Case Study on Fiscal Policy and Energy Efficiency

Baseline Study

Prepared for
The National Round Table on the Environment and the Economy

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Working Paper

Please note that this version of the case study is slightly modified from the version previously available. The modification relates to a paragraph on page B11 dealing with aluminum electrolysis technologies.

National Round Table on the Environment and the Economy | Table ronde nationale sur l'environnement et l'économie

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1 Introduction

The National Round Table on the Environment and the Economy (NRTEE) has launched a program to examine ecological fiscal reform (EFR) in Canada. EFR is the systematic alignment of fiscal policy with other policy tools for the achievement of simultaneous economic and environmental objectives. After an initial phase, the EFR program is examining how to develop and promote fiscal policy that consistently and systematically reduces energy-based carbon emissions, without increasing other pollutants, both in absolute terms and as a ratio of gross domestic product (GDP) in Canada.

The current study explores the role of fiscal policy in promoting the long-term energy efficiency of Canada's industrial sector, with a view to accelerating energy efficiency energy in a way that leads to long-term reductions in energy-based carbon emissions. It is one of three parallel case studies, which seek to deliver pragmatic, policy-relevant recommendations on how fiscal policy can promote the development of renewables, hydrogen, and industrial energy efficiency, in a way that promotes the general program objective. The other objective of the studies is to test out approaches, processes, and methodologies that link issues of energy, climate change, technology development, and fiscal policy, with a view to generating lessons and findings in a way that informs policy development in this area.

This report encompasses the first component of the decarbonization case study, the Baseline Study. In this report we examine the nature of energy efficiency and trends in industrial carbon-based emissions. It culminates in the development of a baseline carbon emission scenario. A second report, the Economic Study, examines specific energy efficiency opportunities available to industry and challenges faced in their adoption. Alternative carbon emission scenarios are developed, economic implications assessed and policy recommendations developed.

1.1 Definitions and Concepts

Industry Scope

For the purposes of the case study, industry is defined as establishments engaged in manufacturing and mining activities. Mining activities are those related to extracting naturally occurring minerals. These can be solids, such as coal and ores; liquids, such as crude petroleum; and gases, such as natural gas. Manufacturing activities involve the physical or chemical transformation of materials or substances into new products. These products may be finished, in the sense that they are ready to be used or consumed, or semi-finished, in the sense of becoming a raw material for an establishment to use in further manufacturing.[1]

Industry in this case study does not include establishments involved in electrical generation, agriculture, or in providing services.[2]

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1 These activities correspond to those defined by the NAICS (North American Industry Classification System) classifications: 21, 31, 32 and 33. For more information on what is encompassed in these activities, see Industry Canada's Strategis website: <strategis.ic.gc.ca>.

2 We do however include the electricity sector in the modelling of carbon shadow prices in the Economic Study to build the alternative scenarios (so that a shadow price for carbon is reflected in the price of electricity seen by the industry sector). For more information, see section 3.2 of the Economic Study.

Decarbonization

In this document and accompanying Economic Study, the term "decarbonization" refers to the reduction of energy-based carbon emissions, both in absolute terms and as a ratio of output, in Canada without an increase of other pollutants.[3] Carbon emissions in the numerical analysis are encompassed by a broader measurement of greenhouse gas (GHG) emissions.

Distinction between Policy and Action

In designing policies and assessing their impact and costs, it is useful to firmly distinguish an *action* from *policy*. An action is a change in equipment acquisition, equipment use rate, lifestyle or resource management practice that changes net carbon emissions from what they otherwise would be. This study focuses on energy efficiency actions from changes in technology acquisition, but considers these actions in relation to other actions to decarbonise. We can estimate the cost of an action individually or as part of a package (portfolio) of actions. The cost is the incremental change in costs (positive or negative) from undertaking the action(s). A policy, or policy instrument, is defined here as an effort by public authorities to bring about an action. In the modelling component of this case study we are careful to distinguish between the two terms.

Direct, Indirect and Total GHG Emissions

In describing current and future carbon-based emissions for only one part of the economy (the industry sector) it is useful to use the concepts of direct and indirect emissions. The term *direct emissions* is used to describe emissions that are produced by a source controlled by an entity (in terms of this project, industry), while the term *indirect emissions* describes emissions that result from that entity's activity, but are produced by a source external to the entity.

When considering the impact of actions, it is important to consider the combined impact on both indirect and direct emissions, since considering only direct emissions would actually show an increase in emissions for an action like cogeneration, while considering direct and indirect emissions together would tend to show lower total emissions (depending on the carbon-intensity of utility electricity generation).

1.2 Outline of this Report

This report is structured as follows. In a background section we 1) discuss basic concepts relating to energy efficiency, 2) review trends in Canadian industrial energy use and greenhouse gas emissions, and 3) provide an overview of current policy relating to industrial energy efficiency. We then go on to describe our method for developing the baseline forecast, discussing in some detail the energy-economy model CIMS, which is used both for this forecast and subsequent alternative forecasting and economic analyses described in the Economic Study. We conclude this report with a presentation of the baseline forecast, disaggregated by industry sub-sector.

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3 The principal energy-based carbon emission described in this report is carbon dioxide (CO_2), which is a key greenhouse gas emission. Methane (CH_4) is also produced in fossil fuel combustion and contributes to increase of greenhouse emissions in the atmosphere; however, its sources are primarily non-combustion based.

2 Background

2.1 Defining Energy Efficiency

Many concepts are used in relation to analyzing energy efficiency. We spend some time clarifying these concepts and discuss how energy efficiency relates to decarbonization objectives.

Energy efficiency refers to the relationship between the output (service) of a device or a system and the energy put into it. Improved energy efficiency is doing more with equal or less energy input, for instance, fewer kilowatts per tonne of aluminum produced. Energy efficiency can be evaluated in terms of both *first law efficiency* and *second law efficiency. First law efficiency* relates to the ratio of energy input to energy output of a device. Many modern devices have low first law efficiencies, indicating substantial room for improvement. Nevertheless, the best way to understand the full scope for improvement is to consider *second law efficiency* – the ratio of energy input of a device to the minimum amount of energy theoretically needed to perform a task. This reduction in the energy consumption is not necessarily associated with technical changes, since it can also result, for instance, from better organization and management.

Energy efficiency analysis can be applied at different points in the energy system, including energy using equipment, major industrial processes, supply technologies, delivery networks, and even urban form and infrastructure. Considering elements of the system together or separately will provide a different picture of energy efficiency.[4] Decisions taken about industrial siting, energy supply infrastructure, and major industrial process will have long-lasting implications on energy efficiency of the system, shaping decisions that take place more frequently regarding individual equipment (motors, air displacement systems, lighting, etc.).

Community energy management and industrial ecology are two overlapping concepts that take a systems approach to energy efficiency (and energy management in general). In community energy management, all land-use and infrastructure decisions that affect the evolution of urban form must include a careful consideration of how to improve the energy efficiency of the urban system. Industrial ecology focuses especially on situating industrial facilities in close enough proximity so that they can economically use each other's energy (and material) wastes.[5] This may involve the cogeneration of electricity and steam, with the latter distributed to adjacent plants, or it may simply involve the capture of waste heat from one plant by another even where electricity is not generated.

The term *energy conservation* is sometimes used interchangeably with the term energy efficiency, but in fact they denote distinct concepts. Energy conservation expresses actions taken to decrease the demand for energy, which is not limited to demand reductions brought on by increased energy efficiency. It could also be used to describe actions taken to reduce consumption of a service (i.e., turning off lights).

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4 The choice of technology for heating provides an example. If an electric resistance heater is used to heat the inside of a building, the first law efficiency of electric space heating is 100%, as virtually all of the electrical energy is converted into heat inside the room that is being heated. But if the electricity is generated in a distant thermal plant, the ratio of the chemical energy of the plant's fuel (say natural gas) to the electricity it produces may be only 40%, the efficiency of the plant. Then, 10% of this electricity may be lost from the high voltage transmission lines (a transport efficiency of 90%). The use of electricity for space heating therefore has a total system efficiency of 40% x 90% x 100% = 36%.

5 This is sometimes referred to as energy cascading because as the quality of energy declines after each use – the second law of thermodynamics – industrial facilities can be matched to energy needs of progressively lower quality.

Measuring Energy Efficiency

Energy intensity is a common indicator in energy analysis used to infer energy efficiency changes, given that energy efficiency cannot be measured directly at an aggregate level. Energy intensity is defined as unit energy per unit output, which can be described for both output in terms of physical units or monetary units (GDP or gross output).[6] Physical-based and monetary unit-based indicators do not measure the same thing; one should avoid a direct comparison between them. While many analysts assume a strong, correlated link between physical and economic output, exceptions are numerous and significant. While improved energy efficiency will tend to reduce energy intensity, a change in energy intensity can be due to factors unrelated to energy efficiency, such as structural shifts in the economy and interaction effects. A number of methodologies have been developed to isolate out these affects and build "structurally adjusted" composite indexes.[7]

Energy Efficiency and Decarbonization

There are various ways of reducing the carbon intensity of energy, including switching away from fossil fuels, switching from high carbon fossil fuels to low carbon fossil fuels, capturing and sequestering carbon emissions, and improving energy efficiency. The latter will result in lower carbon emissions if the carbon intensity of energy (tonnes of carbon per gigajoule energy) does not increase significantly due to the change, which may often be the case.[8] Nevertheless, there are instances where increased energy efficiency is even associated with increased carbon intensity. For instance, a coal-fired boiler is more efficient than a wood-fired or even a natural gas-fired boiler (depending on coal quality). Increasing energy efficiency by using a coal boiler instead of the other options would result in higher carbon emissions.

The intent of this case study is to explore what role energy efficiency could play in promoting the NRTEE program objective of decarbonizing the energy system. Instead of targeting energy efficiency exclusively, this approach considers the role of energy efficiency and its influence on decarbonizing the energy system in conjunction with other options available to industry. This is an important distinction and influences the analytical approach developed in the Economic Study, discussed in more detail in that report.

2.2 Industry Sector Characteristics

Energy Use in Canadian Industry

The industrial sector, which includes mining and manufacturing activities, is a significant GHG-producing sector in Canada. The sector produced 237 Mt CO_2e of direct GHG emissions in 2000,

6 *Gross output* is defined as the total value of goods and services produced by an industry, a sum of the industry's inputs plus the change in value due to labour and capital investment. *GDP* is defined as the change in value due to labour and capital investment. Gross output values are not additive across industries while GDP is.

7 For a detailed review of these approaches and the usefulness of energy intensity indicators as a policy tool, see: M. Nanduri, J. Nyboer, M. Jaccard, "Aggregating Physical Intensity Indicators: Results of Applying the Composite Indicator Approach to the Canadian Industrial Sector," *Energy Policy* 30 (2002): 151-137.

8 *Carbon intensity* has several meanings. It can describe a unit of carbon emissions per a unit output. Output can be expressed in terms of a monetary or physical output. The second meaning describes carbon emissions associated with the energy form, often in terms of tonnes carbon / gigajoule as used here.

the majority of which are energy consumption based.[9] Total energy consumed by industry in that same year was 3,187.2 PJ.[10]

Energy is particularly critical in the production of basic industrial products, which are often used to produce goods for final consumption, either within or outside of Canada. These primary products industries, often referred to as Tier I industries, account for more than 80% of total industrial energy consumption. This includes industries such as iron and steel, pulp and paper, metal smelting, petroleum refining, chemical manufacturing and industrial minerals (cement and lime production). Mining accounts for another 5% of energy consumption. The remaining industries, which are numerous and diverse (food processing, transportation equipment manufacturing, etc.) use relatively little energy, 15%, but are responsible for 60% of industrial economic output as measured by gross domestic product (GDP).[11]

Energy intensity (based on GDP) in Canadian industry has generally decreased since 1990 to a level 27% below 1990 levels in 2002.[12] Trends in carbon intensity are similar (as measured by GHG emissions per unit of GDP). During the same period, the carbon intensity of Canadian industry has declined slowly, levelling off at approximately 34% below 1990 levels in 2002.[13] The decline in energy and carbon intensity is due both to improved efficiency among energy users as well as to structural change in industry. The term "structural change" in this context refers to a change in product or industry mix that determines total industrial production volume. Between 1995 and 2001, the activity share of less energy intensive industries has increased while the share represented by more energy intensive industries has decreased, leading to a decline in total energy use of 11.5% relative to 1995.[14]

Also, trends based on economic output cannot provide an accurate picture of energy intensity because monetary units are affected by many factors not associated with energy, such as costs of labour or selling price of the final product. Composite indicators computed for aggregate physical energy intensity in Canadian industry between 1990 and 1996 suggest a smaller decline in energy intensity relative to the measure based on GDP.[15]

Managers are considered more directly motivated by cost minimization than residential and commercial consumers.[16] As such, firms may have already pursued many cost-effective options to reduce energy consumption, particularly when energy costs make up a high percentage of total

9 Summarized from Table S-1 in: Environment Canada, *Canada's Greenhouse Gas Inventory: 1990–2000* (Ottawa: 2002), 3. Includes combustion, fugitive and process emissions in the following categories: Fossil Fuel Industries, Mining, Manufacturing, Fugitive Total, Industrial Processes Total.

10 Natural Resources Canada, *End-Use Energy Data Handbook 1990 to 2001* (Ottawa, Ontario: 2003), 12.

11 Summarized from data in: Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC), *Development of Intensity Energy Indicators for Industry 1990-2002* (Burnaby: Simon Fraser University, 2004).

12 Ibid., 11.

13 Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC), *Development of Greenhouse Gas Intensity Indicators for Canadian Industry 1990 to 2002* (Burnaby: Simon Fraser University, 2004).

14 Office of Energy Efficiency, *Energy Efficiency Trends in Canada, 1990 to 2001*, Chapter 5: The Industrial Sector (Ottawa, Ontario: Natural Resources Canada, 2003).

15 Nanduri et al., "Aggregating Physical Intensity Indicators," 151-137.

16 W. Golove, "Are Investments in Energy Efficiency Over or Under: An Analysis of the Literature," *Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar, USA, 1994.

production costs. Some sectors are more physically limited in their ability to reduce energy use, and in particular, fossil fuel use. This may be because of minimum thermal requirements of industrial processes (ore refining, pulp production, etc.). Nevertheless, the potential for energy efficiency improvements can still be significant, particularly for some industry sectors.

A number of studies have sought to identify this potential in the Canadian context, both in specific industry analysis and in conjunction with other sectors of the economy. Energy efficiency measures were included in a host of GHG abatement measures analyzed for Issue Tables (Industry Table, Forest Sector Table and the Analysis and Modelling Group) in the National Climate Change Process, and in subsequent modelling analysis.[17] Utilities have also been active in assessing energy efficiency potential to inform demand-side management programs, though these studies focus on one energy type, and are regionally focused.[18] Studies that have evaluated national energy efficiency and conservation potential across industries are less common.[19] Energy efficiency measures are notable for their diversity – a broad range of opportunities exists including those that are already disseminated, those under development, and those poised for market deployment. Their application is unique to different industry sub-sectors, though some crosscutting actions do exist. We examine the energy efficiency options available to industry in detail in the Economic Study part of this project.

2.3 Current Policy Context

We provide a brief overview of current government policy regarding energy and GHG emissions in the industry sector, including a description of current EFR-related policies.

Energy and GHG Policy Related to the Industry Sector

Current policies relating to industrial energy efficiency have their roots in the 1970s. The oil price shock of 1973 made energy security a high priority concern and led to, among other responses, the development of numerous energy efficiency programs internationally and within Canada. *The Canadian Industry Program for Energy Conservation* (CIPEC), first initiated in 1975, is an umbrella organization overseeing a partnership between government and private industry aimed at improving Canada's industrial energy efficiency. CIPEC comprises sectoral task forces, each of which represents companies engaged in similar industrial activities that participate through their trade associations.[20]

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17 See the National Climate Change website <www.nccp.ca/NCCP/national_process/issues/index_e.html> for many of the studies that analyze measures. Industry measures were included in an integration modelling exercise (the Rollup) by the CIMS model and the MARKAL model. See: *Analysis and Modelling Group, The Economic and Environmental Implications for Canada of the Kyoto Protocol* (Ottawa: National Climate Change Process, 2000).

18 For instance, B.C. Hydro recently released a review potential: BC Hydro, *BC Hydro Conservation Potential Review, Industrial Sector Report*, Prepared by Marbek Resources Consultants and Willis Energy Services, Vancouver, July 2003.

19 A 1996 study prepared for Natural Resources Canada found that the technical potential for energy conservation in six major energy consuming industries ranged between 3% and 25% of projected energy consumption in 2010. MK Jaccard and Associates & Willis Energy Services Ltd. *Industrial Energy End-Use Analysis & Conservation Potential in Six Major Industries in Canada*, Prepared for Natural Resources Canada, 1996.

20 Canadian Industry Program for Energy Conservation, *2002/2003 Annual Report* (Ottawa: Natural Resources Canada, 2004).

CIPEC is administered by the Office of Energy Efficiency (of Natural Resources Canada), which has an overall mandate to work with Canadian industry to increase energy efficiency, limit greenhouse gas emissions and increase economic competitiveness. The office, working through CIPEC, also administers the Industrial Energy Innovators Initiative, which recruits and encourages industrial energy users at the corporate level to develop long-term energy management planning and replication strategies for their companies.

Industrial energy efficiency has become closely related to climate change policy initiatives. It has figured strongly in efforts by industry to curtail their GHG emissions as part of the Voluntary Challenge and Registry Inc. The Registry was launched in 1994 to encourage private and public sector organizations to voluntarily limit their net GHGs through actions planned and executed by registrants.[21]

Discussion and debates relating to the formulation of climate change policy intensified during the 1990s. Just prior to ratifying the Kyoto Protocol in December 2002, the Government of Canada released the *Climate Change Plan for Canada* in November 2002, in which it established a three-pronged approach to address emissions from large industrial emitters:[22]

- targets for reductions established through covenants with a regulatory or financial backstop (55 megatonne (Mt) reduction);
- access to a domestic emissions trading system, domestic offsets, and international permits to provide flexibility; and
- complementary measures (an additional 11 Mt reduction).

Small and medium-sized enterprises are encouraged to work towards voluntary energy efficiency targets.

The *Large Final Emitters Group* (LFEG) of Natural Resources Canada was established in late 2002 to implement this part of the Plan, and is adopting an emissions intensity approach for determining targets for large industrial emitters.[23] Emission intensity targets will be set at a level so that they result in the required reduction according to government forecasts. LFEG is working with key industry sectors (as well as other stakeholders) to design policies and measures that encourage reductions of this magnitude. They are expected to use a number of tools to meet these goals, including backstop legislation and regulations, and negotiated covenants, as well as flexible compliance mechanisms such as a domestic emissions trading system, domestic offsets, and the international carbon market.

Included in the federal budget in 2003, which followed up on the *Climate Change Plan*, were budget allocations to provide long-term support for research and development of emerging energy efficient technologies ($250 million) and to subsidize industrial energy efficiency actions and carbon offsets ($303 million).[24] Research and development of advanced end-use efficiency technologies is

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21 Canada's Climate Change Voluntary Challenge and Registry Inc., *Annual Report 2003* (Ottawa: 2004).

22 Government of Canada, *Climate Change Plan for Canada* (Ottawa: 2002).

23 Emission intensity represents the ratio of emissions per unit of output. Large industrial emitters include the electricity supply sector. For more information on who is considered a large emitter, see the LFEG website: <www.nrcan-rncan.gc.ca/lfeg-ggef/>

24 Non-industry initiatives include funds to subsidize residential building shell and heating system improvements and to create programs to encourage energy, efficient purchases among individual Canadians ($131 million).

one of the five priority areas in science and technology (the others are cleaner fossil fuels, decentralized energy production, biofuels and the hydrogen economy).

Outside of federal policy and initiatives, provincial governments and Crown utility corporations have also been active in varying degrees in promoting energy efficiency in industry and in climate change policy in general.

Tax Policy – Energy Efficiency Investments

The fiscal system may provide a non-level playing field for competing energy investments. A 1996 study found that the energy efficiency investments and investments in oil and gas are subject to different tax treatments.[25] This study evaluated prospective investments according to the degree of "uplift" that the tax system provided to an investment through its incentive features (tax credits, tax exemptions or preferential tax rates) relative to a "neutral tax system." Energy efficiency projects received negative uplifts while oil and gas investments (and in particular large oil and gas investments) received uplifts in the order of 5 to 20%). It is important to note that the study's energy efficiency investments – solar wall, district heating and building retrofits – did not include energy efficiency investments in industrial processes, which receive a variety of capital cost allowance (CCA) class treatments.[26] The study's investments receive CCA Class 1 treatment of 4%, whereas energy efficiency investments could be applicable across many different types of property and CCA treatments (that are higher than 4%). Nevertheless, within most rates, both "efficient" and "inefficient" equipment are provided with the same CCA rate.

The exception to this is a special CCA class for "Energy Conservation and Renewable Energy" equipment (Class 43.1), which qualifies certain investments for an annual 30% depreciation rate. This class specifically targets combined heat and power systems, high efficiency gas generation, and heat recovery equipment as energy efficiency investments relevant to the industrial sector. Most targeted investments included in this class are renewable energy systems (thermal solar systems, photovoltaic systems, small hydro, wind energy conversion systems, and electrical generation systems that use landfill gas, geothermal energy, biomass, solution gas, and waste fuels). An important adjunct to this tax incentive is the Canadian Renewable and Conservation Expense. It allows the intangible costs (e.g., feasibility studies, pre-construction expenses, etc.) associated with projects that fall under Class 43.1 either 1) to be expensed the year they are incurred, 2) to be carried forward for deduction in a later year, or 3) to be passed on to investors through Flow Through Share (FTS) agreements. By passing on tax deductions to investors, FTS agreements help encourage investment and facilitate financing.

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25 Natural Resources Canada, *The Level Playing Field: The Tax Treatment of Competing Energy Investments* (Ottawa: Natural Resources Canada; Finance Canada, 1996).

26 Canada uses a declining balance method which requires certain assets to be grouped into classes; capital cost allowances are allowed at a prescribed rate based on the cost of assets in the class. When a firm purchases new equipment, its costs are added to an appropriate CCA classified pool (defined by regulations to the *Income Tax Act*). As equipment is sold or otherwise disposed of, the lesser of either the cost of the asset or the proceeds of disposing of it is deducted from the pool. A taxpayer can deduct from income a prescribed percentage of the pool's unamortized balance of the pool (its undepreciated capital cost, or UCC) in any year in which it uses equipment in that pool to generate income. This amount is also reduced by 50% of the net additions to the CCA class in a year. After the final item of property in a CCA pool is sold or otherwise disposed of, the taxpayer can claim the remaining UCC as a "terminal loss." If the amount deducted from the pool on the sale of an asset (the lesser of cost or proceeds) exceeds the UCC of the pool, this excess amount is added to income as a recapture of depreciation. If the asset is sold for more than its original cost, the difference between the proceeds and the original cost is a capital gain, only one-half of which is currently included in income.

Canada does not employ any other tax incentives as part of the personal or corporate income tax system, though some credits are offered as part of provincial government royalty systems. Saskatchewan provides a royalty credit (the Saskatchewan Petroleum Research Incentive) for up to 30% of eligible project costs to implement new technology in the oil and natural gas sector. This incentive explicitly includes improving the efficiency and cost-effectiveness of oil and natural gas technologies as one of its objectives. Reducing the environmental impacts of production is another. The Alberta government as part of its Otherwise Flared Solution Gas (OFSG) program waives the royalty on otherwise flared solution gas and associated by-products when used in a manner that would normally require payment of royalty (i.e., conserved).

EFR Related to Industrial Energy Efficiency

Outside of the tax system, a few programs by government and utilities provide incentives to promote energy efficiency by industry. Most programs are part of broader policies that include elements such as information provision. For instance, the Industrial Energy Audit Incentive program, which assists companies in identifying ways to increase energy efficiency through helping to fund audits, is administered as part of Natural Resources Canada's CIPEC program.

The *Climate Change Plan for Canada* seeks to develop a tradable permit system to provide an incentive for decarbonization (that as a cost-internalizing and revenue instrument could be considered part of EFR). The development of a domestic emissions trading system is part of the Plan's three-pronged approach for addressing emissions from large industrial emitters ("large final emitters"). This system would allow a company in need of a permit to cover its GHG emissions (in excess of those that are covered by permits), to buy permits from companies in surplus, from international sources, or from domestic developers of "offsets" that reduce emissions in uncovered activities. The government is currently considering how design of its permit system would best develop this market.[27]

A pilot "voluntary" emissions trading system is currently operating. The *Pilot Emission Removals, Reductions and Learning Initiative* (PERRL) is designed to provide Canadian companies, organizations and individuals with an economic incentive to take immediate action to reduce greenhouse gas emissions. Through PERRL, the federal government buys the rights to verified greenhouse gas emission reductions from eligible projects for a fixed price per tonne. The program is set to run until the end of 2007 and $13.2 million has been budgeted to purchase reductions and removals.

