Canadian Energy Research Institute

Study on the Electrical Efficiency of Alberta's Economic Sectors

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Executive Summary

An effective way of reducing air emissions from the consumption of energy is through energy efficiency improvements and energy conservation. This is true of all forms of energy including electricity. In Alberta, electricity is a major energy fuel consumed across the residential, commercial and industrial end-use sectors. Table E.1 illustrates that with the exclusion of natural gas use in space and water heating, the share of electricity in total energy consumption ranges between 11% to 91% across the three energy demand sectors. The share of electricity as illustrated in this table has remained more or less constant through the last decade.

Table E.1
Fuel Shares in Residential, Commercial & Industrial Sectors in Alberta – 2001 (excluding space & water heating)

Sector and Fuel	Share in Sectoral Demand (%)
Residential Electricity	91%
Residential Natural Gas	9%
Residential Oil	0%
Residential Other Fuels	0%
Commercial Electricity	66%
Commercial Natural Gas	20%
Commercial Oil	0%
Commercial Other Fuels	14%
Industrial Electricity	11%
Industrial Natural Gas (incl. Process heat)	69%
Industrial Oil	0%
Industrial Other Fuels	20%

Source: CERI E2020 Database.

Given the importance of the electricity consumption in the total energy use portfolio, the electric use sector holds significant potential for emission reductions through electric use efficiency and conservation. The CERI study was commissioned by CASA to examine elements of this potential. The study identifies gaps in efficiency of the existing stock and the best practices of major end-use appliances in Alberta. The results of the study help understand the extent to which the electricity consumption and corresponding emissions can be reduced in Alberta through the replacement of existing inefficient end-use technologies by the corresponding best practice (state of the art) technologies.

In identifying the efficiency gaps, the study focuses on key end-uses across sectors. These end-uses are selected on the basis of their respective shares in electricity consumption and data availability on both actual efficiency and the corresponding best practices. It needs to be noted though, that the improvements to enduse efficiency are not the only avenues of efficiency improvements, rather other non-enduse technology measures or process improvements may provide an equal benefit. However, not much best practice data at the process level is available in public domain, and is therefore not included in this study.

Table E.2 provides shares of the select end-uses examined in this study.

Table E.2
Electricity Shares in Key Residential, Commercial & Industrial End Uses in Alberta (2001)

End-Use	Share in Sectoral Demand (%)
Residential Lighting	31.7
Residential Refrigeration	29.6
Residential Other substitutable	24.9
Residential Other non-substitutable	13.4
Commercial Air Conditioning	38.7
Commercial Lighting	38.2
Commercial Refrigeration	6.6
Industrial Electric Motors	65 - 97*
Industrial Process heat	0- 29.2*

Source: CERI E2020 Database.

* in select industrial sectors

A wide range of data and previously completed studies were reviewed to identify both the best practices and the existing efficiencies for electricity using equipment. The gaps identified in the study are summarized in Table E.3. The results suggest the residential sector end-use devices offer the largest saving potential in all electricity using equipment across sectors. The largest potential exists in lighting, refrigerators, dishwashers and clothes washers. Just for residential lighting, it is estimated that efficiency gains of approximately 67% to 75% can be achieved by moving to the more efficient compact fluorescent lighting.

The commercial lighting, refrigeration, and air conditioning is another potential source for efficiency improvements. The study suggests a gap of approximately 33% to 56% for commercial sector lighting. Overall the efficiency gap in the industrial sector is small. It is assumed that the existence of the Canadian Industry Program for Energy Conservation (CIPEC) may be instrumental in increased efficiency in this sector. Note, however, that these efficiency gaps in the industry sector are measured at the device level (i.e., electrical motors) and other options for efficiency improvement at the process level, or at the industry benchmarking level have not been considered due to a lack of appropriate data. It is expected that the efficiency gap would be larger if the process level gap is also considered.

To achieve the potential savings identified in the study, a multi-layered approach is suggested. Not only is there a need to move to higher efficiency equipment for certain end-uses, there is also a need to change how consumers use these equipment. A combination of market signals, financial incentives, education and awareness and regulation is required to bring the desired changes in energy efficiency and conservation.

Table E.3
Technical Potential for Electricity Savings Through the Best Practice End-use Appliances in Alberta

Device/Technology	% Savings
Residential Sector	
Lighting	67 - 75
Refrigerator	61
Electric Range	5
Electric Dryer	15
Dishwashers	63 - 77
Clothes washers	67 - 87
Commercial and Institutional Sector	
Lighting	33 - 56
Residential type refrigerator	50
Packaged refrigerator	45
Central Chiller	50-70
Packaged AC	10-15
Industrial Sector	
Chemical Industry	
Electric Motor	2 – 8
Electrolyzer	15
Pulp & Paper	
Electric Motor	1 – 5
Oil sands Industry	
VAPEX technology for in-situ bitumen production	80
Electric motors in oil sands mining	2.5
Conventional oil & gas extraction	
Electric Motor	4-8

Chapter 1

Introduction

1.1 Background

Energy efficiency improvement is a well-accepted option to reduce energy demand and the corresponding environmental emissions without curtailing energy services. In most cases, implementation of this option results in a win-win situation such that there are reductions in emissions (and also less stress on depleting energy resources) as well as net savings in energy payments. The Report of the Energy Efficiency and Conservation Working Group to the CASA Electricity Project Team states the many benefits of efficiency and conservation, including[1]:

- Electrical energy efficiency and conservation measures are among the least expensive means of achieving reductions in emissions from electricity generation;
- Energy efficiency and conservation can yield significant financial savings for industrial and residential end users;
- Making energy efficiency improvements is employment intensive;
- Many efficiency and conservation programs are modular and can be implemented in stages, as resources are available;
- Improvements in efficiency can increase the value of assets, particularly buildings.

Due to the rapid technological innovation in the past decade or so, efficient state of the art (or the best practice) technologies are now commercially available in the market. However, utilization of these technologies is still low for several reasons, particularly, high up-front (i.e., capital) costs associated with these technologies and the lack of consumer awareness. The mechanisms or programs to address the environmental concerns including local air pollution, transboundary environmental issues (e.g., acid rain) and global warming, could now help materialize a faster implementation of the energy efficiency options.

The Clean Air Strategic Alliance (CASA), a non-profit association of stakeholders from governments, industry, NGOs, strongly supports the development and promotion of energy efficiency to contribute to improve air quality in Alberta. The electricity project team of CASA intends to identify the gaps in efficiency of the existing stock and the best practices of major end-use appliances in Alberta. The current study was commissioned to meet this objective. The results of the study help understand the extent to which the electricity consumption and corresponding emissions are reduced in Alberta through the replacement of existing inefficient end-use technologies by the corresponding best practice (state of the art) technologies.

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[1] Energy Efficiency and Conservation Working Group Report to the CASA Electricity Project Team, October 2003

1.2 Objective

The main objective of the study is to assimilate data on efficiency of existing stock of electric end-use appliances/technologies and the corresponding best practices in order to determine the efficiency gap between the existing and the best practice appliances/technologies in Alberta. Such a gap indicates the technical potential for end-use electricity efficiency improvements.

1.3 Scope and Project Tasks

The study comprises three main components. The first component is the establishment of the "Best Practices" for various types of energy using equipment across the residential, commercial and industrial sectors.[2] Under this task, alternate data sources on energy equipment shipments across Canada and the U.S. are reviewed to identify equipment efficiencies. "Best Practices" are defined as the highest possible technical efficiency currently available.

The second component reviews historical data on electricity use in Alberta at the end-use level in each of the three demand sectors. The following end-uses are considered:

- Residential – Space Heating, Water Heating, Other Substitutables, Refrigeration, Lighting, Air Conditioning, Other Non- Substitutables.
- Commercial – Space Heating, Water Heating, Other Substitutables, Refrigeration, Lighting, Air Conditioning, Other Non- Substitutables.
- Industrial – Process Heat, Motors, Other Substitutables, and Miscellaneous.

In the third component, actual electricity efficiency were compared with the "Best Practices" to identify the potential for efficiency improvements across various end-uses.

1.4 Study Outline

Chapter 2 of this report provides the detailed methodology adopted in this study to determine average efficiency of various electrical devices and identify the corresponding best practice efficiencies. Chapter 3 provides the results of the study. These are detailed by sector and end use. Chapter 4 presents key conclusions and next steps. Finally, the Appendix provides detailed data on historical trends in end-use electricity consumption and intensities.

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[2] There is minimal use of electricity in the transportation sector and it is assumed that since much of the electric vehicle stock is newer, it may already be operating at near "Best Practices" level.

Chapter 2

Research Methodology

The overall methodology for this study is presented in Figure 2.1. As can be seen from the figure, the overall methodology consists of the following four steps:

(i) Identification of devices and processes;
(ii) Calculation of average efficiencies for existing devices and processes;
(iii) Identification of the best practice devices and processes and estimation of efficiencies and
(iv) Comparison of efficiencies of existing vis-à-vis best practice devices and processes.

The application of this methodology to each sector considered in this study (i.e., residential, commercial and industrial) is discussed in the sections below:

2.1 Residential Sector

2.1.1 Selection of End-Use

End-use services in the residential sector are classified into 7 categories following the approach used in Energy 2020. These categories are: (i) space heating, (ii) water heating, (iii) lighting, (iv) air conditioning, (v) refrigeration, (vi) other substitutable (e.g., cooking range, clothes dryer) and (vii) other non-substitutable (electronic appliances such as TV, video, computer). The shares of these end-uses in total residential electricity consumption in Alberta in 2001 are presented in Table 2.1.

Table 2.1
End-use Shares in Total Residential Electricity Consumption in Alberta in 2001

End-Use	Share (%)
Space heating	0.0
Water heating	0.0
Lighting	31.7
Air Conditioning	0.4
Refrigeration	29.6
Other substitutable	24.9
Other non-substitutable	13.4

Source: CERI E2020 Database

Figure 2.1
Overall Methodology for the Study

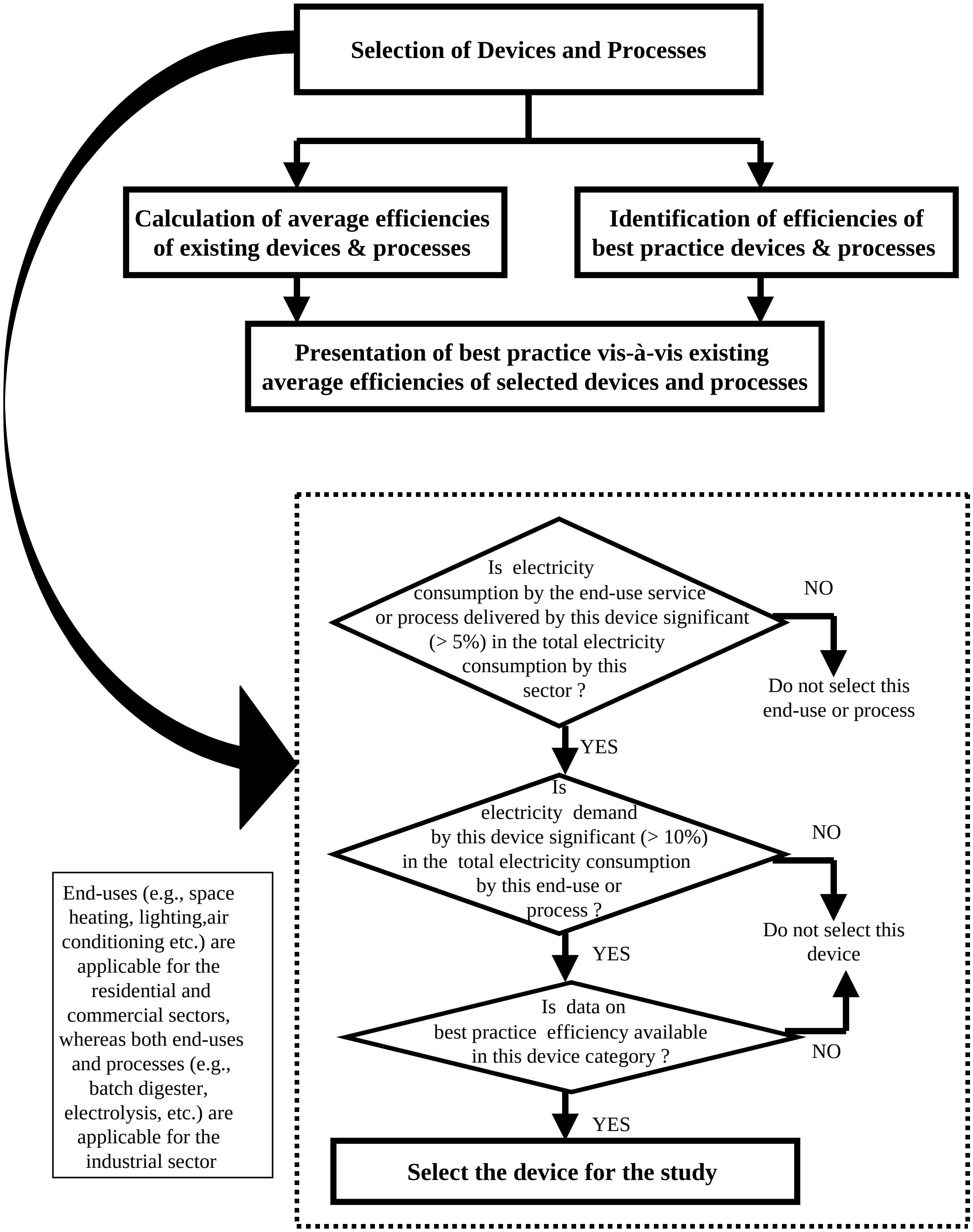

Table 2.1 above suggests that lighting, refrigeration, other substitutable (e.g., oven, clothes dryer) and other non-substitutable (e.g., TV, Video, computer monitor etc.) are the major end-uses in the residential sector. Although electricity is used for auxiliary space heating and to some extent water heating, the consumption of electricity in these end-uses are accounted for under the other non-substitutable category instead of space heating category in Energy 2020. Moreover, the use of air-conditioning in the residential sector is minimal in Alberta as compared with other jurisdictions. Hence, following the device and process selection approach illustrated in Figure 2.1, electric devices for space heating, water heating and air conditioning are not considered in this study.

2.1.2 Selection of Devices or Appliances

Lighting: Various types of lighting systems are used in Alberta households (kitchen, bath, bedroom, foyer, livingroom). The light bulbs used in most of these fixtures are incandescent lamps of 60 to 100 watt ratings. Best practice lighting systems, particularly the lighting fixtures with compact fluorescent lamps are identified.

Refrigeration: Various types of refrigerators in terms of features (e.g., existence and location of freezer) and capacity (i.e., cubic feet) are used in Alberta. The market shares of refrigerators by type and by volume are presented in Table 2.2. The market shares provided in the table are of national level as no provincial level market shares are available.

Table 2.2 illustrates that Type 3 is the main type of refrigerator used in Alberta. Moreover, more than 70% of households use refrigerator of size greater than 16.4 cubic feet. Hence, Type 3 refrigerator with capacity greater than 16.4 cubic feet will be selected as representative refrigerator for this study. The efficiency of refrigerators is measured in terms of electricity consumption per year (i.e., kWh/Year).

Other Substitutable: The main devices or appliances using electricity under this end-use category are cooking range or oven and clothes dryer. The energy efficiency of these appliances is measured in terms of unit energy consumption (i.e., kWh/year). The best practice data in this category are not available in public domain. It is assumed the most efficient type sold in the market in 2002 as representing the best practice.

Other Non-substitutable: A large number of devices using electricity fall under this end-use category. Table 2.3 presents the list of these devices. However, not all devices are used in majority of Alberta households. Note that other non-substitutable as a whole use only 13% of the total residential electricity in Alberta (Please see Table 2.1). Hence, the major appliances considered are clothes- and dish- washers.

Table 2.2
Market Shares of Refrigerators Sold in 2001 by Type and by Volume

By type of refrigerator			
Type	Description	Market Share (%)	Availability of best practice
Type 1	Manual defrosting	3.3	Available, but with slightly different specifications
Type 2	Partial automatic defrosting	0.0	
Type 3	Automatic defrosting with top-mounted freezer	71.0	
Type 4	Automatic defrosting with side-mounted freezer	2.1	
Type 5	Automatic defrosting with bottom-mounted freezer	11.3	
Type 6	Automatic defrosting with top-mounted freezer and through-the-door ice service	0.4	
Type 7	Automatic defrosting with side-mounted freezer and through-the-door ice service	9.1	
Type 11	Compact refrigerators with manual defrosting	2.8	
By volume (i.e., capacity) of refrigerator			
< 8.1 cu. ft.		8.1	Available, but with slightly different specifications
10.5 – 12.4		5.6	
12.5 – 14.4		6.6	
14.5 – 16.4		8.7	
16.5 – 18.4		36.3	
18.5 – 20.5		11.4	
> 20. 5		23.3	

Source: Energy Consumption of Major Household Appliances Shipped in Canada: Trends for 1990–2001, December 2003, Natural Resources Canada.

Table 2.3
List of Devices Under Other-non Substitutable End-use Category

Service	Device
Washing	Clothes washer
	Dish washer
	Dehumidifier
Computer service	CPU
	Monitor
	Printer
Communication	Cordless Phone
	Fax
News & entertainment	TV
	VCR
	DVD Products
	Home Audio
	Set up boxes
	Combination Unit
Musical Instrument	
Physical fitness exercise equipment	
Others	Electric fan
	Electric heater
	Iron

Note that while estimating average efficiency of existing appliances under both other substitutable and other non-substitutable categories, appliances purchased during the period 1990-2001 are considered. This, then, assumes that the operational life of these appliances is not more than 12 years. There might be some households still using appliances greater than 12 years of age, such appliances are, however, not considered in this study due mainly to a lack of historical data. In addition, the market share of various size and type of appliances (e.g., the 7 types of refrigerator by volume) are available only at the national level. The Natural Resources Canada (NRCan) and Canadian Appliance Manufacturers Association (CAMA) were contacted for provincial level data on market shares of various size and type of household appliances, however, no data was found to exist at the provincial level. Although the size and type distribution data if available at provincial level is ideal for use in such analysis, the use of national level data does not introduce significant errors in calculating weighted average efficiency of existing stock of appliances. This is because significant difference in size and type distribution of household appliances across the provinces in Canada is unlikely.

2.2 Commercial Sector

In the Energy 2020 model, commercial sector is divided into the following 14 sub-sectors. (i) government; (iii) education; (iii) health; (iv) private offices and business service; (v) food, lodging and recreation; (vi) wholesale; (vii) retail; (viii) finance, insurance and real estate; (ix) electric utilities (office components); (x) gas utilities (office components); (xi) pipeline (office components); (xii) transportation service offices; (xiii) communication service; (xiv) water and other utility services. In the current study, the 14 sub-sectors are aggregated into two categories: (a) institutional sector and (b) commercial sector. The institutional sector includes the first three sub-sectors mentioned above (i.e., government, education and health) the remainder are included in the commercial sector.

2.2.1 Selection of End-Use

In both institutional and commercial sectors, end-use services are classified into 7 categories following the approach used in Energy 2020. These categories are: (i) space heating, (ii) water heating, (iii) lighting, (iv) air conditioning, (v) refrigeration, (vi) other substitutable (e.g., range, clothes dryer) and (vii) other non-substitutable (electronic appliances such as TV, video, computer). The shares of these end-uses in total commercial electricity consumption in Alberta in 2001 are presented in Table 2.4. The table illustrates that lighting and air conditioning are the two main end-uses for electricity consumption. These two end-uses use about 80% of the total electricity consumption in the commercial sector in 2001. Hence the lighting and air conditioning appliances are selected in the commercial sector. Refrigerator is also selected as its share in the total electricity consumption in the commercial sector is significant (i.e., > 5%).

Table 2.4
End-use Shares in Total Electricity Consumption in the Institutional and Commercial Sectors in 2001

End-Use Category	End-use share (%)	
	Institutional sector	Commercial sector
Space heating	3.2	3.1
Air conditioning (including freezing, space cooling)	39.7	38.7
Water heating	6.5	6.4
Lighting	39.3	38.2
Refrigeration	6.6	6.6
Other substitutable	3.6	4.4
Other non-substitutable	1.1	2.6

Source: CERI E2020 Database

2.2.2 Selection of Devices or Appliances

Lighting: To some extent, the lighting device (or system) used in the commercial and institutional sectors are similar to those used in the residential sector. However, the lamps used in lighting fixtures in the commercial and institutional sectors are fluorescent lamps and metal halide lamps instead of incandescent lamps, which are commonly used in the residential sector. In the institutional sector, the fluorescent lamps such as T12 with magnetic and T8 with standard electronic ballast are mainly used. On the other hand, both fluorescent lamps and metal halide lamps are commonly used in the commercial sectors. The efficient counterpart currently available in market are T8 and T5 fluorescent lamps with low energy consuming electronic ballast, and ceramic metal halide with electronic ballast[3].

