University of Alberta

Development of Greenhouse Gas Mitigation Options for Alberta's Energy Sector

by

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Abstract

Alberta is the third largest economy in Canada and is expected to grow significantly in the coming decade. The energy sector plays a major role in Alberta's economy. The objective of this research is to develop various greenhouse gas (GHG) mitigations scenarios in the energy demand and supply sectors for the Province of Alberta. This is done through an energy-environment planning and forecasting tool called Long Range Energy Alternative Planning system model (LEAP). By using LEAP, a sankey diagram for energy and emission flows for the Province of Alberta has been developed. A reference case also called as business-as-usual scenario was developed for a study period of 25 years (2005-2030). The GHG mitigation scenarios encompassed various demand and supply side scenarios. In the energy conversion sector, mitigation scenarios for renewable power generation and inclusion of supercritical, ultra-supercritical and integrated gasification combined cycle (IGCC) plants were investigated. In the oil and gas sector, GHG mitigation scenarios with carbon capture and sequestration (CCS) option were considered. In Alberta's residential and commercial sector 4-6 MT of CO_2 equivalents per year of GHG mitigation could be achieved with efficiency improvement. In the industrial sector up to 40 MT of CO_2 equivalents per year of GHG reduction could be achieved with efficiency improvement. In the energy conversion sector large GHG mitigation potential lies in the oil and gas sector and also in power plants with carbon capture and storage (CCS) option. The total GHG mitigation possible in the supply side option is between 20 – 70 MT CO_2 equivalents per year.

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Acronyms & Abbreviation

BOE	Barrel of oil equivalent
bbl/d	Barrel per day
Cogen	Cogeneration electricity
C3	Climate Change Central
CCS	Carbon capture and storage
CDN	Canadian dollar
CAPP	Canadian Association of Petroleum Producers
CHP	Combined Heat and Power
cm	Centimeter
cm^3	Cubic centimeter
CO_2	Carbon di-oxide
DFO	Diesel fuel oil
DOE	Department of Energy
EIA	Energy Information Administration
ERCB	Energy Resources Conservation Board (ERCB)
eq	Equivalent
FEI	Final energy intensity
g	Gram
GHG	Greenhouse Gas
GW	Giga-Watt
Gt	Giga Tonne
HHV	Higher Heating Value

Kg	Kilogram
KJ	Kilo Joule
Km	Kilometer
KW	Kilo-Watt
KWh	Kilowatt hour
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
L	Liter
LED	Light emitting diode
LFO	Light fuel Oil
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
m	Meter
M	Million
MJ	Megajoule
mm	Millimeter
MT	Million Tonne
MW	Mega-Watt
MWh	Mega -Watt hr
NEB	National Energy Board
NEV	Net Energy Value
NG	Natural Gas
PK	Passenger Kilometer

SPC	Supercritical power plant
SCO	Synthetic crude Oil
Tcf	Trillion cubic feet
TED	Technical and environmental database
T	Tonne

Chapter 1. Introduction

1.1 Background

Climate Change, caused mainly by the increase of atmospheric concentration of greenhouse gases (GHGs), has emerged as one of the most important environmental issues in recent years. The threat of climate change can be effectively countered by mitigating it at the source by reducing emission of GHGs. Accordingly, there are three broad options for reducing GHG emission from energy systems.

- Efficiency improvement of the energy consuming systems, e.g., in residential and commercial sector, efficiency improvement in lighting and appliance; improvement in fuel efficiency of vehicles and efficiency improvement in the supply sector by reducing the energy intensity of the primary energy conversion process.
- Sequestration of emitted GHGs by using carbon capture and storage technology in various energy consuming sectors.
- Switching over to low or no-carbon fuels such as biodiesel and bioethanol in the transportation sector and incorporation of renewable energy in the electricity generation sector.

Canada is a large consumer of energy. In 2002, it was highest energy consumer along with United States among the G-8 nations, the eight most industrialized countries in the world, in terms of per capita energy consumption. Factors such as long travel distances for the movement of people and goods, prolonged heating and lighting in winter as well as an economy partly based on high energy consuming industries (mining, forestry, petrochemical, pulp and paper, aluminum smelters, refining and steel manufacturing) contribute to Canada's energy consumption (Alberta Electricity System Operator, 2005; Ménard, 2009). Table 1-1 gives the details of total domestic energy production in Canada for year 2005 and 2007 by various primary energy resources.

Table 1-1: Canada's domestic energy production by energy source (in petajoules) [derived from (NEB, 2009)]

Source/year	**2005**	**2007**
Petroleum[a]	6612	7126
Natural Gas	6559	6481
Hydroelectricity	1290	1317
Nuclear	1104	1084
Coal	1401	1482
Wind	6	11
Other[b]	612	636
Total	17584	18137

[a] Includes crude oil, natural gas liquid, bitumen and condensates.
[b] Includes solid wood waste, spent pulping liquor, wood and other fuels for electricity generation.

The total energy demand for Canada is shown in Table 1-2. According to the International Energy Agency (IEA), the United States and Canada are the largest consumers of energy on a per person basis in the world, consuming almost 200 GJ per capita – the equivalent to using more than 5,000 litres (or 32 barrels) of crude oil per year. This is approximately twice the per capita energy consumption seen in other Organization for Economic Co-operation and Development (OECD) countries.

Canadian energy demand trends are driven by changes in population, economic conditions, energy prices, weather, conservation, technology and consumer preferences (NEB, 2009).

Table 1-2: Canada's secondary energy consumption (in petajoules) [derived from (NEB, 2009)]

Demand Sector/Year	2005	2007
Residential	1403	1448
Commercial	1493	1471
Industrial[a]	4857	5166
Transportation	2519	2616
Total	10272	10701

[a] Includes producer consumption energy use and non-energy use.

Alberta is Canada's third largest economy accounting for over 12% of total gross domestic product (GDP) (Government of Alberta, 2008a). The energy sector plays a major role in Alberta's economy both directly and indirectly contributing to GDP, income, employment as well as the total revenue of the province. The major spur to Alberta's economy has been associated with production and processing of oil and gas. Indirect impact of this has been on the development of other sectors catering to energy sector and also eventually on generation of large government revenues. Hence, energy sector has an impact on changing the macroeconomic scenario of Alberta over a period of time.

The province of Alberta is the largest hydrocarbon base in North America. Alberta produces 5 trillion cubic feet (Tcf) of natural gas, 250 million barrels of conventional oil, and 500 million barrels of bitumen from 11 different mines, producing more than 30 million tonnes of coal each year. Electricity generation capacity is more than 12,000 MW, with demand growing at twice the rate of rest of Canada (Government of Alberta, 2008a). According to Statistics Canada, Alberta is Canada's biggest per capita consumer of energy. In 2003, Alberta's per capita consumption was two-and-a-half times higher than the national average. Between 1990 and 2003, per capita energy consumption increased by 11%. A big part of the increase in total energy consumption resulted from increased industrial activity in the province (Ménard, 2009). As shown in Figure 1-1, the per capita energy consumption of Alberta in the year 2003 was 0.85 terajoule which is much higher than the Canadian national average of 0.33 terajoule per person.

A large portion of the total primary energy being produced is exported outside the province. The details of the same are given in Table 1-3. About 80 % of the energy produced is being exported outside Alberta. Hence the per capita energy consumption figures include this large export number.

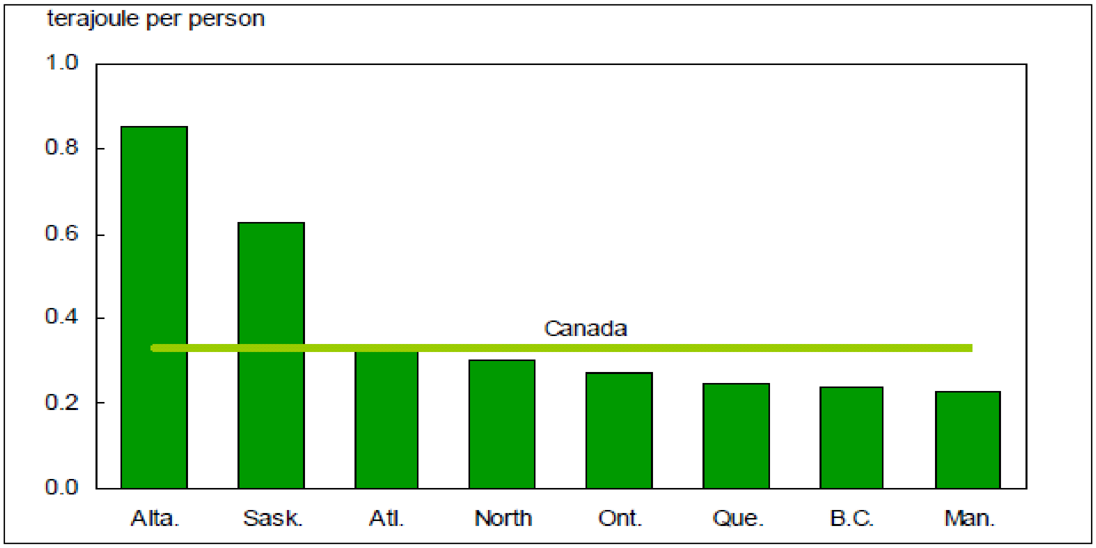

Figure 1-1 Per capita energy consumption in Canada in 2003 [Source: (Ménard, 2009)].

Table 1-3: Alberta oil and gas supply and disposition in 2005 [derived from (ERCB, 2005a; ERCB, 2005b)]

Primary Resource	Total production	Alberta use	Exports
Oil equivalent in million m3	112	27	88
Natural gas equivalent in billion m3	168	23	109

Alberta's growth rate is expected to remain at 2.7% annually for the period 2005 to 2020 (Natural Resource Canada, 2006a). However, conversion of natural resources into energy or fuel requires considerable amount of understanding of the dynamics of energy pathways and the uncertainties associated with the same. In the coming years there would be massive investments in developing and implementing new technologies, infrastructure projects, renewable and non renewable resource development. The growth would be significantly influenced by the growth in the fossil fuel sector. This could also have associated environmental impacts and would lead to the development of right policies and regulatory framework for the province of Alberta challenging.

The most critical issue which goes hand in hand with all these challenges is the indiscriminate use of greenhouse gas (GHG) emissions. Alberta's GHG emissions are about 40% of the whole of Canada (Alberta Electricity System Operator, 2005; Alberta Environment, 2008). This has led to a lot of pressure on Alberta to develop an environmental friendly path of energy production, in order to reduce carbon footprint.

Canada's current and projected GHG emissions are shown in Figure 1-2. In order to achieve the targets as set by federal government, different GHG mitigation strategies need to be initiated. At the provincial level, Alberta is the largest GHG emitter in Canada: there is a need to address this in conjunction with energy perspective. Alberta needs to identify various GHG mitigation options and evaluate these based on extent of mitigated emissions and their abatement cost.

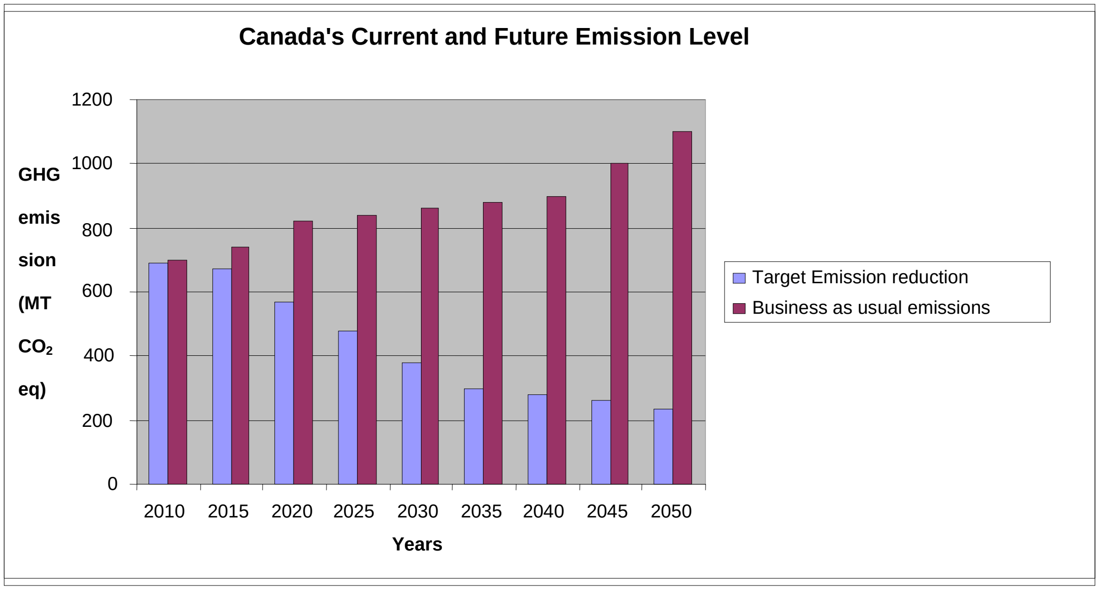

Figure 1-2: Government of Canada's current and future GHG emission levels and targets [derived from (NRTEE, 2009)].

In the past few years, Alberta's electricity consumption has grown by an average of 5% per year. The Alberta Electricity System Operator (AESO) forecasts the peak demand to grow by an average of 2.2% per year for next 20 years (Alberta Electricity System Operator, 2005). The milieu for increasing electricity demand and energy forecast is Alberta's economic outlook, which continues to remain strong. The outlook for upstream energy demand in the coming years is given in Figure 1-3**.** Oil and gas industries have a major impact on Alberta's economy and the demand is projected to be increasing more rapidly than in previous decades. This increase is due to the growth taking place in the oil and gas industry along with other service sectors of Alberta.

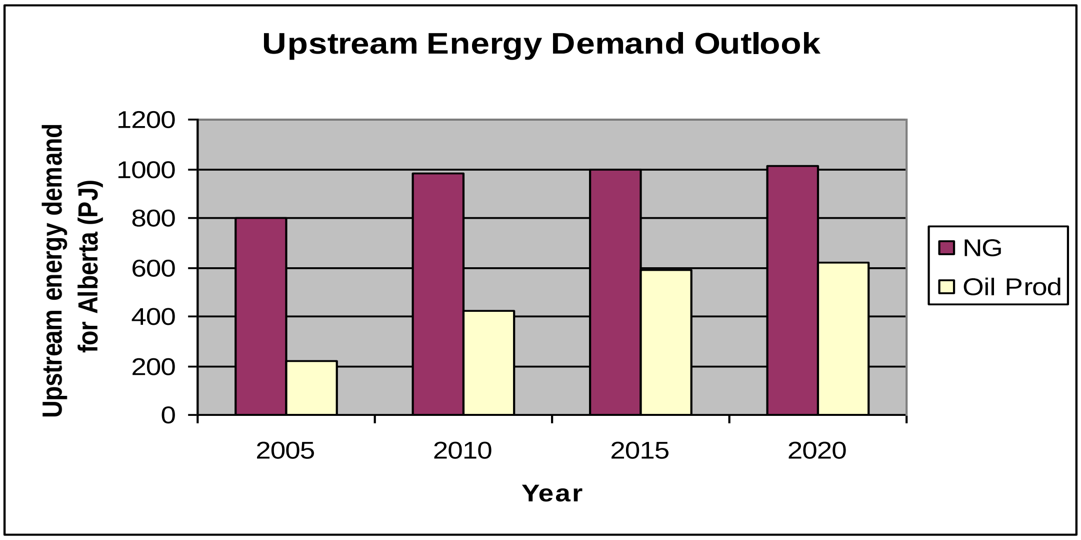

Figure 1-3: Projected upstream energy demand for Alberta [derived from (Natural Resource Canada, 2006a)].

The energy technology and service industry provides a large value-added component to the economy and is instrumental in the development of oil sands in northeastern Alberta. There has been $53 billion investment in new oil sands projects from 1997-2006. There is more than US$100 billion more investment forecasted up to 2020 (Government of Alberta, 2008b).

In the year 2005, which is the base year of this study, the total primary energy production in Alberta was 10,400 PJ. The total energy transformed to secondary fuel was 1,400 PJ and a large fraction (7,400 PJ) of primary energy produced was exported. The energy industry not only provides opportunities for companies involved in production but also provides vast opportunities for companies involved in other sectors, such as business management, consulting, information technology and communications and manufacturing.

In order to develop a long term energy policy and planning, a systematic energy demand and supply assessment tool is needed. Integrated resource planning models are extensively used in developing future energy supply and demand scenarios of a country/region. These are used in projecting energy supply-demand mix and the associated costs and emissions over a long term planning horizon. Some of these models have been used and developed to analyze energy supply and demand mix for various countries. Prominent energy-environment models include: *MARKAL*, *LEAP*, *ENERGY 2020*, *MAPLE C* and *NEMS*. Details on these models and their implementation can be found in various published studies; International Resource Group, Washington (International Resource Group, 2010), Estimating Canada's Greenhouse Gas policies (Jaccard and Rivers, 2007), Energy Environmental Modelling with *MARKEL* (Seebregts et al., 2010), Long Range Energy Alternative Planning (Stockholm Environment Institute, 2009), E2020 Documentation (Systematic Solutions Inc. and Policy Assessment Corp, 2010). The proposed research will use the long-range energy alternative planning systems model (LEAP) model. This model can help in assessing current available choices, constraints and uncertainties with regard to the energy source availability and its use in future. A model specific to Alberta, could incorporate the GHG emissions associated with energy demand and supply in this province.

There is a need to critically understand the energy and emission flows in the Province of Alberta, which will help policy makers in formulating and implementing energy sector related policies. The overall objective of this research is to use the existing knowledge base and develop a long term energy forecasting and planning model for Alberta and use it to analyze the energy and emissions flows over a planning horizon. The details are given in next section. The results of this research work will also help in assessing the impacts of the policy decisions of the Provincial Government on the future energy industry of Alberta.

1.2 The objective of this study

The adequate and reliable supply of energy is a prerequisite of economic development. As the demand for energy is growing with the economic development, detailed planning is required for the energy sector of each province or country. The long term goal of this research is to develop Alberta specific energy forecasting and planning model which could help in deciding on the various energy policies and also evaluating it in terms of GHG mitigation potential and cost effectiveness. Following are the key objectives of this research.

- Development of base year energy demand and supply scenario in LEAP for the Province of Alberta.
- Development of a sankey diagram of energy flows for the Province of Alberta for base year.

- Development of CO_2 emission estimates in the form of a sankey diagram associated with major identified energy flow streams.
- Development of a baseline scenario with business-as-usual energy supply and demand for a study period of 25 years from 2005-2030 in LEAP.
- Identification of various GHG mitigation scenarios for the Province of Alberta based on discussion with the Government of Alberta representatives and development of these scenarios in LEAP for the study period.
- Estimate the amount of GHG mitigation possible by implementation of each of the identified mitigation scenarios using LEAP over the study period.

1.3 The scope and limitations of this study

Energy supply and demand pattern modeling for any province is highly dependent on the demographic and macroeconomic situations.

Data collection on energy demand and supply - The baseline data for this study for a period of 25 years was developed using the various outlook data projected by Natural Resources Canada. The data were further validated by detailed discussion with various provincial organizations like Energy Resources Conservation Board (ERCB, 2009), Natural Resource Canada (NR Canada, 2008b), National Electricity Board (NEB, 2008), Statistics Canada Multidimensional Tables (Statistics Canada, 2009), Canadian Association of Petroleum Producers (CAPP, 2009), Environment Canada (Environment Canada, 2010) and others. The energy supply and demand projections for base year is based on key macro economic assumptions for Alberta and this has been considered on the basis of the provincial and federal government data projecting the same.

Data collection of emissions - The emission data were developed based on existing conditions and technology currently existing in Alberta. Most of the emissions factors were taken from the LEAP's Environmental Database (TED) (Stockholm Environment Institute, 2006). Some of the emissions factors not available through LEAP's TED were developed externally using various sources including literature and discussion with experts.

Development of sankey diagrams of energy and emission flows – An energy flow diagram known as a sankey diagram has been generated for year 2005 which is the base year of this study. The detailed sankey and energy balance diagrams for other years have not been generated for this report but the model has the capability to generate sankey diagrams for any year in the planning horizon.

Development of various GHG mitigation scenarios - The development of GHG mitigation scenarios for Alberta energy sector are based on various assumptions on penetration of new technology in Alberta such as renewable power generation, supercritical and ultra supercritical coal plants and also IGGC plants. The detail is given in subsequent chapters. These scenarios are developed based on inputs from Alberta Innovates - Energy and Environment Solutions (previously called as Alberta

Energy Research Institute) (Alberta Innovates, 2010) and Department of Energy, Government of Alberta (Alberta Energy, 2010) personnel as well as some near to pragmatic approach in order to understand the possible GHG reduction scenario available in the province of Alberta.

1.4 The organization of this thesis

This thesis contains five chapters in addition to a table of contents, a list of tables, a list of figures, a list of abbreviations and appendices.

Chapter 1 includes the background of this study, objective of development of Alberta based energy model, along with scope and limitations of the study.

Chapter 2 describes the details of LEAP as modeling tool, overview of Alberta energy scenario, key assumptions and the detailed modeling methodology using LEAP. It also discusses the output of results of modeling for Alberta energy demand sectors, energy conversion sector along with indigenous resource sector of Alberta.

Chapter 3 discusses the development of sankey diagram from Alberta based LEAP model. It gives the details of sankey diagram software e!Sankey (ifu Hamburg GmbH, 2009). It also discusses various input and output data used to develop Alberta sankey diagram for energy and emissions scenario for the base year 2005.

Chapter 4 includes various GHG mitigation scenarios for Alberta. The methodology of development of various mitigation scenarios along with the input data and assumptions are described in this chapter. Various mitigation scenarios are listed for both demand and supply side of energy sector of Alberta. The extent of GHG mitigation in each of the GHG mitigation scenarios is also discussed.

Chapter 5 discusses the conclusions and recommendations for future work based on this research.

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Chapter 2. Energy Sector Modeling of Alberta using LEAP

2.1 Introduction

Energy accounts for 72% of Alberta's $80 billion in total merchandise exports, and about one quarter of Alberta's GDP (Government of Alberta- Energy Division, 2006). Government of Alberta's energy division has strategized the energy development in Alberta which has been characterized by new approach of energy integration. According to this approach all the future energy development in Alberta must build on the strengths of natural resources as well as renewable resources hydro, wind, solar and biomass energy resources thereby employing integrated strategies that maximize synergies and value added opportunities for the benefit of Albertans (Government of Alberta- Energy Division, 2006). In achieving this goal, the energy planners will have to take into account both energy supply, energy demand and the macroeconomic factors which are prevailing in the province. The demographic and macroeconomic data propels the growth in energy sector and also presents challenges in the policy framework development in any province or country.

The complexity of energy systems and interdependency with other economic factors requires a comprehensive approach to build an integrated energy model involving macroeconomic picture, supply-demand scenario, resource use, transformation of resources and environmental footprint. Integrated resource planning models are extensively used in developing future energy supply and demand scenarios of a country/region. These are used in projecting energy supply-demand mix and the associated costs and emissions over a long term planning horizon. Some of these models have been used and developed to analyze Canadian energy supply and demand mix. The details of these models are described in section 1.1 of this thesis. The following section describes the LEAP model.

2.2 LEAP as modeling tool

Long Range Energy Alternative Planning System Model (LEAP) is an integrated energy-environment modeling system. It can be used as an energy accounting framework, which gives a physical description of an energy system, estimates of abatement costs, and environmental impacts (Stockholm Environment Institute, 2009). It is a demand driven program. The data can be built starting from demand sector to supply sector along with resource sector. This model can be used to analyze data over medium to long term user defined planning horizon (e.g. 30 or 50 years) (Stockholm Environment Institute, 2006). Modeling of energy scenario is highly data intensive and LEAP has extensive in-built database as well as the framework to handle the energy flow characteristics from reserves to final end use.

2.2.1 Methodology of modeling in LEAP

The LEAP modeling methodology is based on building the energy use and supply database and extending it further to simulate the various scenarios of energy demand

and supply. The scenarios can further be studied in terms of emissions and costs for a particular region or country.

LEAP serves several purposes. It can be used as a database. It provides a comprehensive system for maintaining energy information. It can be used as a forecasting tool and enables the user to make projections of energy supply and demand over a long-term planning horizon. It can be used as a policy analysis tool. It simulates and assesses the scenarios in terms of physical, economic, and environmental impacts. LEAP consists of four modules as shown in Figure 2-1.

1. Demand module has the details of the end-use energy demand of both primary and secondary fuel.

2. Transformation module handles the conversion of primary fuel to secondary fuel.

3. Resource module keeps an account of all the primary and secondary fuel in consideration

4. Fourth module is the Technology and Environment Database (TED) which has the detailed account of all the emissions factors of primary and secondary fuels.

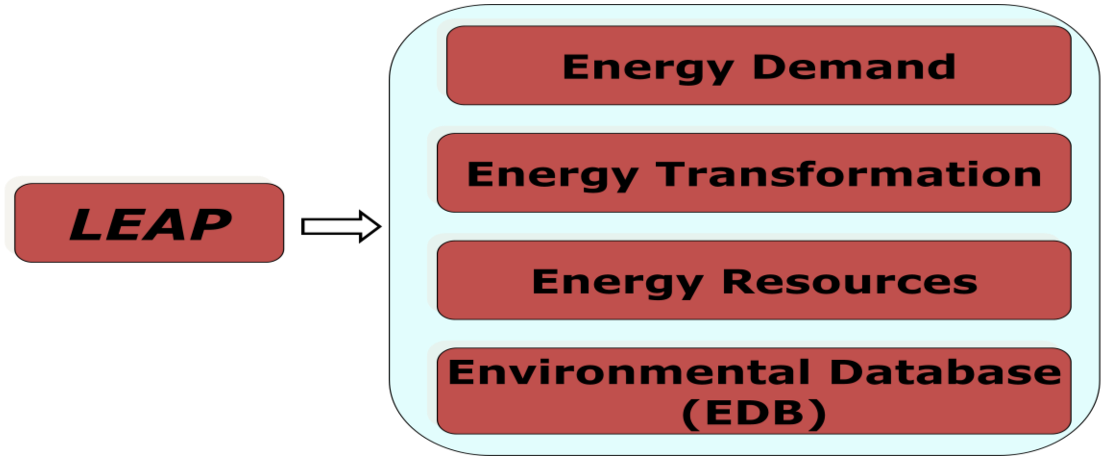

Figure 2-1: LEAP model framework

2.2.2 Key assumptions

One of the key features of LEAP is that the users can input key assumptions related to a particular region or country. This helps the user to create an overall picture of macroeconomic, demographic and other time-series variables for a particular region or country. In the Alberta-based model, energy scenarios are taken from various data sources: National Resource Canada (NR Canada, 2008b); National Energy Board (NEB, 2008); Statistics Canada (Statistics Canada, 2009). All the input data are for the Province of Alberta for base year 2005. Key data for the Province of Alberta includes GDP, industrial output, population, consumption, investment etc. These variables are further used in Demand, Transformation and Resource modules.

2.2.3 Energy demand module

The outlook of demand sector is based on the end-use approach and evaluates the final energy consumption in the region. Depending on the data availability on various demand sectors and end-uses the whole energy demand sector is constructed. This module gives first-hand information on disaggregated consumption of different fuels for all the demand sectors under consideration. The environmental emissions data and costs can also be incorporated. Demand analysis is the starting point for conducting integrated energy analysis, since LEAP is a demand driven program for all the subsequent modules.

2.2.4 Energy transformation module

Transformation module is the intermediate process by which the primary resources get converted to secondary resource which is used by the demand sector. The transformation sector in LEAP is characterized by series of conversion modules where the primary resource is converted to secondary fuel. For Alberta the transformation modules consists of power generation, oil and gas refining, bitumen mining and upgrading, and coal mining.

2.2.5 Energy resource module

The resource analysis module in LEAP is used to enter data on the availability of primary resources, including both fossil and renewable resources, as well as information on costs of indigenous production, imports and exports of both primary resources and secondary fuels. Resource tree branches are subdivided into two categories: primary resources and secondary fuels. The individual fuels consumed and produced in any area are calculated by LEAP itself. The data entered on indigenous resource availability depends on whether the resource is a fossil or renewable energy form. For fossil resources the total available reserve of the resource can be entered in LEAP, while for renewable energy forms the annual energy available from the resource is entered.

2.2.6 Technology and environmental database (TED)

LEAP has in-built database for environmental emissions for various fuels used in the various energy demand sectors. The database also considers the emission factors for various conversion processes. In order to develop the energy demand and supply model with an interface of various emission factors, a lot of input data is required, which is spread across range of sources and sometimes is not easily available. TED provides extensive information describing the technical characteristics and environmental impacts of a wide range of energy technologies including existing technologies, current best practices and next generation devices (Stockholm Environment Institute, 2006).

TED includes data on approximately one thousand technologies, based on data developed by various institutions including the Intergovernmental Panel on Climate Change (IPCC, 2010), the U.S. Department of Energy (US DOE, 2010a), and the

International Energy Agency (IEA, 2010), as well as by various regional institutions that have developed data specific to energy technologies. TED can be used as a standalone tool or as an integral part of LEAP. It is used to calculate the environmental loadings of energy scenarios. TED's core database of emission factors has been supplemented by Canadian and Alberta emission factor data.

2.2.7 Cost benefit analysis in LEAP

LEAP can perform cost-benefit calculations from a societal perspective by counting up all of the costs in the energy system and then comparing the costs of any two scenarios. LEAP can include all of the following cost elements (Stockholm Environment Institute, 2006):

- Demand costs (expressed as total costs, costs per activity, or costs of saving energy relative to some scenario).
- Transformation capital costs.
- Transformation fixed and variable operating and maintenance costs.
- Costs of indigenous resources.
- Costs of imported fuels.
- Externality costs from emissions of pollutants.
- Other miscellaneous user-defined costs such as the costs of administering an efficiency program.

By default, LEAP draws a boundary around the complete energy system, meaning that fuel costs are accounted for only when they are imported or exported or when indigenously produced fuels are extracted as primary resources.

2.3 Scope and assumptions

The scope of this study included development of Alberta based LEAP model to analyze various energy demand and supply sectors in Alberta. The scope also included development of sankey diagrams for energy and emissions flow for Alberta using LEAP output. Development of different mitigation scenarios and their analysis in terms of emissions is the final aim of this study.

Data input for LEAP were developed using various reports and databases. These data were analyzed for development of energy demand and supply modules for Alberta for base year 2005. Once the base year data was built in LEAP, the business-as-usual scenario was developed using various factors over a planning horizon of 25 years i.e. from 2005-2030. In this study the business-as-usual scenario is called as reference scenario. The reference scenario gives a quantitative description of energy demand and supply situation for 25 year study period. In the LEAP model various expressions are developed based on the reports and data given by various federal and provincial agencies including Natural Resources Canada (Natural Resource Canada, 2008), Energy Resources Conservation Board (ERCB, 2009), Alberta Electric System Operator (AESO, 2006a), Statistics Canada Energy Division (Statistics Canada, 2008), National Energy Board (NEB, 2009), Canadian Energy Research Institute (CERI, 2009).

The supply and demand scenarios are based on an end- use driven approach. Both supply and demand data are categorized on the basis of end use energy consumption, energy conversion and energy available as resources. The data for each sector has been developed as an organized structure in a hierarchical manner in the form of a tree. The energy demand and supply trees are discussed in subsequent sections. Each of these sectors is modeled for their specific energy consumption and the end use fuels along with environmental loadings related to demand, transformation and resources.

2.4 Input data and analysis in LEAP

2.4.1 Demand sector - base case

Demand module in LEAP represents the total energy consumption pattern of any country or province under consideration. The demand module is divided into various demand sectors including residential, commercial, industrial, agricultural and transport sector. These are the mainstream end users of primary and secondary energy. Demand sector is characterized by all the end users of energy in the province. The energy consumed in the different end-uses in a particular time is entered in LEAP. This data is entered as separate end user branch with each sector defined in its own quantifiable manner.

Each sector has been formulated based on the various types and number of end use consumers. Each of these sectors is further segregated into the final end user level. The end use gets segregated into different type of primary and secondary fuel e.g. natural gas/electricity/petroleum etc. Hence a highly elaborated and comprehensive database is generated for each sector which has end user energy demand expressed as per unit of the sector parameter, e.g. for household sector it is expressed as MJ/household or for commercial it is expressed as MJ/m^2. The demand tree for Alberta is shown in Figure 2-2.

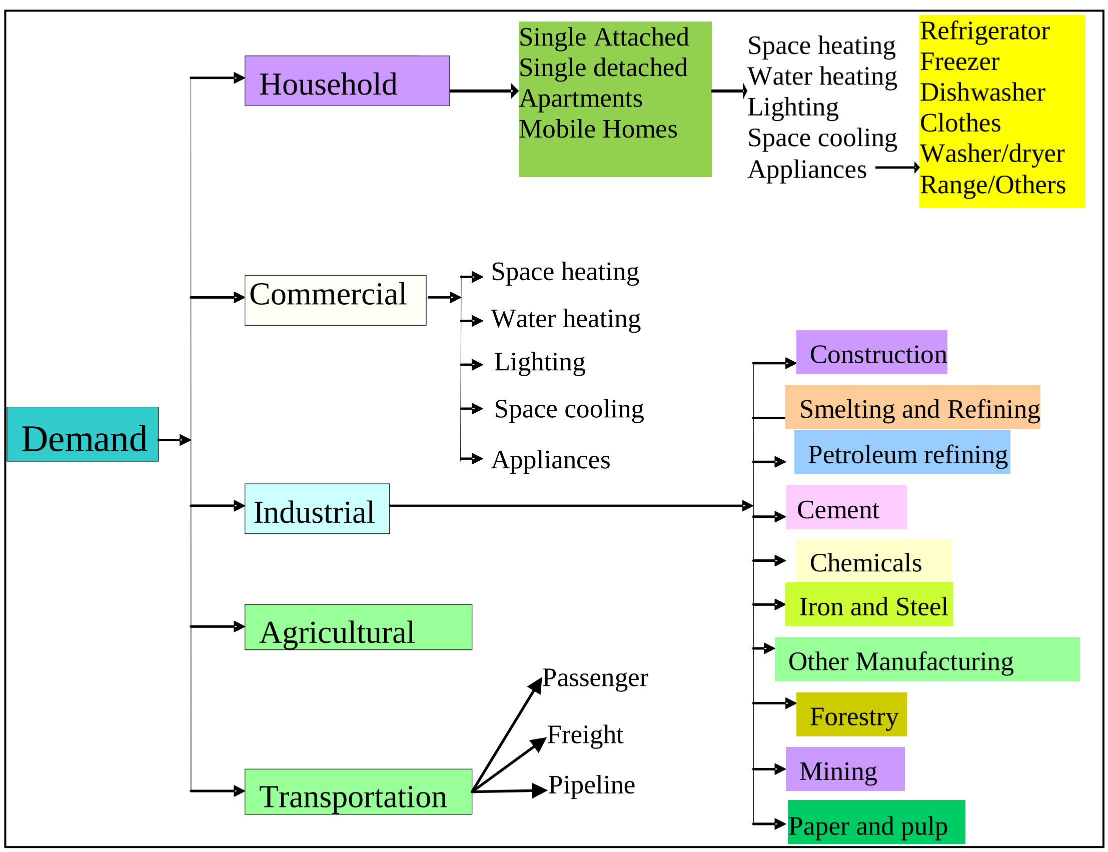

Figure 2-2: Alberta energy demand tree

The demand tree of Alberta has additional branches as pipeline transport, and bitumen upgrading which is also part of demand sector. The demand tree also includes an additional branch shown as non energy use sector and additional natural gas use under natural gas processing and shrinkage sector for Alberta. The three key parameters entered are activity level, final energy intensity, and environmental data pertaining to the different branches. Each of the branches of demand sector of Alberta has different parameter as the basis of simulation. Table 2-1 summarizes the basis of modeling for each sector.

Table 2-1: Alberta's demand sector overview - base year 2005

Sectors	Characteristics
Residential sector[a]	No of household - 1.23 million house hold (size of each household is 3)
Commercial and institutional sector[a]	Total square area - (93.9 million sq. m.)
Industrial sector[a]	GDP based on type of industry (million CDN) Construction : 11.5 Smelting & Refining: 0.1 Petroleum Refining: 0.2 Cement: 0.1 Chemicals:2.3 Iron and steel: 0.1 Other manufacturing:10.7 Forestry: 0.5 Mining: 20.8 Paper and pulp: 0.5 Total: 46.7
Agriculture sector[a]	GDP- 3.23 million (CDN)
Transport sector[a]	Passenger km: 17728 and Freight km[d]: 17186
Bitumen upgrading /refining sector[b]	Total energy consumed-160 PJ (Natural gas not included in mining industry under industrial sector)

Sectors	Characteristics
Other sectors[c], includes natural gas demand in pipeline transport, non energy sector demand and natural gas demand in reprocessing and plant shrinkage.	Total energy consumed Pipeline transport-63 PJ Non energy demand-331 PJ NG reprocessing and shrinkage-200PJ

[a](Natural Resource Canada, 2006a)
[b](Natural Resource Canada, 2006b)
[c](Statistics Canada, 2005b)
[d] Freight km also called tonne km is the unit of measure of goods transport which represents the transport of one tonne over one kilometer.

2.4.1.1 Residential sector

The energy tree for each branch in residential sector in Alberta is shown in Figure 2-3. The tree consists of main sectors which have been divided based on the actual energy consumption in subsectors, followed by the actual end user of energy and intensity of final energy fuel consumption. By doing so, a detailed analysis is performed from final end use energy intensity of appliances/devices to actual energy demand of each type of sector. Alberta's households are classified as single detached, single attached, apartment, and mobile homes. The percentage of each type of house is shown in Figure A-1 in Appendix A.

Single detached houses form the largest (64.3%) subsector in Alberta household followed by other type of dwellings in the province. The end users of each type of household are further classified in terms of primary and secondary fuel consumers. This gives the overall picture of household demand sector in Alberta which consists of space heating, water heating, lighting and appliances. Irrespective of the type of house, the majority of energy demand is from space heating, followed by water heating, appliances and lighting (Natural Resource Canada, 2008). In space and water heating, the demand is both for natural gas and electricity. Some amount of heating oil and other fuels which include propane coal and wood are also used. For the base year 2005 the activity level of each subsector and the final energy intensity is entered in LEAP for each fuel being consumed in that sector. This is expressed as MJ/household as the basis of modeling in this sector is number of households which was 1.23 million in the base year 2005.

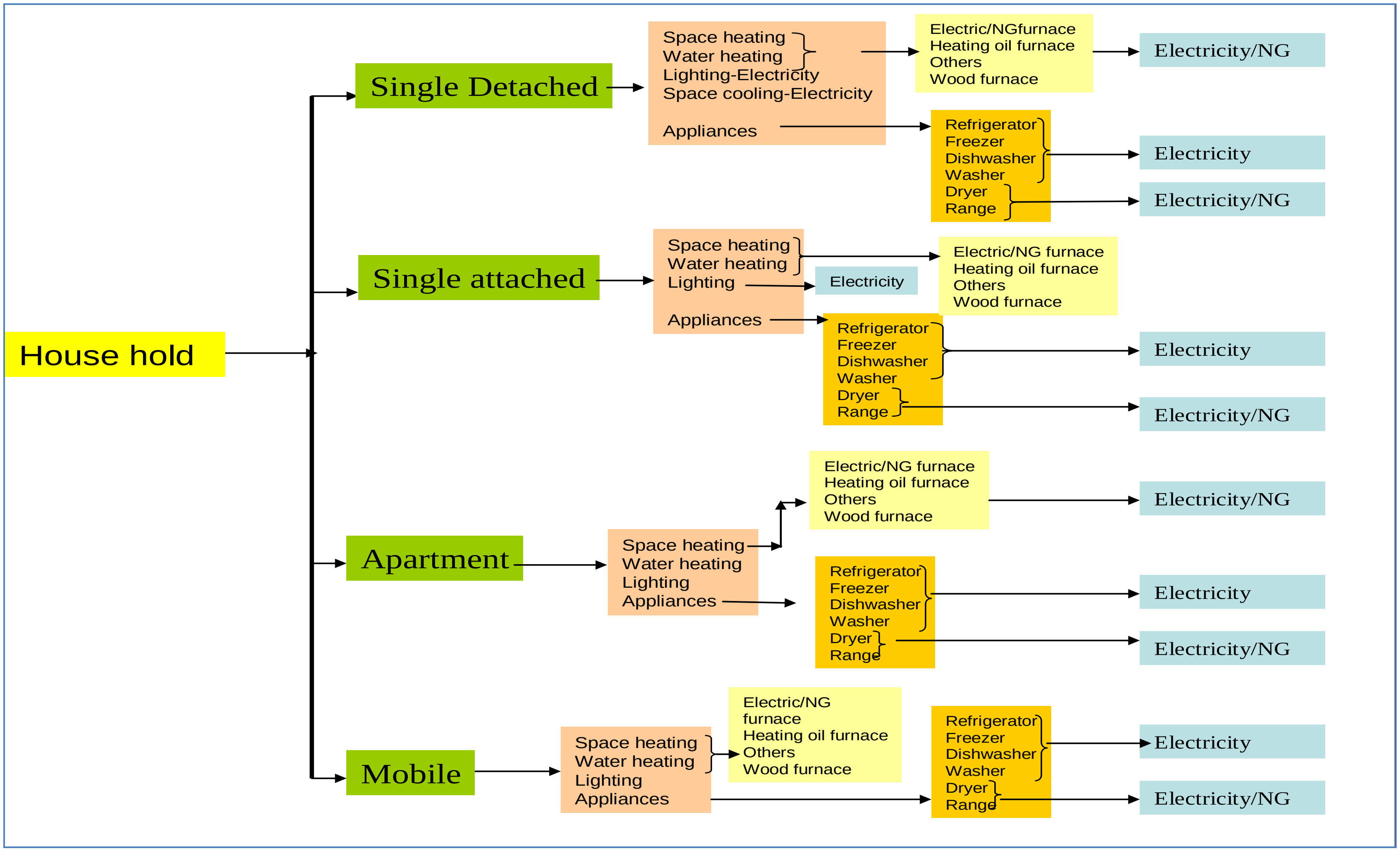

Figure 2-3: Alberta residential sector demand

2.4.1.2 Commercial sector

The energy demand tree for Alberta's commercial sector is as shown in Figure 2-4. The tree has been divided based on the actual energy consumption in sector, followed by the actual end user of energy and intensity of final energy fuel consumption. The main energy users are space heating, water heating, lighting and auxiliary equipment and motors which have end use consumption of electricity, natural gas and fuel oil.

