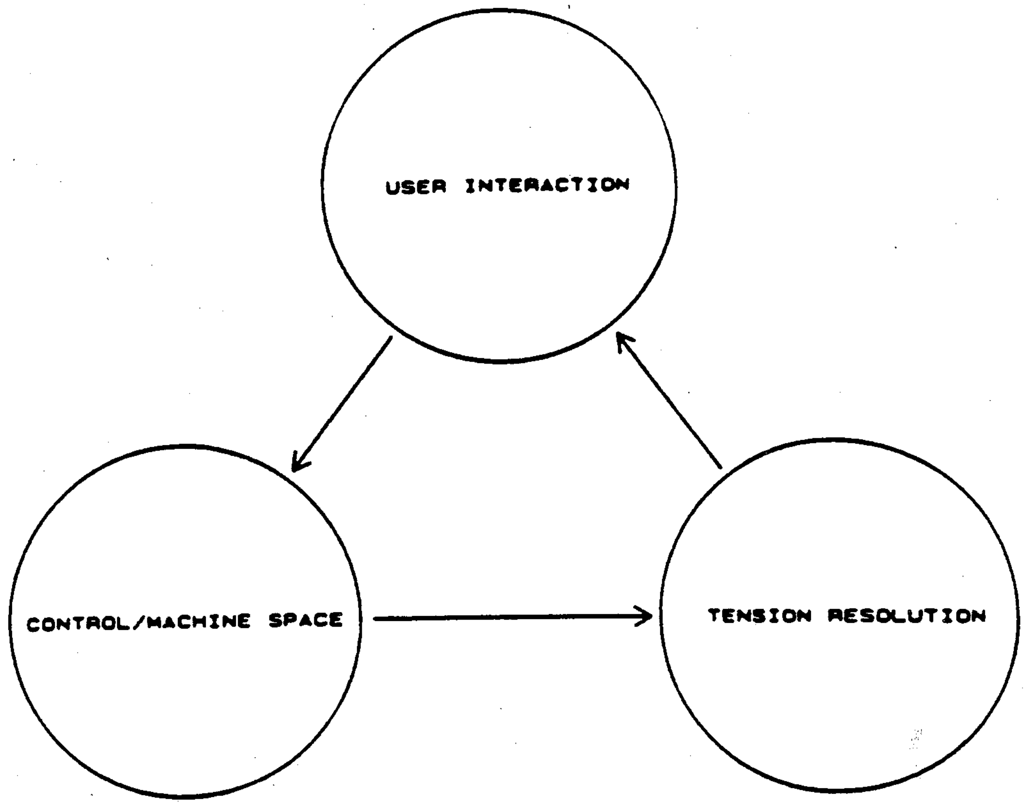

Fig. 1. The design approach.

disaggregation of variables whose linkage was at the macro-level could not adequately handle the stock/flow accounting. Consequently linkages must be made at the micro-level. This has lead to a preference for a bottom-up approach to modeling.

Finally, a great deal was learned with respect to the management of the design, documentation, implementation, and use of large-scale models. Modeling software has traditionally been oriented to the solution algorithm for solving problems, but for these new issues data management have become a more serious, if not the paramount, problem.

Work on the development of a new modeling framework, SERF, designed to incorporate the lessons learned from the LTSM experience commenced in 1982. The first version of SERF became available in 1983 as documented in the *Users Guide to the Socio-Economic Resource Framework* [10]. A second version of SERF became operational in 1987. It is documented in the SERF, Reference Manual [12] Version II.

The Design Approach

From the experience of the Structural Analysis Division in designing and implementing successive generations of input–output type models has emerged an approach to modeling, namely, the design approach.

There are three facets that distinguish the design approach: the interactive role of the user, the separation of physical transformation processes from decision processes, and the concept of tension (Figure 1).

In the design approach the user of the model is an integral part of the system (Figure 2). Here the concept of user extends to include the society he/she represents. The user explores possible future trajectories through simulation. Exploration is a learning process.

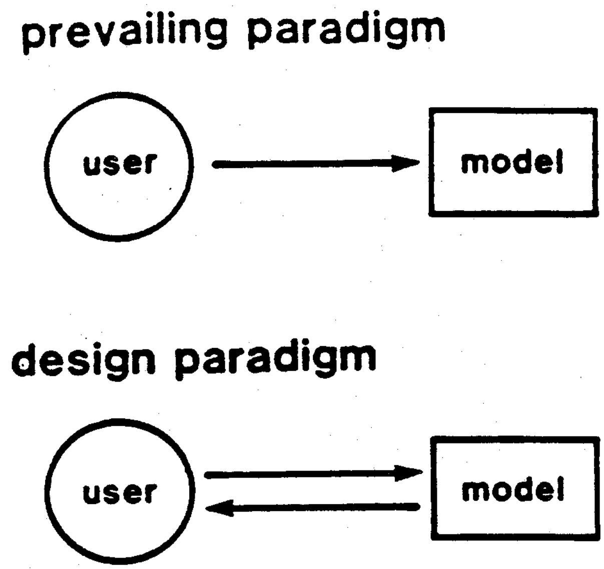

Fig. 2. Comparison of prevailing and design paradigms.

Thus the modeling system is open to the user who is the source of learning or novelty. Open systems have the interesting property that they can restructure themselves when they are far from equilibrium [7]. The restructuring that occurs at a singularity or bifurcation point is not predictable from past system behavior. Consequently, the future is in principle unknowable. This role of the user is in contrast to the macro-econometric paradigm that can be characterized above as applying Newtonian scientific principles that the observer (user) is outside the system and that once the laws of motion of the system are known, the entire trajectory of the system can be known as well. The concept of process is fundamental in the design approach. It is a dynamic concept concerned with the transformation of a stream of input flows into a stream of output flows. According to Capra [1], the concept of process is primary: The structure we observe is the manifestation of underlying processes. In order to understand structure, one must understand the processes that give rise to it.

The design approach distinguishes two kinds of processes: those that transform materials and energy; and those that transform information (Figure 3). The former constitute "machine space"; the latter "control space." Processes in machine space are subject to human influence or control. Some processes occur within human created environments or artifacts. In this case humans control the design and construction of the artifact as well as the operation of the process within it. Other processes occur in the natural environment; these are subject to human influence.

Human designed processes are overdetermined in terms of their control variables. This gives rise to the possibility that the individual processes or machines get out of sync. Tension is a measure of the extent to which the set of a machine are out of sync. Machines are coordinated through control space (Figure 4).

In the design approach the user of a model assures consistency among the machines that are represented in the modeling framework. This he does in one of two ways: Machines are run, and the values of tension variables are calculated. The user resolves tension to his satisfaction by resetting control variables (Figure 5a). This process can be automated by allowing the user to specify feedbacks from output variables back onto selected input or control variables (Figure 5b).

If there are models of decision processes in control space, the control variables are

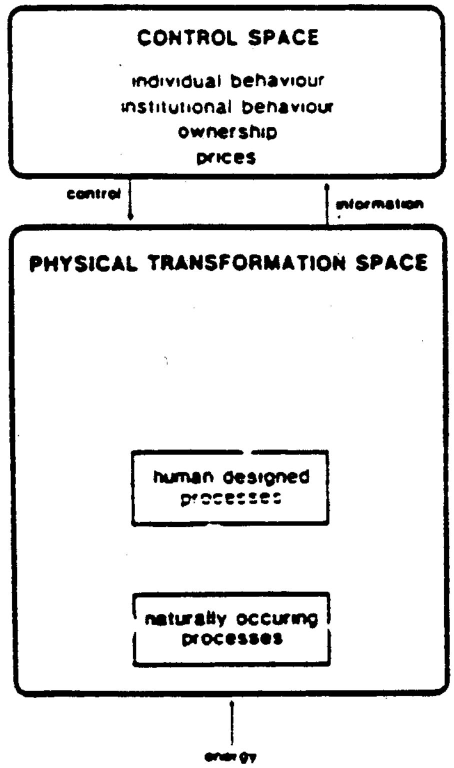

Fig. 3. Control space and machine space.

set according to those models. To the extent that tensions arise when the models that represent machines are executed, the user intervenes by changing the decision rules of the decision processes or by restructuring the control space models (Figure 5c). It is generally the case that there are many ways to resolve a particular tension, so that the model user has the opportunity to explore the various means of tension resolution. Note as well that what constitutes tension may well be subjective.

The design approach is thus an approach to modeling that makes the user or the society that he/she represents an integral part of the modeling system through tension resolution.