Research and Development

As noted above, the *Climate Change Plan* provides for direct funding for research and development (R&D) to energy efficiency technologies. The Office of Energy Research and Development (OERD) coordinates federal energy research and development activities and Canada's participation in international R&D activities. It directs the Program of Energy Research and Development (PERD), which includes a strategy for energy efficiency in industry.

27 Permits will be provided to large final emitters through allocation methods defined in regulation, but the method for allocating permits and the design of the system have important implications for the market that may emerge. This includes such issues as whether permits are distributed ex ante or ex post, when targets are set (annual targets vs. single target for Kyoto commitment period), and what targets are (equal each year vs. progressively tightening). See: Large Final Emitters Group, Natural Resources Canada *Timing Frequency of True up and Permit Distribution* < http://www.nrcan-rncan.gc.ca/lfeg-ggef/English/timing_en.pdf> [accessed January 30, 2004]

Funding is also provided from the Canmet Energy Technology Centre (CETC), which provides repayable and cost-shared contract funding programs, and the Innovative Research Initiative (IRI) for Greenhouse Gas Mitigation to stimulate the undertaking of high-risk, exploratory research directed at finding solutions to the climate change problem (includes energy efficiency projects).[28]

Overall, Canada has favoured fiscal incentives over direct funding to support R&D, and provides one of the most generous systems among all OECD countries. Estimates indicate that in Canada R&D tax credits were equivalent to about 13% of industry R&D expenditures. In the United States in contrast (in 1999), R&D tax incentives represented less than 1.6% of industry R&D spending.[29] R&D provisions in the tax system include:

- allowing tax credits on either actual overhead or an allowance for overheads based on a percentage of the salary or wages paid to research personnel;
- an immediate 100% write-off for R&D equipment expenditures;
- refunds on unused R&D tax credits to smaller Canadian-controlled private corporations (carried back three years or carried forward 10 years);
- tax credits to companies that make payments to approved research institutes or universities for research that relates to the business of the company; and
- tax incentives for basic research conducted by the private sector.

The tax incentives described above are applicable to all R&D investments and do not single out energy efficiency investments.

3 Baseline Methodology

3.1 Overview of Methodology

The diversity in industry requires disaggregation in any modelling exercise to be able to forecast energy demand, emissions and other aspects of the energy system. For this purpose we use the CIMS model, which has a detailed, region-specific portrayal of energy use in Canadian industry as represented by 54 unique sub-models. These sub-models (listed in Figure 3-1) represent stocks of technologies that produce and/or consume energy in that sub-sector, in terms of the annual quantity of intermediate and final products or services they provide (i.e., tonnes of newsprint, cubic metres of refined petroleum products). Product and energy service demands are linked in sub-sector flow models that describe the sequence of activities required to generate that product or service. An example of an industry sub-sector flow model is shown in Appendix A.

28 For fiscal year 2002/2003, CANMET funding to support industrial initiatives is valued at approximately $11 million, provided in part by Natural Resource Canada's Program on Energy Research and Development. IRI is a $1.45 million fund.

29 Organisation for Economic Co-operation and Development (OECD), *Tax Incentives for Research and Development: Trends and Issues* (Paris: 2002).

Forecasts of these service demands drive the model simulation in five-year increments, thus allowing for detailed assumptions about industrial output (by product). The rate of technological change is modelled according to a retirement function that captures the normal, technical lifespan of energy-using equipment, as well as new stocks required to meet additional growth.

Figure 3-1: Industry Sector Sub-models in CIMS

Industrial Sub-sectors	**BC**	**AB**	**SK**	**MA**	**ON**	**PQ**	**AT**
Chemical Products	✓	✓	–	–	✓	✓	–
Coal Mining	✓	✓	✓	–	–	–	✓
Industrial Minerals	✓	✓	–	–	✓	✓	✓
Iron and Steel	–	–	–	–	✓	✓	–
Metal Smelting	✓	–	–	✓	✓	✓	✓
Mining, Metals	✓	–	✓	✓	✓	✓	✓
Natural Gas Extraction	✓	✓	✓	*	*	*	✓
Other Manufacturing	✓	✓	✓	✓	✓	✓	✓
Petroleum Refineries	✓	✓	✓	–	✓	✓	✓
Petroleum Crude	✓	✓	✓	–	✓	–	✓
Pulp & Paper	✓	✓	✓	–	✓	✓	✓

* Transmission only

These industrial sub-models are integrated in an overall modelling framework that simulates the interaction between sectors that use energy (in the industrial, residential, commercial/institutional and transportation sectors) and sectors that produce or transform energy (electricity generation, petroleum crude extraction, petroleum refining, and natural gas extraction and processing). Modelling the interaction between these sectors is important to capture energy price dynamics that guide decision-making; for instance, the widespread adoption of high efficiency electric motor and auxiliary systems would impact the demand for electricity, with potential price impacts that would affect energy-related decisions throughout the economy.

Because CIMS is integral to constructing the baselines and subsequent analysis in the Economic Study, we describe the model in more detail.

3.2 The CIMS Model

CIMS has been in continuous development since 1986 by the Energy and Materials Research Group in the School of Resource and Environmental Management at Simon Fraser University.[30] It currently represents seven regions in Canada, but it can be applied to any country or region. As

30 The energy demand component of the model, previously called ISTUM, was first developed in the early 1980s by the U.S. Department of Energy as an energy use model of the industrial sector.

noted above, the model emphasizes the micro-economic level of analysis in that it simulates in considerable detail the equipment and building decisions of firms and households in response to changes in information, costs and availability of alternatives.[31] However, it can also incorporate indirect feedbacks that are normally associated with macro-economic models, namely shifts in the demand for final and intermediate products as their costs of production change.

A CIMS simulation involves six basic steps:

1. *Assessment of Demand:* Technologies are represented in the model in terms of the quantity of service they provide. This could be, for example, vehicle kilometres travelled, tonnes of paper, or m^2 of floor space heated and cooled. A forecast is then provided of growth in energy service demand.[32] This forecast drives the model simulation, usually in five-year increments (i.e., 2000, 2005, 2010, 2015, etc.).

2. *Retirement:* In each future period, a portion of the initial-year's stock of technologies is retired. Retirement depends only on age.[33] The residual technology stocks in each period are subtracted from the forecast energy service demand and this difference determines the amount of new technology stocks in which to invest.

3. *New Technology Competition/Retrofit Competition:* Prospective technologies compete for this new investment. The objective of the model is to simulate this competition so that the outcome approximates what would happen in the real world. Hence, while the engine for the competition is the minimization of annualized life cycle costs, these costs are substantially adjusted to reflect market research of past and prospective firm and household behaviour.[34] Thus, technology costs depend not only on recognized financial costs, but also on identified differences in non-financial preferences (differences in the quality of lighting from different light bulbs) and failure risks (one technology is seen as more likely to fail than another). Even the determination of financial costs is not straightforward, as time preferences (discount rates) can differ depending on the decision maker (household vs. firm) and the type of decision (non-discretionary vs. discretionary). The model also allocates market shares among technologies probabilistically.[35] More detail regarding the technology competition algorithm is provided in Appendix A.

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31 In this respect CIMS resembles models developed and applied by the electric utility industry in the 1980s for estimating the effects of policies intended to influence technology choices for energy efficiency and fuel switching objectives. CIMS has been used by electric and gas utilities in Canada for this purpose.

32 The growth in energy service demand (e.g., tonnes of steel) is often derived from a forecast provided in economic terms (e.g., dollar value of output from the steel sector).

33 There is considerable evidence that the pace of technology replacement depends on the economic cycle, but over a longer term, as simulated by CIMS, age is the most important and predictable factor.

34 With existing technologies there may be data on consumer behaviour. However, with emerging technologies (especially the heterogeneous technologies in industry) firms and households need to be surveyed (formally or informally) on their likely preferences.

35 In contrast, the optimizing models will tend to produce outcomes in which a single technology gains 100% market share of the new stocks.

Retrofitting: In each time period, a similar competition occurs with residual technology stocks to simulate retrofitting (if desirable and likely from the firm or household's perspective).[36] The same financial and non-financial information is required, except that the capital costs of residual technology stocks are excluded, having been spent earlier when the residual technology stock was originally acquired.

4. *Equilibrium of Energy Supply and Demand:* Once the energy demand sub-models have chosen technologies, the resulting demands for energy are sent to the energy supply models. These models then choose the appropriate supply technologies, assess the change in the cost of producing energy, and if it is significant, send new energy prices back to the demand models. This cycle goes back and forth until energy prices and energy demand have stabilized at an equilibrium.[37]

5. *Equilibrium of Energy Service Demand* (not used in this study)*:* Once the energy supply and demand cycle has stablized, the macro-economic cycle is invoked (if turned on), which adjusts demand for energy services according to their change in overall price, based on price elasticities. If this adjustment is significant, the whole system is rerun from Step #1 with the new demands.

6. *Output:* Since each technology has net energy use, net energy emissions and costs associated with it, the simulation ends with a summing up of these. The difference between a business-as-usual simulation and a policy simulation provides an estimate of the likely achievement and cost of a given policy or package of policies.

3.3 Development of the Baseline Scenario

A baseline forecast of carbon emissions in the industry sector between 2000 and 2030 is developed using the CIMS model according to the simulation Steps 1-3, and 6 described in the preceding section.[38] The forecast is specifically developed by running CIMS's industry and energy supply sub-models.[39]

As noted in Step 1 of the simulation, technologies are represented in the model in terms of the quantity of service they provide. The model contains data on the initial market shares of equipment stocks in 2000. Individual types of equipment are characterized in terms of capacity, capital cost, unit energy consumption (and output for energy conversion equipment), non-energy operating cost, emissions, expected lifespan and first year of market availability for new technologies. The characterizations of existing equipment stocks have some degree of inaccuracy, especially in terms of the current operating characteristics of older equipment. To deal with this challenge, data on existing stocks are tracked with disaggregated, industry-specific, energy consumption data for 2000.

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36 Where warranted, retrofit can be simulated as equivalent to complete replacement of residual technology stocks with new technology stocks.

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

38 Steps 5 and 6 occur when the model is running a policy or non-baseline simulation.

39 While we run the electricity supply model in the baseline and alternative scenarios, we do not report energy consumption or emissions as part of the results.

For the model simulation, an initial macro-economic forecast is required. For this study, assumptions regarding economic growth (more specifically region-specific growth rates for gross output for 2000 to 2020) and future energy prices are adopted from *Canada's Emissions Outlook: An Update* (CEOU).[40] For the simulation past 2020, annual price and growth trends of the 2015-2020 are assumed to continue between 2020 and 2030. Because industrial growth is expressed in terms of the monetary value of output, we convert this into an expected growth in physical output, as required to project energy service demands in Step 1 of the model simulation procedure. While changes in gross output generally indicate changes in physical growth, other information guided the development of the actual physical growth rates used in the model.

The emissions forecast generated by CIMS is calibrated to the official GHG emissions forecast (as of December 2003), which was formulated since the release of the CEOU. CIMS calibrates within 1.6% of the GHG forecast for Canada as a whole in 2010. Industry is calibrated to within 1%.[41] Calibration is achieved by adjusting growth rates and fuel share assumptions in the forecast.

CIMS, as in any model, is a simplification of a system; most variables involve varying degrees of uncertainty which will impact the baseline forecast.[42] We discuss uncertainty as it relates to the modelling analysis in the case study in Appendix A.

3.4 Results and Discussion – Baseline Scenario

In this section, we present the baseline forecast of production, GHG emissions and energy consumption and calculate intensity indicators from this data. Table 3-1 presents a summary of the results for Canada. Overall, emissions in the industry sector (as defined for this case study) grow by 50% over the 30-year simulation period, with direct emissions increasing and indirect emissions decreasing.[43] The share of electricity produced by cogeneration in the sector increases over the simulation period, particularly in oil sands operations. Total emissions grow at an average annual rate of 1.53%, which is slightly faster than growth in net energy consumption (which grows at an annual rate of 1.48%). While the general baseline pattern for both emissions and energy are similar, the emissions picture is determined by trends in fuel shares and non-combustion emissions in addition to energy consumption over the forecast.

40 Although the GHG forecast has been revised since the release of the CEOU, the only comprehensive release of underlying assumptions is contained in the CEOU. Analysis and Modelling Group, *Canada's Emissions Outlook: An Update* (Ottawa: National Climate Change Process, 2000).

41 Industry includes the sectors defined in this study.

42 Some analysts argue that one should never produce a single reference case because this gives a false sense of reduced uncertainty.

43 Indirect emissions describe emissions that result from that entity's activity (electricity consumption), but are produced by a source external to the entity (utilities). Electricity produced and consumed by industry through cogeneration is included in direct emissions.

Table 3-1: Baseline Forecast of GHG Emissions and Energy Consumption for Canada

	2000	2010	2020	2030	Ave. Annual Growth (%)
GHG Emissions (Mt CO_2e)	288	343	396	453	1.53%
Direct	237	307	358	407	1.82%
Indirect	50	36	38	46	-0.30%
Energy (PJ)	4,239	5,030	5,783	6,579	1.48%

The growth in emissions occurs because production in a number of carbon and energy-intensive sub-sectors is expected to grow significantly. The oil and gas sector generates the largest quantity of GHG emissions, driven by a strong growth in oil and gas exports to the United States. We provide sub-sector breakdowns in Tables 3-2 to 3-12. The energy and emissions described in the tables below correspond to the CIMS sub-model universe, which may differ in some cases from Statistics Canada, CEOU or industry association views of the industry.[44] The universe "picture" of the sub-models is discussed along with the sub-sector baseline trends. Principal differences lie in the treatment of fuels and emissions used in cogeneration, off-road emissions and feedstocks. In these tables we show the gross output forecast (based on those assumed in the CEOU) which informs the physical production assumptions used to drive the model. We calculate three intensity indicators. The first two in each table relate direct GHG emissions and energy to physical production, while the last indicator (t CO_2e/GJ energy) suggests the GHG intensity of energy use.

We also provide indirect emissions to give a fuller picture of GHG emissions. Indirect emissions are a factor of both changes in electricity consumption and regional changes in emissions per unit of electricity generation (indirect emission factors). These factors are generated from the simulation of electricity generation sector sub-model. Because factors are region-specific, a relative change in production between provinces will also affect the national picture of indirect emissions. These factors are shown in Appendix A.

44 There are also discrepancies between Statistics Canada data and industry association data, often due to universe differences as well as methodological issues.

Table 3-2: Baseline GHG and Energy Intensity, Chemical Products Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	237	273	328	398	1.75%
Direct GHG Emissions ($Mt\ CO_2e$)	20	24	28	34	1.75%
Indirect GHG Emissions ($Mt\ CO_2e$)	4	3	3	5	0.72%
Total GHG Emissions ($Mt\ CO_2e$)	24	26	32	38	1.61%
Production Physical (kt chemicals)	16,052	20,476	25,829	32,351	2.36%
Gross Output ($1997 millions)	40,279	52,569	68,608	85,933	2.56%
Energy Intensity (GJ / t phys. unit)	14.74	13.33	12.69	12.32	-0.60%
GHG Intensity ($t\ CO_2e$ / t phys. unit)	1.25	1.16	1.10	1.04	-0.60%
GHG Intensity ($t\ CO_2e$ / GJ)	0.085	0.087	0.086	0.085	0.00%

Notes:

- GHG intensity indicators exclude indirect emissions.
- Production is the sum of products modelled in the CIMS model – chlorine, sodium hydroxide, sodium chlorate, hydrogen peroxide, ammonia, methanol, ethylene, propylene and polymers.

The chemical products sub-sector (Table 3-2) produces a large variety of products. Only the most energy intense commodities are modelled to maintain simplicity and yet capture the bulk of the energy-consuming activities in the industry. These products are chlorine, sodium hydroxide, sodium chlorate, hydrogen peroxide, ammonia, methanol, ethylene, propylene and polymers. GHG emissions in this sub-sector include process emissions from ammonia, adipic acid and nitric acid production, as well as CO_2 from non-energy use. Unique regional sub-models describe activity in British Columbia, Alberta, Ontario and Quebec. Direct emissions include those produced from cogeneration (joint steam and electricity production).

Large reductions in GHG intensity have occurred over the past decade in this sub-sector including a major reduction in N_2O emission in adipic acid production. In the forecast period, chemical products are assumed to grow at different rates – the strongest growth occurs in polymer, sodium chlorate and hydrogen peroxide production. More modest growth occurs in basic petrochemicals (ethylene and propylene), ammonia and methanol production, and in chlorine and caustic soda production. This relative growth pattern structurally influences a decline in energy and direct GHG intensity. Because this sub-sector is heavily dependent on natural gas, switching options are limited, which explains why trends in GHG intensity ($t\ CO_2e/GJ$) do not change over the forecast period.

Table 3-3: Baseline GHG and Energy Intensity, Coal Mining Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	19	20	23	27	1.04%
Direct GHG Emissions ($Mt\ CO_2e$)	2	3	3	4	1.44%
Indirect GHG Emissions ($Mt\ CO_2e$)	1	1	0	0	-2.75%
Total GHG Emissions ($Mt\ CO_2e$)	3	3	3	4	0.77%
Production Physical (kt coal)	69,163	81,381	98,872	120,767	1.88%
Energy Intensity (GJ / t phys. unit)	0.28	0.25	0.23	0.22	-0.82%
GHG Intensity ($t\ CO_2e$ / t phys. unit)	0.03	0.03	0.03	0.03	-0.43%
GHG Intensity ($t\ CO_2e$ / GJ)	0.120	0.128	0.133	0.135	0.39%

Notes:

- GHG intensity indicators exclude indirect emissions.
- Base year production source: Statistics Canada, *Coal and Coke Statistics*, December 2000 Cat. 45-002, Table 3.
- Direct GHG emissions include coal-bed fugitive emissions.

The coal-mining model in CIMS encompasses open pit and underground mining in Canada, which is concentrated in the western provinces. While energy efficiency improves over the forecast period in coal mining (Table 3-3), energy intensity also declines because production is assumed to increase relatively more in Alberta, where coal undergoes less processing.[45] CIMS models British Columbia, Alberta, Saskatchewan and the Atlantic region uniquely.[46] GHG emissions in this sub-sector include fugitive coal-bed methane emissions. GHG intensity increases and indirect emissions decline due to a switch to diesel from electricity in mining operations.

The industrial minerals sub-sector (Table 3-4) describes establishments involved in the production of all non-metallic mineral products. The CIMS sub-model focuses on the production of cement and lime and represents British Columbia, Alberta, Ontario, Quebec and the Atlantic region uniquely. CO_2 emissions occur both from fossil fuel combustion and chemical reactions involved in the calcination of limestone to make cement and lime. Considerable energy efficiency gains in this sub-sector have been made in the past, including a switch to the dry kiln process. The use of waste fuel is growing in this sub-sector, and rises over the forecast period, though fossil fuel use dominates. In the forecast, structural change is limited – declining energy intensity occurs principally from continued efficiency improvements.

45 Coal in Alberta is not washed because it is used directly in electricity production.

46 B.C. produces coal for export, while coal production in other regions is mainly used directly in electricity generation.

Table 3-4: Baseline GHG and Energy Intensity, Industrial Minerals Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	80	85	98	120	1.39%
Direct GHG Emissions ($Mt\ CO_2e$)	14	15	18	22	1.55%
Indirect GHG Emissions ($Mt\ CO_2e$)	1	1	1	1	0.88%
Total GHG Emissions ($Mt\ CO_2e$)	14	16	18	23	1.53%
Production Physical (kt of clinker)	13,021	14,920	18,284	23,551	1.99%
Gross Output ($1997 millions)	1,407	1,630	2,014	2,595	2.06%
Energy Intensity (GJ / t phys. unit)	6.12	5.68	5.35	5.12	-0.60%
GHG Intensity ($t\ CO_2e$ / t phys. unit)	1.06	1.02	0.97	0.93	-0.43%
GHG Intensity ($t\ CO_2e$ / GJ)	0.173	0.179	0.181	0.182	0.16%

Note: GHG intensity indicators exclude indirect emissions.

Table 3-5: Baseline GHG and Energy Intensity, Iron and Steel Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	251	267	288	320	0.82%
Direct GHG Emissions ($Mt\ CO_2e$)	17	17	19	21	0.88%
Indirect GHG Emissions ($Mt\ CO_2e$)	1.55	1.58	1.85	2.43	1.51%
Total GHG Emissions ($Mt\ CO_2e$)	18	19	21	24	0.94%
Production Physical (kt molten steel)	16,496	18,678	21,082	23,808	1.23%
Gross Output ($1997 millions)	13,752	15,101	16,544	18,683	1.03%
Energy Intensity (GJ / t phys. unit)	15.21	14.28	13.66	13.46	-0.41%
GHG Intensity ($t\ CO_2e$ / t phys. unit)	1.00	0.93	0.90	0.90	-0.35%
GHG Intensity ($t\ CO_2e$ / GJ)	0.066	0.065	0.066	0.067	0.06%

Note: GHG intensity indicators exclude indirect emissions.

Unique regional sub-models describe iron and steel production in Ontario and Quebec (Table 3-5). CIMS assumes a movement away from integrated steel mills towards mini mills over the scenario period.[47] This contributes to the decline in energy and GHG intensity over the forecast period because the integrated process is considerably more carbon-intense: coke, a coal derivative, reduces iron oxides in ore to pig iron in a blast furnace. Basic oxygen furnaces then purify this liquid iron along with some scrap by injecting high purity oxygen, which is itself an energy-intense product. In mini mill production, electric arc furnaces recycle 100% scrap metal using electricity.

Table 3-5 includes energy contained in metallurgical coal, which is used to convert the coal to coke and then, as coke, to reduce the iron oxide in the ore to pig iron. The coke oven gas generated in the coking process is used throughout the facility as a substitute for natural gas or other fossil fuel. Direct GHG intensity based on energy (t CO_2e/GJ) increases slightly over the forecast period based on the greater use of natural gas (relative to electricity) as a fuel source for casting and finishing processes.

Table 3-6: Baseline GHG and Energy Intensity, Mining Sub-sector

	2000	**2010**	**2020**	**2030**	**Ave. Annual Change**
Energy (PJ)	104	103	103	106	0.06%
Direct GHG Emissions (Mt CO_2e)	4.2	4.0	3.9	3.9	-0.31%
Indirect GHG Emissions (Mt CO_2e)	2.9	1.79	1.81	1.91	-1.34%
Total GHG Emissions (Mt CO_2e)	7.1	5.8	5.7	5.8	-0.69%
Production Physical (kt throughput)	278,086	266,450	280,670	296,510	0.21%
Gross Output ($1997 millions)	54,270	61,737	65,614	69,317	0.82%
Energy Intensity (GJ / t phys. unit)	0.37	0.39	0.37	0.36	-0.15%
GHG Intensity (t CO_2e / t phys. unit)	0.02	0.02	0.01	0.01	-0.52%
GHG Intensity (t CO_2e / GJ)	0.041	0.039	0.037	0.037	-0.37%

Note: GHG intensity indicators exclude indirect emissions.

The mining sub-model in CIMS principally represents metal mines. Specific regional sub-models are described for British Columbia, Saskatchewan, Manitoba, Ontario, Quebec and the Atlantic region. Non-metal mines are not modelled except in Saskatchewan where potash is represented.[48] Activities related to coal mining and oil and gas extraction are covered elsewhere in CIMS.

47 This is based on information in: The Minerals and Metals Working Group of the Industry Table, *Metal Mining and Foundation Paper*, Prepared for the National Climate Change Secretariat, March 1999.

48 We do not represent other non-metals because they currently consume a relatively small percentage of total mining energy.

The energy required to extract and concentrate metals depends more on throughput and ore hardness than on the type of metal; the ore must be crushed sufficiently to release the metal for separation. Over the forecast period, the throughput to final product ratio declines, based on a shift of production from mines with high ratios to mines with low ratios. Growth rate assumptions for the various metals were based on information obtained from the *Canadian Mineral Yearbook*.[49] Iron ore mining (with a throughput to concentrate ratio of 2.7) is assumed to match anticipated world steel industry growth at 1% per year. Limited or no growth for copper-zinc and lead-zinc mines (with significantly higher ratios) is assumed due to the closure of several mines in western Canada, low copper prices, and a lack of prospective producers. Nickel is assumed to grow more strongly in part due to the anticipated opening of new mines in Atlantic Canada and the existence of several other prospective producers. The overall shift to mines with lower throughput to final product ratios influences the trend in GHG and energy intensities in Table 3-6. While overall growth in capacity is anticipated based on mine openings and closures, production levels are tied to economic factors and are difficult to forecast.

