Ecological Fiscal Reform and Energy
Case Study on Energy Efficiency
Economic Study

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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 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 decarbonisation 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 decarbonised 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]

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

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

Decarbonisation

In this document and accompanying Baseline Study, the term "decarbonisation" 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 GHG 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 decarbonate. 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

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

[3] The principle 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..

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.

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

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

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.

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. Optimising 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 A.

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 thirty years has shown that consumers and firms forego 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 occurring.

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

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[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 DC: US Government Printing Office, 1993).

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 additional information to inform their 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 Decarbonisation

Even if energy efficiency opportunities are adopted in greater numbers, how may this impact total energy consumption and decarbonisation? Achievement of the latter is complicated by several factors. First, as noted in the Baseline Study, pursuing energy efficiency can be relevant to decarbonisation; 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 impact 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

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[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 A 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>

[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.*

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 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

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[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.

[15] R. Ayres, L. Ayres, and B. Warr, “Exergy, 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 antes values (e.g. of expected gain) are those that are calculated in advance of the resolution of uncertainty.

estimate of decarbonisation potential. A model also needs to be technological 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.

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 based on performance preferences, cost hetereogeneity, option value and failure risks.

Simulating a carbon emission shadow price in the industrial sector submodels in CIMS can indicate the emission reduction potential from energy efficiency actions. This methodology is based on the principle that the goal of decarbonisation 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 decarbonisation 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

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[18] For example, for any competing devices that consumes 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.

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 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 function 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 decarbonisation case studies. The NRTEE may use the outputs from the case studies as inputs to a macro-economic model at a later stage in their research program.[20]

Deleted: 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 de-carbonisation actions / policies with CIMS.

This project considers a longer timeline than is typically conducted in most GHG emission analysis (which has been focused on the Kyoto target in 6-8 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
Aluminium	Inert anodes / Wetted cathodes
Chemicals	New catalysts
Iron & steel	Thin and strip slab casting
Iron & steel	Direct-reduced Iron
Industrial minerals	Fluidized bed kilns
Pulp and Paper	High intensity drying
Pulp and Paper	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 baseline 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

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[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.

[20] 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 de-carbonisation actions / policies with CIMS. See for example M. Jaccard, N. Rivers and M. Horne, *The Morning After: Optimal GHG Policies for Canada’s Kyoto Commitment and Beyond* (Toronto: CD Howe Institute, 2004).

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 (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 3-12. 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 clear-cut. 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 represents changes to process emissions (metal smelting, chemical products, iron and steel) and fugitive emissions (upstream oil and gas sectors, coal mining). In the chemicals 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 decarbonisation 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

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[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 the Canada as a whole.

[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).

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).

Employing higher carbon prices in the alternative scenario would result in more significant emission reductions, although cost-curve analysis using CIMS suggests the potential for additional emission reductions diminish 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 (both through radical and incremental innovation), increasing the potential for long-term decarbonisation. Also, shifts would also 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	4239	5030	5783	6579
Low Carbon I	4239	4822	5537	6298
Low Carbon II	4239	4818	5497	6232

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[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 Industry

	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	1121.4	1194.7	1413.0	1663.7
Low Carbon I	1121.4	1046.2	1220.7	1461.6
Low Carbon II	1121.4	1044.4	1207.4	1431.4
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	5314.9	4486.0	3935.9	3953.7
Low Carbon I	5314.9	4448.4	3884.9	3892.0
Low Carbon II	5314.9	4452.6	3883.2	3886.2

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

	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	1136.5	1334.0
Low Carbon I	273.7	827.1	1104.2	1305.6
Low Carbon II	273.7	834.7	1093.5	1282.5
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-sectors 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 decarbonisation in the industry sector.

4.1 Economic Analysis Methodology

As noted, the actions that underlie the decarbonisation 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 capital costs that are reported are the new purchase and retrofit

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[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,

'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 rate 10%) are 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 ($billion)

	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 decarbonisation by targeting these actions may help to address a number of other policy issues including concerns regarding energy security, local environment and innovation.

"Modelling the Cost of Climate Policy: Distinguishing Between Alternative Cost Definitions and Long-Run Cost Dynamics."

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 not only linked to a reduction in carbon-emissions, but also 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 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, whose demand 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 later has been more typical.[29]

4.4 EFR Policy Tools

The redirection of a government's taxation and expenditure programs to support the shift to a decarbonised energy system can make use of many fiscal instruments, both in combination and in conjunction with other types of policy instruments such as voluntarism,

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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.

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 GHG emission 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 their emission reduction efforts until each is facing the identical incremental cost for the next unit of reduction. Ideally, the magnitude of the tax would be reflective of 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 decarbonisation 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 ton 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.

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

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[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 ton 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 ton of carbon corresponds to 3.67 tons of CO_2.