Software Tools

Both the scale of SERF and the features of the design approach present considerable challenges for software engineering. From the experience of developing SERF and its predecessors has emerged a number of strategies that have proven to be effective in the resolution of these problems. These strategies are now embodied in a set of software tools which are intended to support the design, documentation, and operation of large-

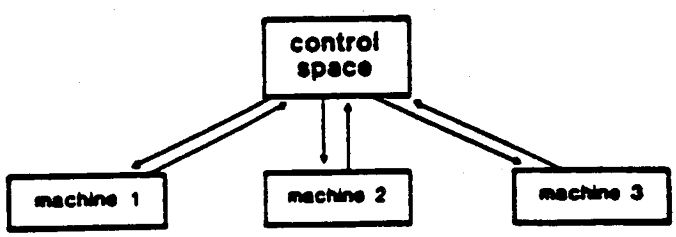

Fig. 4. Interaction between control and machine space.

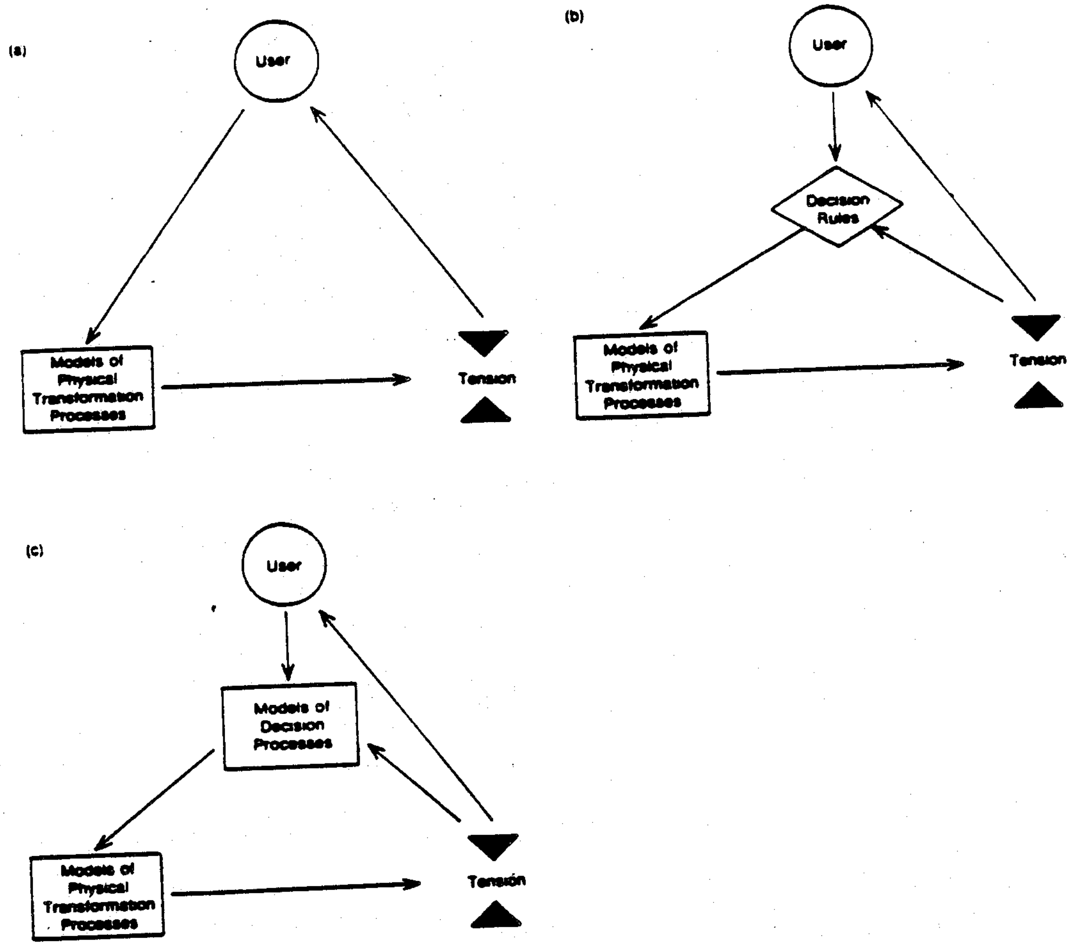

Fig. 5. Tension resolution.

scale models. These software tools consist of an interpreted, interactive, modeling language for managing and manipulating the variables and the relationships among them that constitute a model, and a system for scenario and model management.

The modeling language stores and manipulates multidimensional arrays. For example, "population" may be represented as a single variable where "population" is broken down by sex, age, location, and time. Thus the single variable "population" may contain a set of 2 (sexes) × 100 (age groups) × 10 provinces × 100 (years, 1900–2000) or 2×10^5 values. The description of the variable, "population," includes its name, the ranges of its dimensions and associated title sets, units in which it is measured, and the formula or equation that defines it. Clearly the variable "population" may have more than one set of values associated with it.

Data manipulation is accomplished by operating on multidimensional variables. The operators include the standard arithmetic operations of addition, subtraction, multiplication, and division, operators that change dimensionability such as aggregation, concatenation, extraction, and transposition, and operators that represent special functions such as interpolate, extrapolate. The modeling language is open-ended with respect to the introduction of new operators. It also provides facilities for displaying the values of variables in both tabular and graphic format and for inputting the values of variables from files and by digitizing graphical input.

The model management system provides the interface between models expressed in terms of language statements and the user of those models. It represents the structure of the models under its control and manages scenarios. Scenarios are the sets of the values of input variables that produce values of output variables that constitute an application of a model.

The model manager makes use of multipage diagrams with successive levels of detail to represent the structure of models. The diagramatic language separates symbols that represent variables or the objects to be manipulated by a model from the procedures or equations that represent the relationships among variables.

Variables are connected to procedures by relational flows, which indicate that a variable is input to a procedure or output of a procedure. These relational flows are visually distinct from procedural flows which connect procedures and show order of execution or flow of control. With each graphable object is associated text which constitute the labels on the object, and more detailed information describing the structure of the object and the meaning of the contents of the object.

The model manager facilitates the creation of diagrams through the use of function keys representing different objects. The set of predefined objects is expandable. Connections between objects are easily drawn. These connections are remembered so that diagrams can be redrawn as they are being edited. Menus are associated with object types that prompt for labeling information and for the text associated with each object.

At the lowest level in each diagram symbols representing variables correspond to the data structures and values manipulated by the modeling language and the symbols representing procedures corresponds to files of statements. Higher levels in the hierarchical structure of the diagram contain meta data that describe the meaning of scenarios and the structure of the model.

Creation of a scenario is accomplished by navigating through the hierarchy of multipage diagrams that represent the structure of the model. At each node in the hierarchy, the user can browse the meta data describing existing scenarios. At lowest level nodes the user can view the values of input variables that constitute a scenario or he can create new sets of values. Thus new scenarios can be created by mixing existing sets of input values and by creating new sets of values. The node manager keeps track of the set of input variable values that constitute a user's scenario and stores only unique values. Once a complete scenario has been defined values of output variables can be calculated. Only the code necessary to produce the output variables required need be executed. As well, only the subtrees whose input has been modified need be executed.

At each node in the hierarchy, the model user may enter text which describes the meaning of the scenario he is creating. This text along with graphs and tables of the values of variables form the basis for a document reporting the results of each analysis. Results comparing two or more scenarios can be obtained as well.

The Socio-Economic Resource Framework

SERF is intended for the analysis of issues involving the availability and disposition of human and natural resources, the transition from one resource base to another, the impact of technological change on employment and skills, and the impact of changing population composition on social infrastructure. These problems are characterized by compositional change, substitution and efficiency possibilities, and externalities.