Table 3-7: Baseline GHG and Energy Intensity, Natural Gas Industry

	2000	**2010**	**2020**	**2030**	**Ave. Annual Change**
Energy (PJ)	1,121	1,195	1,413	1,664	1.32%
Direct GHG Emissions (Mt CO_2e)	56	60	71	82	1.27%
Indirect GHG Emissions (Mt CO_2e)	17	15	15	16	-0.08%
Total GHG Emissions (Mt CO_2e)	73	75	86	99	1.00%
Production Physical (1000m^3 of NG)	216,785	273,454	314,929	348,239	1.59%
Energy Intensity (GJ / 1000 m^3)	5,172.92	4,368.98	4,486.57	4,777.53	-0.26%
GHG Intensity (t CO_2e / 1000 m^3)	260.09	219.92	224.14	236.42	-0.32%
GHG Intensity (t CO_2e / GJ)	0.050	0.050	0.050	0.049	-0.05%

Note: GHG intensity indicators exclude indirect emissions.

The natural gas industry model in CIMS captures the production, processing and transmission of natural gas. Energy in Table 3-7 includes natural gas lost through leaks and venting, in addition to fuel consumption. GHG emissions consist of both combustion and fugitive emissions. Over the forecast period, the sub-sector makes steady efficiency gains in provision of natural gas to market. Little fuel switching occurs.

49 Natural Resources Canada, *Canadian Mineral Yearbook* (Ottawa: 2002).

Table 3-8: Baseline GHG and Energy Intensity, Other Manufacturing

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	672	714	775	846	0.77%
Direct GHG Emissions (Mt CO_2e)	24	27	30	32	0.94%
Indirect GHG Emissions (Mt CO_2e)	11	9	9	10	-0.33%
Total GHG Emissions (Mt CO_2e)	36	36	38	43	0.59%
Production Gross Output ($1997 millions)	126,413	159,219	196,854	214,089	1.77%
Energy Intensity (GJ / $97 million)	5,315	4,486	3,936	3,954	-0.98%
GHG Intensity (t CO_2e / $97 million)	193.50	169.23	150.29	151.33	-0.82%
GHG Intensity (t CO_2e / GJ)	0.34	0.36	0.38	0.42	0.72%

Note: GHG intensity indicators exclude indirect emissions.

The CIMS sub-model for "other manufacturing" captures those industries within a region which, on their own, do not consume enough energy to merit the development of a separate sub-model. This includes energy-intense industries that have little presence in a region, and less energy-intense industries such as food, beverage and tobacco product manufacturing, textile mills and clothing manufacturing, wood product manufacturing, printing, plastics and rubber products manufacturing, fabricated metal product manufacturing, computer and electronic product manufacturing and transportation equipment manufacturing (among others). When considered as a group, these industries may consume a significant portion of the energy within any one region.

In Table 3-8, only gross output is portrayed – other manufacturing does not have any single product which dominates the production processes and to which the production of all other products may be easily linked. Over the forecast period, emission and energy intensities (based on gross output) decline, while the direct GHG intensity of energy use increases slightly. The latter occurs due to a decrease in the share of electricity relative to fossil fuel consumption. Efficiency gains are made in heat provision and electrical auxiliary services.

Table 3-9: Baseline GHG and Energy Intensity, Petroleum Crude Extraction Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	274	859	1,137	1,334	5.42%
Direct GHG Emissions (Mt CO_2e)	53	103	126	140	3.27%
Indirect GHG Emissions (Mt CO_2e)	2	-3	-4	-4	-3.97%
Total GHG Emissions (Mt CO_2e)	55	100	122	136	3.06%
Production Physical (1,000 m^3 of pet. crude)	116,360	203,116	244,248	323,015	3.46%
Energy Intensity (GJ / m^3)	2.35	4.23	4.65	4.13	1.89%
GHG Intensity (t CO_2e / m^3)	0.46	0.51	0.51	0.43	-0.19%
GHG Intensity (t CO_2e / GJ)	0.194	0.120	0.111	0.105	-2.04%

Notes:

- GHG intensity indicators exclude indirect emissions.
- Base year crude production is from Statistics Canada, *Oil and Gas Extraction*, Cat. 26-213, Table 7 (supply and disposition of crude oil and equivalent, by source, Canada).

The petroleum crude extraction sub-model (Table 3-9) in CIMS includes conventional and unconventional light and heavy oil extraction, in situ and surface mining bitumen extraction, and upgrading. Unique regional sub-models describe activity in British Columbia, Alberta, Saskatchewan, Ontario and the Atlantic region. Emissions occur both from energy consumption and as fugitive emissions. During the forecast period, both light and heavy oil production are assumed to decline, while bitumen production (in situ and surface mining) increases and becomes the dominant crude produced in Canada.[50] Because bitumen extraction and upgrading is relatively more GHG and energy intense, energy intensity and GHG intensity increase over the first 20 years of the simulation period. This trend reverses between 2020 and 2030. During the whole simulation period, indirect emissions decline and even become negative due to a significant increase in cogeneration in the sub-sector.[51] Negative indirect emissions indicate that electricity from cogeneration is offsetting indirect emissions in other sub-sectors (as electricity is sold to the grid). Fuel used to generate this electricity is included as part of direct GHG emissions.

50 This reflects trends in: National Energy Board, *Canada's Energy Future: Supply and Demand to 2025*. (Calgary: 2003).

51 Athabasca Regional Issues Working Group, *Oil Sands Cogeneration Potential: Survey Results* (Fort McMurray, Alberta, May 2003).

Table 3-10: Baseline GHG and Energy Intensity, Petroleum Refining Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	310	288	327	375	0.64%
Direct GHG Emissions ($Mt\ CO_2e$)	18	22	26	31	1.82%
Indirect GHG Emissions ($Mt\ CO_2e$)	2	0	-1	-2	-2.25%
Total GHG Emissions ($Mt\ CO_2e$)	20	22	25	29	1.27%
Production Physical (1,000 m^3 of RPP)	92,233	102,678	114,771	126,102	1.05%
Gross Output ($1997 millions)	19,667	21,531	24,500	26,918	1.05%
Energy Intensity (GJ / m^3)	3.36	2.81	2.85	2.97	-0.41%
GHG Intensity (t CO_2e / m^3)	0.19	0.21	0.23	0.24	0.76%
GHG Intensity (t CO_2e / GJ)	0.058	0.076	0.080	0.082	1.17%

Notes:

- GHG intensity indicators exclude indirect emissions.
- RPP is refined petroleum products.
- 2000 production values were obtained from Statistics Canada, *Refined Petroleum Products*, Cat. 45-004 and are net of "producer consumption."

Unique regional sub-models describe petroleum refining in British Columbia, Alberta, Saskatchewan, Ontario and Quebec, and the Atlantic region. The refining of crude oil is a complex, energy-intensive process. The type and quality of crude and the processing requirements to generate the end products determine the refinery's complexity and have significant impact on energy consumption in the plant. The petroleum refining sub-model (Table 3-10) does not include bitumen upgrading, which is included in the crude extraction model. During the forecast period, refining production grows modestly. Direct GHG intensity increases slightly over the period, due to lower net electricity consumption.

Table 3-11: Baseline GHG and Energy Intensity, Pulp and Paper Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	901	934	986	1,068	0.57%
Direct GHG Emissions ($Mt\ CO_2e$)	12	13	15	18	1.38%
Indirect GHG Emissions ($Mt\ CO_2e$)	8	5	6	8	0.21%
Total GHG Emissions ($Mt\ CO_2e$)	20	19	21	26	0.96%
Production Physical (kt of pulp and paper)	28,569	32,585	37,232	43,121	1.38%
Gross Output ($1997 millions)	25,497	31,091	36,923	42,763	1.74%
Energy Intensity (GJ / t phys. unit)	31.54	28.68	26.47	24.77	-0.80%
GHG Intensity ($t\ CO_2e$ / t phys. unit)	0.42	0.41	0.40	0.42	0.00%
GHG Intensity ($t\ CO_2e$ / GJ)	0.013	0.014	0.015	0.017	0.81%

Note: GHG intensity indicators exclude indirect emissions.

The pulp and paper sub-model in CIMS (Table 3-11) includes market pulp, newsprint, specialty papers, paperboard, building board and other paper sub-sectors.[52] CIMS explicitly models five regions: British Columbia, Alberta, Ontario, Quebec and the Atlantic region. Energy includes fuels used in cogeneration, which is fairly significant in this sub-sector. Also, a sizable share of energy consumption is based on renewable sources – wood waste residue and spent pulping liquor (in chemical pulping). This combustion is assumed to be CO_2 neutral.

In the forecast period, growth is weaker in market pulp and newsprint, relative to value-added products. The economic availability of wood residue constrains its use as a fuel source, resulting in an increasing share of natural gas use over time, relative to renewable biomass sources. This trend drives an increase in emission intensity ($t\ CO_2e$/GJ).

The non-ferrous metal smelting and refining sub-sector (Table 3-12) represents establishments that are primarily engaged in manufacturing finished metal products excluding iron and steel. CIMS's sub-model for this sector explicitly represents processes related to aluminum, nickel, copper, zinc, lead, magnesium and titanium. Economically important but minor elements such as gold, silver, platinum, cadmium, and others are not represented explicitly because they are often processed in conjunction with the metals listed or are processed in too small a quantity to require direct representation in the model. Unique regional sub-models are described for British Columbia, Manitoba, Ontario, Quebec and the Atlantic region.

52 The above establishments are included in CIMS's sub-models because they are large in size and their products are highly energy intensive when compared to other industry products. Paper products which do not form part of the pulp and paper sub-model include: asphalt roofing, paper box and bag, and other converted paper product industries. They can be found grouped with industries in the "other manufacturing" sub-model.

Table 3-12: Baseline GHG and Energy Intensity, Non-Ferrous Metal Smelting and Refining Sub-sector

	2000	2010	2020	2030	Ave. Annual Change
Energy (PJ)	269	290	303	320	0.58%
Direct GHG Emissions ($Mt\ CO_2e$)	16	18	19	19	0.62%
Indirect GHG Emissions ($Mt\ CO_2e$)	1.11	2.29	4.13	6.25	5.94%
Total GHG Emissions ($Mt\ CO_2e$)	17	21	23	26	1.34%
Production Physical (kt refined product)	4,257	5,220	5,991	6,904	1.62%
Gross Output ($1997 millions)	15,088	19,347	23,404	26,971	1.96%
Energy Intensity (GJ / t phys. unit)	63.27	55.65	50.52	46.39	-1.03%
GHG Intensity ($t\ CO_2e$ / t phys. unit)	3.78	3.54	3.11	2.81	-0.99%
GHG Intensity ($t\ CO_2e$ / GJ)	0.060	0.064	0.062	0.061	0.04%

Notes:

- GHG intensity indicators exclude indirect emissions.
- Energy includes petroleum coke and petroleum pitch process use in aluminum electrodes.

The intensity trends in Table 3-12 reflect significant structural effects during the forecast. Relatively more production is assumed to occur in aluminum, while growth in zinc, copper, lead and nickel smelting and refining is assumed to be relatively lower.[53] Indirect emissions grow due to an increase in electricity-intense aluminum production – while electricity consumption is currently from hydro power where aluminum production is based, a larger share of electricity is assumed to be generated by fossil fuel sources over the forecast period.[54] Emissions in aluminum production are mostly process based; three GHG emissions (CO_2, carbon tetraflouride – CF_4, and carbon hexaflouride C_2F_6) are released in the electrical reduction of aluminum by smelting in Hall-Heroult cells that use carbon anodes. Some of the CO_2 associated with the production of aluminum is actually used to produce aluminum's precursor, alumina, from bauxite.

53 Production trends are based on base metal mining and aluminum growth information in: Natural Resources Canada, *Canadian Mineral Yearbook* (Ottawa: 2002).

54 The average indirect GHG emission factor calculated regionally from the CIMS electricity model is used to calculate indirect emissions. Aluminum production occurs in British Columbia and Quebec, where electricity is largely hydro-based. CIMS does not specifically model electricity generation for the aluminum sector.

GHG intensity in aluminum production (tonne of CO_2e per tonne of aluminum produced) has declined quite significantly – from 5.59 tonnes of CO_2e per tonne of aluminum in 1990 to 3.94 in 2000.[55] This decline is related primarily to the reduction of CF_4 and C_2F_6 (per fluorocarbons) in the Hall-Heroult cells. Declining intensities are assumed to continue as capacity continues to modernize.

In addition to the process emissions described for aluminum production, process emissions also occur from the use of sulphur hexaflouride (SF_6) as a cover gas to prevent oxidization in magnesium production. While emitted in small quantities, SF_6 is a potent greenhouse gas.[56] Magnesium producers have began to alter their production processes to minimize use of this gas. This trend is assumed to continue during the forecast period.

55 Canadian Industry Program for Energy Conservation, *2001/2002 Annual Report* (Ottawa: Natural Resources Canada, 2003), 35.

56 One tonne of SF_6 is equivalent to 23,900 tonnes of CO_2.

Case Study on Fiscal Policy and Energy Efficiency

Baseline Study

Prepared for
The National Round Table on the Environment and the Economy

by
M.K. Jaccard & Associates

June 2004

Working Paper

Please note that this version of the case study is slightly modified from the version previously available. The modification relates to a paragraph on page B11 dealing with aluminum electrolysis technologies.

National Round Table on the Environment and the Economy | Table ronde nationale sur l'environnement et l'économie

Table of Contents

1 Introduction

The National Round Table on the Environment and the Economy (NRTEE) has launched a program to examine ecological fiscal reform (EFR) in Canada. EFR is the systematic alignment of fiscal policy with other policy tools for the achievement of simultaneous economic and environmental objectives. After an initial phase, the EFR program is examining how to develop and promote fiscal policy that consistently and systematically reduces energy-based carbon emissions, without increasing other pollutants, both in absolute terms and as a ratio of gross domestic product (GDP) in Canada.

The current study explores the role of fiscal policy in promoting the long-term energy efficiency of Canada's industrial sector, with a view to accelerating energy efficiency in a way that leads to long-term reductions in energy-based carbon emissions. It is one of three parallel case studies, which seek to deliver pragmatic, policy-relevant recommendations on how fiscal policy can promote the development of renewables, hydrogen, and industrial energy efficiency, in a way that promotes the general program objective. The other objective of the studies is to test out approaches, processes, and methodologies that link issues of energy, climate change, technology development, and fiscal policy, with a view to generating lessons and findings in a way that informs policy development in this area.

This report encompasses the second component of the decarbonization case study, the Economic Study. The first component, the Baseline Study, examined the nature of energy efficiency and trends in Canadian industrial carbon-based emissions, and culminated in the development of a baseline carbon emission scenario. The Economic Study builds on this first study by specifically looking at energy efficiency opportunities and the role that EFR could play in promoting a decarbonized energy system.

1.1 Definitions and Concepts

A number of definitions described in the Baseline Study report also apply in this report. We repeat them here.

Industry Scope

For the purposes of the case study, industry is defined as establishments engaged in manufacturing and mining activities. Mining activities are those related to extracting naturally occurring minerals. These can be solids, such as coal and ores; liquids, such as crude petroleum; and gases, such as natural gas. Manufacturing activities involve the physical or chemical transformation of materials or substances into new products. These products may be finished, in the sense that they are ready to be used or consumed, or semi-finished, in the sense of becoming a raw material for an establishment to use in further manufacturing.[1]

Industry in this case study does not include establishments involved in electrical generation, agriculture, or in providing services.[2]

1 These activities correspond to those defined by the North American Industry Classification System (NAICS) classification 21, 31, 32 and 33. For more information on what is encompassed in these activities, see Industry Canada's Strategis website: <strategis.ic.gc.ca>.

2 We do however include the electricity sector in the modelling of carbon shadow prices to build the alternative scenarios (so that a shadow price for carbon is reflected in the price of electricity seen by the industry sector). See Section 3.2.

Decarbonization

In this document and accompanying Baseline Study, the term "decarbonization" refers to the reduction of energy-based carbon emissions, both in absolute terms and as a ratio of output, in Canada without an increase of other pollutants.[3] Carbon emissions in the numerical analysis are encompassed by a broader measurement of greenhouse gas (GHG) emissions.

Distinction between Policy and Action

In designing policies and assessing their impact and costs, it is useful to firmly distinguish an *action* from *policy*. An action is a change in equipment acquisition, equipment use rate, lifestyle or resource management practice that changes net carbon emissions from what they otherwise would be. This study focuses on energy efficiency actions from changes in technology acquisition, but considers these actions in relation to other actions to decarbonize. We can estimate the cost of an action individually or as part of a package (portfolio) of actions. The cost is the incremental change in costs (positive or negative) from undertaking the action(s). A policy, or policy instrument, is defined here as an effort by public authorities to bring about an action. In the modelling component of this case study we are careful to distinguish between the two terms. Without this distinction, it is impossible to identify the impacts of individual policies or packages of policies and actions to reduce GHG emissions.[4]

Direct, Indirect and Total GHG Emissions

In describing current and future carbon-based emissions for only one part of the economy (the industry sector) it is useful to use the concepts of direct and indirect emissions. The term *direct emissions* is used to describe emissions that are produced by a source controlled by an entity (in terms of this project, industry), while the term *indirect emissions* describes emissions that result from that entity's activity, but are produced by a source external to the entity.

When considering the impact of actions, it is important to consider the combined impact on both indirect and direct emissions, since considering only direct emissions would actually show an increase in emissions for an action like cogeneration, while considering direct and indirect emissions together would tend to show lower total emissions (depending on the carbon-intensity of utility electricity generation).

1.2 Outline of this Report

This report is structured as follows. In section 2, we explore specific energy efficiency opportunities available to industry and challenges faced in their adoption. This informs the methodology for developing alternative carbon emission forecasts, which we present, along with the forecasts, in section 3. These directly serve as the basis for an economic analysis in section 4 where we examine the cost implications of the alternative scenarios and how policy can be directed to achieve the carbon emission reductions identified in these scenarios. We conclude by forwarding policy recommendations.

3 The principal energy-based carbon emission described in this report is carbon dioxide (CO_2), which is a key greenhouse gas emission. Methane (CH_4) is also produced in fossil fuel combustion and contributes to the increase of greenhouse emissions in the atmosphere; however, its sources are primarily non-combustion based.

4 Unfortunately, these two are often confused in public discussions.

2 Energy Efficiency Potential

2.1 Energy Efficiency Opportunities

Energy use in industry can be understood in terms of generic or auxiliary services and unique processes. Generic energy services are those that are not specific to a particular industry, but focus on auxiliary systems that supply energy services to the major process equipment during their operation. These auxiliary systems fall into four general categories: steam generation systems (boilers and cogenerators), lighting, HVAC systems, and electric motor systems (pumps, fans, compressors or conveyors). In some cases, the energy service meets the direct need for heat, pumping or compression, while in other cases, it provides suitable conditions for production to continue – lighting and HVAC systems. While the latter play a relatively minor role, significant reductions can occur through energy efficiency improvements to steam and furnace systems and to electric motors and their attached auxiliary devices.

The efficiency of steam generation varies greatly depending on boiler design, age, and fuel used. Substantial energy efficiency improvements can occur by using cogenerators rather than simple steam boilers. Although substantial potential exists to improve the efficiency of electric motors, there is greater potential to improve the efficiencies of equipment driven by them – pumping, air displacement, compression, conveyance and other types of machine drive.[5]

The remaining energy efficiency opportunities are quite specific to the unique processes of each particular industry. Some industries use large amounts of heat to accomplish their activities. For instance, materials production industries, such as iron, steel, and other primary metals and building materials production, are characterized by heavy use of direct process heat for activities such as metals heating, melting, and smelting, ore agglomeration, lime and cement calcining, clay and brick firing, and glass melting. Other industries are very dependent on electricity to drive large motors (metal mining operations grind ores to release metals) or to generate or purify chemicals or metals in electrolytic cells. Energy-intense industries have typically fewer options for energy (or CO_2) reduction because the processes are straightforward and energy-intense compared to industries where many tens or hundreds of processes, each requiring only a small amount of energy, transform these semi-finished products into their final form.

Energy-efficient technologies can also be conceptualized on a timescale. Many technologies are available currently, and may have been commercialized for some time, but still could make considerable inroads. Others are poised to emerge and are currently at demonstration stages or have been applied in a relatively narrow niche (i.e., direct reduction in iron and steel). Still others have not been technically realized and are the subject of active research and development programs. Technological innovation may be either radical (disruptive) or incremental. Radical technology innovation represents a transition to a new technology or a new paradigm, which often results in changing the way people think about the product or process. Incremental innovation occurs as small and gradual innovation in existing technologies. For instance, process improvement in integrated mills, the dominant method of steel generation that uses coke in blast furnaces to reduce the iron, would represent incremental changes, while the "direct reduced iron" technologies, a new process of iron making that requires no coke ovens, can be seen as a radical innovation.

5 The latter category comprises all electrically driven equipment that is unique to a given production process.

While most of this discussion has focused on specific technologies, the manner in which one operates the process or technology can also have an impact on energy consumption. Optimizing operating procedures, equipment schedules, and general housekeeping procedures, can lead to significant energy efficiency improvements. Also, energy efficiency opportunities can be conceptualized more broadly at a systems level – for instance, by focusing the siting of industrial facilities to economically use each other's energy and material flows (industrial ecology), and in assessing energy flows along the product chain (life cycle assessment).

A detailed discussion of industrial energy efficiency opportunities is provided in Appendix B.

2.2 Challenges to Adopting Energy-Efficient Opportunities

There are numerous technical energy efficiency opportunities, a source of excitement and optimism for many. Indeed, many of these opportunities have also been shown to be cost-effective, when their monetary value of energy savings is assessed against capital costs. However, research during the past 30 years has shown that consumers and firms forgo apparently cost-effective investments in energy efficiency. Consumers and firms appear to discount future savings of energy efficiency investments at rates well in excess of market rates for borrowing or saving; in other words there is a difference between levels of investment in energy efficiency that appears cost-effective and the lower levels that actually occur.

This has often been referred to as the energy efficiency "gap," and has been the subject of debate among energy policy analysts for some time.[6] It is a critical issue for this case study, particularly in estimating an alternative carbon emissions scenario, as well as evaluating the economic cost and potential for EFR policy to influence the uptake of energy-efficient technologies.

Studies have shown that companies are sensitive to risk when it comes to investing in new, not yet commercially proven technologies, specifically with regard to a possible effect on product quality, process reliability, maintenance needs or general uncertainty about the performance of a new technology.[7] For example, in the pulp and paper sector, use of the Thermopulp process for mechanical pulp offers energy consumption savings in the range of 10-20%.[8] Nevertheless, the uptake of this technology is affected by both a brightness loss, which requires additional expenditure in bleaching chemicals, and a narrower operating window and therefore tighter control requirements.[9]

New technologies can carry a greater potential for premature failure. When making irreversible investments that can be delayed, the presence of this uncertainty can lead to a significant investment hurdle rate. The investor perceives a gain in value while postponing investment and waiting for

6 For example, see A. Jaffe and R. Stavins, "The Energy-Efficiency Gap: What Does it Mean?" *Energy Policy 22*, 10 (1994): 804-810; J. Scheraga, "Energy and the Environment: Something New under the Sun?" *Energy Policy 22*, 10 (1994): 811-818; R. Sutherland, "The Economics of Energy Conservation Policy," *Energy Policy* 24, 4 (1996): 361-370.

7 See: Office of Technology Assessment, U.S. Congress, *Industrial Energy Efficiency* (Washington, D.C.: U.S. Government Printing Office, 1993).

8 The Thermopulp process is a variation of the thermo-mechanical pulping process whereby pulp from the primary stage refiner is subject to a high temperature treatment for a short time in a "thermo-mixer" and in the subsequent secondary refiner. See Appendix B for a more complete description.

9 E. Cannel, "Mechanical Pulping Technologies Focus on Reducing Refining Energy," *Pulp and Paper* (May 1999). Retrieved on-line: <http://www.pponline.com/db_area/archive/p_p_mag/1999/9905/contents.htm>.

additional information to inform the decision ("option value").[10] The effect grows when energy and technology price uncertainty is increased and technology costs are falling more quickly.[11] Different consumers in different locations will face varying acquisition, installation and operating costs, and equipment will be more appropriate in some situations than others. For instance, if a piece of equipment is used rarely, there is less incentive to invest in an energy-efficient model. Analysis based on single estimates will inevitably lead to an "optimal" level of energy efficiency that is too high for some portion of purchasers.[12]

Understanding the potential for firms to make energy efficiency improvements is clearly complex. Further challenges are involved in considering how the uptake of energy-efficient technologies would influence total energy consumption and carbon emissions.