Economic growth and population are the key drivers controlling the energy demand of the commercial sector. The buildings and infrastructure in this sector are used to support the services necessary for a growing economy and changing population (National Energy Board, 2003). End use subsectors in this section are government, office buildings, hotels, restaurants, schools, healthcare etc. Similar to the residential sector, space and water heating are primary end uses. In Alberta, the commercial sector had a total area of 93.9 million m^2 in 2005.

2.4.1.3 Industrial sector

The energy tree for industrial sector in Alberta is shown in Figure 2-5. The tree consists of main subsectors which are followed by the actual energy end user in terms of primary and secondary fuel consumption. By doing so, a detailed analysis is performed from final end use energy intensity of each subsector to actual energy demand of each type of sector.

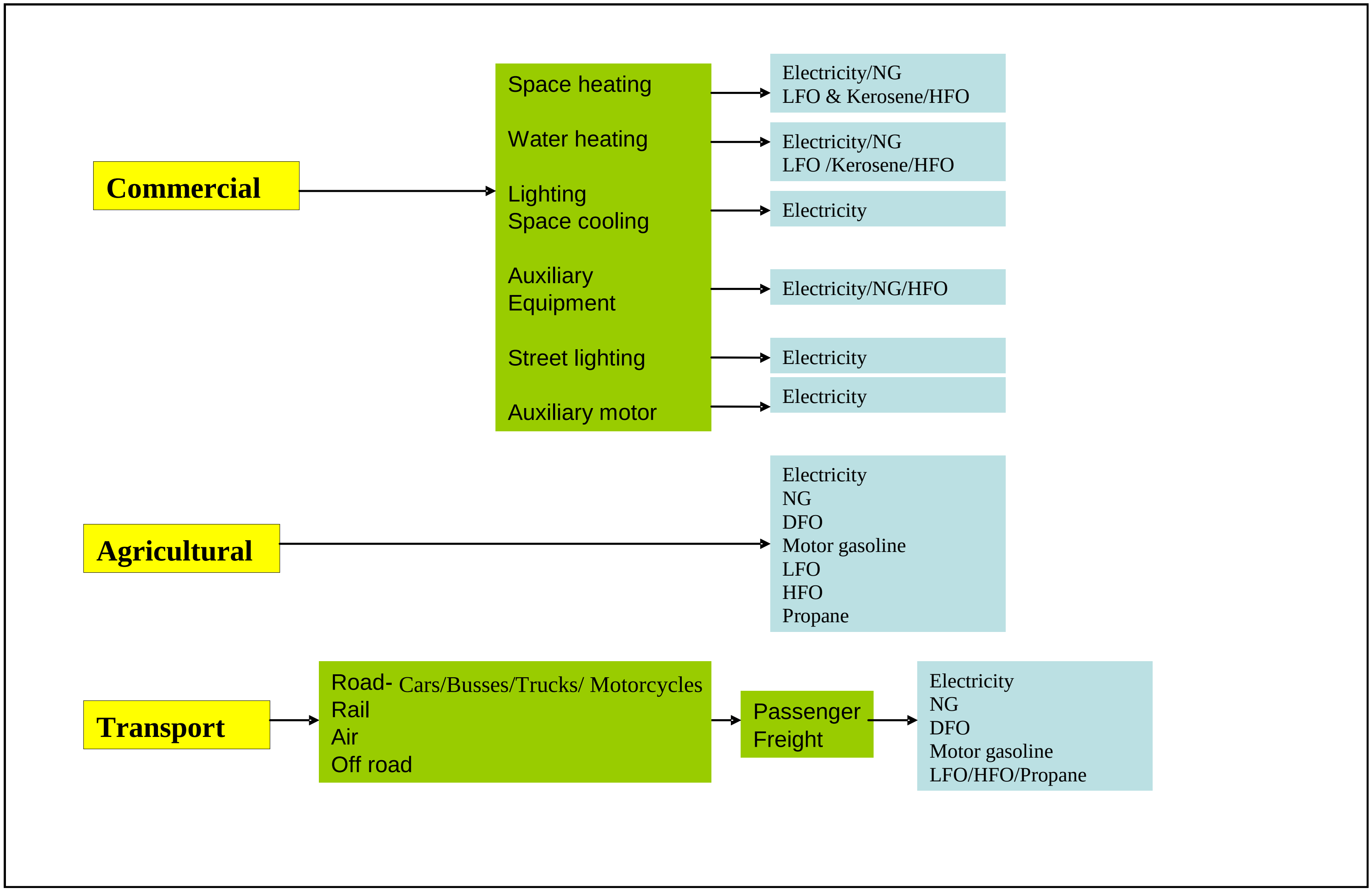

Figure 2-4: Alberta commercial, agriculture and transport sector demand trees

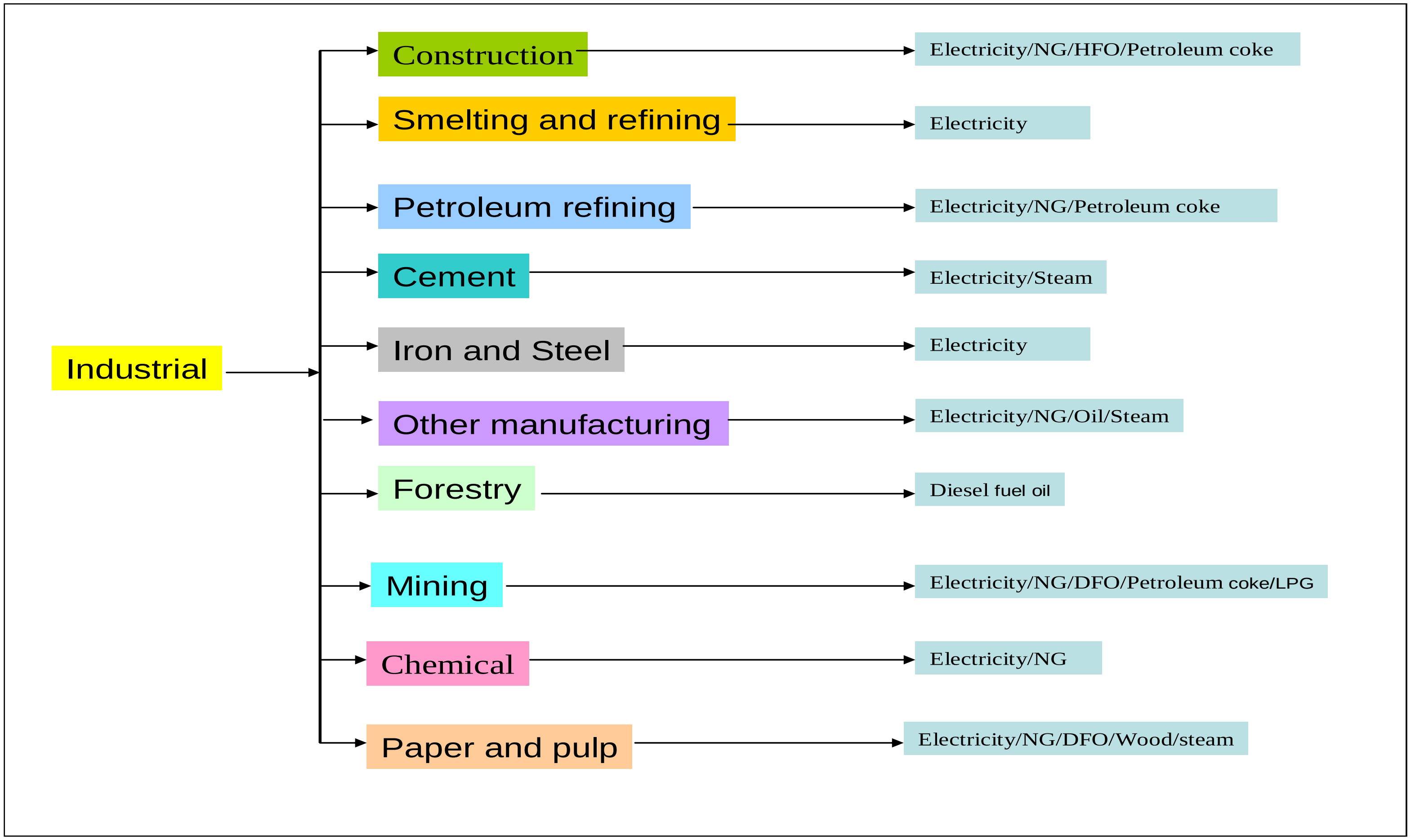

Figure 2-5: Alberta industrial sector demand tree

Total GDP of Alberta's industrial sector together was 107 billion CDN in 2005. Mining industry accounted for 44.5% of the total GDP followed by construction (24.6%) and other manufacturing (22%). Oil and gas produce one-quarter of Alberta's gross domestic product, almost 70% of our exports and 35% of Alberta Government's revenues (Government of Alberta, 2008,).

Alberta government invests about C$30 (or US$26) million per year in energy research and technology, including clean coal technologies, carbon dioxide management, improved oil and gas recovery, bitumen upgrading, alternative and renewable energy technologies, and water management (Government of Alberta, 2010a). Oil sands accounts for more than two-thirds of investment in the province. The industrial sectors mainly consume electricity, natural gas, diesel fuel oil, still gas (any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes and methane, ethane, ethylene, normal butane, butylene, propane, propylene are principal constituents) and petroleum coke. Total energy intensities of construction and petroleum refining sectors are shown in Table 2-2.

Table 2-2: Energy intensity - Alberta industrial sector (2005)

Energy intensity[a] (MJ/CDN)	Electricity	NG	DFO	Motor gasoline	Pro pane	Still gas/ pet coke
Construction sector	0	0.2	0.7	0	0	0.1
Petroleum refining sector	24.8	71.4	0	0	0	199.5
Agriculture sector	2.4	1.4	6.8	4.1	0.1	0

[a](Natural Resource Canada, 2006a)

The total energy consumption is based on activity level of each industrial sector estimated based on GDP. Figure 2-6 shows all the activity levels of industrial sector in the year 2005. The input data for this sector is based on MJ per dollar (CDN) of the sector. The final energy intensity is calculated for each actual end user and is given as MJ per dollar (CND) spent for the respective sector and subsector.

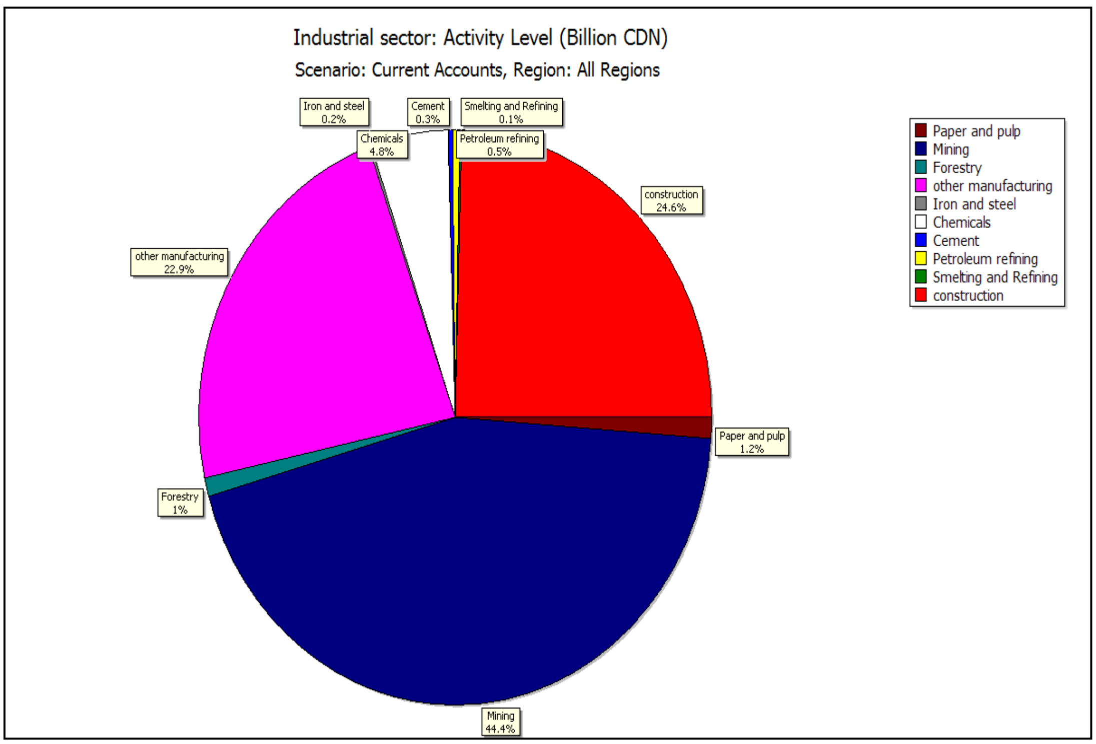

Figure 2-6: Alberta's industrial sector activity level

2.4.1.4 Agriculture sector

The energy demand tree of Alberta's agriculture sector is shown in Figure 2-4. Total energy intensity of all primary and secondary fuel in agriculture sector in 2005 is shown in Figure A-3 in Appendix A. Input data for this sector is entered in LEAP as energy intensity per dollar (CDN) for the base year 2005. In the year 2005 the total GDP for Alberta's agricultural sector was 3.23 billion CDN dollars. The highest energy intensity is from diesel oil which is used for both motive and non motive end users followed by gasoline, electricity, natural gas etc.

2.4.1.5 Transport sector

The energy consumption in the transport sector is based on the population in Alberta. Total passenger km per person for passenger transport and tonne km per person for freight transport is used for entering energy intensity. The demand tree for Alberta transport sector is shown in Figure 2-4. Transportation sector in Alberta is divided into road, air and rail for both passenger and freight subsectors. Passenger road is further classified into cars, trucks and buses. Cars are classified into small cars and big cars. In the passenger subsector, cars have the largest percentage (50%) of passenger km followed by trucks and motorcycle as shown in Figure 2-7.

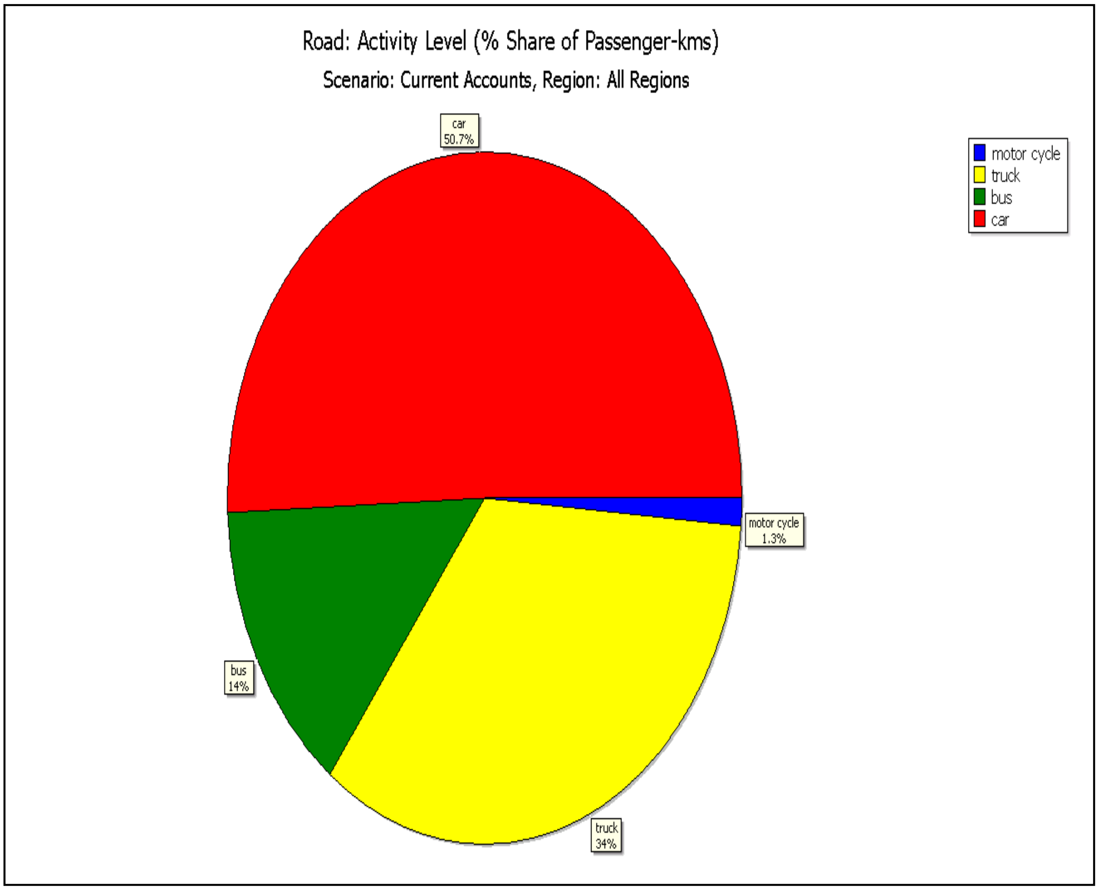

Figure 2-7: Activity level - Alberta's passenger km - road (2005)

About 50.7% of passenger vehicles are cars, 34% are trucks, 14% are buses and 1.3% are motor cycles. Freight transport on road consists of 84% heavy trucks, 9% of medium trucks and 6.5% are light trucks as shown in Figure 2-8.

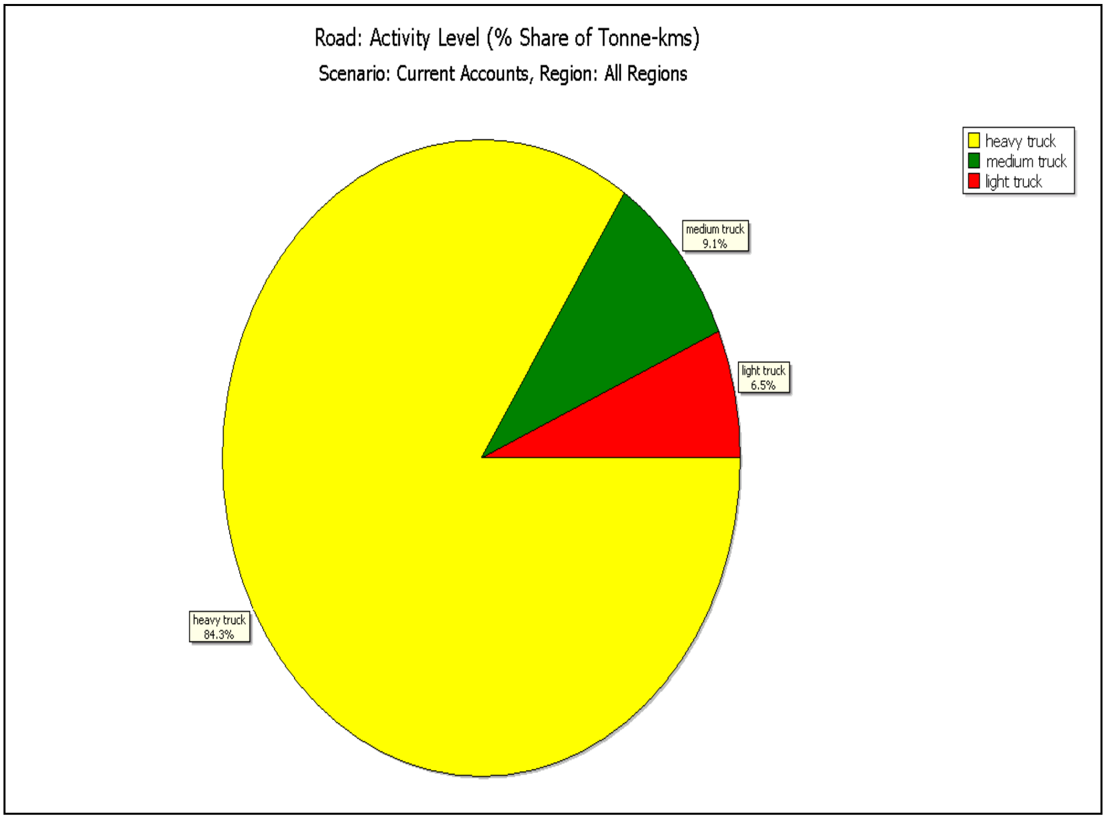

Figure 2-8: Alberta freight road - activity level - 2005

Also as indicated by Figure 2-9 the total energy demand of Alberta's transport sector, freight road accounts for 48% and passenger road accounts for 33% of the overall demand. In passenger rail and air, the energy intensity is 0.3 and 10 GJ per person respectively. In freight transport subsector, the energy intensity is 9.47 MJ/person for rail and 0.279 GJ/person for air.

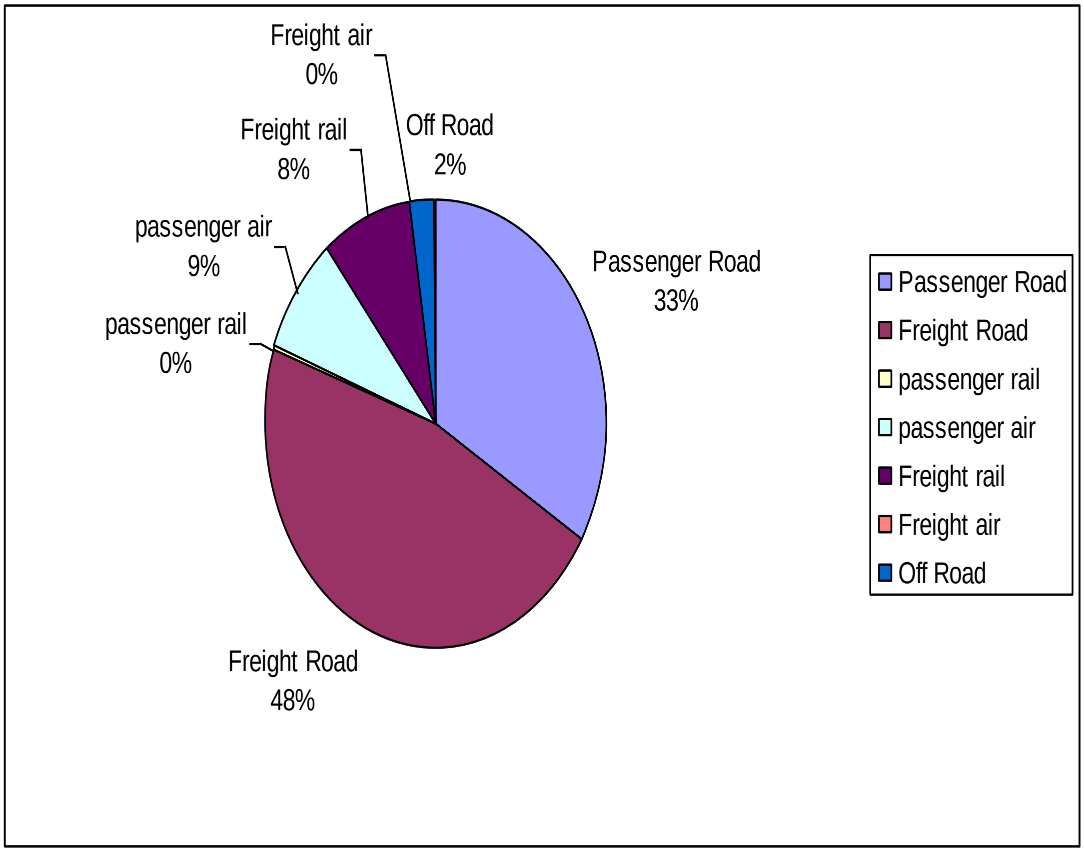

Figure 2-9: Alberta transport sector energy demand

2.4.1.6 Bitumen upgrading

Alberta has huge deposits of oil sands that underlie 140,200 square kilometers of the province. These deposits are separated into three regions: Peace River, Athabasca (Fort McMurray area), and Cold Lake (north of Lloydminster). These oil sands deposits contain approximately 1.7 trillion barrels of bitumen in-place, of which 174 billion barrels are proven reserves that can be recovered using current technology (Alberta Department of Energy, 2005). In 2005, oil sands bitumen production averaged more than 1 million barrels per day (bpd). Of this total, more than 547 thousand bpd was sold as synthetic crude oil (SCO) and distillates, while approximately 438 thousand bpd was sold as clean bitumen. The Alberta Energy and Utility Board (EUB) forecasts 85% of the production of 3.0 million bpd of total Alberta's crude oil and equivalent supply by 2015 will be from non-upgraded bitumen and SCO (Alberta Department of Energy, 2005). Table 2-3 has the details of conventional oil and oil sand reserves in Alberta.

Table 2-3 : Alberta's crude oil reserves - 2005 in billion bbl of oil equivalent[a]

Items	Conventional Oil	Oil Sands
Initial volume in - place	64.7	1694
Remaining established	1.6	173.7
Remaining ultimate potential	19.7	315

[a](Alberta Department of Energy, 2005)

There are two types of oil sands production methods: mining and in-situ. In general, oil sands mines are found in central Athabasca deposits (around Fort McMurray). In-situ recovery methods are used in the Cold Lake, South Athabasca and Peace River (Alberta Department of Energy, 2005). The details of the oil sands sector are discussed later in the transformation module of LEAP. There is a demand of electricity, natural gas and hydrogen in the extraction and upgrading of crude bitumen. The demand of primary and secondary fuel is incorporated in the industrial sector. However, the additional natural gas demand projected is primarily due to the excess natural gas demand in the oils sands sector which was not included in the industrial sector (both in mining and power sector). This has been built into the demand sector of Alberta as an additional user of 160 PJ of energy for the base year 2005.

2.4.1.7 Natural gas reprocessing and shrinkage

In order to account for total natural gas demand in gas production shrinkage and processing, additional demand sector has been generated in LEAP that accounts for natural gas use other than feedstock fuel in injection, flaring etc. Hence to account for the natural gas demand in the natural gas plants for process conversion, a separate demand sector is formulated in LEAP. Table 2-4 has details of the same.

Table 2-4: Natural gas demand for reprocessing and shrinkage

NG Reprocessing plant shrinkage[a]	Natural gas
2005 (in PJ)	200

[a](Statistics Canada, 2005b)

2.4.1.8 Non energy sector Use

In this sector some of the primary fuels which are used in the non energy sector are considered. Non energy sector usage is classified as the use of energy fuels as feedstock material in chemical plants. The details are as shown in Table 2-5.

Table 2-5: Alberta non energy sector use

Non energy sector[a]	Natural gas	Natural gas liquid	Diesel
2005 (in PJ)	108	100	123

[a](Statistics Canada, 2005b)

2.4.2 Demand Sector - reference case

2.4.2.1 Growth rate and outlook of energy: 2005-2030

The reference case or the business as usual scenario is developed for a study period of 25 years starting from 2005 up to 2030. The assumptions and various factors considered for this study period was taken from Natural Resources Canada's 20 year outlook, forecast and assumptions. The input data for reference case scenario for demand sector are listed below (Natural Resource Canada, 2006a).

Table 2-6: Growth rate for reference scenario (2005-2030) in Alberta[a]

Year	2005	2010	2015	2020	2025	2030
Population (million)	3.23	3.41	3.59	3.77	3.95	4.14
Household (million)	1.23	1.33	1.44	1.56	1.68	1.82
Commercial and Institutional sector (floor area m2)	93.9	100	107	113	120	126
Agriculture sector (billion CDN GDP)	3.23	3.47	3.74	4.03	4.35	4.68

[a](Natural Resource Canada, 2006a; Natural Resource Canada, 2008)

a) Population growth rate in Alberta

Population growth rate in Alberta is expected to be 1% annually (Natural Resource Canada, 2006a) and by the end of study period the change in population is expected to be 4.14 million as shown in Table 2-6.

b) Increase in number of households

Growth rate for household is expected to be 1.6% annually (Natural Resource Canada, 2006a). Table 2-6 gives the details of increase in the household over the study period

c) Increase in commercial and institutional floor area

Commercial and institutional area is expected to grow at the rate of 3% annually as shown in Table 2-6 (Natural Resource Canada, 2006a).

d) Increase in GDP of agricultural sector

In agriculture sector the total GDP increase from 2005-2030 has been assumed to have a growth rate of 1.5% per annum based on past trend (Natural Resource Canada, 2008). The GDP increase is projected to be 4.68 billion CDN by the end of study period

e) Industrial sector growth rate

The growth rate for industrial sector is as shown in Table 2-7. Sector wise growth rate of different industrial sectors in Alberta is based on the past trends and some assumptions based on Natural Resources Canada outlook report (Natural Resource

Canada, 2006a). Growth rate for the chemical sector is assumed to be 2.1%. Growth rate for the mining sector is 3%, whereas growth rate of the paper and pulp industry is relatively less at 0.4 % (Natural Resource Canada, 2006a).

Table 2-7: Alberta's industrial sector growth rate

Type of industry/year (billion CDN)[a]	2005	2010	2015	2020	2025	2030
Construction	11.5	11.5	11.5	11.5	11.5	11.5
Smelting and refining	0.1	0.1	0.1	0.1	0.1	0.1
Petroleum refining	0.2	0.2	0.2	0.2	0.2	0.2
Cement	0.1	0.1	0.1	0.1	0.1	0.1
Chemicals	2.3	2.5	2.8	3.1	3.4	3.8
Iron and steel	0.1	0.1	0.1	0.1	0.1	0.1
other manufacturing	10.7	10.7	10.7	10.7	10.7	10.7
Forestry	0.5	0.5	0.5	0.5	0.5	0.5
Mining	20.8	24.1	27.9	32.3	37.5	43.4
Paper and pulp	0.5	0.6	0.6	0.6	0.6	0.6
Total	46.7	50.3	54.4	59.1	64.6	71

[a](Natural Resource Canada, 2006a)

2.4.3 Transformation sector

2.4.3.1 Overview

In a transformation analysis, LEAP simulates the conversion and transportation of energy forms from the point of withdrawal of primary resources and imported fuels all the way to the point of final fuel consumption. The fuel could be combusted, or used to produce energy. These modules have one or more processes and further divided into input and output processes.

In the subsequent sections, different modules and processes are created. Processes represent the individual technologies that convert energy from one form to another or transmit or distribute energy (e.g., individual power plant or groups of power plants). For each process, technology characteristic data such as capacities, efficiencies, capacity factors, capital and operating and maintenance costs can be defined in order to give the overall scenario of the actual plant under discussion (Stockholm Environment Institute, 2006).

2.4.3.2 Alberta's transformation sectors developed by LEAP

Alberta's energy supply and primary fuel conversion industry mainly consists of electricity generation and oil and gas industry. Coal mining sector also forms a part of energy transformation module. The transformation sector for Alberta consists of the following key modules.

- Transmission and distribution module.
- Electricity generation module
- Natural gas and coal bed methane module
- Alberta oil refining module
- Crude oil production module
- Synthetic crude oil production module
- Crude bitumen production module
- NGL production
- Coal mining

Each process has one or more feedstock fuel (e.g., coal, natural gas, crude oil) as input and could also have one or more auxiliary fuel. This is the fuel which is consumed during the production of any secondary fuel (e.g. electricity, gasoline, diesel). Output fuel in any module is equivalent to final demand of the demand sectors after accounting for transmission losses. LEAP is a demand driven model. Hence the final secondary fuel production is controlled by conversion efficiencies of the process in the transformation module and also by the final requirement set by demand program which includes both domestic demand and any export requirement set earlier. The fuel imported into the model is always taken care by the transformation module and is subtracted from the total requirement.

2.4.3.3 Transmission and distribution

The first module represents electricity transmission and distribution losses and also natural gas pipeline losses. Electricity transmission and distribution losses have been assumed to be 7% of the electricity generated in 2005 in Alberta province (AESO, 2006b). In the reference scenario these are assumed to reduce to 5% and less for the future years (AESO, 2010; The Pembina institute, 2009) Natural gas pipeline losses have been assumed to be 3% in base year 2005. In the reference scenario it is assumed to decrease to 2% over the study period of 25 years (2005-2030) (Stockholm Environment Institute, 2009).

2.4.3.4 Electricity generation

Electricity generation is one of the significant transformation modules of the Province of Alberta. Alberta's electricity generation mix consists of coal, natural gas, oil and renewables. There is a choice of exogenous or endogenous calculation methodology by LEAP. Exogenous capacity is the capacity entered by user and explicitly specifies the actual and planned capacities as well as additions and deletions of the region under consideration. Endogenous capacity is the capacity that is calculated by the model in order to maintain a minimum planning reserve margin. In the current model only the exogenous capacities have been considered. The input data will also have the variables like endogenous and exogenous capacities, availability of plant, historical production, dispatch rule, merit order and process efficiency as some of the input variables for each type of selected power generation plants.

2.4.3.4.1 Alberta's electricity generation capacity

Table 2-8 shows the overall generating capacity in the province for the year 2005. This number also includes the total production of electricity exclusively at Alberta oil sands for bitumen production and upgrading. However on an average about 500 MW excess electricity is produced which is sent to the grid. Table 2-9 gives the details of reference case scenario for 25 year study period. All the capacities mentioned for various plants are taken after considering all the new capacity additions and retirements as planned by Alberta Electric System Operator (AESO, 2006c).

Table 2-8: Alberta power plant characteristics

Plant/ Characteristics	Coal fired generation	Gas fired generation	Wood waste	Wind	Hydro	Other	Cogen electricity
Generation (MW)[a]	6182	4606	133	298	900	30	1400
Maximum availability (%)[a]	90	90	90	40	65	95	100[d]
Historical production[b] (2004) (million MWhr)	47.2	10.5	0.6	0.7	2.3	0.2	20
Efficiency[c]	33	50	36	60	90	37	80

[a](AESO, 2006a; LeBlanc and McColl, 2006; Nyboer and Groves, 2008)
[b](Statistics Canada, 2008)
[c](Alberta Electricity System Operator, 2005; Statistics Canada, 2007)
[d]It is considered as imported electricity and is surplus of the oil sands.

Table 2-9: Total Alberta's production capacity - reference case scenario[a]

Exogenous Capacity (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	6182	7632	8972	8972	8972
Gas fired generation	4606	6075	6330	7094	7094	7094
Wood waste	133	150	150	150	150	150
Wind	298	727.3	1863.6	3000	3000	3000
Hydro	900	971.4	1000	1000	1000	1000
Other	30	286.7	543.3	800	800	800
Import	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0
CCS power plant	0	0	0	0	0	0
Supercritical coal plant	450	450	450	450	450	450
Supercritical coal plant with CCS	0	0	0	0	0	0
Ultra supercritical coal plant	0	0	0	0	0	0
Ultra supercritical coal plant with CCS	0	0	0	0	0	0
IGCC plant	0	0	0	0	0	0
IGCC plant with CCS	0	0	0	0	0	0
Cogen electricity surplus from oil sands	500	500	500	500	500	500
Total	12649	15342.4	18469	21966	21966	21966

[a](Alberta Electricity System Operator, 2005; LeBlanc and McColl, 2006)

a) Maximum availability of plants

The maximum availability of a process is the ratio of the maximum energy produced to what would have been produced if the process ran at full capacity for a given period (expressed as a percentage). Maximum availability is normally defined by planned and forced outages. It is entered along with capacity data, and the product of the two is the maximum available capacity in any given period. The values for various power plants for Alberta are given in Table 2-8. These are the available capacities assumed for different plants in Alberta based on their actual running capacities.

b) Historical production (year 2004 for this study)

This variable specifies annual energy production or output of earlier years which can be considered if LEAP is allowed to model based on previous year's production. In this study the outputs of one year before the base year, i.e., 2004 values are considered as historical production values and the values for Alberta's power plants are given in Table 2-8.

c) Process efficiency

The efficiency of the various power plants in Alberta is given in Table 2-8. For the reference case scenario the efficiency is assumed to be same for all the years.

d) Dispatch rule and merit order

Dispatch rule can be expressed in various ways, e.g., by process share in proportion to available capacity or in ascending merit order. Merit order of a process indicates the order in which the power plant will be dispatched in LEAP. Processes with the lowest value merit order are dispatched first (base load plant) and those with the highest merit order are dispatched last (peak load). Processes with equal merit order are dispatched together in proportion to available capacity (i.e. capacity x availability). Merit order is defined for each dispatch period in a year. If the system load shape is defined exogenously then only one dispatch period will be defined. In LEAP, there is a provision for endogenously specifying load curves in which case there will be more than one dispatch periods and merit order will be defined for each one of them. This allows processes to be dispatched differently in different seasons of a year. For example, a hydro plant can be dispatched as base load in wet season (merit order = 1) and as a peak load in dry season. In this study there is only one dispatch order considered which has been entered exogenously in the model and is shown in Table 2-10.

Table 2-10: Dispatch rule for power plants in Alberta

Dispatch rule	**Coal fired**	**Gas fired**	**Wood waste**	**Wind**	**Hydro**	**Other**	**Import**	**Co gen**
2005	1	2	1	2	1	2	1	3

In order to develop the electricity generation profile of Alberta in LEAP initially a load curve is generated which is based on annual variation in energy consumption and production. For any given year the instantaneous power requirement varies. This ranges from maximum (peak) to minimum requirement which in turn helps electric system to be designed to meet its requirements.

e) Planning reserve margin for Alberta

Planning reserve margin is the estimate of total generation capacity required to exceed the peak demand of any region to obtain the final capacities. For the Province of Alberta the planning reserve margin is considered to be 10% (AESO, 2006c)**.**

f) Alberta load curve generation

In Alberta both base load and peak load plants exist. Base load plants (coal, nuclear, hydro) provide the minimum amount of power that a distribution company must make available to its customers. It should produce energy at constant rate usually at a low cost. These plants typically run at all times throughout the year except for maintenance. Base load plants have high fixed cost but cheap running and fuel costs, whereas peak load plants like natural gas plants have lower fixed costs but have high running and fuel cost. Peaking plants usually run only when there is a high demand for electricity and can be brought online in shorter duration as compared to base load plants. These are designed to run for short periods to supply peaking loads for unpredictable fluctuations in demand and supply. The plants running in between base and peak load plants are intermediate plants which fills the gap in supply between base and peak load plants. Some of the intermediate plants are gas plants and some old coal fired stations. Hence, the load curve of the province gives a full picture of all types of plants and their dispatch schedule and also the type of dispatch and planning of power plants in the reference scenario for the entire study period. The details of various types of load curves used in LEAP are described in the following section.

g) System load curve as developed in LEAP

Load curve is the set of data that gives an indication of how the instantaneous power requirement varies within any given year. Load curve in LEAP has been calibrated for 80% load factor for Alberta (AESO, 2006c). Load duration curve for a typical power plant is shown in Figure 2-10.

LEAP provides three alternative methods for describing electric system load

1) *Load duration curve for the entire system*: In this method an exogenous load duration curve is specified based on the existing scenario of the region. The curve describes in percentage terms how the peak power requirement varies from the highest load to the lowest load.

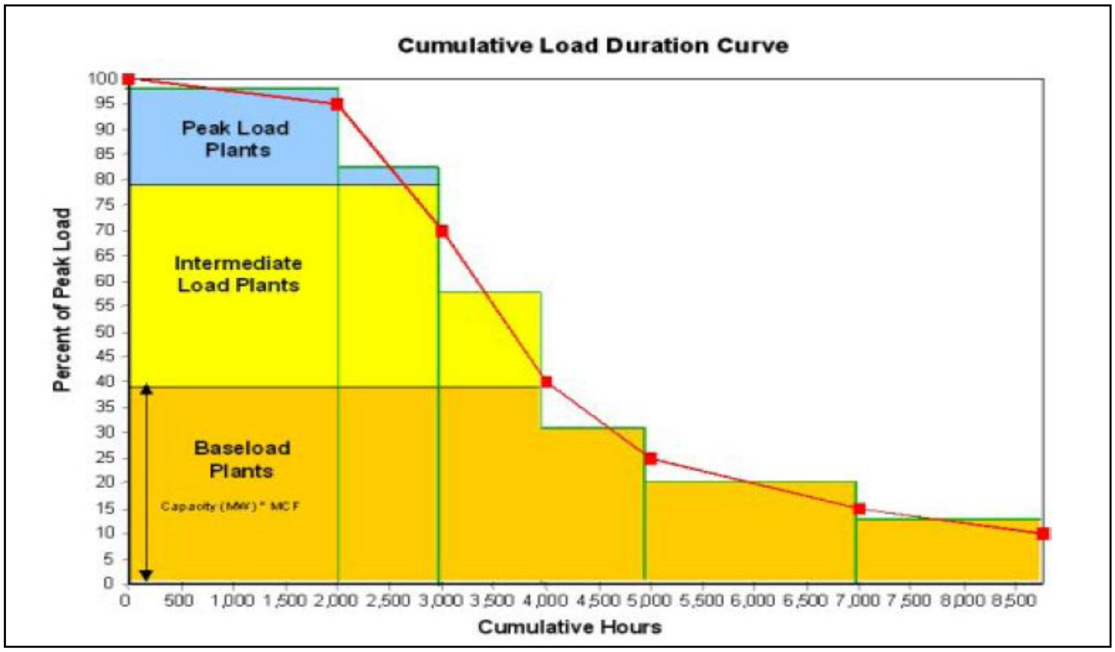

Figure 2-10: LDC curve of a typical power plant (Stockholm Environment Institute, 2006)

2) *Seasonal /Time of day load shape curve for each demand technology*: In this method load shape is specified separately for each demand technology. This is done by selecting the type of load curve for each demand technology in the final energy intensity section. In this method the season and time of day information can be entered into any different time slices.