SERF Version II consists exclusively of models of physical transformation processes in the "machine" space of the Canadian socio-economy. There are 43 independently executable models or calculators in all. It is convenient to use the concept of hierarchy for the purpose of exposition and management. The conceptual hierarchy is shown in

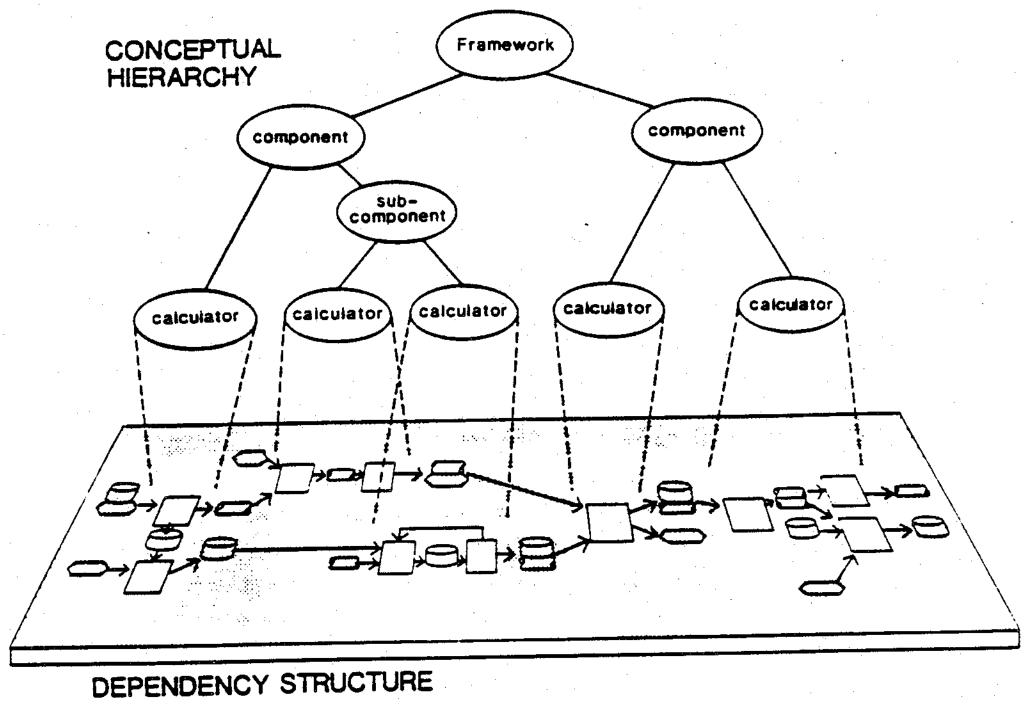

Fig. 6. Hierarchy and dependency.

Figure 6. In SERF Version II the calculators are grouped into 20 subcomponents which in turn are grouped into four components. The complete hierarchy is shown in Figure 7.

The four components and the major flows of information among them are shown in Figure 8. The demography component represents the basic demographic processes of population dynamics, household formation, and labor force participation. It keeps track of population by age and sex, families characterized by size and age, and the availability of labor by age and sex. Spatial distribution is represented as well. The control variables reflect decisions with respect to fertility, migration, family formation, and labor force participation.

The consumption component represents the infrastructure or stocks of goods that yield services required by human society. In general, it calculates the flows of goods, energy, and labor that is required to put infrastructure in place and to operate it. The consumption component keeps track of dwellings, consumer goods, hospitals, schools, motor vehicles, highways, airports, railroads, port facilities, hotels, restaurants, department stores, banks, recreational and cultural facilities. It is clear that the consumption component does not correspond to "consumption" according to national accounting definitions. The emphasis here is on the availability of stock, not on the measurement of the value of the flow. The control variables reflect decisions to put infrastructure in place. By having the consumption component follow the demography component, these decisions can take the form of parameters that reflect accessibility or intensity of use per capita or per family. In this way consistency between population and infrastructure can be assured. It is clear that the models in the consumption component are dominated by stock/flow accounting and, as such, are analogous to population accounting. For goods with short lives the stock/flow models become their flow equivalents.

The fabrication and assembly component represents the processes that transform materials and primary energy into finished goods that are required by both the consumption and material resources components. It keeps track of the stock of productive capacity

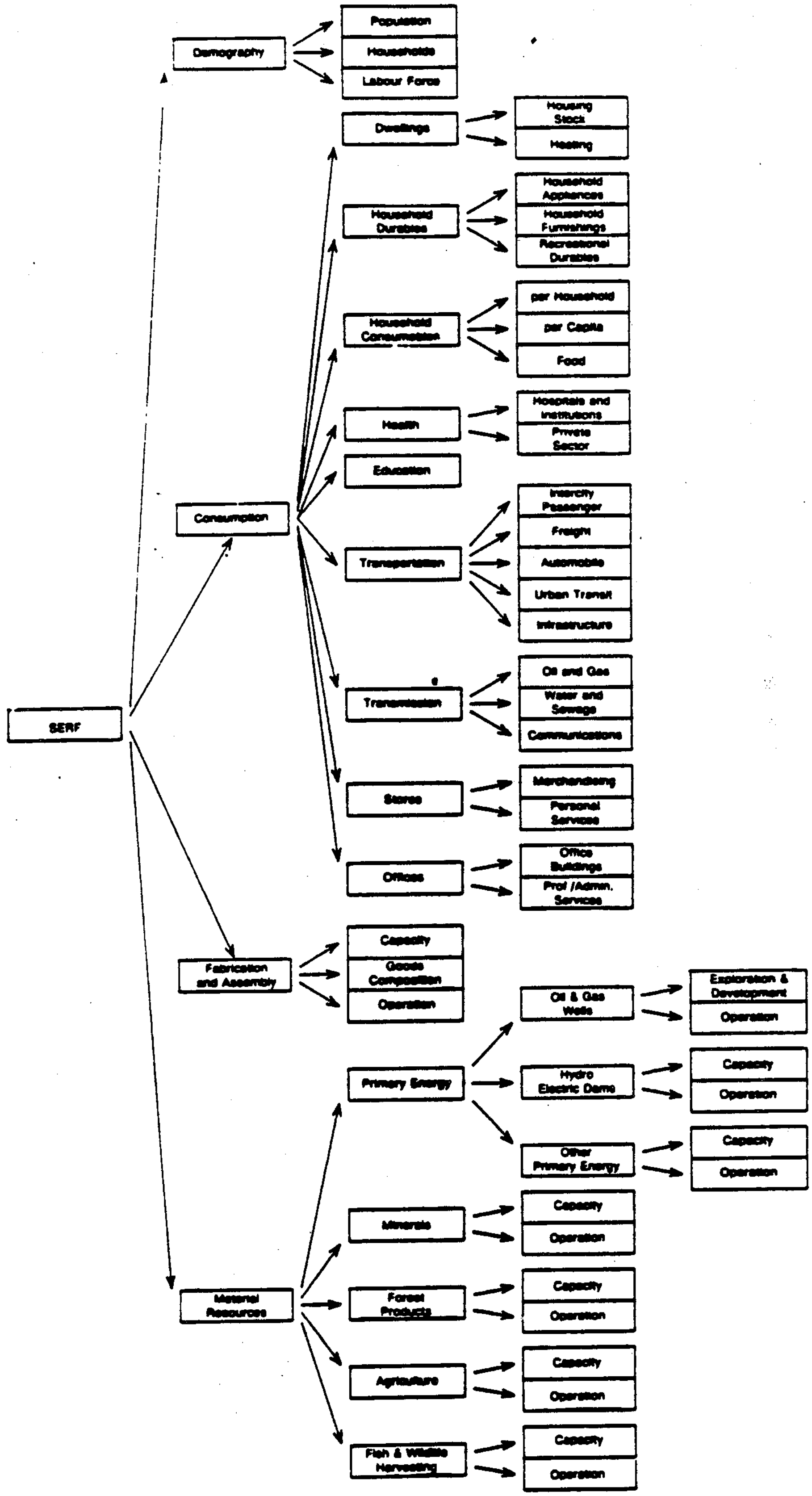

Fig. 7. SERF conceptual hierarchy.