Air Conditioning or space cooling: Air conditioning is the main end-use consuming electricity in both institutional and commercial sectors including offices, hospitals, food stores, hotels & restaurants. Table 2.5 presents various types of air-conditioning devices in institutional and commercial sectors in Prairies and their shares in total electricity consumption for air-conditioning in the commercial sector. The table indicates central chillers (or central air-conditioning system) and packaged air-conditioning units are the main devices used for air conditioning in the commercial and institutional sectors. Hence, these two devices are selected in this study. Moreover, residential type air conditioner is also used significantly in the commercial sector (11%) particularly in hotels and hospitals. In fact, residential type AC has two basic configurations of residential central systems: (1) a "split system," in which the condensing unit is located outside and the other components are inside and (2) a packaged-terminal air-conditioning (PTAC) unit that both heats and cools, or only cools. This system contains all components encased in one unit and is usually found in a "utility closet"[4]. In this study, we have considered both split and packaged system under the packaged AC.

Table 2.5
Shares of Air Conditioning Devices in Total Electricity Consumption for Air Conditioning in the Commercial and Institutional Sectors

Air conditioning device	% share in total electricity consumption for air conditioning
Individual room air conditioners	2
District-chilled water from outside source	3
Central chillers	49
Packaged air-conditioning units	42
Composite	4

Source: Commercial and Institutional Building Energy Use Survey 2000, Detailed Statistical Report, Natural Resources Canada, Dec. 2002

Efficiency of air conditioners are measured in terms of energy efficiency ratio (EER), which is cooling capacity divided by power consumption. The higher the EER, the more efficient the air conditioner.

Refrigeration: Institutional establishments tend to use similar type of refrigerators as in households. However, the size of refrigerators would obviously be larger as compared to what is used in households. Hence refrigerators with size greater than 25 cubic feet in capacity will be

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[3] For more information, please see Throne, J. and S. Nadel (2002), *Commercial Lighting Retrofits: A Briefing Report for Program Implementers, ACEEE Report No. A032*. American Council for an Energy Efficient Economy, Washington.

[4] *Commercial and Institutional Building Energy Use Survey 2000, Detailed Statistical Report, Natural Resources Canada,* Dec. 2002.

selected for this institutional sector. The refrigerator and freezer used in commercial sector are mainly the packaged refrigeration systems that include reach-in refrigerators and freezers, icemakers, refrigerated vending machines, beverage merchandisers, and walk-in refrigerators and freezers.

2.3 Industrial Sector

2.3.1 Selection of Sector

This study considers major industrial sectors. The selection is based on two key factors: (i) share of the sector in the total industrial electricity consumption and (ii) electric intensity (i.e., electricity consumption per unit of sectoral output). Table 2.6 presents shares of individual industries in electricity consumption and the electricity-industrial output ratio (i.e., electricity intensity).

It is interesting to note that oil and gas mining alone consumes about half of the total electricity consumption in the industrial sector in Alberta. Chemicals and pulp and paper are other main industries consuming electricity. In 2001, the shares of chemicals and pulp and paper in the total industrial electricity consumption are 15% and 10%, respectively. It is also interesting to note that these industries are not only the major electricity consuming industries in Alberta, but are amongst the highest electricity intensive industries in the province. While oil sands industry uses more than 4000 kWh to produce a thousand dollars worth of output; pulp and paper and chemicals need about 2000 kWh and 600 kWh of electricity respectively to produce a thousand dollar worth of output. Thus, oil sands, conventional oil and gas production, pulp and paper and chemicals industries are selected in this study.

Table 2.6
Industrial Sector Electricity Share and Intensity in Alberta
(2001)

Industrial sectors	Electricity consumption share	Electricity intensity
	(%)	kWh/$
Agriculture	5.21	0.224
Conventional Oil Mining	16.34	1.260
Oil Sands Mining	18.29	4.159
Gas Mining	15.49	0.228
Coal Mining	0.12	0.058
Metal Mining	0.01	0.319
Non-metal mining	0.05	0.056
Food & Tobacco (NAICS 311 & 312)	4.48	0.233
Textiles (NAICS 313 & 314)	0.02	0.056
Apparel (NAICS 315)	0.02	0.019
Leather (NAICS 316)	0.00	0.003
Lumber (NAICS 321)	1.31	0.220
Pulp & Paper (NAICS 322)	9.68	1.979
Printing (NAICS 323)	0.09	0.041
Petroleum Products (NAICS 324)	3.51	0.322
Chemicals (NAICS 325)	14.69	0.617
Rubber & Plastics (NAICS 326)	0.30	0.107
Non-metallic minerals excluding cement (NAICS 327)	0.12	0.072
Cement	0.86	1.364
Iron & Steel (NAICS 331a)	1.03	0.227
Nonferrous (NAICS, 331b)	7.23	1.317
Fabricated Metals (NAICS 332)	0.34	0.053
Machines (Machinery, NAICS 333)	0.21	0.025
Computer and Electronic Products (NAICS 334)	0.01	0.052
Electric Equipment (NAICS 335)	0.09	0.052
Transport Equipment (NAICS 336)	0.43	0.122
Furniture (NAICS 337)	0.03	0.012
Other Manufacturing (NAICS 339)	0.03	0.014

Source: CERI E2020 Database

2.3.2 Selection of Processes/End-Uses and Devices

***Pulp and Paper Industry*:** Pulp and paper industry consists of various processes (e.g., wood debarking and chipping; pulping; washing and bleaching; drying; evaporation; paper forming, pressing and finishing, etc.). Each process consumes a range of energy commodities (gas, oil, pulping liquor, electricity.) for providing various services such as pumping, compression, and direct drive.. Table 2.7 presents key processes and services requiring electricity[5].

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[5] Only those processes, which use electricity, are listed.

Table 2.7
Processes and Services Consuming Electricity in the Pulp and Paper Industry

Major output		Process		Service		Device		Energy
Newsprint Linerboard Uncoated Coated Tissue	←	Wood de-barking & chipping; Pulping; Washing; Bleaching; Drying; Evaporation; Paper forming, pressing & finishing	←	End-use: Electric Motor			←	Electricity
				Pumping; Air - Displacement; Compression; Conveyance Direct drive	←	Electric motors of various type & size		
				End-use: Lighting and HVAC				
				Lighting; Heating; Ventilation; Air - Conditioning	←	Electric bulbs boiler Heater, AC		

Table 2.7 suggests three main end-uses requiring electricity in the pulp and paper industry. These are electric motors, lighting and HVAC (i.e., heating, ventilation and air-conditioning). Table 2.8 presents share of these end-uses in total electricity consumption in the pulp and paper industry in 2001.

Table 2.8
End-use Shares in Total Electricity Consumption in the Pulp and Paper Industry (2001)

End-use	Share (%)
Process heating	0.0
Electric Motors	96.8
Other Substitutable (e.g., hot water, drying that is not part of primary process heat)	0.8
Miscellaneous (e.g., Lighting, HVAC, electro-mechanical devices etc)	2.4

Source: CERI E2020 Database

The end-use shares presented in Table 2.8 clearly indicate that electric motors are the main end-use to consume electricity in the pulp and paper industry. Since electric motors consume more than 96% of the total electricity consumption in this sector, only the electric motors will be selected in this study for this sector.

***Chemicals Industry*:** The main outputs from chemical industries (i.e., chemical products) include Chlor-alkali (i.e., chlorine and caustic soda); hydrogen peroxide, ammonia and other nitrogen products, methanol, ethylene. The major processes involved in producing these outputs are electrolysis, air-reformation and synthesis; pyrolysis and polymerization. Each of these processes consume energy commodities (gas, oil, electricity etc.) to provide a range of services such as electrolysis, synthesis, pumping, compression, direct drive and others. Table 2.9 presents key processes and services requiring electricity in the chemicals industry.

Table 2.9
Processes and Services Consuming Electricity in the Chemicals Industry

Major output		Process		Service		Device		Energy
Chlor-Alkali; Hydrogen Peroxide; Ammonia And Other Nitrogen Products; Methanol; Ethylene	←	Electrolysis; Air-Reformation And Synthesis; Pyrolysis; Polymeri-Zation	←	End-use: Electrolysis			←	Electricity
				Electrolysis	←	Electrolyzer		
				End-use: Electric Motor				
				Pumping; Air - Displacement; Compression; Conveyance Direct drive	←	Electric Motors of Various Type & Size		
				End-use: Lighting and HVAC				
				Lighting; Heating; Ventilation; Air - conditioning	←	Electric Bulbs Boiler Heater, AC		

Table 2.9 illustrates, there are four main end-uses that require electricity in the chemicals industry. These are electrolysis, electric motors, lighting and HVAC (i.e., heating, ventilation and air-conditioning). Table 2.10 presents share of these end-uses in total electricity consumption in the chemicals industry in 2001. From Table 2.10, it is evident that electrolysis and electric motors together consume about 95% of the total electricity consumption in this sector, hence these two end-uses are selected in this study.

Table 2.10
End-use Shares in Total Electricity Consumption in the Chemicals Industry (2001)

End-use	Share (%)
Electrolysis process	29.2
Electric Motors	65.5
Other Substitutables (e.g., hot water, drying other than primary process heat)	0.5
Miscellaneous (e.g., Lighting, HVAC, electro-mechanical devices etc)	4.9

Source: CERI E2020 Database

***Oil and Gas Extraction Industry*:** Oil and gas extraction consists of various processes (e.g., ore crushing and screening; mixing crude bitumen with hot water; separating sands from bitumen; upgrading of bitumen to synthetic crude). Table 2.11 presents key processes and services requiring electricity.

Table 2.11
Processes and Services Consuming Electricity in the Oil Sands Industry

Major output		Process		Service		Device		Energy
Crude oil	←	Ore Crushing and Screening; Mixing crude Bitumen with hot water; Separating sands from Bitumen; Upgrading of Bitumen to Synthetic Crude	←	End-use: Electric Motor			←	Electricity
				Compression; Pumping; Conveyance; Direct drive	←	Electric Motors of Various Type & Size		
				End-use: Lighting and HVAC				
				Lighting; Heating; Ventilation; Air - conditioning	←	Electric Bulbs Boiler Heater, AC		

There are three main end-uses that require electricity in the upstream oil and gas industry: electric motors, lighting and HVAC. Table 2.12 presents shares of these end-uses in total electricity consumption in the oil and gas industry (including oil sands, conventional oil production and gas production) in 2001.

Table 2.12
End-use Shares in Total Electricity Consumption in the Oil & Gas Industry (2001)

End-use	Share (%)
Process heat	0.0
Electric Motors	93.1
Other Substitutables (e.g., hot water, drying that is not part of primary process heat)	0.3
Miscellaneous (e.g., Lighting, HVAC, electro-mechanical devices etc)	6.6

Source: CERI E2020 Database

As indicated from the table above, the electric motors is the main end-use consuming electricity (93%) in the oil sands industry and hence only the electric motors are selected in this study.

Oil sands industry is of two types depending upon the process of oil recovery. If oil sands or bitumen deposits are available near the earth's surface and mining technologies, like in other surface mining industries, are used to extract oil, the production process is called oil sands mining. On the other hand, if deposit is buried deeper into the earth surface and extracted by using drilling technologies, the process is referred to as in-situ recovery. In 2003, 153.2

thousand cubic meters of crude bitumen was produced per day, with surface mining accounting for 64% and in situ for 36%[6].

Conventional oil and gas producing industries are less energy intensive as compared to oil sands industry as the process or technologies in the former are simpler and require smaller amount of energy. In the case of conventional oil production, artificial lift technique is mainly used in Alberta. A down hole pump, either driven by electric motors or diesel, is used in this process. Less pumping service is required in gas production, as pressure of gas in the well drives the flow. If pumps are used to enhance the flow, they are of the same type as used in conventional oil production process.

The common types of motors used in the pulp and paper, chemicals, non-ferrous and oil mining are presented in Table 2.13. However, the mix of motors differs between industries. This implies that the weighted average efficiency of existing motors would be different across industries. Moreover, for each type of induction AC motors, two categories are currently in use: (i) standard motors and (ii) efficient motors (not necessarily the best practice). The weighted average of these categories is used for an average efficiency of each type of AC induction motor. The efficiency of the best practice motor of any size or type will be presented along with the average efficiency of the existing motors of the corresponding size or type.

Table 2.13
Common Types of Motors Considered in the Study

Standard AC Induction Motor 1-5 Hp
Efficient AC Induction Motor 1-5 Hp
Standard AC Induction Motor 6-25 Hp
Efficient AC Motor 6-25 Hp
Standard AC Induction Motor 26-100 Hp
Efficient AC Induction Motor 26-100 Hp
Standard AC Induction Motor 101-200 Hp
Efficient AC Induction Motor 101-200 Hp
Standard AC Induction Motor 201-500 Hp
Efficient AC Induction Motor 201-500 Hp
Synchronous Induction Motor 201-500 Hp
Direct Current Motor Generator Electric Motor 201-500 Hp
Direct Current Solid State Electric Motor 201-500 Hp
Standard AC Induction Motor >500 Hp
Efficient AC Induction Motor >500 Hp
Synchronous AC Induction Motor >500 Hp
Direct Current Motor Generator Electric Motor >500 Hp
Direct Current Solid State Electric Motor >500 Hp

Source: CIEEDAC

Note that energy efficiency in the industrial sector can be measured at two levels: (i) process level (e.g., compression, pumping, air-displacement) and (ii) device level (e.g., electric motors).

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[6] Alberta's Reserves 2003 and Supply/Demand Outlook 2004-2013, Alberta Energy and Utilities Board, Statistical Series (ST) 98, 2004.

The efficiency gaps (i.e., difference in efficiency between existing and the best practice) would vary depending upon the level at which these are measured. Efficiency gap measured at the process level (i.e., gap between the existing and best practice industrial processes) would normally be higher than measured at the device level. Using the most efficient device is not the only way to reduce energy consumption. A number of other measures can be undertaken to improve efficiency including better configuration and operation of devices (e.g., appropriate control of motor speed), selection of appropriate motor size consistent with the load requirement, reducing friction in drive, conveyance, air displacement through proper maintenance and others. Since efficiency data are not available at the process level for existing- as well as best practices, only device level efficiencies are considered.

2.4 A Short Note on ENERGY 2020

E2020 is an integrated multi-region, multi-sector model that simulates the supply, price and demand for all fuels. It is a causal and descriptive model, which dynamically describes the behaviour of both energy suppliers and consumers for all fuels and for all end-uses, and simulates the physical and economic flows of energy users and suppliers. It is an outgrowth of the FOSSIL2/IDEAS model developed for the US Department of Energy (DOE) and used for national energy policy analysis since the Carter administration.[7] E2020 is flexible and could define as many geo-political regions as required by users. Currently, it defines 13 Canadian regions, 50 US States. On the US side, the 50 States were re-grouped for the Canadian climate change work into 5 regions for ease of computation and presentation[8]. It is historically parameterized and can simulate any groupings of the 3500 interacting energy suppliers in North America. It can also be linked with macroeconomic models to determine the economic impacts of energy/environmental policies. Currently, it has been linked with a dynamic input-output approach based macroeconomic model developed by Informetrica for economic analysis in Canada and with the REMI[9] macroeconomic model in the case of U.S. One of the attractive features of E2020 is that, unlike most energy models, it houses enormous historical database to econometrically estimate all model parameters (e.g., price response of demand, price response of supply).

The model has been used extensively by several State Departments and Electric Utilities in the US. In Canada, Natural Resources Canada was instrumental in the construction of the national model in the early 90s. The model was used within the department for technology assessments. The Department of Energy & Mines in Saskatchewan has used the model since 1993. The Canadian Energy Research Institute (CERI) is an important Canadian participant in the building of the current North American version of E2020. Since E2020 is capable of producing long-term energy market forecasts and analyzing impacts of policy changes to the markets; it's use would

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[7] FOSSIL2 was the original version but was renamed to IDEAS later to reflect its evolutionary development since its original construction. The early version of the E2020 model was developed in 1978 at Dartmouth College for the DOE's Office of Policy Planning and Analysis.

[8] Several stand-alone versions focusing on individual jurisdictions also exist for E2020. For Canada, one such version is the E2020 model for Saskatchewan.

[9] Regional Economic Models, Inc., Amherst, Massachusetts.

continue in future for a range of studies starting from energy market forecasting to specific policy issues such as energy sector restructuring, promotion of clean energy technologies. There is also a possibility of using it for developing countries and economies of transitions in analyzing impacts of GHG mitigation options under the Clean Development Mechanism and Joint Implementation.

It should be noted that in this study the model has been utilized only for its historical data. No simulations have been undertaken.

Chapter 3

Efficiency of Existing vis-à-vis the Best Practice End-use Devices and Technologies

The efficiency of the existing stock and the best practices for end-use appliances are derived from various sources. In most cases, multiple sources are referred to obtain the best data available. The bibliography indicates the extent of review undertaken to derive the best possible data. The key sources of data for both existing as well as the best practice device/technology are presented in Table 3.1.

Discussion on the average efficiency of existing stock of devices and technologies and the efficiency of corresponding best practices in the residential, commercial and industrial sectors follows in the sections below.

3.1 Residential Sector

Lighting, refrigeration, other substitutables (e.g., electric cooking range, clothes dryer) and other non-substitutables (e.g., clothes washer and dishwasher) are the major end-uses consuming electricity in the residential sector in Alberta. These end-uses altogether account for more than 95% of the total electricity consumed in the residential sector in 2001. The existing and best practices efficiencies for each of these end-uses are presented below.

3.1.1 Lighting

The residential lighting systems (e.g., lamps, fixtures, architectural lighting systems, etc.) in Alberta mainly use incandescent lamps[10]. A preliminary survey of lighting equipment suppliers located in Calgary area indicates that about 90% of existing households in Alberta use incandescent lamps. Although lamps with varying levels of power input (i.e., Watt) are available in the market, the most commonly used are incandescent lamps with 60, 75 and 100 Watts. The best practice lighting device for the residential sector is the compact fluorescent lamp. Table 3.2 presents the most common lamps in the existing residential lighting system and the corresponding best practice compact fluorescent lamps that are commercially available.

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[10] 1997 Survey of Household Energy Use, Natural Resources Canada, 2000.

Table 3.1
Key Sources of Data for Existing as Well as Best Practice Devices and Technologies

Devices/technologies	Data Source	
	Existing Stock	Best Practice
Residential Sector		
Lighting	1997 Survey of Household Energy Use, Natural Resources Canada, 2000	US Department of Energy, Energy Star Program Shedding Light on Home Lighting Use, Home Energy Magazine Online January/February 1997
Refrigerators, dishwashers, clothes washers,	Energy Consumption of Major Household Appliances Shipped in Canada — Trends for 1990–2001, December 2003, Natural Resources Canada	US Department of Energy, Energy Star Program
Electric ranges and electric dryers	Energy Consumption of Major Household Appliances Shipped in Canada — Trends for 1990–2001, December 2003, Natural Resources Canada	Energy Consumption of Major Household Appliances Shipped in Canada — Trends for 1990–2001, December 2003, Natural Resources Canada US Department of Energy, Energy Efficiency and Renewable Energy
Commercial Sector		
Lighting	Commercial and Institutional Building Energy Use Survey 2000, Detailed Statistical Report, NRCan, Dec. 2002	Commercial Lighting Retrofits: A Briefing Report for Program Implementers, ACEEE Report No. A032. American Council for an Energy Efficient Economy, Washington.
Residential type Refrigerators	Energy Consumption of Major Household Appliances Shipped in Canada — Trends for 1990–2001, December 2003, Natural Resources Canada	US Department of Energy, Energy Star Program
Packaged Refrigerators		
Air conditioners	To be determined	To be determined
Industrial Sector		
Electric motors	Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC)	National Electricity Motor Association
Electrolyzers	Chlorine Industry Review 2002 – 2003, Euro Chlor, 2004	

Table 3.2
Specification of Existing Vis-à-Vis the Best Practice Lighting System

Specification	Existing (Incandescent)	Best practice (Compact fluorescent lamps)
Capacity (Watt)	60	15
Life Expectancy (hour)	1000	6,000
Efficiency (Lumen/Watt)	15	59
Capacity (Watt)	75	25
Life Expectancy (hour)	1000	6000
Efficiency (Lumen/Watt)	16	48
Capacity (Watt)	100	32
Life Expectancy (hour)	1000	10,000
Efficiency (Lumen/Watt)	17	54

The best practice lamps (i.e., compact fluorescent lamps) are 3 to 4 times more efficient than the existing incandescent lamps. Moreover, the best practice lamps are 6 to 10 times more durable than the existing lamps in the residential sector. For example, a 15-Watt compact fluorescent lamp not only provides as much illumination as a 60-Watt incandescent lamp, but also lasts six times longer than the incandescent lamp.

3.1.2 Refrigeration

As discussed in the methodology section, various types of refrigerators in terms of features (e.g., existence and location of freezer) and capacity (i.e., cubic feet) are used in Alberta. More than 70% of households in Canada use the refrigerator with automatic defrosting with top-mounted freezer (Type 3). Moreover, more than 70% of households use refrigerators with size greater than 16.4 cubic feet[11]. Hence, the Type 3 refrigerator with capacity greater than 16.4 cubic feet has been selected as representative refrigerator for this study. The efficiency of refrigerators is measured in terms of electricity consumption per year (i.e., kWh/Year). Efficiency (i.e., unit energy consumption) of existing vis-à-vis best practice refrigerator in the residential sector are presented in Table 3.3.