3) *Seasonal /Time of day load shape for entire system*: This method is a hybrid of the above two methods. Although this is most data intensive than method 2 but generates the season and time of day load shape information hence allows a more accurate simulation of different seasonally available characteristics and time of day load shape information.

For the present case for Alberta's power plant module, the first method has been adopted and the base year (2005) data has been taken from existing figures and values as given by Alberta Electricity System Operator (AESO) for the same(AESO, 2006a). The assumption regarding the dispatch rule in the future scenario remains the same. It is assumed that there is no significant change in the climatic, seasonal conditions in next 10-20 year period (average day and night time temperatures and average seasonal highs and lows are relatively constant over the study period).

2.4.3.5 Natural gas production and processing

At present natural gas is produced from two main sources in Alberta. Majority of the gas is produced from conventional sources. However, natural gas production from coal (coal bed methane – CBM), is growing rapidly since past two years. The possibility of natural gas production from other sources, such as shale gas, may prove to be an additional source in the near future (ERCB, 2008). Natural gas production in Alberta has been modeled in the transformation sector by exogenously specifying the production capacity of Alberta in the year 2005 and other parameters such as historical production values, process efficiencies and availability over the year. In the base year 2005, 5,800 million GJ of feedstock was processed, which includes reprocessing and other demands such as shrinkage in oil and gas sector. In the reference case, natural gas production is projected to slow down over next few years as shown in Table 2-11.

Table 2-11: Natural gas production capacity - reference case scenario[a]

Exogenous capacity (billion GJ/Y)	2005	2010	2015	2025	2030
Natural Gas	5.8	5.3	4.9	4	3.5

[a](Natural Resource Canada, 2006a)

2.4.3.6 Alberta oil refining

In Alberta there are five refineries. This includes two smaller ones which mainly use crude oil, butanes, natural gas, synthetic crude oil (SCO), bitumen, and pentanes to produce a wide variety of refined petroleum products (RPPs). The key determinants of crude oil feedstock requirements for Alberta refineries are domestic demand for RPPs, shipments to other western Canadian provinces, exports to the United States, and competition from other feedstock. In 2005, Alberta refineries, with total inlet capacity of 75,500 m^3/d of crude oil which is equivalent to 32,400 m^3/d of processed crude oil. Synthetic crude oil, bitumen, and pentanes constituted the remaining feedstock (ERCB, 2006).

2.4.3.6.1 Input data

Table 2-12 shows the total percentage of feedstock fuel for Alberta refinery. The detail of Alberta refinery capacities for the reference case scenario is shown in Table 2-13.

Table 2-12: Alberta's refinery input stream

Alberta Refining (Feedstock Fuel)	Crude Oil	SCO	Pentanes Plus	Condensates	Total
2005	48	44	6	2	100

Table 2-13: Exogenous capacity oil and equivalent products in Alberta

Exogenous capacity (million BOE/Y)	2005	2010	2015	2020	2025	2030
All Refinery[a]	178	295.9	364.4	400	400	400
Crude oil production[b]	275	230	185	140	110	80
Bitumen refining[b]	200	333	665	730	965	1200
Bitumen extraction[b]	388	642.9	1150	1982	2141	2300

[a](Claudia and Hording, 2005)
[b](ERCB, 2008)

2.4.3.6.2 Alberta oil refineries

Alberta has five major oil refineries. Figure 2-11 show the details of Alberta oil refineries and their capacities. Largest is the Imperial Edmonton with 29,000 m^3 per day of plant capacity. Refinery finished products include: gasoline, diesel, aviation turbo, pet coke, residual fuel oil, aviation gasoline and LPG.

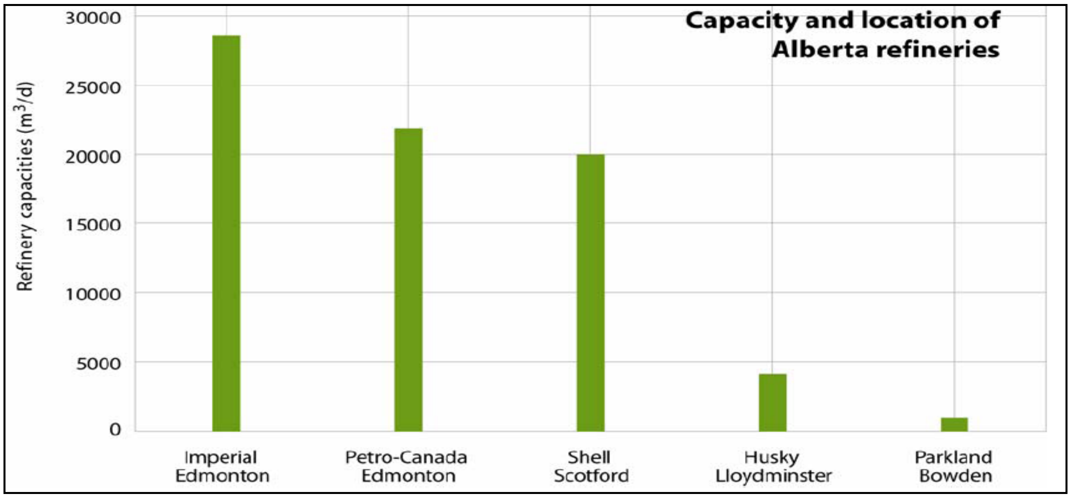

Figure 2-11: Output products from Alberta's refinery

2.4.3.7 Crude oil production

Alberta's production of conventional crude oil totaled 33.1 million m3 (209 million barrels) in 2005. This equates to 90,800 m3/day (or 571,400 barrels/day). According to ERCB crude oil production is from both existing wells and also from upcoming new wells. According to Electricity and Utility Board (EUB) estimate of the remaining reserves of conventional crude oil in Alberta is about 254.8 million m3 (as of Dec 31 2005) (ERCB, 2006). This is estimated after all the revisions of the reserves, production and also additions from new drilling which occurred during 2005. In the reference case scenario there is a decline in crude production rate over the next years. The details are given in Table 2-13

2.4.3.8 Synthetic crude oil and crude bitumen production

In 2005, Alberta produced 228 million barrels of bitumen from the mineable area and 160 million barrels from the in situ area, totaling 388 million barrels. This is equivalent to 1.06 million barrels per day. Bitumen produced from mining was upgraded, yielding 200 million barrels of SCO. In situ production was mainly marketed as non upgraded crude bitumen. A comparison of conventional oil and bitumen production over the last 10 years clearly shows the increasing contribution of bitumen to Alberta's oil production. This ability to shift from conventional oil to bitumen is unique to Alberta, allowing the province to offset the continued decline in conventional oil with bitumen production. The EUB estimates that bitumen productions will more than double by 2015. The share of non upgraded bitumen and SCO production in the overall Alberta crude oil and equivalent supply is expected to increase from 58 per cent in 2005 to 85 per cent by 2015 (ERCB, 2006). The reference case scenario for bitumen production and upgrading are given in Table 2-13.

2.4.3.9 NGL production

Natural gas liquids (NGL) refer to the liquid hydrocarbon products extracted from the natural gas stream and are initially recovered as a hydrocarbon mix. The component can then be further separated into marketable products such as ethane, propane and butanes. Propane and butanes are also produced from crude oil refining and upgrading processes. Products from these processes are also referred to as liquefied petroleum gases (LPG). It is estimated that in 2006, 87 percent of propane and 69 percent of butane supplies came from natural gas production (NEB, 2006). In 2005, Alberta had 600 GJ of NGL processing capacity. In the reference case scenario there is no major change in NGL liquid as significant component ethane largely remains same at 14.2 million m^3 per year by 2017.

2.4.3.10 Coal mining

Alberta produces three types of marketable coal: sub bituminous, metallurgical bituminous and thermal bituminous. Sub bituminous coal is mainly used for electricity generation in Alberta. Metallurgical bituminous coal is exported and used for industrial application, such as steel making. Thermal bituminous coal is also exported and used to fuel electricity generators in distant markets. The higher calorific content of bituminous thermal coal makes it possible to economically transport the coal over long distances. While sub bituminous coal is burned without any form of upgrading, both types of export category coals are sent in raw form to a preparation plant, whose output is clean coal. Sub bituminous coal and clean bituminous coal are collectively known as marketable coal. Production of coal is from mines and is called raw coal. Some coal, particularly coal from the mountain and foothills regions of Alberta, needs to be processed prior to marketing; this processed coal is also called as clean coal. Clean coal (normally sold internationally) and raw coal (normally sold within Alberta) are termed marketable coal (ERCB, 2006). The EUB estimated that the remaining established reserves of all types of coal in Alberta was 33.5 gigatonnes (Gt) on Dec 31 2005. Of this amount, 22.7 Gt (or about 68%) is considered recoverable by underground mining methods, 10.8 Gt is recoverable by surface mining methods and 1.16 Gt is within permit boundaries of mines active in 2005 (ERCB, 2006).

2.4.4 Resource sector

Input data for Alberta resource sector includes the following details.

2.4.4.1 Primary resources

This is generated based on the province's current scenario. The variables listed include base year reserves, addition to reserves, resource imports and exports, and the cost related data. The details of the input data as entered in LEAP for base year 2005 is given in Table 2-14.

Table 2-14: Alberta's base year reserves (as of 2005)

Base year reserves	NG	Crude oil	Coal bituminous	Bitumen	Coal unspecified	NGL	Pentanes	Total
2005 (thousand PJ)	37	9.3	6	1,170	896.6	1.6	0.4	2,121

2.4.4.2 Secondary resources

Secondary resources include all secondary fuel as specified by transformation and demand sector of LEAP. For Alberta, this includes electricity, steam and refinery finished products (gasoline, diesel etc). The details of the same are mentioned in the earlier sections.

2.4.5 Environmental inputs and emission factors

LEAP has built-in environmental emission factors for large number of processes; and these emission factors could be easily associated with a process particular to a region or country to estimate the total emission. The Technology and Environmental database (TED) has the environmental loadings associated with a technology, i.e., the amount of fuel consumed and CO_2 emitted per unit of fuel. This fuel could be combusted, or otherwise used to produce energy consumed, produced or lost. Environmental data is given in LEAP for different kinds of pollutants characterized as CO_2 biogenic, non-biogenic, CO, CO_2 equivalent, methane NOx, particulates, and SOx etc. Their global warming potential is also listed under effects. TED has also a feature which can used to develop database for a new technology based on its energy conversion efficiencies and emission factors which is prevalent in the province.

2.4.5.1 Environmental data inputs for demand sector

In the demand sector TED database is segregated under different headings. These headings include industry, household, agriculture, transport and generic technologies. In the industry sector there are hundreds of different technologies listed which have the energy conversion efficiency as well as the detailed emissions per unit of fuel consumed. Also the IPCC Tier 1 and Tier 2 emission factors for coal, biomass, natural gas and wood are given in the database. IPCC Tier 1 and Tier 2 default emission factors for various end users of household sector such as space heating, water heating, and appliances are listed in the database (Stockholm Environment Institute, 2006). Farm machines and general IPCC emission factors for all the fuels are listed for the agriculture sector. Under the transport sector, road, rail, trucks and other vehicles' fuel usages and their corresponding emission factors are listed. Some of the generic technologies like cogeneration and other power generation technologies have also been listed under TED.

2.4.5.2 Environmental data input for transformation and resource sector

In the energy conversion sector the TED database has energy and emission data for different conversion processes including oil refining, biomass conversion, resource production and electricity generation, natural gas processing and coal processing. In the oil refining sector, LEAP has a built-in database for crude oil refining in South Africa. Using the expression builder emission factor for Canadian refineries has been developed for this study. The emission factor for Alberta refinery has been calculated as 30 kg of CO_2 equivalents per bbl of crude produced based on earlier studies (Alberta Environment, 2008; IPCC, 2007; Len Flint, 2004; Pembina Institute, 2008). Under biomass conversion sector, the available technologies are for gasification and charcoal making processes for South Africa and Thailand. There is an option of developing the gasification technology emission factor for Alberta cogeneration plants. Under resource production the subsectors included are coal mining, oil and gas production, biomass production and harvesting, bitumen production and conventional oil production. All the sectors above have been developed in accordance with Alberta resource development and the emissions associated with the same.

The various technologies for electricity generation have been included in the database. Various fossil fuel technologies built into the LEAP database are based on IPCC Tier 1 and 2 emission factors. For example, in the case of coal power plants the emission factor data includes conventional steam turbine, fluidized bed combustion, combined cycle and gasification cycle technologies. Emission factors are also included for biomass, hybrid and natural gas conversion technologies.

In LEAP, natural gas processing and conversion for South Africa are included in the database. For Canadian natural gas processing and refining a new set of data has been developed. An emission factor for coal mining in Alberta has been developed. An additional subsector has been created for bitumen production and upgrading and also for H_2 production sector.

2.5 Results and discussion

2.5.1 Demand sector

The overall energy demand of Alberta energy demand for the base year 2005 as developed by LEAP is given in Table 2-15.

Table 2-15: Alberta energy demand - base case scenario

Demand by various sectors	Base year 2005 (million GJ)
Household	174.67
Commercial and institutional sector	159.19
Industrial sector	760.93
Agriculture sector	47.87
Transportation sector road	302.66
Passenger rail	0.97
Passenger air	32.99
Freight rail	30.59
Freight air	0.9
Pipeline transport	63.2
OFF road	9
NG reprocessing plant shrinkage	200
Bitumen production and upgrading	160
Non energy sector use	331
Total	2273.95

The Province of Alberta's energy sector demand is dominated by industrial sector use, which is 35% of the total demand and excludes the natural gas used for oil and gas operations. The extra use of natural gas is shown separately in natural gas reprocessing and bitumen production and upgrading sections. The transport sector is next largest energy consuming sector in the province.

The total energy demand in Alberta is about 2,274 PJ, which also includes energy demands for bitumen upgrading and oil refining sectors. The other use of energy in the production of energy itself (auxiliary power) is discussed in a separate section. The total energy demand in Alberta is distributed between household, commercial, industrial, transport, agricultural and oil sand sectors. Although the industrial sector consumption is the largest at 760 PJ, there is a substantial amount of additional energy demand from oil sands sector which has been discussed in detail in subsequent sections. The details of primary and secondary fuels used in the various demand sectors are shown in Table 2-16.

Table 2-16: Alberta energy demand - base case scenario fuel use[a]

Sectors	Biomass	Electricity	Heat (steam)	NG	Oil products	Solid fuels	Total
Household	0.37	23.68	0	149.57	1.05	0	174.6
Commercial and institutional sector	1.03	51.29	0	102.54	1.42	2.91	159.1
Industrial sector	56.26	119.8	9.07	328.7	247.1	0	760.9
Agriculture sector	0	7.85	0	4.36	35.66	0	47.87
Transportation sector road	0	0.56	0	0.11	301.99	0	302.6
Passenger rail	0	0	0	0	0.97	0	0.97
Passenger air	0	0	0	0	32.99	0	32.99
Freight rail	0	0	0	0	30.59	0	30.59
Freight air	0	0	0	0	0.9	0	0.9
OFF road	0	0	0	0	9	0	9
Pipeline transport	0	2.2	0	61	0	0	63.2
Bitumen production and upgrading	0	0	0	160	0	0	160
NG Reprocessing plant shrinkage	0	0	0	200	0	0	200
Non energy sector use	0	0	0	108	223	0	331
Total	57	205	9	1,114	884	2	2,273

[a]As developed by LEAP model

2.5.1.1 Residential sector

2.5.1.1.1 Base case scenario

The total energy used by the residential sector is given in Table 1. The total consumption is 174 PJ for the base year 2005. Details of energy demand by different type of houses and also by end user type is detailed in Table A-2, A-3, A-4 and A-5 in Appendix A. The majority of energy consumption is in single detached houses in Alberta. Energy consumption in the residential sector is largely by space heating and water heating appliances, and lighting. Space heating plays a major role as Alberta has one of the coldest winters across the globe. Water heating is also a major energy consuming uses as hot water is consumed throughout the day for all purposes in the household. There is also some amount of energy shown for space cooling which is not very significant. The residential sector in Alberta is divided into single detached, single attached, apartment and mobile homes.

a) Single detached houses

In Alberta most single detached houses consume energy for space heating, water heating, space cooling, lighting, and for other appliances. The actual energy used is 132.4 PJ is as shown in Table A-2 in Appendix A. In the total energy consumption, natural gas is used the most, followed by electricity. Propane, wood, and oil have very small energy usage, which again is in space heating applications. Both electricity and natural gas consumption are highest in space heating applications. This is especially true during winter when Alberta's temperature goes 20 deg below zero on an average during peak winter periods.

b) Single attached

Single attached houses have total energy demand of 14 PJ for year 2005 in Alberta as shown in Table A-3 in Appendix A. Space heating again has the highest energy demand followed by water heating and others. The highest energy fuel consumed is natural gas.

c) Apartment

Apartments in Alberta have the same pattern of highest space heating energy demand of 11 PJ out of total 19.6 PJ for the base year 2005. The details are given in Table A-4 in Appendix A.

d) Mobile homes

Mobile homes have total energy demand of 8.7 PJ with majority of energy demand comes from natural gas followed by electricity and other fuels. The details are as given in Table A-5 in Appendix A.

2.5.1.1.2 Reference Scenario for business as usual case

For the residential sector, growth rate is projected to be 2% for the study period. This is based on the past data of increase in population over the last 15 years which is about 1.6% (Natural Resource Canada, 2006a). On the basis of increase in population over the past years, increase in number of household is assumed to be 2%. Consequently there is an overall increase in demand of primary and secondary fuel in the sector. Table A-6 in Appendix A gives the overall scenario of the residential sector in Alberta over 25 year studies period. Based on the assumed growth rate, the increase in demand is projected from 174 PJ in 2005 to 286 PJ in 2030. As calculated by LEAP, energy demand for single detached houses is expected to increase from 132 PJ in 2005 to 217 PJ in 2030. Natural gas demand in the residential sector is going to increase from 149 PJ in 2005 to 245 PJ in 2030 which is attributed to increase in space and water heating demand over the 25 year period. Demand in electricity and oil products for the residential sector also shows an increase from 24 PJ and 1.05 PJ to 9 PJ and 1.72 PJ, respectively.

2.5.1.1.3 Environmental results – residential sector

In the base year 2005, GHG emissions from the Alberta household sector was 7 MT of CO_2 equivalents. The details are given in Table A-8 and A-9 in Appendix A. The increase in GHG emissions from 2005 to 2030 is projected to be 11 MT of CO_2 equivalents. Major contributor to this is emissions from single detached houses in the province contributing to more than 70% of the emissions in household sector. The GHG emissions from single detached houses are expected to increase from 5.2 MT to 8.5 MT of CO_2 equivalents in 2005 to 2030. Single attached and apartment shows marginal increase in the study period. This increase in emissions is primarily due to the increase in demand of natural gas which contributes to overall increase in emissions from 7 MT of CO_2 equivalents in the base year 2005 to 11 MT of CO_2

equivalents in 2030. Emissions resulting from use of other fuels show a marginal increase over the 25 year study period as shown in Table A-10 in Appendix A.

2.5.1.2 Commercial Sector

2.5.1.2.1 Base case

Details on energy consumption of Alberta's commercial and institutional sector are given in Figure 6 in Appendix A. The energy demand in commercial and institutional sector is from space and water heating along with auxiliary equipment and motor. The details of commercial sector end use for base year energy consumption are given in Table A-11 in Appendix A. About 60% of the energy demand is from space heating followed by auxiliary equipment and water heating. Fuel choice in commercial sector depends mainly on availability and local delivery infrastructure. For Alberta demand for natural gas is 103 PJ for different subsectors.

2.5.1.2.2 Reference scenario for business as usual case

In the business as usual case, increase in commercial space is a major factor and is expected to grow over the planning horizon from 2005 to 2030. The increase in area in the commercial sector is expected to grow from 93 million m^2 (2005) to 190 million m^2 in 2030 (Natural Resource Canada, 2006a). The overall increase in energy demand over the study period is shown in Table A-12 in Appendix A. Total demand is expected to grow from 159 PJ to 234 PJ over 25 year study period. This increase is mainly due to increase in demand for space heating followed by increase in lighting and auxiliary equipment energy demand. Space heating demand is expected to grow from 95 PJ in 2005 to 132 PJ in the year 2030. Auxiliary equipment demand is likely to increase from 17 PJ in 2005 to 23 PJ in 2030 whereas lighting energy demand is expected to rise from 15 PJ to 35 PJ over 25 years. The increase in energy demand of end users in commercial and institutional sector is projected in terms of fuel usage as shown in Table A-13 in Appendix A. Natural gas demand increases from 102 PJ in 2005 to 137 PJ in 2030 and electricity demand is projected to increase from 52 PJ to 89 PJ in 2030.

2.5.1.2.3 Environmental results – commercial sector

The details of GHG emissions in the reference scenario for commercial sector are shown in Table A-14 and A-15 in Appendix A. The GHG emissions are projected to increase from 6.2 thousand kg of CO_2 equivalents in 2005 to 8.2 thousand kg of CO_2 equivalents in 2030.

2.5.1.3 Industrial sector

The industrial sector of Alberta consists of construction, petroleum refining, cement, chemicals, paper and pulp and other manufacturing and mining industry. The total energy demand for 2005 was 760 PJ. The majority of which was from mining, paper and pulp and petroleum refining followed by other industries. Table B-1 in Appendix B shows the overall consumption of the entire industrial sector. Alberta's industrial sector has energy intensive industries such as mining, petroleum refining, chemical manufacturing and paper and pulp. Main end use fuels in industrial sector are electricity, natural gas, diesel, fuel oil, heavy fuel oil, LPG, petroleum coke and still gas. The highest energy demand comes from mining followed by chemical, paper and pulp and petroleum refining. Mining demand was highest and was 455 PJ in 2005. In case of oil refining (petroleum and mining), the additional requirement of hydrogen and natural gas along with cogen electricity has not been included in the final demand of industrial subsector. These have been discussed separately in the bitumen upgrading and petroleum refining sector. The details on the energy demand of different industrial subsectors are given below.

The detailed energy consumption in chemical industries is shown in Table B-2 in Appendix B. Overall energy intensity is 97.7 PJ in which 74.7 PJ is for natural gas. Electricity demand is chemical industries was 18.8 PJ in the base year 2005.

In mining subsector the total energy demand (primary and secondary fuel) was 455 PJ in 2005. Among different fuels, natural gas had the largest demand at 188 PJ followed by still gas and pet coke with 141 PJ. Electricity demand in mining subsector for the year 2005 was 73 PJ. Oil products like diesel oil and LPG had a demand of 30 PJ and 22 PJ respectively.

The pulp and paper subsector also has a significant demand of primary and secondary fuels. The total demand in the base year (2005) is 79 PJ. There is a large amount of reprocessing and reuse of wood and pulping liquid which is considered as industrial biomass usage. Electricity and natural gas requirement were 11.8 PJ and 9.8 PJ, respectively, as detailed in Table B-4 in Appendix B.

2.5.1.3.1 Industrial sector reference case scenario

In the business as usual case, Pulp and Paper, mining, and construction industries are the largest energy users, accounting for more than 90% of the energy demand. Mining and construction industries have the maximum growth rate of 23% projected in business as usual scenario over 25 year study period. Other manufacturing and cement industries have projected growth rate of more than 40% in the 25 year study period. The details of primary and secondary fuel consumption and their growth in the reference case scenario are shown in Table B-7 and B-8 in Appendix B. The largest growing sector is mining industry with a projected increase in demand from 455 PJ in 2005 to 702 PJ in 2030 which is followed by chemicals and paper and pulp industries.

2.5.1.3.2 Environmental results - industrial sector

In the industrial sector the largest GHG emitters are the mining and petroleum refining sectors. The total growth in GHG emissions for the business as usual case from 2005 to 2030 is projected to be from 41 MT to 89 MT of CO_2 equivalents. The majority of the emissions (>95%) is from mining and petroleum refining sector. The increase in emissions from mining sector is expected to be from 28 MT of CO_2

equivalents (2005) to 72 MT CO_2 equivalent in 2030. These emissions are quantified in terms of usage of primary and secondary fuel. Table B-9 and B-10 in Appendix B show the details of emissions in the industrial sector. Emissions due to oil products are expected to increase from 22 MT CO_2 equivalents (2005) to 41 MT CO_2 equivalents in 2030. Natural gas related emissions are expected to increase from 18 MT CO_2 equivalents in 2005 to 47 MT CO_2 equivalents in 2030. The huge increase in natural gas emissions is attributed to both combustion and fugitive emissions in the oil and gas industry.

2.5.1.4 Agriculture sector

2.5.1.4.1 Energy demand - base case scenario

In Alberta's agricultural sector the overall energy demand for 2005 was 48 PJ. Diesel and gasoline have the highest usage at 22 PJ and 13 PJ respectively. These are followed by electricity at 7.8 PJ and natural gas at 4.4 PJ as shown in Table B-11 in Appendix B.

2.5.1.4.2 Reference scenario for agricultural sector

The growth in Alberta agricultural sector is assumed to be at a rate of 1.5% based on the past trend. Hence the overall growth rate is expected to be from 48 PJ to 162 PJ over the 25 year study period. The details are as shown in Table 12 in Appendix B. Total demand for oil and natural gas is expected to increase from 35.7 PJ to 51 PJ and

4.4 PJ to 6.3 PJ respectively over the study period. Electricity demand is also expected to rise from current (2005) levels from 8 PJ to 11 PJ in 2030.

2.5.1.4.3 Environmental results – agricultural sector

For the base year 2005 the emissions from agricultural sector are shown in Table B-13 in Appendix B. Total emissions were 2,807 million kg of CO_2 equivalents originating from oil products and natural gas. Oil products like gasoline and diesel form the major components of overall energy demand and emissions. In the reference scenario the increase in emissions are projected from 2,807 million kg to 4,073 million kg of CO_2 equivalents over 25 year study period. Oil products related to emissions are expected to increase from 2,563 to 3751 million kg. The details of reference case scenario are given in Table B-14 in Appendix B.

2.5.1.5 Transport sector

2.5.1.5.1 Energy demand - base year scenario

The transport sector energy demand is governed by the population and economy of the city or province of interest. In Alberta, the transportation sector constitutes about 19% of the total secondary energy demand. Amongst the various modes of transport, road transport energy demand (both by freight and passenger) accounts for 80% of the total demand. The rest of the demand comes from rail, air and some off road activities. Freight road has a larger energy demand of 176 PJ compared to passenger road energy demand of 126 PJ. In year 2005 all the major secondary fuel demand came from diesel, gasoline, and jet kerosene and aviation gasoline. The details are given in Table C-1 in Appendix C.

2.5.1.5.2 Reference scenario for business as usual case

In the business- as- usual scenario, the population growth is assumed to be 1% which is taken as the basis for growth in passenger and freight km travelled each year. In the road transport subsector total increase in demand for oil products is expected to increase from 302 PJ in 2005 to 497 PJ in 2030. The overall increase is detailed in Table C-2 in Appendix C. Both passenger and freight subsectors energy demand is expected to increase over the 25 year study period. As shown in Table C-3 in Appendix C, the total demand in passenger road subsector is expected to increase from 126 PJ to 207 PJ whereas for freight subsector it is going to increase from 176 PJ to 290 PJ over the planning horizon.

Passenger rail demand increase is as shown in Table 52 and is expected to increase from 1 PJ to 1.24 PJ in 2030 as detailed in Table C-4 in Appendix C. Passenger air subsector demand is shown in Table C-5 in Appendix C. It is expected to increase from 33 PJ in 2005 to 42 PJ in 2030. Freight rail subsector demand is shown in Table C-6 in Appendix C. It is expected to increase from 30 PJ in 2005 to 39 PJ in 2030. Freight air subsector demand is as shown in Table 7 in Appendix C. It is expected to increase from 0.89 PJ in 2005 to 1.14 PJ in 2030.

2.5.1.5.3 Overall transport scenario for business as usual case

For business as usual case, the increase in energy demand in all the subsectors is projected in Figure 4 in Appendix C. The growth in road transport is expected to be larger than rail and air transport subsectors for both passenger and freight.

2.5.1.5.4 Environmental results – transport sector

In the year 2005, the GHG emissions from transport sector for Passenger, freight and pipeline transport are given in Figure 5 in Appendix C. Passenger, freight and pipeline transport together generated 30 MT of GHG emissions. For the business as usual case for 25 year study period, the increase in emissions in the transport sector is shown in Table C-9 in Appendix C. The total increase in emissions from transport sector is expected from 30 MT in 2005 to 46 MT of CO_2 equivalents in 2030.

2.5.1.5.5 Energy demand and emissions in pipeline transport

Table C-10 in Appendix C gives the details of energy requirements of pipeline transport for the reference case. Total demand is projected to increase from 66 PJ to 81 PJ in 2030.

Emission results are given in Table C-11 in Appendix C. Overall increase in GHG emissions is projected to increase from 3.5 MT to 4.3 MT of CO_2 equivalents over 25 years.

2.5.1.6 Natural gas reprocessing

Natural gas which is used for reprocessing and production of gas itself has been modeled as a demand sector, which is assumed to be constant at about 200 PJ per year over the study period.

2.5.1.7 Bitumen upgrading

The process is very energy intensive and requires a considerable use of resources. Table B-5 in Appendix B gives the details of fuel requirement for bitumen production and upgrading. The actual process conversion methods and overall energy requirement for in situ excavation are given in the transformation section.

2.5.1.8 Non energy process

Table B-6 in Appendix B has some of the major non energy process demands for the Province of Alberta.

2.5.1.9 Alberta energy demand sector - business as usual case

The overall energy requirement for the base year 2005 and the growth in energy demand sector of Alberta over the 25 years study period is projected in Table D-1 in Appendix D. The sector wise fuel demand growth rates are projected in Table D-2 in

Appendix D. Over the period of 2005-2030 the growth in demand of energy is projected to be from 2274 PJ to 3496 PJ. The rate of increase in energy demand is attributed to increase in industrial sector intensity as the Alberta mining, petroleum and chemical industries are expected to grow at a faster pace than other sectors. The commercial and household energy demands are also shown to increase in the business as usual case over 25 year period. Energy demand in household sector is expected to grow from 175 PJ in the base year 2005 to 287 PJ in 2030. Energy demand in commercial and institutional sector is expected to grow from 159 PJ to 307 PJ whereas in the transport sector the overall increase in energy demand is expected to grow from 367 PJ to 582 PJ over a period of 25 years. Increase in fuel demand is shown in Table D-2 in Appendix D. The overall increase in governed by natural gas and oil demand. Natural gas demand is projected to grow from 1114 to 1728 PJ from 2005-2030, whereas oil products shows an increase in demand from 885 PJ to 1328 PJ over the study period of 25 years. Electricity demand is expected to increase to about two times over the study period of 25 years.

2.5.1.10 Environmental results for demand sector

2.5.1.10.1 Base case scenario

In the demand sector most of the emissions are combustion related and is pertaining to fuel usage in these sectors. Overall emissions from the sectors are given in Table G-1 in Appendix G. In the base year total emissions from the demand sectors of Alberta is 87 MT of CO_2 equivalents.

Industrial sector contributes to the majority of emissions followed by transportation sector which is rooted by natural gas and petroleum products. Industrial sector emissions for base year 2005 were about 41 MT CO_2 equivalents whereas road transport emits about 21 MT of CO_2 equivalents. Overall emissions from oil products for Alberta demand sector is about 52 MT of CO_2 equivalents and from natural gas is about 35 MT of CO_2 equivalents. The details of the oil and natural gas emissions and sector wise contribution are given in Table G-1 in Appendix G. Major portion of crude oil based product usage GHG emissions are from transportation and industrial sectors, whereas the natural gas usage based GHG emissions are generated largely by industrial sector. The other sectors emitting natural gas usage based GHG emissions are household, commercial and pipeline transport sector. In household and commercial sectors, majority of natural gas use is in space and water heating. In industrial sector both oil and natural gas have a large demand in Alberta and hence constitutes majority of GHG emissions.

2.5.1.10.2 Reference scenario

In the reference case scenario the GHG emission for baseline scenario is developed for 2005 - 2030 study period. The increase in GHG emissions originating from demand sector is shown in Table G-2 in Appendix G. Based on the growth rates of various demand sectors and increase in primary and secondary fuel consumptions over the baseline, the emissions are expected to increase from 87 MT in 2005 to 149 MT of CO_2 equivalents in 2030. The increase in emissions is again attributed to increasing demand of energy in industrial, transport, household and commercial sectors. The increase in demand for oil products results in increasing emissions from 52 MT to 88 MT of CO_2 equivalents from 2005-2030. For natural gas usage based emissions are projected to increase from 34 MT to 60 MT over the study period of 25 years. The details are given in Table G-3 in Appendix G.

2.5.2 Transformation sector

Alberta Transformation sector has been modeled for power generation sector, oil and gas sector and coal mining sector.

2.5.2.1 Power generation sector

2.5.2.1.1 Base case scenario

In the base year 2005, power generation sector of Alberta mainly produced power from coal and natural gas followed by wind hydro and others which included biomass and some oil fired generation. The details of base year power generation are given in Table E-1 in Appendix E. Various time slices for one year period and the corresponding generation for each slice are shown in the Table E-1 in Appendix. Figure 2 in Appendix E shows the proportion of various mixes in Alberta power plant. About 70% of generation came from coal in 2005.

a) Input

Table E-2 in Appendix E summarizes input data on the annual fuel feedstock consumed by electricity generation sector. The largest production of power was coal based followed by natural gas.

b) Output

Tables E-3 in Appendix E shows the output power from different power plants in 2005. The output data is dependent on the demand requirements of that year, the capacities of the plants, efficiency of the plants and maximum availability in that year.

c) Power dispatched

The results in this category give a detailed report of how processes (power plants) were dispatched to meet the power requirements in a module. Table E-1 in Appendix E gives the details of power dispatched in the time slices of 1000 hrs in 2005 for Alberta. All the processes have been assigned a merit order and these processes are dispatched based in ascending merit order. Hence both base and peak load plants are dispatched accordingly. This dispatch schedule is maintained for the entire study.

2.5.2.1.2 Environmental results

The environmental results for electricity generation module for 2005 are given in Table E-4 in Appendix E. Total emission in 2005 produced by power plants in Alberta was 51 million tonne of CO_2 equivalents. It was mainly generated by coal and natural gas plants.

2.5.2.1.3 Reference case scenario

The following data are generated in the reference scenario for the power sector in Alberta.

a) Requirements

In the reference case (business as usual) scenario the overall increase in requirement as determined by LEAP model is 113 million MWh in 2030 as shown in Table E-5 in Appendix E. This is more than twice the base year requirement.

b) Inputs

The increase in input feedstock fuel consumption would increase from 728 PJ to 1212 PJ over 25 year study period. The details are given in Table E-6 in Appendix E.

c) Outputs

Total output would increase from 63 million MWh to 113 million MWh over the base case scenario from 2005 - 2030 as shown in Table E-7 in Appendix E.

d) Capacity

The overall capacity of the plants increases from 12,650 MW to 21,966 MW over 25 year study period. This is the overall power generation capacity including cogeneration plants the details are given in Table E-8 in Appendix E.

e) Peak power requirements

In the reference scenario the peak power requirement is expected to be increase from 9.6 thousand MW to 16 thousand MW over the study period (2005-2030) as shown in Table E-9 in Appendix E.

2.5.2.1.4 Module balance

Table E-10 in Appendix E shows the overall module balance of the electricity generation module over the 25 years study period. Domestic requirements increase from 241 PJ to 406 PJ in 25 years from 2005-2030.

2.5.2.1.5 Reference scenario - environmental results

The reference scenario results are given in Table E-11 in Appendix E. The anticipated increase in GHG emissions by the end of study period for the base case scenario is 99 MT of CO_2 equivalents. The GHG emission increase is from usage of coal and natural gas in power plants. Coal fired plants' GHG emissions increase from 44 MT to 71 MT of CO_2 equivalents by 2030 in the business as usual scenario. In the based case scenario no major change is expected in the Alberta power generation mix. Gas fired plants show a large increase in GHG emissions from 3 MT to 17 MT of CO_2 equivalents by 2030. This is due to addition of new gas plants planned from 2010 to 2030.

2.5.2.2 Natural gas production and processing

Table E-12 in Appendix E summarizes the overall balance of supply and demand of natural gas in Alberta. Total output in 2005 was 4,898 PJ of which 858 PJ was consumed in domestic sectors, and the remaining was exported to other provinces of Canada and to the US.

2.5.2.2.1 Results and discussion - reference case scenario

Based on the results of the reference case scenario as shown in Table E-13 in Appendix E for 25 year study period, there are two significant features. First, the energy output is decreasing from 4,952 PJ in 2005 to 3,430 PJ in 2030. Domestic demand is expected to increase from 858 PJ to 2,143 PJ in 2030. However export numbers are constant over the base case scenario.

2.5.2.2.2 Environmental results

Total GHG emissions which results from natural gas production and processing are expected to reduce from 27 MT (2005) to 19 MT of CO_2 equivalents in 2030 as shown in Table E-14 in Appendix E.

2.5.2.3 Alberta oil refining

The module balance for Alberta refinery finished products is shown in Table E-15 in Appendix E for the base year 2005. The total output is 1,035 PJ of which the domestic requirement is 686 PJ. In the reference scenario, as shown in Table E-16 in Appendix E, domestic requirements increase from 686 PJ to 1130 PJ over 25 year study period. As shown in Table E-17 in Appendix E, the oil refining GHG emissions are projected to increase from 17 MT to 24 MT of CO_2 equivalents in the reference case scenario over 25 year period.

2.5.2.4 Crude oil production

The module balance for Alberta's conventional crude oil is shown in Table E-18 in Appendix E for the base year 2005. The total output is 1,214 PJ of which the domestic requirement is 167 PJ. In the reference scenario, as shown in Table 19 in Appendix E, domestic requirement increases from 167 PJ to 503 PJ over 25 year study period. As shown in Table 20 in Appendix E, the crude oil emissions are projected to decrease from 4 MT to 1.4 MT of CO_2 equivalents in the reference case scenario over 25 year period as the outputs from conventional crude is projected to decrease over the study period.

2.5.2.5 Synthetic crude oil production

The module balance for Alberta SCO is shown in Table E-21 in Appendix E for the base year 2005. The total output is 1,147 PJ in 2005 of which the domestic requirement is 455 PJ. In the reference scenario as shown in Table E-22 in Appendix E domestic requirement increases from 455 PJ to 663 PJ over 25 year study period. Exports also increases from 690 PJ in 2005 to 3,599 PJ in 2030 in accordance with increasing output. As shown in Table E-23 in Appendix E, the crude oil emissions are projected to increase from 14 MT to 53 MT of CO_2 equivalents in the reference scenario over 25 year period as the outputs from SCO crude is projected to increase significantly over this study period.

2.5.2.6 Crude bitumen production

The module balance for Alberta crude bitumen is shown in Table E-24 in Appendix E for the base case 2005. The total output is 1,917 PJ in 2005, of which the domestic requirements are 1,147 PJ. In the reference scenario as shown in Table E-25 in Appendix E, domestic requirement increases from 1147 PJ to 4262 PJ over 25 year study period. Exports also increases from 872 PJ in 2005 to 2,000 PJ in 2030 in accordance with increasing output. As shown in Table E-26 in Appendix E the crude oil GHG emissions are projected to increase from 35 MT to 114 MT of CO_2 equivalents in the reference scenario over 25 year period as the outputs from crude bitumen is projected to increase significantly over the study period.

2.5.2.7 Natural gas liquid extraction

The module balance for Alberta crude bitumen is shown in Table E-27 in Appendix E for the base year 2005. The total output is 429 PJ in 2005, of which the domestic requirements are 100 PJ. In the reference scenario, as shown in Table E-28 in Appendix E, domestic requirement is projected to be steady over the 25 year study period. As shown in Table E-29 in Appendix E, natural gas emissions are constant at 5.7 MT of CO_2 equivalents per year over the study period of 25 years.

2.5.2.8 Coal Mining

The module balance for Alberta coal mining is shown in Table E-30 in Appendix E for the base year 2005. The total output is 560 PJ in 2005, of which the domestic requirements are 513 PJ. In the reference scenario, as shown in Table 31 in Appendix E domestic requirement is projected to increase from 513 PJ to 805 PJ over 25 year study period. GHG emissions result is given in Table E-32 in Appendix E. It is expected to remain constant at 0.083 MT of CO_2 equivalents per year in the reference scenario.

2.5.2.9 Alberta Cogeneration

The module balance for Alberta cogeneration is shown in Table E-33 in Appendix E for the base year 2005. The total output is 10 million MWh in 2005 which is produced by Alberta oil sands for bitumen production and upgrading. In the reference scenario, as shown in Table 34 in Appendix E, domestic requirement is projected to increase from 10 million MWh to 30 million MWh over 25 year study period. Emission results are given in Table E-35 in Appendix E. It is expected to increase from 2.5 MT to 6.5 MT of CO_2 equivalents in the reference scenario over 25 year study period.

2.5.3 Overall environmental results

2.5.3.1 GHG emissions - demand sector

Alberta demand sector emissions in the reference scenario are shown in Table G-2 in Appendix G. The increase in emissions is expected to be from 87 MT in 2005 to 149 MT of CO_2 equivalents in 2030. The contribution of emission is mainly from industrial sector which is expected to double from 41 MT to 74 MT of CO_2 equivalents in 2030.

2.5.3.2 GHG emissions –transformation sector

In the transformation sector, GHG emissions from the energy conversion sector is expected to grow from 157 MT in the year 2005 to 325 MT of CO_2 equivalents in 2030 as shown in Table 2-17.