2.3 Challenges in Linking Energy Efficiency to Long-term Energy Consumption and Decarbonization

Even if energy efficiency opportunities are adopted in greater numbers, how may this impact total energy consumption and decarbonization? Achievement of the latter is complicated by several factors. First, as noted in the Baseline Study, pursuing energy efficiency can be relevant to decarbonization; one must keep in mind that primary fuels differ substantially in terms of their carbon emissions per unit of energy consumed. For instance, a producer could switch from a low-efficiency oil boiler to a high-efficiency oil boiler, or to a high-efficiency natural gas boiler. The ultimate choice has a different impact on carbon emissions.

Of significant importance too are the "second order" feedbacks that would occur in the economy. This includes the interaction between the energy demand and supply sectors of the economy, and shifts in the demand for final and intermediate products as their costs of production change. For instance, the widespread adoption of high-efficiency electric motor and auxiliary systems would affect the demand for electricity, with potential price impacts that would affect energy-related decisions throughout the economy. In cases where energy-efficient technologies achieve substantial market penetration, the resulting lower cost of energy services elicits a rebound effect of increased energy service demand and thus greater energy consumption. This can lead to a substantial adjustment of the estimated gains from energy efficiency. The magnitude of the rebound effect is contentious, however, with estimates ranging widely depending on the energy service in question.[13] A recent study, which used econometric analysis to explore the rebound effect in the U.S. manufacturing sector, estimated the rebound effect to be 24%.[14] In general, economists point out

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10 R. Pindyck, "Irreversibility, Uncertainty and Investment," *Journal of Economic Literature* 29, 3 (1991): 1110-1152.

11 Jaffe and Stavins, "The Energy-Efficiency Gap: What Does it Mean?"

12 M. Jaccard, J. Nyboer and A. Fogwill, "How Big is the Electricity Conservation Potential in Industry?" *The Energy Journal* 14, 2 (1993): 139-156; Jaffe, Newell and Stavins, *Energy Efficient Technologies and Climate Change Policies: Issues and Evidence.*

13 In 2000, an entire issue of *Energy Policy* was devoted to research on the rebound effect; for an overview, see L. Schipper, ed., "On the Rebound: The Interaction of Energy Efficiency, Energy Use and Economic Activity," *Energy Policy* 28, 6-7 (2000): 351-354. See also M. Jaccard and C. Bataille, "Estimating Future Elasticities of Substitution for the Rebound Debate," *Energy Policy* 28 (2000): 451-455.

14 J. Bentzen, "Estimating the Rebound Effect in US Manufacturing Energy Consumption," *Energy Economics* 26 (2004) 123-134. The author's method of calculating an aggregate production function from historical data has trouble detecting all long-run effects. See M. Jaccard, J. Nyboer, C. Bataille and B. Sadownik, "Modelling the Cost of Climate Policy: Distinguishing Between Alternative Cost Definitions and Long-Run Cost Dynamics," *The Energy Journal* 21, 1 (2003): 49-73.

that aggregate improvements in energy productivity (energy efficiency) have been associated with technological change and economic growth, and that these productivity gains encourage the use of more energy.[15]

3 Alternative Forecasts

3.1 The Use of Models to Estimate Energy Efficiency Potential

A variety of energy-economy models can be used to estimate how changes in the energy efficiency, fuel type or emission controls of technologies could lead to different levels of GHG emissions. Of these, those with detailed technological representation are most applicable to modelling the case studies in this NRTEE research agenda. Typically, in an energy efficiency analysis, technologies (boilers, light bulbs, electric motors) that provide the same energy service (heating, lighting, industrial motive force) are generally assumed to be perfect substitutes except for differences in their financial costs and their emissions of GHGs and other pollutants. When their financial costs (capital and operating) in different time periods are converted into present value using a social discount rate, many current and emerging technologies available for reducing GHG emissions appear to be profitable or just slightly more expensive relative to existing equipment. These analyses often show that substantial GHG emission reduction can be profitable or low-cost were these low-emission technologies to increase from their small market share to achieve market dominance.[16]

Nevertheless, these types of analyses overlook the complexities of adopting energy-efficient technologies by focusing on a single, ex ante (anticipated) estimate of financial cost.[17] An assessment of an alternative scenario that examines the adoption of energy efficiency by industry needs to explicitly acknowledge the "efficiency gap" issues highlighted in section 2.2. An energy-economy model that is behaviourally explicit will provide a more realistic estimate of decarbonization potential. A model also needs to be technologically explicit. In industry this means that the unique technologies, processes and technological interactions of that sector's diverse sub-sectors should be adequately represented. It is also important that a model be integrated between supply and demand sectors because price feedbacks matter in terms of adjustments caused by technical change in one sector.

3.2 Development of Alternative Scenarios

These concerns have guided the development of the CIMS model. This model was used to develop the baseline forecasts in the Baseline Study, and is used in the Economic Study to develop the alternative scenarios.

15 R. Ayres, L. Ayres, and B. Warr, "Energy, Power and Work in the US Economy, 1900-1998," *Energy* 28 (2003): 219-273.

16 For examples, see: M. Brown, M. Levine, J. Romm, A. Rosenfeld and J. Koomey, "Engineering-Economic Studies of Energy Technologies to Reduce Greenhouse Gas Emissions: Opportunities and Challenges," *Annual Review of Energy and the Environment* 23 (1998): 287-385; A. Lovins and H. Lovins, "Least-Cost Climate Stabilization," *Annual Review of Energy and the Environment* 16 (1991): 433-531.

17 Ex ante is Latin for "beforehand." In models where there is uncertainty that is resolved during the course of events, the ex ante values (e.g., of expected gain) are those that are calculated in advance of the resolution of uncertainty.

CIMS was described in some detail in the Baseline Study (section 3.2). We focus here on the methodology for developing the alternative scenarios.

Methodology

The CIMS model allows the analyst to explore an "achievable" potential, rather than that which may be only technically feasible. Energy efficiency actions (as represented by technologies that produce less carbon emissions) are adopted in the model according to the technology competition step outlined in Step 3 of the CIMS simulation (section 3.2, Baseline Study). This competition seeks to represent firm purchasing decisions based not only on minimization of annualized life cycle costs, but also on performance preferences, cost hetereogeneity, option value and failure risks.

Simulating a carbon emission shadow price in the industrial sector sub-models in CIMS can indicate the emission reduction potential from energy efficiency actions. This methodology is based on the principle that the goal of decarbonization would drive the formulation of an alternative GHG scenario (as simulated by a shadow price for carbon), which would indicate what role energy efficiency investments could play in decarbonization amongst other options – fuel switching, reducing fugitive emissions, reducing process emissions, and CO_2 capture and storage. Carbon abatement actions occur up to the specified marginal abatement cost for carbon.

Because CIMS describes energy services in flow models which show the sequence of activities required to generate particular products or services (see section 3.1, Baseline Study), efficiency actions can be modelled in an integrated way. This approach is important because as the literature on energy efficiency has consistently shown, a focus on individual energy efficiency actions in isolation will produce different estimates of efficiency potential and cost than will an integrated systems approach. Energy efficiency actions are often interrelated and only a systems approach can explore this interplay.[18]

For this study, two alternative forecasts, *low carbon I* and *low carbon II*, are produced by simulating two different shadow prices over a 25-year simulation period (2005-2030). In addition to applying this shadow price to the industry sector sub-models, we also apply the price to the electricity sector so that a carbon price can be reflected in the electricity price used to evaluate technology investment decisions in the industry sub-sector models.[19] In both cases investment patterns and energy flows change from their baseline evolution to produce a forecast with lower carbon emissions. We model a price of \$15/tonne CO_2e in low carbon I, and \$30/tonne CO_2e in low carbon II to influence a shift in investment patterns in CIMS, which reflects relatively modest "achievable potential" that could be influenced by EFR policy.

Although the energy price and demand feedback functions are included in the simulation, we were requested not to incorporate the macro-economic feedback function in CIMS. This was done to maintain consistency with the other two decarbonization case studies. The NRTEE may use the outputs from the case studies as inputs to a macro-economic model at a later stage in its research

18 For example, for any competing devices that consume both steam and electricity (directly and through auxiliary services) in differing ratios, a change in electricity price, electricity demand or the cost of an auxiliary service would affect steam demand.

19 As described in Step 5 of the CIMS simulation description (section 3.2, Baseline Study), these simulations include integrated feedbacks between energy demand and supply, although these are only applied in the case of coal and electricity to maintain consistency with modelling analysis assumptions in National Climate Change Process "roll-up" studies.

program. This often creates methodological inconsistencies because of differences in macro-models and a technology-rich model, such as CIMS. An alternative would be to simulate this and other decarbonization actions/policies with CIMS.[20]

This project considers a longer timeline than is typically conducted in most GHG emission analysis (which has been focused on the Kyoto target of six to eight years). Emerging technologies have a greater ability to gain market acceptance in a 25-year time frame. In order to capture the long-term promotion of these technologies through R&D and commercialization support, we adjust the "intangible costs" in the model in the alternative scenarios to reflect a more targeted commercialization effort. These adjustments were made to the following technologies:

Table 3-1: Emerging Technologies

Sector	Technology
Aluminum	Inert anodes / Wetted cathodes
Chemicals	New catalysts
Iron & steel Iron & steel	Thin and strip slab casting Direct-reduced iron
Industrial minerals	Fluidized bed kilns
Pulp and paper Pulp and paper	High-intensity drying Black liquor gasification
Metals	Hydrometallurgy (nickel)

3.3 Results / Discussion – Alternative Scenarios

Table 3-2 summarizes the results of the low carbon I and low carbon II scenarios relative to the scenario presented in the Baseline Study. The low carbon I and II scenarios result in GHG reductions of 46 Mt CO_2e and 58 Mt CO_2e by 2030. Though the shadow price doubles between the two scenarios (from a \$15/t CO_2e to a \$30/t CO_2e price), only 26% more reductions result from an increase in price. This non-linear relationship between the shadow price and emission reductions reflects the relative cost of actions that underly the results.[21]

Direct emissions make up most of these emission reductions, though the response of indirect emissions to the imposition of a shadow price is stronger than the response of direct emissions

20 See, for example: M. Jaccard, N. Rivers and M. Horne, *The Morning After: Optimal GHG Policies for Canada's Kyoto Commitment and Beyond* (Toronto: C.D. Howe Institute, 2004).

21 For more information on these relationships, see: M.K. Jaccard & Associates Inc., *Construction and Analysis of Sectoral, Regional and National Cost Curves of GHG Abatement in Canada,* Prepared for the Office of Energy Efficiency, Natural Resources Canada, Ottawa, March 2003; and M.K. Jaccard & Associates Inc., *Construction and Analysis of Sectoral, Regional and National Cost Curves of GHG Abatement in Canada*, Prepared for Cost Curves Working Group, Analysis and Modelling Group, National Climate Change Implementation Process, March 2002. In these studies, the CIMS model was used to develop cost curves of emission reductions relative to a series of shadow prices (from \$10 to levels of \$250 t /CO_2e). Cost curves were developed for regions, sub-sectors, and Canada as a whole.

(indirect emissions decline by 53-62% in 2030, while direct emissions only decline by 5-7%). Actions behind this strong indirect response include the greater adoption of cogeneration systems and actions that improve the overall efficiency of auxiliary motor systems.

Results for individual sub-sectors are shown in Tables 3-3 to 3-13. Only total emissions are shown (sum of direct and indirect). For each sector we show the relative trends in direct GHG intensities (t CO_2e/GJ) and energy intensities (GJ/physical production) in each simulation. These indicators suggest the relative role of energy efficiency compared to fuel switching in the results. However, for some sectors these are not clearcut. For instance, changes in the energy intensity indicator also represent saved natural gas from leak programs (natural gas extraction sector), and changes in the GHG intensity indicator represent changes to process emissions (metal smelting, chemical products, iron and steel) and fugitive emissions (upstream oil and gas sectors, coal mining). In the chemical products and the pulp and paper sectors, total emissions decline in the low carbon I and II scenarios despite increasing energy consumption. This is due to the increased adoption of cogeneration, which results in increases in total energy, which offset by indirect emissions savings associated with cogenerated electricity.

Energy efficiency actions figure among a variety of different types of actions in the GHG reductions in each sub-sector. The upstream oil and gas sector, which is responsible for significant emission reductions in each time period, makes many reductions through actions that curtail fugitive emissions.[22] The metal smelting and refining sector, petroleum refining, and iron and steel sub-sectors contribute the most emission reductions due to improved energy efficiency in the alternative scenario simulations.

The decarbonization potential described in the alternative scenarios are likely conservative based on the following.

1. Neither operating and maintenance actions nor all industrial ecology relationships are included in this analysis.[23]
2. Over a long forecast horizon, emerging technology options may see their capital costs decline through market deployment. Also, these technologies may become more attractive to firms as their prevalence in the economy increases. These factors are not incorporated into this analysis.
3. Future radical technology innovation cannot be anticipated by the model. Rather, the model represents the greater deployment of current and emerging technologies (though some, such as direct reduced iron, represent radical innovation).

22 Fugitive emissions are the intentional or unintentional releases of GHGs from the production, processing, transmission, storage and delivery of fossil fuels. Releases include some carbon dioxide but the bulk is methane, a more powerful GHG.

23 CIMS can model improved operating and maintenance practices if exogenous estimates of potential are provided, but does not include such estimates in the version used in this study. CIMS is currently limited in its ability to portray all potential industrial ecology relationships (for instance steam transfers between industry sub-sectors).

Employing higher carbon prices in the alternative scenario would result in more significant emission reductions, although cost-curve analysis using CIMS suggests that the potential for additional emission reductions diminishes past a shadow price of $50/tonne CO_2e.[24] Nevertheless, it is important to consider that higher shadow prices would potentially have a stronger effect in inducing technological innovation in low-carbon and energy-efficient technologies (through both radical and incremental innovation), increasing the potential for long-term decarbonization. Also, shifts would likely occur in the specific types of products produced by industry towards those requiring less carbon-intense inputs.

Table 3-2: GHG Emissions and Energy for Alternative Scenarios, Canada

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	288	343	396	453
Low Carbon I	288	322	365	407
Low Carbon II	288	316	355	395
Direct GHG Emissions (Mt CO_2e)				
BAU	237	307	358	407
Low Carbon I	237	292	339	386
Low Carbon II	237	293	335	378
Indirect GHG Emissions (Mt CO_2e)				
BAU	50	36	38	46
Low Carbon I	50	29	26	22
Low Carbon II	50	23	20	17
Energy (PJ)				
BAU	4,239	5,030	5,783	6,579
Low Carbon I	4,239	4,822	5,537	6,298
Low Carbon II	4,239	4,818	5,497	6,232

24 M.K. Jaccard & Associates, *Construction and Analysis of Sectoral, Regional and National Cost Curves of GHG Abatement in Canada*, Prepared for the Office of Energy Efficiency, Natural Resources Canada, Ottawa, March 2003, 24.

Table 3-3: Emissions, Energy and Intensity Indicators, Chemical Products Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	24	26	32	38
Low Carbon I	24	21	25	31
Low Carbon II	24	21	25	30
Total Energy (PJ)				
BAU	236.7	272.9	327.8	398.5
Low Carbon I	236.7	287.4	352.6	433.8
Low Carbon II	236.7	281.6	346.9	433.4
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.08	0.09	0.09	0.08
Low Carbon I	0.08	0.09	0.09	0.09
Low Carbon II	0.08	0.09	0.09	0.09
Energy Intensity (GJ / t chemical)				
BAU	14.7	13.3	12.7	12.3
Low Carbon I	14.7	14.0	13.7	13.4
Low Carbon II	14.7	13.8	13.4	13.4

Table 3-4: Emissions, Energy and Intensity Indicators, Coal Mining Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	3.1	3.2	3.4	3.9
Low Carbon I	3.1	2.8	2.7	3.0
Low Carbon II	3.1	2.2	2.2	2.5
Total Energy (PJ)				
BAU	19.5	20.4	22.7	26.6
Low Carbon I	19.5	18.8	19.9	23.0
Low Carbon II	19.5	15.6	16.9	20.7
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.12	0.13	0.13	0.14
Low Carbon I	0.12	0.12	0.11	0.12
Low Carbon II	0.12	0.12	0.11	0.11
Energy Intensity (GJ / t coal)				
BAU	0.3	0.3	0.2	0.2
Low Carbon I	0.3	0.2	0.2	0.2
Low Carbon II	0.3	0.2	0.2	0.2

Note: Reductions in GHG emissions also occur through demand reductions (as a result of demand and supply feedbacks between the sub-models that demand coal and the coal mining sub-model).

Table 3-5: Emissions, Energy and Intensity Indicators, Industrial Minerals Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	14.4	15.8	18.4	22.7
Low Carbon I	14.4	14.6	16.6	20.6
Low Carbon II	14.4	14.7	15.2	18.2
Total Energy (PJ)				
BAU	79.7	84.8	97.9	120.5
Low Carbon I	79.7	81.3	92.8	114.7
Low Carbon II	79.7	81.5	89.1	108.0
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.17	0.18	0.18	0.18
Low Carbon I	0.17	0.18	0.18	0.18
Low Carbon II	0.17	0.18	0.17	0.17
Energy Intensity (GJ / t clinker)				
BAU	6.1	5.7	5.4	5.1
Low Carbon I	6.1	5.4	5.1	4.9
Low Carbon II	6.1	5.5	4.9	4.6

Table 3-6: Emissions, Energy and Intensity Indicators, Iron and Steel Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	18.1	19.0	20.9	23.9
Low Carbon I	18.1	18.4	19.7	22.2
Low Carbon II	18.1	18.4	19.6	22.1
Total Energy (PJ)				
BAU	250.9	266.6	288.0	320.4
Low Carbon I	250.9	252.7	261.3	281.3
Low Carbon II	250.9	253.1	260.8	280.0
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.07	0.07	0.07	0.07
Low Carbon I	0.07	0.07	0.07	0.07
Low Carbon II	0.07	0.07	0.07	0.07
Energy Intensity (GJ / t steel)				
BAU	15.2	14.3	13.7	13.5
Low Carbon I	15.2	13.5	12.4	11.8
Low Carbon II	15.2	13.5	12.4	11.8

Table 3-7: Emissions, Energy and Intensity Indicators, Mining Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	7.1	5.8	5.7	5.8
Low Carbon I	7.1	5.6	5.4	5.4
Low Carbon II	7.1	5.6	5.4	5.3
Total Energy (PJ)				
BAU	103.7	102.6	103.1	105.8
Low Carbon I	103.7	100.4	99.1	100.6
Low Carbon II	103.7	100.5	98.7	99.7
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.04	0.04	0.04	0.037
Low Carbon I	0.04	0.04	0.04	0.036
Low Carbon II	0.04	0.04	0.04	0.035
Energy Intensity (GJ / t throughput)				
BAU	0.4	0.4	0.4	0.4
Low Carbon I	0.4	0.4	0.4	0.3
Low Carbon II	0.4	0.4	0.4	0.3

Table 3-8: Emissions, Energy and Intensity Indicators, Natural Gas Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	73.2	75.3	86.1	98.7
Low Carbon I	73.2	66.3	74.4	86.0
Low Carbon II	73.2	66.2	73.8	84.5
Total Energy (PJ)				
BAU	1,121.4	1,194.7	1,413.0	1,663.7
Low Carbon I	1,121.4	1,046.2	1,220.7	1,461.6
Low Carbon II	1,121.4	1,044.4	1,207.4	1,431.4
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.05	0.05	0.05	0.05
Low Carbon I	0.05	0.05	0.05	0.05
Low Carbon II	0.05	0.05	0.05	0.05
Energy Intensity (GJ / 1000m^3)				
BAU	5.2	4.4	4.5	4.8
Low Carbon I	5.2	3.8	3.9	4.2
Low Carbon II	5.2	3.8	3.8	4.1

Table 3-9: Emissions, Energy and Intensity Indicators, Other Manufacturing Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	35.6	35.6	38.3	42.5
Low Carbon I	35.6	32.9	35.6	39.6
Low Carbon II	35.6	33.3	35.5	39.2
Total Energy (PJ)				
BAU	671.9	714.2	774.8	846.4
Low Carbon I	671.9	708.3	764.8	833.2
Low Carbon II	671.9	708.9	764.4	832.0
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.34	0.36	0.38	0.42
Low Carbon I	0.34	0.35	0.38	0.41
Low Carbon II	0.34	0.35	0.38	0.41
Energy Intensity (GJ / $97 million)				
BAU	5,314.9	4,486.0	3,935.9	3,953.7
Low Carbon I	5,314.9	4,448.4	3,884.9	3,892.0
Low Carbon II	5,314.9	4,452.6	3,883.2	3,886.2

Table 3-10: Emissions, Energy and Intensity Indicators, Petroleum Crude Extraction Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	55.1	100.0	121.7	135.9
Low Carbon I	55.1	104.7	124.1	132.2
Low Carbon II	55.1	99.4	119.0	129.2
Total Energy (PJ)				
BAU	273.7	858.5	1,136.5	1,334.0
Low Carbon I	273.7	827.1	1,104.2	1,305.6
Low Carbon II	273.7	834.7	1,093.5	1,282.5
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.19	0.12	0.11	0.10
Low Carbon I	0.19	0.12	0.11	0.11
Low Carbon II	0.19	0.12	0.11	0.11
Energy Intensity (GJ / m^3)				
BAU	2.4	4.2	4.7	4.1
Low Carbon I	2.4	4.1	4.5	4.0
Low Carbon II	2.4	4.1	4.5	4.0

Table 3-11: Emissions, Energy and Intensity Indicators, Petroleum Refining Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	19.9	21.9	25.1	29.1
Low Carbon I	19.9	21.8	24.7	28.4
Low Carbon II	19.9	21.8	24.5	28.1
Total Energy (PJ)				
BAU	310.0	288.3	327.3	374.9
Low Carbon I	310.0	287.8	325.8	370.8
Low Carbon II	310.0	287.6	325.5	370.5
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.06	0.08	0.08	0.08
Low Carbon I	0.06	0.07	0.08	0.08
Low Carbon II	0.06	0.08	0.08	0.08
Energy Intensity (GJ / m^3)				
BAU	3.4	2.8	2.9	3.0
Low Carbon I	3.4	2.8	2.8	2.9
Low Carbon II	3.4	2.8	2.8	2.9

Table 3-12: Emissions, Energy and Intensity Indicators, Pulp and Paper Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	19.7	18.5	21.2	26.3
Low Carbon I	19.7	15.2	16.8	20.3
Low Carbon II	19.7	14.6	14.7	17.0
Total Energy (PJ)				
BAU	901.2	934	986	1,068
Low Carbon I	901.2	929	1,007	1,100
Low Carbon II	901.2	928	1,005	1,101
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.01	0.01	0.02	0.02
Low Carbon I	0.01	0.01	0.01	0.01
Low Carbon II	0.01	0.01	0.01	0.01
Energy Intensity (GJ / t product)				
BAU	31.5	28.7	26.5	24.8
Low Carbon I	31.5	28.5	27.0	25.5
Low Carbon II	31.5	28.5	27.0	25.5

Table 3 13: Emissions, Energy and Intensity Indicators, Non-Ferrous Metal Smelting and Refining Sector

	2000	2010	2020	2030
Total GHG Emissions (Mt CO_2e)				
BAU	17.2	20.8	22.8	25.6
Low Carbon I	17.2	18.9	20.3	22.0
Low Carbon II	17.2	18.8	19.9	21.3
Total Energy (PJ)				
BAU	269.4	290.5	302.6	320.3
Low Carbon I	269.4	282.1	286.6	296.3
Low Carbon II	269.4	281.7	285.2	293.9
GHG Intensity (t direct CO_2e / GJ)				
BAU	0.06	0.06	0.06	0.06
Low Carbon I	0.06	0.06	0.06	0.06
Low Carbon II	0.06	0.06	0.06	0.05
Energy Intensity (GJ / t product)				
BAU	63.3	55.6	50.5	46.4
Low Carbon I	63.3	54.0	47.8	42.9
Low Carbon II	63.3	54.0	47.6	42.6

4 Economic and Policy Analysis

The alternative scenario simulations revealed that up to 58 Mt CO_2e could be reduced by 2030. These changes are brought about by a combination of actions that represent changes in equipment acquisition, leading to greater energy efficiency by industry. We estimate the cost of these actions for each industry sub-sector and qualitatively discuss co-benefits. We then turn to examining what the modelling results suggest about EFR policy, and more specifically, how the choice of policy tools could influence the cost and ability to achieve the reductions (economic and environmental effectiveness). We also more broadly consider issues in EFR policy choice and design directed at decarbonization in the industry sector.