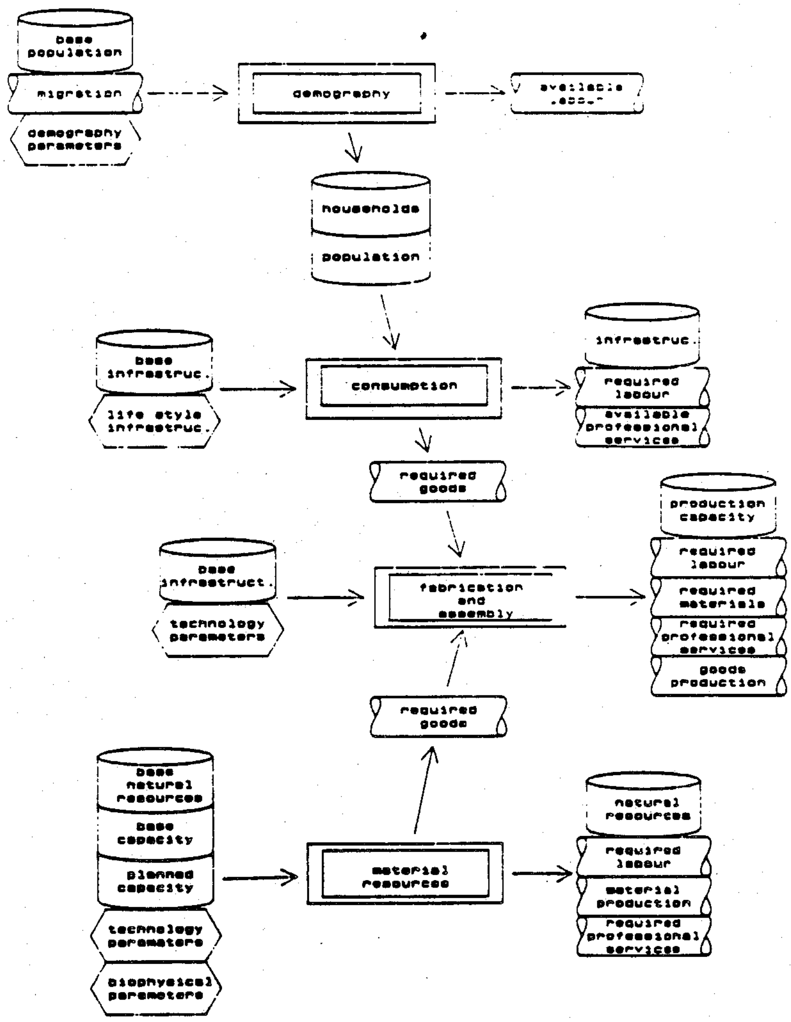

Fig. 8. SERF dependency structure.

and the investment required to maintain capacity at desired levels. An input–output model that distinguishes 200 sectors and 500 commodities is used to represent goods production. The fabrication and assembly component requires raw materials and primary energy from the material resources component, professional services from the consumption component, and labor from the demographic component.

The material resources component represents the activities of exploration, extraction, and refining of nonrenewable resources—coal, oil, gas, metals, and nonmetallic minerals—and those of managing and harvesting renewable resources—livestock, crops, forest products, and fish. It also includes the generation of electricity from hydro sites. This component shares many design features with the production component. Note that the boundary between material resources and the fabrication and assembly components is arbitrary and is chosen to portray the tension between the availability of raw materials and the requirements for them. The material resources component also keeps track of the availability of resources to the extent that it is known. Additions to the stock of "producible reserves" of nonrenewable resources are the result of exploration activity; withdrawals, the result of extraction activity. For renewable resources such as forestry, additions are the result of growth which may be enhanced by forest management activities, but may be retarded by pollutants that are the result of human activity. Land use and the evolution of land characteristics such as soil quantity and quality are accounted for in this component.

The information flows among the four components of SERF, or the dependency structure, have been designed to highlight three sets of tensions. These include tensions between:

- The availability of labor in the demographic component and the use of labor in the consumption, the material resources, and the fabrication and assembly components.
- The availability of materials and primary energy in the material resources component and their use in both the fabrication and assembly and material resources components.
- The availability of professional services in the consumption component and their use in the consumption, material resources, and fabrication and assembly components.

These are by no means the only tensions identifiable with SERF. For example, there is also tension:

- In the exchange of domestically produced materials, goods, and services for those produced in other countries.
- Between the stock of productive capacity and its utilization.
- Between exploration activity which yields producible reserves and extraction from these reserves.

In the absence of models of decision processes in "control space," tension resolution is achieved by user intervention. Facilities have been put in place to incorporate user defined feedback structures.

SERF Version II is large in scale and rich in compositional detail. It consists of about 2000 multidimensional variables that are equivalent to about 400,000 times series. These variables represent vintaged stocks such as houses, infrastructure facilities, consumer durables, and vehicle stocks, and as well the 500 goods and 200 activities of the input–output tables for Canada.

Most components in SERF are national in scope and recognize no spatial distribution of activities within these boundaries. A number of subcomponents, including population and dwellings, are implemented using provincial or regional geography. In principle, subcomponents can be represented at any meaningful spatial scale, for example, basins for oil and gas activities.

The time horizon for SERF is relatively long term, from 30 to 50 years. It is a time horizon that long is required to analyze decisions that must be made in the near future that involve investments in facilities that have useful lives of 20 or more years.

The time step of one year is common to all components in SERF. Short term phenomena such as seasonal changes or business cycles are not addressed. The structure of SERF makes it possible to have different time steps for each component provided that communication among components occurs at one-year time intervals.

Application

This section of the paper briefly describes a series of simulations that were performed in order to analyze the availability and disposition labor in Canada over the longer term

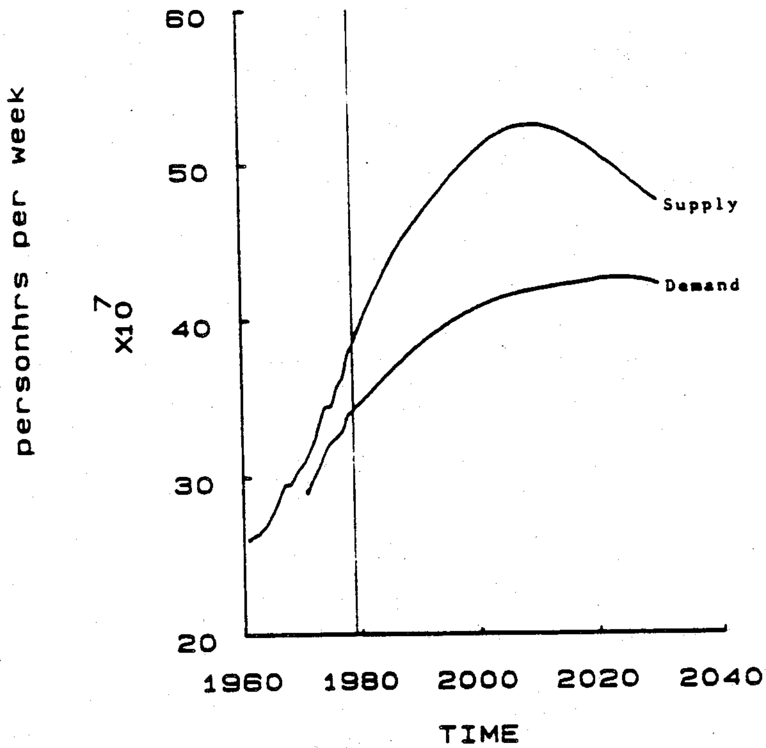

Fig. 9. Labor service supply and demand reference simulation.

particularly with respect to the impact on youth unemployment [8]. The simulations were designed to identify the major factors that determine labor availability and disposition and to test the sensibility of results to changes in them. Note that SERF distinguishes two concepts with respect to the measurement of labor. The first is a flow concept measured in units of labor per unit of time, usually person hours per week; the second is a stock concept measured in numbers of people at a point in time. The stock concept is used in the familiar measures of unemployment. The relationship between the stock and flow concepts is not fixed.

The simulations focused on the tension between the availability of labor and the requirements for it. This tension is expressed in terms of the flow concept; accordingly it should not be equated with unemployment. Figure 9 characterizes the results of the simulation in terms of the tension. The results of the analysis are described as follows.

The most general results of this analysis would seem to be that the combination of demographic changes, saturation effects, and increases in productivity are likely, under most of the conditions projected here, to substantially increase unemployment until some time after the turn of the century. The two most promising strategies for reducing unemployment (other than decreased productivity) would seem to be a shorter average work week or substantial increases in consumption of nondurable goods. However, the former could simply represent another version of increased unemployment (i.e., a smaller fulltime work force creating a shorter *average* work week) unless significant job-sharing were to occur. Either version of a shorter work week raises significant distributional issues.

It is important to reemphasize here the nonpredictive nature of this analysis. Most of the scenarios and variants shown here indicate a labor service tension that is approaching 20% by the end of this century. Clearly one could expect significant social and institutional changes to occur before such values would be reached. This analysis, therefore, by no means predicts the future. Instead it suggests the existence of certain trends and relationships that must be taken account of in our attempts to create a desirable future.

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Received 25 June 1987.