Table 2-17: Alberta energy transformation sector emissions - reference case scenario

Sectors (MT of CO_2 eq)	2005	2010	2015	2020	2025	2030
Electricity Generation	51.06	58.79	72.66	85.23	92.05	99.31
Natural gas and coal bed methane extraction	27.06	25.84	24.9	23.93	21.44	18.95
Alberta Oil Refining	17.04	18.69	19.95	21.34	22.98	24.81
Crude oil production	4.02	3.98	3.2	2.42	1.91	1.39
Synthetic crude oil production	14.47	24.43	46.3	52.6	53.16	53.78
Crude bitumen production	35.28	58.46	100.87	113.52	114.32	115.23
NG liquid extraction	5.47	5.47	5.47	5.47	5.47	5.47
Coal mining	0.08	0.08	0.08	0.08	0.08	0.08
Electricity Generation1	2.68	3.72	5.2	6.01	6.28	6.52
Total	157.17	199.47	278.63	310.6	317.68	325.54

Electricity generation sector with the current mix of generation by coal, natural gas, wind, hydro and others has been projected to have a large increase in GHG emissions from 51 MT to 99 MT of CO_2 equivalents in the year 2030. Natural gas production and processing plant shows a declining trend of GHG emissions as there is a reduction in overall natural gas production over the 25 year study period of 2005-2030. Similar situation is expected for conventional crude oil and the reduction in GHG emissions is projected from 4 MT to 1.4 MT of CO_2 equivalents in the year 2030. However, Alberta's crude bitumen and synthetic crude oil production have a significant increase from year 2005 to year 2030. For crude bitumen production the emissions are likely to increase from 35 MT in 2005 to 115 MT of CO_2 equivalents in 2030. In case of synthetic crude oil production the increase is projected from 14 MT to 53 MT of CO_2 equivalents in 2030.

2.5.3.3 Total GHG emissions

Total Alberta's GHG emissions from energy demand and transformation sector is likely to increase from 244 MT (including the entire auxiliary fuel requirement) in 2005 to 494 MT of CO_2 equivalents in 2030 as shown in Table 2-18.

Table 2-18: Alberta emissions - demand and transformation - reference case scenario

Sectors (MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Demand	87.62	99.87	112.9	128.3	146.7	169.0
Transformation	157.17	199.4	278.6	310.6	317.6	325.5
Total	244.79	299.3	391.5	438.9	464.4	494.6

2.5.4 Resource sector

2.5.4.1 Primary requirements

Total primary energy requirement for Alberta is given in Table F-1 in Appendix F. Total energy requirement is 5,102 PJ, of which natural gas requirement is 1,813 PJ oil products along with crude oil have a requirement of 2,626 PJ.

2.5.4.2 Reserves

Table F-2 in Appendix F shows the remaining reserves of depletable fossil fuels in Alberta. Total reserves of Alberta from 2005 are estimated at 2,121 billion GJ.

2.5.4.3 Indigenous production

In 2005 total indigenous production was 10,358 PJ as shown in Table F-3 in Appendix F. Natural gas production was highest at 5,506 PJ.

2.5.4.4 Exports

Table F-4 in Appendix F gives the details of total Alberta's exports in 2005. Largest energy export was in terms of natural gas at 4,040 PJ followed by oil products and crude oil at 1,435 and 814 PJ respectively.

2.6 Alberta's energy balance

2.6.1 Supply and demand for Alberta

Alberta's energy balance is shown in Table 2-19. This is the generic view of primary and secondary fuel flow chain in Alberta. There is primary resource sector which has wood, coal, natural gas and oil as the primary fuels. The secondary fuel is generated in the transformation sectors such as electricity generation and oil refinery. Total demand of energy in 2005 was 2,274 PJ (inclusive of non energy sector use of 330 PJ). Total transformed energy was 1,896 PJ and total primary supply was 4,107 PJ which was the energy available for direct demand sectors and for the secondary fuel conversion.

Table 2-19: Alberta energy balance data

Scenario: Reference, Year: 2005 (PJ)	Solid Fuels	Natural Gas	Crude Oil	Hydro	Renewable	Biomass	Elect.	Oil Products	Heat	Total
Production	563	5852	1349	0	0	13	0	2866	0	10643
Imports	63	347	567	22	2	57	2	230	9	1298
Exports	-60	-4040	-1506	0	0	0	-2	-1812	0	-7420
Total Primary Supply	566	2159	410	22	2	70	-1	1284	9	4521
Electricity Generation(oil sands)	0	-22	0	0	0	0	14	0	4	-3
NG liquid extraction	0	0	0	0	0	0	0	-361	0	-361
Crude bitumen production	0	-249	0	0	0	0	-12	-338	0	-600
Synthetic crude oil production	0	-72	1147	0	0	0	-3	-1147	0	-75
Crude oil production	0	0	-450	0	0	0	0	315	0	-135
Alberta Oil Refining	0	-7	-1107	0	0	0	0	952	0	-162
Natural gas and coal bed methane extraction	0	-1000	0	0	0	0	0	0	0	-1000
Electricity Generation	-563	-105	0	-22	-2	-12	219	-1	0	-485
Transmission and Distribution	0	-34	0	0	0	0	-38	0	0	-72
Total Transformation	-563	-1490	-410	-22	-2	-12	180	-580	4	-2894
Household	0	150	0	0	0	0	24	1	0	175
Commercial and Institutional sector	3	103	0	0	0	1	51	1	0	159
Industrial sector	0	329	0	0	0	56	120	247	9	761
Agriculture sector	0	4	0	0	0	0	8	36	0	48
Transportation sector Road	0	0	0	0	0	0	1	302	0	303
Passenger Rail	0	0	0	0	0	0	0	1	0	1
Passenger Air	0	0	0	0	0	0	0	33	0	33
Freight Rail	0	0	0	0	0	0	0	31	0	31
Freight Air	0	0	0	0	0	0	0	1	0	1
Pipeline transport	0	61	0	0	0	0	2	0	0	63
OFF Road	0	0	0	0	0	0	0	9	0	9
NG Reprocessing plant shrinkage	0	200	0	0	0	0	0	0	0	200
Bitumen production and upgrading	0	160	0	0	0	0	0	0	0	160
Non energy sector use	0	108	0	0	0	0	0	223	0	331
Total Demand	3	1114	0	0	0	58	205	885	9	2274

2.6.2 Energy balance overview – LEAP results

The energy balance in LEAP details the primary energy production followed by imports and exports, total energy transformed and finally the actual energy demand for a particular year in study. In case of Alberta, for year 2005, the total energy demand as calculated by LEAP is 2,274 PJ which is inclusive of non energy sector usage and some amount of natural gas which is lost in shrinkage, venting and flaring used in oil and gas sector. Therefore the actual demand will be difference of these amounts and is about 1,700 PJ of actual energy use.

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Chapter 3. Development of Sankey Diagrams for Energy and Emission Flows for Alberta

3.1 Introduction

Sankey diagrams are a specific type of flow diagram, in which the width of the arrows is shown proportionally to the flow quantity. They are typically used to visualize energy or material transfers between processes. Sankey diagrams are used in the field of engineering to show flow quantities in process systems. They are also commonly used to visualize the energy accounts or material flow accounts on a regional or national level. Sankey diagrams put a visual emphasis on the major transfers or flows within a system. They are helpful in locating dominant contributions to an overall flow and as such are popular during times of resource scarcity. They are named after Captain Henry Matthew Sankey, an engineer from Cork, Ireland who worked in the steam engine improvement (ifu Hamburg GmbH, 2009). He was the first to publish an energy content diagram, so the type of diagram with arrow width proportional to the flow quantity is named after him. Sankey diagrams are one of the visualization modes of material flows available in Umberto (ifu Hamburg GmbH, 2009). Umberto is a material flow modeling software package that allows modeling any type of process system calculating all flows from the process specifications, analyzing and displaying the inventory results. Furthermore flow cost accounting can be developed for the process system and assess the results under environmental and/or economic perspectives, using key performance indicators or valuation systems (ifu Hamburg GmbH, 2009). e!Sankey software has been developed only for making Sankey diagrams. e!Sankey has numerous options to make flow charts allowing user to add labels, additional graphical elements and also to scale the flows (ifu Hamburg GmbH, 2009).

There are a number of software tools that support the drawing of sankey diagrams:

1. e!Sankey Pro - Software for sankey diagrams (ifu Hamburg GmbH, 2009).
2. Sankey Editor - Static and dynamic sankey diagrams (Phineas, 2008).
3. Umberto - Material flow software with sankey diagrams (ifu Hamburg GmbH, 2009).
4. SankeyHelper - a free tool to create sankey diagrams in MS Excel (Phineas, 2008).

For the purpose of developing sankey diagram for Alberta's energy and emission flows "e!Sankey" has been chosen (ifu Hamburg GmbH, 2009). It is user friendly software which is low-priced software tool for the display of the flows of a process system. It enables user to draw high-quality sankey diagrams easily and quickly. The latest version of the same has an interface with excel and the data can be linked to the excel sheet. The advantage of this feature is that there is a live link between Sankey diagram and excel data, hence each time there is a change in data it be automatically updated in the diagram.

In this study, sankey diagrams for energy and emission flows for the province of Alberta are developed. The Alberta energy diagrams are characterized by supply and demand sectors. Hence, it has a complete scenario of primary resources, transformation of primary resources to secondary resources and the demand of primary and secondary resources in different sectors. There are flows indicating the total useful and rejected energy in the entire scheme. The relative width of flow in the sankey diagram is a constraint sometimes as some flows are significantly higher than the others and hence the diagram is skewed.

3.2 Development of sankey diagram using LEAP data

Sankey diagrams in this study has been linked to LEAP through excel database. LEAP has different views like analysis view, results view, diagram and energy balance view. All these charts and tables generated from LEAP can be exported to excel in the form of excel tables. This can be further exported to e!sankey Pro windows through the live links. The output data from LEAP is given as overall energy balance of Alberta supply and demand scenario. The results of demand sector are discussed in the chapter 2. The results of each sector are exported to excel and from there these are directly used in the sankey diagram. Various sankey diagrams for the province of Alberta are discussed later in this chapter.

Alberta sankey diagrams have been developed based on the final energy demand and supply data obtained by LEAP for the base year 2005. Sankey diagram for Alberta gives the detailed energy flow pattern indicating the proportional flows of primary and secondary energy consumption in the different demand sectors. This diagram also shows the total useful and rejected energy indicated after the demand sector.

3.3 Alberta sankey diagram

Sankey diagrams for Alberta are generated for the entire energy scenario including the supply and demand sectors.

3.3.1 Basic sankey diagram of energy flows for Alberta

Figure 3-1 shows the basic sankey diagram for energy flows for Alberta for the base year 2005. This gives the details of energy flows from resource to their transformation and utilization in the demand sectors. The details of primary fuels are on the extreme left. In the centre the primary resource conversion sectors mainly including electricity generation, oil refining, and coal mining sectors are laid out. On the right hand side the demand sectors are located. The values of useful and rejected energy from each sector are also given. All units are in petajoules (PJ).

3.3.2 Sankey diagram of energy flows with exports

Figure 3-2 gives the overall picture of Alberta's primary and secondary energy scenario with complete data on imports and exports pertaining to each sector in the province. As Alberta is a large exporter of oil and natural gas, a separate sankey diagram indicating the comparative flows data has been generated.

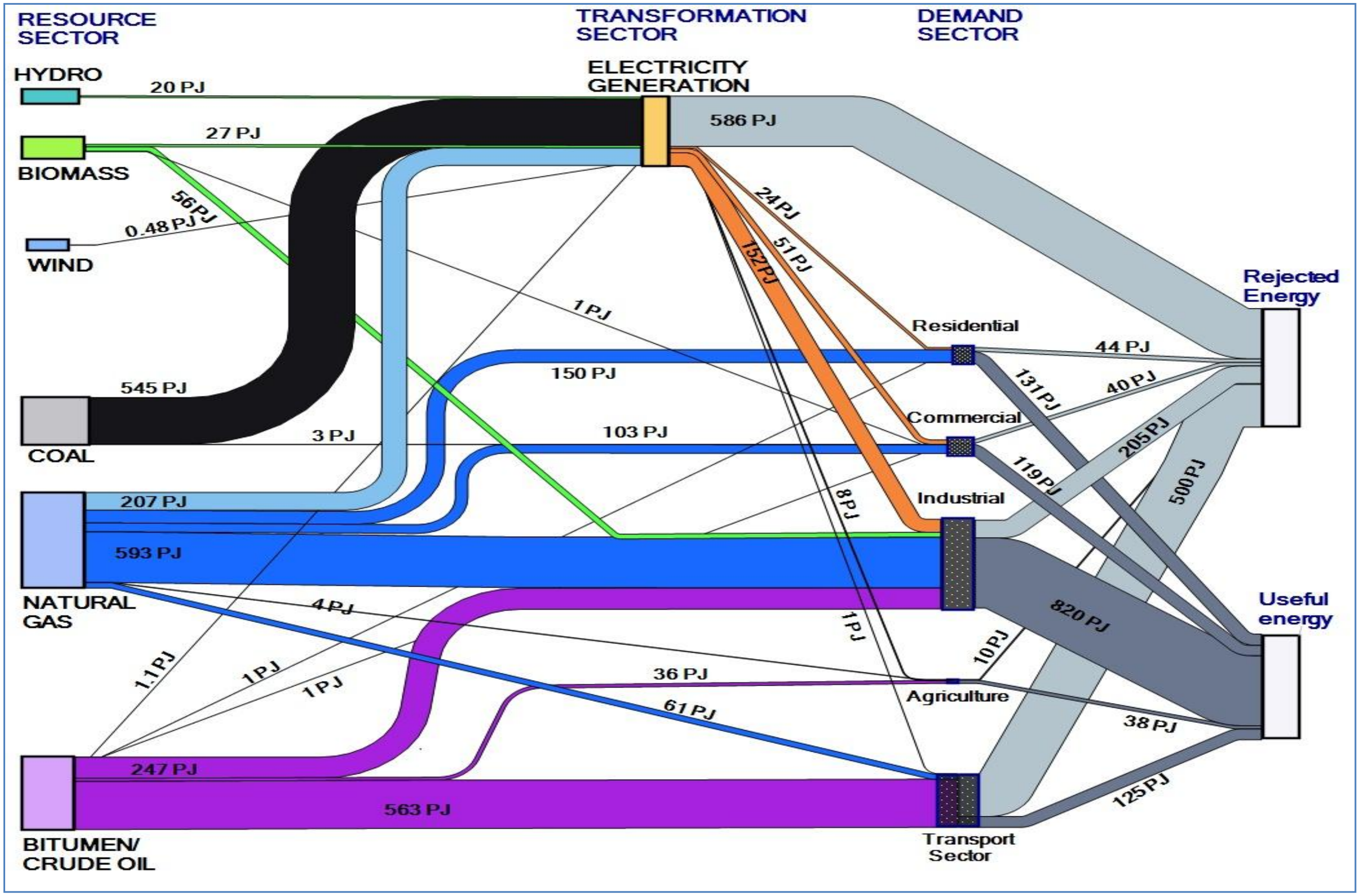

Figure 3-1: Alberta sankey diagram for the base year 2005

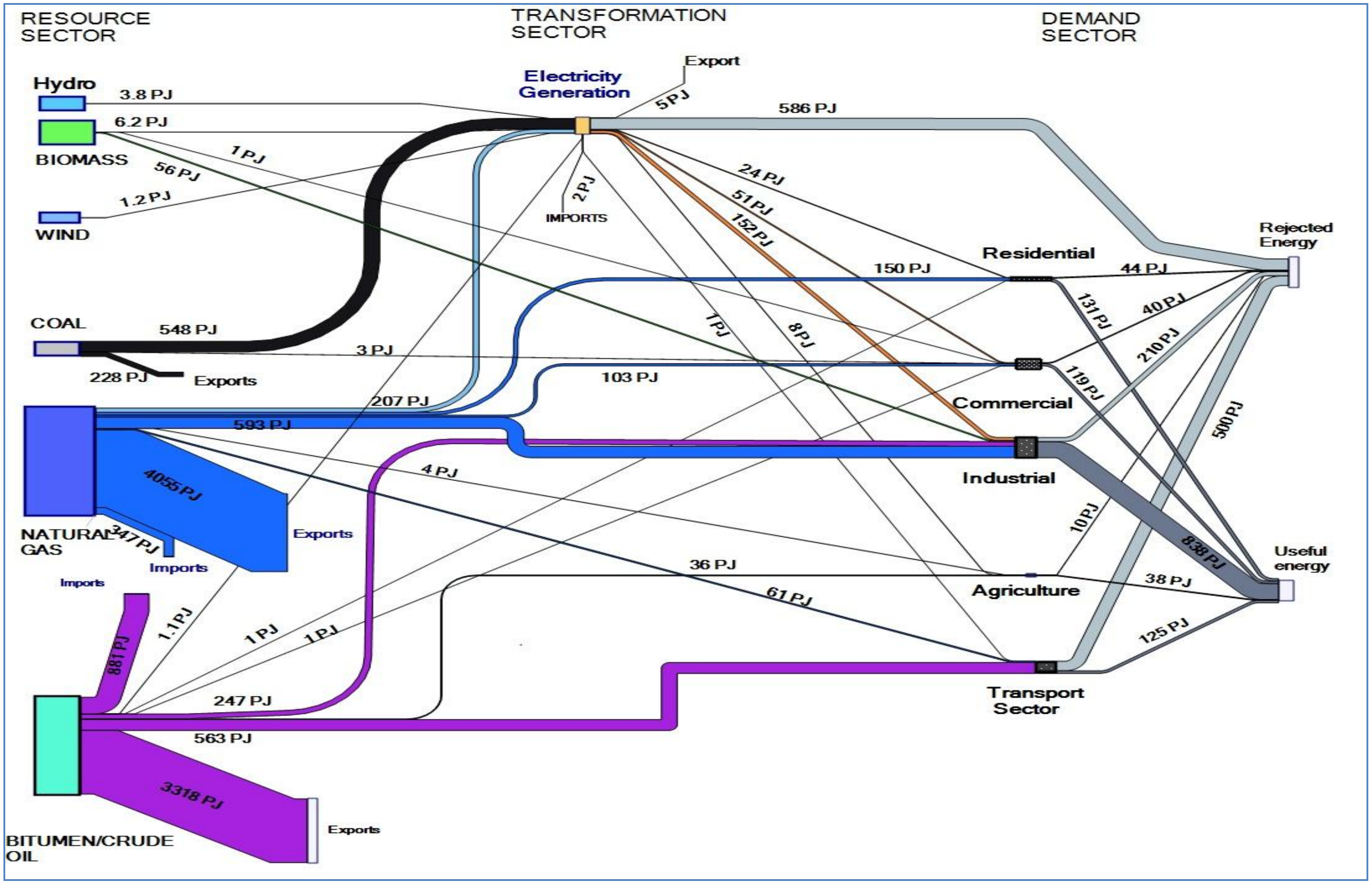

Figure 3-2: Alberta sankey diagram with exports

3.3.3 Sankey diagram of energy flows for industrial sector

Figure 3-3 has the details of industrial sector sankey diagram. This sankey diagram is developed based on the details of energy consumption in the industrial sector of Alberta. This diagram basically helps in understanding the energy inputs and outputs in the oil and gas industry.

3.3.4 Sankey diagram for GHG emissions

Figure 3-4 has the details of Alberta GHG emissions in megatonne of CO_2 equivalents from the energy sector. In order to obtain the sankey diagram for emission flows, LEAP's inbuilt environmental database (emission factor) was used for each end use technology. The results obtained from LEAP for GHG emissions for each of the demand and transformation sectors were used to develop the sankey diagram for Alberta's GHG emissions.

3.3.5 Overall sankey diagram for Alberta

Sankey diagram for Alberta has three major modules. On the extreme left there are primary fuels and on the right hand side there are demand sectors of Alberta. Only electricity generation is shown in the transformation sector of Alberta. On the extreme right there are two segments showing the total useful and rejected energy from the demand and transformation sectors. This segment is generated outside

LEAP but is based on the assumptions of energy conversion and usage efficiencies. All these sankey diagrams are developed for the base year 2005.

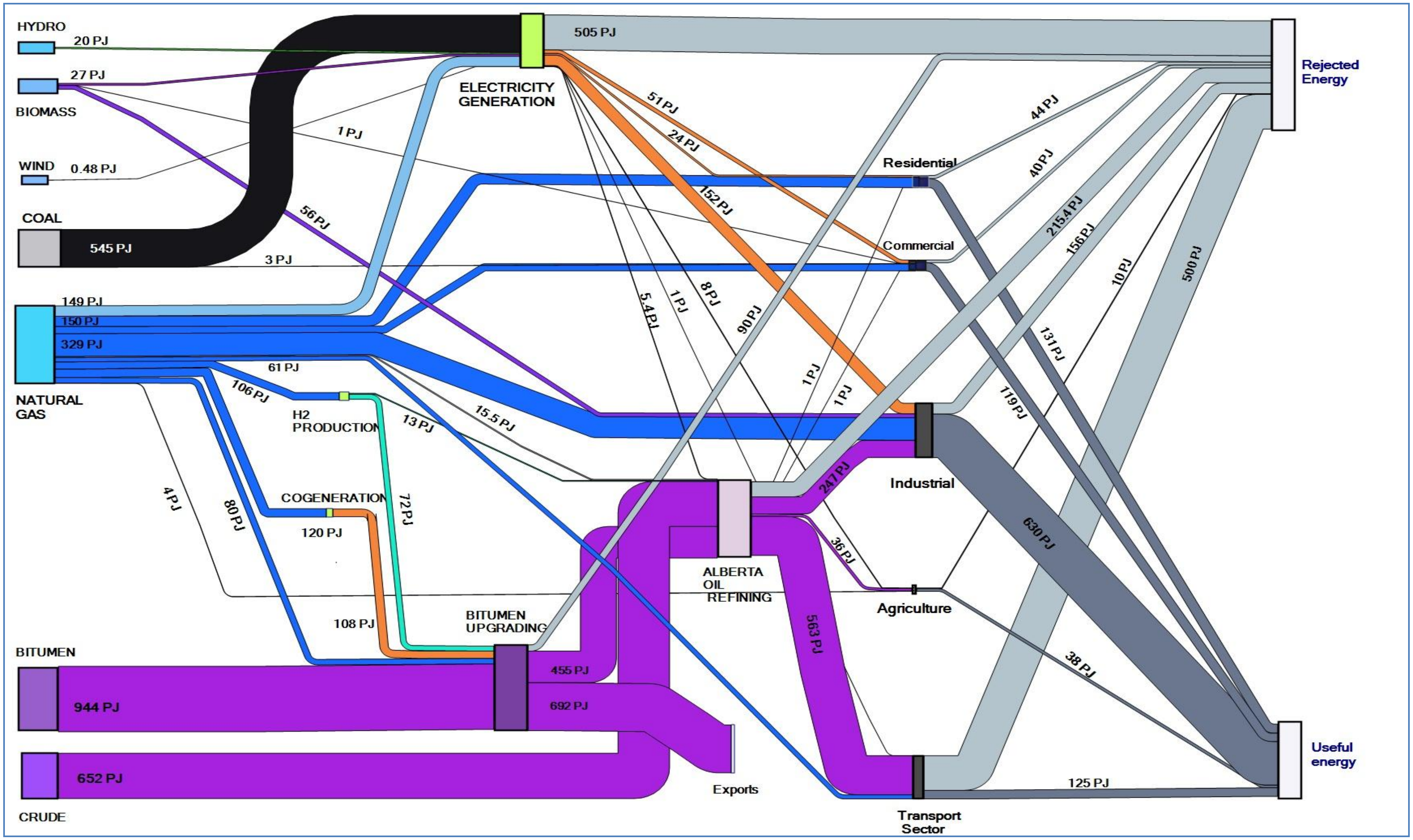

Figure 3-3: Alberta industrial sector sankey diagram

With the energy balance diagram of LEAP these sankey diagrams can be developed for any year in the study period i.e. 2005-2030. Sankey diagrams of Alberta helps in understanding the type of energy flows and developing other useful energy of emission related protocol for the province.

3.3.5.1 Primary and secondary fuel consumption in sankey diagram

The following primary fuels are shown on the sankey diagram of Alberta for base year 2005.

Table 3-1: Details of primary and secondary fuel consumption in sankey diagram

Primary energy produced	Secondary energy produced	Energy demand from various sectors
Hydro = 20 PJ	Electricity = 20 PJ	
Biomass = 83 PJ	Electricity = 26 PJ	Industrial sector = 56 PJ Commercial sector = 1 PJ
Wind = 0.48 PJ	Electricity = 0.48 PJ	
Coal = 548 PJ	Electricity = 545 PJ	Commercial sector = 3 PJ
Natural gas = 1118 PJ	Electricity = 207 PJ	Residential sector = 150 PJ Commercial sector = 103 PJ Industrial sector = 593 PJ Agriculture sector = 4 PJ Pipeline transport = 61 PJ
Bitumen/Crude oil = 849	Electricity=1.1 PJ	Residential Sector=1 PJ of Commercial Sector=1PJ Industrial Sector= 247 PJ Agriculture Sector=36 PJ Transport Sector= 563 PJ

3.3.5.2 Calculation of useful and rejected energy

For the Alberta's Sankey diagram, the overall energy input and output are developed based on sector wise fuel efficiencies. This efficiency value is dependent on heat rate of fuel which is expressed as btu per kWh. In developing sankey flow diagrams for energy, the thermal energy conversion factors are taken into account. These factors are individually developed for each of the energy fuels and then weighted for the entire sector depending on various fuels being used. The heat content as calculated for a particular sector depends on the source, year of production, and technology for use of fuel. Heat rates give the conversion efficiency of the fuel and are used to determine the proportion of "useful" to "rejected" energy (Kaiper, 2001).

3.3.5.2.1 Electricity generation sector

Alberta's electricity sector uses a large amount of primary energy from fossil fuels. Electricity generation plant's conversion efficiencies in Alberta fall in the range of 33% (most of the coal plants) to 34% for natural gas plants (Statistics Canada, 2005a). Total energy actually utilized by all sectors is about 30% of the total energy produced. About 70% of the energy is the rejected or wasted energy. Figure 3-1 has the details of Alberta's sankey diagram showing the actual energy utilized from Alberta's power sector in the base year 2005. Total useful energy in the electricity generation sector is 227 PJ whereas total rejected energy is 586 PJ for the base year 2005.

3.3.5.2.2 Residential and commercial sector

For residential and commercial sectors the conversion efficiencies are based on various devices used for space heating, space cooling and other domestic and commercial appliance in house and offices. Space heating devices are assumed to be 60% efficient (Kaiper, 2001) whereas other electrical equipment such as motors are assumed to be 90% efficient (Kaiper, 2001). Hence a weighted average value of 75% is considered for conversion efficiency calculations for residential and commercial sectors. For the base year 2005, the total useful energy consumptions for residential and commercial sectors are 131 PJ and 119 PJ, respectively, as shown in Figure 3-1. The total wasted or rejected energy for the two sectors are 44 PJ and 40 PJ, respectively.

3.3.5.2.3 Industrial sector

In the industrial sector the primary and secondary fuels used are natural gas, petroleum products and electricity. Since for heat and electricity Alberta's industrial sector has their own cogeneration plants, the overall plant efficiency is higher. Also assuming the efficiency of electrical equipment like auxiliary motors to be 90% (Kaiper, 2001) the weighted average value is calculated to be 80%. For the base year 2005, Figure 3-1 has the details of useful and rejected energy in Alberta's industrial sector. Total useful energy for Alberta's industrial sector in the base year 2005 is 609 PJ whereas the rejected energy is 152 PJ.

3.3.5.2.4 Transport sector

For transportation sector, an overall efficiency of 20% is assumed (Kaiper, 2001) which corresponds to an average efficiency of internal combustion engine (it's defined as the amount of energy that actually reaches the drive train of a vehicle, compared to the amount of energy consumed). The peak efficiencies of 33-35% for gasoline engines and 41-45% for diesel engines are not representative of actual conversion efficiencies (Kaiper, 2001). Transport sector's useful and rejected energy are represented in Figure 3-1 in the Alberta's sankey diagram. For the base year 2005 total useful energy in the transport sector was 76 PJ and the rejected energy was 302 PJ.

3.3.6 Sankey with exports and imports

The overall sankey diagram was modified to incorporate exports and imports data in order to obtain the overall picture of Alberta's energy flows. Total exports from oil and gas accounts for major portion of energy flows in Alberta as shown in Figure 3-2.

Table 3-2: Alberta primary fuel exports and import

Primary Fuel	Exports	Imports
Coal	228 PJ	347 PJ (for balance)
Natural gas	4055 PJ	881 PJ (mainly pentanes and condensates)
Crude oil and equivalent	3318 PJ	

3.3.7 Sankey for industrial sector

Sankey diagram for industrial sector shows the detailed energy flows representing Alberta's oil and gas conversion module along with electricity generation sector as shown in Figure 3-3. The details of energy inputs and outputs are indicated in Alberta's oil refining and bitumen upgrading sectors. Total energy requirement for bitumen upgrading is calculated based on energy consumptions for different processes. There is a requirement of electricity, natural gas and hydrogen for crude bitumen production and upgrading process. Total energy requirement is as shown in Figure 3-3.

Table 3-3: Alberta's oil and gas demand in the bitumen upgrading process for industrial sector

Items	Values
H2	72 PJ
Electricity	106 PJ
Natural gas	180 PJ
Total energy input for bitumen upgrading	1304 PJ
Energy output (useful energy)	1147 PJ
Rejected (wasted energy)	150 PJ

3.3.8 Sankey diagram for GHG emissions

Alberta's energy sector consists of mainly coal, natural gas, and crude oil. The emission flow diagram indicates the primary fuel emissions pertaining to each end-use in the demand sector as shown in Figure 3-4. Emissions from each sector are characterized by both combustion and fugitive emissions. Combustion emissions are produced by burning of fuel whereas fugitive emissions are the emissions due to equipment and valve leakages, and escape of pollutants from confined vessels, pipes etc.

These emissions are from both upstream and downstream processes produced as a result of processing, transmission and transportation of fossil fuels. The emissions are characterized by three different fossil fuel usages on the resource side. The emissions flows are traced for each demand sector of Alberta as detailed below.

- *Electricity generation*: Emissions are related to use of coal and natural gas as feedstock fuel for electricity generation which is based on their usage in residential, commercial and industrial sectors. In 2005 about 50 MT of CO_2 equivalents was produced by coal for electricity generation sector.

- *Natural gas production and use*: About 100 MT of CO_2 equivalents were generated by combustion and fugitive emissions of natural gas.

- *Petroleum*: About 82 MT of CO_2 equivalents were generated in 2005 of which 25 MT of CO_2 equivalents were emitted in industrial sector. About 16 MT was generated in bitumen production and extraction and about 40 MT was generated in the transport sector.

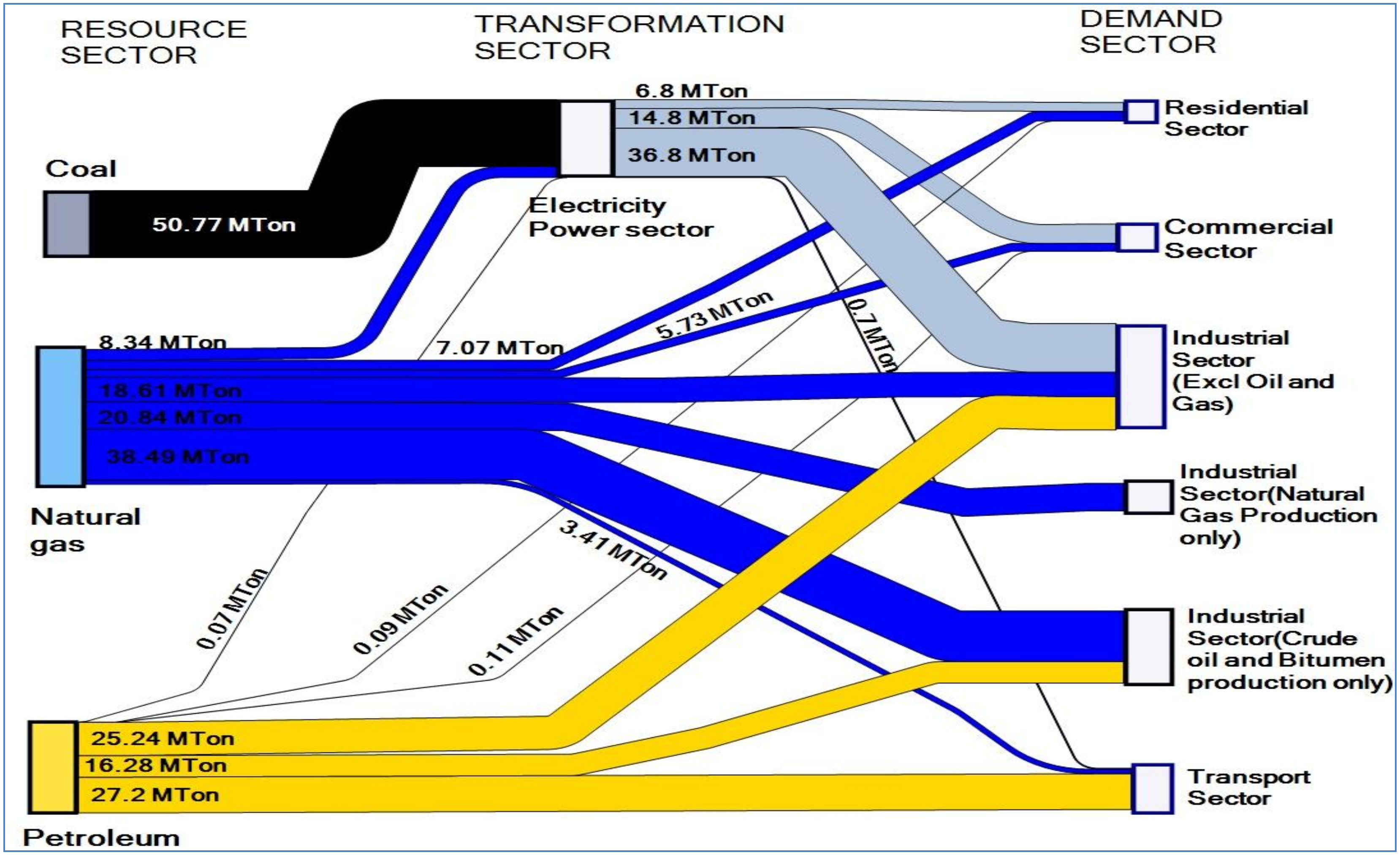

Figure 3-4: Alberta GHG emission sankey for base year 2005

Reference

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Chapter 4. Development of GHG Mitigation Scenarios for Alberta using LEAP Model

4.1 Introduction

Alberta has abundant renewable biomass feedstock in the forestry and agriculture sector (Government of Alberta, 2010b). This is very promising for successful transition of fossil fuel into renewable energy in the province of Alberta. Renewable resource in Alberta also includes good wind and hydro capacities and the prospects of nuclear energy inclusion in the power generation sector.

Another technological option for reducing net CO_2 emissions to the atmosphere is carbon capture and sequestration(CCS) (Alberta Department of Energy, 2008). There are three main components of the process. Capturing CO_2, for example, by separating it from the flue gas stream of a fuel combustion system and compressing it followed by transporting it to a storage site for storage. Several types of storage reservoir may provide storage capacity of large magnitude. In some cases injection of CO_2 into oil and gas fields could lead to enhanced production of hydrocarbons, which help to offset the cost. This is called enhanced oil recovery (EOR) (Government of Alberta, 2005). In other cases it could be applied to electric power generation facilities and other large industrial source of emission like bitumen production and upgrading facilities (IPCC, 2005). Alberta government's initiative for carbon capture and sequestration (CCS) projects in recent months is one of the largest initiatives towards reduction in GHG emissions and a key step toward meeting Canada's Kyoto agreement (Alberta Department of Energy, 2008). This has become evident after the 2 billion dollar commitment that Alberta government has made towards CCS initiatives in the province (CAPP, 2010). In order to realize Alberta's vision as global energy leader, Alberta's Department of Energy has developed an integrated energy strategy to develop the large energy resources of the province (Alberta Department of Energy, 2008). This approach takes into account both energy and environment considerations and hence is aimed at sustainable development. According to Alberta's Provincial Energy Strategy (2008) 'renewable energy sources are growing a very small base, but their viability is improving over time and the technology is improving too. As such, these have the potential to become a significant part of the global energy mix in this century, but based on demand here in Alberta and globally, they cannot entirely replace fossil fuels any time soon (Government of Alberta, 2008c). Alberta's role in the development and use of renewable energy sources will help in reducing greenhouse gas emissions, enhance Alberta's diversity of energy supply, stimulate regional activity, and fortify collaboration across industry sectors (Government of Alberta, 2008a).

Energy integration is fundamental to Alberta's future energy development and marks a significant shift in direction. Integration means that energy projects and commodities are no longer treated on a stand-alone basis but as part of a larger energy system (Alberta energy, 2006). One of the most significant visions of the strategy is environmentally responsible energy development. This will be applied to both renewable and non renewable energy supply sectors. An integrated systems approach has to be essentially a synergy of socioeconomic factors involved in bitumen upgrading, refining, processing, and secondary fuel manufacturing in using the natural resources in Alberta. This in turn will increase value-added opportunities for Albertans and will ensure that the resources are used optimally. Hence, a well coordinated energy development with other resource development industries to ensure sustainable access to resources while minimizing the environmental footprint of energy and all other operations is the main objective of the Integrated Energy Vision of the Government of Alberta (Government of Alberta- Energy Division, 2006).

Alberta government's integrated energy development strategy will be focused on innovations and improvements in the following areas (Alberta energy, 2006).

- Achieving greater extraction of both conventional and non conventional oil and gas resources in an economic and environmentally sustainable way.
- Development of renewable energy sources (e.g., wind, hydro, solar) in a cost effective way by way of technological advancements.
- Increasing the efficiency of mining and upgrading operations along with efficiency improvements in coal based power generation based on clean coal technologies like supercritical and ultra supercritical. It also includes decreasing capital and operating costs while reducing total impact on environment.
- Focus on CCS to increase oil recovery and increasing CO_2 mitigation options.

- Develop, improve and adapt alternate and renewable energy technologies such as hydrogen fuel cells, geothermal and bioenergy.

It is important to evaluate the impact of above mentioned scenarios in terms of GHG emissions mitigation over a longer period of time. This chapter discusses the different GHG emission mitigation scenarios in both energy demand and conversion sectors. The GHG emission mitigation scenarios are developed over the planning horizon of 25 years from 2005-2030. The GHG emissions in these mitigation scenarios are compared to the baseline scenario and total possible GHG emissions mitigation are estimated. The GHG emissions for different scenarios are estimated using the Alberta based LEAP model. These are discussed in subsequent sections.

4.2 Development of reference scenarios for Alberta

The reference scenario is the business as usual scenario for all the sectors. In the baseline scenario, the growth rate and energy intensity of energy consuming devices and sectors are indicative of the province's current situation. In the baseline scenario it is assumed that there is no additional change in any policy or any technological advancement built into the model.

Scenarios are self-consistent storylines of how a future energy system might evolve over time in a particular socio-economic setting and under a particular set of policy conditions. Using LEAP, scenarios are built and then compared to assess their energy requirements, and environmental impacts. All scenarios start from a common base year, the first year of the analysis period for which current account data are established in LEAP (Stockholm Environment Institute, 2006). In LEAP, baseline scenarios have been built using various reports and database (Alberta Environment, 2008; Benitez et al., 2008; Drouet, 2005; Environment Canada, 2010; IPCC, 2007; NRTEE, 2009) These scenarios are projected for a study period of 25 years. This takes into consideration all the demographic and macroeconomic changes anticipated in this time frame. Both demand and supply side have been built for the same.

4.3 Development of mitigation scenarios for Alberta

Mitigation scenarios are usually defined as a description and a quantified projection of how GHG emissions can be reduced with respect to some baseline scenario. These contain new emission profiles associated with the emission reduction (IPCC, 2001). Mitigation scenarios are developed in order to understand the vital information on all the possible technological and socioeconomic factors including the implications involved in cutting down the GHG emissions of a region. These measures are built in LEAP in order to give us a comprehensive overview of all the technologies and policies pertaining to the province of Alberta. In LEAP these scenarios can be built to ask "what if" questions such as: what if more efficient appliances are introduced; what if different electricity generation plan are pursued; what if more indigenous reserves of oil and gas are discovered; what if new renewable energy technologies are introduced, etc. In LEAP, mitigation scenarios are developed in both energy demand

and transformation sectors. Mitigation potential is related to economic potential by means of possible “scenario options” available for a particular region.

Mitigation potential is estimated using two types of approaches: “bottom up” and “top down”. Bottom-up studies are based on assessment of mitigation options, emphasizing specific technologies and regulations. They are typically sector-based studies taking macro economy as unchanged. Top- down studies assesses the economy–wide potential of mitigation options. These use globally consistent frameworks and aggregated information about mitigation options and capture macroeconomic and market feedbacks (IPCC, 2007). In general, relation between the economy, energy sector and the environment are described based on the above mentioned top down and bottom up models respectively. The first category approaches the problem from a description of macro-economic relations in the region under consideration, where as the bottom-up models propose a technology- rich description of an energy system and place the emphasis on the correct description of energy options and their cost structure. These two models are complementary, the former capturing a larger set of economic interactions (i.e., inter-industrial relations and macroeconomic feedbacks) without representing explicitly energy technology options, and the latter representing the details of the energy sector and the technology ranking procedures in a world characterized by technological innovation (Drouet, 2005). Essentially the top down models are based on optimization models in which a least-cost scenario is eventually built taking into consideration all the technical constraints and emission restriction.

LEAP, although based on energy accounting framework, can be classified as the bottom- up approach, wherein an energy emission analysis is conducted for each of the emission options called a scenario. For each mitigation scenario, a database is built for the processes involved, starting from resource production to final end use and all the GHG emissions are recorded in the pathway. Hence the final result is the generation of total emissions from production to combustion of the fuel. Each of the mitigation options comes from various sectors of demand and supply side of the energy flow. Hence a wide range of scenarios can be created based on different technological options, macroeconomic conditions, availability of technology, and policies.. For the province of Alberta, scenarios are mainly based on efficiency and clean energy technology, which ranges from clean coal to penetration of renewable in the power sector and also carbon capture and sequestration in both the power and oil and gas sectors.