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[11] Energy Consumption of Major Household Appliances Shipped in Canada: Trends for 1990–2001, December 2003, Natural Resources Canada.

Table 3.3
Existing Vis-à-Vis the Best Practice Refrigerator in the Residential Sector

Specification	Unit energy consumption (kWh/year)	
	Existing	Best practice
Automatic defrosting with top-mounted freezer (Type 3) of size 16.4 cubic feet	738	291

As can be seen from the table, there is a large potential of savings in electricity consumption in residential sector refrigeration system in Alberta. If the best practice refrigerator is used instead of the existing, more than a half of electricity (in fact, 61%) consumed by the existing refrigerator can be saved.

Refrigerators are becoming more efficient due largely to the ongoing efforts of manufacturers and the implementation of minimum energy performance standards (MEPS). The market share of refrigerators requiring less than 50 kWh per cu. ft. per year has increased from 5.4% in 1990 to 91.7% in 2001. The greatest increase in market share was for refrigerators that used less than 30 kWh per cu. ft. per year (i.e., less than 492 kWh/year by refrigerators of the most common size, 16.4 cu.ft). Although the unit energy consumption of new stock of refrigerators has significantly decreased in the past 10 years; the weighted average unit energy efficiency of the existing stock is still high due to the high share of old (i.e., inefficient) refrigerators in the existing stock.

3.1.3 Other Substitutables

The major devices or appliances using electricity under this end-use category are cooking range or oven and clothes dryer. The efficiency of these appliances is measured in terms of electricity consumption per year or unit energy consumption (i.e., kWh/Year). The existing electric ovens are classified into five categories based on their unit energy consumption. These are as follows:

(i) Range with unit energy consumption less than700kWh/year;
(ii) Range with unit energy consumption between 700kWh/year and 750kWh/year;
(iii) Range with unit energy consumption between 750kWh/year and 800kWh/year;
(iv) Range with unit energy consumption between 800kWh/year and 850kWh/year;
(v) Range with unit energy consumption higher than 850kWh/year.

Based on the market share of each of these categories, the weighted average unit energy consumption of the existing stock was calculated. The existing and best practice efficiencies (i.e., unit energy consumption) are presented in Table 3.4. Note that, the best practice range considered here is the most efficient range available in Canada in year 2001. It is possible that electric ovens available in the international market are more efficient than what is considered here. However, no additional information is available in public domain on those appliances.

Table 3.4
Existing Vis-à-Vis Best Practice Electric Range and Electric Dryer in the Residential Sector

	Unit energy consumption (kWh/year)	
	Existing	**Best practice**
Electric Range or Electric Oven		
Specification	Various types with manual cleaning to self cleaning units	Commercially available most efficient self cleaning unit
Unit Energy Consumption	777	741
Electric Dryer		
Specification	Various types with size ranging from below 800kWh/year to higher than 1050kWh/year	
Unit Energy Consumption	865	735

The best practice electric range considered in this study is the most efficient electric range available in the marketplace in Canada in the year 2001. Since this may not necessarily be the best practice range, the efficiency gap between the most efficient available in 2001 and the existing stock may be underestimated. Other, more efficient, best practice ranges may be available on the international market.

Like the electric oven, electric dryers are classified into five categories based on their unit energy consumption. These are as follows:

(i) Dryer with unit energy consumption less than 800kWh/year;
(ii) Dryer with unit energy consumption between 800kWh/year and 900kWh/year;
(iii) Dryer with unit energy consumption between 900kWh/year and 950kWh/year;
(iv) Dryer with unit energy consumption between 950kWh/year and 1050kWh/year;
(v) Dryer with unit energy consumption higher than 1050kWh/year.

Based on the market share of each of these categories, a weighted average unit energy consumption of the existing stock of clothes dryers was calculated (see Table 3.4.). No explicit information (i.e., unit energy consumption) is available for the best practice clothes dryers. However, information available from the Office of the Energy Efficiency and Renewable Energy of the US Department of Energy[12] suggests that that the best practice clothes-dryer uses 15% less electricity than the existing clothes dryer. Based on this information, the unit energy consumption of the best practice clothes dryer is derived (see Table 3.4).

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[12] http://www.consumerenergycenter.org/homeandwork/homes/inside/appliances/dryers.html#electric

3.1.4 Other Non-substitutables

A large number of devices using electricity fall under this end-use category. Examples are: clothes washer, dish washer, dehumidifier, iron, computer CPU, computer monitor, computer printer, cordless phone, fax machine, scanner, radio, cassette player, television, VCR, DVD products, home audio system, set up boxes, combination unit, musical instruments etc. Electricity consumption by each type of appliance is not significant, however, electricity consumption by all of these appliances together is substantial (13% of the total residential electricity consumption in 2001). Moreover, although the total electricity consumption by these appliances is available, electricity consumption by each type of appliance is not available. In addition, even if the existing energy consumption data is available, information on the best practice appliance is not available. Hence, only those appliances for which existing as well as best practice efficiency data is available have been selected in this study, and these include clothes- and dish- washers. Like other appliances such as a refrigerator, cooking range, the efficiency of these appliances is measured in terms of electricity consumption per year or unit energy consumption (i.e., kWh/Year).

The existing dishwashers are classified into five categories based on the unit energy consumption. These are as follows:

(i) Dishwasher with unit energy consumption less than 600kWh/year;
(ii) Dishwasher with unit energy consumption between 600kWh/year and 700kWh/year;
(iii) Dishwasher with unit energy consumption between 700kWh/year and 800kWh/year;
(iv) Dishwasher with unit energy consumption between 800kWh/year and 1000kWh/year;
(v) Dishwasher with unit energy consumption higher than 1000kWh/year.

The weighted average unit energy consumption of the existing stock of dishwasher is calculated based on the market share of the above mentioned categories. The existing and best practice efficiencies (i.e., unit energy consumption) are presented in Table 3.5.

Table 3.5
Existing Vis-à-Vis the Best Practice Dishwasher and Clothes Washer in the Residential Sector

	Unit energy consumption (kWh/year)	
	Existing	**Best practice**
Dishwasher		
Specification	Various types with size ranging from below 600kWh/year to higher than 1000kWh/year	Various models with different brands (identified by US Energy Star Program of the USDOE)
Unit Energy Consumption	734	166 – 271
Clothes Washer		
Specification	Various types with size ranging from below 800kWh/year to higher than 1500kWh/year	Various models with different brands (identified by US Energy Star Program of the USDOE)
Unit Energy Consumption	910	115 – 298

There is a large difference in efficiency (or unit energy consumption) between the existing stock and the best practice dishwasher. This is due to the significant improvement in energy efficiency of dishwashers in the last 10 years. 68% of dishwashers sold in 1990 consumed more than 1000 kWh of electricity per year. Unit energy consumption decreased by about 40% by 2001. More than 70% of the total dishwashers sold in 2001 consumed electricity between 600 to 700 kWh per year[13]. Although there is an increasing trend for using high efficiency dishwashers, there is still a large gap in efficiency of existing stock and the best practice dishwasher.

Like the dishwasher, the clothes washers are classified into five categories based on their unit energy consumption. These are as follows:

(i) Clothes washer with unit energy consumption less than 800kWh/year;
(ii) Clothes washer with unit energy consumption between 800kWh/year and 900kWh/year;
(iii) Clothes washer with unit energy consumption between 900kWh/year and 950kWh/year;
(iv) Clothes washer with unit energy consumption between 950kWh/year and 1050kWh/year;
(v) Clothes washer with unit energy consumption higher than 1050kWh/year.

Based on the market share of each of these categories, a weighted average unit energy consumption for the existing stock of clothes washers was calculated (see Table 3.5.). Again like the dishwashers, there is a large gap in unit energy consumption of the existing stock of clothes washers and the best practice clothes washers. Significant improvement has occurred in energy efficiency of clothes washers in the last 10 years. More than 60% of the clothes washers manufactured in 1990 consumed more than 1000 kWh electricity per year. The unit energy consumption dropped to 470 kWh by 2001. About 17% of the total clothes washers shipped in 2001 were ENERY STAR products[14]. The best practice clothes washers indicate that there is still a large room to improve energy efficiency of existing stock of clothes washers.

3.1.5 Some Issues with Best Practice End-use Appliances in the Residential Sector

Phantom Load

Most electronic devices including home entertainment (audio/video) require electricity even while switched off to keep them instantly operational. Such electricity load is termed 'phantom load' or 'standby power' or 'standby losses' or 'off-mode power'. An electronic appliance requires standby power or phantom load if it has any of the following features:

- It gets power through a stand-alone power supply (e.g., UPS in computer system);
- It has a remote control;
- It has a soft touch keypad;
- It charges the battery of a portable device;

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[13] Energy Consumption of Major Household Appliances Shipped in Canada: Trends for 1990–2001, December 2003, Natural Resources Canada.

[14] Energy Consumption of Major Household Appliances Shipped in Canada: Trends for 1990–2001, December 2003, Natural Resources Canada.

- It is warm to touch near the switch when switched on;
- It does not have an "off" switch.

A research team of Lawrence Berkeley National Laboratory LBNL)[15] led by Alan Meier surveyed standby power use in hundreds of appliances and found that consumption of standby power vary at a wide range for the same type of appliance. For example, compact audio systems have standby varying from 1.3 watts to 28.6 watts. This is due to the variability in features (e.g., certain audio devices have larger and brighter displays than others) and the additional electricity required to deliver these features. Certain appliances also consume nearly as much power while switched off as switched on. Most television cable boxes, compact audio equipment and VCRs consume almost the same amount of electricity no matter whether they are in on or off mode. The LBNL research team also estimates that US households, on average, require Phantom load of 50Watts. Applying the same estimate to 1014.2 thousand Alberta households[16] in 2001, standby or phantom load electricity demand amounts to 444 GWh, which is about 6% of the total residential electricity consumption (7723 GWh[17]) in Alberta in 2001. Although the electricity consumption by phantom load is significant in Alberta, the total load consists of hundreds of different types of appliances for which neither the average efficiency nor the best practice efficiency are publicly available.

3.2 Commercial and Institutional Sector

The major end-uses consuming electricity in the commercial and institutional sectors are lighting, refrigeration and air-conditioning. These end-uses account for about 85% of the total electricity consumption in both commercial and institutional sectors in Alberta. The efficiencies of representative devices under each of these end-uses are presented below for both existing and best practice categories.

3.2.1 Lighting

The most common lighting system in the commercial and institutional sectors are fluorescent lamps and metal halide lamps. While fluorescent lamps such as T12 with magnetic and T8 with standard electronic ballast are mainly used in the institutional sector, both fluorescent lamps and metal halide lamps are commonly used in the commercial sectors[18]. A preliminary survey of

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[15] Meier, A., Reducing Leaking Electricity to a Trickle, Lawrence Berkeley National Laboratory http://www.lbl.gov

[16] Canada Mortgage and Housing Corporation (CMHC), 2001 Census Housing Series: Issue 2: The Geography of Household Growth and Core Housing Need, 1996-2001, Socio-economic Series 04-001, February 2004

[17] Statistics Canada, Quarterly Report on Energy Supply-Demand in Canada, Catalogue No. 57-003, 2001-IV issue.

[18,] Kyoto and Beyond: The Low Emission Path to Efficiency and Innovation, The David Suzuki Foundation and The Canadian Climate Action Network (2002). Fluorescent lamps are generally used in areas where ceiling height is lower than 15 feet (e.g., office spaces), whereas metal

lighting equipment suppliers located in Calgary area indicates that about 60-70% of existing commercial/institutional establishments in Alberta use T12 lamps, whereas the rest use T8 lamps. The survey also indicates that 95% of the new commercial/institutional establishments in the province use T8 lamps[19].

This study considers T8 fluorescent lamps, metal halide lamps and halogen lamps as representative lamps in the existing lighting system in the institutional and commercial sectors. The efficient counterpart currently available in market are T8 and T5 fluorescent lamps with low energy consuming electronic ballast; ceramic metal halide with electronic ballast[20]. Table 3.6 presents existing vis-à-vis the best practice lighting systems for the commercial and institutional sector.

Table 3.6
Existing Vis-à-Vis the Best Practice Lighting System for the Commercial and Institutional Sectors

(a) Fluorescent Lamps[a]

Specification	Existing	Best practice
Capacity (Watt with 1 Lamps)	30[b]	25
Illumination output (Lumen)	2850	3200
Efficiency (Lumen/Watt)	95	128
Capacity (Watt with 2 Lamps)	58	48
Illumination output (Lumen)	5700	6400
Efficiency (Lumen/Watt)	98	133
Capacity (Watt with 3 Lamps)	87	73
Illumination output (Lumen)	8550	9600
Efficiency (Lumen/Watt)	98	132
Capacity (Watt with 4 Lamps)	114	96
Illumination output (Lumen)	11400	12800
Efficiency (Lumen/Watt)	100	133

[a] Existing lamps are T8 standard lamps with standard electronic ballast; Best practice lamps are T8 efficient lamps with efficient electronic ballast

[b] In case of T12 lamp, the lamp rating is 34 Watt instead of 30 Watt.

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halide or HID lamps are normally used in areas where ceiling height is 15 feet or higher (e.g., shopping stores, ware house).

[19] Personal communications with Calgary based lighting equipment wholesale suppliers.

[20] For more information, please see Throne, J. and S. Nadel (2002), Commercial Lighting Retrofits: A Briefing Report for Program Implementers, ACEEE Report No. A032. American Council for an Energy Efficient Economy, Washington.

(b) Metal Halide and Halogen Lamps

	Specification	Watt
Existing	Standard Metal Halide with Magnetic Ballast	455
Best Practice	T5 System (Four lamp with 54 Watt rating) with electronic ballast	234
Existing	Halogen IR PAR Lamp	100
Best Practice	Ceramic Metal Halide with ballast	44

As can be seen from Table 3.6(a), the best practice fluorescent lamps could save 16 to 17% electricity consumption and provide 33 to 37% improved illumination. A large potential of energy savings could be realised in the metal halide and halogen lamp systems. For example, if T5 system (with 4 lamp each of 54 Watts) is used instead of standard metal halide lamp with magnetic ballast, almost a half of electricity consumption can be saved. Similarly, if ceramic metal halide lamps with ballast are used instead of halogen IR PAR lamp, electricity consumption can be reduced by about 56%[21].

3.2.2 Refrigeration

Institutional establishments tend to use a similar type of refrigerator as the households. However, the size of the refrigerator is obviously larger as compared to what is used in the households. Hence refrigerators with size greater than 25 cubic feet in capacity is selected for the institutional sector. Table 3.7 presents the efficiency (i.e., unit energy consumption) of representative refrigerators in the institutional sector.

Table 3.7
Existing Vis-a-Vis Best Practice Refrigerator in the Institutional Sector

Specification	**Unit energy consumption (kWh/year)**	
	Existing	**Best practice**
Refrigerator with size greater than 25 cubic feet	1125	561 - 565

As reflected in the above table, there is also a large saving potential on electricity consumption in the institutional sector refrigeration system in Alberta. If the best practice refrigerators are used instead of the existing, 50% of the electricity consumption can be saved.

The refrigerators and freezers used in the commercial sector are mainly the packaged refrigeration systems, which include reach-in refrigerators and freezers, ice-makers, refrigerated vending machines, beverage merchandisers, and walk-in refrigerators and freezers. The reach-in

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[21] Throne, J. and S. Nadel (2002), Commercial Lighting Retrofits: A Briefing Report for Program Implementers, ACEEE Report No. A032. American Council for an Energy Efficient Economy, Washington D.C.

refrigerators and icemakers are mainly used in food stores, food service establishments, hospitals, schools and hotels. Its market is characterized with the diversity of system types; complex distribution, sales, and service chains; and the large variety and size of users.

There exist substantial opportunities to improve the efficiency of the packaged refrigeration system. A study conducted by the American Council for an Energy-Efficient Economy (ACEEE) reports that about 45% of energy consumption of reach-in refrigerators and freezers can be reduced if the existing stock is replaced by their efficient parts currently available in the market[22].

3.2.3 Air Conditioning

Central air-conditioning system and packaged air-conditioning units (including both split and packaged units) are the main devices used for air conditioning in the commercial and institutional sectors. Table 3.8 and Table 3.9 present efficiencies of the best practice vis-a-vis existing packaged as well as central AC systems used in the commercial sector.

Table 3.8
Existing vis-a-vis Best Practice Packaged AC used in the Commercial and Institutional Sectors

Capacity (Btu/hr)	Energy Efficiency Ratio (EER)	
	Existing	Best Practice
14,500 – 15,000	10.0	11.1 – 11.5
17,300 – 20,000	9.7	10.0 – 11.0
> 20,000	8.6	9.8

Table 3.9
Existing vis-a-vis Best Practice Central AC used in the Commercial and Institutional Sectors

Capacity (Tons)	Seasonal Energy Efficiency Ratio (SEER)	
	Existing	Best Practice
4	11	16.0 – 17.25
5	10	15.4 – 17.0

The use of the best practice packaged AC (instead of their existing counterparts), can improve energy efficiency by 10 to 15%. On the other hand, efficiency gap is significantly high in the case of central chiller, where efficiency can be improved by about 50 to 70%. The main reason for the higher efficiency gap for central chiller is the widespread use of the inefficient air cooling systems.

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[22] S. Nadel (2002), Packaged Commercial Refrigeration Equipment: A Briefing Report for Program Planners and Implementers, ACEEE Report No. A032. American Council for an Energy Efficient Economy, Washington D.C.

3.3 Industrial Sector

Based on the two key parameters, namely, the share in the total industrial electricity consumption and electric intensity (i.e., electricity consumption per unit of sectoral output), four industries are selected for this study. These are chemicals, pulp and paper, oil sand mining and conventional oil and gas extraction. While electric motors are the primary end-uses consuming electricity in pulp and paper, oil sands mining and conventional extraction, both electric motors and electrolysis are the major electricity consuming end-uses or process technologies in chemical industry. Efficiency of existing and best practice devices (i.e., electric motors and electrolyzers) for these industries are presented and discussed below.

It should be noted that energy efficiency in the industrial sectors can be measured at the process level (e.g., compression, pumping, air-displacement) instead of device level (e.g., electric motors). The efficiency gaps measured at the process level (i.e., gap between the existing and best practice industrial processes) could be higher than what is measured at the device level. This occurs since using the most efficient device is not the only way to reduce energy consumption, rather a number of other ways can be adopted to increase operational efficiency including better configuration and operation of devices (e.g., appropriate control of motor speed), reducing friction in drive, conveyance, and air displacement through proper maintenance. However, it is a challenge to obtain existing- as well as the best practice process level efficiency (or unit energy consumption) data. Thus, only device level energy efficiency is measured and as such the total gap or the potential for savings may be underestimated. The gap on the process efficiency end may be larger.

3.3.1 Chemical Industry

In the chemical industry, electrical motors and electrolyzers accounted for, respectively, 67% and 29% of the total electricity consumption in the industry in Alberta in 2001. The existing electric motors and the corresponding best practices are presented in 3.10. Also presented in the table are the market shares of various types of existing electric motors in the chemical industry. As can be seen from the table, energy efficiency of electric motors can be improved by 2 to 8% if existing electric motors are replaced by their best practice counterparts.

Table 3.10
Efficiency of Existing and Best Practice Motors in the Chemical Industry

	Existing market Share (%)	Average efficiency of existing stock	Efficiency of the Best Practice
Standard AC Induction Motor 1-5 Hp	5.7	84.0	89.5
Standard AC Induction Motor 6-25 Hp	25.1	86.7	93.6
Standard AC Induction Motor 26-100 Hp	17.4	91.8	94.5
Standard AC Induction Motor 101-200 Hp	13.0	93.1	96.2
Standard AC Induction Motor 201-500 Hp	9.7	93.9	96.2
Synchronous Induction Motor 201-500 Hp	1.9	97.0	-
Standard AC Induction Motor >500 Hp	22.8	93.9	96.2
Synchronous AC Induction Motor >500 Hp	4.4	97.0	-

The process of electrolysis is mainly used in the production of chlorine and caustic soda, one of the main products under the chemical industry. No data is available for energy efficiency (or unit energy consumption) of existing eletrolyzers used in chlorine and caustic soda plants in Alberta. A study conducted by Lawrence Berkeley National Laboratory (LBNL) estimates that about 4380 kWh of electricity is required to produce one ton of chlorine using the existing electrolysis technologies[23]. There are three main electrolysis cell types that are normally used to separate and produce the chlorine gas and caustic soda. These technologies are: mercury flow, diaphragm, and ionselective membrane. In the diaphragm and membrane cells the caustic soda requires an additional step of concentrating the solution so that it can meet market specifications for most products. Of the three cell types the membrane cell requires the least energy to operate and is currently considered the state-of-the-art technology. It is estimated that if the mercury process, which is the most common technology in North America and Europe, is replaced by the state of art membrane technology, electricity consumption can be reduced by 15%[24].