Appendix B

Statistical Annex

Exhibit B-1

Residential Energy Use* by Fuel and by Scenario (petajoules)

	Oil	Natural Gas	Electricity	Other	Total
1988					
SERF-FE	196.3	557.3	465.8	39.1	1,258.5
SERF-EP	171.8	500.9	447.7	39.1	1,159.5
EMR/EC	203.1	534.6	446.8	39.0	1,223.5
Savings(FE-EP)	24.5	56.4	18.1	0.0	99.0
1995					
SERF-FE	195.8	603.4	531.8	59.9	1,390.9
SERF-EP	98.2	405.3	422.7	59.8	986.0
EMR/EC	167.7	613.1	490.7	40.4	1,311.9
Savings(FE-EP)	97.6	198.1	109.1	0.0	404.8
2000					
SERF-FE	195.0	632.7	574.3	72.9	1,474.9
SERF-EP	90.3	387.8	423.7	73.0	974.8
EMR/EC	144.0	628.6	535.4	41.0	1,349.0
Savings(FE-EP)	104.7	244.9	150.6	0.0	500.2
2005					
SERF-FE	194.1	661.3	618.4	83.4	1,557.2
SERF-EP	88.7	398.6	448.8	83.4	1,019.5
EMR/EC	134.1	641.0	593.6	41.8	1,410.5
Savings(FE-EP)	105.4	262.7	169.6	0.0	537.7
2010					
SERF-FE	193.0	688.7	661.5	93.0	1,636.1
SERF-EP	87.8	411.6	478.4	93.1	1,070.9
EMR/EC	131.4	656.5	646.3	42.7	1,476.9
Savings(FE-EP)	105.2	277.1	183.1	0.0	565.4
2015					
SERF-FE	190.9	712.4	700.2	101.3	1,704.9
SERF-EP	86.8	422.7	505.8	101.3	1,116.5
EMR/EC	N/A	N/A	N/A	N/A	N/A
Savings(FE-EP)	104.1	289.7	194.4	0.0	588.2
2020					
SERF-FE	186.6	730.7	732.4	109.7	1,759.4
SERF-EP	85.4	430.9	528.8	109.7	1,154.8
EMR/EC	138.2	708.8	747.8	45.8	1,640.6
Savings(FE-EP)	101.2	299.8	203.6	0.0	604.6

* excludes biomass

Exhibit B-2

Commercial Energy Use by Fuel and by Scenario (petajoules)

	Oil	Natural Gas	Electricity	Other	Total
1995					
SERF-FE	112.3	365.0	351.0	26.6	854.9
SERF-EP	112.3	365.0	351.0	26.6	854.9
EMR/EC*	111.6	361.8	357.1	16.9	847.4
Savings(FE-EP)	0.0	0.0	0.0	0.0	0.0
1995					
SERF-FE	138.5	434.2	431.7	33.4	1,037.8
SERF-EP	93.5	362.8	334.9	33.3	824.5
EMR/EC*	116.1	422.0	452.3	20.6	1,011.0
Savings(FE-EP)	45.0	71.4	96.8	0.0	213.2
2000					
SERF-FE	153.6	490.5	489.6	37.8	1,171.4
SERF-EP	73.5	339.8	299.7	37.8	750.9
EMR/EC*	129.5	437.0	522.6	24.5	1,113.6
Savings(FE-EP)	80.1	150.7	189.9	0.0	420.7
2005					
SERF-FE	166.7	539.7	548.1	42.2	1,296.7
SERF-EP	80.3	376.1	336.2	42.1	834.7
EMR/EC*	149.3	462.1	593.7	26.9	1,232.0
Savings(FE-EP)	86.4	163.6	211.9	0.0	461.9
2010					
SERF-FE	179.1	589.9	609.8	46.5	1,425.3
SERF-EP	86.7	412.1	372.6	46.6	918.0
EMR/EC*	163.5	494.5	640.0	27.8	1,325.8
Savings(FE-EP)	92.4	177.8	237.2	0.0	507.4
2015					
SERF-FE	192.1	643.4	676.4	50.9	1562.8
SERF-EP	93.2	449.7	409.7	50.8	1,003.4
EMR/EC*	N/A	N/A	N/A	N/A	N/A
Savings(FE-EP)	98.9	193.7	266.7	0.0	559.3
2020					
SERF-FE	205.5	700.9	749.8	55.0	1,711.2
SERF-EP	99.9	488.3	447.2	54.9	1,090.3
EMR/EC*	193.5	594.8	758.7	30.9	1,577.9
Savings(FE-EP)	105.6	212.6	302.6	0.0	620.8

* includes street lighting

Exhibit B-3

Industrial Energy Use* by Fuel and by Scenario (petajoules)

	Oil	Natural Gas	Electricity	Other	Total
1988					
SERF-FE	323.2	730.3	707.9	231.9	1,993.3
SERF-EP	323.2	730.0	707.8	232.2	1,993.2
EMR/EC	325.4	700.5	709.8	275.8	2,011.5
Savings(FE-EP)	0.0	0.3	0.1	-0.3	0.1
1995					
SERF-FE	396.3	891.1	857.5	282.8	2,427.7
SERF-EP	325.7	886.6	774.6	231.5	2,218.4
EMR/EC	313.4	893.2	867.5	299.9	2,374.0
Savings(FE-EP)	70.6	4.5	82.9	50.0	208.0
2000					
SERF-FE	440.5	1,005.4	966.3	318.2	2,730.4
SERF-EP	316.0	977.8	807.2	241.0	2,342.0
EMR/EC	327.8	946.3	1,002.3	322.1	2,598.5
Savings(FE-EP)	124.5	7.6	159.1	95.6	386.8
2005					
SERF-FE	482.2	1,117.7	1,074.6	353.6	3,028.1
SERF-EP	297.5	618.5	823.9	201.7	1,941.6
EMR/EC	356.4	992.8	1,134.1	343.1	2,826.4
Savings(FE-EP)	184.7	499.2	250.7	150.0	1,084.6
2010					
SERF-FE	525.0	1,231.3	1,182.2	389.6	3,328.1
SERF-EP	322.9	683.2	906.3	222.5	2,134.9
EMR/EC	395.8	1,080.3	1,277.7	370.6	3,124.4
Savings(FE-EP)	202.1	548.1	275.9	165.1	1,191.2
2015					
SERF-FE	567.4	1,346.3	1,291.9	425.4	3,631.0
SERF-EP	347.8	748.4	990.3	243.1	2,329.6
EMR/EC	N/A	N/A	N/A	N/A	N/A
Savings(FE-EP)	219.6	597.9	301.6	180.2	1,299.3
2020					
SERF-FE	604.9	1,424.0	1,362.0	455.7	3,846.6
SERF-EP	370.0	797.1	1,044.5	260.4	2,472.0
EMR/EC	498.5	1,342.0	1,606.0	436.4	3,882.9
Savings(FE-EP)	234.9	626.9	317.5	193.1	1,372.4

* Excludes biomass

Exhibit B-4

Transportation Energy Use by Fuel and by Scenario (petajoules)

	Natural Gas	LPG'S	Motor Gasoline	Other	Total
1988					
SERF-FE	0.0	29.2	1,286.5	741.3	2,057.0
SERF-EP	0.0	29.2	1,286.5	741.3	2,057.0
EMR/EC*	2.9	24.6	1,177.3	723.5	1,928.3
Savings(FE-EP)	0.0	0.0	0.0	0.0	0.0
1995					
SERF-FE	0.0	68.7	1,597.2	1,038.1	2,704.0
SERF-EP	0.0	42.5	1,033.1	838.0	1,913.6
EMR/EC*	5.6	30.3	1,240.8	867.9	2,144.6
Savings(FE-EP)	0.0	26.2	564.1	200.1	790.4
2000					
SERF-FE	0.0	81.8	1,831.9	1,239.0	3,152.7
SERF-EP	0.0	46.5	1,095.9	963.3	2,105.7
EMR/EC*	6.7	33.6	1,328.2	922.8	2,291.3
Savings(FE-EP)	0.0	35.3	736.0	275.7	1,047.0
2005					
SERF-FE	0.0	92.2	2,061.9	1,409.6	3,563.7
SERF-EP	0.0	52.3	1,232.9	1,076.4	2,361.6
EMR/EC*	8.7	36.4	1,415.9	987.8	2,448.8
Savings(FE-EP)	0.0	39.9	829.0	333.2	1,202.1
2010					
SERF-FE	0.0	102.2	2,283.1	1,548.2	3,933.5
SERF-EP	0.0	57.9	1,366.0	1,171.9	2,595.8
EMR/EC*	11.2	38.8	1,526.6	1,073.7	2,650.3
Savings(FE-EP)	0.0	44.3	917.1	376.3	1,337.7
2015					
SERF-FE	0.0	112.0	2,487.3	1,660.0	4,259.3
SERF-EP	0.0	63.5	1,487.8	1,254.4	2,805.7
EMR/EC*	N/A	N/A	N/A	N/A	N/A
Savings(FE-EP)	0.0	48.5	999.5	405.6	1,453.6
2020					
SERF-FE	0.0	121.4	2,680.6	1,737.5	4,539.5
SERF-EP	0.0	68.9	1,602.1	1,315.0	2,986.0
EMR/EC*	14.8	44.4	1,808.6	1,288.9	3,156.7
Savings(FE-EP)	0.0	52.5	1,078.5	422.5	1,553.5