4.4 Mitigation scenarios for Alberta

At the provincial level, in addition to Government of Alberta's initiative for sustainable and green energy development, Climate Change Central (C3), a non-profit organization working in this area has developed various consumer rebate programs and demonstration projects (Climate change central, 2007). The organization is also instrumental in the collective effort of developing a provincial carbon market, the first in Canada. C3 has developed three focus areas in order to seek environmental solutions and create new economic opportunities: clean energy, clean air and clean technology (Climate change central, 2007). Clean energy focuses on conservation of energy and resources, which are the low cost solutions to reduce energy. Among the few initiatives in this focus area are municipal energy efficiency assistance program, Alberta solar and Eco-energy retrofit program. Clean energy solutions to Alberta could deliver programs to building, community's municipalities, agriculture, and transportation sectors. In the focus area of clean air mainly emissions offset development and industry outreach is targeted, which has initiatives like carbon capture and storage, emission offset development, etc. The clean technology focus group has initiatives such as C3 Enviro Tech solutions, which would accelerate commercialization of environmental technologies by improving access to capital in the pilot and demonstration phase of product development (Climate change central, 2007).

In accordance with the focus of Alberta on clean energy/technology, mitigation scenarios are built to identify the low GHG emission pathways that are substantiated by well defined technology. Implementation of various mitigation options including renewable energy in Alberta is modeled and projected using LEAP. GHG mitigation scenarios are developed in order to identify the various pathways leading to low GHG emissions based on clearly defined and feasible technologies.

4.4.1 Modeling using LEAP

Mitigation actions can be developed for energy supply, energy use and non energy emissions in LEAP. As discussed earlier, each of the sectors has subsectors. Modeling in LEAP are done for energy supply sectors such as power sector, oil and gas sector, coal mining whereas energy use sector are mainly residential, commercial, industrial and transport sectors. The mitigation scenario modeling options includes input of the key parameters on the characteristics of the energy system (e.g., activity level or penetration rates of various mitigation actions and final energy intensity of a particular energy efficient activity for reference and mitigation cases).

Following mitigation scenarios are projected based on the available data and resource use in Alberta. Both supply and demand side scenarios for Alberta are considered for developing the same. Supply side mitigation is developed for renewable energy option such as nuclear, hydro and wind generation in Alberta. Also the mitigation options in supply side include clean coal technologies such as supercritical and ultra supercritical coal power plants. In oil and gas sector the incorporation of CCS forms a major scenario in non conventional oil (bitumen) extraction and upgrading processes. In demand side management, scenarios are built based on efficiency improvement in residential and commercial sector for various mitigation options. In order to incorporate this, the required mitigation options related to the energy devices like lighting and appliances are modeled for reduction in overall energy; and this is projected for a study period of 25 years (2005-2030).

4.5 Input data and assumption

Following sections give the details on various input data and assumptions for the mitigation scenarios developed in LEAP for the province of Alberta.

4.5.1 Mitigation scenario 1 - Alberta's residential sector - efficient lighting

In this scenario all the houses in Alberta are expected to have efficient lighting by end of the study period. The average household in Canada has about forty light bulbs of which sixteen are used regularly. The majority of lamps are 60 watt incandescent (NRTEE, 2006c). Over the study period (2005-2030), it is assumed that all households will have compact fluorescent lamps (CFL) and use of LED lighting will be common. In order to build this scenario the following inputs are introduced in LEAP.

Final energy intensity is the overall energy intensity of any device, which is given as total energy per unit of measurement of that sector (e.g. kWh of energy consumed per household per year). In the case of Alberta, the basis is number of households. The energy intensity of efficient lighting is 30% lower than existing systems (NRTEE, 2006b). Table 4-1 gives the details of energy intensities of existing and efficient bulbs. The penetration rate of new efficient lighting systems is assumed to be 100% by the end of the study period (2030).

Table 4-1: Data for efficient lighting scenario in Alberta's residential sector

Type of House	Energy intensity (MJ/household) (2005)	Energy intensity (MJ/household) (2030)
Single detached	6,700	4,790
Single attached	4,264	2,985
Apartments	1,860	1,302
Mobile homes	4,270	2,989

4.5.2 Mitigation scenario 2 - Alberta's residential sector - efficient appliances

Over the past few decades, the average efficiency of major household appliances has increased dramatically. The average energy consumption by fridges and freezers has dropped by 40%. Over the next 50 years, average electrical appliance efficiency is expected to increase further by 25%. Stoves and dryers are expected to become 20% more efficient (NRTEE, 2006b). Table 4-2 gives the details of energy intensities of all types of households and major appliances considered for efficiency improvement.

Table 4-2: Data for efficient appliance scenario in Alberta's residential sector

Type of Household	Final energy intensity (MJ/household)[a] (2005)	Final energy intensity (MJ/household)[a] (2030)
Single detached		
Refrigerator	3,351	2,513
Freezer	1,260	1,008
Dishwasher	287	215
Cloth washer	207	165
Clothes dryer (NG dryer)	3,023	2,418
Range	234	187
Single attached		
Refrigerator	3,156	2,376

Type of Household	Final energy intensity (MJ/household)[a] (2005)	Final energy intensity (MJ/household)[a] (2030)
Freezer	1185	948
Dishwasher	270	215
Cloth washer	195	156
Clothes dryer (NG dryer)	2,848	2,278
Range	221	176
Apartment		
Refrigerator	2,313	1,735
Freezer	880	704
Dish washer	198	158
Cloth washer	143	114
Clothes dryer (NG dryer)	2,084	1,667
Range	161	128
Mobile homes		
Refrigerator	3,087	2,315
Freezer	1,163	930
Dish washer	265	212
Cloth washer	191	152
Clothes dryer (NG dryer)	2,791	2,232
Range	216	172

[a](NRTEE, 2006b)

The penetration rate of new efficient appliances is assumed to be linear over the planning horizon. It is zero in the base year and projected to be 100% by the end of study period (2030).

4.5.3 Mitigation scenario 3 - Alberta's commercial sector – efficient lighting

In the commercial sector of Alberta there is a significant opportunity for efficiency improvement in the lighting sector. All the existing bulbs can be replaced with CFL or LED bulbs by the end of study period (i.e. 2030). According to National Round Table on the Environment and the Economy (NRTEE) long term strategy on climate change, there is a potential for high efficiency T8 systems with electronic ballasts, occupancy sensors and day lighting which can become a standard (NRTEE, 2006b). High-efficiency electronic ballast is described as one that provides the same level of light output as similar standard electronic ballast, but does so more efficiently. High-efficiency ballasts can be used in any general fluorescent lighting application and are ideally suited for use with 25W, 28W and 30W energy-saving T8 lamps and high-lumen T8 lamps (Efficient buildings.org, 2006).

In the base case scenario, the existing lighting in the commercial sector has an energy intensity of 0.16 GJ/m^2 in the base year 2005. This is assumed to reduce by 50% by 2030 as a result of use of efficient lighting. Hence in 2030 the final energy intensity is 0.08 GJ/m^2. The penetration of new efficient appliances is assumed to be 0 in the base year and it is assumed to penetrate 100% of the sector by the end of study period (2030) (NRTEE, 2006a).

4.5.4 Mitigation scenario 4 – Alberta's commercial sector – efficient auxiliary equipment and motor

Auxiliary equipment and motors in commercial sector have a large potential for energy efficiency improvements. In the mitigation scenario the final energy intensity is assumed to be decreasing over the study period of 25 years. It is assumed that there is a reduction of final energy intensity by 20% by year 2020(NRTEE, 2006a). The final energy intensities of auxiliary equipment and motors from 2005 to 2030 are given in Table 4-3.

Table 4-3: Data for efficient auxiliary equipment and motor in Alberta's commercial sector

Energy intensity (GJ/m2) [a]	2005	2010	2015	2020	2025	2030
Electricity	0.173	0.159	0.147	0.136	0.136	0.136
Natural gas	0.006	0.006	0.005	0.005	0.005	0.005
Light fuel oil and kerosene	0	0	0	0	0	0
Heavy fuel oil	0.002	0.002	0.002	0.002	0.002	0.002
Steam	0	0	0	0	0	0
Other	0.006	0.006	0.006	0.006	0.006	0.006

[a](NRTEE, 2006b)

There is an increase of total area of commercial sector from 93.9 million m^2 in 2005 to 190 million m^2 by 2030 (Natural Resource Canada, 2006a).

4.5.5 Mitigation scenario 5 – Alberta's commercial sector – efficient water heating

In the commercial sector, water heating consumes a significant amount of energy and has the potential for GHG mitigation. In the mitigation scenario the use of natural gas and heavy fuel oil is expected to decrease after 2025 as projected in a countrywide study (NRTEE, 2006a). Table 4-4 has the details of final energy intensity for 25 year period. There is an increase of total area from 93.9 million m^2 in 2005 to 190 million m^2 by 2030 of commercial sector (Natural Resource Canada, 2006a).

Table 4-4: Data for efficient water heating in Alberta's commercial sector

Final Energy Intensity (GJ/m2)[a]	2005	2010	2015	2020	2025	2030
Electricity	0.004	0.004	0.004	0.004	0.004	0.004
Natural gas	0.16	0.146	0.13	0.11	0.10	0.104

Final Energy Intensity (GJ/m2)[a]	2005	2010	2015	2020	2025	2030
Heavy fuel oil	0.002	0.002	0.002	0.001	0.001	0.001
Other	0.005	0.005	0.005	0.005	0.005	0.005

[a](NRTEE, 2006b)

4.5.6 Mitigation scenario 6 – Alberta's industrial sector – efficiency improvement

In the Alberta's industrial sector, GHG mitigation is possible in oil and gas, construction, mining, paper and pulp and chemical industries.

4.5.6.1 Construction industry

No change in final energy intensity over the 25 year study period (NRTEE, 2006b). The base year final energy intensity is shown in Table 4-5.

Table 4-5: Alberta construction industry

Construction (MJ per CDN)	Electricity	Natural gas	Diesel fuel oil	Still gas and petroleum coke
2005	0	0.182	0.67	0.087

4.5.6.2 Petroleum industry

No change in final energy intensity over 25 years study period (NRTEE, 2006b). It remains same as in 2005 and is shown in Table 4-6.

Table 4-6: Final energy intensity in Alberta's petroleum industry

Petroleum refining final energy intensity (MJ per CDN)	Electricity	NG	DFO	Heavy fuel oil	Still gas and petroleum coke
2005	24.8	71.42	0	0	199.5

4.5.6.3 Cement industry

There is a decrease in energy intensity for cement industry at the rate of 0.1% annum as shown in

Table 4-7 (NRTEE, 2006b).

Table 4-7: Final energy intensity in Alberta's cement industry

Cement industry (MJ per CDN)	2005	2010	2015	2020	2025	2030
Other	2.9	2.92	2.91	2.89	2.88	2.8

4.5.6.4 Chemical industry

There is a decrease in energy intensity at the rate of 2.5% per annum as shown in Table 4-8 (NRTEE, 2006b).

Table 4-8: Final energy intensity in Alberta's chemical industry

Energy intensity (MJ per CDN)	2005	2010	2015	2020	2025	2030
Electricity	8.31	7.32	6.45	5.68	5.00	4.4

Natural gas	33.0	29.1	25.65	22.6	19.91	17
Other (steam)	1.85	1.63	1.43	1.26	1.11	0.9

4.5.6.5 Other manufacturing industry

There is a decrease in energy intensity at the rate of 2.85 % per annum as shown in Table 4-9 (NRTEE, 2006b) for the other manufacturing industries.

Table 4-9: Final energy intensity in Alberta's other manufacturing industry

Energy intensity (MJ per CDN)	2005	2010	2015	2020	2025	2030
Electricity	0.99	0.859	0.745	0.64	0.56	0.48
Natural gas	3.61	3.132	2.718	2.35	2.04	1.77
Heavy fuel oil	0.009	0.008	0.007	0.006	0.005	0.004
Other	0.317	0.275	0.239	0.20	0.18	0.15

4.5.6.6 Forest industry

There is no change in the final energy intensity of forest industries based on the NRTEE report which has no projections in consideration for forest industry (NRTEE, 2006b). This is the basis of assumption in this scenario. For the base year (2005) the final energy intensity is 2.09 MJ per CND.

4.5.6.7 Mining industry

There is a decrease in final energy intensity of mining industry at the rate of 1% per annum. This assumption is based on earlier studies (NRTEE, 2006b). Table 4-10 shows the final energy intensity in Alberta's mining industry.

Table 4-10: Final energy intensity in Alberta's mining industry

Energy intensity (MJ per CDN)[a]	2005	2010	2015	2020	2025	2030
Electricity	3.53	3.357	3.192	3.036	2.887	2.746
Natural gas	9.06	8.616	8.194	7.792	7.41	7.047
Diesel fuel oil	1.45	1.379	1.311	1.247	1.186	1.128
still gas and Petroleum coke	6.8	6.467	6.15	5.848	5.562	5.289
LPG	1.1	1.046	0.995	0.946	0.9	0.856

[a](NRTEE, 2006b)

4.5.6.8 Pulp and Paper industry

Increase in final energy intensity is expected to be at the rate of 10% per annum. Although total energy intensity increases but the activity level (utilization) of electricity and other primary fuels reduces. It is projected that 80% of the energy will come from wood and biomass (NRTEE, 2006b). Table 4-11 shows the final energy intensity in Alberta's pulp and paper industry.

Table 4-11: Alberta pulp and paper industry's activity level[a]

Increase in GDP (billion CDN)	2005	2010	2015	2020	2025	2030
Pulp and paper[a]	541	551	563	574	586	597

[a](NRTEE, 2006b)

4.5.6.9 Crude bitumen production and upgrading

It is assumed that the final energy intensity in crude bitumen production and upgrading would decrease at the rate of 1% per year. Table 4-12 shows the final energy intensity in Alberta's bitumen production and upgrading process.

Table 4-12: Final energy intensity for bitumen production and upgrading[a]

Auxiliary Fuel use (MJ)	2005	2010	2015	2020	2025	2030
Bitumen production						
Electricity	0.007	0.006	0.006	0.006	0.005	0.005
Natural Gas	0.13	0.124	0.118	0.112	0.106	0.10
Bitumen upgrading						
Electricity	0.003	0.003	0.003	0.002	0.002	0.002
Natural Gas	0.063	0.06	0.057	0.054	0.051	0.04

[a]Diesel use is considered in the mining sub sector

In the reference scenario all the other sectors except mining and paper and pulp are expected to maintain constant GDP. Mining sector GDP is projected to grow at 3% per annum and Pulp and paper is expected to increase at 0.4% per annum. Chemical industry sector is expected to have growth of 2.7% per annum (NRTEE, 2006b). Table 4-13 shows the different activity levels for different mitigation scenarios in Alberta's industrial sector.

Table 4-13: Alberta industrial sector - activity levels for different mitigation scenarios

Activity level (billion CDN)[a]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Construction	11.492	11.49	11.49	11.49	11.49	11.49
Smelting and refining	0.05	0.05	0.05	0.05	0.05	0.05
Petroleum refining	0.217	0.22	0.22	0.22	0.22	0.22
Cement	0.136	0.14	0.14	0.14	0.14	0.14
Chemicals	2.26	2.507	2.782	3.087	3.425	3.8
Iron and steel	0.073	0.073	0.073	0.073	0.073	0.073
Other manufacturing	10.7	10.7	10.7	10.7	10.7	10.7
Forestry	0.478	0.478	0.478	0.478	0.478	0.478
Mining	20.75	24.055	27.886	32.328	37.477	43.446
Paper and pulp	0.541	0.552	0.563	0.574	0.586	0.598
Total	46.697	50.265	54.382	59.14	64.638	70.994

[a](NRTEE, 2006c)

4.5.7 Mitigation Scenario 7- Nuclear power generation in Alberta

4.5.7.1 Exogenous capacity

In the reference scenario, there is no projection of nuclear power plant in the planning horizon of 25 years. In the mitigation scenario a nuclear plant is assumed to be commissioned by 2017, hence there is an inclusion of nuclear power plant of 1000 MW capacity serving as base load plant for Alberta. Efficiency of the plant is considered to be 34.6% (IEA, 2005). Merit order of 1 is assigned based on the fact that nuclear plant will be operating as base load plant. The maximum availability of 90% is assigned to the nuclear power plant (IEA, 2005). Table 4-14 shows the exogenous capacity of nuclear power plants in Alberta.

Table 4-14: Alberta nuclear power plant exogenous capacity for mitigation scenario[a]

Nuclear plant (MW)	2005	2017	2030
Exogenous capacity	0	1000	1000

[a]assuming by 2017 the nuclear plant is constructed

4.5.8 Mitigation Scenario 8- Wind power generation in Alberta

4.5.8.1 Exogenous capacity

In this mitigation scenario, it is projected that all the coal power plants are shut down after 2015 and replaced by wind plant of similar capacity. The details of capacity additions are given in Table 4-15.

Table 4-15: Alberta wind power generation

Exogenous capacity (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	6182	1286	0	0	0
Wind[a]	298	750	6545	897	897	897

[a]assuming by 2015 there is a capacity addition of 5800 MW of new wind plants

In this scenario, there is an assumption that by 2015 wind power generation capacity in Alberta will be about 6,545 MW which will eventually become 8,900 MW by 2020 replacing all the coal plants in that year. This scenario is developed based on the discussion with Alberta's Department of Energy personnel (Alberta Innovates, 2010).

4.5.9 Mitigation Scenario 9- Hydro power generation in Alberta

4.5.9.1 Exogenous capacity

In this mitigation scenario for hydro based generation, it is projected that hydro generation will remain at 1000 MW till 2015 (AESO, 2006c). After 2020, the projected capacity of hydro generation would be 4000 MW which is assumed to be coming from new run of river hydro plant. This will be in place of additional coal plants. The coal plants are projected to have only 4,972 MW of generation capacity in 2020. The details of the capacity additions are given in Table 4-16.

Table 4-16: Alberta hydro power generation

Exogenous capacity (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5932	6432	4972	4972	4972
Hydro	900	983	100	4000	4000	4000

4.5.10 Mitigation Scenario 10-Mitigation options for coal power plants in Alberta

In order to understand the possible mitigation options for Alberta coal power plants two different categories of scenarios have been built in LEAP. First one uses efficiency improvement option with either IGCC, supercritical or ultra supercritical boilers in the power plants whereas the second option is to integrate carbon capture and storage (CCS) units in the existing power plants as well as in the new high efficient power plants.

In supercritical and ultra supercritical plants, increasing the temperature and pressure in a steam turbine increases the efficiency of the rankine steam cycle used in power generation, hence decreases the amount of fossil fuel consumed and the emissions generated (Susta and Seong, 2004). Table 4-17 illustrates the various parameters for supercritical and ultra supercritical power plants.

Table 4-17: Thermal characteristics of different coal plants[a]

Plant type	Steam Pressure	Steam Temperature	Efficiency
Conventional	165	538°C / 538°C	< 40.0
Supercritical	290	580°C/580°C	> 42.0
Ultra supercritical	365	700°C /700°C	> 48.0

[a](Susta and Seong, 2004)

In IGCC plants synthetic gas is generated by gasification of coal. This synthetic gas is used for power generation in a gas turbine and exhaust of the gas turbine is used to raise steam in a heat recovery boiler. The generated steam is further used in a steam turbine to produce power (US DOE, 2010b). This increases the overall efficiency as compared to direct coal combustion plants. The use of these two types of turbines - a combustion turbine and a steam turbine - in combination, known as combined cycle, is one reason why gasification-based power systems can achieve high power generation efficiencies (US DOE, 2010b). Hence, results in reduction of GHG emissions compared to the direct combustion option. IGCC plant has an energy efficiency of 38.4% (International Energy agency and Nuclear energy agency, 2005)

The second option of carbon capture and storage (CCS) is considered a leading technology for reducing CO_2 from fossil fuel based electricity generation plant and could permit the continued use of coal and gas while meeting GHG reduction targets (Page et al., 2009). A typical configuration of retrofitting a power plant with CCS is shown in Figure 4-1. The process without CCS simply comprises combustion, steam production, electricity generation via a turbine and flue gas discharge. With CCS, the extra stages of flue gas separation and either high- or low-pressure compression or liquefaction are required. The generation capacity of the turbine is reduced due to the heat (as steam) required for separation. Electricity requirements for separation, compression and liquefaction further reduce the net power output of the plant (Page et al., 2009).

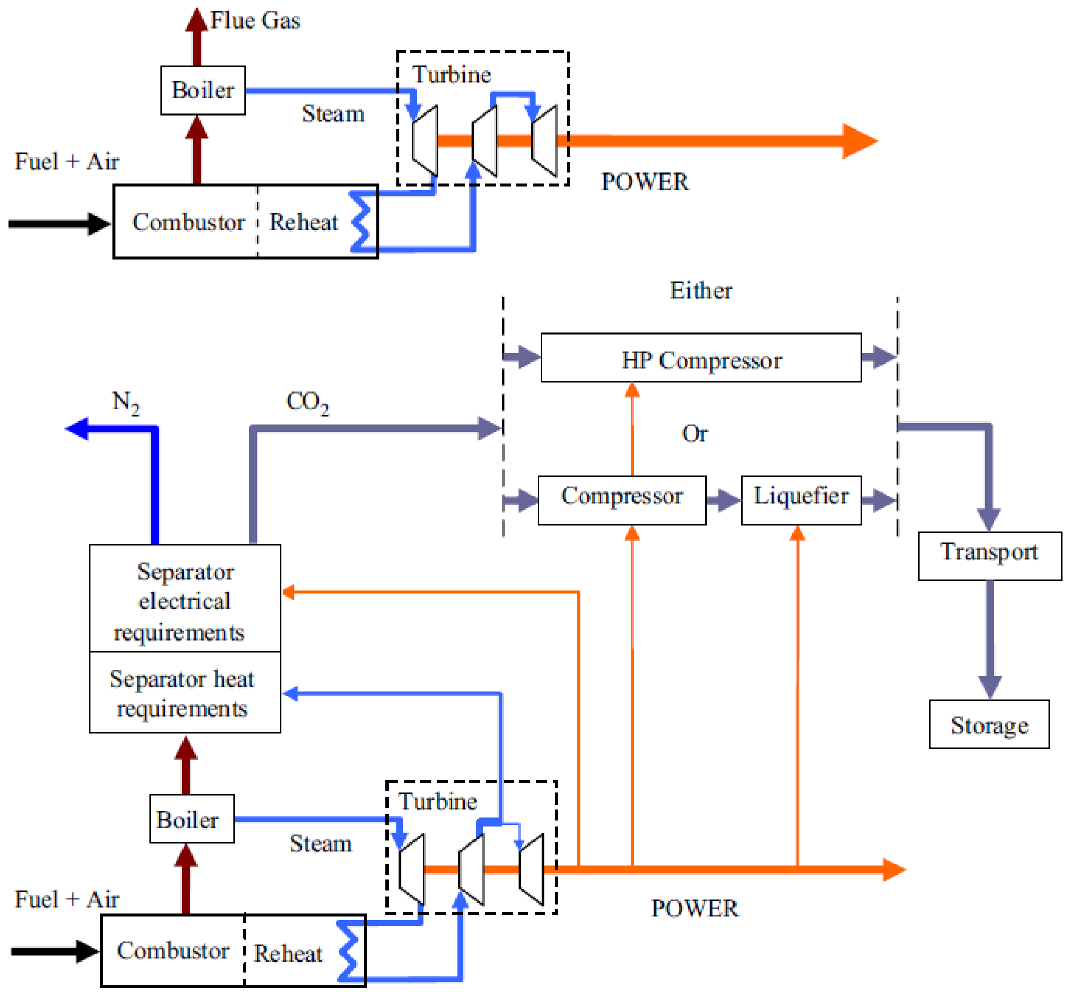

Figure 4-1: Schematic of a coal power plant with and without CCS (Page et al., 2009)

4.5.10.1 Existing subcritical coal plant with CCS - exogenous capacity

The existing power plants of Alberta are all subcritical plants except for Genesee 3 (Acton et al., 2006) which is a supercritical plant. In a subcritical plant, the super heater pressure and temperature are 150 bar and 540°C whereas in a supercritical plant such as Genesee 3 the super heater pressure and temperature are 280 bar and

600 ^{o}C (Rezvani et al., 2007). In order to understand the mitigation options with carbon capture and sequestration available in the existing coal plants, CCS technology is assumed to be penetrating significantly after 2015 and the scenario is developed based on converting all the existing coal plants (8,972 MW) with CCS option. The capacity of the same is shown in Table 4-18. This scenario is developed based on the discussion with Alberta's Department of Energy personnel (Alberta Innovates, 2010) and also on assumption of retrofitting all the existing coal plants of Alberta.

Table 4-18: Alberta subcritical plant with CCS

Sub Critical plant with CCS (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5932	0	0	0	0
CCS power plant	0	0	7632	8972	8972	8972

The auxiliary fuel requirement for the same is 0.14 PJ/PJ of energy produced (Harkin et al., 2009).

4.5.11 Mitigation Option 11- Alberta future coal power plants with and without CCS options

This scenario is developed in order to study the GHG mitigation in Alberta's coal power plants with efficiency improvement. All the existing old coal plants are subcritical plants with process efficiency of 34% (HHV) except the 450 MW Genesee plant with 38% efficiency (Alberta Electricity System Operator, 2005). Hence the scenarios are developed to understand the possible mitigation options of converting all the plants to supercritical (38%) and ultra supercritical (43%) plants thereby reducing the total emission from the plant (Acton et al., 2006). The increase in efficiency of the plant will result in less fuel consumption per kWh of electricity produced. Hence, the overall reduction in total fuel use will result in less GHG emission in the plant.

The possibility of integrated gasification combined cycle (IGCC) plant is studied as a mitigation option for Alberta. All the above mitigation options are also developed incorporating the CCS technology. The energy penalty (the extra energy that a CCS plant must generate to cater for the needs of increased auxiliary power consumption) also renders the reduction in power plant's operating efficiency and eventually shows up in the overall efficiency reduction when CCS is incorporated (Ordorica-Garcia et al., 2006).

4.5.11.1 Supercritical coal plant without and with CCS

In the first mitigation option under this category there is an assumption of converting all the coal plants into supercritical plant with efficiency improvement. The details of the exogenous capacities are given in Table 4-19.

Table 4-19: Exogenous capacities of supercritical plants (SPC) without CCS in Alberta

SPC - Exogenous capacity (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5932	5932	0	0	0
Supercritical coal plant	450	700	950	8972	8972	8972

The second mitigation option is to develop the supercritical coal plant incorporating CCS technology. The capacity additions are detailed in Table 4-20. The auxiliary power requirement is 0.131 PJ/PJ of energy produced (Page et al., 2009).

Table 4-20: Exogenous capacities of supercritical plants (SPC) with CCS in Alberta

Exogenous capacity SPC with CCS (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5932	1186	0	0	0
Supercritical coal plant with CCS	0	700	6535	8972	8972	8972

4.4.11.2 Ultra supercritical plant without and with CCS

This mitigation option is developed for ultra supercritical coal plant technology. The capacity additions in development of ultra supercritical plants without and with CCS are given in Table 4-21 and Table 4-22. The auxiliary fuel requirement in case of ultra supercritical coal plants with CCS are 0.133 PJ/PJ of energy produced (Page et al., 2009).

Table 4-21: Exogenous capacity - ultra supercritical plant without CCS

USPC (Exogenous capacity) (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5466	1000	0	0	0
Ultra supercritical coal plant	0	750	6645	8972	8972	8972

Table 4-22: Ultra supercritical plant with CCS - exogenous requirement

USPC with CCS (exogenous capacity) (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5932	1186	0	0	0
Ultra Supercritical Coal Plant with CCS	0	700	6535	8972	8972	8972

4.4.11.3 IGCC without and with CCS

This mitigation option is developed for IGCC coal plant to be developed in Alberta to study the impact of CCS implementation in these IGCC plants. The capacity additions for IGCC without and with CCS are detailed in Table 4-23 and Table 4-24.

Table 4-23: IGCC without CCS - exogenous capacity

IGCC without CCS	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	6182	1286	0	0	0
IGCC Plant	0	0	6345	8472	8472	8472

Table 4-24: IGCC with CCS - exogenous capacity

IGCC with CCS	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	6182	1286	0	0	0
IGCC plant with CCS	0	0	6345	8472	8472	8472

The auxiliary fuel requirement in case of IGCC plant without and with CCS option are 0.15 PJ and 0.182 PJ per PJ of energy produced, respectively (Page et al., 2009).

4.4.12 Mitigation Option 12- Biofuel options in Alberta

In this mitigation scenario both biodiesel and ethanol based fuels are incorporated in the transportation sector of Alberta. Biodiesel and ethanol are considered as renewable liquid fuels. These liquid fuels are considered carbon neutral over the life cycle as the amount of carbon released during its combustion is nearly the same taken up by the plant during its growth (NR Canada, 2008a). The use of these biofuels in place of diesel and gasoline can help in mitigation of GHG in the transportation sector. Biofuels (both ethanol and biodiesel) are projected to penetrate gradually at a similar level over the study period. The final energy intensity in the end use sectors of road and rail are calculated based on the total availability of biofuels at present and also projected intensity for the future based on Renewable portfolio standard (Environment Canada, 2006). For biofuels scenario in Alberta's transport sector, the activity level or penetration level is assumed to be 5% (by volume) of ethanol in all the vehicles with Gasoline and 2% of biodiesel in all the diesel vehicles. This remains same for all types of road and rail transportation (both freight and passenger). The details are as shown in Table 4-25.

Table 4-25: Alberta biofuel activity level

Activity level (%by volume)	2005	2012	2020	2025
Ethanol	0	5	5	5
Biodiesel	0	2	2	2

The final energy intensities for passenger small cars, passenger big cars, school buses, urban transit, intercity transport, trucks, passenger rail and freight rail will be same as the reference scenario as the total energy required remains constant.

4.4.13 Mitigation option 13- Hybrid cars options for Alberta

Hybrid electric vehicles also known as HEVs or hybrids are equipped with IC engines and electric motors. A hybrid's ICE engine, as in any ICE powered car, produces power through continuous, controlled explosions that push down pistons connected to a rotating crankshaft. That rotating force (torque) is ultimately transmitted to the vehicle's wheels. A hybrid's electric motor is energized by a battery, which produces power through a chemical reaction. The battery is continuously recharged by a generator that—like the alternator of a conventional car—is driven by the ICE (NREL, 2009). Implementation of hybrid cars in the transport sector would help in reduction of GHG emissions as the emission per unit distance travelled by a hybrid car is lower than the fossil fuel based cars (van Vliet et al., 2010). The mitigation option for hybrid cars is developed based on the assumption that by 2020 there will be about 70% penetration of the hybrid car technology in Alberta road sectors. This assumption is based on earlier study wherein fast and deep penetration scenario is considered for hybrid vehicles in Canada (NRTEE, 2009). Also with regard to the final energy intensity, the total gasoline energy consumption of hybrid cars is estimated to be 60% of the conventional vehicles (US DOE Energy Efficiency and Renewable Energy, 2010). The final energy intensities for passenger small cars and passenger big cars are given in Table 4-26.

Table 4-26: Final energy intensities for hybrid cars in Alberta

Hybrid car scenario(MJ/PK)	2005	2010	2015	2020	2025	2030
Natural gas	0	0	0	0	0	0
Motor Gasoline	1.6	1.6	1.6	1.6	1.6	1.6
Hybrid (ethanol)	0	1	1	1	1	1
Hybrid (Electricity)[a]	0	0.6	0.6	0.6	0.6	0.6

[a]Hybrid cars have reduced consumption of gasoline but have electricity requirement

4.4.14 Mitigation Option 14- CCS in oil sands - crude bitumen production

Carbon capture and storage (CCS) in oil and gas sector is a process that captures carbon dioxide (CO_2) emissions from the large produces of CO_2 like bitumen up graders and stores them in geological formations deep inside the earth. It takes CO_2 that would otherwise be emitted into the air and stores it one to two kilometers deep underground. CCS is successfully being used in Norway, Australia and in Denmark without adverse effects. This technology is successfully being used to enhance oil recovery in older fields throughout Alberta (CAPP, 2010).

This mitigation option is developed for carbon capture and sequestration option of CO_2 produced during the production of crude bitumen in oil sands operation. This operation is highly energy intensive and contributes to large GHG emissions in Alberta. In the year 2005, oil sands facilities were the second largest emitter of GHG with 20 MT CO_2 equivalents which represents 19% of the total reported GHG emissions of Alberta (Alberta Environment, 2006). In this mitigation scenario it is assumed that by 2015 the first Alberta CCS plant in the oil sands will be operational and slowly the capacity of production will increase over the study period of 25 years. This assumption is developed based on NRTEE's fast and deep carbon pricing pathway in which there is a major contribution of GHG emission reduction indicated by means of incorporation of CCS plant (NRTEE, 2009). The exogenous capacity for this scenario is shown in Table 4-27.

Table 4-27: CCS in oil sands crude bitumen production - exogenous capacity

CCS in crude bitumen production (Million BOE/Y)	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Bitumen extraction	388	494	600	782	782	300
Bitumen extraction with CCS	0	0	550	1200	1200	2000
Total	388	494	1150	1982	1982	2300

By 2020 about 1200 million BOE/Y, (out of total 1982 million BOE/Y) will be produced by using CCS technology. By 2030 CCS is assumed to penetrate up to 2000 million BOE/Y. The auxiliary fuel requirement is shown in Table 4-28.

Table 4-28: CCS in oil sands crude bitumen production - auxiliary fuel requirement

Auxiliary fuel use (MJ/GJ of energy produced)	2005	2030
Electricity (without CCS)	6.5	6.5
Natural gas (without CCS)	130	130
Electricity (with CCS)	8.5	8.5

4.4.15 Mitigation Option 15- CCS in oils sands with SCO production

This mitigation option is developed for carbon capture and sequestration option for crude bitumen upgrading process in the upgraders in Alberta, which is also highly energy intensive and contributor of significant GHG emissions in Alberta. In this mitigation scenario it is assumed that by 2015 the first Alberta's CCS plant in the oil sands will be operational and slowly the capacity of production will increase over the study period of 25 years. This assumption is based on earlier published studies for the fast and deep emission reduction pathway to Government of Canada's target for GHG reduction using CCS technology (NRTEE, 2009). The exogenous capacity for this mitigation scenario is shown in Table 4-29.

Table 4-29: CCS in oil sands with SCO production - exogenous capacity

CCS in SCO production	2005	2010	2015	2020	2025	2030
Bitumen refining	200	350	465	365	365	400
Bitumen refining with CCS	0	0	200	400	400	800
Total	200	350	665	765	765	1200

By 2020 about 400 million BOE/Y (out of total 765 million BOE/Y) will be produced by using CCS technology. By 2030 CCS is assumed to penetrate up to 800 million BOE/Y. The auxiliary fuel requirement for the upgrading process with CCS is shown in Table 4-30.

Table 4-30: CCS in oil sands with SCO production - auxiliary fuel requirement

Auxiliary fuel use (MJ/GJ of energy produced)	2005	2030
Electricity (without CCS)	2.9	2.9
Natural Gas (without CCS)	62.6	62.6
Electricity (with CCS)	3.8	3.8

4.5 Results and discussion

4.5.1 Results of implementation of mitigation scenarios in residential sector of Alberta

For Alberta's residential sector two mitigation scenarios were developed. The first one is in the lighting subsector and the second is in the appliance subsector. Both were modeled for efficiency improvement. The results of the mitigation scenario for efficiency improvement are evident in both demand and transformation sectors. In these scenarios, there is a reduction in demand of energy and as a result there is reduction in transformation output. The details of the demand sector are given in Table 4-31.

Table 4-31: Alberta residential sector mitigation- demand reduction

Energy demand (PJ)	2005	2010	2015	2020	2025	2030
Reference case	2274	2573.7	2923.4	3347.6	3905.2	4662.5
Efficient appliances	2274	2572.2	2920.2	3342.3	3897.4	4651.7
Demand reduction (Efficient appliance vs. Reference)	0	-1.5	-3.2	-5.3	-7.8	-10.8
Efficient lighting	2274	2573.3	2922.5	3346	3902.8	4659.2
Demand reduction (Efficient lighting vs. Reference)	0	-0.4	-0.9	-1.6	-2.4	-3.3

Results indicate that the overall energy demand reduction in 2030 is 11 PJ by use of efficient appliances and 3 PJ due to the use of efficient lighting. The total energy transformation output after use of mitigation strategies is as shown in Table 4-32.

Table 4-32: Alberta residential sector mitigation - transformation output reduction

Output (million GJ)	2005	2010	2015	2020	2025	2030
Reference	225.1	274.5	338.5	399.3	462.6	528.8
Efficient appliances	225.1	273	335.6	393.8	456.9	522.6
Output reduction (Efficient appliance vs. reference)	0	-1.5	-2.9	-5.5	-5.7	-6.2
Efficient lighting	225.1	274.1	337.6	397.6	460.9	527.1
Output reduction (Efficient lighting vs. reference)	0	-0.4	-0.9	-1.7	-1.7	-1.7

For the appliance subsector, the overall energy output reduction is 6.2 PJ whereas for the lighting sector it is 1.7 PJ by 2030. The total energy conversion output reduction is a result of lower production requirement, corresponding decreased transmission and distribution losses and also lesser auxiliary fuel consumption.

The overall GHG reduction achievable is shown in Table H-1 in Appendix H and also in Figure 4-2 below. The total reduction in GHG in the appliance subsector is 1.72 MT of CO_2 equivalents per year by 2030 and in the lighting subsector it is about 0.5 MT of CO_2 equivalents per year by 2030.

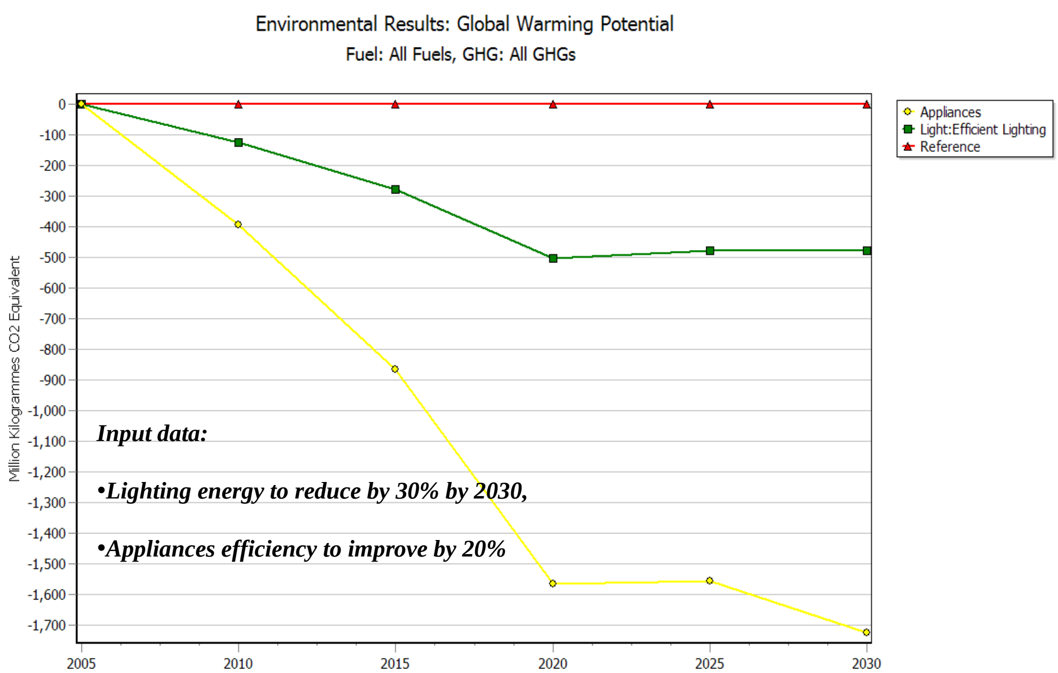

Figure 4-2: Alberta's residential sector GHG mitigation due to efficient lighting and appliances

In Figure 4-2, the spike in the year 2020 (indicating higher GHG mitigation) is due to increase in natural gas plants (new additions) which offsets the capacity increase by coal plants and Alberta grid dispatches more power by gas plant rather than coal plant. Since GHG emission from natural gas based power plants is lower as compared to coal power plants (DOE, 2000), the reduction in GHG is more when more natural gas based power is generated. After 2020, no new additions of plants are considered; hence there is a balanced dispatch from coal and gas plants. The approximate GHG mitigation between 0.5 and 1.7 MT of CO_2 equivalents per year can be achieved depending on the kind of dispatch in any year between 2010 and 2030.

4.5.2 Results of implementation of mitigation scenarios in commercial sector of Alberta

Commercial sector GHG mitigation options are in lighting, water heating and auxiliary equipment and motor. GHG mitigation is studied for efficient lighting, high efficiency motors and efficient auxiliary equipment. The demand and transformation output reductions are given in Table H-2 and H-3 in Appendix H. The total reduction in transformation output is estimated to be 14 PJ/yr in commercial auxiliary equipment and motor, none in commercial water heating and 1 PJ/yr in lighting sector by 2030. The total GHG emission reduction is estimated to be 1.8 MT of CO_2 equivalents per year by 2030 for commercial auxiliary equipment and motor, 0.6 MT of CO_2 equivalents in commercial water heating and 0.8 MT of CO_2 equivalents in commercial lighting sector. The spike in year 2020 is due to Alberta's grid dispatch primarily by gas plant during that period. There are new capacity additions which lowers the capacity of power dispatched by coal plant. The total mitigation possible is between 0.9 and 1.8 MT of CO_2 equivalents between 2015 and 2030.