3.3.2 Pulp and Paper Industry

Electric motors are the main end-use consuming most of the electricity in the pulp and paper industry. In 2001, this end-use accounted for more than 96% of total electricity consumption in the pulp and paper industry. Table 3.11, presents various types of existing electric motors used in this industry, their market shares and efficiency. Best practice efficiencies of corresponding

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[23] Ernst Worrell, Dian Phylipsen, Dan Einstein and Nathan Martin, 2000. Energy Use and Energy Intensity of the U.S. Chemical Industry, Study No: LBNL-44314, Ernest Orlando Lawrence Berkeley National Laboratory, April 2000

[24] Chlorine Industry Review 2002 – 2003, Euro Chlor, 2004.

motors are also presented in the same table. The efficiency numbers in the table indicates that the pulp and paper industry in Alberta has already used efficient electric motors. If the existing motors are replaced by their best practice counterparts, only a small gain in efficiency (i.e., 1 to 5%) can be achieved.

Table 3.11
Efficiency of Existing and Best Practice Motors in the Pulp and Paper Industry

Type of Motor	Existing market Share (%)	Average efficiency of existing stock	Efficiency of the Best Practice
Standard AC Induction Motor 1-5 Hp	1.0	85.9	89.5
Standard AC Induction Motor 6-25 Hp	9.0	89.4	93.6
Standard AC Induction Motor 26-100 Hp	17.0	92.3	94.5
Standard AC Induction Motor 101-200 Hp	13.0	93.1	96.2
Standard AC Induction Motor 201-500 Hp	5.2	93.9	96.2
Synchronous Induction Motor 201-500 Hp	1.3	95.1	96.2
Direct Current Motor Generator Electric Motor 201-500 Hp	10.4	63.7	NA
Direct Current Solim State Electric Motor 201-500 Hp	1.2	83.3	NA
Standard AC Induction Motor >500 Hp	12.2	92.0	96.2
Scynchronous AC Induction Motor >500 Hp	2.9	95.1	96.2
Direct Current Motor Generator Electric Motor >500 Hp	24.2	63.7	NA
Direct Current Solim State Electric Motor >500 Hp	2.7	83.3	NA

3.3.3 Oil Sands Industry

As discussed in Chapter 2, oil sands industry employs two processes to recover oil from oil sands: mining and in-situ recovery. The mining process mainly involves excavators, conveyor belts and heavy trucks. The main device used in this process is electric motor. Although no specific information is available on the size of electric motors used in this process, it is assumed that given the nature of the process, large size (greater than 200 Hp) motors are more likely to be used. The characteristics of an electric motor of a particular size are the same irrespective of the industry in which the motors are used. For example, efficiency of standard AC motor of size 200-500 Hp is 93.9% whether it is used in chemicals or pulp & paper industry (see Table 3.10 and 3.11). Assuming that the same type of motor is used in oil sands mining industry, the efficiency gap between the existing and best practice motors in this process is about 2.5%[25]. Note however that higher level of energy saving could be feasible if efforts are made to improve efficiency at the process level than at the device level. For example, a new truck-and shovel mining method significantly improves energy efficiency and reduces the total cost of production. Moreover, if the long conveyor belt type transport system is replaced by a new system called hydrotransport[26], energy consumption can be reduced significantly.

In the case of in-situ recovery process, a number of techniques are used. These include steam injection, solvent injection and firefloods or oxygen injection. To date, steam injection is the most common technique. Steam injection technologies could be further divided into three categories: Cyclic Steam Stimulation (CSS), Steam Assisted Gravity Drainage (SAGD), Toe-to-Heal Air Injection (THAI). While the Cold Lake project, Canada's largest in-situ bitumen recovery project, mainly uses the CSS technology, most Athabasca in-situ projects use SAGD technology[27]. THAI technology is being used as pilot technologies and has not been commercially used for in-situ recovery. The emerging in-situ recovery technology, which is the most energy efficient technology to date, is the VAPEX technology. In contrast to the steam-based technologies mentioned above, VAPEX is solvent-based technology. As it uses solvent instead of steam, energy consumption used for steam generation can be saved. It is estimated that more than 80% of total energy (not only electricity) used in in-situ recovery process can be reduced if VAPEX technology is used instead of the existing CSS and SAGD technologies. Although initial test results, reservoir simulation and field trails are promising, the VAPEX technology has yet to be commercialized.

3.3.4 Conventional Oil Extraction and Gas Production Industry

In the case of conventional oil, the production technologies depend upon recovery technologies such as primary, secondary and enhanced. In Alberta, conventional oil is mainly produced using an artificial lift technique. This technique uses down hole pump driven by electric motors[28]. Standard AC electric motors of size less than 50 Hp are mainly used for this purpose. Efficiency of existing AC motors of size less than 50 Hp varies between 86% to 90%. The best practice motors in this size range are 93.6% efficient. Hence there are about 4% to 8% efficiency gaps between the existing and best practice motors used in conventional oil production industry. In the case of gas production, less pumping service is required as pressure of gas in the well drives

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[25] Efficiency of existing 200-500 Hp standard AC motor is 93.9%, whereas the efficiency of its best practice counterpart is 96.2%.

[26] The hydrotransport technique uses hydraulic and electricity powered shovels with heavy trucks that can carry 400 tonnes at a time. The trucks dump their load into a machine that breaks up lumps and removes rock from the sand, then mixes it with water to create a slurry carried by pipeline to the processing plant.

[27] Oil Sands Supply Outlook 2003-2017, Study No. 108, Canadian Energy Research Institute (CERI), 2004 and Our Petroleum Challenge: Sustainability into the 21st Century, Canadian Centre for Energy Information, 2004.

[28] In places without electricity access diesel pumps instead of electric pumps are used.

the flow. Pumps can be used to enhance the flow. The size of electric motors used for such pumping service is the same as that used in conventional oil production.

Electric motor is the primary electricity-consuming device in all industries selected in this study. Replacement of existing motors by the corresponding best practices can reduce electricity consumption by 1% to 5% in the pulp and paper industry and 2% to 8% in the chemical industry. As mentioned earlier, these efficiency gaps are measured at the device level (i.e., at the level of electrical motor) and thus are small. If other options for energy efficiency such as improvement of efficiency at the process level, benchmarking at the industry level are considered, (which have not been considered due to a lack of data[29]), gap in energy efficiency or energy intensity would be higher than what is estimated in this study. For example, a study conducted by Natural Resources Canada[30] estimates that electricity consumption by modern newsprint mills would be 15% lower than the average electricity consumption by the existing newsprint mills in Canada. Moreover, the study also suggests that changes in pumping and agitation throughout the mill may save electricity consumption by another 5%.

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[29] There are, however, some studies on benchmarking in Europe and Australia. The Government of Alberta and the industry may find it useful to conduct studies that present international comparison of energy consumption in industrial sub-sectors. Benchmarking Alberta industry against international standards will provide additional information on where to focus energy efficiency policies.

[30] Energy Cost Reduction in the Pulp and Paper Industry: An Energy Benchmarking Perspective, Natural Resources Canada, 2004.

Chapter 4

Conclusions and Next Steps

4.1 Conclusions

The study compares the efficiencies of existing stock and best practices of major devices and technologies consuming electricity in the residential, commercial and industrial sectors in Alberta. It also determines the technical potential of savings in electricity consumed by these devices and technologies. The technical potential of various end-use devices and technologies are summarised in Table 4.1.

Table 4.1
Technical Potential of Electricity Savings Through the Best Practice End-use Appliances in Alberta

Device/Technology	% Savings
Residential Sector	
Lighting	67 – 75
Refrigerator	61
Electric Range	5
Electric Dryer	15
Dishwashers	63 – 77
Clothes washers	67 – 87
Commercial and Institutional Sector	
Lighting	33 – 56
Residential type refrigerator	50
Packaged refrigerator	45
Central Chiller	50-70
Packaged AC	10-15
Industrial Sector	
Chemical Industry	
Electric Motor	2 – 8
Electrolyzer	15
Pulp & Paper	
Electric Motor	1 – 5
Oil sands Industry	
VAPEX technology for in-situ bitumen production	80
Electric motors in oil sands mining	2.5
Conventional oil & gas extraction	
Electric Motor	4-8

As indicated in the table, residential sector end-use devices offer the highest level of electricity saving potential as compared to devices in other sectors. Most households in Alberta use incandescent lamps with varying ratings (60, 75, 100 Watt). These lamps are inefficient in terms of electricity consumption. However, households use these types of lamps from the architectural or aesthetic perspective. Currently, much more efficient compact fluorescent lamps (CFL) are available in the market. If CFL are used instead of incandescent lamps, about 67% to 75% of electricity can be saved.

Refrigerators, dishwashers and clothes washers are other main devices in the residential sector which exhibit a large efficiency gap. Although more and more efficient appliances are being used especially in new households, the average efficiency of the existing stock of these devices is much lower as compared with the best practice devices currently available in the market. While the best practice refrigerators are 50% more efficient than the existing stock, the best practice dishwashers and clothes washers are 63% to 87% more efficient than the corresponding existing stocks. These results clearly imply that specific programs need to be launched to improve end-use efficiencies in lighting, refrigeration, dishwashing and clothes washing in the residential sector.

The best practice lighting systems in the commercial and the institutional sectors also offer significant energy efficiency improvement. Most commercial and institutional facilities currently use fluorescent (T8, T12) and metal halide lamps. These lamps either use high energy consuming magnetic ballast or standard electronic ballast. On the other hand, T8 and T5 fluorescent lamps with energy efficient electronic ballast and ceramic metal halide with ballast are 33% to 56% more efficient than their existing counterparts. This result suggests that lighting is one of the promising end uses in the commercial and institutional sectors for launching energy efficiency programs.

Industry sector exhibits relatively small efficiency gap between the existing and the best practice devices. It appears that significant efficiency has already been achieved in this sector due to energy efficiency programs such as the Canadian Industry Program for Energy Conservation (CIPEC), which has been operating for more than 25 years. This program has helped Canadian industries improve their energy efficiency significantly.

The bridging of this "efficiency gap" will require action on several fronts and a multi-pronged policy approach. While research and development and improvements in technologies would increase the efficiency of the equipment available in the market, the key challenge will be to increase the penetration of such equipment in the market. The consumer inclination to buy the higher efficiency equipment not just to replace a "dead" equipment, but to replace an "operational" inefficient equipment is an important element in moving to an end-use efficient energy platform. Both replacement and retrofit decisions are critical in moving to higher efficiency. Also important is how the equipment is being used. It is not just enough to use a high efficiency furnace, but also a thermostat that controls the delivered degree of heat to what and when it is needed. The consumer needs to be motivated to make these changes. A combination of market signals, financial incentives, education and awareness and regulation is required to bring the desired changes in energy efficiency and conservation.

4.2 Next Steps

This study has determined the technical gap between the existing stock and best practice end-use devices and technologies. Although determining efficiency targets is an important step towards achieving energy efficiency and conservation, much more needs to be undertaken. As such, several initiatives are identified as a possible follow-up to this study.

- Several information gaps were identified during the course of this study. The gap pertains to a lack of information for certain end-uses as well as the level of disaggregation that will be required for specific end-use efficiency programs. Some primary data collection through surveys of builders, manufacturers of electricity using equipment, and the end-users is valuable.
- The study only identifies the efficiency gap and as such the "technical" potential for energy efficiency improvements. However, the technical potential has limited meaning if it is not associated with economics for achieving this potential. Together with what is presented in this study, the costs of the Best Practice equipment also needs to be identified. This concept fits well with what has already been identified for the Energy Efficiency and Conservation Implementation Team in Recommendation 65. The recommendation states that the "implementation team will undertake a detailed technical assessment as to the feasibility of developing a province-wide electric energy efficiency target and, if feasible, define what the target amount should be and costs to meet the target…"
- Economic viability, however, does not fully guarantee the penetration needed to achieve the full goal for energy efficiency and conservation. An important element of the implementation plan would be the identification of barriers and formulation of strategies or policies to overcome such barriers. A review of actions, policies, and programs, in other jurisdictions and areas to identify success stories and what works and what does not may be a useful next step. The establishment and operation of CIPEC could be considered a success story for the industrial energy efficiency. Such undertakings for other end-use sectors in collaboration with other provinces may also be an initiative to consider.
- Finally a quantitative assessment of long term energy and environmental benefits that could be achieved through the realization of the full technical and economic potential of efficiency improvements in order to justify the implementation of energy efficiency improvement policies and programs is warranted. Such an exercise could be undertaken with the use of an energy-environmental modelling framework. An option for such economic modelling is Energy 2020.

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GLOSSARY

ELECTRICITY/ENERGY INTENSITY: Electricity/total energy consumption by an economic sector or industry per unit dollar value of output produced.

BEST PRACTICE: The highest possible technical efficiency available currently in the marketplace.

OTHER SUBSTITUTABLES: Energy end-use appliances or processes that can use electricity and other energy commodity (e.g., cooking range, clothes dryer).

OTHER NON- SUBSTITUTABLES: Energy end-use appliances or processes that can not use any energy commodity other than electricity (e.g., electronic appliances such as TV, video, computer).

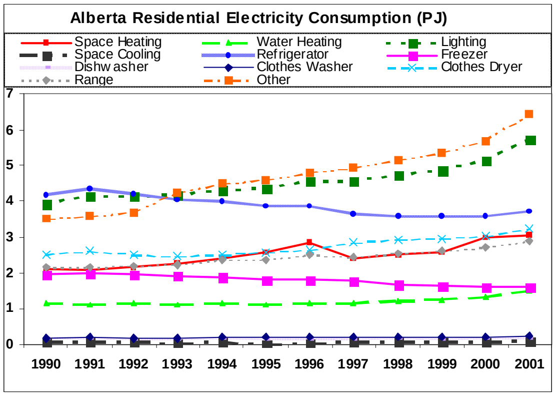
CENTRAL CHILLERS (OR CENTRAL AIR-CONDITIONING SYSTEM): A type of cooling equipment that is centrally located and that produces chilled water or cool air which is then distributed throughout the building for space cooling.

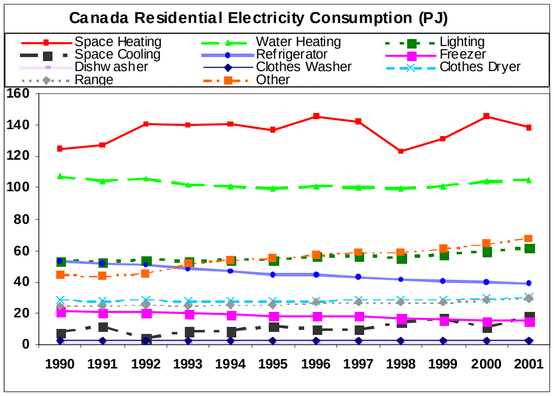
PACKAGED AIR-CONDITIONING: Air-conditioning system with a packaged-terminal air-conditioning unit that both heats and cools, or only cools.

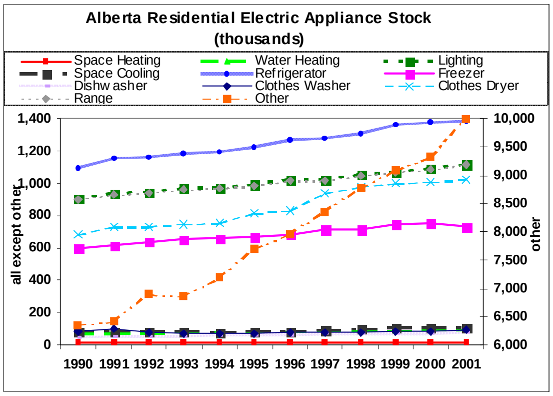
PACKAGED REFRIGERATION: Refrigeration system that includes reach-in refrigerators and freezers, icemakers, refrigerated vending machines, beverage merchandisers, and walk-in refrigerators and freezers.

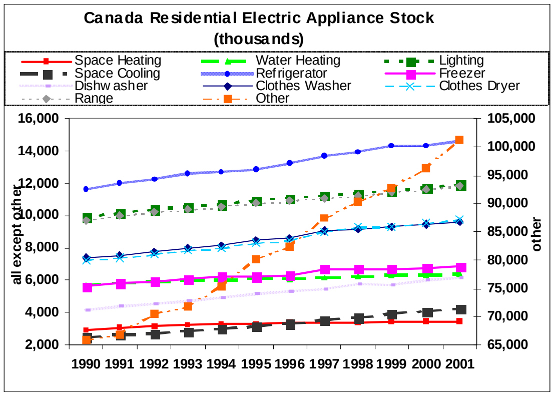
Annex 1

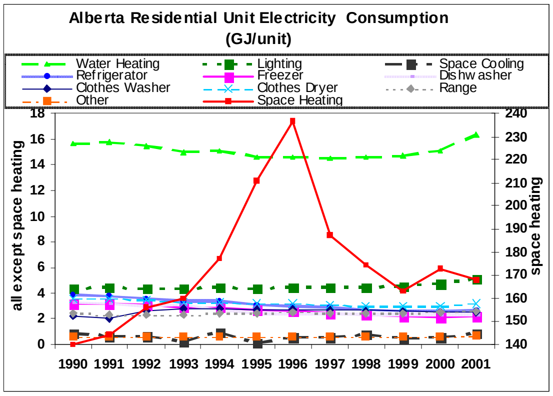
TOTAL ELECTRICITY CONSUMPTION, HOUSEHOLD STOCK AND END-USE ELECTRICITY INTENSITY TRENDS IN THE RESIDENTIAL SECTOR IN ALBERTA AND CANADA

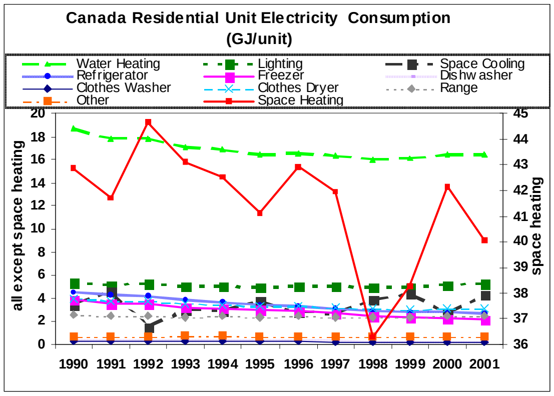












Source: CERI E2020 Database; Natural Resources Canada, OEE Energy Database (available at http://oee.nrcan.gc.ca/english/)

The main difference between Alberta and Canada in terms of electricity use in the residential sector occurs in electricity consumption for space and water heating. While these two end-uses are the main consumers of electricity in Canada, these end-uses consume only a small fraction of the total residential electricity in Alberta. Since there is no change in the stock of electric space heaters (i.e., electric base board) and electric water heaters during the 1990-2001 period in both Alberta and Canada, there is no significant change in total as well as unit electricity consumption for space heating and water heating during this period.

As household stock has increased smoothly during the 1990-2001 period, the stock of household energy appliances such as lighting devices, cooking ovens, dishwashers and clothes washers and dryers have followed a similar path. However, the total electricity consumption of some appliances particularly refrigerators and freezers has decreased significantly. This clearly implies a significant improvement in energy efficiency of these devices over the years.

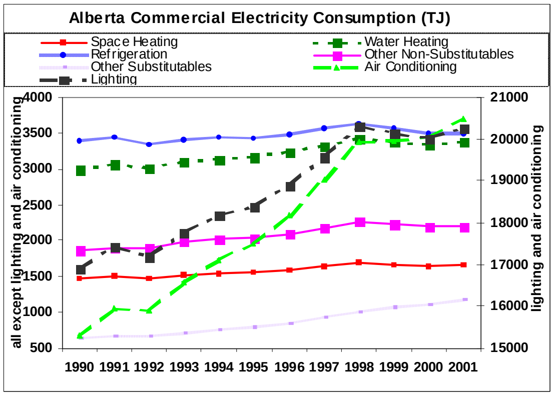
Unit electricity consumption of cooking ovens, dishwashers and clothes washers & dryers has decreased slightly, but electricity consumption in these devices has increased. This suggests an increase in utilization of these devices. The result provides an interesting policy implication, i.e., although there is significant improvement in energy efficiency of devices (i.e., more and more efficient devices are manufactured) there is no noticeable change in the unit consumption. This results from two factors, one there is an overall increase in disposable income through time resulting in an overall increase in the consumption of all products and services. Second, as efficiency increases, and there are energy savings, there is a “take-back” effect, which dampens the initial gain from efficiency. The take-back effect results in increased utilization. An interesting example pertains to lighting; if a consumer has efficient lighting, he is less motivated to turn off the lights when not in use. This phenomenon suggests that policies targeting a change in consumer behaviour through education and awareness may be effective in achieving those additional conservation savings.