* Includes farm motor gasoline, farm diesel and commercial aviation fuel

Exhibit B-5

Secondary Energy Use* by Fuel and by Scenario (petajoules)

	Oil	Natural Gas	Electricity	Other	Total
1988					
SERF-FE	2,470.3	1,652.6	1,524.7	516.0	6,163.6
SERF-EP	2,445.8	1,595.9	1,506.5	516.3	6,064.5
EMR/EC	2,542.9	1,599.3	1,513.8	357.7	6,013.7
Savings(FE-EP)	24.5	56.7	18.2	-0.3	99.1
1995					
SERF-FE	3,153.9	1,928.7	1,821.0	656.7	7,560.3
SERF-EP	2,201.3	1,654.7	1,532.2	554.3	5,942.5
EMR/EC	2,707.9	1,933.7	1,810.5	389.3	6,841.4
Savings(FE-EP)	952.6	274.0	288.8	102.4	1,617.8
2000					
SERF-FE	3,614.5	2,128.6	2,030.2	756.2	8,529.5
SERF-EP	2,341.7	1,725.4	1,530.6	575.7	6,173.4
EMR/EC	2,852.3	2,018.6	2,060.3	421.2	7,352.4
Savings(FE-EP)	1,272.8	403.2	499.6	180.5	2,356.1
2005					
SERF-FE	4,032.2	2,318.7	2,241.1	853.7	9,445.7
SERF-EP	2,564.1	1,393.2	1,608.9	581.3	6,147.5
EMR/EC	3,043.6	2,104.6	2,321.4	448.1	7,917.7
Savings(FE-EP)	1,468.1	925.5	632.2	272.4	3,298.2
2010					
SERF-FE	4,408.8	2,509.9	2,453.5	950.8	10,323.0
SERF-EP	2,805.4	1,506.9	1,757.3	649.9	6,719.5
EMR/EC	3,291.0	2,242.5	2,551.4	492.8	8,577.7
Savings(FE-EP)	1,603.4	1,003.0	696.2	300.9	3,603.5
2015					
SERF-FE	4,743.1	2,702.1	2,668.5	1,044.1	11,157.8
SERF-EP	3,019.2	1,620.8	1,905.8	709.5	7,255.3
EMR/EC	N/A	N/A	N/A	N/A	N/A
Savings(FE-EP)	1,723.9	1,081.3	762.7	334.6	3,902.5
2020					
SERF-FE	5,032.1	2,855.6	2,844.2	1,124.9	11,856.8
SERF-EP	3,201.9	1,716.3	2,020.5	764.3	7,703.0
EMR/EC	3,927.5	2,660.6	3,112.5	557.5	10,258.1
Savings(FE-EP)	1,830.2	1,139.3	823.7	360.6	4,153.8

* Excludes biomass

Exhibit B-6

TOTAL SECONDARY ENERGY ECONOMIC POTENTIAL - 1995
BREAKDOWN BY ENERGY TYPE AND BY REGION (PJ)

	REGIONS					
ENERGY TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
OIL	64.30	91.90	119.97	60.47	51.85	388.48
NATURAL GAS	1.05	17.81	113.68	108.27	33.19	274.00
COAL	0.03	4.11	44.95	0.81	0.00	49.90
ELECTRICITY	23.95	103.79	96.35	33.90	30.81	288.80
GASOLINE	43.58	106.63	225.07	122.73	66.09	564.10
AVIATION FUEL	1.89	5.53	8.68	4.19	4.42	24.70
NGL's	0.29	1.47	11.24	8.55	4.64	26.20
TOTAL ENERGY	135.08	331.24	619.94	338.92	191.01	1,616.19

Exhibit B-7

TOTAL SECONDARY ENERGY ECONOMIC POTENTIAL - 2000
BREAKDOWN BY ENERGY TYPE AND BY REGION (PJ)

	REGIONS					
ENERGY TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
OIL	89.41	127.73	162.83	84.81	72.01	536.78
NATURAL GAS	1.95	31.79	157.84	160.81	50.80	403.20
COAL	0.06	7.85	85.94	1.56	0.00	95.41
ELECTRICITY	40.89	177.89	167.16	59.96	53.70	499.60
GASOLINE	56.86	139.13	293.65	160.13	86.23	736.00
AVIATION FUEL	3.68	10.79	16.94	8.17	8.62	48.20
NGL's	0.39	1.98	15.15	11.53	6.26	35.30
TOTAL ENERGY	193.25	497.16	899.51	486.96	277.62	2,354.49

Exhibit B-8
TOTAL SECONDARY ENERGY ECONOMIC POTENTIAL - 2005
BREAKDOWN BY ENERGY TYPE AND BY REGION (PJ)

	REGIONS					
ENERGY TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
OIL	105.97	152.39	188.82	104.75	87.15	639.08
NATURAL GAS	2.12	115.11	376.78	319.09	112.40	925.50
COAL	0.09	12.32	134.85	2.44	0.00	149.70
ELECTRICITY	50.92	230.72	207.15	75.25	68.17	632.20
GASOLINE	64.05	156.71	330.76	180.37	97.12	829.00
AVIATION FUEL	5.40	15.83	24.85	11.98	12.65	70.70
NGL's	0.44	2.23	17.12	13.03	7.07	39.90
TOTAL ENERGY	228.98	685.30	1,280.32	706.91	384.56	3,286.08

Exhibit B-9

TOTAL SECONDARY ENERGY ECONOMIC POTENTIAL - 2010
BREAKDOWN BY ENERGY TYPE AND BY REGION (PJ)

	REGIONS					
ENERGY TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
OIL	113.36	163.60	201.54	113.40	94.38	686.28
NATURAL GAS	2.29	125.75	407.89	345.19	121.89	1,003.00
COAL	0.10	13.56	148.42	2.69	0.00	164.77
ELECTRICITY	56.04	253.65	228.36	83.05	75.11	696.20
GASOLINE	70.85	173.36	365.91	199.54	107.44	917.10
AVIATION FUEL	6.86	20.10	31.56	15.22	16.06	89.80
NGL's	0.49	2.48	19.01	14.46	7.85	44.30
TOTAL ENERGY	249.99	752.50	1,402.69	773.54	422.73	3,601.45

Exhibit B-10

TOTAL SECONDARY ENERGY ECONOMIC POTENTIAL - 2015
BREAKDOWN BY ENERGY TYPE AND BY REGION (PJ)

	REGIONS					
ENERGY TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
OIL	119.70	172.93	211.60	120.02	100.13	724.38
NATURAL GAS	2.47	136.74	438.98	371.57	131.55	1,081.30
COAL	0.11	14.80	162.00	2.93	0.00	179.84
ELECTRICITY	61.35	277.09	250.61	91.30	82.34	762.70
GASOLINE	77.22	188.94	398.78	217.46	117.10	999.50
AVIATION FUEL	7.93	23.24	36.48	17.59	18.57	103.80
NGL's	0.54	2.71	20.81	15.84	8.60	48.50
TOTAL ENERGY	269.31	816.45	1,519.27	836.72	458.28	3,900.02

Exhibit B-11

TOTAL SECONDARY ENERGY ECONOMIC POTENTIAL - 2020
BREAKDOWN BY ENERGY TYPE AND BY REGION (PJ)

	REGIONS					
ENERGY TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
OIL	124.58	179.96	218.45	124.32	104.37	751.68
NATURAL GAS	2.69	144.69	460.92	392.07	138.94	1,139.30
COAL	0.12	15.86	173.60	3.14	0.00	192.71
ELECTRICITY	66.31	297.24	271.97	99.18	88.99	823.70
GASOLINE	83.32	203.87	430.30	234.65	126.35	1,078.50
AVIATION FUEL	8.58	25.16	39.50	19.05	20.11	112.40
NGL's	0.58	2.94	22.53	17.14	9.31	52.50
TOTAL ENERGY	286.19	869.71	1,617.27	889.56	488.07	4,150.80

Exhibit B-12
TOTAL PRIMARY ENERGY ECONOMIC POTENTIAL - 2020
BREAKDOWN BY FUEL TYPE AND BY REGION (PJ)