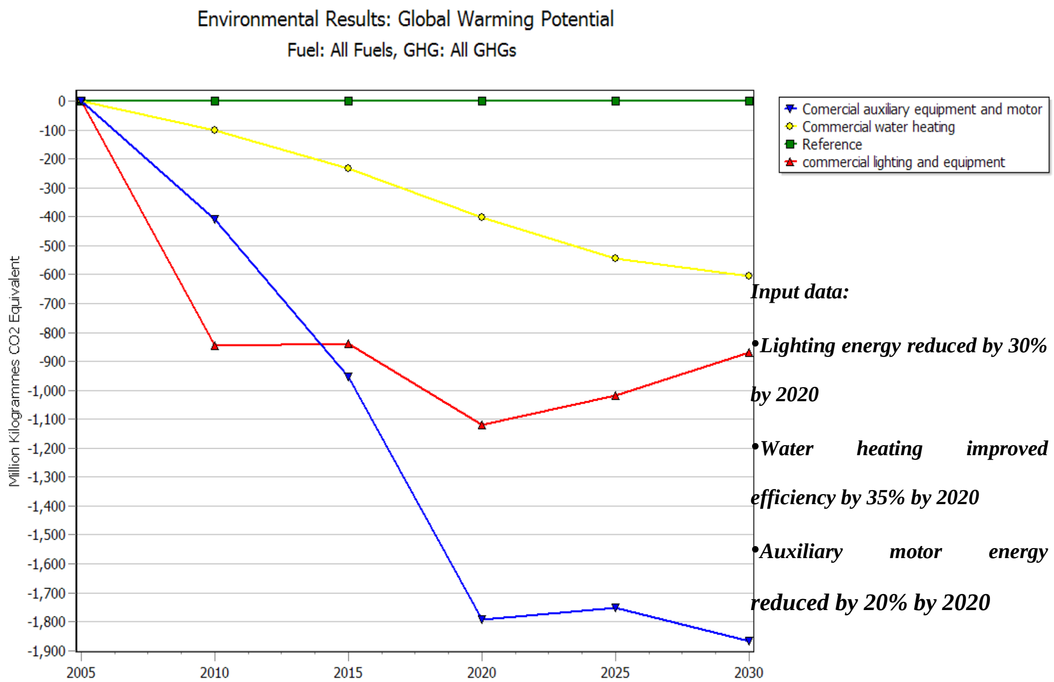

Figure 4-3: Alberta's commercial sector GHG mitigation scenarios (due to efficient lighting, water heating and auxiliary equipment and motor)

4.5.3 Results of implementation of mitigation scenarios in industrial sector of Alberta

Alberta's industrial sector GHG mitigation scenario has been developed for energy intensity improvement in oil and gas sector and efficiency improvements in different industrial sectors which also include the oil and gas sector auxiliary fuel usage reduction. The total demand reduction is estimated to be 340 PJ per year by 2030 as detailed in Table H-5 in Appendix H. Table H-6 in Appendix H gives the transformation output reduction which is about 76 PJ by 2030. Total GHG mitigation achievable is 46 MT of CO_2 equivalents per year by 2030 as shown in Figure 4-4. Hence a large mitigation potential is possible in the industrial sector of Alberta.

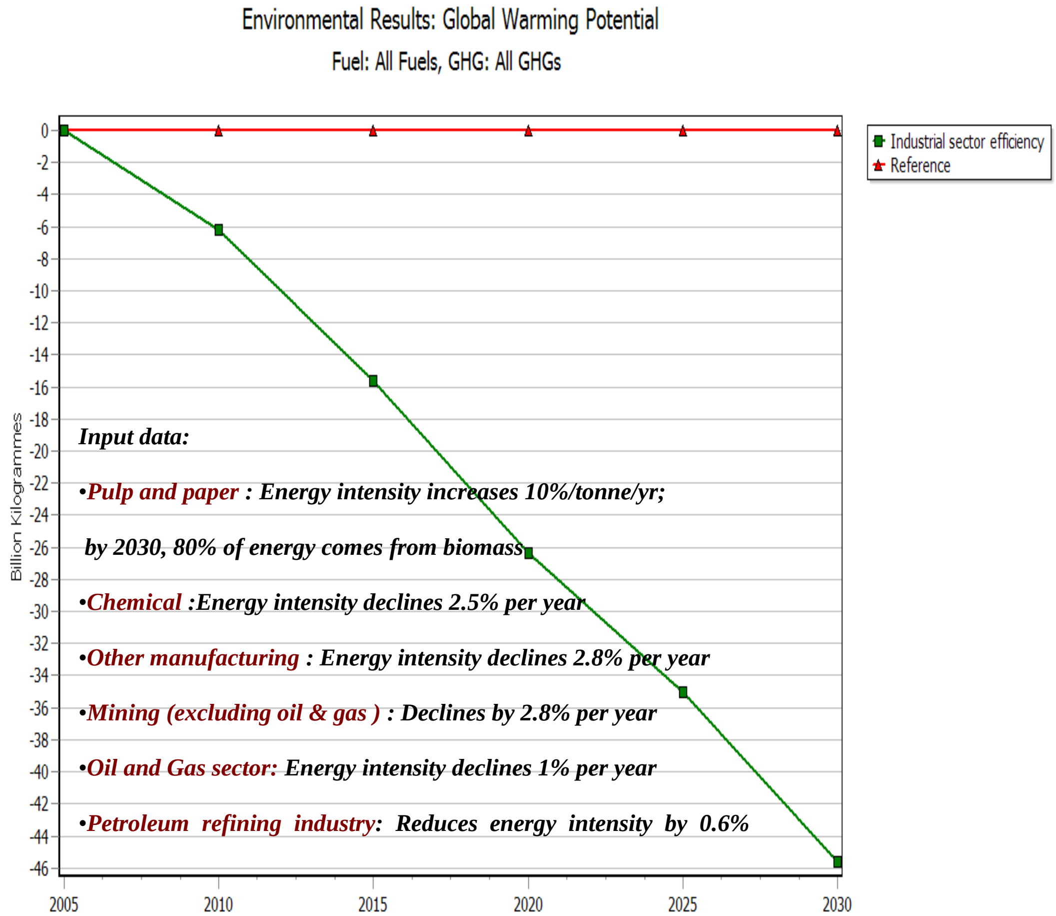

Figure 4-4: Alberta's industrial sector GHG mitigation scenario results

4.5.4 Results of implementation of mitigation scenario in transport sector of Alberta

Alberta's transport sector mitigation scenarios are characterized by inclusion of biofuels in the road and freight sector, and also penetration of hybrid cars into the passenger cars in road subsector. The total GHG reduction in the transport sector by penetration of hybrid cars and biofuel is estimated to be 3.38 MT and 1.92MT of CO_2 equivalents per year respectively by 2030; as detailed in Table H-8 in Appendix H and Figure 4-5 below. Hybrid cars although have reduction in gasoline related emission but since the plug- in vehicles consume electricity for charging the battery, there is a net increase in electricity requirement due to increase in penetration of hybrid which will result in lowering the overall GHG reduction achievable in the transport sector. In case of biofuel blend there is a considerable increase in ethanol and biodiesel fuel consumption to achieve the equivalent energy demand provided by the fossil fuel.

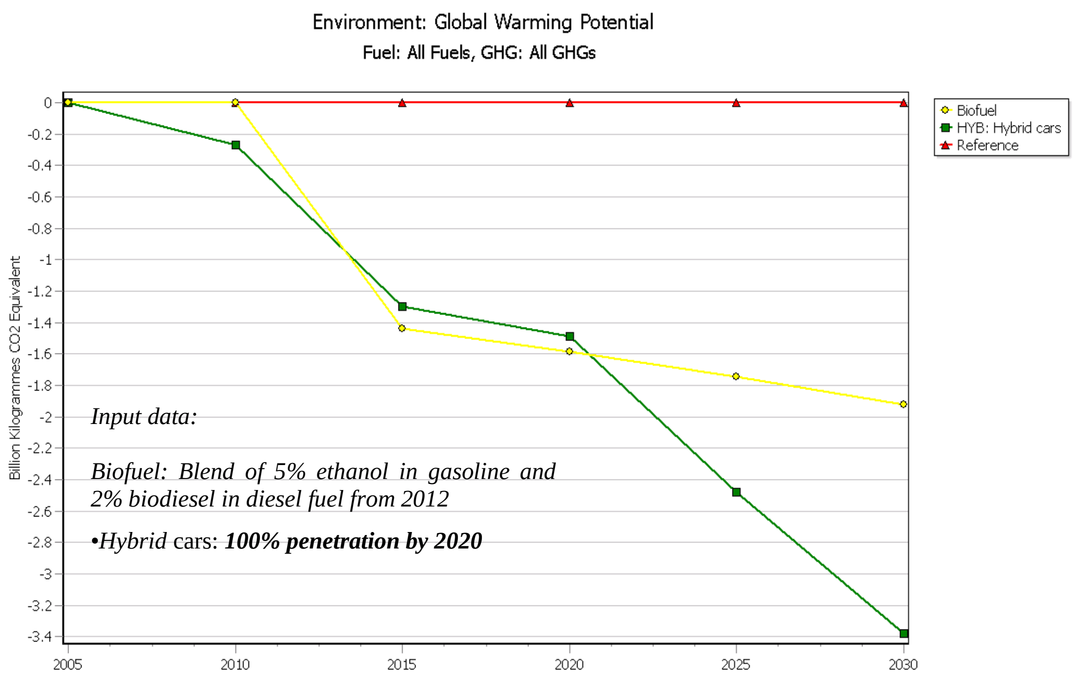

Figure 4-5: Alberta's transport sector mitigation scenario results

4.5.5 Results of implementation of mitigation scenarios in Alberta's power sector

Alberta's power sector has been studied for various GHG mitigation options in this study. Following are the results of some of the scenarios developed for efficiency improvement and total GHG reduction options for Alberta's power generation sector.

4.5.5.1 Supercritical coal plant with and without CCS

The reduction in total transformation output is shown in Table I-1 in Appendix I. The efficiency improvement and the total capacity of new plants replacing the existing coal plants will contribute in the overall GHG emission reduction. The incorporation of CCS plant to the supercritical coal plant results in more auxiliary power requirement and hence the overall efficiency of the plant is reduced.

The overall reduction in GHG emissions for both the above mentioned cases is given in Table I-2 in Appendix I. The total estimated reduction by 2030 is estimated to be 20 MT of CO_2 equivalents per year for a supercritical coal plant without CCS whereas with CCS the estimated reduction is about 21 MT of CO_2 equivalents per year, as shown in Figure 4-6 below. The difference in GHG reduction with and without CCS plants is marginal because of the higher auxiliary power requirement with a CCS plant and also due to the overall decrease in efficiency with an increase in number of operating units due to CCS.

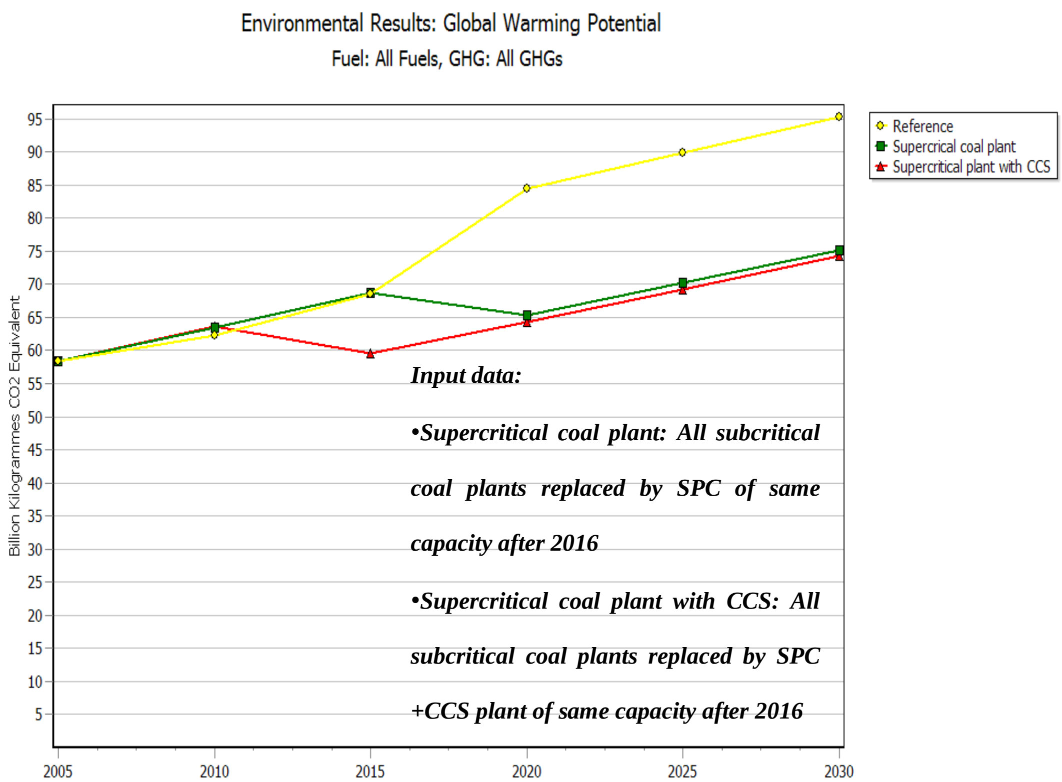

Figure 4-6: Results of power plant mitigation scenarios in Alberta (implementation of supercritical plant with and without CCS)

4.5.5.2 Ultra supercritical coal plant with and without CCS

In ultra supercritical plant, there is a further efficiency improvement as compared to supercritical plant. The total number of new plants (capacity in MW) replacing the existing subcritical coal plants will contribute to total reduction of transformation output. For an ultra supercritical plant there is no net total reduction in output by the end of year 2030. The overall reduction in GHG emissions for both the above mentioned cases is given in Table I-3 in Appendix I. The total estimated reduction by 2030 is estimated to be 18 MT of CO_2 equivalents per year for an ultra supercritical coal plant without CCS. On the other hand, with CCS the estimated reduction is about 69 MT of CO_2 equivalents per year by 2020. There is a significant amount of GHG reduction in the ultra supercritical coal plant with CCS as the overall decrease in fuel consumption (due to increased efficiency). Replacement of existing coal plant by ultra supercritical coal plant with and without CCS enables a significant GHG reduction. Figure 4-7 gives the details of this GHG mitigation.

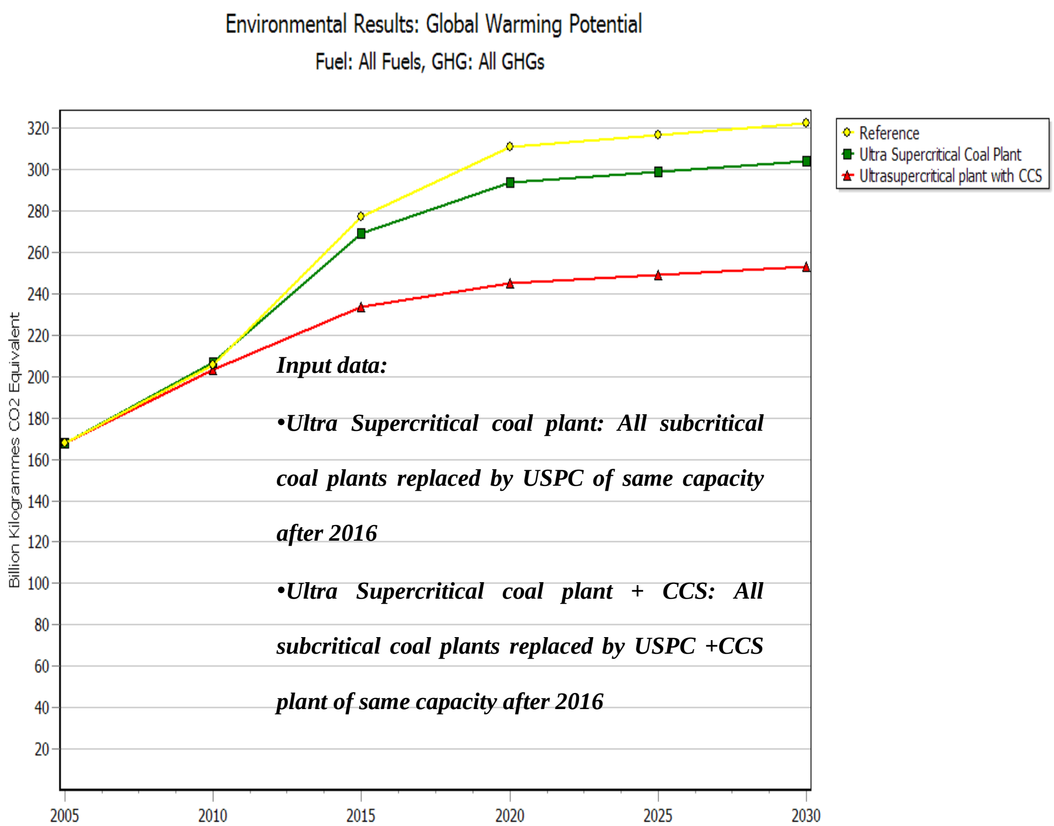

Figure 4-7: Results of power plant mitigation scenarios for Alberta (implementation of ultra supercritical plant with and without CCS)

4.5.5.3 IGCC coal plant with and without CCS

The IGCC coal plant scenario is based on the assumption that Alberta will have an IGCC coal plant facility by 2016 and in this scenario it is assumed that all the existing coal plants will be replaced by IGCC coal plants. The GHG emission reduction is shown in Table I-4 of Appendix I. The total GHG emission reduction by 2030 is estimated to be 8 MT of CO_2 equivalents per year without CCS plant and about 67 MT of CO_2 equivalents per year with CCS plant as shown in Figure 4-8.

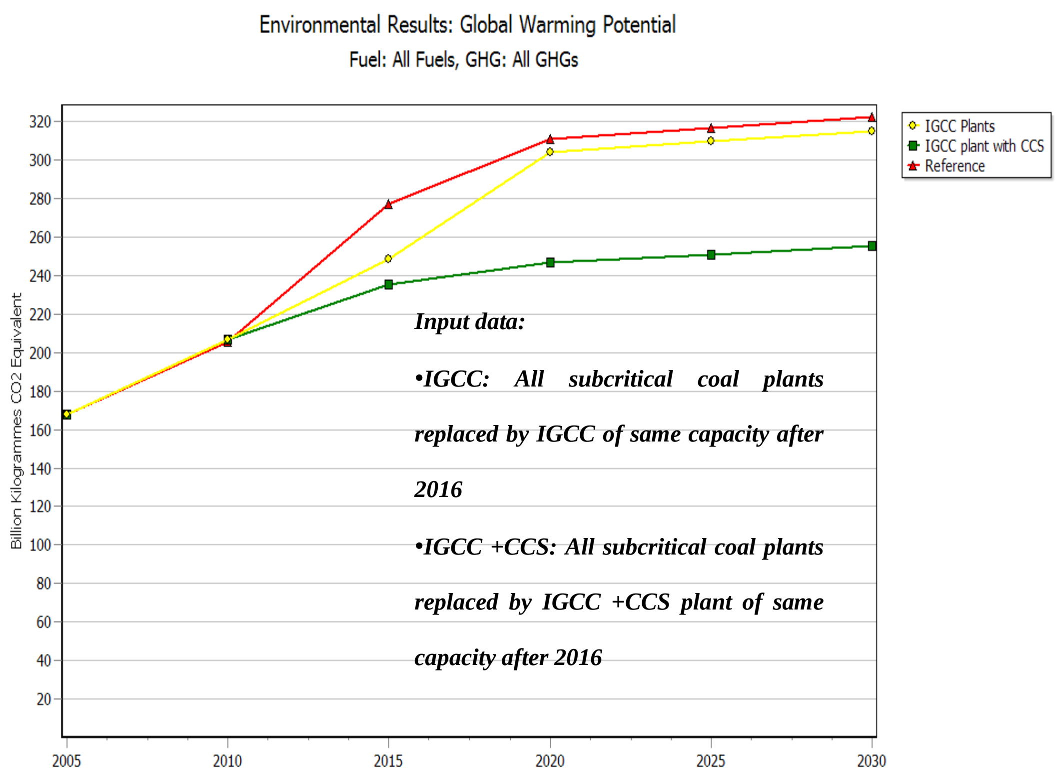

Figure 4-8: Results of power plant mitigation scenarios for Alberta (implementation of IGCC with and without CCS)

4.5.6 Results of oil sands mitigation scenario for Alberta

Total GHG mitigation achievable with CCS incorporation in crude bitumen production is 50 MT of CO_2 equivalents per year by 2030 as detailed in Table I-5 in Appendix I. In case of bitumen upgrading (synthetic crude oil production) with CCS plant the total achievable GHG reduction is 27 MT of CO_2 equivalents per year by 2030 as given in Table I-6 in Appendix I. In both cases there is no CCS operational in the reference case scenario. The overall mitigation is shown in Figure 4-9 below.

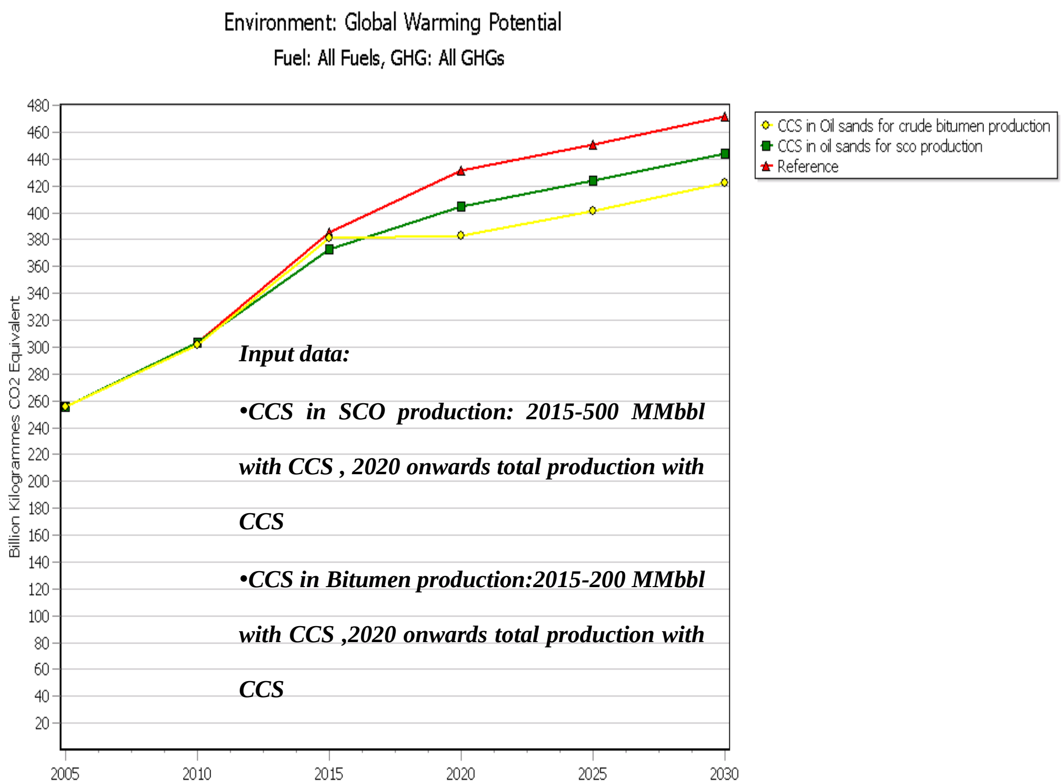

Figure 4-9: Total GHG mitigation achievable with CCS in Alberta oil sands

4.5.7 Results of implementation of mitigation scenarios related to renewable resources in power plant for Alberta

In LEAP three renewable resources have been modeled viz., wind, hydro and nuclear (although there is a considerable argument about nuclear being renewable). However for the sake of convenience of this study, nuclear plant has been modeled under the renewable sector. The total change in output is detailed in Table I-7 in Appendix I. In case of hydro and nuclear there is no change in the output. For wind the output reduction is 47 PJ by 2030. The overall GHG mitigation is shown in Table I-8 in Appendix I and also in Figure 4-10 below. GHG mitigation achievable with hydro power implementation under all the assumptions for Alberta is 29 MT of CO_2 equivalents by 2030. For wind and nuclear, GHG mitigations are 62 MT and 18 MT of CO_2 equivalents, respectively. Wind plants in Alberta have capacity factor of 35%, which is much lower than coal power plants. With such low capacity factor, substitution of coal power plant by wind results in increase in gas plant output as shown in Table 4-33.

Table 4-33: Transformation output (electricity generation) wind scenario vs. reference scenario

Change in output due to wind generation (PJ)[a]	2005	2010	2015	2020	2025	2030
Coal fired generation[a]	0	0	0	-241.8	-248.4	-253
Gas fired generation[b]	0	4.9	7.4	130.6	119.7	101.7
Wood waste	0	0	0	0.2	0.1	0
Wind	0	-0.7	-3.2	88	89.9	89.3
Hydro	0	0	0	1	0.5	0.1
Other	0	0.2	0.7	15.6	14.2	12.1
Import	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0
CCS power plant	0	0	0	0	0	0
Supercritical coal plant	0	0	0	0.6	0.3	0.1
Supercritical coal plant with CCS	0	0	0	0	0	0
Ultra supercritical coal plant	0	0	0	0	0	0
Ultra supercritical coal plant with CCS	0	0	0	0	0	0
IGCC plant	0	0	0	0	0	0
IGCC plant with CCS	0	0	0	0	0	0
Cogen electricity surplus from oil sands	0	-4.5	-4.8	1.6	3	3.2
Total	0	0	0	-4	-20.7	-46.5

[a]Negative values refer to decrease in output w.r.t reference scenario.
[b]Positive values indicate increase in output w.r.t reference scenario.

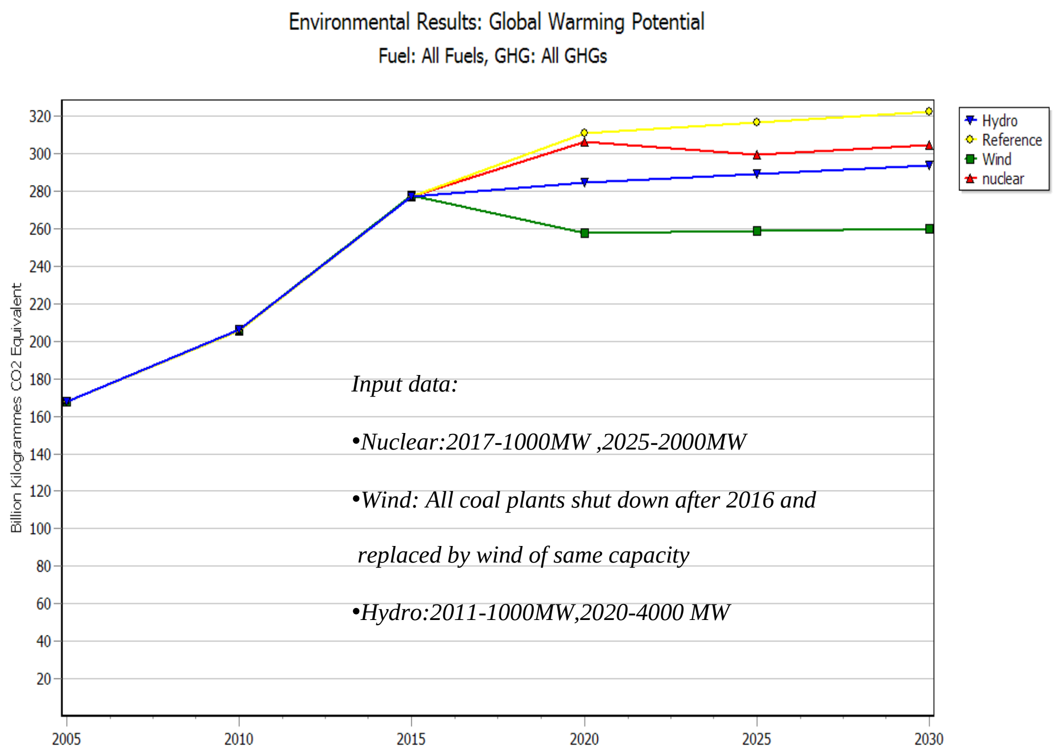

Figure 4-10: Results of power plant mitigation scenarios for Alberta due to implementation of renewable resource based technologies

4.5.8 Overall GHG mitigation achievable by various options in Alberta energy sector

The various mitigation options developed for Alberta energy sector is given in Table 4-34. Power Sector with Supercritical, Ultra supercritical and IGCC power plants with CCS options have a large potential for GHG reduction options, followed by CCS in oil sands and renewable power options. Ultra Supercritical and IGCC power plant have a GHG reduction potential of 65-70MT CO2 eq/year by 2030.

Industrial sector efficiency improvement also has a potential of 45 MT of GHG reductions by the year 2030. Residential and commercial sectors have lower GHG mitigation possibilities.

In the renewable power sector wind power generation has the GHG reduction option achievable up to 62MT CO_2 eq per year. In the transport sector GHG reduction of 4MT of CO_2 eq per year is achievable.

Table 4-34: Summary of GHG mitigation option projected for Alberta energy sector

GHG Mitigation Option ($MT\ CO_2$ eq/year)	Proposed Energy Sector	2010	2020	2030
Mitigation Option 1	Residential Sector (Appliances)	0.4	1.6	1.7
Mitigation Option 2	Residential Sector (Lighting)	0.2	0.5	0.4
Mitigation Option 3	Commercial Sector (Lighting)	0.9	1.1	0.8
Mitigation Option 4	Commercial sector(Auxiliary equipment and motor)	0.4	1.8	1.8
Mitigation Option 5	Commercial sector(water heating)	0.1	0.4	0.6
Mitigation Option 6	Industrial sector efficiency improvement	6.2	26.4	45.6
Mitigation Option 7	Transport sector(bio fuel)	-	1.58	1.92
Mitigation Option 8	Transport sector(Hybrid)	-	1.48	3.38
Mitigation Option 9	Supercritical Coal Plant with / without CCS	-	20/18.5	20/19
Mitigation Option 10	Ultra Supercritical coal plant with / without CCS	-	66/17.5	69/18.2
Mitigation Option 11	IGCC plant with / without CCS	-	64/6.8	67/7.5
Mitigation Option 12	Alberta Crude bitumen production with CCS	-	50	50.6
Mitigation Option 13	Alberta Synthetic crude oil production with CCS	-	27	27.8
Mitigation Option 14	Hydro power generation	-	26.4	28.7
Mitigation Option 15	Wind power generation	-	53.2	62
Mitigation Option 16	Nuclear power generation	-	4.6	17.5

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Chapter 5. Conclusions and Recommendation for Future Work

5.1. Conclusions

The province of Alberta is one of the largest hydrocarbon bases in North America. Energy sector is a major contributor to Alberta's economy both directly and indirectly contributing to GDP, income, employment as well as the total revenue of the province. In this research, critical issues pertaining to energy sector including their impacts have been analyzed. The key objectives of this research work included development of an energy flow sankey diagram for Alberta, development of emissions flow sankey diagram for Alberta and development of greenhouse gas mitigation scenarios for the Province of Alberta. These objectives were achieved by the using Long Range Energy Alternative Planning Systems Model (LEAP). The developed energy environment model based on LEAP gives the details of complete energy structure of Alberta covering all the major and minor energy demand users for entire energy demand and supply sectors. A reference case also called business as usual scenario is developed for a study period of 25 years (2005-2030) along with various plausible GHG mitigation scenarios. The GHG mitigation scenarios encompass the various demand side management scenarios such as efficient lighting and appliances in the residential and commercial sector as well as the supply side options such as renewable power generation, etc.

5.1.1 Development of Alberta's energy demand and supply for base year 2005 in LEAP

For the base year, all the energy demand as well as energy conversion sectors for Alberta were modeled in LEAP. The demand sectors included residential, commercial and institutional, industrial, agricultural and transport. These are the mainstream end users of primary and secondary energy generated in Alberta. Total energy produced in Alberta in 2005 was 10,643 PJ. The total energy demand in Alberta for the base year 2005 was 2,274 PJ from the energy demand sector and the remaining energy was transformed into secondary fuel in the transformation sector. This includes electricity generation, bitumen production and upgrading and also non energy sector energy demand which accounts to 2894 PJ. Total energy exported was 7,420 PJ in the base year 2005. Some of the energy in the oil and gas sector has been accounted from small imports into the province which mainly constitute of pentanes and condensates.

In the demand sector, most of the emissions are combustion related and is pertaining to the fuel usage in these sectors. In the base year, total emissions from the demand sectors of Alberta are 87 MT of GHG. The Industrial sector contributes to the majority of emissions followed by transportation sector which is based on natural gas and petroleum products. Industrial sector emissions for base year 2005 were about 41 MT CO_2 equivalents whereas road transport emits about 21 MT of CO_2 equivalents. Overall emission from oil products for Alberta demand sector is about 52 MT and from natural gas are about 35 MT of CO_2 equivalents. In the transformation sector, GHG emissions from the energy conversion sector were 157 MT in the year 2005. Electricity generation sector with the current mix of generation by coal, natural gas, wind, hydro and others had the total emissions of 51 MT in 2005. The rest of the emissions are form oil and gas sector of Alberta. Total Alberta emissions for the base year 2005 were 244 MT as modeled in LEAP.

5.1.2 Development of a sankey diagram of energy flows for the province of Alberta for base year

Sankey diagrams for Alberta were developed for the entire energy sector including the supply and demand sectors. The sankey diagram for energy flows includes Alberta energy supply and demand pattern shows the sankey diagram with exports. Figure 5-1 shows the details of energy use and supply patterns. As Alberta is a large exporter of oil and natural gas, a separate sankey diagram indicating the comparative flow data has been developed which is shown in Figure 5-2. This gives the overall picture of total energy production of Alberta and the in-house demand and the total exports out of the province. Exports are a significant portion of the total energy produced in Alberta. The third sankey diagram shows the detailed representation of industrial sector sankey diagram detailing the entire inputs fuel requirement to various oil and gas sector.

Figure 5-3 shows the sankey diagram for industrial sector. This is based on the details of energy consumption in the industrial sector. Total energy input into bitumen upgrading process is 1304 PJ. Total energy exported from upgrading process was 692 PJ. The input to Alberta refining sector was 455 PJ of SCO and 652 PJ of conventional crude oil.

5.1.3 Development of sankey diagram for GHG emission flows associated with major identified energy flow streams

The final sankey diagram representing the Alberta's GHG emission flows was developed. This gives the detailed view of emission flow from supply side to energy demand side.

Figure 5-4 shows the sankey diagram of GHG emission flows. In order to generate the sankey diagram, LEAP's inbuilt environmental database (emission factor) was used for each end use technologies. The results obtained from LEAP for GHG emissions from each of the demand and transformation sectors were used to develop the emission flow sankey diagram. Alberta's energy sector consists mainly of coal, natural gas, and crude oil. The emission flow diagram indicates the primary fuel emissions pertaining to each end user in the demand sector. Total emissions from Electricity generation sector were 50 MT in 2005. About 100 MT of CO_2 equivalents were generated by combustion and fugitive emissions of natural gas. Totally 82 MT of CO_2 equivalents was generated in 2005 of which 25 MT of CO_2 equivalents was emitted in industrial sector.