4.1 Economic Analysis Methodology

As noted, the actions that underlie the decarbonization in the alternative scenarios are the basis for a detailed economic analysis.

Detailed Costing Methodology

We calculate ex ante financial costs, which are the difference in the net present value of capital, energy and operating and maintenance costs in 2004 (Cdn $2000) discounted at a social discount rate, for the period 2005-2030 between the baseline and each of the alternative scenarios.[25] The

25 Ex ante financial costs describe single point estimates of the anticipated financial cost differences of technologies, which do not include estimates of risk. For a discussion of alternative cost definitions used in modelling, see: Jaccard et al., "Modelling the Cost of Climate Policy: Distinguishing Between Alternative Cost Definitions and Long-Run Cost Dynamics."

capital costs that are reported are the new purchase and retrofit "sticker price" expenditures over the 10-year span. If, however, the life of a piece of equipment extends beyond 2030, the capital costs include only the costs occurring up to 2030. Operations and energy costs are yearly costs over the 25-year span.

4.2 Results/Discussion – Economic Analysis

Ex ante financial costs for both alternative scenarios are summarized in Table 4-1. All industry sub-sectors show negative costs because the value of energy savings (discounted to 2004 at a rate 10%) is greater than any increase in upfront capital costs in adopting these measures. Welfare costs may be, and usually are, much higher and are embodied in the technology choices of firms and households.

Table 4-1: Ex ante Financial Costs for 2005–2030 ($ billions)

	Low Carbon I	Low Carbon II
Chemical Products	-4.98	-4.04
Coal Mining	-0.99	-2.19
Industrial Minerals	-1.16	-2.08
Iron and Steel	-1.84	-1.93
Metal Smelting and Refining	-1.42	-1.76
Mining	-0.26	-0.59
Other Manufacturing	-1.92	-2.75
Petroleum Crude Extraction	-0.04	-0.03
Petroleum Refining	-0.19	-0.38
Pulp and Paper	-3.39	-4.80
Natural Gas Industry	-1.45	-4.32
Total	-17.64	-24.87

Note: These figure are reported in $2004.

Because the CIMS simulation did not incorporate macro-economic feedbacks (Step 5 of the CIMS simulation), the results provide only a partial equilibrium portrayal of the response to the shadow price of CO_2e. Aggregate, macro-economic effects include trade and structural repercussions resulting from changes in energy prices, and in turn the prices of other intermediate and final products. Where energy-efficient technologies achieve substantial market penetration, the resulting lower cost of energy services could also elicit a rebound effect of increased energy service demand and thus greater energy consumption.

4.3 Co-benefits

The environmental objective of this case study is focused on the future level of energy-based carbon emissions. This goal seeks to address concerns associated with these emissions and our ability to meet current and future international climate change commitments. In addition, pursuing decarbonization by targeting these actions may help to address a number of other policy issues including concerns regarding energy security, local environment and innovation.

Because declining energy intensity will reduce the energy costs per unit of service output, economic growth will be less constrained by future energy costs, and economic growth will be more resilient to fluctuations in the price of energy, contributing to greater energy security. Energy security may also be enhanced by the extension of Canada's available supply of non-renewable fossil fuel resources, depending on whether conserved fuel is saved or exported.

Reductions may also contribute to reducing environmental externalities that are linked not only to a reduction in carbon emissions, but also to harm associated with other ongoing impacts and risks that relate to the interaction of fossil fuel-related activities with air, water and land. This includes the negative health effects associated with poor urban air quality influenced by the release of criteria air contaminants (CACs). While a reduction in fossil fuel consumption usually leads to a reduction in CACs, this is not always the case, for instance if biomass use increases or if CACs are fugitive or process-based rather than simply fuel-based. Even if CACS are reduced, this does not always produce a net benefit.[26] Unlike GHG emissions, the negative impact of which is indifferent to location, the impact of these CAC changes on ambient air quality depends on the location of the emissions and their proximity to population centres.

Promoting greater energy efficiency can support Canada's innovation goals by enhancing Canadian expertise and manufacturing in energy-efficient technologies. The Government of Canada emphasizes that innovation is becoming increasingly important in Canada's knowledge-based economy. Innovation of efficient technologies will enable Canada to reduce its GHG emission abatement costs per unit of economic output, and enable Canada to attain more ambitious GHG emissions abatement targets without compromising economic performance.[27] However, one should consider innovation in energy efficiency against other investments – investments in energy efficiency may "crowd out" investments that otherwise would have occurred and that may have done even better at increasing productivity through innovation.

Successful technological innovation is also an opportunity to increase exports of energy-efficient technologies, the demand for which will likely increase as the international community pursues climate change policies.[28] This can occur to the extent that Canadian firms become developers of new technology, rather than acquiring needed technology through machinery and equipment imports and other vehicles of technology acquisition such as foreign direct investment and the hiring of foreign expertise. The latter has been more typical.[29]

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26 D. Burtraw and M. Toman, "Ancillary Benefits of Greenhouse Gas Mitigation Policies," in M. Toman (ed.), *Climate Change Economics and Policy: An RFF Anthology* (Washington, D.C.: Resources for the Future, 2001), 80-92.

27 Government of Canada, "Achieving Excellence: Investing in People, Knowledge and Opportunity" (Ottawa: Industry Canada, February 2002).

28 Technology Issues Table, *Enhancing Technology Innovation for Mitigating Greenhouse Gas Emissions* (Ottawa: National Climate Change Process, December 1999).

29 Industry Table, *Overview Report, Options Paper* (Ottawa: National Climate Change Process, 2000), 7.

4.4 EFR Policy Tools

The redirection of a government's taxation and expenditure programs to support the shift to a decarbonized energy system can make use of many fiscal instruments, both in combination and in conjunction with other types of policy instruments such as voluntarism, and informational and regulatory tools. EFR, as defined by the NRTEE, is a broad approach, which can employ suites of instruments in a reinforcing package to support the shift to sustainable development. As described in the report *Toward a Canadian Agenda for Ecological Fiscal Reform: First Steps*, the common purpose of these instruments is to provide incentives for producers and consumers to alter their decisions and behaviour – either internalizing environmental costs or to reward more sustainable practices.[30] We relate three key policy tools to the modelling analysis: the application of environmental taxes, tradable permits (as part of market-oriented regulation), and subsidies. The first two tools internalize environmental costs, while subsidies reward more sustainable practices. Later, we discuss the relative merit of these tools as a policy package.

Environmental Taxes and Tax Shifting

The modelling results directly suggest the application of a GHG tax – a charge paid on each fossil fuel, proportional to the quantity of GHGs emitted when it is burned.[31] The Low Carbon I scenario describes a tax of \$15/tonne CO_2e and the Low Carbon II scenario represents a tax of \$30/tonne CO_2e, equivalent to the shadow price imposed in the model simulations. However, because the carbon price was applied to all GHG emissions represented in the industry sub-sectors (including process and fugitive emissions), non-fuel combustion emissions were also subjected to the shadow price, and the results would overestimate the impact relative to a tax applied strictly to fuel combustion. A GHG tax applied across the industry sector prompts each sub-sector to increase or decrease its emission reduction efforts until each is facing the identical incremental cost for the next unit of reduction. Ideally, the magnitude of the tax would reflect the magnitude of environmental damage caused. For example, the carbon content of a fuel might be used as a proxy for its contribution to climate change. Taxes that meet this requirement are sometimes referred to as "Pigouvian" taxes.[32]

A number of specific environmental taxes could be applied to pursue decarbonization objectives:

1. A *carbon tax* is a charge to be paid on each fossil fuel, proportional to the quantity of carbon emitted when it is burned. A *CO_2 tax* is specified per tonne of CO_2 emitted instead of carbon, and a GHG tax also applied to other GHG emissions that result from fuel combustion.[33]
2. An *energy tax* depends on the quantity of energy consumed, and is specified in some common unit. While an energy tax can influence energy efficiency actions, it could be onerous for zero CO_2 fuels like wind power.

30 National Round Table on the Environment and the Economy, *Toward a Canadian Agenda for Ecological Fiscal Reform: First Steps* (Ottawa: 2002), 5.

31 A CO_2 tax is specified per tonne of CO_2 emitted instead of carbon. It can be easily translated into a carbon tax – 1 tonne of carbon corresponds to 3.67 tonnes of CO_2. A GHG tax covers other GHGs, and is measured in tonnes of CO_2e.

32 A Pigouvian tax is a tax levied on each unit of a polluter's output in an amount just equal to the marginal damage it inflicts at the efficient level of output.

33 It can be easily translated into a carbon tax – 1 tonne of carbon corresponds to 3.67 tonnes of CO_2.

Revenues from environmental taxes can be used for different purposes, for instance as part of general revenues, ear marked to specific environmental projects, as rebates, or to reduce other taxes. Each option has different costs to different members and sectors of the economy. In practice, environmental tax design has used varying degrees of refunds, differentials in the tax rates applied to industry and households, and exemptions to address equity and competitiveness concerns.

Tradable Permits (Market-Oriented Regulation)

An important area of policy innovation has been in the development of market-oriented regulation, which allows individual flexibility in terms of achieving a compulsory limit or requirement. Unlike traditional command-and-control regulation, the manner of participation is at the discretion of the firm or household (whether to reduce emissions or acquire the designated technology, or pay others to do so). Tradable permits (rights to discharge pollution) can be exchanged through either a free or a controlled permit market.[34]

The model results suggest an emissions cap and tradable permit (ECTP) system applied to all industry with auctioned permits, with a cap equivalent to the emission levels reported in the alternative scenarios – 407 Mt CO_2e in 2030 in Low Carbon I, and 395 Mt CO_2e in Low Carbon II (Table 3-2). The tradable permit prices correspond with the shadow prices applied in those simulations ($15/tonne CO_2e and $30/tonne CO_2e respectively). In ECTP systems, government sets a maximum level of emissions (a cap), then allocates tradable emission permits to all emitters covered by the program. Usually the permits decrease in number or value over time, gradually lowering the aggregate emissions cap.

Considerable design options exist with ECTP systems including how permits are allocated (auctioning or grandfathering or a mix of the two) and target participants (single sector, whole economy). Market-oriented regulation can also focus on technologies and energy forms by specifying the desirable market outcome, rather than the environmental outcome.[35] In California, automobile manufacturers are required to guarantee that a minimum percentage of vehicle sales meet different categories of maximum emission levels. To some extent, there is flexibility in these requirements (timing, trading among participants) in order to minimize the costs of compliance.

A Renewable Portfolio Standard (RPS), which requires providers of electricity to guarantee that a minimum percentage of their electricity is produced using renewable energy, has been applied in many countries.[36] An RPS can also be extended to include electricity produced more efficiently by cogeneration (an "Electricity Emissions Standard"), as many European states are currently exploring, and as the Walloon region in Belgium currently practises.

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34 Those whose pollution abatement costs are relatively high have an incentive to bid for the permits. Permit buyers therefore tend to produce more emissions that permit sellers, yet overall environmental standards remain unaltered because just enough permits are issued to achieve the standard in aggregate.

35 M. Jaccard and Y. Mao, "Making Markets Work Better," in T. Johansson and J. Goldemberg (eds.), *Energy for Sustainable Development: A Policy Agenda* (New York: United Nations Development Programme, 2002).

36 T. Berry and M. Jaccard, "The Renewable Portfolio Standard: Design Considerations and an Implementation Survey," *Energy Policy* 29 (2001): 263-277.

Subsidies

EFR can support decarbonization through the removal or redirection of existing subsidies, and through the provision of new subsidies. Financial support in the form of direct grants, guaranteed or low interest rate loans and tax incentives can be used to directly support the greater adoption of energy-efficient technologies, and the long-term research and development efforts of new energy-efficient technologies. Also, EFR can remove or lower subsidies to fuels that currently lead to an inefficient energy supply mix and prices, which may discourage energy-efficient technology development and adoption.[37]

The alternative scenarios could suggest the impact of a subsidy program that is perfectly designed to target cost-effective actions. Although a complete assessment of actions that underlie the modelling results was not undertaken, GHG reductions are focused in the following industry sub-sectors: pulp and paper, metal smelting, industrial minerals, and natural gas. These reduction potentials do not isolate the potential from energy efficiency actions. Targeting only energy efficiency opportunities (not fuel-switching, for instance) would result in a smaller impact.

The size of the incentive required to target the actions inherent in the model simulation can be estimated by calculating the perceived private costs of the alternative scenarios. This is done by calculating the area under a curve which plots cumulative emission reductions against rising CO_2e shadow prices. The area under the resulting marginal cost curve, up to the shadow price of the alternative scenario, represents the compensation required to have firms undertake actions that they would not have undertaken otherwise (their perceived private cost). These costs reflect cost heterogeneity, risk, option value, and the qualitative and quantitative advantages of technology choices, as well as the financial costs (or benefits) associated with the change in technologies. We create marginal cost curves for each year of the simulation by conducting multiple CIMS runs at different CO_2e shadow price levels, and then determining the emission reductions (both direct and indirect) achieved at each price level. Costs calculated from the area under the curve are discounted to 2005 using a 10% discount rate. Table 4-2 shows these perceived private cost estimates for the alternative scenarios.

37 Particularly relevant to this case study is the greater hurdle that energy efficiency options face when assessed based on a subsidized (lower) energy price.

Table 4-2: Cost of Incentive (Perceived Private Cost) for 2005–2030 ($ billions)

	Low Carbon I	Low Carbon II
Chemical Products	0.528	1.284
Coal Mining	0.026	0.104
Industrial Minerals	0.047	0.194
Iron and Steel	0.070	0.158
Metal Smelting and Refining	0.124	0.309
Mining	0.015	0.036
Other Manufacturing	0.189	0.436
Petroleum Crude Extraction	0.101	0.093
Petroleum Refining	0.003	0.026
Pulp and Paper	0.203	0.608
Natural Gas Extraction	0.707	1.636
Total	2.012	4.885

Note: These figures are reported in $2004.

The cost estimates in Table 4-2 do not include expenditures required to subsidize firms that would have undertaken to purchase energy-efficient technologies in the baseline ("free riders"). Evaluations of energy efficiency incentive programs suggest that the share of free riders can be significant. For instance, an evaluation of the Dutch Energy Bonus found that the subsidy measure seemed to suffer from a considerable "free-rider effect" in the order of 85% of the energy savings.[38] This was echoed by a similar assessment of the effectiveness of U.S. utility demand side management (DSM) programs, as well as earlier empirical studies.[39] In a recent study, CIMS was utilized to estimate the impact of subsidy programs aimed at industrial auxiliary technologies (pumps, conveyors, compressors and motors) as well as on equipment in the residential sector like refrigerators and clothes washers, and on equipment in the commercial sector like lighting and cooling technologies. The results showed the free-rider share to range from 40% to 82% of the subsidy recipients and depended on the type of end use and the magnitude of the subsidy – the share of free riders declined at higher subsidies.[40]

For example, in one of the study's simulations, the most efficient classes of pumps were given a subsidy level equivalent to 20% of the capital cost. The total adoption of new efficient pumps in 2010 in the subsidy simulation was 5,193 pumps. In comparison, when no subsidy was offered, the

38 J. Farla and K. Blok, "Energy Conservation Investments of Firms:" *Industrial Energy Efficiency Policies: Understanding Success and Failure,* workshop organized by the International Network for Energy Demand Analysis in the Industrial Sector, Utrecht University, Netherlands, November 1998. The energy bonus was a large-scale tax credit subsidy scheme in the Netherlands that existed between 1980 and 1988 for stimulating energy efficiency improvement and renewable energy.

39 See: D. Loughran and J. Kulick, "Demand-Side Management and Energy Efficiency in the United States," *The Energy Journal* 25, #1 (2004): 19-40. This DSM study examined data from 324 utilities spanning 11 years and found that DSM expenditures do poorly at targeting consumers on the margin of making energy efficiency investments, and for this reason most utilities overstated the effectiveness and understated the costs of these programs. For earlier empirical investigations of DSM programs, see: D. Waldman and M. Ozog, "Natural and Incentive-Induced Conservation in Voluntary Energy Management Programs," *Southern Economic Journal* 62, 4 (1996): 1054-71; K. Train, "Incentives for Energy Conservation in the Commercial and Industrial Sectors," *The Energy Journal* 9, 3 (1988): 113-28.

40 M.K. Jaccard & Associates Inc., "Comparison of How Absolute vs. Intensity-based GHG Emissions Reduction Strategies Might Affect Energy Efficiency Actions and Programs," prepared for Natural Resources Canada, 2004.

total adoption of efficient pumps was only 3,767 pumps. Seventy four percent of firms are calculated to be free-riders in the subsidy simulation. This high level of free-ridership occurs because the subsidy must be paid not only to the incremental 5,193 – 3,767 = 1,426 firms who bought efficient pumps when the subsidy was implemented, but also to the 3,767 firms who would have bought efficient pumps even in the absence of the subsidy, because there is no way to distinguish between these two groups when administering the subsidy program. These 3,767 free-riders increase the cost of the subsidy program without contributing to its effectiveness.

Potential avenues for new subsidies may be as direct financial transfers (as grants or preferential / low-interest loans) or through tax incentives, for instance the expansion of CCA 43.1 to include more energy efficiency technologies. A subsidy's effectiveness depends significantly on program design. Financial incentives can be directed to reduce the upfront or the operating costs of energy-efficient investments, and can be based on prescriptive or custom (performance-based) criteria. Subsidies directed at upfront capital costs recognize that the higher capital cost of energy-efficient technologies can be a deterrent to investment. An empirical study of the behaviour of industrial firms with regard to cogeneration investments found that investment subsidies are likely to be as much as nine times as effective on a per dollar of subsidy basis as production subsidies.[41] However, measures that target upfront costs are not based on the actual performance of the investment to meet the desired policy objective, and may not be as effective in meeting the environmental objective. Performance-based subsidies can be more flexible in allowing firms to meet "demonstrated" improvements in energy efficiency or carbon emission reduction.

The design of subsidies also needs to consider the differences in how firms may respond to incentive tools.[42] Small and medium-sized enterprises do not have the same access to capital to make use of tax incentives and are likely to require shorter pay-back periods for investments in energy efficiency. These firms may find loans, loan-guarantees, and interest rate subsidization programs more valuable, as well as support through private sector incentive mechanisms such as energy performance contracts, leases and venture capital.[43] The use of revolving loans programs to finance energy-efficient and other environmental investments by municipalities has gained popularity in Canada, and could be applied in an industry context.[44] Revolving loan funds circulate capital among many borrowers in order to finance many projects over several years. A program is established with seed money, which constitutes a base from which the revolving fund makes loans.

Considerable options exist in the design of such a fund, for instance, the use of commercial financial institutions, scope of objective (a fund may have a broader environmental objective or pertain specifically to efficiency projects) and the degree to which technical-economic analysis is

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41 N. Rivers, *Behavioural Realism in a Technology Explicit Energy-Economy Model: The Adoption of Industrial Cogeneration in Canada,* Energy and Materials Research Group, Simon Fraser University; Prepared for the Office of Energy Efficiency, Natural Resources Canada, September 2003.

42 R. Elliott and M. Pye, "Investing in Industrial Innovation: A Response to Climate Change," *Energy Policy* 26, 5 (1998): 417.

43 Energy performance contracts are a form of third-party financing, in which energy service companies (ESCOs) provide technical expertise and financing for energy efficiency investments, with a guarantee of reductions in energy costs. ESCOs can lower the difficulties of selecting and installing new energy-efficient equipment, which may otherwise seem prohibitive compared to the simplicity of buying energy. See: Interlaboratory Working Group, *Scenarios for a Clean Energy Future* (Oak Ridge, TN; Oak Ridge National Laboratory and Berkeley, CA; Lawrence Berkeley National Laboratory, 2000) 5.22.

44 The Government of Canada established two complementary funds to stimulate investment in innovative municipal infrastructure projects and environmental practices for Canadian municipal governments and their public and private sector partners. The funds leverage investments from municipal, provincial and territorial governments, and stimulate public and private partnerships.

carried out in-house or outsourced. An Energy Efficiency Fund Practitioner Workshop sponsored by the World Bank noted that this type of program is useful when market-based prices and supporting government policy create a demand for energy efficiency projects.[45] Other recommendations include:

- having a clear objective that will guide fund organization and operation;
- maximizing the transparency of procedures to minimize government interference in financing decisions;
- keeping it simple and avoiding complex procedures and structures; and
- using third parties such as energy service companies to market and develop project for the fund, avoiding high transaction costs.

4.5 Policy Design

The relative emphasis on certain policy tools, and the ultimate design of a policy package, involves many considerations. For instance, what may be most economically efficient or effective in realizing environmental benefits may be difficult from a standpoint of administrative feasibility or political acceptability. To address these tradeoffs, we consider the policy tools against criteria of: effectiveness at achieving environmental targets, economic efficiency, administrative feasibility, and political acceptability. In this discussion we draw on extensive literature on this topic that has developed in recent decades in the context of climate change mitigation policy.[46]

Many other design considerations, such as competitiveness, distributional and budgetary impacts, require detailed empirical analysis. We do not do this here, but do offer a general discussion of these considerations.[47]

Effectiveness at Reaching Environmental Targets/Objective

Because an ECTP specifies the emission reduction, this type of policy tool would be most effective in realizing a specific environmental objective. In the case of a subsidy, sufficient reductions may not be realized if the subsidy is too low, or not directed properly. In the case of an environmental tax, the level of the tax must be high enough to achieve the intended environmental objective. In both cases, poor design can weaken the intended policy impacts. It is also important to consider that the imposition of reform measures does not take place in a static world, and other factors may overwhelm expected impacts of the reform. Broad-based economic instruments (taxes and permit systems) are more efficient than subsidies in preventing the rebound effect. The cost of using polluting forms of energy – if properly designed to reflect the specific damages of each form of energy – remains high so that firms and consumers must turn to alternatives.

45 Energy Efficiency Operational Exchange Program, World Bank, *Energy Efficiency Fund Practitioners Workshop: Workshop Summary* (Washington, D.C.: The World Bank, 2000), 12.

46 For a survey of domestic policy design issues, see: chapter 8 in M. Jaccard, J. Nyboer and B. Sadownik, *The Cost of Climate Policy* (Vancouver, UBC Press, 2002).

47 We have explored these issues using the macro-economic function in CIMS in other studies.

Economic Effectiveness

Of the tools available as part of an EFR program to promote decarbonization, the imposition of a uniform carbon tax or an emissions cap and tradable permit system is theoretically the most efficient way of achieving a decarbonization objective because of its inherent flexibility in stimulating the least expensive reductions throughout the economy to be undertaken first – agents make reductions only up to the point where it is cost-effective to do so. A tax or permit price policy is more efficient than a subsidy because the subsidy may be captured by firms with higher costs of reduction (unless it is allocated via a bidding process). Another downside of a subsidy is that they can require large public expenditures per unit of effect since firms that would have undertaken to purchase energy-efficient technologies in the absence of the subsidy, are now subsidized for their purchases (free-riders). In a time of fiscal constraints on public spending, this raises questions about the feasibility of subsidies that would be sizable enough to have the desired effect.[48] Also, a subsidy requires that revenue be raised somewhere else in the economy, which can also produce dead-weight losses.[49]

Administrative Feasibility

Different approaches to market-oriented regulation and subsidies can have different administrative costs. For instance, an emissions cap and permit trading system is more administratively complex the wider its scope, particularly if it covers small firms. High administrative complexity occurs with detailed and inventive schemes that attempt to address competitiveness, distributional concerns and increase the political acceptability of a policy. A lack of disaggregate statistical data can make the development, and monitoring of focused "sub-sector specific" policies more difficult.

Tax incentive systems that specifically promote energy-efficient investments can be difficult to target precisely, and therefore difficult to administer. It is often problematic for industries to segregate expenditures for energy efficiency from other process-related expenditures. From a policy standpoint, what constitutes energy-efficient activities needs to be monitored and strict compliance guidelines erected. If government chooses to target only specific classes of equipment, significant data and resources are required to keep this list current.

In addition to administrative costs borne by government, there may be time and cost burdens for firms in applying for grants and loans and in submitting tax credit claims. This may be particularly burdensome for smaller firms. For instance, a Finance Canada study found that compliance costs for small firms equalled 15% of the value of the R&D tax credit compared to 5.5% for larger firms.[50] Firm transaction costs will depend significantly on audience target and subsidy design. Transaction costs may be incurred by participants in completing a trade of allowances and receiving regulatory approval from trade in ECTP systems. However, these costs may be relatively low – the market for SO_2 allowances in the U.S. helped demonstrate that the private sector can play an important role in minimizing these costs, particularly those of identifying partners and negotiating a trade. Entrepreneurs have stepped in to make available a variety of services, including private brokerage, electronic bulletin boards, and allowance price forecasts.[51]

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48 Jaffe, Newell and Stavins, *Energy Efficient Technologies and Climate Change Policies*, 11.