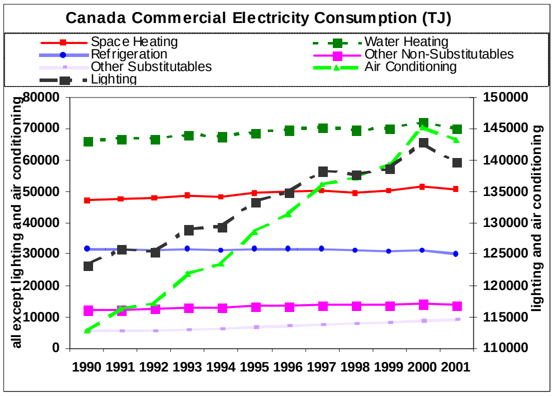
Use of other appliances, particularly the home electronics (e.g., computer, fax machine, television and home audio systems) has rapidly increased during the 1990-2001 period. This may result from an increase in real household income and the household capacity to consume “luxury” goods.

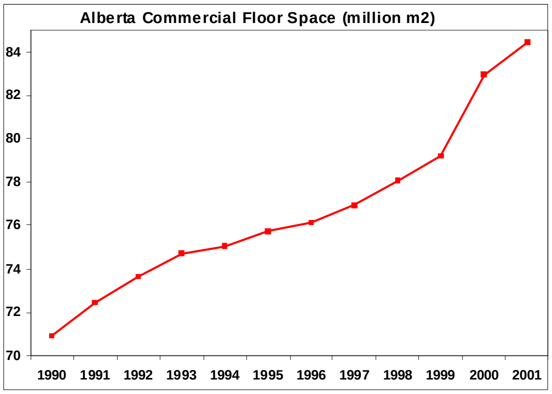
An anomaly is observed in the case of unit electricity consumption for space heating, where UEC abnormally increases in 1996 and decreases thereafter. In general, electricity is not used in the main heating equipment (e.g., furnace) in Alberta. It is only used in auxiliary heating devices such as electric baseboards. Such auxiliary heating equipment is utilized only to augment extremities in weather when space heating from the main heating equipment is insufficient or consumers want to use individual room heaters instead of central heating system. This particular problem could be created either by erroneous data or winter temperature during those years (1995 to 1997). Since the problem exists both in Alberta and Canada, we suspect there is a problem in data.

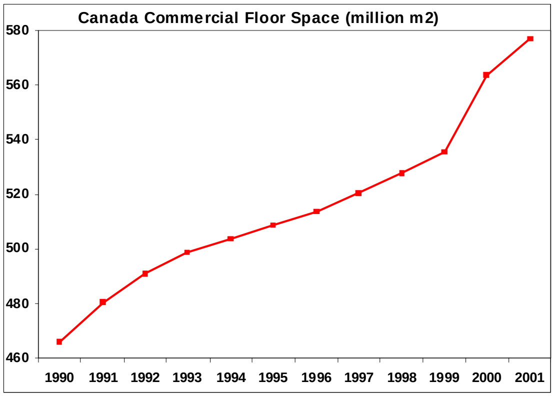
Annex 2

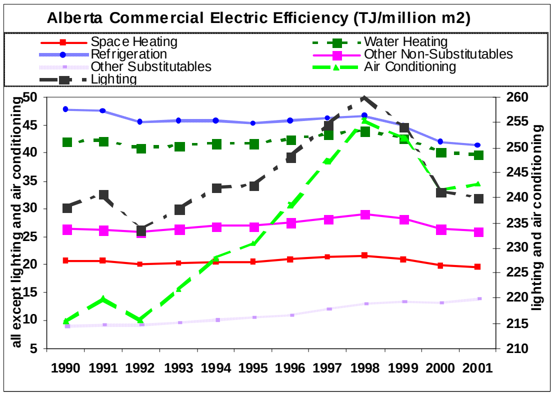
TOTAL ELECTRICITY CONSUMPTION, TOTAL FLOOR SPACE AND END-USE ELECTRICITY INTENSITY TRENDS IN THE COMMERCIAL & INSTITUTIONAL SECTORS IN ALBERTA AND CANADA

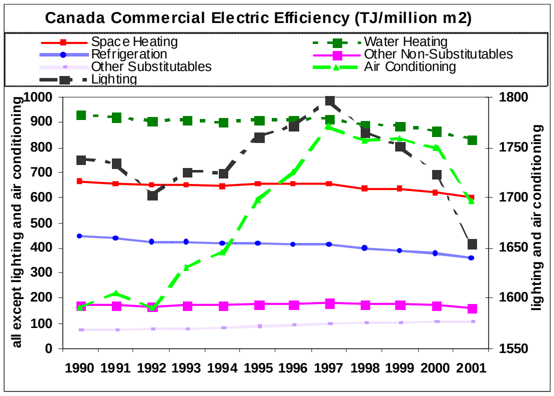

Alberta Commercial Electricity Consumption (TJ)


Canada Commercial Electricity Consumption (TJ)


Alberta Commercial Floor Space (million m2)


Canada Commercial Floor Space (million m2)


Alberta Commercial Electric Efficiency (TJ/million m2)


Canada Commercial Electric Efficiency (TJ/million m2)

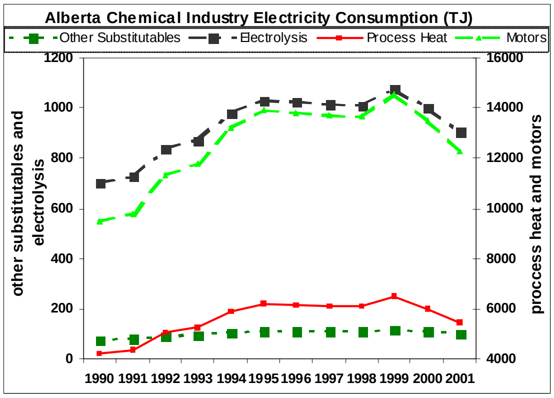
Source: CERI E2020 Database; Natural Resources Canada, OEE Energy Database (available at http://oee.nrcan.gc.ca/english/)

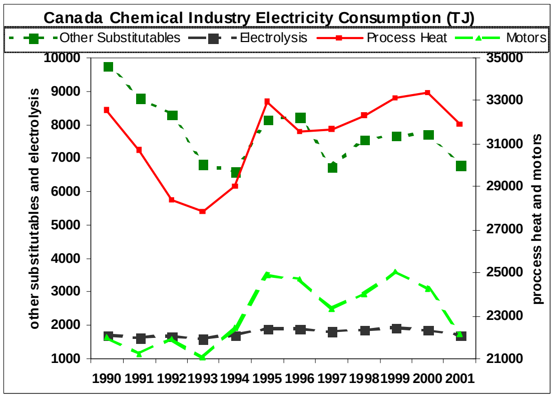
There is no significant difference in the patterns of total and unit electricity consumption of end-use appliances between Alberta and Canada with a few small exceptions. Lighting and air conditioning consume majority of electricity in both Alberta and Canada. Energy consumption in these end-uses has increased rapidly during the 1990-2001 period along with increase in total floor space. However, unit energy consumption in these end-uses has decreased since 1997. This could result from electricity conservation programs in commercial and institutional buildings. Earlier, most commercial establishments had a practice to keep their buildings with lights “ON” during night hours. With the conservation impetus, the practice has changed. Higher electric rates may be a motivating factor in this trend.

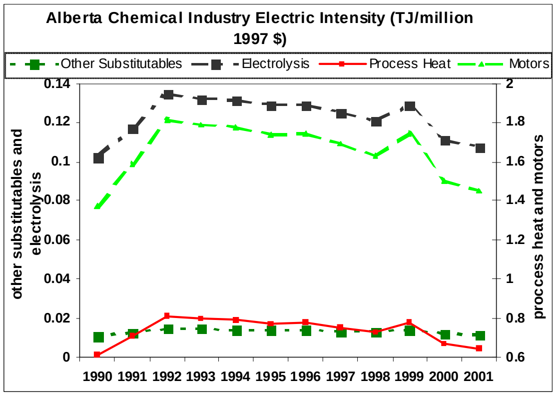
The trend of unit electricity consumption in other end-uses such as refrigeration, other substitutable (i.e., cooking & drying) and other non-substitutable (i.e., office equipment) is also slightly decreasing for the 1990-2001 period in both Alberta and Canada. This indicates that, in contrast to the residential sector, there are overall improvements in end-use energy efficiencies in the commercial and institutional sectors.

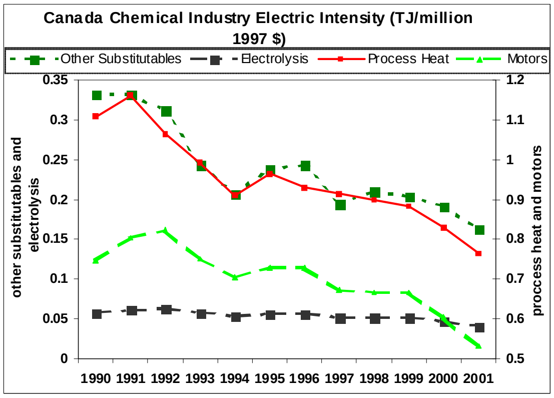
Annex 3

TOTAL ELECTRICITY CONSUMPTION AND END-USE ELECTRICITY INTENSITY TRENDS IN THE CHEMICAL INDUSTRIES IN ALBERTA AND CANADA









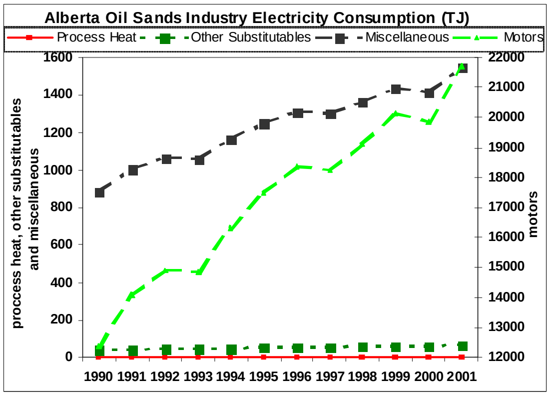
Source: CERI E2020 Database

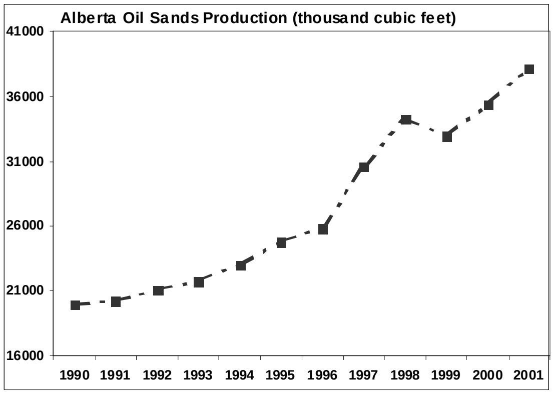
In both Alberta and Canada, unit electricity consumption has decreased during the 1990-2001 period despite the fact that sectoral output (see Annex 7) has increased during the period. This clearly implies that there have been improvements in energy efficiency in the chemical industry, especially since 1992.

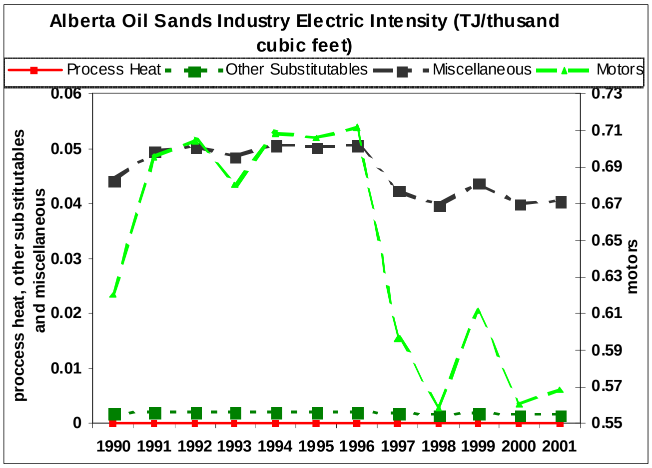
The rate of energy efficiency improvement (or the rate of decrease in unit electricity consumption) in Alberta are smaller than the average rate of energy efficiency improvement in Canada, particularly in electric motors and processes (e.g., process heat, electrolysis).

Annex 4

TOTAL ELECTRICITY CONSUMPTION AND END-USE ELECTRICITY INTENSITY TRENDS IN THE OIL SANDS INDUSTRY IN ALBERTA





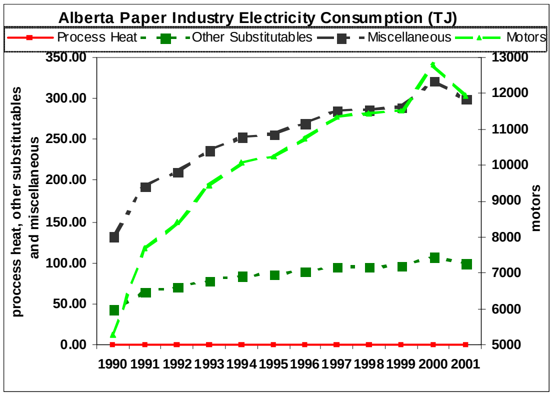


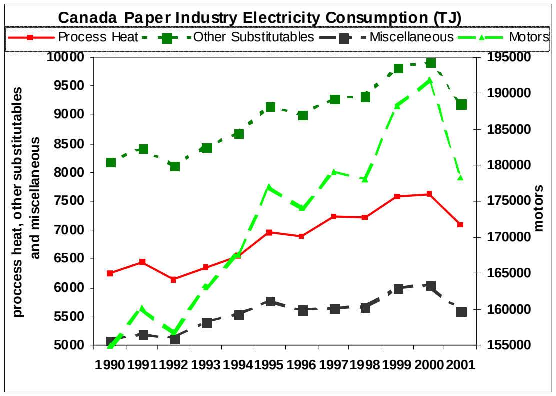
Source: CERI E2020 Database

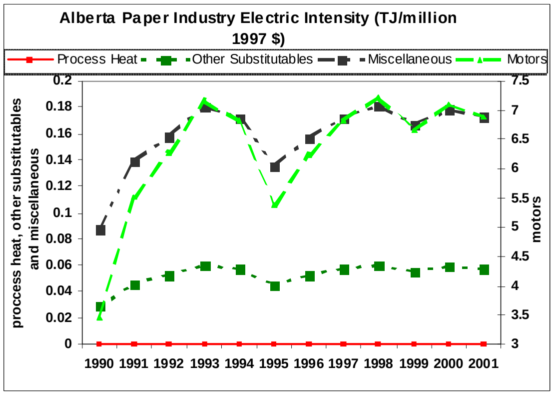
While electricity consumption in and total output from the oil sands industry has increased, unit electricity consumption has decreased. This clearly suggests a significant improvement in energy efficiency of oil sands extraction technologies. This is in line with the fact that oil sand industries have exhibited shift in technologies from more energy intensive SAGD technology to less energy intensive VAPEX technology.

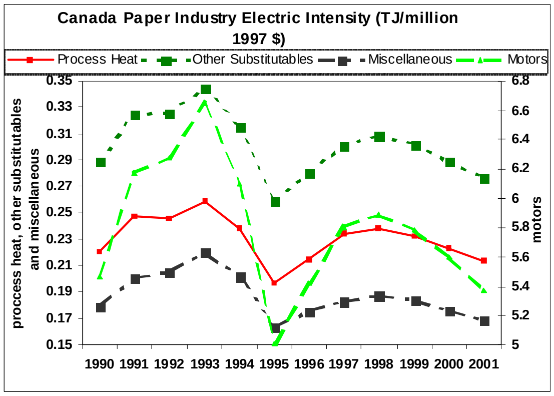
Annex 5

TOTAL ELECTRICITY CONSUMPTION AND END-USE ELECTRICITY INTENSITY TRENDS IN THE PULP & PAPER INDUSTRIES IN ALBERTA AND CANADA


Alberta Paper Industry Electricity Consumption (TJ)


Canada Paper Industry Electricity Consumption (TJ)


Alberta Paper Industry Electric Intensity (TJ/million 1997 $)


Canada Paper Industry Electric Intensity (TJ/million 1997 $)

Source: CERI E2020 Database

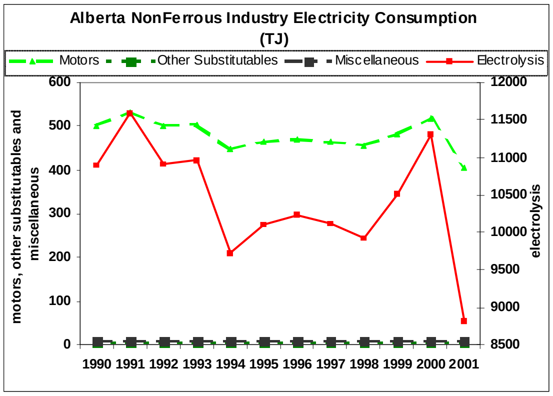
In both Alberta and Canada, total electricity consumption has increased during the 1990-2001 period except in 2001.

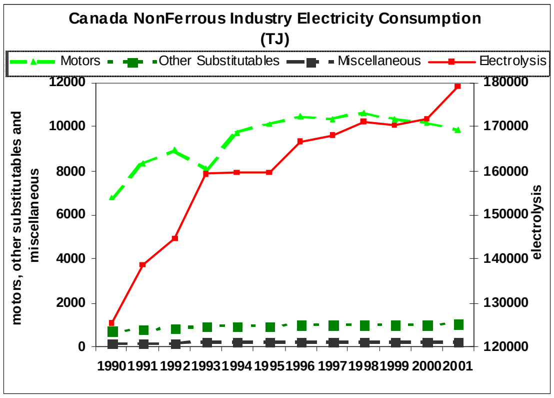
The average unit electricity consumption at the national level (i.e., Canada) has decreased since 1992, but this is not the case in Alberta. This implies that no efficiency improvement measures have been implemented in Alberta or the measures have failed to show their effects.

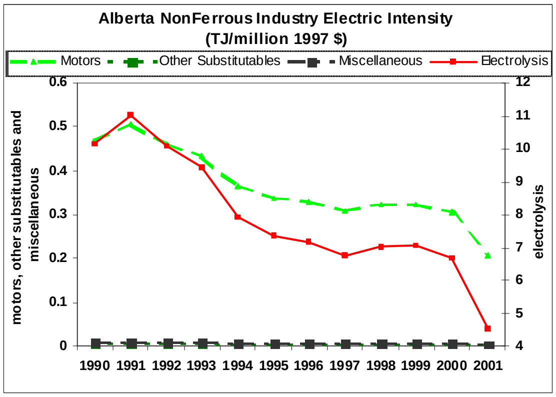
The sudden drop in unit electricity consumption could be caused by data problem in gross output in that year.

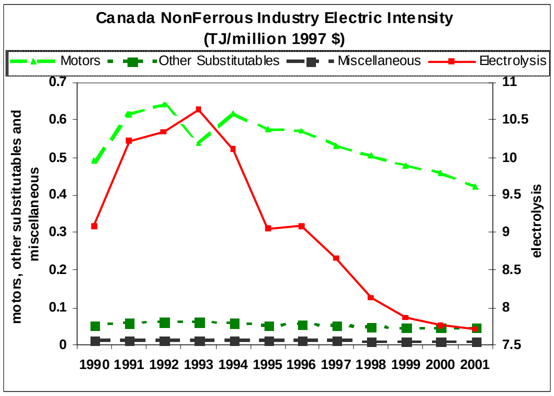
Annex 6

TOTAL ELECTRICITY CONSUMPTION AND END-USE ELECTRICITY INTENSITY TRENDS IN THE NON-FERROUS METAL INDUSTRIES IN ALBERTA AND CANADA


Alberta NonFerrous Industry Electricity Consumption (TJ)


Canada NonFerrous Industry Electricity Consumption (TJ)


Alberta NonFerrous Industry Electric Intensity (TJ/million 1997 $)

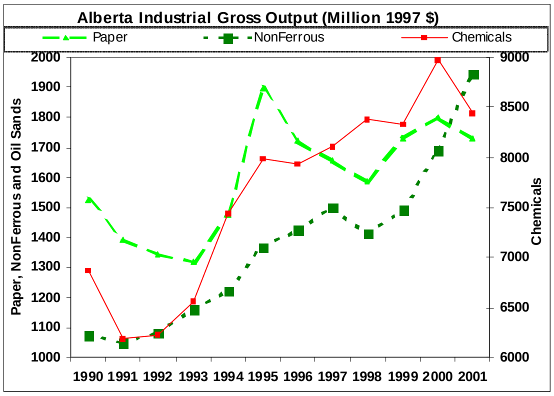

Canada NonFerrous Industry Electric Intensity (TJ/million 1997 $)

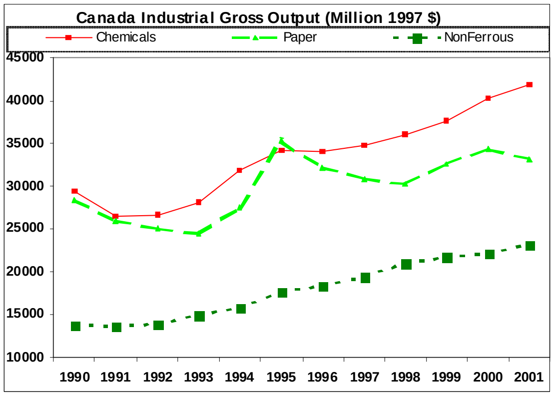
Source: CERI E2020 Database

Significant drop in unit electricity consumption in electrolysis and electric motors have occurred during the 1990-2001 in both Alberta and Canada. This implies switching into efficient electrolysis technologies and use of energy efficient electric motors.