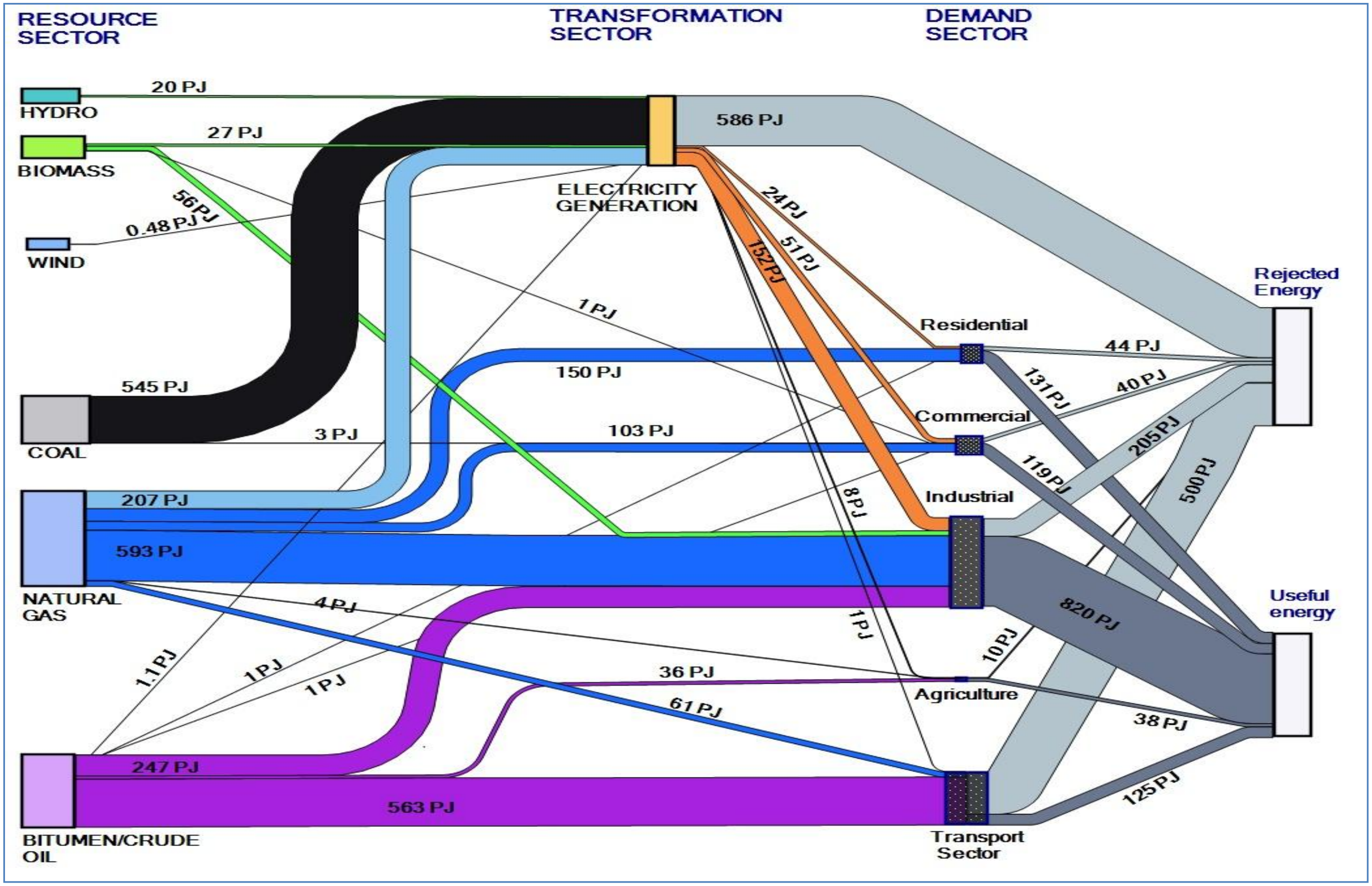

Figure 5-1: Alberta sankey diagram for the base year 2005

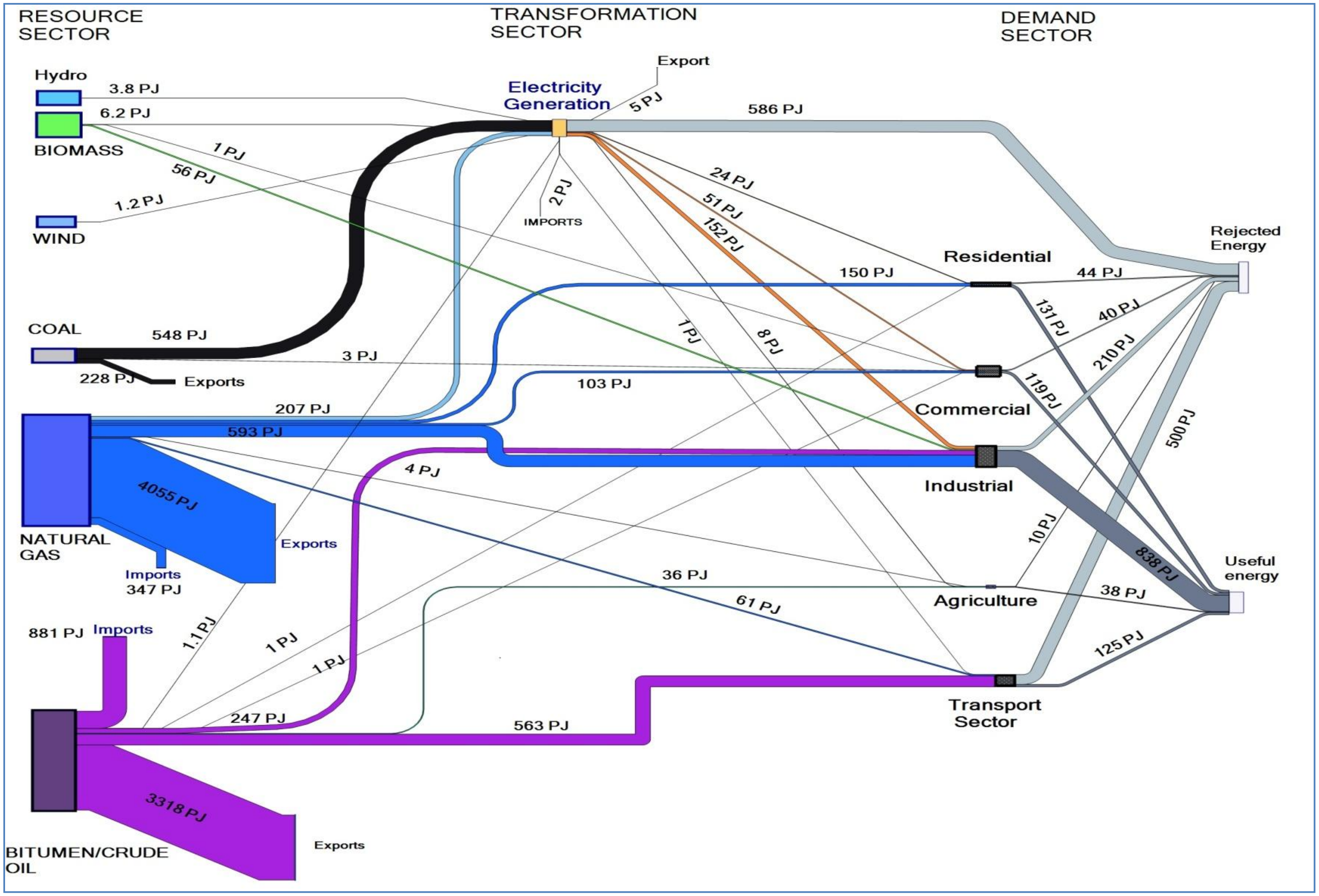

Figure 5-2: Alberta sankey diagram with exports

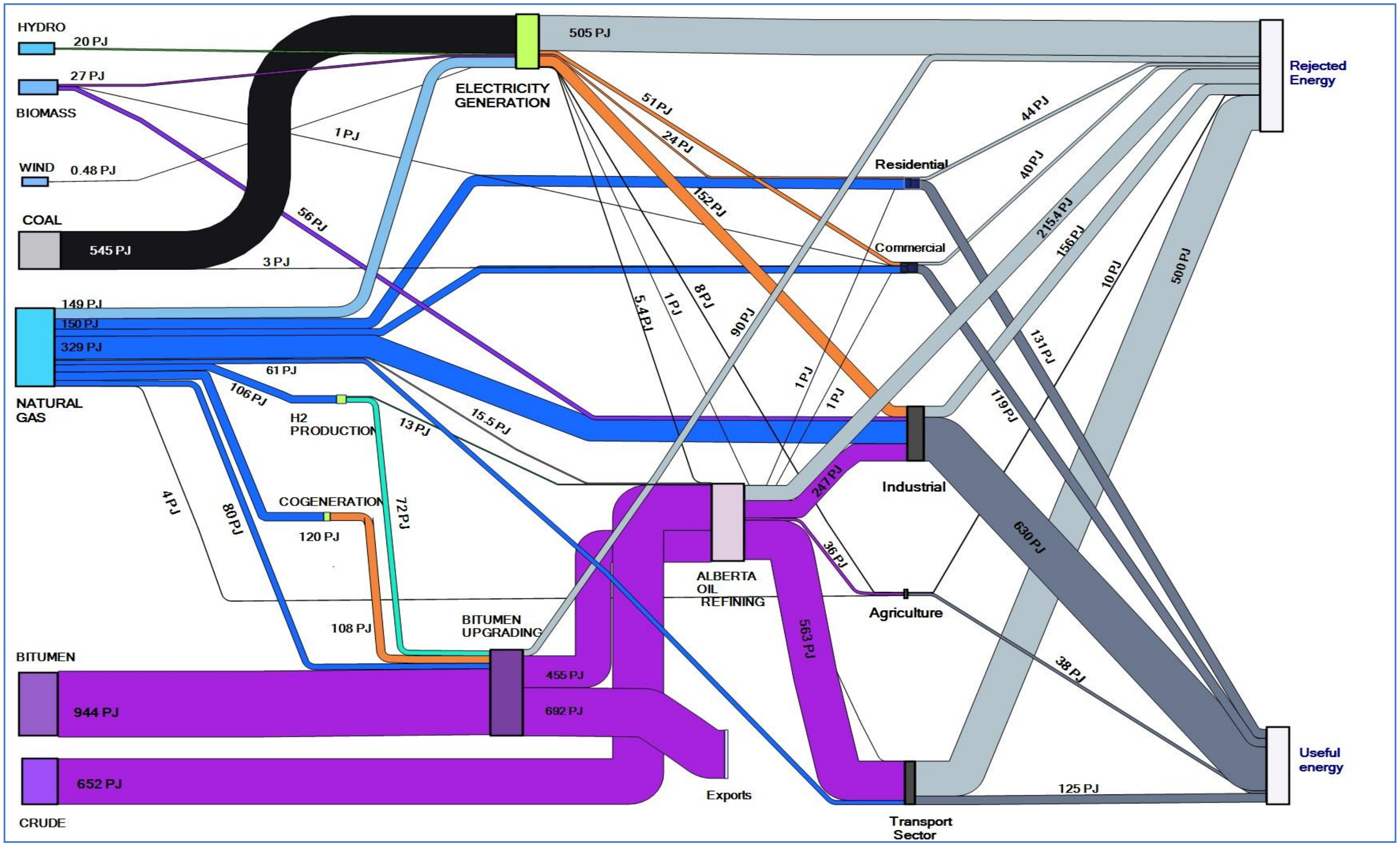

Figure 5-3: Alberta industrial sector sankey diagram

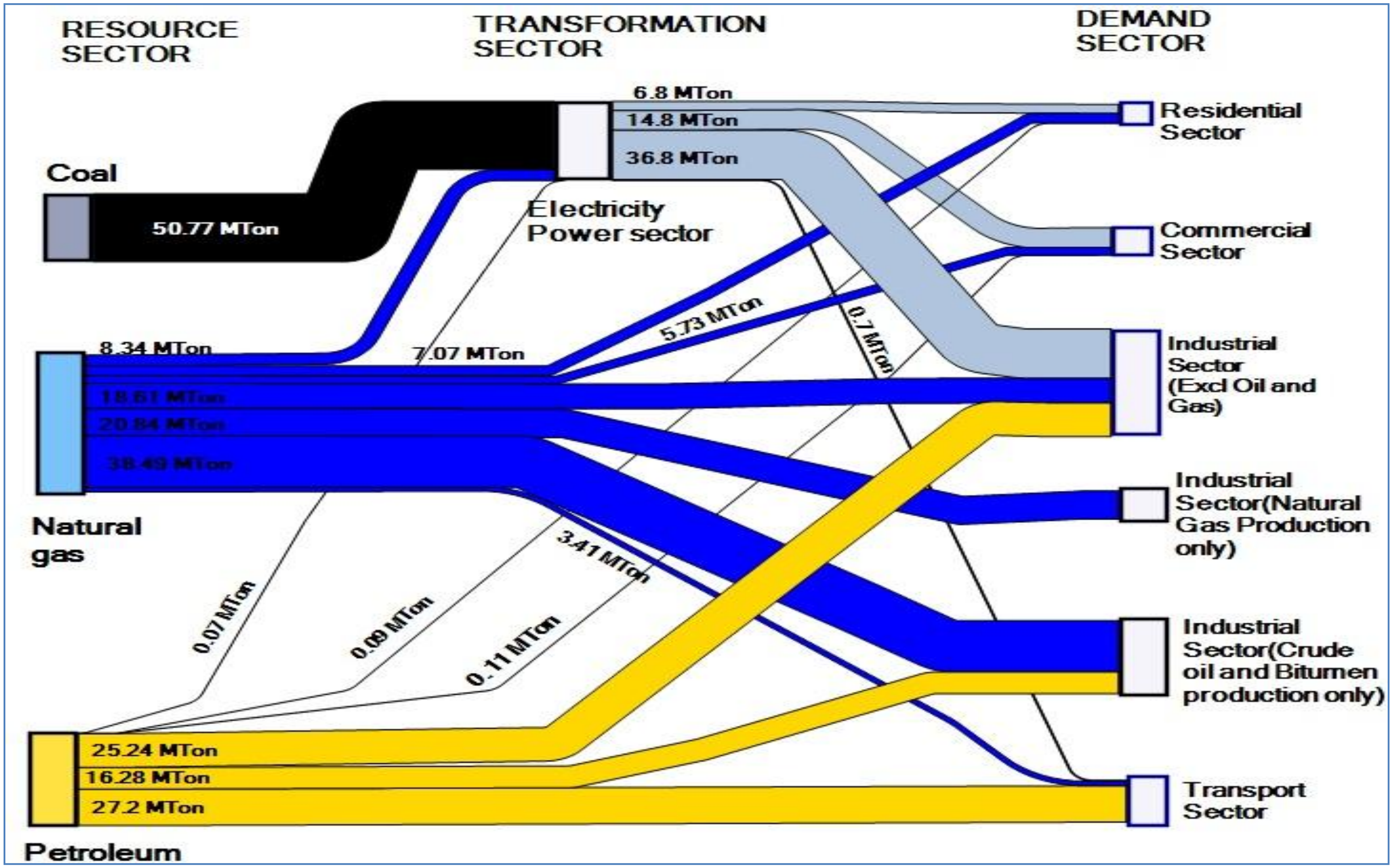

Figure 5-4: Alberta GHG emission sankey for base year 2005

5.1.4 Development of a baseline scenario representing business-as-usual energy supply and demand for Alberta over a study period of 25 years from 2005 to 2030

Reference scenario was developed for 25 year study period in LEAP. This is also called as business as usual scenario of the energy sector of Alberta. Different parameters such as population and household growth rate, commercial area increase and increase in GDP of industrial sector were chosen as the basis for development of business as usual case for Alberta energy demand sector. In the transport sector, growth is governed by increase in population and also changes in economic model of the province in terms of increased passenger and freight vehicles over a period of time.

In the supply side the business as usual scenario is mainly the growth in existing power plants and with the composition of power plants operating with coal and natural gas following the same historical trend. Also the increase in bitumen production and upgrading operations is the highlight of supply side business usual growth rate of Alberta.

Over the period of 2005-2030, the growth in demand of energy is expected to be from 2274 PJ to 3496 PJ. The rate of increase in energy demand is attributed to increase in industrial sector intensity as Alberta's mining, petroleum and chemical industries are expected to grow at a faster pace than other sectors. The commercial and household energy demands also increases in the business as usual case over 25 year period.

Energy demand in household sector is expected to grow from 175 PJ in the base year 2005 to 287 PJ in 2030. Energy demand in commercial and institutional sector is expected to grow from 159 PJ to 307 PJ whereas in the transport sector the overall increase in energy demand is expected to grow from 367 PJ to 582 PJ over a period of 25 years. Table 5-1 shows the fuel demand over the study period.

Table 5-1: Fuel demand increase in the reference case scenario

Demand (Million GJ)	2005	2010	2015	2020	2025	2030
Biomass	57.7	59.1	60.5	61.9	63.4	64.9
Electricity	205.4	231.5	259.2	289	321	356
Heat	9.1	9.6	10.1	10.7	11.3	12
Natural Gas	1114	1213	1323	1444	1579	1728
Oil Products	884.7	954.1	1031.7	1119.1	1217.6	1328
Solid Fuels	2.9	3.5	4.1	4.7	5.3	5.9
Total	2274	2471.6	2689	2930	3198	3496.

The overall increase is governed by natural gas and oil demand. Natural gas demand is projected to grow from 1,114 to 1,728 PJ from 2005-2030, whereas oil products show an increase in demand from 885 PJ to 1328 PJ over the study period of 25 years. Electricity demand is expected to increase 1.5 times over the study period of 25 years as compared to base year. Based on the growth rates of various demand sectors and increase in primary and secondary fuel consumptions over the baseline, the emissions are expected to increase from 87 MT in 2005 to 149 MT of CO_2 equivalents in 2030. The increase in emissions is again attributed to increased demand of energy in industrial, transport, household and commercial sectors. In the transformation sector, GHG emissions from the energy conversion sector is expected to grow from 157 MT in the year 2005 to 325 MT of CO_2 equivalents in 2030. Electricity generation sector with the current mix of power generation plants mainly based on coal, natural gas, wind and hydro results in large increase in GHG emissions. The emission increase is from 51 MT to 99 MT of CO_2 equivalents over 25 years. Natural gas production and processing plant shows a declining trend in terms of GHG emissions as there is a reduction in overall natural gas production over the 25 year study period of 2005-2030. Similar situation is expected for conventional crude oil and the reduction in GHG emissions is projected from 4 MT to 1.4 MT of CO_2 equivalents over the study period. However, Alberta's crude bitumen and synthetic crude oil production have a significant increase from year 2005 to year 2030. For crude bitumen production the emissions are likely to increase from 35 MT in 2005 to 115 MT of CO_2 equivalents by 2030. In case of synthetic crude oil production the increase in GHG emissions are projected from 14 MT to 53 MT of CO_2 equivalents by 2030. Total Alberta's GHG emissions from energy demand and transformation sector is likely to increase from 244 MT (including the entire auxiliary fuel requirement) in 2005 to 494 MT of CO_2 equivalents in 2030.

5.1.5 Development and analysis of GHG mitigation scenarios for the province of Alberta

Various GHG mitigation scenarios for Alberta were developed for both energy supply and demand side. Each of these sectors has subsectors which are further classified into final energy end user and the device pertaining to each subsector. Supply side mitigation scenarios were developed for renewable energy options like nuclear, hydro and wind generation in Alberta. Also the mitigation options in supply side included clean coal technologies such as supercritical and ultra supercritical coal power plants. In the oil and gas sector the incorporation of carbon capture and storage (CCS) formed a major scenario in non conventional oil (bitumen) extraction and upgrading processes.

Demand side mitigation scenarios included efficiency improvement in residential and commercial sectors' energy use. To achieve the required mitigation, energy devices such as lighting and appliances were modeled for reduction in overall energy and this is projected for study period of 25 years (2005-2030). In the residential sector, implementation of efficient lighting and appliances in the mitigation scenario results in overall GHG reduction between 0.5 MT - 1 MT CO_2 equivalents per year by the end of study period. Similarly, implementation of efficient lighting, motor and water heating in commercial sector in the mitigation scenario results in overall GHG mitigation of 0.3 - 0.7 MT CO_2 equivalents per year by 2030.

In the industrial sector the total GHG mitigation achievable is about 50-70 MT of CO_2 equivalents per year by 2030. In the transport sector total GHG mitigation achievable is 1 MT per year by the end of study period 2030.

For the supply side, there is a large scope of GHG reduction achievable by means of replacing existing coal plants with supercritical and ultra supercritical coal plants. The range of reduction is between 20 - 60 MT of CO_2 equivalents by the end of study period. In the bitumen production sector there is a huge potential of GHG mitigation by means of including CCS plants in the production and upgrading sectors. The total reduction potential is estimated to be between 20 and 60 MT of CO_2 equivalents per year by year 2030. In Alberta's power sector implementation of power generation through renewable resources have a huge potential for GHG reduction. It is estimated that by the end of year 2030, wind, hydro and nuclear have the GHG reduction potential of 20-60 MT of CO_2 equivalents per year. Overall mitigation potential for Alberta is estimated between 100 MT of CO_2 equivalents (without CCS plants) to 160 MT (with CCS plants) by the end of year 2030 by implementation of various scenarios.

5.2. Recommendations for future work

This study involved development of energy and environment model for Alberta based on LEAP. By using LEAP as a modeling tool, sankey diagrams for energy and emission flows for the Province of Alberta have been developed. Using the reference case scenario developed in the model, a set of GHG mitigation scenarios were obtained using the prevailing conditions and policies of Alberta government. The opportunities of future work are given below.

- The study has been conducted for base year as 2005. This is due to the availability of data when the project was started in 2007. This base year data will have to be updated with more recent data for year 2008.

- GHG mitigation scenarios should be further developed for cost benefit analysis. The abatement cost of each mitigation option should be developed for demand, transformation and resource sectors. Both demand and transformation sectors costs have to be developed based on capital costs of the processes/devices involved in conversion of primary fuel into secondary fuel as well as end use of the fuel by the demand device. Fixed and variable operating and maintenance costs, costs of indigenous resources and costs of imported fuels also need to be developed for the evaluation of overall GHG mitigation costs.

- Energy-environment planning models for Alberta can be further developed using the available database and by including optimization capability. These optimization models are typically used to generate least cost configurations of energy systems based on different limitation. An optimization model for the energy scenarios of Alberta can be developed by linking macroeconomic model with a detailed energy supply model. Using these models further evaluation of energy performance standard, demand side management and incorporation of renewable and clean technologies can be studied.

- Development of GHG mitigation scenarios cost curves for province of Alberta could be a key future activity. Abatement costs for different GHG mitigation scenarios could be used to develop the cost curve for a particular year under consideration. These cost curves can be very handy as it helps in evaluating the relative costs per tonne of GHG mitigated in a particular time frame and thereby helping in evaluation of policy for a province. These can be basically generated to give an insight of the techno economic feasibility of the mitigation option under consideration. Cost curves represent the estimates of annual abatement cost in dollar per tonne required to avoid million tonne of CO_2 equivalent in that year. Figure 5-5 shows typical cost curve.

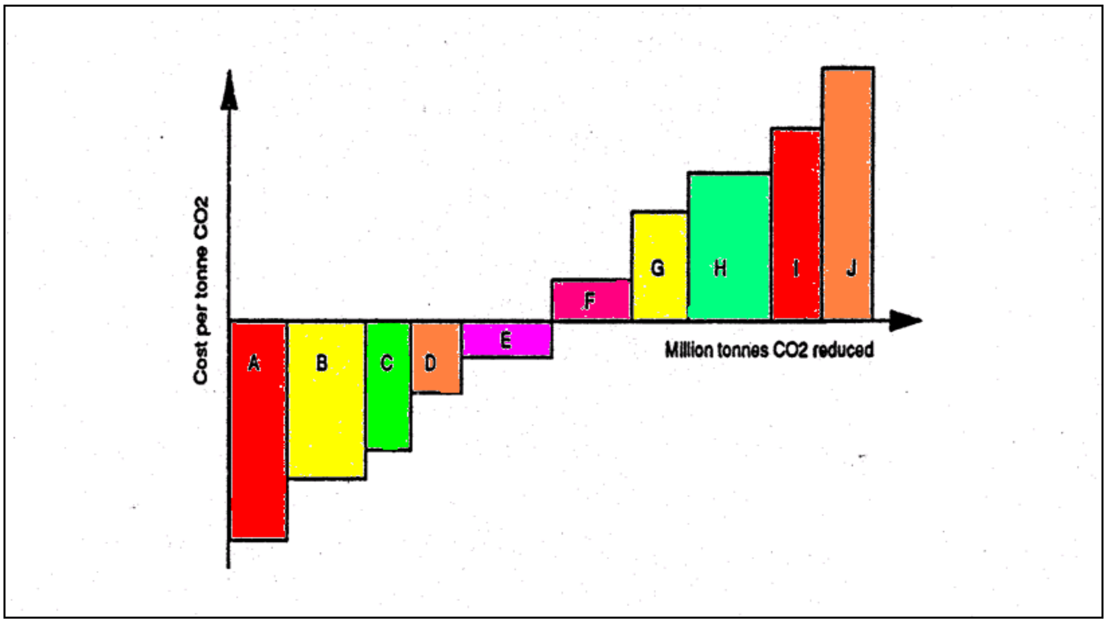

Figure 5-5: Typical cost curve

- By using a model similar to LEAP called WEAP estimation of water utilization factor (L of water/kWh of energy produced or consumed) for various energy sectors of Alberta can also be developed. These factors will have to be generated based on specific technology prevailing now and for the new technologies likely to come up in future.

APPENDIX

Appendix A

Alberta Demand Sector- Residential sector

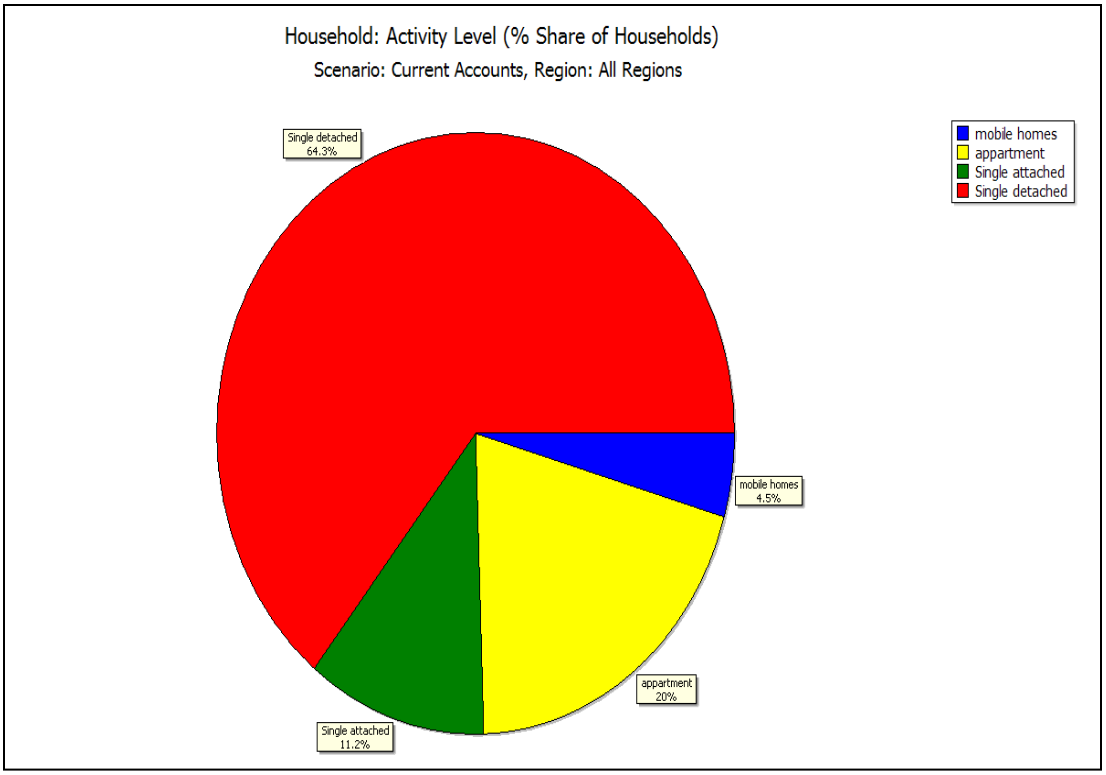

Figure A-1: Alberta residential sector activity level

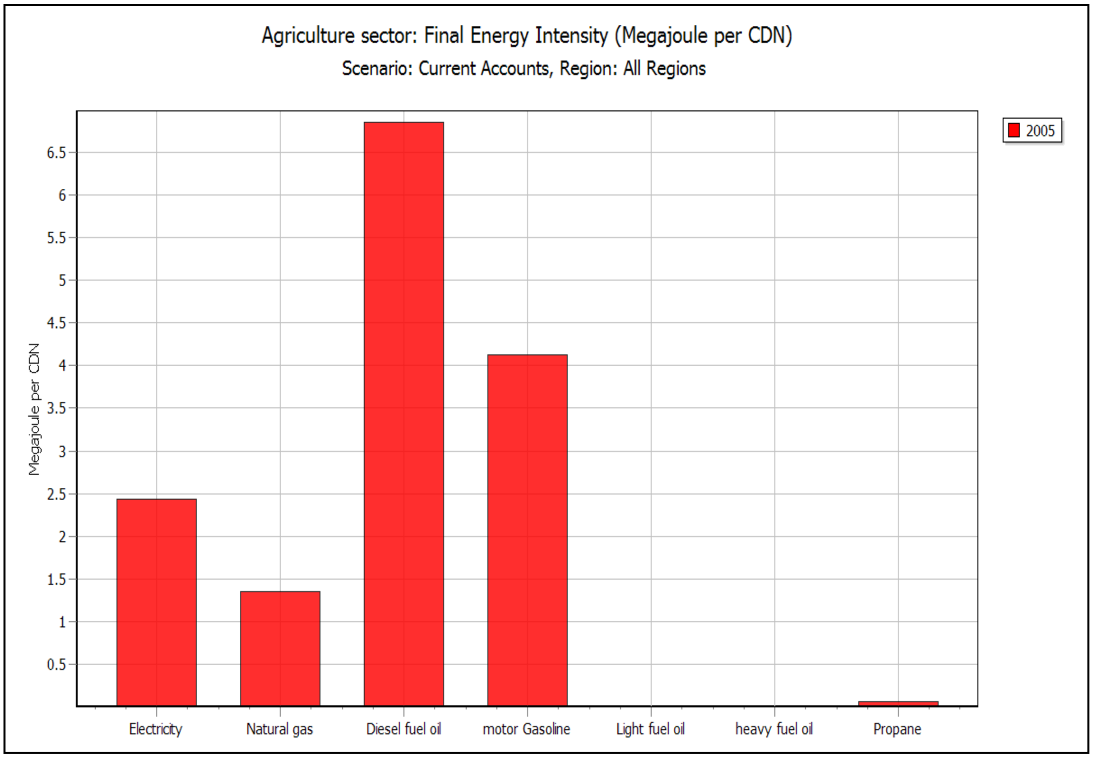

Figure A-2: Total energy –Alberta agriculture sector

Table A-1: Alberta residential sector energy demand-type of house

Energy Demand (Household) in PJ	**Biomass**	**Electricity**	**Natural Gas**	**Oil Products**	**Total**
Single detached	0.3	16.71	114.37	0.98	132.35
Single attached	0.02	3.46	10.51	0	13.98
Apartment	0.04	2.56	17.02	0	19.62
Mobile homes	0.02	0.95	7.67	0.07	8.71
Total	0.37	23.68	149.57	1.05	174.67

Table-A-2: Alberta single detached houses energy demand

Demand (PJ)	Electricity	Natural Gas	Oil	Propane	Wood	Total
Space heating	2.8	87	0.1	0.8	0.3	91
Water heating	0.4	22.9	0	0.1	0	23.4
Lighting	5.3	0	0	0	0	5.3
Space cooling	0.1	0	0	0	0	0.1
Appliances	8.1	4.5	0	0	0	12.6
Total	16.7	114.4	0.1	0.9	0.3	132.4

Table A-3: Alberta single attached houses energy demand

Demand(PJ)	Biomass	Electricity	Natural Gas	Oil Products	Total
Space heating	0.02	1.58	6.49	0	8.08
Water heating	0	0	3.66	0	3.66
Lighting	0	0.59	0	0	0.59
Appliances	0	1.3	0.36	0	1.66
Total	0.02	3.46	10.51	0	13.98

Table A-4: Alberta apartments energy demand

Demand(PJ)	Biomass	Electricity	Natural Gas	Oil Products	Total
Space heating	0.03	0.35	10.67	0	11.0
Water heating	0.01	0.09	5.46	0	5.56
Lighting	0	0.46	0	0	0.46
Appliances	0	1.66	0.89	0	2.55
Total	0.04	2.56	17.02	0	19.6

Table A-5: Alberta mobile homes energy demand

Demand(PJ)	Electricity	Natural Gas	Oil	Propane	Wood	Total
Space heating	0.2	5.9	0	0.1	0	6.2
Water heating	0	1.5	0	0	0	1.5
Lighting	0.2	0	0	0	0	0.2
Appliances	0.5	0.3	0	0	0	0.8
Total	1	7.7	0	0.1	0	8.7

Alberta Residential Sector Energy Demand –Reference Scenario (2005-2030)

Table A-6: Alberta residential sector reference scenario - end use

Demand(PJ)	2005	2010	2015	2020	2025	2030
Single detached	132.35	146.08	161.22	177.94	196.39	216.76
Single attached	13.98	15.44	17.05	18.82	20.78	22.94
Apartment	19.62	21.66	23.92	26.41	29.15	32.19
Mobile homes	8.71	9.62	10.62	11.72	12.94	14.29
Total	174.67	192.8	212.81	234.89	259.27	286.18

Table A-7: Alberta residential sector reference scenario fuel demand

Fuel demand/Year (PJ)	2005	2010	2015	2020	2025	2030
Oil Products	1.05	1.16	1.28	1.41	1.56	1.72
Natural Gas	149.57	165.14	182.32	201.3	222.25	245.38
Electricity	23.68	26.14	28.86	31.87	35.18	38.84
Biomass	0.37	0.41	0.45	0.5	0.55	0.61
Total	174.67	192.85	212.92	235.08	259.55	286.56

Residential Sector –Emissions

Table A-8: Emission from Alberta household sector - base case scenario

Emissions (Million Kg CO_2 Eq)	mobile homes	apartment	Single attached	Single detached	Total
Biomass	0	0	0	1	2
Natural Gas	428	950	587	5103	7069
Oil Products	6	0	0	84	89
Total	434	951	587	5188	7160

Table A-9: Emissions from Alberta residential sector - reference scenario

Year (MT of CO_2 eq)	2005	2010	2015	2020	2025	2030
single detached	5.2	5.7	6.3	7	7.7	8.5
single attached	0.6	0.6	0.7	0.8	0.9	1
apartment	1	1	1.2	1.3	1.4	1.6
mobile homes	0.4	0.5	0.5	0.6	0.6	0.7
Total	7.2	7.9	8.7	9.6	10.6	11.7

Table A-10: Emissions associated with fuels - Alberta residential sector

Year (MT of CO_2 eq)	2005	2010	2015	2020	2025	2030
Oil Products	0.09	0.1	0.11	0.12	0.13	0.15
Natural Gas	7.07	7.8	8.62	9.51	10.5	11.6
Biomass	0	0	0	0	0	0
Total	7.16	7.9	8.73	9.64	10.64	11.75

Alberta Commercial sector

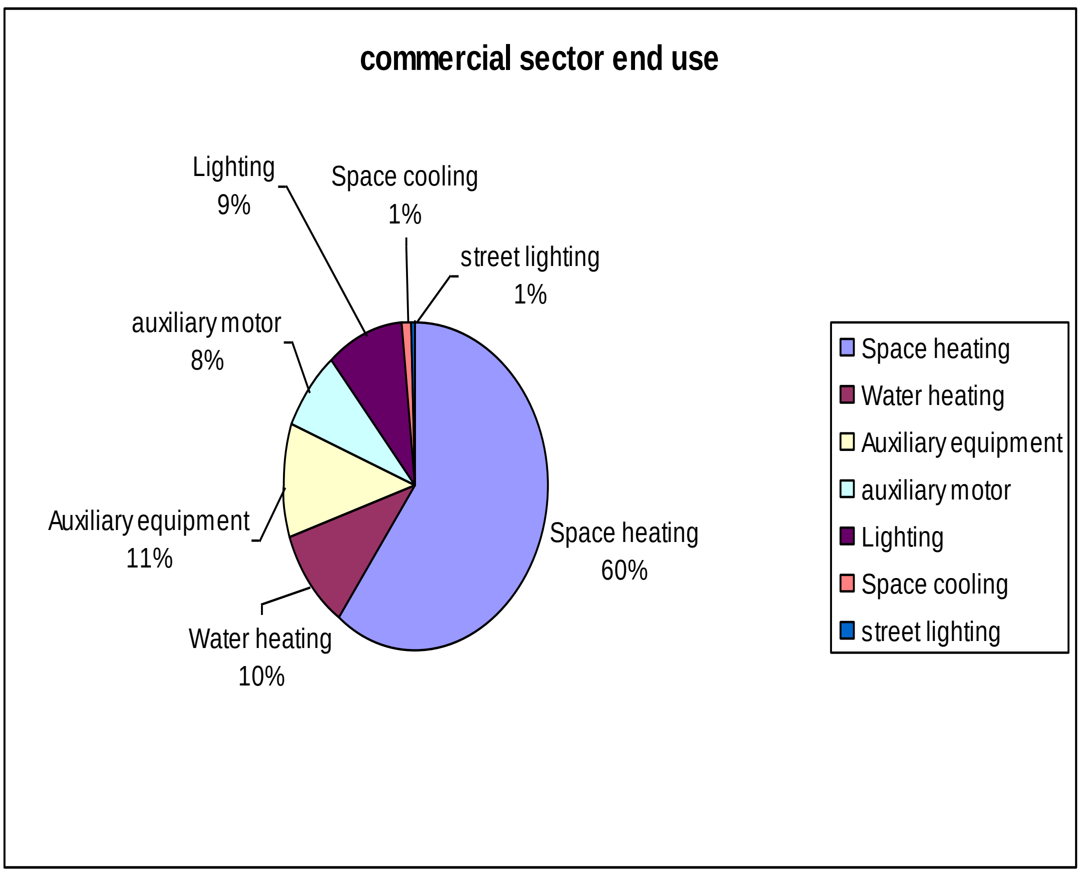

Figure A-3: Alberta commercial sector end use in base year- 2005

Table A-11: Alberta commercial sector energy requirement

Commercial sector(PJ)	Biomass	Electricity	Heat	Natural Gas	Oil Products	Solid Fuels
Space heating	0	4.5	0	86.7	1	2.9
Water heating	0.5	0.4	0	15	0.2	0
Auxiliary equipment	0.6	16.2	0	0.6	0.2	0
auxiliary motor	0	12.7	0	0	0	0
Lighting	0	15	0	0	0	0
Space cooling	0	1.5	0	0.3	0	0
Street lighting	0	0.9	0	0	0	0
Total	1	51.3	0	102.5	1.4	2.9

Table A-12: Alberta commercial sector reference scenario-end use based

Commercial sector (PJ)	2005	2010	2015	2020	2025	2030
Space heating	95.12	102.2	109.44	116.84	124.44	132.27
Water heating	16.08	17.23	18.39	19.57	20.76	21.98
Auxiliary equipment	17.57	18.47	19.65	20.83	22.01	23.2
auxiliary motor	12.68	14.04	14.94	15.84	16.74	17.64
Lighting	15.02	17.98	21.44	25.47	30.15	35.59
Space cooling	1.78	1.91	2.03	2.15	2.27	2.39
Street lighting	0.94	1	1.07	1.13	1.2	1.26
Total	159.19	172.84	186.95	201.83	217.58	234.33

Table A-13: Alberta commercial sector reference scenario - fuel usage

Commercial Sector(PJ)	2005	2010	2015	2020	2025	2030
Solid Fuels	2.91	3.11	3.31	3.51	3.71	3.91
Oil Products	1.42	1.51	1.61	1.71	1.81	1.9
Natural Gas	102.54	109.55	116.56	123.57	130.58	137.59
Heat	0	0	0	0	0	0
Electricity	51.29	57.56	64.3	71.8	80.17	89.54
Biomass	1.03	1.1	1.17	1.24	1.32	1.39
Total	159.19	172.84	186.95	201.83	217.58	234.33

Table A-14: Alberta commercial sector environmental results - end used based

Commercial Sector(Thousand Kg CO_2 eq)	2005	2010	2015	2020	2025	2030
Space heating	5,197.80	5,553.17	5,908.55	6,263.93	6,619.30	6,974.68
Water heating	856.23	914.77	973.31	1,031.85	1,090.39	1,148.93
Auxiliary equipment	48.65	51.98	55.31	58.63	61.96	65.29
Space cooling	15.75	16.83	17.91	18.99	20.06	21.14
Total	6,118.43	6,536.75	6,955.07	7,373.40	7,791.72	8,210.04

Table A-15: Alberta commercial sector environmental results - fuel based

Commercial Sector(Thousand Kg CO_2eq)	2005	2010	2015	2020	2025	2030
Solid Fuels	271.55	290.12	308.69	327.25	345.82	364.39
Oil Products	107.27	114.61	121.94	129.28	136.61	143.94
Natural Gas	5,734.55	6,126.62	6,518.70	6,910.77	7,302.85	7,694.92
Biomass	5.06	5.4	5.75	6.09	6.44	6.79
Total	6,118.43	6,536.75	6,955.07	7,373.40	7,791.72	8,210.04

Appendix B

Alberta Industrial Sector

Table B-1: Alberta industrial sector energy demand - base year2005

Industrial Sector (PJ)	**Biomass**	**Electricity**	**Heat**	**Natural Gas**	**Oil Products**	**Total**
Construction	0	0	0	2.1	8.7	10.8
Petroleum refining	0	5.4	0	15.5	43.3	64.2
Cement	0	0	0.4	0	0	0.4
Chemicals	0	18.8	4.2	74.7	0	97.7
Iron and steel	0	0	0	0	0	0
other manufacturing	0	10.6	3.4	38.6	0.1	52.7
Forestry	0	0	0	0	1	1
Mining	0	73.2	0	188	194	455.3
Paper and pulp	56.3	11.8	1.1	9.8	0	78.9
Total	56.3	119.8	9.1	328.7	247.1	760.9

Table B-2: Alberta mining sector energy demand

Mining Sector(PJ)	Electricity	Natural Gas	Oil Products	Total
Electricity	73.2	0	0	73.2
Natural gas	0	188	0	188
Diesel fuel oil	0	0	30.1	30.1
still gas and Petroleum coke	0	0	141.1	141.1
LPG	0	0	22.8	22.8
Total	73.2	188	194	455.3

Table B-3: Alberta chemical sector energy demand

Chemical Sector (PJ)	Electricity	Heat	Natural Gas	Total
electricity	18.8	0	0	18.8
Natural gas	0	0	74.7	74.7
other	0	4.2	0	4.2
Total	18.8	4.2	74.7	97.7

Table B-4: Bitumen upgrading energy demand

Primary and Secondary fuel	Demand (PJ)
Hydrogen	72
Natural gas	250
Electricity	72
Total	394

Table B-5: Alberta pulp and paper energy demand

Pulp and paper(PJ)	Biomass	Electricity	Heat	Natural Gas	Oil Products	Total
Electricity	0	11.8	0	0	0	11.8
Natural gas	0	0	0	9.8	0	9.8
Diesel fuel oil	0	0	0	0	0	0
Wood waste and pulping liquid	56.3	0	0	0	0	56.3
Steam and other waste fuel	0	0	1.1	0	0	1.1
Total	56.3	11.8	1.1	9.8	0	78.9

Table B-6: Non energy process energy demand

Non energy sector (PJ)	Natural Gas	Oil Products	Total
Natural Gas	108	0	108
Natural Gas Liquid	0	100	100
Diesel	0	123	123
Total	108	223	331

Industrial Sector Reference Scenario

Table-B-7: Alberta industrial sector reference case scenario - fuel based

Energy PJ	2005	2010	2015	2020	2025	2030
Oil Products	247.1	255.58	263.79	272.33	281.21	290.46
Natural Gas	328.7	365.29	406.74	453.98	507.84	569.24
Heat	9.07	9.56	10.09	10.68	11.33	12.05
Electricity	119.8	125.14	130.76	136.77	143.18	150.05
Biomass	56.26	57.4	58.56	59.74	60.94	62.17
Total	760.93	812.98	869.94	933.49	1,004.50	1,083.97

Table B-8: Alberta industrial sector reference case scenario - sector based

Industrial sector(PJ)	2005	2010	2015	2020	2025	2030
construction	10.79	10.79	10.79	10.79	10.79	10.79
Smelting and Refining	0	0	0	0	0	0
Petroleum refining	64.17	65.06	65.06	65.06	65.06	65.06
Cement	0.4	0.41	0.41	0.41	0.41	0.41
Chemicals	97.65	108.35	120.21	133.38	147.98	164.19
Iron and steel	0	0	0	0	0	0
Other manufacturing	52.71	52.71	52.71	52.71	52.71	52.71
Forestry	1	1	1	1	1	1
Mining	455.25	494.12	537.6	586.33	641.05	702.58
Paper and pulp	78.95	80.54	82.16	83.82	85.51	87.23
Total	760.93	812.98	869.94	933.49	1,004.50	1,083.97

Industrial Sector –Emissions

Table B-9: Alberta industrial sector environmental results

GHG emissions (MT of CO_2 eq)	2005	2010	2015	2020	2025	2030
Construction	0.8	0.8	0.8	0.8	0.8	0.8
Petroleum refining	5.5	5.6	5.6	5.6	5.6	5.6
Chemicals	4.2	4.6	5.1	5.7	6.3	7
Other manufacturing	2.2	2.2	2.2	2.2	2.2	2.2
Forestry	0.1	0.1	0.1	0.1	0.1	0.1
Mining	27.8	33.5	40.5	49	59.4	72.3
Paper and pulp	0.5	0.6	0.6	0.6	0.6	0.6
Total	41.1	47.3	54.8	63.9	75	88.5

Table B-10: Alberta industrial sector environmental results - fuel based

MT CO_2 eq	2005	2010	2015	2020	2025	2030
Oil Products	22.7	25.5	28.7	32.4	36.7	41.7
Natural Gas	18.4	21.8	26.1	31.5	38.3	46.9
Total	41.1	47.3	54.8	63.9	75	88.5

Alberta Agricultural sector

Table B-11: Alberta agricultural sector emissions base year (2005)

Emissions (MT of CO_2 eq)	Electricity	Natural Gas	Oil Products	Total
Electricity	7.8	0	0	7.8
Natural gas	0	4.4	0	4.4
Diesel fuel oil	0	0	22.1	22.1
motor Gasoline	0	0	13.3	13.3
Light fuel oil	0	0	0	0
heavy fuel oil	0	0	0	0
Propane	0	0	0.2	0.2
Total	7.8	4.4	35.7	47.9

Table B-12: Alberta agricultural sector - reference case

Emissions (MT of CO_2 eq)	2005	2010	2015	2020	2025	2030
Oil Products	35.7	38.4	41.4	44.6	48	51.7
Natural Gas	4.4	4.7	5.1	5.5	5.9	6.3
Electricity	7.8	8.5	9.1	9.8	10.6	11.4
Total	47.9	51.6	55.6	59.9	64.5	69.5

Agriculture sector –Emissions

Table B-13: Alberta agriculture sector - base year emissions

Fuel	Emissions (Million Kilogrammes CO_2 eq)
Natural gas	243.86
Diesel fuel oil	1639.95
Motor Gasoline	923.7
Light fuel oil	0
Heavy fuel oil	0
Total	2807.52

Table B-14: Alberta agricultural sector emissions - reference scenario

Emissions (Million Kg CO_2 equivalent)	2005	2010	2015	2020	2025	2030
Natural Gas	243.9	262.7	283	304.9	328.4	353.8
Oil Products	2563.7	2761.8	2975.2	3205.2	3452.9	3719.7
Total	2807	3024	3258	3510	3781	4073

Appendix C

Transport Sector

Table C-1: Alberta transport sector energy demand

Transport Sector	Electricity	Natural Gas	Oil Products	Total
Passenger Road	0.6	0.1	125.6	126.3
Freight Road	0	0	176.3	176.3
passenger rail	0	0	1	1
passenger air	0	0	33	33
Freight rail	0	0	30.6	30.6
Freight air	0	0	0.9	0.9
Off Road			9	9

Table C-2: Alberta transport sector reference scenario

Fuels(PJ)	2005	2010	2015	2020	2025	2030
Oil Products	301.99	333.47	368.35	406.89	449.46	496.49
Natural Gas	0.11	0.12	0.13	0.14	0.16	0.17
Electricity	0.56	0.62	0.69	0.76	0.84	0.93
Total	302.66	334.2	369.17	407.79	450.46	497.58

Table C-3: Alberta transport sector (road) reference scenario

Road Sector	2005	2010	2015	2020	2025	2030
passenger	126.31	139.42	154.01	170.12	187.92	207.58
freight	176.34	194.78	215.16	237.67	262.54	290.01
Total	302.66	334.2	369.17	407.79	450.46	497.58