49 IPCC (Intergovernmental Panel on Climate Change), *Climate Change 2001: Mitigation.* Metz, Bert, Ogunlade Davidson, Rob Swart and Jiahua Pan (eds.), *Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2001)

50 Finance Canada, *The Federal System of Income Tax Incentives for Scientific Research and Experimental Development* (Ottawa: 1998).

51 Robert N. Stavins, "What Can We Learn from the Grand Policy Experiment? Lessons from SO2 Allowance Trading," *Journal of Economic Perspectives* 12, 3 (1998): 69-88.

Political Acceptability

Political acceptability factors will need to be balanced against goals of environmental effectiveness and economic efficiency, which, as noted above, are theoretically met by a broad-based economic instrument such as a CO_2 tax or an ECTP. Concern about political acceptability has limited the use of policy tools such as green taxes to achieve decarbonization ends, even in countries where they are currently applied. The use of subsidy policies attempts to circumvent the politically dangerous act of imposing costs on firms by instead enhancing the competitiveness of selected lower-carbon emitting technologies by improving the financial returns for producers and the prospect for these less established technologies to compete with more established forms. However, the government must acquire the funds from somewhere else in the economy – with perhaps significant effects on efficiency and overall competitiveness – and as such they have not escaped criticism. Tax incentives have the advantage of being a less visible form of public subsidy since their effect is to reduce government tax revenues rather than increasing direct financial transfers.

Industry groups have argued for voluntary and tax incentive approaches in the debate about climate change policy. They have also argued that any tax or fiscal measures that are introduced to accelerate climate change action must be situated within an overall framework that is consistent with the broad fiscal and economic direction for the country. For instance, the Industry Table of the National Climate Change Process stated in its Options Paper that it is important that such measures not detract from the needed focus on tax reform and reducing the burden of taxation on Canadian business and individual Canadians.[52] The position of many industry associations and umbrella organizations is that the tax system that applies to industries in Canada must allow firms to be competitive in the international marketplace, and that the recent tax reform does not go far enough in removing barriers that inhibit competitiveness.[53]

Distributional and Competitiveness Issues

With a CO_2 tax or emissions cap and tradable permit, the manner of participation is at the discretion of the firm. It can make changes within its own firm up to which it is cost effective to do so, and buy emission permits or pay the tax where it is not. Competitiveness impacts will arise if the policy imposes different levels of costs on competing firms, either because countries have different policies, regulations are different among domestic firms, or simply because firms have different specific carbon intensities, substitution possibilities and trade levels.

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52 Industry Table, *Industrial Table Overview Report, National Climate Change Process*, Ottawa, 2000. The NCCP was formed as a forum assessing the social, economic and environmental implications of policies and programs to develop the National Implementation Strategy in response to Canada's Kyoto commitments. For this task, the NCCP created, in the spring of 1998, numerous sector and issue-based working groups, known as Issue Tables, as part of a National Engagement Process to provide advice, obtain information and assess implementation options available to Canada to reduce GHG emissions in order to meet a Kyoto-based target. Over the subsequent two years, the Issue Tables outlined various alternatives and avenues of potential emissions reduction in Options Papers.

53 A Five-Year Federal Tax Reduction Plan was instituted after the elimination of the deficit, with anticipated tax reductions of $10.1 billion to corporate taxes between 2000 and 2005. This encompassed a fall in the corporate tax rate from 28% to 21% by 2004 for non-resource income and 2007 for resource income. Ontario, Alberta, New Brunswick and Manitoba are currently, or are planning, corporate tax rate cuts. Also, some provinces are reducing or eliminating capital taxes.

Policy design is critical in minimizing distributional and competitiveness impacts. A policy instrument can lead to indirect costs that either offset or accentuate the direct costs of reducing emissions. For example, a subsidy could be financed by different means of revenue collection, each with different costs to different members and sectors of the economy. Likewise, the revenue from a CO_2 tax could be dealt with by government in many different ways (debt reduction, other tax reductions, increased social program expenditures), each with different costs to different members and sectors of the economy. In the development of EFR reforms in Europe, governments addressed distributional and competitiveness concerns by using varying degree of refunds, differentials in the tax rates applied to industry and households, and exemptions.

Tax shifting as a strategy can bring about winners and losers in the industry sector due to the heterogeneous makeup of the sector in which firms employ varying mixes of capital, energy and labour in production. An alternative use of tax revenues may be to earmark funds to projects that assist in the adaptation to the new prices. In the case of an emissions cap and tradable permit program, the cost of the permits will ultimately be reflected in the cost of energy (or other activities) to the extent that the production and use of energy requires the acquisition of emission permits. Thus, the price of gasoline, heating oil, natural gas and even electricity (if produced by energy sources that emit GHG emissions) will increase to reflect the cost of permit acquisition and/or technology changes, raising distributional and competitiveness issues.

Innovative policy design could be used to avoid these price impacts, for instance, sector-specific market-oriented regulation can minimize average price increases because only a small percent of the market is devoted to the newer, higher cost technologies, and manufacturers will average these costs with their lower cost, conventional technologies in determining prices. Thus, producers are provided with the long-run signal that will induce technological change without the politically unacceptable act of substantially raising energy prices in a short period of time. In the case of subsidies and tax credits to support favoured technologies, it is difficult to judge the distributional and competitiveness impacts. Support programs may require that undesirable and/or regressive taxes be higher than they otherwise need to be in order to offset the resulting lost government tax revenue. Because the percentage of free-riders in subsidy programs is high, subsidies can have significant redistribution impacts by transferring money from taxpayers to program participants.

Technological Innovation

The level of technological innovation of environmentally related technologies will be below the theoretically social optimal in the presence of externalities, such as environmental damages. This argues for the use of environmental taxes and market-based instruments that internalize this externality and provide a "pull" to innovation and deployment. Other policies that support innovation directly by raising the expected private returns by lowering the costs of doing R&D – for instance subsidizing R&D expenditures, encouraging joint ventures – may be most valuable at the earliest stage of deployment.[54] However, subsidies run the risk of supporting private R&D that would have happened anyway and supporting inappropriate technologies.

54 T. Foxon, *Inducing Innovation for a Low-Carbon Future: Drivers, Barriers and Policies* (London, U.K.: The Carbon Trust, 2003).

5 Conclusions and Recommendations

The potential for industrial energy efficiency actions to contribute to the decarbonization of the energy system is complex. This potential depends on the degree to which the technical potential can be further developed through innovation; the degree to which energy efficiency technology and habits can be adopted; the degree to which this adoption translates into reduced aggregate energy use; and the carbon intensity of conserved energy. The adoption of energy efficiency as a means to lower energy-based carbon emissions in industry is complicated by the fact that energy efficiency is only one among a number of options that industry can use to reduce carbon-based emissions. Other possibilities include switching away from fossil fuels, switching from high carbon fossil fuels to low carbon fossil fuels and capturing and sequestering carbon emissions. Due to this complexity, this case study chose to consider the role of energy efficiency and its influence on decarbonizing the energy system in conjunction with other options available.

In forwarding policy recommendations in this case study, it is important to consider the degree to which EFR policy should specifically focus on the promotion of industrial energy efficiency in itself, relative to a broader focus on the objective of decarbonization. The alternative scenario simulations demonstrate that improved energy efficiency in industry is closely interrelated with fuel switching and other means of carbon emission reduction, suggesting that it should be considered amongst other actions to move towards a decarbonized energy system. Focusing on energy efficiency alone as the means to achieving decarbonization in industry may run the risk of orienting incentives and efforts in a direction that is not cost-effective.[55]

While we have described specific policy tools in the context of the modelling results and have noted a number of design considerations for each tool, no one policy tool is optimal in its performance against criteria of environmental effectiveness, economic efficiency, administrative feasibility and political acceptability. Using a portfolio of policy instruments can enable a government to combine the strengths, while compensating for the weaknesses, of individual policy instruments. Such a policy package should focus on measures that might be politically acceptable today while nonetheless influencing technological innovation. Considerable potential exists to use EFR to create conditions under which “winners” can emerge and attract sufficient investment in order to develop and be widely adopted.

With this in mind, we offer the following policy design recommendations:

- *Tradable permits as part of market-oriented regulation should be emphasized in driving fundamental change.* Long-term progress towards a decarbonized energy system requires key changes in the financial incentives facing firms. This can best be provided by market-oriented regulation, which can drive profound technological change including reductions in the costs of emerging technologies. The principles of an emissions cap and tradable permit system can be applied at the sectoral level for setting targets for emissions, energy forms or technologies.
- *A complementary role can be played for by subsidies to support energy-efficient technologies.* Subsidies score well on political acceptability and may be effective if designed carefully and with an understanding of relative costs in different sectors and activities in the economy. Nevertheless, the impact and cost (including free-rider costs) should be realistically assessed in the design of

55 Jaffe, Newel and Stavins, *Energy Efficient Technologies and Climate Change Policies*, 13.

any program. A revolving loan fund program may be a good candidate by virtue of its relatively small financial outlay. Tax credits and grants should also be designed to minimize government's role in picking technologies by being more performance-based.

These recommendations should build on current energy efficiency programs and climate change policy (as surveyed in the background section of the Baseline Study). In particular, our recommendation supports the continued development of the domestic ECTP currently being formulated for Large Final Emitters. Nevertheless, a fixed emission reduction approach would be more effective compared to an intensity-based approach in promoting technological innovation and in realizing aggregate emission reductions. An expectation of a rising permit ceiling would also be useful in spurring technological development.

There is also a history of policy support in promoting energy efficiency through information and awareness programs, and in subsidies for research and development. Voluntary programs not only have laid the groundwork for ERF policies in stimulating awareness of decarbonization opportunities, but also provide needed complements to any new EFR policy initiatives that are developed. For instance, CIPEC, which is the central federal framework mechanism for coordinating the development of industrial energy efficiency goals, is an institution that could provide the target groups with know-how about how to respond most cost effectively to the EFR programs that enhance price signals to decarbonize. Similarly, subsidies are most effectively framed in a broader network and support system. Finally, there may be a role too for EFR to connect with traditional command-and-control policy. While EFR policy can drive technological gains, standards that phase out the sale of inefficient equipment can serve to consolidate change. Standards may be economically efficient and effective in cases where sources of emissions are relatively similar and where monitoring and enforcement is difficult and costly.[56]

56 See: R. Newell and R. Stavins, "Cost Heterogeneity and the Potential Savings of Market Based Policies," *Journal of Regulatory Economics* 23, 1 (2003): 43-59; D. Cole and P. Grossman, "When is Command and Control Efficient? Institutions, Technology, and the Comparative Efficiency of Alternative Regulatory Regimes for Environmental Protection." *Wisconsin Law Review*, 5 (1999): 887-938.

Case Study on Fiscal Policy and Energy Efficiency

Baseline Study

Appendix A:
CIMS Model Details

1 Introduction

In this appendix, we describe key input parameters and assumptions in the modelling analysis (section 2) and provide a more detailed description of the underlying structure of CIMS, including an example of an industry sub-sector flow model (section 3) and the technology competition algorithm (section 4). We also provide a qualitative discussion of uncertainty (section 5).

2 Key Inputs

Key inputs include the physical energy conversion and emission factors used in the CIMS model, as well as forecasts relating to macro-economic growth and energy prices. The physical and economic production growth forecasts are described in the baseline summary result tables in the main report (Tables 3-2 to 3-12). The remaining inputs are summarized in the tables below.

Table A-1: Physical Energy Conversion and Fuel Emission Factor Assumptions

Fuel Type	**Physical Unit**	**Physical Conversion Factor (TJ / unit)**	**CO_2 (t / unit)**	**CH_4 (g / unit)**	**N_2O (g / unit)**
Canadian Bituminous Coal	tonne	26	1.85	0.03	0.02
Canadian Lignite Coal	tonne	15	1.49	0.03	0.02
Foreign Bituminous Coal	tonne	29.82	2.4	0.03	0.02
Foreign Anthracite Coal	tonne	27.7	2.39	0.03	0.02
Coal Coke	tonne	28.83	2.48	0.03	0.02
Coke Oven Gas	000 m^3	19.14	1.6	0.037	0.035
Petroleum Coke	m^3	38.65	3.8	0.1	0.053
Still Gas	m^3 HFOequiv	42.5	2	0.037	0.002
Heavy Fuel Oil	m^3	42.5	3.09	0.12	0.064
Propane	m^3	25.31	1.5	0.024	0.108
LPG	m^3	27.12	1.5	0.024	0.108
Natural Gas	000 m^3	37.99	1.89	0.037	0.033
Wood	tonne	18	0.95	0.05	0.02
Spent Pulping Liquor	tonne	14	1.43	0.05	0.02

Notes:

- Factors are assumed to be constant over the forecast period.
- Biomass (wood and spent pulping liquor) is assumed to be CO_2 neutral.
- Table Sources: Physical Conversion Factors – Statistics Canada, *Quarterly Report on Energy Supply and Demand 2000*, Cat. 57-003 XIB (Ottawa: 2001). Emissions Factors – Environment Canada, *Canada's Greenhouse Gas Inventory: 1990-2001* (Ottawa, 2003), Annex 6.

Table A-2: Average Indirect GHG Emissions Factors (tonnes CO_2e / TJ)

	2000	2010	2020	2030
Alberta	240.33	216.58	183.10	161.06
Atlantic region	77.25	76.07	76.71	76.89
British Columbia	15.37	18.02	30.17	40.16
Manitoba	4.16	18.28	27.25	31.98
Ontario	72.82	61.22	61.12	69.86
Quebec	0.67	5.85	12.47	18.86
Saskatchewan	244.64	199.22	177.98	160.86

Notes:

- GHG emissions include CO_2, CH_4 and N_2O.
- Base year (2000) emission factors are from Natural Resources Canada and are based on Statistics Canada, *Electric Power Generation, Transmission and Distribution*, Cat.#57-202-XPB. Other years are calculated from the CIMS electricity model baseline forecast.

Table A-3: Real Fuel Prices in CIMS Industry Sub-models ($1995/GJ)

	Coal & Coke	Diesel	Natural Gas	HFO	Electricity	LPG
Alberta						
2000-2005	2.85	12.59	1.40	4.21	14.56	9.05
2005-2010	2.80	12.40	1.47	4.09	14.34	8.89
2010-2015	2.79	12.28	1.47	4.08	14.11	8.84
2015-2020	2.79	12.08	1.47	4.03	13.81	8.84
2020-2025	2.79	11.74	1.40	3.99	13.76	8.84
2025-2030	2.79	11.54	1.38	3.95	13.59	8.84
Atlantic Region						
2000-2005	2.86	15.68	4.05	3.62	14.65	9.05
2005-2010	2.82	15.46	4.06	3.50	14.42	8.89
2010-2015	2.80	15.28	4.01	3.47	14.19	8.84
2015-2020	2.77	15.01	3.96	3.42	13.89	8.84
2020-2025	2.77	14.46	3.73	3.37	13.53	8.84
2025-2030	2.77	14.17	3.64	3.32	13.28	8.84
British Columbia						
2000-2005	2.40	14.33	1.67	3.45	10.67	9.05
2005-2010	2.36	14.13	1.73	3.34	10.50	8.89
2010-2015	2.34	13.99	1.72	3.33	10.34	8.84
2015-2020	2.32	13.76	1.71	3.29	10.12	8.84
2020-2025	2.32	13.39	1.53	3.27	9.94	8.84
2025-2030	2.32	13.16	1.48	3.24	9.78	8.84

Table A-3: cont'd

	Coal & Coke	Diesel	Natural Gas	HFO	Electricity	LPG
Manitoba						
2000-2005	1.44	13.07	3.36	3.61	10.52	9.05
2005-2010	1.42	12.88	3.41	3.50	10.36	8.89
2010-2015	1.41	12.74	3.38	3.48	10.20	8.84
2015-2020	1.40	12.54	3.36	3.44	9.98	8.84
2020-2025	1.40	12.12	3.25	3.40	9.68	8.84
2025-2030	1.40	11.89	3.20	3.35	9.49	8.84
Ontario						
2000-2005	2.11	13.69	3.30	3.89	12.42	9.05
2005-2010	2.08	13.47	3.32	3.77	12.23	8.89
2010-2015	2.07	13.31	3.27	3.74	12.04	8.84
2015-2020	2.05	13.08	3.22	3.69	11.78	8.84
2020-2025	2.05	12.62	3.07	3.67	9.63	8.84
2025-2030	2.05	12.37	3.00	3.63	8.81	8.84
Quebec						
2000-2005	3.71	15.21	4.05	4.18	10.18	9.05
2005-2010	3.65	14.96	4.06	4.04	10.02	8.89
2010-2015	3.62	14.79	4.01	4.01	9.86	8.84
2015-2020	3.59	14.54	3.96	3.96	9.65	8.84
2020-2025	3.59	14.07	3.73	4.08	9.35	8.84
2025-2030	3.59	13.80	3.64	4.07	9.16	8.84
Saskatchewan						
2000-2005	2.81	13.89	2.21	4.00	14.27	9.05
2005-2010	2.77	13.69	2.26	4.00	3.89	8.89
2010-2015	2.75	13.53	2.24	3.87	13.83	8.84
2015-2020	2.72	13.31	2.22	3.82	13.54	8.84
2020-2025	2.72	12.90	1.98	3.76	13.26	8.84
2025-2030	2.72	12.66	1.91	3.71	13.03	8.84

Notes:

- Based on data in: Analysis and Modelling Group, *Canada's Emissions Outlook: An Update* (Ottawa: National Climate Change Process, 2000). Their forecast applied to 2020. For 2020 onwards we extrapolated prices based on linear assumptions.
- Although natural prices are lower than the current reality, the natural gas forecast was kept to allow consistency with other national analysis based on the macro-economic assumptions in *Canada's Emissions Outlook: An Update.*

3 Industry Flow Models in CIMS

In CIMS, the product and energy service demands in a sub-sector are linked in a flow model that describes the sequence of activities required to generate that product. Because of the heterogeneity of equipment and processes, major industrial sub-sectors each have their own flow models.[1] An example of an industry sub-sector flow model is shown in Figure A-1 on the next page. A CIMS flow model is geared towards representing technology evolution and energy consumption rather than economic criteria (as in an econometric model where units are typically in monetary terms) or actual mechanical processes (as in the blueprints or process flow diagrams used by engineers). Because the emphasis is on energy consumption and not material flow, the nodes in the flow model represent process stages in which energy consumption can be distinctly estimated.

The flow model describes the hierarchical nodes, which are linked by engineering ratios translated into CIMS computer format. The unshaded boxes indicate the energy services where technology competitions take place. Not all nodes are applicable to each region, and technology stock may not necessarily be represented at some nodes.

1 While the CIMS industrial sector has great technological detail, its level of sectoral disaggregation is much less than for a typical macro-economic model. This is because a few, energy-intensive sectors are represented in great detail while the rest of the economy, including the entire service sector, is lumped into a single, aggregate sector.

Figure A-1: Energy Flow Model of the Iron and Steel Industry

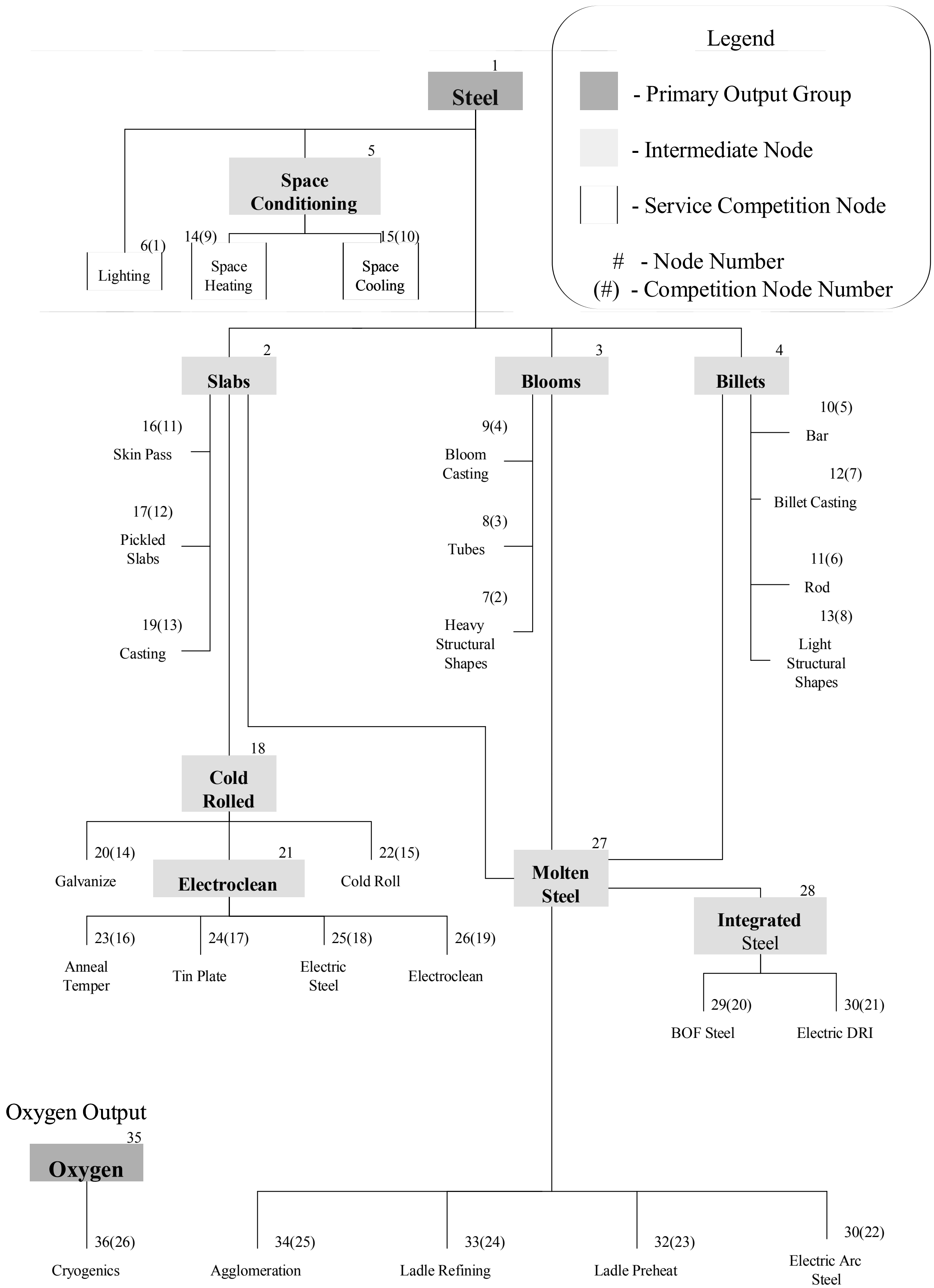
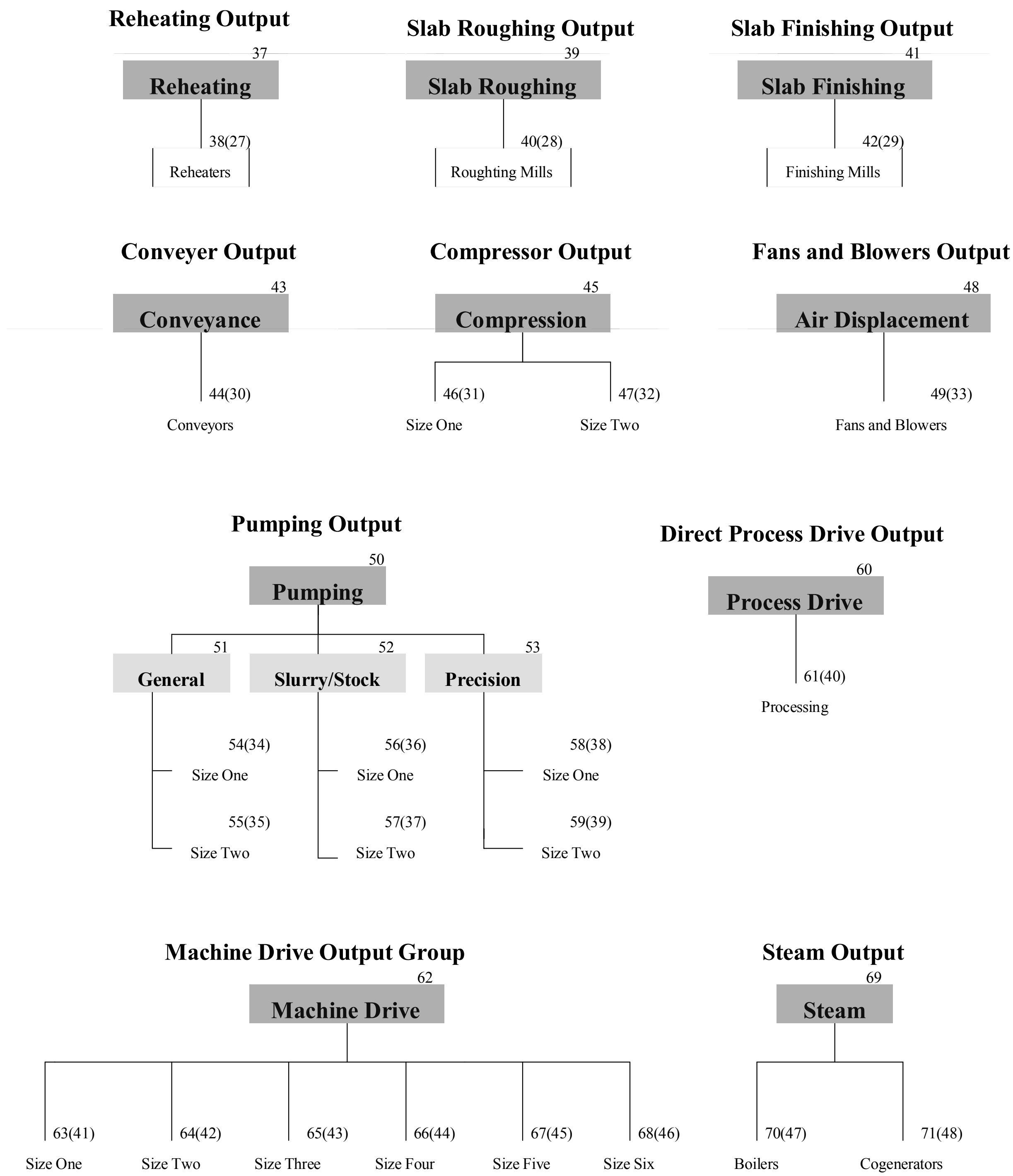