Annex 7

SECTORAL OUTPUT TRENDS IN THE SELECTED INDUSTRIES IN ALBERTA AND CANADA





Source: CERI E2020 Database

Annex 8

Modelling climate change policies: An application of ENERGY2020

Modelling climate change policies: An application of ENERGY2020[31]

Govinda Timilsina and Abha Bhargava *Canadian Energy Research Institute, Calgary*
George Backus *Policy Assessment Corporation, Arvada, Colorado*

Abstract. A large number of modelling tools have been used to analyze economic and energy sector impacts of the Kyoto Protocol. The models range from large, long-term general equilibrium to detailed econometric models. The representation of energy sectors in these models ranges from very aggregated single commodity specification to the very detailed technology, fuel and end-use disaggregation. In Canada, a model called ENERGY2020 (hereafter 'E2020') has been widely used by the federal and provincial governments to analyze sectoral and provincial impacts of implementing the Kyoto Protocol. The basic foundations of E2020 are: (i) "Stocks and Flow" simulation that captures the physical aspects of the processes utilizing energy and (ii) the Qualitative Choice Theory (QCT) capturing human behavioural aspects. In contrast to the many existing policy analysis models, E2020 has a database containing 20 years of time-series on all economic, environmental, and energy variables. The database enables the model to derive most parameters endogenously through econometric estimations. E2020 is equally capable of producing long-term energy market forecasts as well as analyzing impacts of any policy shock in the markets. The most notable use of E2020 in recent years in Canada is the analysis of Kyoto options. The paper discusses the structure and capability of E2020 and the modelling of various climate change policies using this model.

JEL Classification: Q21, Q41, Q43

1. Introduction

After the Kyoto agreement in 1997, researchers and policy makers focused on analyzing economic impacts of the Kyoto Protocol at national, regional and global levels. The analyses are based on numerical models integrating energy, environment and the economy. The models ranged from partial equilibrium types (e.g., PRIME, POLES) to complex multi-sector general equilibrium models (e.g., EPPA, GTEM, G-CUBED, MS-MRT, SGM)[32]. While these models are best suited to analyze economic effects such as the impacts on economic welfare, employment, gross domestic product (GDP), sectoral outputs and international trade, most of these models represent the energy sector (i.e., activities related to production, conversion and utilization of energy) at an aggregate level. This limits the ability of the models to reflect details of the sectors, primarily responsible for greenhouse gas (GHG) and Criteria Air Contaminants (CAC) emissions. On the other hand, energy models such as US DOE's NEMS and the Stockholm

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[31] Co-authored by Abha Bhargava, George Backus and Govinda R. Timilsina and presented by Govinda R. Timilsina. For correspondence: Fax 403 284 4181. E-mail: Gtimilsina@ceri.ca

[32] Weyant and Hill (1999) presents a number of general equilibrium models analyzing economic impacts of the Kyoto Protocol at national and global levels.

Environmental Institute's LEAP model represent the energy sector in detail; accounting for energy demand at the end-use level. While these models are more appropriate in analyzing and forecasting of energy markets (i.e., energy supply, demand and price), they are incapable of incorporating macro-economic feedback and, hence, are inappropriate for analyzing economic impacts of energy-environmental policies. Such models, however, could be linked with other macro-economic models to analyze economic impacts of energy-environmental policies. Energy 2020 (hereafter "E2020") is an example of this category of energy-environment model.

E2020 is an integrated multi-region, multi-sector model that simulates the supply, price and demand for all fuels. It is a causal and descriptive model, which dynamically describes the behaviour of both energy suppliers and consumers for all fuels and for all end-uses, and simulates the physical and economic flows of energy users and suppliers. It is an outgrowth of the FOSSIL2/IDEAS model developed for the US Department of Energy (DOE) and used for national energy policy analysis since the Carter administration.[33] E2020 is flexible and could define as many geo-political regions as required by users. Currently, it defines 13 Canadian regions, 50 US States. On the US side, the 50 States were re-grouped for the Canadian climate change work into 5 regions for ease of computation and presentation[34]. It is historically parameterized and can simulate any groupings of the 3500 interacting energy suppliers in North America. It can also be linked with macroeconomic models to determine the economic impacts of energy/environmental policies. Currently, it has been linked with a dynamic input-output approach based macroeconomic model developed by Informetrica for economic analysis in Canada and with the REMI[35] macroeconomic model in the case of U.S. One of the attractive features of E2020 is that, unlike most energy models, it houses enormous historical database to econometrically estimate all model parameters (e.g., price response of demand, price response of supply).

The model has been used extensively by several State Departments and Electric Utilities in the US. In Canada, Natural Resources Canada was instrumental in the construction of the national model in the early 90s. The model was used within the department for technology assessments. The Department of Energy & Mines in Saskatchewan has used the model since 1993. The Canadian Energy Research Institute (CERI) is an important Canadian participant in the building of the current North American version of E2020. Since E2020 is capable of producing long-term energy market forecasts and analyzing impacts of policy changes to the markets; it's use would continue in future for a range of studies starting from energy market forecasting to specific policy issues such as energy sector restructuring, promotion of clean energy technologies. There is also a possibility of using it for developing countries and economies of transitions in analyzing impacts of GHG mitigation options under the Clean Development Mechanism and Joint Implementation.

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[33] FOSSIL2 was the original version but was renamed to IDEAS later to reflect its evolutionary development since its original construction. The early version of the E2020 model was developed in 1978 at Dartmouth College for the DOE's Office of Policy Planning and Analysis.

[34] Several stand-alone versions focusing on individual jurisdictions also exist for E2020. For Canada, one such version is the E2020 model for Saskatchewan.

[35] Regional Economic Models, Inc., Amherst, Massachusetts.

The application of energy-environmental models in analyzing national climate change policies in Canada started with the establishment of the Analysis and Modelling Group (AMG)[36]. AMG has conducted an integrated assessment of economic and environmental implications for Canada of implementing the Kyoto Protocol using various models. During the first phase of the analysis, the AMG used two Canadian energy-technology models (hereafter 'micro' models), an optimizing model, MARKAL operated by McGill University and the a behavioural model, Canadian Integrated Modelling System (CIMS), developed by the Energy Research Group at the Simon Fraser University[37]. The analyses provided estimates of the energy savings and emissions reduction required in achieving the Kyoto target (ERG and MKGA, 2000; Loulou et al. 2000). Since the micro models are incapable of analyzing economic impacts of climate change policies, the AMG also used two economic models (hereafter 'macro' models) for this purpose: The Informetrica Model developed by Ottawa based Informetrica Ltd. and the Canadian Sectoral General Equilibrium Model (CaSGEM) developed by the Department of Finance. Taking results from the micro models as inputs, the Informetrica model simulated economic impacts (e.g., impacts on GDP, employment, international trade etc.) of climate change mitigation policies (Cebryk, et al 2000). The CaSGEM model further complemented Informetrica model by focusing on the long-term effects of the climate change policies (Iorwerth, et al 2000).

In the second phase of AMG (hereafter 'AMG2'), E2020 and MARKAL (instead of CIMS and the MARKAL in AMG1), were used as micro models and the Informetrica model (TIM) as macro model to analyze a number of policy options for the federal and provincial governments in meeting Canada's Kyoto commitments. Under the AMG2, three working groups, namely, Domestic Emissions Trading Working Group (DETWG), Targeted Measures Working Group (TMWG), and Emissions Allocation Burden Sharing Working Group (EABSWG) provided necessary data and assumptions to E2020 to examine micro impacts (e.g., impacts on energy demand, prices and investments and GHG emissions) and to the Informetrica model to analyze macro impacts (e.g., GDP, employment, trade and investment).

Since E2020 is one of the main tools in analyzing GHG mitigating options, programs and plans in Canada, the model methodology and capabilities are of interest to researchers, policy makers, academia and other stakeholders. This paper presents the overall structure of E2020 and a brief overview of how key climate change policies are analyzed using this model.

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[36] Analysis and Modelling Group (AMG) is one of the 16 working groups established by the Joint Ministers of Energy and Environment Meeting (JMM) to manage the National Climate Change Process in 1998. It is mandated to address issues related to data, analytical and modelling needs in developing a national climate change implementation strategy. The objectives of AMG included (i) ensure baseline data coherency in evaluating various climate change mitigation measures/options, (ii) provide a consistent and comparable analytical framework to evaluate the mitigation measures/options, and (iii) direct analysis and modelling of various implementation scenarios.

[37] For more information on Canada's National Climate Change Process and Analytical and Modelling Group, interested readers may want to visit at http://www.nccp.ca/NCCP/national_process/issues/analysis_e.html.

2. The structure of E2020

The basic structure of Energy 2020 is provided in Figure 1. Like other energy models, the energy demand sector affects with the energy supply sector to determine energy prices in the equilibrium. The economic sector is the driving agent for energy demands, which in turn provides inputs to the economy sector in terms of investments in energy using equipment and processes and energy prices. The stand-alone model does have a simplified economy sector to capture the linkages between the energy system and the macro-economy. However, the model is best run in full integration with a macroeconomic model such as REMI. Given the modular nature of Energy 2020, additional sectors or modules from other models (macroeconomic, supply such as oil, gas, renewables etc.) can be incorporated directly into the E2020 framework.

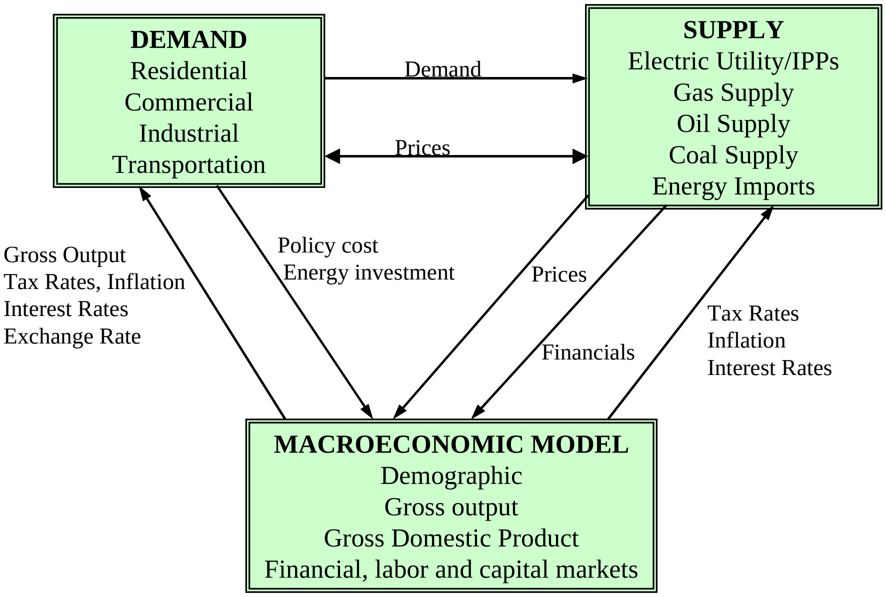

FIGURE 1 Overall structure of E2020

2.1 Energy demand

Sectors, end-uses and fuels: The demand sector of the model represents the interacting geographic areas to be simulated, disaggregated into four major economic sectors and their sub-sector detail, based on energy services. The sectors and end uses considered in E2020 are presented in Table 1. As can be seen from the table, the residential sector is divided into 3 sub-sectors with 7 end-uses, the commercial sector into 14 sub-sectors with 7 end-uses, the industrial sector into 28 sub-sectors with 4 end-uses, and the transportation sector into 3 sub-sectors with 6 modes. The oil mining is further divided into 5 types: heavy, light, frontier, oil sands, bitumen mining. For each of the end-uses, up to six fuels are modelled, for example, the residential space heating has the choice of a gas, oil, coal, electric, solar and biomass space heating technologies. The model has the flexibility to include additional economic categories, end-uses, technologies, fuels and modes to accommodate the needs of particular projects. In most cases, data availability is the limiting factor to detailed specifications. For all end-uses and fuels, the model is parameterized based on historical locale-specific data. Each demand sector is identical in equation and structure to all the other demand sectors.[38] The sector considers the demand for energy or transportation services as the driving consideration. Thus, the energy demands to satisfy those energy or transportation services are derived demands.

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[38] The demand sectors are by end-use, fuel, mode, and province for residential (Single family, multi-family, rural) commercial (14 economic categories), Industrial (28 economic categories) and transportation (3 categories).

Table 1. Economic sectors and end-use in E2020

Sector →	Residential	Commercial	Industrial	Transportation
Sub- sector →	1. Single family 2. Multifamily 3. Rural/agricultural	1. SIC 45 transportation 2. Pipelines 3. Communication 4. Electric utilities 5. Gas utilities 6. Water & other utilities 7. Wholesale 8. Retail 9. FIRE 10. Offices/Business services 11. Education 12. Health 13. Food, Lodging, Recreation 14. Government	1. Food, beverage & tobacco 2. Textiles 3. Apparel 4. Lumber 5. Furniture 6. Paper 7. Printing 8. Chemicals 9. Petroleum products 10. Rubber 11. Leather 12. Non metallic minerals 13. Iron & Steel 14. Nonferrous metal 15. Fabricated Metals 16. Machinery 17. Electrical Equipment 18. Electronic & computers 19. Transport Equipment 20. Other Manufacturing 21. Metal Mining 22. Non-metal Mining 23. Oil Mining 24. Gas Mining 25. Coal Mining 26. Construction 27. Forestry 28. Agriculture	1. Residential transportation 2. Commercial transportation 3. Industrial transportation
End-use → or Modes	1. Space heating 2. Water heating, 3. Lighting 4. Air conditioning 5. Refrigeration 6. Other substitutable[a] 7. Other non-substitutable[b]	1. Space heating 2. Water heating 3. Cooling 4. Refrigeration 5. Lighting 6. Other substitutable[a] 7. Other non-substitutable[b]	1. Process heat 2. Electric motors 3. Other substitutables[c] 4. Miscellaneous[d]	1. Highway (automobiles & trucks) 2. Buses 3. Trains 4. Planes 5. Marine 6. Others (electric vehicles, fuel cells and ethanol)

[a] an aggregate category to include cooking and drying end-use services. *[b] represents miscellaneous electric appliances* *[c] hot water or drying that is not part of the primary-process heat* *[d] lighting and electrochemical process*

The modelling approach: E2020 falls in the league of "hybrid" models. Following are the two conceptual linchpins form the theoretical perspective used in the model to determine energy demand:

- First, a "Stocks and Flow" simulation captures the physical aspects of the process, specifically the physical flow of entities within a system. For example, new investments increase the number of energy using devices, and retirements reduce the number of energy using devices. This function is similar to many other end-use accounting type models, which keep track of the energy using stock.
- Second, the qualitative choice theory (QCT) as put forth by the Nobel Laureate Daniel McFadden determines how consumers make their energy decisions. All consumer decisions affecting the flow part of the stock are simulated with QCT[39].

Determining energy demand is a four-step process: (i) new capital formation and corresponding stock energy demand due to economic growth, (ii) determining technology and fuel mixes to meet the energy demand, (iii) stock and flow accounting and (iv) converting energy requirement to annual energy demand. Figure 2 presents mechanisms to derive energy demand in E2020.

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[39] A key feature of the QCT is the inclusion of a number of factors in addition to price in making decisions. The factors represent tastes and preferences that the decision-makers use to determine the best (utility maximisation) choice for them. Because the information on the factors is uncertain, QCT uses a distribution to determine the probability of choice being made. On average, the choices that are made correspond to this probability. The data needed to parameterize the distribution are readily obtained from historical time-series. Because the uncertainty has more to do with the decision-maker than the object (technology) of the decision, the parameterisation is applicable to new technologies and conditions not experienced historically.

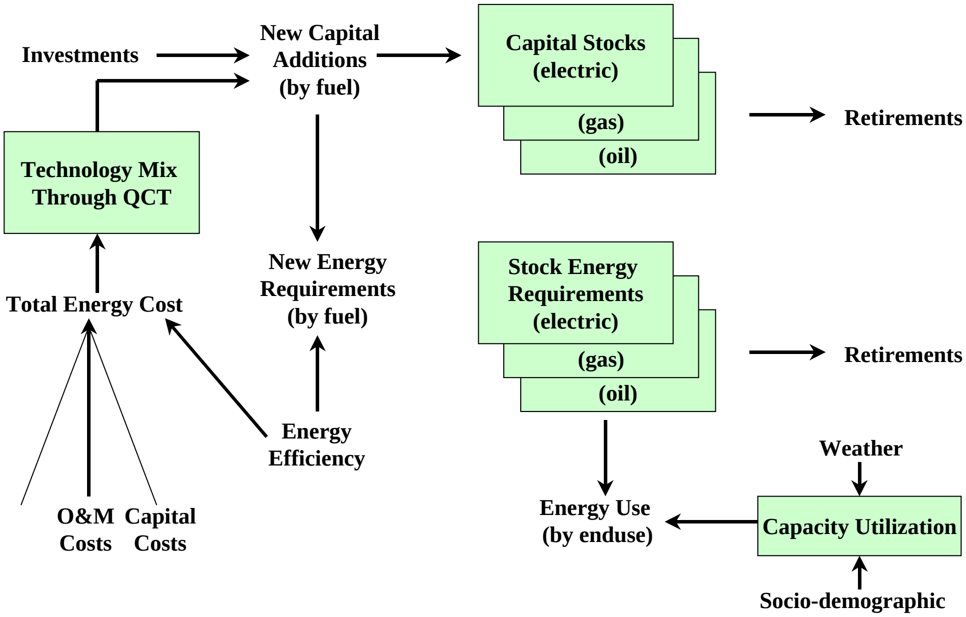

FIGURE 2 Mechanism to derive energy demand in E2020

The starting point in the model is to establish relationship between energy demand and capital stock in the production of goods and services. For example, the industrial sector produces goods in factories, which require energy for production; the commercial sector requires buildings to provide services; and the residential sector needs housing to provide sustained labour services. The occupants of these buildings require energy for heating, cooling, and electromechanical appliances. Thus any new capital formation is the starting point for any new energy demand. The estimate of capital formation is an exogenous variable in the model derived either from the interactions with the macroeconomic model or other exogenous sources.

The second step is the choice of fuel (technologies) and the corresponding efficiencies. For each demand sector, the consumer has a choice what fuel (technology) should be used in meeting the energy service (e.g., space heating in the residential sector). QCT is used here to make the decision. The model considers price factors (e.g., marginal cost of technology use) and non-price factors (e.g., tastes, income-adjusted preferences, technology availability) to decide the selection of fuels (technologies) in meeting need for energy service[40]. Both price and non-price factors enter directly into the QCT equations and, thereby, the distribution that determines market shares. QCT is used to both determine market shares for modes or fuels as well as to determine the efficiency of particular technologies utilised. The choice of the efficiency is based on the price of the fuel and the perceived trade-off between efficiency and capital plus O&M costs[41]. Since this

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[40] In the case of the transportation sector, the consumer decides between the various transportation modes to satisfy the need for transportation services.

[41] O&M costs are considered a function of capital cots. Therefore, the QCT derived the trade-off is explicitly between efficiency and capital costs.

decision making process constitutes the focal point of the model, it is explained in detail in the Appendix.

The model, in the third step, calculates energy using capital stocks in terms of energy requirements (e.g., space heating requirements) based on the additions to the stock of energy using processes determined in Step 1 and the additions to the stock of energy using devices determined in Step 2. Both retirement and loss (e.g., due to fire or other disasters) of processes and devices are accounted in the model. The retired and lost stock is replaced by the new stock subject to the demand for energy service. Thus new stock is introduced for two purposes: (i) to replace the retired stock, which satisfies the existing demand for energy service and (ii) to meet the new demand for energy service associated with economic growth. Note that for any given year, the model keeps track of energy using stock in terms of its energy requirements (e.g., space heating requirements) rather than the number of physical units (e.g., number of furnaces).

Finally, the application of capacity utilisation factor to the stock of energy requirements determines the actual demand for energy. The stock energy requirements are calculated on the assumption that the stock is fully utilised. However, the reality is that the stock may not be fully utilised depending upon such factors as weather, socio-economics, current economic conditions, exogenous policies, and others. Utilisation of capital stock can also change due to new requirements on operation of the devices. For example, a reduced speed limit reduces the energy use per kilometre for an automobile or truck because it has to use less energy to counter the created air-pressure.

2.2 Energy supply

On the energy supply side, E2020 models electricity, oil, gas and coal. Electric supply is modelled extensively for more than 60 nodal levels with details in load dispatching, capacity expansion, regulation and financing. On the other hand, the supply for oil and gas is represented through incorporation of supply elasticities derived through consensus discussions with the Canadian Association of Petroleum Producers (CAPP) and Natural Resource Canada (NRC).