Table C-4: Alberta transport rail - reference scenario

Passenger rail (PJ)	2010	2015	2020	2025	2030
Oil Products	1	1	1.1	1.1	1.2

Table C-5: Alberta passenger air - reference scenario

Passenger air(PJ)	2005	2010	2015	2020	2025	2030
Oil Products	32.99	34.67	36.44	38.3	40.25	42.3

Table C-6: Alberta freight rail - reference scenario

Freight rail (PJ)	2005	2010	2015	2020	2025	2030
Oil Products	30.59	32.15	33.79	35.51	37.32	39.23

Table C-7: Alberta freight air reference scenario

Freight Air (P)	2005	2010	2015	2020	2025	2030
Oil Products	0.9	0.9	1	1	1.1	1.1

Table C-8: Alberta transport sector GHG emissions by type

Type of transport(2005)	MT of CO2 eq
Passenger	11.13
Freight	15.93
Pipeline	3.41

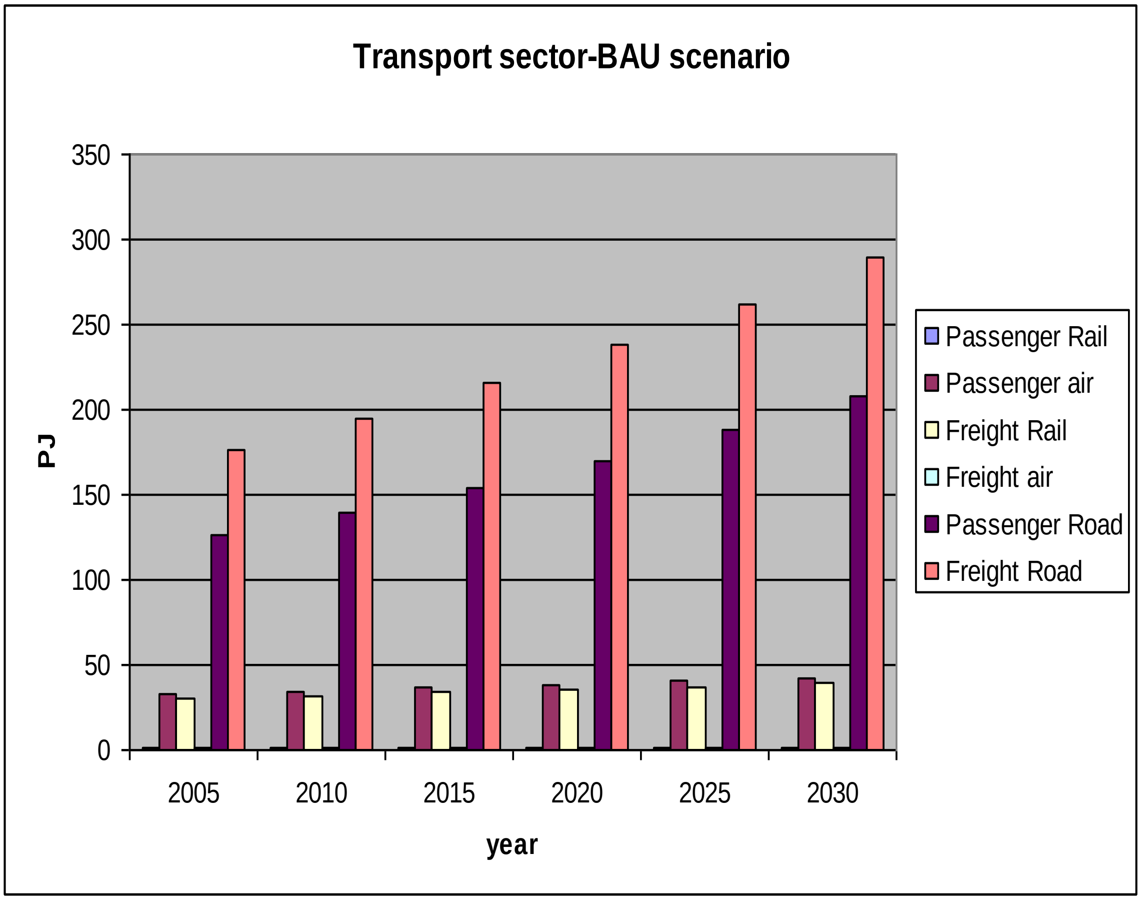

Figure C-1: Alberta transport sector reference scenario (all subsector)

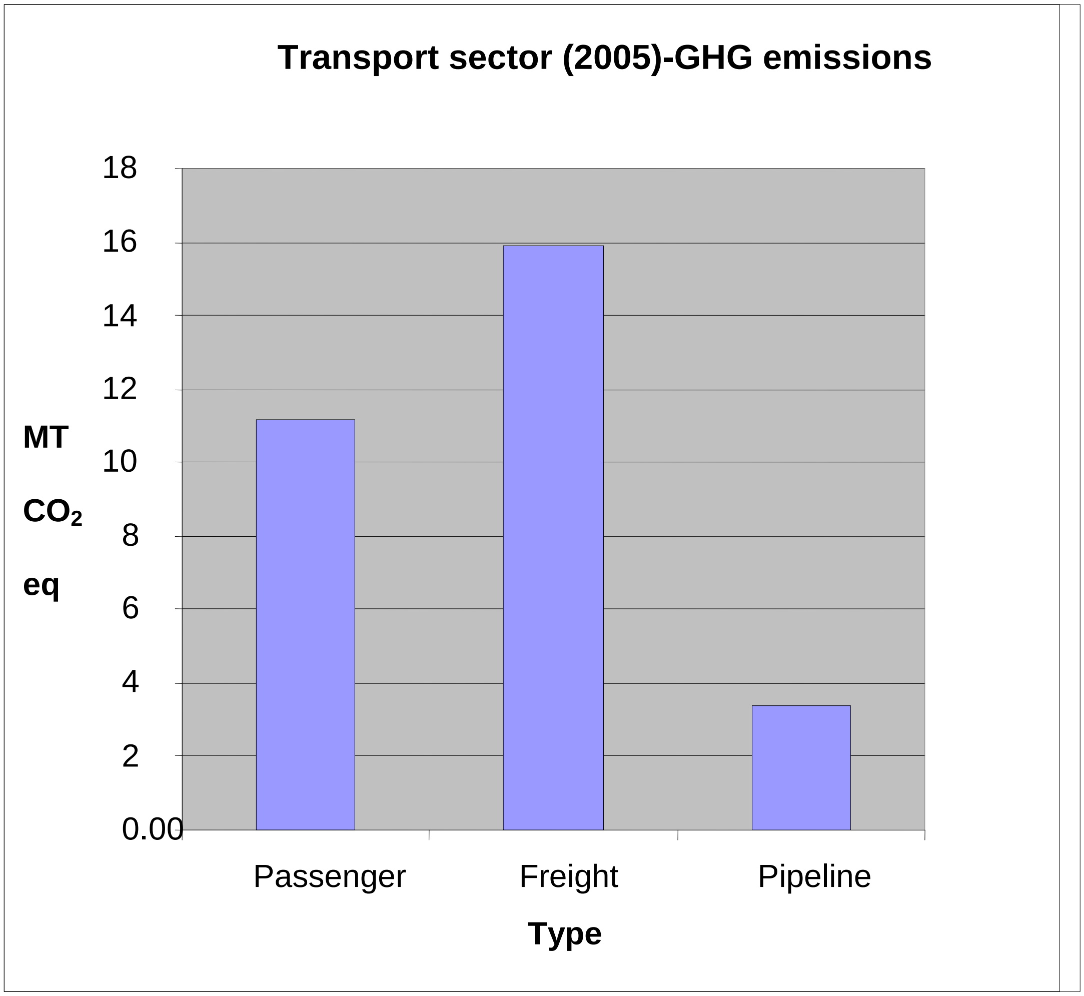

Figure C-2: Alberta transport sector GHG emissions - base case

Table C-9: Alberta GHG emissions reference scenario

Type/Emissions in MT CO_2 eq	2005	2010	2015	2020	2025	2030
Passenger	11.134	12.153	13.288	14.493	15.797	17.4
Freight	15.924	17.327	18.93	20.734	22.638	24.842
Pipeline	3.4	3.5	3.7	3.9	4.1	4.3
Total	30.458	32.98	35.918	39.127	42.535	46.542

Table C-10: Alberta pipeline transport energy demand

PJ-Demand Pipeline transport	2010	2015	2020	2025	2030
Electricity	2.31	2.43	2.55	2.68	2.82
Natural Gas	64.11	67.38	70.82	74.43	78.23
Oil Products	0	0	0	0	0
Total	66.42	69.81	73.37	77.12	81.05

Table C-11: Environmental results: Alberta pipeline transport

Million Kg CO_2 eq- Pipeline transport	2010	2015	2020	2025	2030
Natural Gas	3585.48	3768.38	3960.6	4162.64	4374.97
Oil Products	0	0	0	0	0
Total	3585.48	3768.38	3960.6	4162.64	4374.97

Table C-12: Additional natural gas demand for bitumen production and upgrading

(PJ) NG demand for Bitumen Production and upgrading	2010	2015	2020	2025	2030
Natural Gas	181.03	204.81	231.73	262.18	296.63

Table C-13: Non energy sector end use

Non energy sector use (PJ)	2010	2015	2020	2025	2030
Natural Gas	108	108	108	108	108
Oil Products	223	223	223	223	223
Total	331	331	331	331	331

Appendix D

Alberta Demand sector –Base case and Reference Scenario

Table D-1: Alberta energy demand - reference case scenario

Demand by various sectors	2005	2010	2015	2020	2025	2030
Household	175	192.8	212.8	234.9	259.3	287
Commercial and Institutional sector	159.2	190.2	220.4	250	278.9	307.3
Industrial sector	760.9	846.6	944.2	1056.4	1185.7	1334.6
Agriculture sector	47.9	51.6	55.6	59.9	64.5	69.5
Transportation sector Road	302.7	334.2	369.2	407.8	450.5	497.6
Passenger Rail	1	1	1.1	1.1	1.2	1.2
Passenger Air	33	34.7	36.4	38.3	40.3	42.3
Freight Rail	30.6	32.1	33.8	35.5	37.3	39.2
Freight Air	0.9	0.9	1	1	1.1	1.1
Pipeline transport	63.2	66.4	69.8	73.4	77.1	81
OFF Road	9	9	9	9	9	9
NG Reprocessing plant shrinkage	200	200	200	200	200	200
Bitumen production and upgrading	160	181	204.8	231.7	262.2	296.6
Non energy sector use	331	331	331	331	331	331
Total	2274	2471.6	2689	2930	3198	3496.7

Table D-2: Alberta energy demand reference scenario - fuel wise

Primary and secondary fuel (PJ)	2005	2010	2015	2020	2025	2030
Biomass	57.7	59.1	60.5	61.9	63.4	64.9
Electricity	205.4	231.5	259.2	289	321.3	356.6
Heat	9.1	9.6	10.1	10.7	11.3	12
Natural Gas	1114.3	1213.8	1323.4	1444.7	1579.1	1728.7
Oil Products	884.7	954.1	1031.7	1119.1	1217.6	1328.6
Solid Fuels	2.9	3.5	4.1	4.7	5.3	5.9

Appendix E

Alberta Electricity generation –Base Year (2005)

Table E-1: Alberta electricity generation - power dispatched over a year

Total Power Dispatched(MW)-2005	**0000-1000 hrs**	**1001-2000 hrs**	**2001-3000 hrs**	**3001-4000 hrs**	**4001-5000 hrs**	**5001-6000 hrs**	**6001-7000 hrs**	**7001-8000 hrs**	**8001-8760 hrs**	**Total**
coal fired generation	5158.8	5158.8	5158.8	5158.8	5158	5158.8	4998.9	4790	4374	45116
Gas fired generation	3485.68	2506.05	1281.52	791.71	546.8	56.99	0	0	0	8668
Wood waste	133	133	133	133	133	133	128.88	123.51	112.77	1163
wind	100.23	72.06	36.85	22.77	15.72	1.64	0	0	0	249
Hydro	585	585	585	585	585	585	566.88	543.26	496	5116
other	23.96	17.23	8.81	5.44	3.76	0.39	0	0	0	59
Supercritical coal plant	405	405	405	405	405	405	392.45	376.1	343	3541
Total	9891.67	8877.14	7608.98	7101.7	6848.	6340.8	6087.18	5833.5	5326	63915

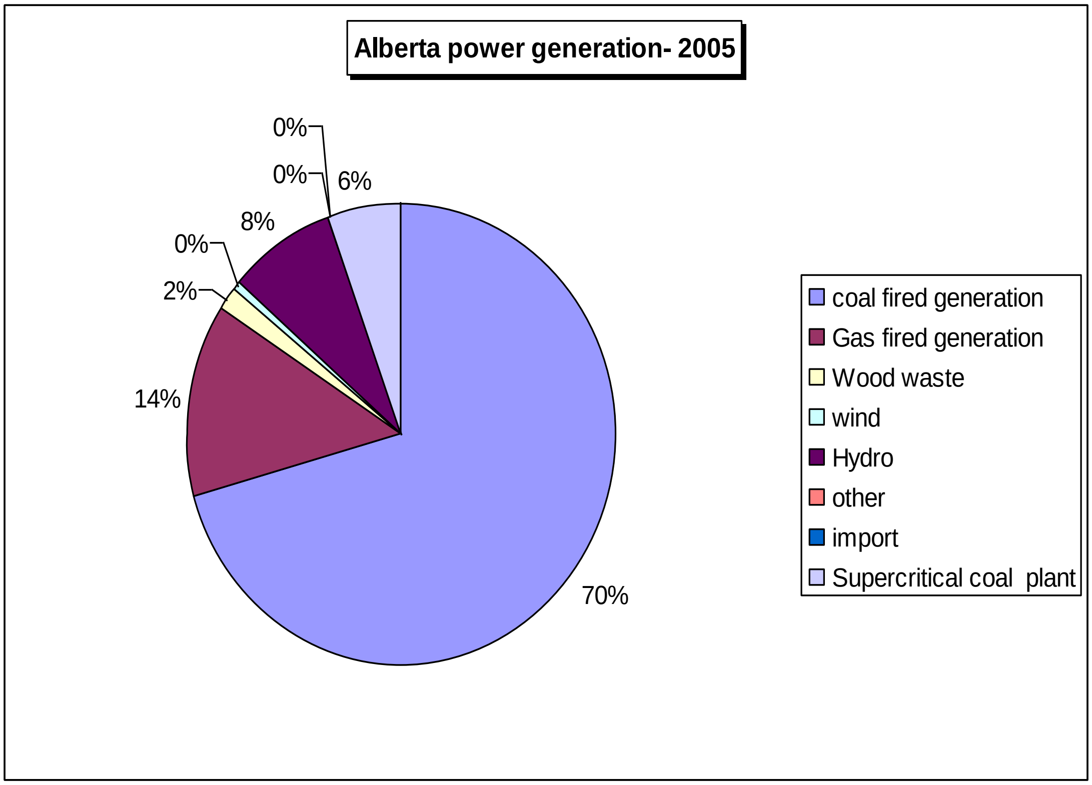

Figure E-1: Alberta power generation in 2005 as obtained by LEAP

Table E-2: Fuel inputs for Alberta power generation

Inputs for 2005 (million GJ)	**Auxiliary fuels**	**Feedstock fuels**	**Total**
coal fired generation	15.86	480.73	496.59
Gas fired generation	3.12	56.74	59.86
Wood waste	0.41	11.36	11.77
wind	0.09	1	1.09
Hydro	1.8	19.99	21.79
other	0.02	0.58	0.6
import	0	0	0
Supercritical coal plant	1.25	32.77	34.02
Total	22.55	603.17	625.7

Table E-3: Output of various power plants in 2005

Output -2005 (million MWh)	Supercritical coal plant	other	Hydro	wind	Wood waste	Gas fired generation	coal fired generation	Total
Electricity	3.46	0.06	5	0.25	1.14	8.67	44.07	62.64

Table E-4: Alberta power plant emissions - base year 2005

Emissions (MT CO_2 eq)	Supercritical coal plant	other	Wood waste	Gas fired generation	coal fired generation	Total
Biomass	0	0	0.02	0	0	0.02
Natural Gas	0	0	0	3.17	0	3.17
Oil Products	0	0.04	0	0	0	0.04
Solid Fuels	3.05	0	0	0	44.77	47.82
Total	3.05	0.04	0.02	3.17	44.77	51.06

Electricity Generation –Reference Case Scenario

Table E-5: Alberta electricity generation - reference case scenario

Requirement (million MWh)	2005	2010	2015	2020	2025	2030
Electricity	63	73.2	82	91.5	101.8	113

Table E-6: Alberta electricity generation inputs - reference case scenario

Million GJ (input feed stock fuel)	2005	2010	2015	2020	2025	2030
Biomass	12.4	14.2	14.3	13.7	14.1	14.4
Electricity	24.3	26.6	29.8	33.2	36.9	40.9
Hydropower	21.9	23.9	24.8	23.8	24.4	24.9
Natural Gas	104.8	127.9	143.4	90.5	140	199.3
Nuclear	0	0	0	0	0	0
Oil Products	0.9	8.6	17.6	14.6	22.5	32.1
Renewables	1.6	3.8	10.4	9.4	14.6	20.8
Solid Fuels	562.6	586.2	637.8	841.1	864.1	880
Total	728.6	791.2	877.9	1026.3	1116.7	1212.3

Table E-7: Alberta electricity generation output - reference scenario

Output –million MWh	2005	2010	2015	2020	2025	2030
Electricity	64	73.8	82.6	92.1	102.4	113.6

Table E-8: Alberta electricity generation capacity of power plants - reference case

Capacity (MW)	2005	2010	2015	2020	2025	2030
Coal fired generation	5732	5932	6432	8972	8972	8972
Gas fired generation	4606	6075	6330	7094	7094	7094
Wood waste	133	150	150	150	150	150
Wind	298	727.3	1863.6	3000	3000	3000
Hydro	900	971.4	1000	1000	1000	1000
Other	30	286.7	543.3	800	800	800
import	0	0	0	0	0	0
nuclear	0	0	0	0	0	0
CCS power plant	0	0	0	0	0	0
Supercritical coal plant	450	450	450	450	450	450
Supercritical coal plant with CCS	0	0	0	0	0	0
Ultra Supercritical Coal Plant	0	0	0	0	0	0
Ultra Supercritical Coal Plant with CCS	0	0	0	0	0	0
IGCC Plant	0	0	0	0	0	0
IGCC Plant with CCS	0	0	0	0	0	0
Cogen Electricity surplus from oil sands	500	500	500	500	500	500
Total	12649	15092.4	17269	21966	21966	21966

Table E-9: Alberta peak power requirement - reference scenario

Years/thousand MW	2005	2010	2015	2020	2025	2030
Electricity Generation	9.6	10.5	11.8	13.1	14.6	16.2

Table E-10: Alberta electricity generation module balance - reference scenario

Module balance	2005	2010	2015	2020	2025	2030
Domestic Requirements	-241.1	-263.5	-295.2	-329.3	-366.3	-406.8
Export Requirements	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3
Imports	1.8	1.8	1.8	1.8	1.8	1.8
Outputs	243.5	265.8	297.5	331.6	368.7	409.1
Unmet requirements	0	0	0	0	0	0

Electricity generation –Emission Results

Table E-11: Electricity generation - reference case scenario

MT CO_2 eq	2005	2010	2015	2020	2025	2030
coal fired generation	44.77	49.35	61.11	71.87	71.87	71.87
Gas fired generation	3.17	5.75	7.15	8.3	12.97	17.87
Wood waste	0.02	0.02	0.02	0.02	0.02	0.02
other	0.04	0.55	1.25	1.91	2.98	4.1
CCS power plant	0	0	0	0	0	0
Supercritical coal plant	3.05	3.12	3.13	3.13	3.13	3.13
Supercritical coal plant with CCS	0	0	0	0	0	0
UltraSupercritical Coal Plant	0	0	0	0	0	0
UltraSupercritical Coal Plant with CCS	0	0	0	0	0	0
IGCC Plant	0	0	0	0	0	0
IGCC Plant with CCS	0	0	0	0	0	0
Cogen Electricity surplus from oil sands	0	0	0	0	1.07	2.32
Total	51.06	58.79	72.66	85.23	92.05	99.31

Natural Gas Processing

Table E-12: Module balance for Alberta natural gas processing

Module Balance(PJ)	Natural gas and coal bed methane extraction
Domestic Requirements	-858.47
Export Requirements	-4040
Imports	347
Outputs	4898.47
Unmet requirements	0
Total	347

Table E-13: Alberta natural gas processing - reference case

Module balance(PJ)	2005	2010	2015	2020	2025	2030
Domestic Requirements	-858	-1025	-1205	-1413	-1745	-2143
Export Requirements	-4040	-3651.84	-3300.97	-2983.82	-2697.14	-2438
Imports	347	347	347	412.34	909.3	1498.5
Outputs	4898	4676	4506	4331	3880	3430
Unmet requirements	0	0	0	0	0	0
Total	347	347	347	347	347	347

Table E-14: Alberta natural gas processing - emissions reference case

MT CO_2 eq	2005	2010	2015	2020	2025	2030
Processes	27.06	25.84	24.9	23.93	21.44	18.95

Alberta Oil Refining

Table E-15: Alberta oil refining - energy demand base case

Module balance(PJ)	Oil Products
Domestic Requirements	-686.8
Export Requirements	-377.3
Imports	29.09
Outputs	1035.02
Unmet requirements	0
Total	0.01

Table E-16: Alberta oil refining - reference case

Module balance(PJ)	2005	2010	2015	2020	2025	2030
Domestic Requirements	-686.8	-758.33	-834.64	-918.94	-1018.6	-1130.1
Export Requirements	-377.3	-377.3	-377.3	-377.3	-377.3	-377.3
Imports	29.09	0.01	0.01	0.01	0.01	0.01
Outputs	1035.02	1135.63	1211.94	1296.24	1395.97	1507.4
Total	0.01	0.01	0.01	0.01	0.01	0.01

Table E-17: Alberta oil refining emissions - reference case scenario

GHG emissions(MT)	2005	2010	2015	2020	2025	2030
Processes	17.04	18.69	19.95	21.34	22.98	24.81

Alberta Crude Oil Production

Table E-18: Alberta crude oil production - base case

Module Balance(PJ)	Crude oil production
Domestic Requirements	-167.65
Export Requirements	-1046.65
Imports	567.21
Outputs	1214.29
Unmet requirements	0
Total	567.21

Table E-19: Alberta crude oil production - reference case

Module Balance (PJ)	2005	2010	2015	2020	2025	2030
Domestic Requirements	-167.65	-239.08	-293.26	-353.11	-423.92	-503.05
Export Requirements	-1046.65	-1046.65	-1046.65	-1046.65	-1046.65	-1046.65
Imports	567.21	649.3	938.97	1234.32	1462.13	1698.25
Outputs	1214.29	1203.64	968.15	732.65	575.66	418.66
Total	567.21	567.21	567.21	567.21	567.21	567.21

Table E-20: Alberta crude oil production emissions - reference case scenario

Emissions(MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Processes	4	3.9	3.2	2.4	1.9	1.4

Alberta SCO production

Table E-21: Alberta SCO production module balance - base case

Module Balance(PJ)	Synthetic crude oil production
Domestic Requirements	-455.41
Export Requirements	-691.95
Imports	0
Outputs	1147.36
Total	0

Table E-22: Alberta SCO production module balance - reference case

Module Balance (PJ)	2005	2010	2015	2020	2025	2030
Domestic Requirements	-455.41	-499.68	-533.25	-570.34	-614.23	-663.26
Export Requirements	-691.95	-1667.37	-3137.03	-3599.3	-3599.3	-3599.3
Imports	0	230.75	0	0	0	0
Outputs	1147.36	1936.3	3670.28	4169.64	4213.52	4262.56
Unmet requirements	0	0	0	0	0	0
Total	0	0	0	0	0	0

Table E-23: Alberta SCO production emissions - reference case

Emissions(MT)	2005	2010	2015	2020	2025	2030
Processes	14.47	24.43	46.3	52.6	53.16	53.78

Alberta Crude Bitumen Production

Table E-24: Alberta crude bitumen production - base case

Module Balance (PJ)	Oil Products
Domestic Requirements	-1147.36
Export Requirements	-872.21
Imports	101.87
Outputs	1917.69
Total	0

Table E-25: Alberta crude bitumen production - reference case

Module Balance (PJ)	2005	2010	2015	2020	2025	2030
Domestic Requirements	-1147.36	-1936.3	-3670.28	-4169.64	-4213.52	-4262.56
Export Requirements	-872.21	-1342.23	-1812.25	-2000.26	-2000.26	-2000.26
Outputs	1917.69	3177.32	5482.53	6169.9	6213.78	6262.82

Table E-26: Alberta crude bitumen production - emissions - reference case scenario

Module Balance (PJ)	2005	2010	2015	2020	2025	2030
Processes	35.28	58.46	100.87	113.52	114.32	115.23

Alberta NGL Production

Table E-27: Alberta NGL extraction - base case

Module Balance (PJ)	Oil Products
Domestic Requirements	-99.77
Export Requirements	-330
Imports	0.23
Outputs	429.77
Total	0.23

Table E-28: Alberta NGL extraction - reference Case

Module Balance (PJ)	2005	2010	2015	2020	2025	2030
Coproduction	0	0	0	0	0	0
Domestic Requirements	-99.77	-99.77	-99.77	-99.77	-99.77	-99.77
Export Requirements	-330	-330	-330	-330	-330	-330
Imports	0.23	0.23	0.23	0.23	0.23	0.23
Outputs	429.77	429.77	429.77	429.77	429.77	429.77
Total	0.23	0.23	0.23	0.23	0.23	0.23

Table E-29: NGL extraction emissions - reference case

Emissions(Million Kilogrammes)	2005	2010	2015	2020	2025	2030
Processes	5,470.80	5,470.80	5,470.80	5,470.80	5,470.80	5,470.80

Alberta Coal Mining

Table E-30: Alberta coal mining - base case

Module Balance (PJ)	Solid Fuels
Domestic Requirements	-513.5
Export Requirements	-60
Imports	13.5
Outputs	560
Total	0

Table E-31: Alberta coal mining - reference case scenario

Module Balance (PJ)	2005	2010	2015	2020	2025	2030
Domestic Requirements	-513.5	-563.37	-689.77	-805.27	-805.27	-805.27
Export Requirements	-60	-60	-60	-60	-60	-60
Imports	13.5	63.37	189.76	305.27	305.27	305.27
Outputs	560	560	560	560	560	560
Total	0	0	0	0	0	0

Table E-32: Alberta coal mining - emission - reference case scenario

Emissions (Million KG)	2005	2010	2015	2020	2025	2030
Processes	83.49	83.49	83.49	83.49	83.49	83.49

Alberta Cogeneration Capacity in oil Sands

Table E-33: Alberta cogeneration capacity in 2005

Module Balance(Million MWh)	Electricity	Heat	Total
Coproduction	0	2.66	2.66
Domestic Requirements	-10.65	0	-10.65
Outputs	10.65	0	10.65
Total	0	2.66	2.66

Table E-34: Alberta cogeneration capacity - reference case

Module Balance (Million MWh)	2005	2010	2015	2020	2025	2030
Coproduction	2.66	3.7	5.16	5.97	6.24	6.48
Domestic Requirements	-10.65	-14.92	-22.31	-25.59	-27.8	-30.17
Export Requirements	0	0	0	0	0	0
Imports	0	0.14	1.65	1.7	2.85	4.27
Outputs	10.65	14.78	20.66	23.89	24.95	25.91
Total	2.66	3.7	5.16	5.97	6.24	6.48

Table E-35 Alberta cogeneration - emissions in reference case

Emissions(MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Processes	2.6	3.7	5.2	6	6.2	6.5

Appendix F

Resource Sector

Table F-1: Total primary requirement of Alberta energy sector

PJ	Coal	Condensates	Pentanes Plus	NGL	Biomass	Coal Unspecified	Bitumen	Hydro	Wind	Wood	Coal Bituminous	Crude Oil	Natural Gas	Total
Solid Fuels	-60	0	0	0	0	3	0	0	0	0	605	0	0	548
Renewable	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Oil Products	0	-116	-116	281	0	0	1486	0	0	0	0	0	0	1534
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	1813	1813
Hydropower	0	0	0	0	0	0	0	20	0	0	0	0	0	20
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	1102	0	1102
Biomass	0	0	0	0	56	0	0	0	0	27	0	0	0	84
Total	-60	-116	-116	281	56	3	1486	20	1	27	605	1102	1813	5102

Table F-2: Alberta fossil fuel reserves - base year

Billion GJ	Coal SB	Cond	Pentanes Plus	NGL	Coal Unspecified	Bitumen	Nuclear	Coal Bituminous	Crude Oil	Natural Gas	Total
Solid Fuels	0	0	0	0	897	0	0	6	0	0	903
Oil Products	0	0	0	2	0	1170	0	0	0	0	1172
Nuclear	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	37	37
Crude Oil	0	0	0	0	0	0	0	0	9	0	9
Total	0	0	0	2	897	1170	0	6	9	37	2121

Table F-3: Alberta indigenous production - base year

Billion GJ	Coal SB	NGL	Coal	Bitumen	Wood	Coal Bituminous	Crude Oil	NG	Total
Solid Fuels	0	0	3	0	0	605	0	0	608
Renewable	0	0	0	0	0	0	0	0	0
Oil Products	0	610	0	2256	0	0	0	0	2866
Nuclear	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	5506	5506
Hydropower	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	1349	0	1349
Biomass	0	0	0	0	27	0	0	0	27
Total	0	610	3	2256	27	605	1349	5506	10358

Table F-4: Alberta exports - base year

Billion GJ	Coal SB	Condensates	Pentanes Plus	Natural Gas Liquid	Bitumen	Crude Oil	Natural Gas	Total
Solid Fuels	60	0	0	0	0	0	0	60
Renewables	0	0	0	0	0	0	0	0
Oil Products	0	116	116	330	872	0	0	1435
Nuclear	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	4040	4040
Hydropower	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	814	0	814
Biomass	0	0	0	0	0	0	0	0
Total	60	116	116	330	872	814	4040	6349

Appendix G

Emissions –Demand Sector

Table G-1: Alberta environmental results - base case scenario 2005

Emissions (MT CO_2 eq)	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Household	7.2	7.9	8.7	9.6	10.6	11.7
Commercial and Institutional sector	6.1	7.4	8.6	9.9	11.1	12.4
Industrial sector	41.1	46	51.7	58.2	65.7	74.4
Agriculture sector	2.8	3	3.3	3.5	3.8	4.1
Transportation sector Road	21.4	23.6	26.1	28.8	31.8	35.2
Passenger Rail	0.1	0.1	0.1	0.1	0.1	0.1
Passenger Air	2.4	2.5	2.6	2.7	2.9	3
Freight Rail	2.5	2.6	2.8	2.9	3.1	3.2
Freight Air	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline transport	3.4	3.6	3.8	4	4.2	4.4
OFF Road	0.7	0.7	0.7	0.7	0.7	0.7
Total	87.6	97.5	108.3	120.5	134.1	149.3

Table G-2: Total emissions - demand sector reference case scenario

Emissions (MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Household	7.2	7.9	8.7	9.6	10.6	11.7
Commercial and Institutional sector	6.1	7.4	8.6	9.9	11.1	12.4
Industrial sector	41.1	46	51.7	58.2	65.7	74.4
Agriculture sector	2.8	3	3.3	3.5	3.8	4.1
Transportation sector Road	21.4	23.6	26.1	28.8	31.8	35.2
Passenger Rail	0.1	0.1	0.1	0.1	0.1	0.1
Passenger Air	2.4	2.5	2.6	2.7	2.9	3
Freight Rail	2.5	2.6	2.8	2.9	3.1	3.2
Freight Air	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline transport	3.4	3.6	3.8	4	4.2	4.4
OFF Road	0.7	0.7	0.7	0.7	0.7	0.7
Total	87.6	97.5	108.3	120.5	134.1	149

Table G-3: Total emission - demand sector - fuel based emissions

Emissions(MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Biomass	0	0	0	0	0	0
Natural Gas	34.8	39.1	43.7	48.9	54.5	60.7
Oil Products	52.5	58	64.2	71.2	79.1	88
Solid Fuels	0.3	0.3	0.4	0.4	0.5	0.5
Total	87.6	97.5	108.3	120.5	134.1	149.3

Appendix H

Mitigation Scenario

Table H-1: Alberta residential sector GHG mitigation (appliance and efficient lighting)

MT CO_2 eq	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Reference	255.6	303.2	385.3	431.5	450.9	471.5
Appliances	255.6	302.8	384.4	429.9	449.3	469.8
GHG avoided (appliance vs. Reference)	0	-0.4	-0.9	-1.6	-1.6	-1.7
Efficient Lighting	255.6	303	385	431	450.4	471.1
GHG avoided (efficient Lighting vs. Reference)	0	-0.2	-0.3	-0.5	-0.5	-0.4

Table H-2: Alberta commercial sector mitigation - demand reduction

Energy Demand reduction (PJ)	2005	2010	2015	2020	2025	2030
Reference	2274	2471.6	2689	2930	3198	3496.7
Commercial auxiliary equipment and motor	2274	2469.2	2683.4	2920.4	3187.2	3484.7
Demand reduction (auxiliary equipment vs. reference)	0	-2.4	-5.6	-9.6	-10.8	-12
Commercial water heating	2274	2470	2685.2	2923.6	3188.3	3485.9
Demand reduction (water heating vs. reference)	0	-1.6	-3.8	-6.4	-9.7	-10.8
Commercial lighting and equipment	2274	2471.5	2688.7	2929.6	3197.3	3495.8
Demand reduction (lighting vs. reference)	0	-0.1	-0.3	-0.4	-0.7	-0.9

Table H-3: Alberta commercial sector mitigation - output reduction vs. reference scenario

Transformation Output (PJ)	2005	2010	2015	2020	2025	2030
Reference	243.5	265.8	297.5	331.6	368.7	409.1
Commercial auxiliary equipment and motor	243.5	263.1	291.2	320.9	356.5	395.6
Output reduction(auxiliary equipment vs. reference scenario)	0	-2.7	-6.3	-10.7	-12.2	-13.5
Commercial water heating	243.5	265.8	297.5	331.6	368.7	409.1
Output reduction(water heating vs. reference scenario)	0	0	0	0	0	0
Commercial lighting and equipment	243.5	265.7	297.2	331.1	367.9	408
Output reduction(lighting vs. reference scenario)	0	-0.1	-0.3	-0.5	-0.8	-1.1

Table H-4: Alberta commercial sector mitigation - GHG reduction vs. reference scenario

GHG mitigation (MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Reference	255.6	303.2	385.3	431.5	450.9	471.5
Commercial auxiliary equipment and motor	255.6	302.8	384.3	429.7	449.1	469.7
GHG Avoided(auxiliary equipment vs. Reference scenario)	0	-0.4	-1	-1.8	-1.8	-1.8
Commercial water heating	255.6	303.1	385	431.1	450.4	470.9
GHG Avoided(water heating vs. Reference scenario)	0	-0.1	-0.3	-0.4	-0.5	-0.6
commercial lighting and equipment	255.6	302.3	384.4	430.4	449.9	470.7
GHG Avoided(lighting vs. Reference scenario)	0	-0.9	-0.9	-1.1	-1	-0.8

Table H-5: Alberta industrial sector mitigation - demand reduction vs. reference scenario

Demand Reduction(PJ)	2005	2010	2015	2020	2025	2030
Industrial sector efficiency	2274	2421.5	2581.6	2756.6	2947.9	3157.3
Reference	2274	2471.6	2689	2930	3198	3496.7
Demand reduction(industrial efficiency vs. reference)	0	-50.1	-107.4	-173.4	-250.1	-339.4

Table H-6: Alberta industrial sector mitigation - transformation output reduction vs. reference scenario

Transformation output(PJ)	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Industrial sector efficiency	243.5	254	272.4	291.7	311.7	332.8
Reference	243.5	265.8	297.5	331.6	368.7	409.1
Output reduction (industrial efficiency vs. reference)	0	-11.8	-25.1	-39.9	-57	-76.3

Table H-7: Alberta industrial sector mitigation - GHG emissions reduction vs. reference scenario

GHG mitigation (MT CO_2 eq)	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Industrial sector efficiency	255.6	297	369.6	405.1	415.8	425.9
Reference	255.6	303.2	385.3	431.5	450.9	471.5
GHG avoided (industrial efficiency vs. reference)	0	-6.2	-15.7	-26.4	-35.1	-45.6

Table H-8: Alberta transport sector mitigation - GHG reduction vs. reference scenario

GHG mitigation (MTCO_2eq)	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Biofuel	255.63	303.16	383.83	429.9	449.16	469.61
Reference	255.63	303.16	385.27	431.48	450.9	471.53
GHG avoided (bio fuel)	0	0	-1.44	-1.58	-1.74	-1.92
HYB: Hybrid cars	255.63	302.89	383.97	430	448.42	468.15
GHG avoided(hybrid)	0	0.27	1.3	1.48	2.48	3.38

Appendix I

Alberta Power sector mitigation

Table I-1: Supercritical coal plant - change in output vs. reference scenario

Transformation output (PJ)	2005	2010	2015	2020	2025	2030
Reference	225.1	274.5	338.5	399.3	462.6	528.8
Supercritical coal plant (SPC)	225.1	274.5	338.5	399.3	459.7	522.9
Output reduction (SPC vs. reference scenario)	0	0	0	0	-2.9	-5.9
Supercritical plant with CCS	225.1	274.6	340.6	399.7	462.8	528.9
Output change(SPC with CCS vs. reference)	0	0.1	2.1	0.4	0.2	0.1

Table I-2: Supercritical coal plant - GHG reduction in output vs. reference scenario

MT CO_2 eq	2005	2010	2015	2020	2025	2030
Reference	244.3	298.2	385.5	438.9	463.5	492.7
Supercritical coal plant (SPC)	244.3	299.3	385.7	420.4	444.7	473.5
GHG reduction (SPC vs. reference scenario)	0	1.1	0.2	-18.5	-18.8	-19.2
Supercritical plant (SPC) with CCS	244.3	299.8	377.2	418.6	443.2	472.3
GHG reduction (SPC with CCS vs. reference scenario)	0	1.6	-8.3	-20.3	-20.3	-20.4

Table I-3: Ultra supercritical coal plant - GHG reduction vs. reference scenario

GHG emissions (MT CO_2 eq)	2005	2010	2015	2020	2025	2030
Reference	255.6	303.2	385.3	431.5	450.9	471.5
Ultra Supercritical Coal Plant (USPC)	255.6	304.3	377.5	414	433	453.3
GHG avoided (USPC vs. reference)	0	1.1	-7.8	-17.5	-17.9	-18.2
Ultra Supercritical plant with CCS (USPC+CCS)	255.6	300.8	342.2	365.5	383.1	402.5
GHG avoided (USPC with CCS vs. reference)	0	-2.4	-43.1	-66	-67.8	-69

Table I-4: IGCC coal plant - GHG reduction vs. reference scenario

GHG (MT CO2 eq)	2005	2010	2015	2020	2025	2030
Reference	255.6	303.2	385.3	431.5	450.9	471.5
IGCC Plants	255.6	304.2	356.8	424.7	443.7	464
GHG avoided (IGCC vs. reference)	0	1	-28.5	-6.8	-7.2	-7.5
IGCC plant with CCS	255.6	304.2	343.8	367.3	385	404.5
GHG avoided (IGCC with CCS vs. reference)	0	1	-41.5	-64.2	-65.9	-67

Alberta Oil sands sector mitigation

Table I-5: Alberta oil crude bitumen production - GHG reduction vs. reference scenario

GHG mitigation (MT CO_2 eq)	2005	2010	2015	2020	2025	2030
CCS in Oil sands for crude bitumen production	35.3	57.2	96.57	63.5	63.94	64.43
Reference	35.3	58.5	100.8	113	114.2	115
GHG avoided (CCS for bitumen production vs. reference scenario)	0	-1.3	-4.27	-50	-50.2	-50.6

Table I-6: Alberta SCO production - GHG reduction vs. reference scenario

GHG mitigation (MT CO_2 eq)	2005	2010	2015	2020	2025	2030
CCS in oil sands for SCO production	14.5	24.4	29.78	25.3	25.57	25.85
Reference	14.5	24.4	46.28	52.5	53.05	53.64
GHG avoided (CCS for SCO production vs. reference)	0	0	-16.5	-27	-27.5	-27.8

Alberta Renewable resource mitigation

Table I-7: Alberta renewable mitigation - Output reduction vs. reference scenario

Output (PJ)	2005	2010	2015	2020	2025	2030
Reference	243.5	265.8	297.5	331.6	368.7	409.1
Hydro	243.5	265.8	297.5	331.6	368.7	409.1
Output reduction (Hydro vs. Reference)	0	0	0	0	0	0
Wind	243.5	265.8	297.5	327.6	348	362.7
Output reduction (wind vs. Reference)	0	0	0	-4	-20.7	-46.4
Nuclear	243.5	265.8	297.5	331.6	368.7	409.1
Output reduction (nuclear vs. Reference)	0	0	0	0	0	0

Table I-8: Alberta renewable mitigation - GHG mitigation vs. reference scenario

GHG mitigation(MT CO_2eq)	2005	2010	2015	2020	2025	2030
Reference	255.6	303.2	385.3	431.5	450.9	471.5
Hydro	255.6	303.4	385.3	405.1	423	442.8
GHG avoided(Hydro vs. reference scenario)	0	0.2	0	-26.4	-27.9	-28.7
Wind	255.6	303.5	386.1	378.3	393.1	409.4
GHG avoided(Wind vs. reference scenario)	0	0.3	0.8	-53.2	-57.8	-62.1
Nuclear	255.6	303.2	385.3	426.9	433.7	454
GHG avoided(nuclear vs. reference scenario)	0	0	0	-4.6	-17.2	-17.5