FUEL TYPES	REGIONS Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
Fuel Oil						
-Light	50.9	60.0	82.7	12.0	19.2	224.9
-Heavy	64.4	57.8	38.4	11.6	28.9	201.1
-Diesel	34.0	61.3	92.8	83.8	60.0	331.8
Gasoline	83.3	203.9	430.3	234.7	126.4	1,078.5
Aviation Fuel	8.6	25.2	39.5	19.0	20.1	112.4
Natural Gas	2.7	144.7	460.9	407.5	146.6	1,162.4
NGL (Propane)	0.6	2.9	22.5	17.1	9.3	52.5
Coal						
-Bituminous	17.0	0.0	42.0	4.3	0.0	63.3
-Imported	0.0	14.0	143.0	0.0	0.0	157.1
-Sub-Bitum.	0.0	0.0	0.0	147.5	0.0	147.5
-Lignite	0.0	0.0	21.0	55.7	0.0	76.7
Coke & Coke Oven Gas	0.1	1.8	154.0	0.0	0.0	155.9
Petroleum Coke	0.8	3.3	7.9	17.2	0.8	30.0
Total Fossil Fuel	262.4	574.9	1,535.2	1,010.4	411.3	3,794.1
Nuclear & Hydro	50.9	296.5	201.7	26.1	85.3	660.5
TOTAL ENERGY	313.3	871.4	1736.9	1036.5	496.5	4454.6

Exhibit B-13

RESIDENTIAL PRIMARY ENERGY CONSERVATION POTENTIAL - 2020 BREAKDOWN BY FUEL TYPE AND BY REGION (PJ)

FUEL TYPES	REGIONS					Canada
	Atlantic	Quebec	Ontario	Prairies	B.C.	
Fuel Oil						
-Light	22.5	26.8	38.5	4.7	9.0	101.5
-Heavy	7.0	0.6	0.6	0.0	0.0	8.3
-Diesel	0.1	0.0	0.0	0.0	1.0	1.2
Natural Gas	0.4	9.5	140.7	119.3	34.7	304.6
Coal						
-Bituminous	6.3	0.0	9.4	0.8	0.0	16.6
-Imported	0.0	0.0	32.1	0.0	0.0	32.1
-Sub-Bitum.	0.0	0.0	0.0	28.9	0.0	28.9
-Lignite	0.0	0.0	4.4	10.9	0.0	15.3
Total Fossil Fuel	36.4	36.9	225.7	164.7	44.7	508.5
Nuclear & Hydro	13.8	77.5	49.7	5.2	19.6	165.8
TOTAL ENERGY	50.3	114.4	275.4	169.9	64.3	674.3

Exhibit B-14
COMMERCIAL PRIMARY ENERGY CONSERVATION POTENTIAL - 2020 BREAKDOWN BY FUEL TYPE AND BY REGION (PJ)

FUEL TYPES	REGIONS					Canada
	Atlantic	Quebec	Ontario	Prairies	B.C.	
Fuel Oil						
-Light	23.5	28.0	40.3	4.9	9.4	106.1
-Heavy	9.5	0.6	1.1	0.0	0.0	11.2
-Diesel	0.2	0.0	0.0	0.1	1.7	2.0
Natural Gas	2.2	32.1	56.0	96.6	35.3	222.3
Coal						
-Bituminous	3.1	0.0	16.5	1.9	0.0	21.5
-Imported	0.0	0.0	56.4	0.0	0.0	56.4
-Sub-Bitum.	0.0	0.0	0.0	64.3	0.0	64.3
-Lignite	0.0	0.0	7.7	24.2	0.0	31.9
Total Fossil Fuel	38.5	60.8	178.0	192.0	46.4	515.7
Nuclear & Hydro	20.6	82.1	87.3	11.6	32.1	233.6
TOTAL ENERGY	59.1	142.9	265.3	203.6	78.5	749.4

Exhibit B-15
TRANSPORTATION PRIMARY ENERGY CONSERVATION POTENTIAL - 2020
BREAKDOWN BY FUEL TYPE AND BY REGION (PJ)

FUEL TYPES	REGIONS					Canada
	Atlantic	Quebec	Ontario	Prairies	B.C.	
Fuel Oil						
-Light	0.0	0.0	0.0	0.0	0.0	0.0
-Heavy	8.1	12.2	6.9	0.0	10.3	37.5
-Diesel Rail	3.7	6.9	19.0	25.6	9.6	64.9
-Diesel Marine	13.7	4.8	5.0	0.2	11.2	34.8
-Diesel Road	10.8	41.1	57.1	42.1	21.7	172.8
Gasoline	83.3	203.9	430.3	234.7	126.4	1,078.5
Aviation Fuel	8.6	25.2	39.5	19.0	20.1	112.4
Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0
NGL (Propane)	0.6	2.9	22.5	17.1	9.3	52.5
TOTAL ENERGY	128.8	297.0	580.3	338.7	208.5	1,553.4

Exhibit B-16
INDUSTRIAL PRIMARY ENERGY CONSERVATION POTENTIAL - 2020 BREAKDOWN BY FUEL TYPE AND BY REGION (PJ)

	REGIONS					
FUEL TYPES	Atlantic	Quebec	Ontario	Prairies	B.C.	Canada
Fuel Oil						
-Light	5.0	5.2	4.0	2.3	0.8	17.3
-Heavy	39.8	44.3	29.8	11.6	18.6	144.2
-Diesel	5.4	8.5	11.7	15.7	14.8	56.1
Natural Gas	0.0	103.0	264.2	191.7	76.6	635.5
Coal						
-Bituminous	7.6	0.0	16.1	1.6	0.0	25.2
-Imported	0.0	14.0	54.5	0.0	0.0	68.5
-Sub-Bitum.	0.0	0.0	0.0	54.2	0.0	54.2
-Lignite	0.0	0.0	8.8	20.6	0.0	29.4
Coke & Coke Oven Gas	0.1	1.8	154.0	0.0	0.0	155.9
Petroleum Coke	0.8	3.3	7.9	17.2	0.8	30.0
Total Fossil Fuel	58.7	180.1	551.1	315.0	111.6	1,216.4
Nuclear & Hydro	16.5	136.9	64.7	9.4	33.6	261.1
TOTAL ENERGY	75.1	317.0	615.8	324.3	145.2	1,477.5

Exhibit B-17

Residential Sector - Environmental Emissions* by Type and by Scenario - (kilotonnes)

	CO2	VOC	CH4	NOX	SO2	CO	NO
1988							
SERF-FE	57,164	2.2	1.8	41.5	220.2	8.2	0.1
SERF-EP	51,983	2.0	1.6	37.4	209.7	7.3	0.1
Savings(FE-EP)	5,181	0.2	0.2	4.1	10.5	0.9	0.0
1995							
SERF-FE	61,561	2.4	1.8	44.3	248.1	8.6	0.1
SERF-EP	41,043	1.6	1.1	28.7	190.4	5.3	0.1
Savings(FE-EP)	20,521	0.8	0.8	15.7	57.7	3.3	0.0
2000							
SERF-FE	64,338	2.5	1.9	46.1	266.0	8.9	0.1
SERF-EP	39,629	1.6	1.0	27.5	189.9	5.0	0.1
Savings(FE-EP)	24,713	0.9	0.9	18.6	76.1	3.8	0.0
2005							
SERF-FE	67,126	2.6	1.9	47.8	284.5	9.1	0.1
SERF-EP	40,863	1.6	1.0	28.2	200.4	5.1	0.1
Savings(FE-EP)	26,266	1.0	0.9	19.7	84.2	4.0	0.0
2010							
SERF-FE	69,806	2.7	1.9	49.5	302.7	9.4	0.1
SERF-EP	42,404	1.7	1.0	29.1	212.8	5.2	0.1
Savings(FE-EP)	27,405	1.1	0.9	20.4	89.9	4.1	0.0
2015							
SERF-FE	72,087	2.8	2.0	50.9	318.8	9.6	0.1
SERF-EP	43,773	1.8	1.0	29.8	224.3	5.3	0.1
Savings(FE-EP)	28,318	1.1	0.9	21.1	94.5	4.2	0.0
2020							
SERF-FE	73,728	2.9	2.0	51.9	331.9	9.7	0.1
SERF-EP	44,824	1.8	1.0	30.4	233.8	5.4	0.1
Savings(FE-EP)	28,906	1.1	0.9	21.4	94.1	4.3	0.0

* Excludes emissions generated from coal, LPG's and renewables.