Electricity: The electricity supply module of E2020 endogenously simulates capacity expansion including planning, construction, operation and retirement of generating plants and transmission facilities. Each step is financed in the model by revenues, debt, and the sale of stock. The regulator, where applicable, sets the allowed rate of return, divides revenue responsibility among customer classes, approves rate base, revenues and expenses, and sets fuel adjustment charges. Figure 3 presents an overview of the electricity supply module.

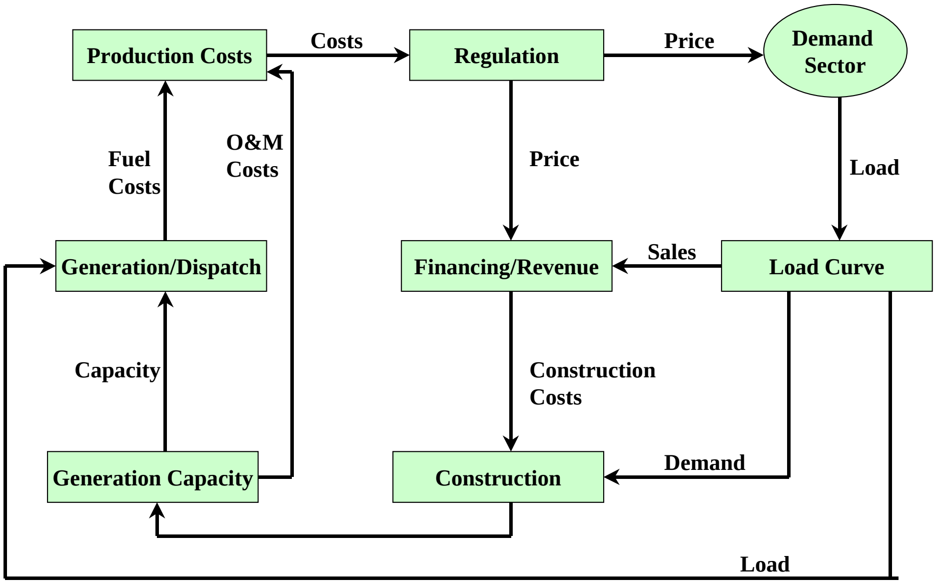

FIGURE 3 An overview of the electricity supply module in E2020.

End-use electricity demand is endogenously forecasted based on stock of end-use appliances, their load curves and utilization rates[42]. Electricity load thus forecasted would serve as basis for capacity expansion plan. The expansion plan takes into account plants already under construction. Capacity expansions are differentiated for meeting peak and base loads. The model allows the minimum reserve margin to be temporarily violated at the peak if new base load capacity is scheduled to be available within the year. Minimum plant size is exogenous to the model. The mix of new base load plants (i.e. alternative coal technologies, hydro, or nuclear) is user-specified in the standard E2020 configuration. The model also evaluates the financial implications of new construction, including total construction costs, cost schedules and AFUDC/CWIP. It can also be configured to consider intermediate load units, firm purchase contracts, external sales, independent power producers, and demand-side management.

Financial requirements/performance of utilities can also be simulated in E2020. The model forecasts funding requirements and follows corporate policies for obtaining new funds. It simulates borrowing and issuing of stock, repurchase stock or making investments in the situation of excess cash. Cash flows are explicitly modelled, as are any decisions that affect them. Coverage ratios, intermediate- and long-term debt limits, capitalization, rates of return, new stock issues, bond financing, and short-term investments are endogenously calculated. The model keeps track of gross, net, and tax assets. It also calculates the depreciation values used for the income statement and tax obligations. E2020 produces a complete set of utility financial reports.

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[42] Each end-use in E2020 has a related set of load shape factors. Typically, these factors define the relationship between peak, minimum and average load for each season. These factors when combined with the weather-adjusted energy demand by end-use and corrected for co-generation, resale, and load management programs, form the basis of the approximated system load duration curve. Alternatively, representative hours over each season are used.

The model is equipped to deal with both regulated and unregulated markets. Where electric utilities are regulated, it follows the allowed rates-of-return regulation. The utility rate-base is calculated according to a detailed conventional rate making formula. The model allows the user to adjust allowable costs, and has been used extensively to evaluate alternative rate-base scenarios for individual plants. The regulatory sub-module of E2020 automatically factors in a wide variety of regulatory policies and options. More importantly, the model can be readily modified to consider a wide spectrum of scenarios. Environmental constraints, such as air pollution restrictions, can also be included in the model. When E2020 is configured as a regional or state-wide system, municipal utilities, with their unique tax and rate structures, are also incorporated. Similarly, regional or power pool interchange is also recognised.

Oil, gas and coal: Oil and gas production in E2020 is based solely on a supply price-response determined through discussions with CAPP and NRC. Production has process (type) detail (tar sand, bitumen, frontier, light, and heavy) by province. Production is broken out by province based upon the provincial share in each type of oil production. Each type of oil responds to the world price of oil, which is exogenous to the model. The production response (supply elasticity) varies by type of oil to capture the variations in costs, maturity of oil basins, resource potential, and the overall ability to respond to changes in price.

Coal production is by type and province. Its production can be price sensitive, but is determined through supply demand balancing (i.e., production and import are equal to demand and export). Imports are exports are exogenous to the model.

2.3 Emissions estimation

Greenhouse gases (GHGs) and the criteria air contaminants (CACs) are the main emissions related to the combustion of energy. Using emission coefficients for each of these pollutants, the model tracks emissions for these pollutants by fuel, sector, and jurisdiction. In addition, the model also tracks non-combustion and non-energy/fugitive emissions. These are emissions associated with processes not directly associated with the use of energy (e.g., CO_2 released from chemical process in cement manufacturing, leakage of Hydrofluorocarbons (HFCs) from air-conditioning, methane emission from gas production) can lead to the venting of methane into the atmosphere.

Gas, oil, and coal are also used for feedstock in production of goods such as fertilizers, paints solvents. Emissions in such cases are not produced from combustion but from the decay or evaporation of these goods. The emissions that come from the use of a fuel for the purposes other than combustion are designated as non-combustion emissions. In both the cases of non-combustion and non-energy use, emissions coefficients are expressed in terms of per unit of sectoral output.

2.4 Linkage of E2020 with macroeconomic model

E2020 is linked with a macroeconomic model developed by Ottawa based Informetrica Ltd[43] to capture the interactions between the energy sector and the economy. For example, a change in price affects demand that then affects future supply and price. These energy market dynamics is captured within E2020. But energy demand also changes due to increased economic activity and in turn a higher demand increases the investment in new supplies. The new investment affects the economy and energy prices. The energy prices also affect the economy. These (indirect) impacts are captured through interactions with the macroeconomic model. The linkage between E2020 and Informetrica model (i.e., TIM/RIM) is presented in Figure 4.

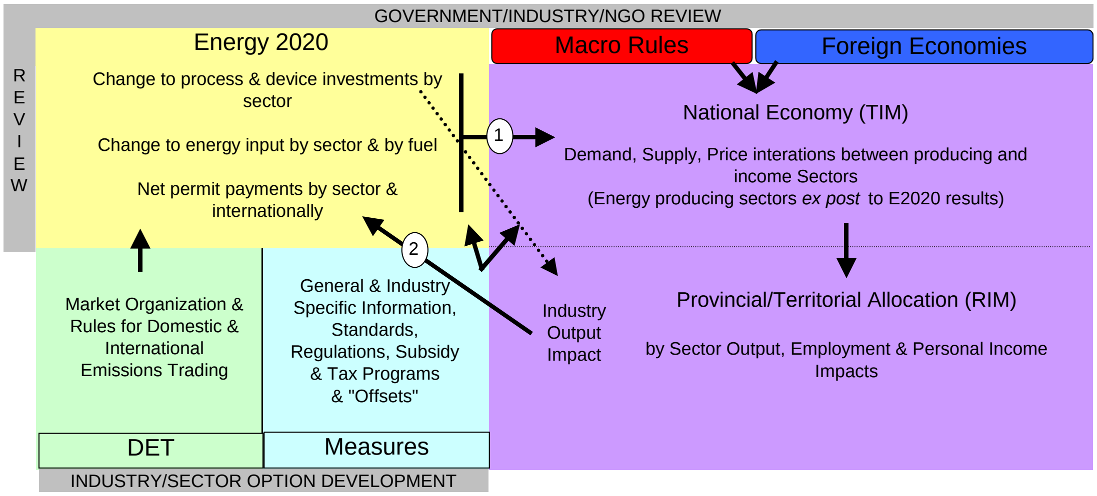

FIGURE 4 Linkage between E2020 and the Informetrica macroeconomic model

Source: Sonnen and Saunders (2002)

E2020 and TIM/RIM models are simulated as two separate models, however, they are soft-linked with input and output flows. Simulation begins with E2020 estimating the direct impacts of climate change policies. Three outputs from E2020 are submitted to TIM/RIM to be included as model inputs. They are: (i) changes to investments in energy using equipment and structures by sector and industry; (ii) changes to energy intensity (energy input per unit of output) by sector, industry and fuel; and (iii) net emissions permit purchases/sales by industry and government for sectors covered under domestic emission trading systems. Incorporating the E2020 output, TIM/RIM are then simulated to generate the output, employment and personal income impacts by industry and jurisdiction. Three outputs from TIM/RIM are used as inputs to E2020. They are:

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[43] There are two models owned and operated by Informetrica, TIM (The Informetrica Model capturing the interactions of the economy nationally) and RIM (a Regional-Industrial Model estimating the impacts on production and incomes at the provincial/territorial levels).

(i) gross output by industry and jurisdiction; (ii) personal income by jurisdiction; and (iii) inflation, interest rates, tax rates, and exchange rates. Figure 4 shows information/data flows between the two models. The data input-output flows are iterated twice and the final results from E2020 reflect the inclusion of the second-pass results from TIM/RIM. This in essence is the third iteration and completes the process.

3. Modelling Climate Change Policies in E2020

E2020 has an immense capacity to analyze consumer and business responses over a wide range of policy initiatives. An illustrative subset includes tax initiatives or disincentives, energy taxes, regulatory standards for buildings, equipment and motor vehicles, grants, rebates and subsidy initiatives, consumer awareness initiatives (education and awareness), technology improvements (R&D), moratoriums and mandated cut-backs, and emissions permit trading. In this section, we focus largely on the type of policies modelled as part of AMG 2. The AMG 2 policies can be divided into three broad categories.

- Market instruments: carbon tax[44], and emissions permit trading.
- Targeted Measures: a wide range of initiatives (or programs) comprising those that enhance consumer understanding of available technologies and options (education and awareness) to building and device standards.
- Exogenous supply cost curves and reduction measures: This corresponds to supply cost curves for the oil and gas sector initiatives; Landfill gas supply curve; forestry and agricultural sector carbon sinks and offsets.

3.1 Market Instruments

Market based policies (instruments) send a signal to the market to change behaviour. The most common and widely used market instruments are energy and emission taxes, which by increasing end use price, results in a lower energy demand. In the context of climate change, there are two widely used market instruments, namely carbon tax and emissions permit. Under both these policy mechanisms, the price of energy rises to encourage investments in more efficient energy using processes and devices to reduce energy demand and consequently energy related emissions.

Under a carbon tax, a tax is imposed on all fuels in proportion to their carbon content. The cleaner the fuel (lower the carbon content), the lower the tax rate. This type of tax has three effects. First, a temporary budget response, or an income effect that decreases the disposable income due to the higher price and therefore leads to lower demand for all energy fuels. Second, a fuel switching effect caused by changes to the relative prices of energy fuels. Thus the demand

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[44] Although carbon tax was not included as part of the AMG 2 policies, it is discussed briefly here to explain the difference between a carbon tax and permit trading in terms of modelling within E2020.

for lower taxed (cleaner) fuels increases and the demand for higher taxed (dirtier) fuels decreases. Third, the increase in energy prices causes the consumer to move to more efficient use of energy. This may result in the same level of energy service demand but at the cost of lower fuel consumption.

Emission permits are generally considered a more politically acceptable approach to reducing GHG emissions. Policy makers have seen the use of permits as a means to avoid many of the revenue collection and recycling problems of carbon tax. The requirement of an emissions permit works much in the same way as the carbon tax. A non-zero cost of the permit results in an increase in the price of energy fuels based on the carbon content. This again sends the signal to the energy consumer to change behaviour (reduce demand and emissions, and the need for buying emissions permits). However, the permits have a much different dynamics than does a carbon tax. Permits represent a market and possibly one with a rigid supply. There is a demand for permits (the emissions) and there is a supply for permits (the compliance level). Based on the demand and supply, there is an equilibrium price at which the demand for permits equals the supply. Contrary to emission permits, there is no equilibrium carbon tax that is determined in a market although there may be an “optimum” level of carbon tax, which leads to a “desired” level of reductions. In terms of the treatment of these two alternate market instruments from the perspective of modelling, the level of carbon tax is an input to the model, as opposed to the price of permit, which can be an output of the model dynamics or determined exogenously.

Under AMG2, a domestic emissions trading (DET) scheme was considered, the modelling of which is different from that normally used for carbon tax and emission permit system, in three ways. First, part of the permit requirement is distributed by the government as Gratis, and although the threat of having to pay for added permits provides an incentive to reduce emissions, the price signal is much weaker than a policy case where permits are fully auctioned. Second, the permit trading is not economy wide and is limited to the large final emitters (LFE) including the electricity sector. The residential, commercial and transportation sectors are exempt from domestic emissions trading. Third, two alternate price scenarios are examined for DET. The US$6 and US$30 per tonne of CO_2 are assumed as alternate prices for permits in the international market. Indirectly, these permit price levels assume that a significant portion of Canada’s Kyoto obligation will be met through permit purchases in the international market. The LFE sector will make reductions domestically up to the amount of the international permit price (US$6 or US$30). The last feature implies that the DET scheme is modelled as a carbon tax, at alternate tax levels of US$6 and US$30.

3.2 Targeted Measures

Targeted measures (TM)[45] can be defined as a set of targeted initiatives to reduce energy demand and or shift it to cleaner fuels, thus reducing emissions. A subset of these TMs is akin to regulatory standards such as building codes or automobile standards targeted largely to increasing efficiency of marginal (new) stock of energy using devices and processes. As stock turnover takes place with old stock being retired and replaced by new stock, the efficiency of the entire stock increases. Approximately 75 TMs were included in AMG 2 as direct initiatives to reduce emissions. The list of TMs considered is presented in Table 2. Most of these measures relate directly to those described in the Issue Tables.

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[45] The origins of the TMs can be traced back to the establishment of the sixteen Issue Tables/Working Groups, comprised of 450 experts from government, industry, academia and non-governmental organizations following the April 1998 JMM meeting to manage the National Climate Change Process. The overall mandate of the Issue Tables was to estimate the cost and amount of GHG emissions that could be achieved in individual sectors.

Name of measure modelled	Description
Residential Sector	
RES_AE-1	National Standards Program for Equipment & Appliances
RES_AE-5	Energy Star Labeling/Premium Energy Performance Labeling Program
RES-C8-A	Multi-Residential Retrofit Program
RES_R3	National Energy Efficient Housing Renovation & Retrofit Program
RES-R-4A	Adoption of More Stringent MNECH by Provinces
RES-R-5A	Strengthened R2000 Program
RES_R6B	R-2000 for Existing Dwellings Renovation Program
RES_R-7V	EnerGuide for Houses – Voluntary
RES-R10	Residential Retrofit Guidelines and Installation Standards
Commercial Sector	
COM_AE-1	National Standards Program for Equipment & Appliances
COM _AE-5	Energy Star Labeling/Premium Energy Performance Labeling Program
COM _C2B	Improved MNECB
COM _C7	Public Building Initiative
COM _NewC8	Additional Commercial Building Retrofit Program
COM_CHP	Commercial Cogeneration
Municipal Sector	
COM _MUN22	Develop and Finance Viable CES Projects
ELEC_MUN009	Capital Infrastructure Funding Program
IND_ MUN16	Municipal Green Fund Incentives for Integrated Waste Management
IND_ MUN2425	Revolving Fund for Energy Efficiency Retrofits
Industrial Sector	
IND_ Aluminum	Aluminum Recycle
IND_ Audits	Audit Identified
IND_ Capture	CO2 Capture
IND_ CIPEC	Expanded CIPEC
IND_ ENERGUIDE	Industry EnerGuide
IND_ FUND	Facilitation Fund
IND_ Minerals	Concrete Fly Ash
IND_ LfgOffsets	Capital Infrastructure Funding Program for Landfill Gas
IND_ Steel	Steel Recycle
Transport Sector	
TRAN_A-1	Enhancements to the Pedestrian and Bicycle Environment
TRAN_A3H	Transit Service Improvements (Includes A2H)
TRAN_A-5	Telecommuting
TRAN_A-7	Car Sharing
TRAN_A-14	Accelerated Light Duty Vehicle Scrappage
TRAN_A-15	Syncronized Traffic Signals
TRAN_A-16L	Driver Education and Awareness Program
TRAN_B-7	Rigid Pavements (Cement)
TRAN_B-16	Advanced vehicle Control Systems (AVCS)
TRAN_D-1	Short-term Aviation Measures
TRAN_F-3	Trucking Load Matching
TRAN_F-5A	Truck Central Tire Inflation
TRAN_F-6	Truck Lubricants
TRAN_F-10H	Driver Education Program
TRAN_G-6	Marine Code of Practice I
TRAN_G-7	Marine Code of Practice II
TRAN_H-1BL	Fleet Average Fuel Consumption Target Harmonized
TRAN_H-2A	AFV Fleet Purchase
TRAN_TRA-101	50% Ethanol
TRAN_TRA-115	Biodiesel from waste greases, stressed Canola
TRAN_TRA-117	Freight inter-modal system improvements (High Scenario)
TRAN_TRA-119	Off-road Efficiency Improvements
TRAN_TRA-120	Anti-idling Technology for Heavy Truck Fleets
TRAN_TRA-121	Light Duty Vehicle Tire Pressure Warning System
Electricity Sector	
ELEC_CHPMIP	Combined Heat and Power
ELEC_WPPI	Wind Power Generation
ELEC_Capture	CO_2 Capture
Oil & Gas Sector	
Gas_AcidCapture	CO_2 Capture
Oil_InfraCapture	CO_2 Capture

Source: http://db.nccp.ca/cfmsite/nmd/cfmlpriv/

Table 2 Examples of targeted measures

To describe how each of these measures is modelled within E2020, the discussion below is categorised by the type of measure. The measures are implemented at the point, where they affect decision process. The primary measure categories and their associated decision points for the demand sectors are shown in Figure 5. Wherever possible, the measures are implemented in their logic rather than in their impact. Thus, most measures are implemented as "Measures" and not as "Actions"[46]. The AMG 2 targeted measures can be grouped into the following six categories based on how they are modelled and the decision points they impact.

Informetrica transferred measures: These measures are modelled through the macroeconomic impacts captured in Informetrica's TIM & RIM. Examples of such measures are agriculture related (AE001 to AE009), where costs are captured through factor-input changes on the macro side. Other examples include the enforcement of speed limits where the fuel cost savings are measured on the micro side, but the added costs from law enforcement activities are included on the macro side.

Regulatory standards: Standards affect the minimal efficiency decision of investments (for marginal or retrofits) for energy using devices and processes. Device standards are defined in terms of GJ-out/GJ-in and process standards as $of output/GJ. As a result of these standards, the consumers are forced to choose a higher level of efficiency, assuming of course that the standards are set at a level above the marginal efficiency. Thus both process and device efficiency decisions are impacted. Good examples of this category of measure are AE-1, R10 and C2-B.

Financial measures: In this category fall the various cost support measures as well as the financial incentive measures. Cost support measures reduce the cost of the desired device and process, and therefore encourage the consumer decision to invest in the desired technology. Examples of this measure include C8-A, R3 and R6B. The financial incentive measure work in much the same way as the cost support measures through reduction in costs of the devices and processes. Low interest loans are good examples of this measure. These loans reduce capital payments.

Operational efficiency measures: Some measures reduce the utilisation (or energy use) of a device or process without changing its intrinsic mechanical efficiency. The use of synchronised traffic lights would be an example that reduces highway vehicle energy-use and emissions but not the design of the car engine. These reductions require external engineering analysis. Many of the transportation measures fall in this category. For this type of measure, the Issue Table information is used to derive the reductions in utilisation. These types of measures effect the operational efficiency decisions, which impact the energy-use emissions.

Information measures: The information measures result in consumers making better-informed decisions. Information programs affect the uncertainty relative to efficiency versus fuel trade off

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[46] This is a change from the micro modelling of AMG1, where the impact information from the Issue Tables was incorporated in its entirety as "Actions".

choices. For devices, this uncertainty parameter is Device Fuel Trade-off Coefficient and for process, it is the Process Fuel Trade-off Coefficient. AE-5 and R5-A are again good examples of this category of measures. Although generally, a reduction in uncertainty would lead to more efficient decisions, in some cases, due to preferences, the decrease in uncertainty may not necessarily move the consumer towards greater energy efficiency.