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 practices.

Subsidies

EFR can support decarbonisation through the removal or redirection of existing subsidies, and through the provision of new subsidies. Financial support in the form of direct grants,

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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 emit 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.

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 / 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.

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.

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[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.

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 and 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 total adoption of efficient pumps was only 3,767 pumps. 74% 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

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[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 in 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.

deterrent to investment. An empirical study of the behaviour of industrial firms with regards 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 period 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 have 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 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; minimize government interference in financing decisions;

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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 otherwise 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.

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

- 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; avoid 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 trade-offs, 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.

Economic Effectiveness

Of the tools available as part of an EFR program to promote decarbonisation, the imposition of a uniform carbon tax or an emissions cap and tradable permit system is theoretically the most efficient way of achieving a decarbonisation objective because of its inherent flexibility in stimulating the least expensive reductions throughout the economy to be undertaken first – agents make reduction 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

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[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.

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 which 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 born by government, there may be time and cost 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 equaled 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]

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 decarbonisation ends, even in countries where they are currently applied. The use of

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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 SO_2 Allowance Trading," *Journal of Economic Perspectives* 12, 3 (1998): 69-88.

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 Option 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 market place, 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.

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

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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 the 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.

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 make-up 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 a 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 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 of private R&D that would have happened anyway and supporting inappropriate technologies.

5 Conclusions and Recommendations

The potential for industrial energy efficiency actions to contribute to the decarbonisation 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

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

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 decarbonising 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 decarbonisation. 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 decarbonised energy system. Focusing on energy efficiency alone as the means to achieving decarbonisation 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 decarbonised 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 provided 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 any program. A revolving loan fund program may be a good candidate by virtue of its relatively small financial outlay. Tax

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

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 decarbonisation opportunities, but also provide needed complements to any EFR new 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 decarbonate. 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 drives 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]

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[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.

Ecological Fiscal Reform and Energy

Case Study on Energy Efficiency

Economic Study

Appendix A:

Energy Efficiency Opportunities

6 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.

7 Generic / Auxiliary services

7.1 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 improvement 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 contract 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 save 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.

7.2 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.[57] 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 percent and 100 percent 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

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[57] This dominance is declining as induction motor speed control technology improves.

in each of these components and by optimizing the whole system. Although fan technologies are mature—no major design changes have 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).

8 Process Specific Services

8.1 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, which, 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 analysing 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.

8.2 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 re-thickening 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 that 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 (i.e., 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 (120ºC), 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 heat 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.

8.3 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; and 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 gages are being used to determine particle flow, and Program Logic Controllers combined with the advent of powerful microcomputers has 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.[58] Large SAG mills utilize liners

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58 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.

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 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. Over grinding 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 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.

8.4 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 1000°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 3 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 1000 to 1200°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 percent 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 1600°C and 1700°C. The gas leaving the fluidized bed contains 65% to 70% CO, 20 to 25 percent 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 are already reduced. All EAFs in Canada operate with 3 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.[59]

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 re-heating 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.

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[59] 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.

Heat Recovery from Reheat Furnaces – Examples of heat recovery from reheat furnaces include:

- 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.
- 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 (1100 to 1300°C) and then re-shaped / 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 for 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.

8.5 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 (Aluminium Production) – Separation of aluminium 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 aluminium 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 AlF_3 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.

Stable Anodes and Stable Cathodes / Inert anodes and Wetted Cathodes (Aluminium Production) – Stable anodes and stable cathodes are pre-commercial technologies that would completely eliminate carbon-based anodes from electrolysis, as well as improve electrical efficiency by about 25% in a pre-bake plant, slightly less in a Soderberg plant. Alcoa hopes to commercialize the technology by 2005. Stable anodes are ceramic / metal ("cermet") electrical conductors that deteriorate very slowly and contain no carbon. Energy needed for the manufacture of stable anodes would be far less than for carbon anodes, since they last about 130 times as long for the same rate of aluminium production. Generating stable anode material requires about 14.3 GJ / tonne (of anode) while pre-baked carbon anodes require about 7.96 GJ / tonne and Soderberg anodes require 3.7 GJ / tonne during melting and mixing stages. Prebaked anodes must be replaced every 14 - 18 days, while stable anodes last about 5 years.

Near Net Shape / Thin Strip Casting (Aluminium) – Currently, the casting and rolling stage of aluminium 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 (1-10mm, the current slab thickness is about 120-300 mm). Energy consumption is greatly reduced because of the eliminated pre-heating step.

Improved Recycling (Aluminium) – Producing aluminium with recycled process scrap and used aluminium products is both less energy intensive and has lower operating costs than primary aluminium production. Current aluminium 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 of 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 commercialised.

8.6 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 6 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 its 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 gives 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 show 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%.

8.7 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 1590°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 is 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.