Figure A-1: Energy Flow Model of the Iron and Steel Industry, cont'd



4 Technology Competition Algorithm

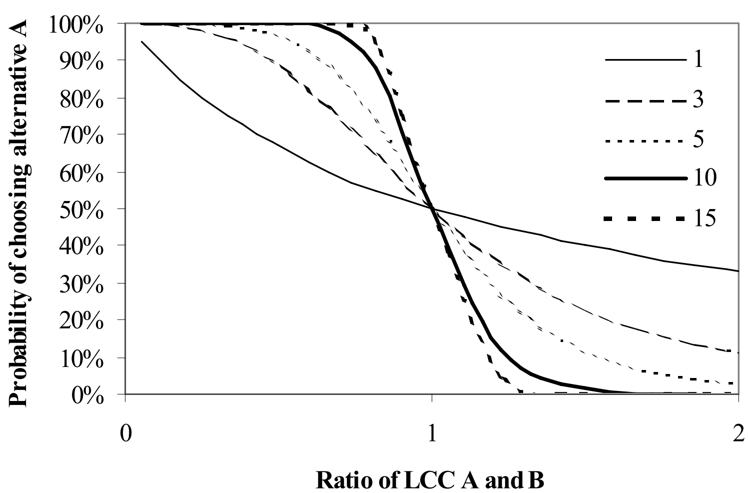
New market shares of competing technologies in CIMS are simulated at each competition node based on their life cycle cost according to the following formula:[2]

$$MS_j = \frac{\left[CC_j * \dfrac{r}{1-(1+r)^{-n}} + MC_j + EC_j + i_j \right]^{-v}}{\sum_{k=1}^{K} \left\{ \left[CC_k * \dfrac{r}{1-(1+r)^{-n}} + MC_k + EC_k + i_k \right]^{-v} \right\}}$$

Where MS_j = market share of technology j, CC = capital cost, MC = maintenance and operation cost, EC = energy cost, i = intangible cost, r = private discount rate, and v = measure of market heterogeneity.

The main part of the formula (the part inside the square brackets) is, in essence, simply the levelized life cycle (LCC) cost of each technology. In this formulation, the inverse power function acts to distribute the penetration of that particular technology "j" relative to all other technologies "k." A high value of "v" means that the technology with the lowest LCC captures almost the entire new market share. A low value for "v" means that the market shares of new equipment are distributed fairly evenly, even if their LCCs differ significantly. Figure 3-2 is a graphical representation of the simple case where two technologies with different life cycle costs are competing for new market share with different values of "v."

Figure A-2 CIMS Logistic Curve



2 CIMS can employ a number of hard controls to limit the penetration of technologies to certain levels (e.g., a maximum of one washing machine per household) as well as a declining capital cost function to simulate learning-by-doing and economies of scale exhibited particularly for new technologies.

The “v”, “i” and “r” preference parameters in CIMS are estimated from empirical studies of consumer and business decision-making, in some cases based on past consumption patterns and in some cases (especially with new technologies) based on surveyed preferences for specific technology attributes.[3] The default value for “v” in CIMS is 10, meaning that where a technology has an LCC advantage of at least 15% over its competitor(s) it would capture at least 80% of new stock. Default values for “r” are between 20 and 50% for industrial process technologies, and 50% for auxiliary technologies.[4] The default value for “i” is zero. However, there are numerous cases in which research suggests a specific value for “i.” Also, “i” is used as a calibration parameter when the values for “v” and “r” are inadequate for simulating the historical penetration rate of certain technologies.

5 Uncertainty Issues

Sources of model uncertainty in policy analysis include the adequacy of the model to represent the complex systems relationships involved, the natural variability in the system being described, systematic errors such as bias and imprecision in estimating the parameters in the model, and a lack of information regarding future conditions and changes in parameter values.[5] CIMS, as in any model, is a simplification of a system; most variables involve varying degrees of uncertainty which will impact the baseline forecast.[6] This impact will increase the further into the future, although short-term economic cycles can also lead to wide divergences in a very short time period.

Modelling uncertainties can be considered as exogenous or endogenous to CIMS. Exogenous uncertainties include those related to energy prices, economic growth and structural change. Endogenous uncertainties relate to either the model’s representation of current reality (technico-economic uncertainties) or to dynamic factors (behavioural uncertainties). We comment on endogenous uncertainties.[7]

Technico-economic Uncertainties

CIMS explicitly represents unique process flow models for various industrial branches to address uncertainty in energy-economy modelling when processes are represented in aggregate. Research into energy use in industry has found that a) sub-sectors respond quite differently to changes in energy prices, b) structural shifts in production played an important role in the level of energy consumption, and c) better analysis can be achieved with variables for each fuel than with a single variable for all energy.[8]

3 The Energy and Materials Research Group is currently conducting revealed preference research to empirically estimate these parameters. For a recent study in the industry sector, see: N. Rivers, M. Jaccard, J. Nyboer, K. Tiedemann, “Confronting the Challenge of Hybrid Modelling: Using Discrete Choice Models to Inform the Behavioural Parameters of a Hybrid Model.” In: *Sustainability in Industry: Increasing Energy Efficiency, Reducing Emissions.* 6th Biennial American Council for an Energy Efficient Economy, Rye Brook, New York, July 29-August 1, 2003, 182-193.

4 For more information on the setting of parameters, see: J. Nyboer, *Simulating Evolution of Technology: An Aid to Energy Policy Analysis*, Ph.D. diss., Simon Fraser University, Burnaby, 1997.

5 M. Morgon and M. Henrion, *Uncertainty* (Cambridge, UK: Cambridge University Press, 1990).

6 Some analysts argue that one should never produce a single reference case because this gives a false sense of reduced uncertainty.

7 Considerable uncertainty exists in forecasting economic growth and energy prices, particularly over a 25-year period, though we are not in the position to comment about the particular forecast used in the CEOU. We have found that CIMS is sensitive to relative energy prices over the period of the forecast.

8 Nyboer, *Simulating Evolution of Technology: An Aid to Energy Policy Analysis*, 40.

Key technico-economic uncertainties in CIMS are:

- the structure of current major processes,
- market shares of current technologies,
- energy efficiencies and fuel shares of current technologies,
- technology costs (capital and operating, for future competition), and
- technology energy efficiencies (for future competition).

The primary constraint to a disaggregated energy analysis has been the availability of data, at the appropriate level, within an industry or sector. In spite of this constraint, end-use analysis and modelling has made significant inroads. Data on technology stock and characteristics come from many sources, including: existing databases completed for other studies; publications like *Lockwood & Post Directory* (pulp and paper) and the *Oil and Gas Journal*; utilities; consultants; and experts in the sector. Although databases that describe technology characteristics are increasing, there are no systematic data to confirm estimations of both equipment stock or technology characteristics. To deal with this challenge, data on existing stock are calibrated to disaggregated, industry-specific energy consumption data and estimates of end-use technology allocation.

Over a 25-year timeframe, dramatic technological change may occur with equally dramatic implications for decarbonization. While we attempt to characterize emerging technologies in the model, we cannot fully predict the direction of innovation. In addition, the financial costs of such technologies are not independent of public policy, although the relationship is highly uncertain.

Dynamic Uncertainties

The critical dynamic uncertainty of models that simulate technology change in the long run is technology acquisition behaviour ("preference uncertainties"). Other dynamic uncertainties are a) the rates of retirement of equipment stock, b) rates of utilization of equipment stock and c) retrofit of equipment stock. Uncertainty about technology retirement is not large because, although retirement rates can fluctuate dramatically with the short-term business cycle, they average out over longer time periods, generally approximating the expected lifespan of different types of equipment. Likewise, periods of accelerated retrofit of existing capital stocks are not critical to the accurate portrayal of long-run stock evolution.[9]

Empirical data on the technology acquisition behaviour of firms and households are limited, and considerable uncertainty exist in the "v," "i" and "r" parameters of the technology acquisition algorithm described in section 4. More recently, efforts have been made to portray the uncertainty associated with each parameter by basing these estimates on utility function of the Discrete Choice Models developed from market research.[10]

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9 Ibid., 44.

10 See M. Horne, "Incorporating Preferences for Personal Urban Transportation Technologies into a Hybrid Energy-Economy Model," Master of Natural Resources Management Research Project, Report No. 339, School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C., 2003; N. Rivers, "Behavioural Realism in a Technology Explicit Energy-Economy Model: The Adoption of Industrial Cogeneration in Canada," Master of Natural Resources Management Research Project, Report No. 341, School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C., 2003; M. Sadler, "Home Energy Preferences and Policy: Applying Stated Choice Modelling to a Hybrid Energy-Economy Model," Master of Natural Resources Management Research Project, Report No. 342, School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C., 2003.

It is impossible to verify definitively the non-financial purchasing parameters of a model that seeks to simulate how firms and household will behave when faced with future technology choices that may differ from past technology choices.[11] As a technology becomes better known in the market, the willingness of firms to adopt it undergoes a transformation in which many intangible concerns can decrease significantly. Preferences may or may not adjust in response to future policies and public concerns.[12]

This is an ongoing research area for the Energy and Material Research Group at Simon Fraser University.

11 This is complicated by the fact that purchasing data demonstrate that consumers' stated preferences for the characteristics of energy consuming equipment are often very different from their revealed preferences.

12 M. Jaccard, J. Nyboer, C. Bataille, B. Sadownik, "Modelling the Cost of Climate Policy: Distinguishing Between Alternative Cost Definitions and Long-Run Cost Dynamics," *The Energy Journal* 21, 1 (2003): 49-73.

Case Study on Fiscal Policy and Energy Efficiency

Economic Study

Appendix B: Energy Efficiency Opportunities

1 Introduction

In this appendix, we provide a survey of the key energy systems and efficiency technology opportunities in the industry sector. While the survey attempts to be fairly comprehensive by including both commercialized and newly emerging technologies, the list is not exhaustive. For instance, this appendix focuses on technological opportunities; we do not describe industrial system (industrial ecology, energy cascading) concepts, though some technologies noted here (i.e., cogeneration) are relevant to these system approaches.

Opportunities are classified in terms of generic services (auxiliary, crosscutting) and unique processes. Generic energy services are those that are not specific to a particular industry, but focus on auxiliary systems that supply energy services to the major process equipment during their operation. In surveying process-specific opportunities, we focus on the most energy-intense industries in Canada, and do not describe, for instance, unique actions in less energy important sectors (i.e., food processing, leather working, etc.).

Most of the technologies described here are included in the CIMS model. However, not all efficiency actions described below can be represented by CIMS model parameters and structure.

2 Generic / Auxiliary Services

2.1 Steam Generation

The efficiency of steam generation varies greatly depending on boiler design, age, and fuel used. For modern oil and gas boilers, thermal efficiencies may be 85% or higher. Boiler system performance can be optimized through regular maintenance, as well as small-scale improvements such as adjusting steam operating pressure, adding insulation and minimizing heat distribution losses. Boiler efficiencies can be improved by introducing non-condensing and condensing heat recovery systems and by installing regenerative burners with computerized fuel/air mixtures to maximize fuel efficiency. Current research is aimed at reducing the amount of nitrogen in contact with oxygen during high flame temperatures (high-efficiency/low NO_x burners).

Significant system energy efficiency improvements can occur by using cogeneration (combined heat and power), which produces both electricity and useful thermal energy simultaneously from the same fuel (or fuels) with less input fuel than the stand-alone alternatives. Cogeneration also achieves greater energy efficiency by reducing or eliminating the transmission and distribution losses associated with transmitting electricity. Energy savings from cogeneration will vary depending on the system type and the percentage of electricity that the system produces. Typically cogeneration saves between 20% and 40% above stand-alone systems. The type of prime mover used to drive the electrical generator classifies cogeneration systems. The four main types currently in use include steam turbines, gas turbines, reciprocating engines and combined cycle gas turbines. New systems currently under development are fuel cells and micro-turbines. Although this technology reduces overall emissions (both direct and indirect), switching to cogeneration will typically increase an industry's direct emissions due to greater fossil fuel use to generate electricity.

2.2 Electric Auxiliary Systems

The vast majority of electricity consumed by industry is used by motor systems. A motor is the core component of a much broader system of electrical and mechanical equipment that provides services, including hydraulic power, compressed air, motive power and air flow. Opportunities for efficiency improvement exist in both the motor itself, and in the latter systems – pumping, air displacement, compression, conveyance as well as other types of machine drive that are unique to a given production process.

Motors

The AC (alternating current) induction motor is the dominant motor technology in use today. Induction motors are a mature technology. Manufacturers continue to make slow improvements in efficiency and performance, but no major changes in the technology are on the horizon. Currently, high-efficiency motors use from 1% to 4% less electricity than standard motors.

Other types of motors are:

- DC motors, which are used in many large-motor (> 200 hp) industrial applications because they are able to undergo continuous operation at low speeds and high torques, and have an inherent ability to provide speed control.[1] Newer DC motor systems use solid-state rectification at an efficiency of 85%.
- AC synchronous motors, which are designed for applications where constant speeds are required. The opportunity for electricity conservation with synchronous motors is limited because of their already high efficiencies and special industrial applications.

Considerable energy savings can be achieved by optimizing the motor system through appropriate motor sizing and the use of variable speed drives. Because motors operate at their highest efficiency between about 60% and 100% of their full-rated load, significant efficiency improvements can be gained by installing a smaller motor if a motor is operated below its optimum range. Variable speed drives (VSD) control motor speed so that it finely corresponds to varying load requirements. These systems can provide significant energy savings, improve power factor and process precision, and afford other performance benefits such as soft starting and overspeed capability. Some types of loads are more conducive to VSD technology.

Pumps – Historically, pump efficiency has not been a major concern. The technology is mature: the best new pumps available are only 3% to 10% better than the average new pump. Replacing valve control with a variable speed drive can improve system efficiency by 20% to 30%; however, most pump systems have already been converted since variable speed drives are used to accurately control processes and for easy maintenance.

Air Displacement Systems – Systems such as fans and blowers consume a significant amount of electricity in the industrial sector, typically accounting for 20% of electricity demand. Fan systems often consist of a speed control device, a motor, a fan, a control vane or damper and a duct system. There are usually opportunities for efficiency improvements in each of these components and by optimizing the whole system. Although fan technologies are mature – no major design changes have

1 This dominance is declining as induction motor speed control technology improves.

occurred in the last 20 years – room remains for engineered efficiency improvements. Improved impeller designs and better construction materials may achieve a 10% efficiency improvement over the next 20 years.

Conveyance Systems – A conveyance system is a horizontal or inclined device for moving bulk material. The simple nature of conveyance systems means that the potential for increased efficiency is small compared to other systems. They also account for a small portion of industrial electricity demand, typically less than 5%.

Compressor Systems – These systems are designed to increase the pressure of a gas to a useful level. They are the least efficient auxiliary system: total system efficiency averages between 15% and 20%. This is due to the compressible nature of a gas, which absorbs energy as it is compressed, and the loss of pressure from air leakage. Substantial opportunities for power savings exist. Current developments include compressed air system management (25% energy savings), and advanced compressor control (3.5% energy savings).

3 Process-Specific Services

3.1 Petroleum Refining

Canadian refinery capacity has been declining and, because new refineries are not being built, new process technologies are not expected to have a major impact on energy intensity within this sector. However, the following list of technologies, although not new, can be applied much more extensively in most Canadian refineries to reduce operating costs by improving energy efficiency. The list briefly describes these technologies.

Split Tower Arrangement – This is a type of atmospheric distillation where a high-pressure tower and a lower pressure tower are operated in parallel. The high-pressure tower condenser is used as a source of heat for other operations in the unit, such as the low-pressure tower reboiler, reducing the overall energy consumption of the distillation process.

Vapour Recompression – The overhead vapours from the distillation tower can be compressed, then condensed in a reboiler and returned to the tower as reflux. This is a heat pump process that can significantly reduce the energy consumption but at a significant capital cost. It is the most advantageous when the fractionation system has a low-temperature difference across the column. Note that the primary objective of recompression remains product recovery, not energy efficiency improvement.

Reduced Crude Processing / Heavy Oil Upgrading – Upgrading processes have been developed which minimize vacuum distillation and thermal cracking. They involve converting reduced crude, coming from the atmospheric distillation tower, directly to lighter valuable products through other processes. Two such processes are reduced crude cracking (RCC) and residfining.

Pressure-Let-Down Turbines – Flue gas can be emitted from the catalytic cracking process at a pressure, which is high enough to produce electrical or mechanical power through the use of pressure-let-down turbines or expanders. These turbines generally would not be retrofit to the cracker; engineers would build the system with this in mind.

Improved Process Control – Major advances have been made with respect to process optimization through increased computer control and monitoring. The refinery process is very interactive; dynamic changes at one stage affect the efficiency of other stages. Computers can enable operators to optimize the process as these changes are occurring.

Pinch Technology – Different processes in petroleum refining requires heat of different levels and different grades. In some cases, waste heat from one process may be of sufficient quality and temperature to be usable in another process. Pinch technology, not really a hard technology, involves analyzing all of the heating and cooling requirements in an industrial process in order to optimize heat recovery and waste heat utilization. This technology has been used to a certain extent in many refineries but more opportunities to fully utilize this approach exist and are most easily assessed when the site is in the blueprint stage of construction.

3.2 Pulp and Paper

The following describes new and emerging technologies that have a potential for significant direct or indirect impact on energy demand in the pulp and paper industry.

Transport of Medium-Consistency Slurries – Traditionally, the transporting of pulp from thick-stock storage or bleach towers involves first diluting the slurry prior to pumping and then rethickening for the next process stage. These transport systems with auxiliary filtrate tanks, dilution pumps, and controls are both capital and energy intensive. Medium-consistency pumps and mixers have been developed so that thick-stock can be transported, eliminating the need for dilution and subsequent thickening. This technology will also reduce the volume of water required and so reduce water cleanup costs.

Chemically Modified Mechanical Pulping (CTMP Processes) – Chemical treatments of chips prior to refining and/or chemical additions during refining were initially investigated as means of reducing energy requirements. However, it soon became apparent that while some energy savings can result, the principal effect is to alter the qualities of the resultant pulps. There have been a number of different CTMP processes employed to obtain different product quality requirements (i.e., brightness, opacity, strength, etc.).

Black Liquor Gasification – Rather than direct combustion of black liquor in recovery boilers, black liquor is gasified and then combusted in either a recovery boiler, or better yet in specialized combined cycle gas turbines. Full replacement of recovery boiler/steam turbine combinations with black liquor gasification combined with gas turbine cogeneration systems would result in higher overall energy efficiency as well as higher electricity to heat ratios and lower emissions. This technology could be commercially viable within the next several years, and will be spurred on by its ability to increase pulp yields.

Dry Sheet Forming – This option can apply to the manufacturing of sanitary and specialty paper products such as diapers, feminine products, etc. Dry sheet forming involves the layering of fibres to form a web without the use of water. Fibres are held together by a resin or polymer-latex that is sprayed onto the web form. Significant energy savings, up to 50%, can be realized because of the elimination of the need to evaporate water from the sheet. However, air layering does require an increase in electricity consumption and the technology is slightly more expensive than conventional paper machines for this purpose. Another benefit is that the process eliminates the production of wastewater. The technology is commercially available.

Deinking – Deinking of waste paper will grow in importance, especially in areas where supplies of raw material (recycled paper) exist and as the paper industry increases its use of recycled pulp. Deinking is done by either washing or flotation; the latter process has been adopted by plants in Canada (e.g., the Kruger facility in Bromptonville, PQ). In this process the waste paper is pulped and large pieces of debris are screened out. Chemicals are added to the pulp, and the pulp moves to flotation cells. The ink particles are removed with the froth produced by air injection. Explosion deinking is the most recent deinking option. In this process, the waste paper pulp is subjected to varying pressures and retention times and then released to the atmospheric pressure. The moisture flashing to steam fractures the ink, which is then removed by conventional screening and washing methods.

High-Intensity Refining – High-intensity refining is the optimization of the refining energy in mechanical pulping. The refining intensity depends on the rotational speed of the single-disk or double-disk refiners. Changing the rotational speed and the refiner plate configuration can reduce energy consumption. In order to change the refining intensity, changes and modifications to the drive motors are required. New control equipment will also have to be used. These changes will save approximately 25% of the electricity consumed in double-disk refiners and 10% for single-disk refiners.

Hot Pressing – Hot pressing combines pressing and drying processes. In a hot press, the pressing rollers are heated with low-pressure steam. The dryness of the paper sheet leaving the hot press is typically 4% to 10% greater than in a conventional press. Hot pressing increases the strength of the finished paper and improves its surface smoothness. The increased dryness of the paper sheet reduces the energy required in the drying process; however, the amount of saved energy has not been determined.

Impulse Drying – Impulse drying combines pressure and high temperatures prior to the drying stage to remove excess water from the pulp. Impulse driers are installed between the press and drying sections. The paper web exits the pulp press and is fed into a “nip” that consists of one large metal roll heated by electrical induction to high temperatures (120°C), and a felt covered roll. Upon contact with the high-temperature metal roll, water in the web is flashed into steam which is then caught in the felt of the second roll, reducing the moisture content of the “web” to 38% or less. Impulse dryers can be retrofit into existing machines or incorporated as part of a new unit. The use of impulse drying can reduce the length of the drying section, or increase the speed of the drying process and improve the strength of the paper.

Condensing Belt Drying (Condebelt) – This technology, in contrast to the conventional drying process where the mechanically processed paper is moved through a series of steam heated rollers, dries the paper through contact with a long, heated steel band in a drying chamber. Opposite the heated steel band are layers of steel gauze and a cooled steel band where the steam that is emitted from the drying paper condenses and is removed. The drying rate of the Condebelt is between 5 and 15 times faster than conventional methods. Commercial installations to date are in South Korea (1999) and Finland (1996) where the Condebelt served as an add-on technology, rather than replacing the existing stock.

Heat Recovery Using Enclosing Hoods (in Paper Making) – Drying is the most energy-intensive step in the papermaking process. The water vapour that is released is a saturated, low-pressure steam. Existing heat recovery systems are based on air-to-air heat transfer in canopy hoods and recover approximately 15% of the energy from the waste heat (steam). Newer systems aim to improve the amount of heat recovered from the waste steam using enclosed hoods and sensors. Heat pumps and mechanical vapour recompression (MVR) can also be used to help upgrade the energy content of the waste heat. With the use of the enclosed hoods alone primary energy savings are estimated at 41% and electricity savings at 35%. These technologies can be used in the production of all paper grades, although the main installations will likely be in larger, newer papermaking machines.