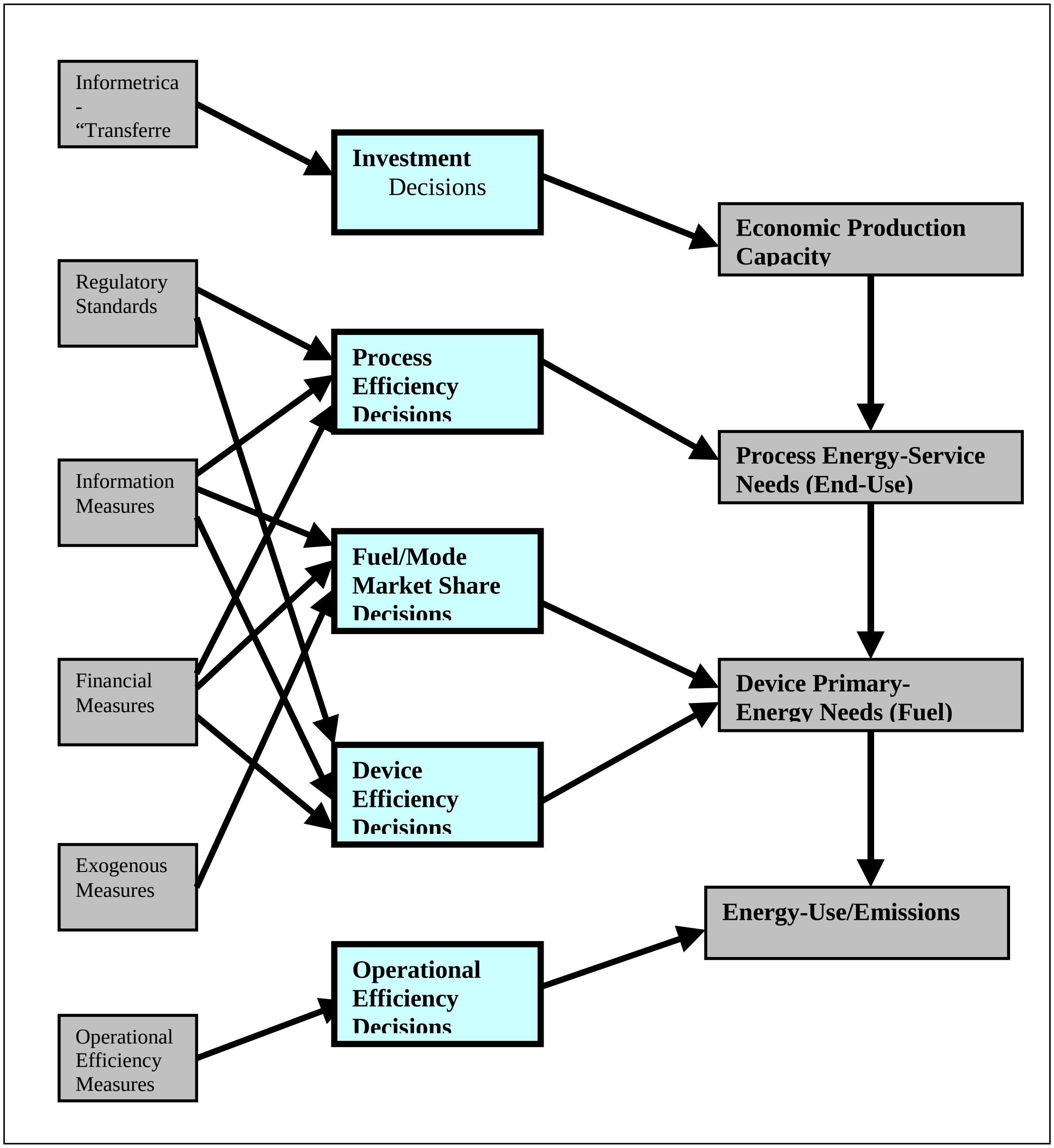

FIGURE 5 Targeted measure Categories & model decision points

3.3 Exogenous supply cost curves and reduction measures

Exogenous measures: Finally, there is a range of measures, which have been included as exogenous measures. The effect of these measures has been incorporated as an exogenous impact taken either from the Issue Tables or described by the experts within the government departments. An example is the forced use of ethanol, where a percent of market share is allocated to ethanol vehicles (TRA-101).

Finally, it should be noted that AMG measures have "penetration levels" (PL). This does not really reflect penetration per se but rather how intensely the measure is pursued compared to what is specified in the Issue Tables. For example, if an efficiency standard was to improve furnace efficiency by 10%, a 50% PL would imply a 5% efficiency improvement should be included in the model. If strict enforcing of the speed limit caused a 3% reduction of motor vehicle emissions, then a 200%PL would cause a 6% reduction

In cases of "overlapping" measures, such as the efficiency standards being applied multiple times to the same end-use, fuel, and sector, the final effective standard is the maximum of all the imposed standards. Whenever there are multiple overlapping measures, the model acts to logically/physically reflect the combined impacts rather the naively adding measures as if they were independent.

Several CO_2 abatement cost curves to account for sectoral initiatives on reducing GHGs are incorporated in E2020 under AMG 2 analysis. These curves include the oil & gas cost curves based on the Issue Table information; a CO_2 sequestering cost curve was developed by the Canadian Energy Research Institute and the landfill gas cost curve provided by Environment Canada. Based on these curves, the model endogenously generates the amount of CO_2 reduction at a given permit price.

While the model does have the dynamics and cost curves for measures associated with the agriculture and forestry, the AMG decided to exogenously specify the CO_2 sequestration through carbon sinks associated with agriculture and forestry. Forestry cost-free sinks are set to 20MT per year for all years. Agriculture cost-free sinks are set to 4MT/yr. Combined agricultural measures produce 10.1 MT/yr. by 2010 and 10.3/yr by 2020. There are no endogenous dynamics. These are "forced-in" exogenous values specified by the AMG.

4. Conclusions

E2020 is one of the key tools used in analyzing Federal and Provincial government's plans in meeting Canada's GHG mitigation commitments under the Kyoto protocol. It is an integrated multi-region, multi-sector model, which dynamically describes the behaviour of both energy suppliers and consumers for all fuels and for all end-uses, and simulates the physical and economic flows of energy users and suppliers. Stocks and flow simulation and the qualitative choice theory are the two basic foundations of E2020. It is flexible to define geo-political region, number of economic sector, fuel, end-use as required by users. The most important feature of E2020 is that, unlike most energy models, it houses a huge historical database to econometrically estimate all model parameters. For the purpose of capturing macroeconomic impacts of a policy change, it has been linked with a dynamic input-output model developed by Informetrica for Canada and with the REMI model in the case of U.S. In Canada, E2020 was used mainly to analyze various climate change options of federal and provincial governments under the framework of Analysis and Modelling Group established by the Joint Ministers of Energy and Environment Meeting (JMM) to manage the National Climate Change Process.

E2020 has an immense capacity to analyze consumer and business responses over a wide range of policy initiatives such as energy-environmental taxes, regulatory standards for buildings, equipment and motor vehicles, grants, rebates and subsidy initiatives, consumer awareness initiatives (education and awareness), technology improvements (R&D), moratoriums and mandated cut-backs, and emissions permit trading. Under AMG study series, it was used to model particularly three types of GHG mitigation measures. These were (i) market instruments: such as carbon tax and emissions permit trading; (ii) a wide range of initiatives (or programs) comprising those that enhance consumer understanding of available technologies and options (education and awareness) to building and device standards and (iii) exogenous supply cost curves and reduction measures.

Since E2020 is equally capable of producing long-term energy market forecasts as well as analyzing impacts of any policy shock in the market, its will serve as a useful analytical tool for a range of issues. These may span from general energy supply-demand forecasting at provincial and federal levels to modelling of specific issues such as re-structuring of the electricity sector, and impacts of clean energy technologies (e.g., renewable energy technologies). There is also a possibility of using it for developing countries and economies of transitions in analyzing impacts of GHG mitigation options under the Clean Development Mechanism and Joint Implementation.

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Appendix

Choosing Fuels (technology) & Efficiencies in E2020

If all behaviour were cost-minimizing and the technologies were available without any constraints, the total market share would be assigned to the least cost technology. This is more or less the assumption that underlies the Linear Programming (LP) models. However, consumer behaviour is not always cost minimizing due to a range of non-price factors including individual tastes & preferences. Additionally, consumers do not have perfect information. A sampling of the population shows different perceptions of actual costs and personal preferences. Figure A.1 below shows the illustrative distribution of perceived price for three technologies (choices). Preferences are excluded to make the example clear. Comprehensive statistical methods determine the shape of the distribution as a function of costs and preferences in the model. In the figure below Tech 1 – 3 are shown to compete for market share. The region of overlap of the density distribution curves for the three technologies reflects the zone of competition. The fraction of the time Technology 1 would be picked would be the region to the left of the red line and half the region between the left red and left green line under the blue distribution. (The half comes from the price having a 50% chance of the cost of Technology 1 being perceived as lower than Technology 2.)

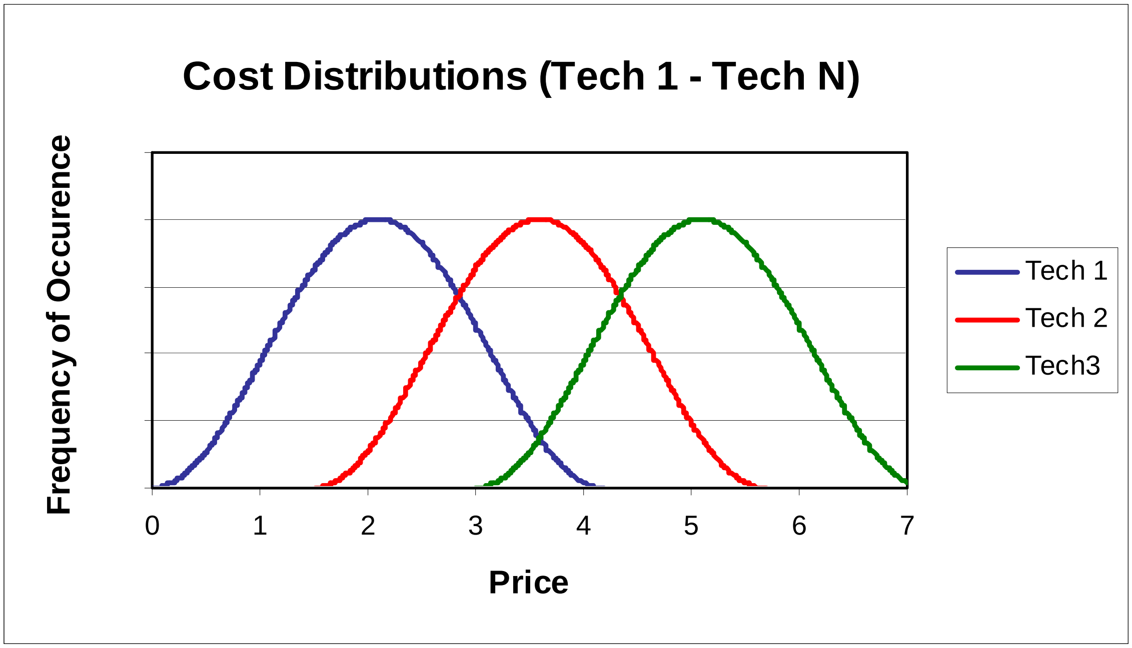

Figure A.1. Illustrative choice distribution

Technology 2 would be picked by the fraction amount equal to one-half the area between the left red line and right of the blue line. Technology 3 would be picked the fraction amount equalling one-half of the area between the left green line and the right blue line under the blue curve. This is the fraction of the instances that Technology 3 is perceived as having a lower cost than Technologies 1 or 2. The width of the distribution reflects the uncertainty in the information about the technology.

Figure A.2 illustrates a derived market share curve for Technology 1 as a function of perceived costs for Technology 1 versus Technology 2. As the price of Technology 1 becomes small compared to the other choices, its market share would go to unity. If the uncertainly is large (as in the residential sectors), the slope is gradual. If there is significant effort to reduce costs (have less uncertainty), the curve is steeper as shown for industrial choices. If there is perfect information, as assumed in an unconstrained linear programming (L-P) framework, then the market share would jump form 0.0 to 1.0 with the smallest of price differentials.

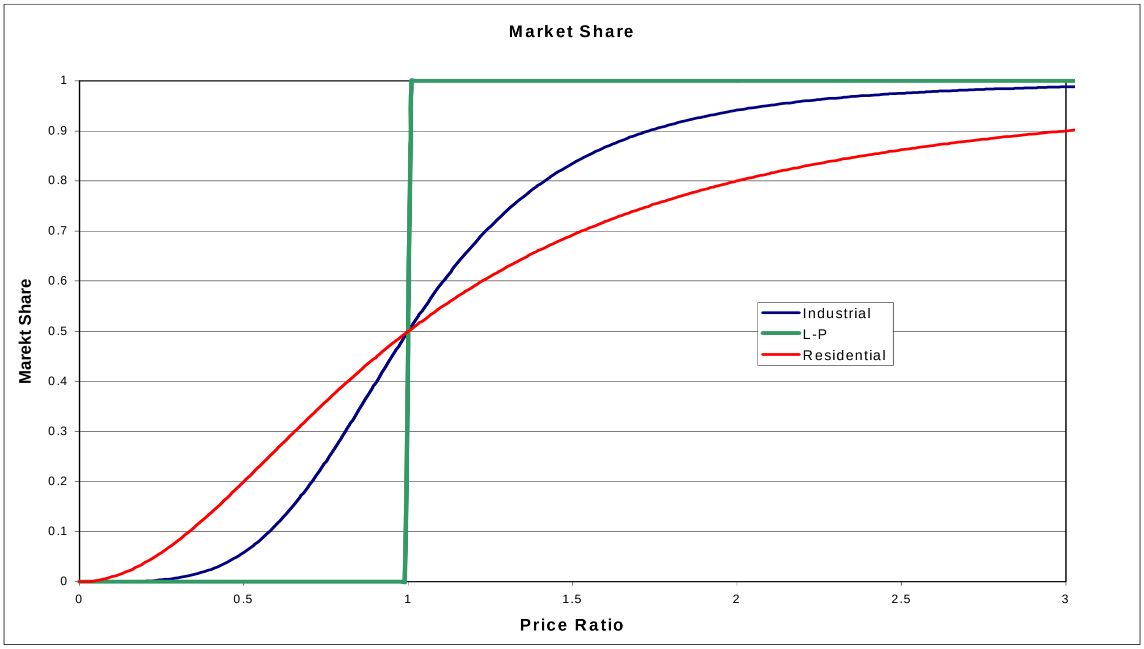

Figure A.2. Illustrative market share response

If Technology 1 through 3 represents fuel choices, then Figure A.2 would represent the fuel market shares on the margin. If there are many technologies, the shape of Figure A.2 only changes quantitatively but not qualitatively. It is then possible to make a curve of efficiency where the choice goes from the lowest efficiency technology (when energy costs are low) to the highest efficiency (when energy costs are high). Preferences also play into this, but for simplicity, these can be thought of as added perceived costs in this example.

The market share response curve reflects the choice of technology at a given price. Each chosen Technology indirectly reflects the choice of efficiency since each technology is associated with some level of efficiency (units of Joules of input-fuel per Joule of energy service). Therefore, embedded in the market share response curve is a choice of efficiency at a given price. The Purple line in Figure A.3 illustrates the selected marginal efficiency at the current price and preferences. The efficiency ratio (Efficiency/Maximum-technological-efficiency) goes between 0.0 and the maximum (1.0). This curve is referred to as the price/cost – efficiency trade-off curve. It is expected that as the fuel price increase, higher efficiency is chosen. The curve flattens out at the top as the technological maximum is achieved. The green line represents a "standards" policy (regulate the efficiency of a energy using device or process) and sets the floor for the marginal efficiency. Efficiency would only improve more at a price above that where the standard's efficiency and price intersect on the graph.

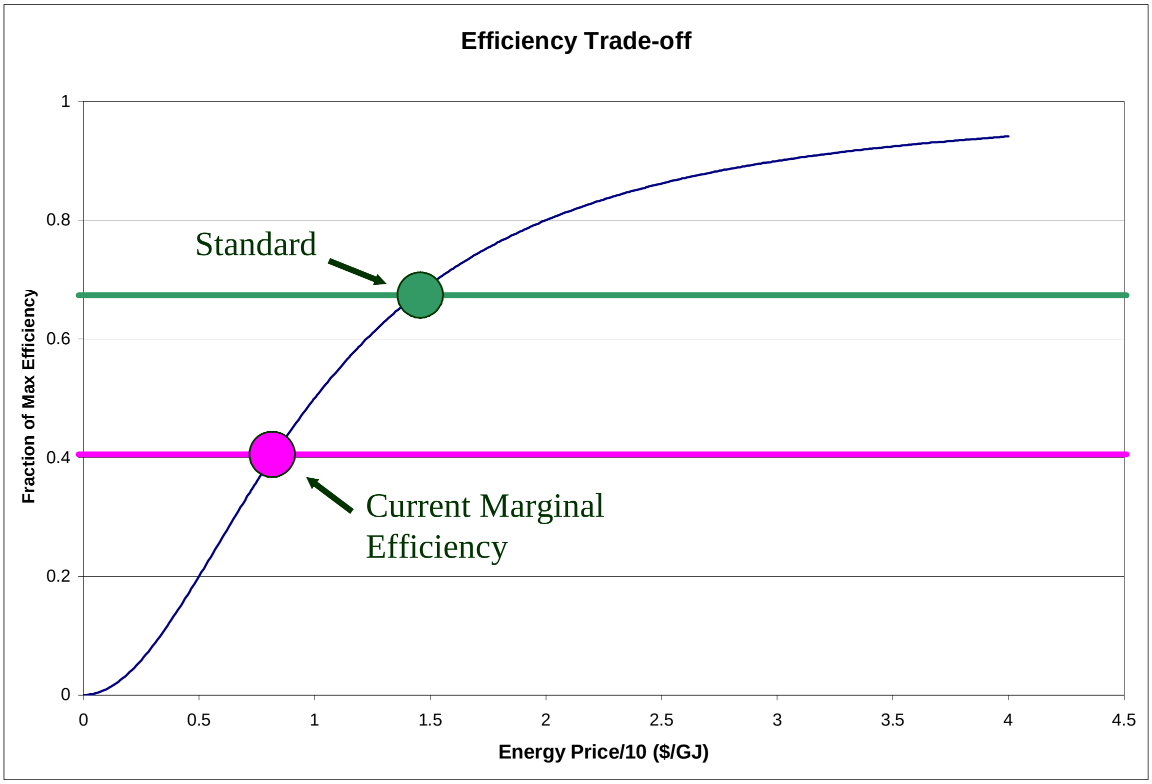

Figure A.3. Illustrative price-efficiency trade-off curve.

Higher efficiency (better technology) comes at a cost, and hence the higher the efficiency, the higher the capital cost of a device or process. The market share dynamics can be used to determine the capital cost of the choice as efficiency improves. The maximum efficiency can be increased over time (general technological advance) and the model can automatically (based on historical relationships) determine the new costs as technology potential improves. The complementary capital cost curve to the Figure A.3 price-efficiency trade-off curve is shown in Figure A.4.

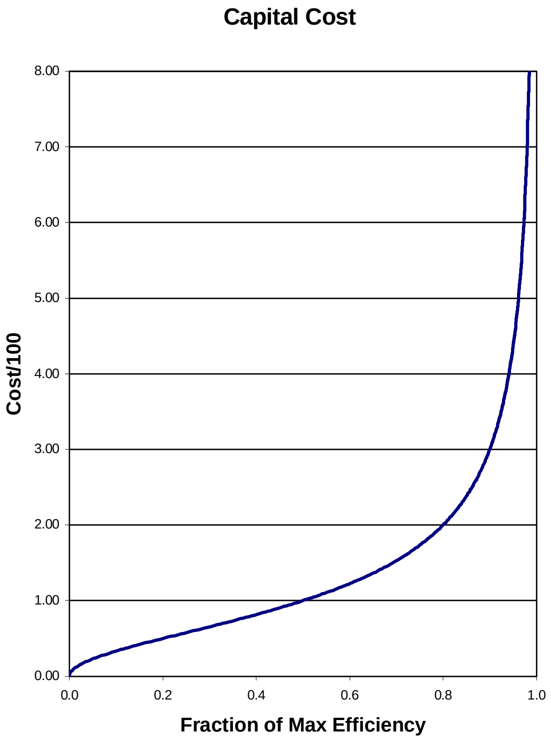

Figure A.4. Illustrative cost-efficiency trade off curve

About CERI

The Canadian Energy Research Institute (CERI) is a co-operative research organization established through an initiative of government, academia, and industry in 1975. The Institute's mission is to provide relevant, independent, objective economic research and education in energy and related environmental issues Related objectives include reviewing emerging energy issues and policies as well as developing expertise in the analysis of questions related to energy and the environment.

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