Exhibit B-18

Commercial Sector - Environmental Emissions* by Type and by Scenario - (kilotonnes)

	CO2	VOC	CH4	NOX	SO2	CO	NO
1988							
SERF-FE	39,398	1.2	0.6	27.9	156.1	5.9	0.1
SERF-EP	39,398	1.2	0.6	27.9	156.1	5.9	0.1
Savings(FE-EP)	0	0.0	0.0	0.0	0.0	0.0	0.0
1995							
SERF-FE	47,752	1.5	0.7	33.7	192.0	7.2	0.1
SERF-EP	37,316	1.2	0.5	26.4	147.3	5.6	0.1
Savings(FE-EP)	10,437	0.3	0.1	7.3	44.7	1.6	0.0
2000							
SERF-FE	53,807	1.7	0.8	37.9	217.4	8.1	0.1
SERF-EP	33,402	1.1	0.5	23.6	130.6	5.0	0.1
Savings(FE-EP)	20,405	0.6	0.3	14.3	86.7	3.1	0.0
2005							
SERF-FE	59,384	1.8	0.8	41.7	242.7	8.9	0.1
SERF-EP	37,060	1.2	0.5	26.1	146.3	5.5	0.1
Savings(FE-EP)	22,324	0.6	0.3	15.6	96.4	3.4	0.0
2010							
SERF-FE	65,079	2.0	0.9	45.6	269.3	9.7	0.1
SERF-EP	40,670	1.3	0.6	28.6	161.9	6.0	0.1
Savings(FE-EP)	24,409	0.7	0.3	17.0	170.4	3.7	0.0
2015							
SERF-FE	71,165	2.2	1.0	49.7	297.9	10.6	0.1
SERF-EP	44,394	1.4	0.6	31.2	177.7	6.6	0.1
Savings(FE-EP)	26,771	0.8	0.3	18.5	120.2	4.0	0.0
2020							
SERF-FE	77,730	2.4	1.1	54.1	329.4	11.5	0.1
SERF-EP	48,196	1.6	0.7	33.8	193.8	7.1	0.1
Savings(FE-EP)	29,535	0.8	0.4	20.3	135.6	4.4	0.1

* Excludes emissions generated from coal and LPG's.

Exhibit B-19

Industrial Sector - Environmental Emissions* by Type and by Scenario - (kilotonnes)

	CO2	VOC	CH4	NOX	SO2	CO	NO
1988							
SERF-FE	111,867	9.3	2.4	308.1	443.6	91.3	0.2
SERF-EP	111,848	9.3	2.4	308.1	443.6	91.3	0.2
Savings(FE-EP)	19	0.0	0.0	0.0	0.0	0.0	0.0
1995							
SERF-FE	136,299	11.4	3.0	375.7	539.7	111.2	0.2
SERF-EP	122,676	9.6	2.7	326.3	468.9	96.7	0.2
Savings(FE-EP)	13,624	1.8	0.3	49.5	70.9	14.5	0.0
2000							
SERF-FE	153,127	12.7	3.3	421.0	605.3	124.7	0.2
SERF-EP	127,904	9.6	2.8	330.4	474.4	97.9	0.2
Savings(FE-EP)	25,223	3.1	0.5	90.6	130.9	26.8	0.0
2005							
SERF-FE	169,633	14.0	3.7	465.1	669.6	138.0	0.3
SERF-EP	106,606	8.7	2.2	298.1	468.5	89.5	0.2
Savings(FE-EP)	63,026	5.2	1.5	167.0	201.1	48.5	0.1
2010							
SERF-FE	186,316	15.2	4.0	509.8	734.2	151.4	0.3
SERF-EP	117,105	9.5	2.4	326.5	513.4	98.1	0.2
Savings(FE-EP)	69,211	5.7	1.6	183.3	220.8	53.3	0.1
2015							
SERF-FE	203,124	16.5	4.4	554.6	799.4	164.8	0.3
SERF-EP	127,654	10.3	2.7	354.9	558.7	106.7	0.2
Savings(FE-EP)	75,470	6.2	1.7	199.7	240.7	58.1	0.1
2020							
SERF-FE	215,509	17.6	4.7	589.3	847.1	175.1	0.3
SERF-EP	135,608	10.9	2.8	377.0	591.4	113.3	0.2
Savings(FE-EP)	79,901	6.7	1.8	212.3	225.7	61.7	0.1

* Excludes emissions generated from steam, LPG's and renewables.

Exhibit B-20

Transportation Sector - Environmental Emissions by Type and by Scenario - (kilotonnes)

	CO2	VOC	CH4	NOX	SO2	CO	NO
1988							
SERF-FE	141,600	785.4	78.7	1,061.0	124.4	6,639.8	0.1
SERF-EP	141,600	785.4	78.7	1,061.0	124.4	6,639.8	0.1
Savings(FE-EP)	0	0.0	0.0	0.0	0.0	0.0	0.0
1995							
SERF-FE	186,102	706.7	70.8	1,031.1	178.3	5,409.4	0.1
SERF-EP	131,982	477.1	47.9	757.8	138.6	3,570.3	0.1
Savings(FE-EP)	54,120	229.6	22.9	273.3	39.7	1,839.1	0.0
2000							
SERF-FE	217,114	724.9	72.6	1,095.9	220.2	5,405.9	0.1
SERF-EP	145,389	462.9	46.4	775.9	167.9	3,320.9	0.1
Savings(FE-EP)	71,726	262.0	26.2	320.0	52.3	2,085.0	0.0
2005							
SERF-FE	245,487	807.5	80.8	1,224.6	254.7	6,048.2	0.1
SERF-EP	163,073	515.4	51.6	861.3	193.6	3,702.0	0.1
Savings(FE-EP)	82,414	292.1	29.3	363.2	61.1	2,346.2	0.0
2010							
SERF-FE	270,915	907.0	90.8	1,359.1	284.2	6,696.6	0.1
SERF-EP	179,183	578.2	57.8	952.2	216.0	4,093.0	0.1
Savings(FE-EP)	91,731	328.8	33.0	406.9	68.3	2,603.6	0.0
2015							
SERF-FE	293,326	994.2	99.6	1,468.2	308.4	7,295.5	0.1
SERF-EP	193,663	633.4	63.4	1,027.8	234.8	4,455.4	0.1
Savings(FE-EP)	99,663	360.9	36.2	440.4	73.7	2,840.1	0.0
2020							
SERF-FE	312,458	1,070.1	107.3	1,550.9	329.3	7,789.0	0.1
SERF-EP	205,982	681.0	68.2	1,084.8	251.1	4,751.4	0.1
Savings(FE-EP)	106,476	389.1	39.1	466.1	78.2	3,037.7	0.9

Exhibit B-21

Total - Environmental Emissions* by Type and by Scenario - (kilotonnes)

	CO2	VOC	CH4	NOX	SO2	CO	NO
1988							
SERF-FE	350,028	798	84	1,439	944	6,745	0
SERF-EP	344,828	798	83	1,434	934	6,744	0
Savings(FE-EP)	5,200	0	1	5	10	1	0
1995							
SERF-FE	431,715	722	76	1,485	1,158	5,536	0
SERF-EP	333,017	490	52	1,139	945	3,678	0
Savings(FE-EP)	98,701	232	24	346	213	1,858	0
2000							
SERF-FE	488,386	742	79	1,601	1,309	5,548	1
SERF-EP	346,323	475	51	1,157	963	3,429	0
Savings(FE-EP)	142,066	267	28	444	346	2,119	0
2005							
SERF-FE	541,629	826	87	1,779	1,452	6,204	1
SERF-EP	347,602	527	55	1,214	1,009	3,802	0
Savings(FE-EP)	194,030	299	32	566	443	2,402	0
2010							
SERF-FE	592,117	927	98	1,964	1,590	6,867	1
SERF-EP	379,364	591	62	1,336	1,104	4,202	0
Savings(FE-EP)	212,756	336	36	628	486	2,665	0
2015							
SERF-FE	639,702	1,016	107	2,123	1,725	7,480	1
SERF-EP	409,483	647	68	1,444	1,195	4,574	0
Savings(FE-EP)	230,222	369	39	680	529	2,906	0
2020							
SERF-FE	679,425	1,093	115	2,246	1,838	7,985	1
SERF-EP	434,609	695	73	1,526	1,270	4,877	0
Savings(FE-EP)	244,818	398	42	720	568	3,108	0

* Note emission exclusions in Exhibits B-17, B-18, and B-19.