High-Consistency Forming (HCF) – In forming, the slurry pulp is formed into a uniform web. In high consistency forming, the slurry enters the forming stage at a higher consistency, which in turn requires less time in the forming stages, and energy savings due to reduced dewatering and vacuum requirements (pumping power). The process also increases paper strength and decreases material input requirements, but is only applicable to heavier weight papers such as boxboard and liquid containers. This technology – commercially available as either a unique installation or as an add-on – has been slow to catch on with only a few large-scale installations.

3.3 Mining

Numerous energy efficiency opportunities have been identified for grinding, disposal and mineral separation processes. Grinding operations are highly energy intensive and inefficient. For example, typically only 3% of grinding energy goes into breaking the intercrystalline bonding; as a result, a large potential for energy conservation exists in this stage of the mining process. Significant energy is also used to dispose of waste material. On the other hand, standard mineral separation techniques such as froth flotation, or gravity separation do not consume a major portion of the energy used in mineral processing (less than 10% compared to grinding's 60%) but there is energy conservation potential in this stage. In addition, the techniques used in this stage can impact the energy requirements in the prior grinding stage and in succeeding smelting/refining stages.

Grinding Circuit Automation – Disturbances in the grinding process (which arise from such things as variations in ore characteristics, uncontrolled water additions and feed rate upsets) occur with a frequency that is difficult for an operator to detect and react to efficiently. Thus the energy efficiency of grinding can be improved with automatic control. Increasingly sophisticated models of grinding circuits are being developed, which incorporate a large number of variables that affect grinding. For example, ultrasonic and nuclear gauges are being used to determine particle flow, and Program Logic Controllers combined with the advent of powerful microcomputers have enabled complicated control logic sequences to be used.

Lifter / Liner Design in Semiautogenous Grinding (SAG) Mills – There has been a lot of development and testing work performed to determine the effect that different liner materials and lifter designs have on energy consumption.[2] Large SAG mills utilize liners to protect the rotating shell from wear and to reduce slip between the shell and the grinding media. Lifters are bars attached to the liner, which catch the ore material and lift it as the shell rotates. Because mill liners are the mechanical link between machine and ore, the way in which the lifters and liners transfer energy to media and ore determines production rates, liner wear rates, maintenance costs, energy

2 While the most common liner material has been cast and rolled steel, different rubber materials have also been introduced. Lifter designs can differ in the spacing, height and shape of the bars.

use, mill availability and grinding efficiencies. There is no doubt that the grinding efficiency of many if not most mills could be improved by optimizing liner/lifter design.

Sonic Grinding – Due to the large ultimate energy saving potential that exists in the grinding stage, in a 20-year planning horizon completely new grinding techniques could have a major impact on energy consumption. Sonic grinding is one example of such a technique. It uses an electro-magnetic drive capable of generating high power at high frequencies and, when immersed in a liquid or slurry medium, creates intense cavitation and high-energy pressure pulsation in the fluid. The sonic grinder was developed by ARC Sonics Inc. This technology may have applications in the grinding of coal, magnetite and limestone. There is still not enough information available to determine the magnitude of the energy saving potential with the application of this technology.

Unit Column Flotation – Grinding processes are designed to reduce the ore to a size range that will yield the highest recovery of the valuable minerals. Frequently, larger mineral particles continue to be ground although they are already free of all waste material. Overgrinding can be reduced if the ore is ground in a stage-wise fashion with an intermediate step to recover the mineral particles that have already been liberated from the waste rock. A new approach is to use an intermediate flotation step, a flotation column designed specifically to float larger free mineral particles. This will not only reduce the requirements for grinding, but it will also improve recoveries, since losses to tailings increase as the particle size gets smaller. Both of these improvements will save energy.

Pulp Thickening and Heating Before Flotation – In some flotation circuits, it becomes necessary to heat the ore material to promote flotation or to cleanse mineral surfaces before proceeding to the next stage. This heating process can consume significant amounts of energy. Removal of water by thickening before heating and then recombining with water after the heating process would be more efficient. Some work has been done to substantiate the energy savings but a large-scale demonstration is required to verify the results.

Water Disposal – Water is typically pumped back from tailing ponds as part of the water requirements for many base metal mineral processing plants. The water to be recycled may not have to be cleaned to the same extent or at all. Recycling has advantages and disadvantages for different processes; in some cases it improves productivity and increases energy efficiency by reducing pumping and heating requirements. For example, in gravity plants, recycling water will increase slurry temperature, decrease apparent viscosity and improve overall performances.

Waste Coal Utilization – Large amount of coal-ash materials from washeries and refuse dumps may be used to produce a pulverized end product or a coal/water slurry that would be suitable for firing steam generators. On-site electric power generating plants using coal rejects could generate substantial amounts of energy.

Gravity Versus Pumping in Tailings Disposal – For many mines, the lowest capital cost alternative for tailings disposal involves pumping tailings in a slurry form to settling ponds. It is often possible, albeit at an additional capital cost expenditure, to replace the pumping systems with gravity systems.

3.4 Iron and Steel

The following describes new and emerging technologies that have a potential for significant direct or indirect impact on energy demand in the iron and steel industry.

Coke Dry Quenching – Conventionally, production of coke involves heating coal to about 1,000°C for 12 to 18 hours. At the end of this process, water quenches the red-hot coal pushed from the coke oven, sending great clouds of steam above the steel works. In coke dry quenching (CDQ), a specially designed bucket catches the discharged coke. It, in turn, empties into a special vessel containing an inert gas medium that quenches the coke. Steam recovered from the process serves as an energy source for electricity generation and reheating purposes. CDQ reduces energy consumption by about 14% and also improves the quality of coke. Even though CDQ has been commercialized for some years, no Canadian mill currently employs this technology.

Top Gas Recovery Turbine (TRT) – Blast furnaces operate at high top pressures of up to 250 kPa. In order to recover and reuse top gas, the pressure must be reduced to between 5 and 8 kPa, an acceptable pressure for gas storage chambers or gas lines. TRTs were developed to recover the latent compression energy of the top gas as the gas expands to the lower pressure, energy usable in other parts of the plant. No Canadian furnaces are equipped with top pressure capability because it would take a complete blast furnace rebuild to become so equipped.

Direct Reduced Iron (DRI), Midrex Process – The Midrex process converts iron oxide in pellet or lump form, to a porous “sponge iron” which competes with scrap. Normally, these would act as a feedstock to EAFs rather than BOFs. (BOFs require molten iron poured over scrap metal; direct reduction processes do not produce molten metal).

The Midrex process consists of three main components: shaft furnace, reformer and a heat recovery unit. Iron oxide, fed to the top of the shaft furnace, flows downwards by gravity to be discharged in a reduced form at the bottom, a product known as direct reduced iron. Two processes occur in the shaft furnace: reduction and cooling. In the reduction zone, iron oxide comes into contact with a hot, counterflowing gas comprised of H_2 and CO, reducing it to iron, H_2O and CO_2. In the cooling zone, reduced iron is carbonized and cooled by counterflowing cooling gas.

A gas tight, refractory lined furnace containing alloy tubes filled with catalyst generates the reducing gas by reforming a preheated mixture of natural gas and recycled top gas from the shaft furnace. The reducing gas, heated to 950°C, leaves the reformer containing 90% to 92% hydrogen and carbon monoxide.

The heat recovery unit recaptures heat from the reformer flue gas to preheat combustion air (for reformer burners) to 675°C and to preheat the feed gas (mixture of top gas and natural gas fed to the reformer) to 540°C.

An alternative process generates briquettes from the reduced iron. Briquetting machines receive hot direct-reduced iron, preparing it for use in electric arc furnaces, eliminating the need for the cooling zone in the shaft furnace.

Direct Smelted Iron, Corex Process – The Corex process, a direct smelting process, differs from the direct-reduced iron process in that direct smelting generates a molten product similar to pig iron. The Corex process consists of two main components: a melter gasifier and a shaft furnace. Coal falls by gravity into the melter-gasifier and passes through a reducing gas atmosphere at a temperature of approximately 1,000 to 1,200°C to be instantaneously dried and devolatilized (i.e., coked). The process cracks all higher hydrocarbons into CO and H_2, except for a small quantity of methane; therefore, no by-products (tars, benzols, ammonia, etc.) are produced. The reducing gas, produced in the fluidized bed of the melter-gasifier by partial oxidation of the coal with oxygen (98% purity), is injected through radially disposed tuyeres; oxidized carbon (CO_2) reacts with free carbon to form carbon monoxide (CO).

The gas temperature in the fluidized bed varies between 1,600°C and 1,700°C. The gas leaving the fluidized bed contains 65% to 70% CO, 20% to 25% H_2, and 2% to 4% CO_2 with small amounts of methane, nitrogen and steam. Upon leaving the melter-gasifier, the hot gases are cooled to about 900°C, cleaned and directed to the shaft furnace as reducing gas. The iron ore, fed into the shaft furnace, descends by gravity to be reduced to metal with a carbon content of 3% to 6%. A melter-gasifier continuously receives the hot direct-reduced iron (800 to 900°C). Reducing the falling velocity of the reduced iron in the melter-gasifier permits complete reduction of the iron, heating it until it is molten. Hot metal and slag drop to the bottom of the melter-gasifier to be tapped off at intervals.

Basic Oxygen Furnace (BOFs) Efficiency Improvements – No new alternatives to the BOFs exist. Some available technologies can capture and utilize BOF top gas, which has a fairly high energy content (up to 1 GJ/tonne of steel produced). A movable skirt built around the hood and vessel captures the BOF gas; this capital-expensive option often cannot compete with technologies that consume relatively inexpensive fuel. Boilers can utilize this gas funnelled through the boiler system to heat water, but the dirty gas generates increased maintenance costs. A variant, "half boiler," with radiant section only, may be used. Although such a boiler shows a lower rate of heat recovery than a full boiler system, the problems of cleaning and high maintenance costs are eliminated.

Traditionally, most BOFs are designed with top blowing lances. The introduction of both top and bottom blowing lances provides two advantages: a greater utilization of chemical energy of the off-gas through post-combustion is promoted by top blowing; and a closer chemical equilibrium in the bath through bath agitation is achieved by bottom blowing.

The process increases iron yield and reduces slag oxidation. In the LD-KGC process, argon and nitrogen are injected through a number of small tube assemblies, allowing a larger variation in gas flow rates. Oxygen blowing creates more vigorous stirring compared to stirring by inert gas and produces steel with lower carbon content. The process may be improved to produce steel with low to high carbon content by varying the stirring rate with inert gas. In the LD-KGC process, argon and nitrogen are injected through a number of small tube assemblies to vary the stirring rate. In Canada, Dofasco and Algoma use the LBE process, which is similar to this process.

Electric Arc Furnace (EAF) Efficiency Improvements – EAFs are less energy-intensive than blast furnace / BOF operations because the scrap or sponge iron used as feeds already reduced. All EAFs in Canada operate with three AC electrodes, primarily of the Ultra High Power (UHP) variety. These technologies, along with injected oxygen and carbon, not only reduce the tap-to-tap time, but also use up to 20% less energy than older installations.

Other available technologies and process changes include:

- The provision of a ladle lid to maximize heat retention. This eliminates the need for preheating the ladle between heats.
- The Consteel Process uses furnace off-gas to preheat the scrap. The preheater, a refractory-lined tunnel, uses counter current gases flow to heat scrap charges. Air is drawn into the preheater through slots in its sides to combust CO. An after-burner (if needed) can be installed after the preheating process to burn off any remaining CO.
- Promoting a faster mass and heat transfer rate by gas stirring in an EAF. The liquid-liquid mass transfer increases proportionally to the stirring energy and better results were obtained with lance injection. This method also improves the refining process.
- Ladle treatment, a secondary refining process that occurs in a vessel outside the EAF, has been added to most steel plants. In the ladle treatment station, precise adjustments to the steel temperature and final chemistry are made. This process shortens the time spent at very high temperatures and also improves productivity.
- In a conventional EAF, large amounts of electrical energy and metal scraps are used. Experiments have been conducted to replace electric energy with fossil energy. The characteristics of metal scrap can be altered to suit the fossil fuel used.[3]

Continuous Casting – Since 1980, the industry has moved completely towards the continuous casting process. This eliminated pouring the liquid steel into moulds to form ingots and the consequent stripping and reheating of ingots in preparation for rolling. Continuous casting converts the molten steel into its semi-finished shape (slabs, billets, blooms) and reduces energy use by about 50% over ingot casting processes.

Thin Slab Casting – The thin slab and thin strip casting process captures heat in the metal that leaves a casting machine and allows it to be processed in-line into hot strip or slab with very marginal heat input. The casting machine is modified to produce a slab thickness of 30 to 60 mm using a “funnel” mould. Similarly, in the thin strip casting method, a slab thickness of 40 mm to 60 mm is produced. Thin slab and thin strip casting bypasses the semi-finished product stage, reducing reheating and eliminating a number of rolling steps, thus providing for considerable energy savings and significant improvements in productivity.

Research to reduce the slab thickness to 15 mm or less continues. So far, problems related to the geometry of the strip, surface quality and physical properties have been encountered. An alternative to strip casting, known as spray casting, is also being explored. Spray casting atomizes liquid steel into droplets. The droplets are then deposited on a substratum that is 1m wide, 2 m long and 3 mm thick. Strips of 12 to 20 mm thickness have been produced by this method.

Heat Recovery from Reheat Furnaces – The temperature of exhaust gas exiting the recuperator of a reheating furnace may be as high as 600°C. In some cases, a high-temperature booster fan directs a high velocity jet of hot gas onto the surface of a charge slab to preheat it.

3 The impact on total GHG emissions of fuel switching to direct fossil fuel use will depend on the carbon intensity of the avoided electricity use.

The waste flue gas generally attains a temperature of about 700°C. The heat, recovered by installation of a recuperator, preheats combustion air.

Continuous Cold Rolling – Continuous cold-rolling processes have been developed where pickling and cold rolling or pickling, cold rolling and annealing are incorporated into one continuous process. Pickling and annealing are final product processes applied to a portion of steel products.

Low NO_x Oxy-fuel Combustion in Reheat Furnaces – In reheating furnaces steel is heated to very high temperatures (1,100 to 1,300°C) and then reshaped/rolled. Unfortunately, high flame temperatures lead to high NO_x emissions as well. Attempts to increase the energy efficiency of burners and to recover waste heat have often led to even higher NO_x emissions. An alternative method to increase energy efficiency is the use of Oxy Fuel burners. The newest designs of these burners carefully balance the amount of oxygen in the fuel, which in turn limits the amount of NO_x formation. Also, gases enter the burner at high velocities, which encourages a more complete combustion at a lower temperature and a better heat distribution in the furnace. In test installations where the purpose was increased energy efficiency, energy savings were as high as 50%. This technology has been commercially available since 1998 and can be installed in existing furnaces without having to rebuild.

3.5 Non-Ferrous Metal Smelting and Refining

The following describes new and emerging technologies that have a potential for significant direct or indirect impact on energy demand in the non-ferrous metal smelting and refining industry.

Electrode Efficiency (Aluminum Production) – Separation of aluminum metal from oxygen is done electrolytically when alumina is dissolved in a bath of molten cryolite. Theoretically, only 5.64 kWh/kg are required to separate aluminum and oxygen in this process, but old plants use as much as 17.6 kWh/kg. Newer plants use 14.3 kWh/kg and a more modern Alcoa version of the process is said to use only 11 kWh/kg. Maximum efficiency may hover around 8.8 kWh/kg. There are a number of retrofit options available that would increase electrode efficiency including improved conductivity of anode materials, bottom heat recovery, increased furnace insulation, improve electrolyte chemistry, and operation with a low AlF3 ratio. Depending on the configuration of the existing operation, energy savings can be as high as 20%, and the retrofits often result in reduced production costs as well.

Inert Anodes and Wetted Cathodes (Aluminum production) – Inert anodes and wetted cathodes are pre-commercial technologies that together could completely eliminate carbon-based anodes from electrolysis and reduce energy requirements. Inert anodes are ceramic/metal ("cermet") electrical conductors that deteriorate very slowly and contain no carbon. Wetted cathodes refer to cell designs that use new cathode materials and which allow for reduced anode-cathode distance, better aluminium drainage and improved cell operation. The combination of inert anodes and wetted cathodes has been studied the Lawrence Berkeley Laboratory, and has been projected to reduce energy requirements by 25% or more from current levels.

Near Net Shape / Thin Strip Casting (Aluminum) – Currently, the casting and rolling stage of aluminum production is a multi-step process involving ingot casting, transportation, reheating of the ingots and rolling into the desired shape. Thin strip casting eliminates the need to reheat the ingots before rolling, by instead immediately casting the metal into very thin strips (1-10 mm; the current slab thickness is about 120-300 mm). Energy consumption is greatly reduced because of the eliminated pre-heating step.

Improved Recycling (Aluminum) – Producing aluminum with recycled process scrap and used aluminum products is both less energy intensive and has lower operating costs than primary aluminum production. Current aluminum recycling processes begin with the sorting of scrap metal, which is then charged in a melting furnace. The contaminants in the metal can be removed either through pyrometallurgical, hydrometallurgical or catalytic methods. Once treated, the scrap is charged in a furnace whose type depends on the quality of the scrap – there are different furnaces.

Continuous Smelting – Traditional technology for the treatment of copper, nickel and copper/nickel sulphide concentrates based on separate roasting, smelting and converting steps or by the reverberatory smelting/converting process, is inefficient in terms of energy use, sulphur fixation and disposal. The combination of these steps into a continuous process has long been a goal of metallurgical engineers. Many continuous smelting technologies are relatively mature and include installations in Canada.

Direct Smelting – Primary lead production from lead concentrates is traditionally carried out by first roasting the concentrate on a sinter strand to produce oxide for reduction with coke in a blast furnace followed by a whole series of kettle refining steps. During the last 20 years several energy efficient, environmentally friendly, new pyrometallurgical lead smelting processes (i.e., the Kivcet Process and the QSL Process) have been developed.

Hydrometallurgy – In hydrometallurgical processes, an acidic chemical solution dissolves the minerals and the metals are extracted from the solution through leaching or pressure leaching. This process is widely applied in zinc extraction from oxide ores. The use of hydrometallurgy to treat metal sulphides has often been seen as the answer to the environmental problems encountered in pyrometallurgy (particularly sulphur dioxide air emissions), and its role is expected to increase. Many commercial processes exist. Lead hydrometallurgy has also been of considerable interest over the years, yet so far no process has been commercialized.

3.6 Industrial Minerals

On-Line Analyzers (Preliminary Preparation) – On-line analyzers make use of microchip technology to provide instantaneous readings of particle size, fineness and mass flow measurements. The analyzer helps to monitor and maintain uniform raw meal compositions, reducing the need for energy-intensive blending systems and improving the fuel efficiency of the kiln.

Meal Blending Systems (Preliminary Preparation) – Raw dry meal can be mixed by gravity as it exits the storage silo through multiple outlets. This method can save up to 2 kWh for each tonne of raw meal mixed when compared to air fluidized systems.

Roller Mills (Grinding Mills) – Roller mills consume 10% to 15% less energy than ball mills. In the ball mill, grinding of raw materials occurs through impact and friction between the grinding media. In a roller mill, grinding is achieved by compressing the raw materials between the rollers and a table. Most recent cement plant expansions utilize roller mills.

Preheaters (Kiln Systems) – Preheaters that include six cyclone stages are more efficient than the 4 cyclone stages units conventionally used in Canada. These new systems reuse exhaust gas heat and total fuel consumption by 0.12 GJ/t. Further research efforts focused on reducing the pressure drop across the cyclones while maintaining separation efficiency are expected to reduce electrical power consumption.

Precalciners – Precalciners consume up to 60% of fuel burned in a kiln. Research focused on achieving complete combustion of low-reactivity fuels promises better performance in future precalciners.

Kiln Design – The following are examples of overall improvements in kiln design:

a) Reducing kiln volume by achieving more heating in the precalciner. Kilns recently installed have reduced length/diameter ratios from 20 to 10, cutting down radiative heat loss through the kiln body (i.e., short dry kilns).

b) Preheating primary air by using waste gas, using effective flame shaping and reducing nitrous oxide emission improves kiln burner efficiency.

Fluid Bed Process – In this process, hot air suspends pellets of raw materials as they pass along a reactor hot bed. Air cools the clinker as it leaves the reactor. The fluidized bed process has not been successfully commercialized (largely because of its higher fuel consumption relative to modern preheater kilns).

Cement Advanced Furnace (CAF) – This furnace utilizes a preheater shaft to convey raw materials to a fluid bed combustion chamber. Rising combustion gases preheat the raw materials fed into the top of the shaft on their way to the fluidized bed. The raw materials are suspended in the flame over the fluid bed and the clinker pellets go through a chute to a cooler located underneath the chamber.

Reciprocating Grate Coolers (Clinker Cooling) – Cement manufacturers typically use either planetary coolers or reciprocating grate coolers to cool clinker. Greater dependability and efficiency favour reciprocating grate coolers. Recent improvements with grate coolers involve designing grates with smaller open areas. The grates with smaller areas give higher resistance to the material and, as a result, a more uniform distribution of cooling air over the entire grate surface. This provides for hotter secondary combustion air and better overall fuel efficiency. Other developments in the grate coolers include the use of pulsating cooling air and intermediate roller crushers instead of a crusher at the point of discharge.

Roller Mills (Finish Grinding) – Roller mills may replace ball mills as the primary technology for the finish grinding in the future. Roller presses, already used in some plants in conjunction with ball mills, pre-grind clinker before it enters the ball mill. Roller presses to replace ball mills are currently being tested; technical problems associated with cement quality still need to be resolved. Clinker ground only with the roller press process shows higher water demands, shorter setting time and poorer workability. Industry specialists expect that continued research will overcome these problems. Potential savings in electrical energy are considerable.

High-Efficiency Separators (Finish Grinding) – These technologies reduce energy consumption by cutting down on recycling of ground material and avoiding overgrinding. In a closed-circuit grinding system, the conventional, second generation separator recycles up to 60% of the product for further grinding, a process which wastes energy and affects product quality. In a recent development, the airstream in the separation zone of a high-efficiency separator is horizontal rather than vertical as in a conventional separator. This design allows for longer retention time in the separating zone and therefore more efficient separation of the particles. This can reduce energy use by 8% and increase mill output by 15% in larger plants after retrofitting plants with this technology.

Vertical Roller Mills (Finish Grinding) – These mills have been developed by the Pfeiffer Company (Germany) and installed at the Teutonia plant in Germany. Because cement produced by the mill has quality problems due to high water requirements of the finished cement, which affects the strength of concrete, progress with this technology has been slow. Research to develop roller press technology may outstrip advancements in this technology.

Intelligent Systems – Low-cost computer systems are being used to implement high-level control systems, which provide faster kiln response times to changing operating conditions – devices known as "intelligent systems." At present, 8 to 10 plants in Canada have installed such systems. The benefits of these systems include:

- lower specific fuel consumption (2% to 3%) due to better control of combustion;
- process in response to fluctuation in the kiln;
- improved thermal stability of kiln operation leading to improved refractory life and more uniform crystal size of clinker compounds;
- higher production rates due to proper process control; and
- reduction in electrical energy consumption by 2% to 4%.

3.7 Chemicals

Many of the technologies presently in the industry can be thought of as "mature"; the potential for major energy efficiency improvement can be considered minimal. Cogeneration is already widely used in this industry to meet heat and electricity demand. Development of new and alternative chemical products consumes most of the time and funds available for research and development.

The following is a review of new and emerging technologies or processes with potential for significant reduction in energy consumption. It is difficult to obtain detailed information on new and more efficient technologies because often the companies developing these technologies wish to keep them confidential.

ALCET Process – In the production of ethylene, naphtha, commonly used as feedstock, is initially cracked at 1,590°C and 200 kPa and ethylene is recovered at low temperature (29.4°C) and 3,792 kPa. The ALCET process eliminates the ethylene and methane refrigeration system and replaces it with a less expensive solvent absorption system. ALCET reduces capital equipment costs by 25% and energy requirements by 10%.

Methanol – A new method in the production of methanol uses a synthesis gas comprised of carbon dioxide, carbon monoxide and hydrogen. Carbon dioxide, mainly from off-gases generated in the combustion of fossil fuels, provides the carbon. Generation of methane occurs when the gases contact a unique Cu/ZnO catalyst, a proprietary catalyst developed by Lurgi. Methane formation is favoured at low temperature and high pressure. The catalyst chosen is active at temperatures lower than 200°C and subsequently produces high-pressure steam making it possible to cogenerate electricity. This cogeneration activity, an economic necessity in most cases, helps to reduce energy consumption by about 20% over the conventional process.

New Catalysts – Catalysts lower the activation energy required for a reaction to complete and are used to produce most chemicals. There has been enormous progress in understanding the underlying molecular mechanisms, which has had an explosive effect on the development of new catalyst systems that can allow for more energy efficiency chemical processes.