Development of Energy, Emission and Water Flow Sankey Diagrams for the Province of Alberta Through Modeling

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Submitted by

Amit Kumar
Veena Subramanyam
Md Ruhul Kabir

Department of Mechanical Engineering, University of Alberta, Edmonton, Canada

Prepared for
Alberta Innovates – Energy and Environmental Solutions (EES)
Suite 500, Phipps McKinnon Building
10020 – 101 A Avenue
Edmonton, Alberta T5J 3G2

and

Department of Energy, Government of Alberta
10th Floor Petroleum Plaza NT, 9945 – 108 Street
Edmonton, AB T5K 2G6

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All conclusions, recommendations and opinions are solely the authors, and are not endorsed by either the financial sponsors of this work or the many people who offered comments and suggestions.

Executive Summary

Alberta has 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. This research was initiated by the Department of Energy, Government of Alberta (DOE-GOA) and Alberta Innovates – Energy and Environment Solutions (AI-EES) in order to critically understand the energy, emissions and water flow patterns in the Province of Alberta through the development of Sankey diagrams. Sankey diagrams are a specific type of diagram in which the width of the arrows is proportional to the quantity of flow. A key objective of this research is developing an Alberta-specific energy forecasting and planning model for studying different greenhouse gas (GHG) mitigation scenarios for the energy demand and supply sectors of the Province of Alberta.

This research developed a data intensive energy-environment planning and forecasting tool using the *Long Range Energy Alternative Planning Systems model* (*LEAP*). The Alberta-specific *LEAP* model consists of the characteristics of supply and demand in energy sectors. Developed for Alberta it can be used as an energy accounting framework, which provides a physical description of Alberta's energy system, including estimates of GHG abatement costs, and environmental impact. It is a demand driven program. Demand, supply and resource data specific to Alberta have been built into *LEAP*. In its current form this model can be used to analyze data over a medium to long term user-defined planning horizon (e.g. 30 to 50 years). This model has a framework capable of dealing with the energy flow characteristics from reserves to final end-use. The Alberta-specific *LEAP* model we have developed consists of four modules. The first is the demand module, which contains the details of the demand for end-use energy (both primary and secondary fuel) for the residential, commercial, industrial, agricultural and transportation sectors of Alberta. These five demand sectors have been further divided into subsectors. For example, the residential sector is divided into the rural and urban subsectors, which are further divided into end-use of energy for cooking, lighting, heating, etc. Each end-use is associated with different types of devices that use energy. Data specific to each of these Alberta energy-demand sectors, subsectors, end-uses and devices have been developed in this *LEAP* model. The second module is the transformation module. It consists of all the energy transformation processes, such as electricity generation, oil refining, coal mining, etc. In the electricity generation module, characteristics of all the power plants currently operating in Alberta and planned for the future have been developed. The electricity planning of various agencies has been analyzed and, based on this analysis, data have been developed in *LEAP*. The third module deals with the resources available in Alberta. The fourth module is related to technology and the environmental database. *LEAP* has its own built-in database for emissions factors for both the demand and transformation technologies for different primary and secondary fuels. We have also developed Alberta-specific emissions factors for technologies and conversion processes which are not available in *LEAP*. Development of all these modules in *LEAP* using Alberta-specific data is useful for developing a variety of GHG mitigation scenarios for Alberta.

Alberta Sankey diagrams have been developed using the final energy demand and supply data obtained by *LEAP* for the base year 2005. The Sankey diagram for Alberta gives a detailed flow pattern indicating the proportional consumption of primary and secondary energy in different energy demand sectors. It also shows the total useful and rejected energy for the demand

sector. Figure E1 is a Sankey diagram showing energy flow within the Province of Alberta for 2005. This gives the details of energy flow pathways from resource to their transformation and utilization within Alberta's demand sectors. Coal, bitumen/crude oil and natural gas together approximately represented about 96% of Alberta's total primary energy. As a percentage of the total primary energy consumed in Alberta, coal, bitumen/crude oil and natural gas contributed about 21%, 32% and 43%, respectively in 2005. Renewable energy sources including hydro, biomass and wind together contributed only 4% of the total primary energy. Nearly all coal was used for electricity generation. A major consumer of bitumen/crude oil was the transportation sector (about 66%). Figure E2 is the Sankey diagram which shows in greater detail the energy flow for the industrial sector in 2005. As Alberta is a large exporter of oil and natural gas, a separate Sankey diagram has been generated which illustrates the comparative flow data. About 72% of the net production of natural gas was exported in 2005. Similarly, about 58% of the net production of bitumen/crude was exported. Figure E3 presents the overall picture of Alberta's primary and secondary energy pathways with complete data regarding imports and exports pertaining to each sector. Using emissions factors from the *LEAP* model, a Sankey diagram of emissions flow in the Province of Alberta was developed. Figure E4 is the Sankey diagram showing Alberta's emissions flow for 2005 in megatons of CO_2 equivalents. Although the Sankey diagrams have been developed for 2005, which is the base year for this study, the developed LEAP model has the capability of developing for a Sankey diagram for any year in the study planning horizon.

A reference case, also called a business-as-usual scenario, was developed for a study period of 25 years (2005-2030). The preliminary GHG mitigation scenarios encompass various demand and supply scenarios. In the energy conversion sector, mitigation scenarios were investigated for renewable power generation and inclusion of supercritical, ultra-supercritical, and integrated gasification combined cycle (IGCC) plants. In the oil and gas sector, GHG mitigation scenarios were considered that use carbon capture and sequestration (CCS) options. In Alberta's residential and commercial sector a GHG mitigation of 4-6 MT of CO_2 equivalents per year could be achieved as a result of the efficiency improvement based on the assumed penetration of efficiency light bulbs and appliances. In the industrial sector up to 40 MT of CO_2 equivalents per year of GHG reduction could be achieved as a result of efficiency improvement. In the energy conversion sector large GHG mitigation potential lies in the oil and gas sector as well as in power plants using carbon capture and storage (CCS) option. The GHG mitigation made possible by the supply side options totals 20 – 70 MT CO_2 equivalents per year.

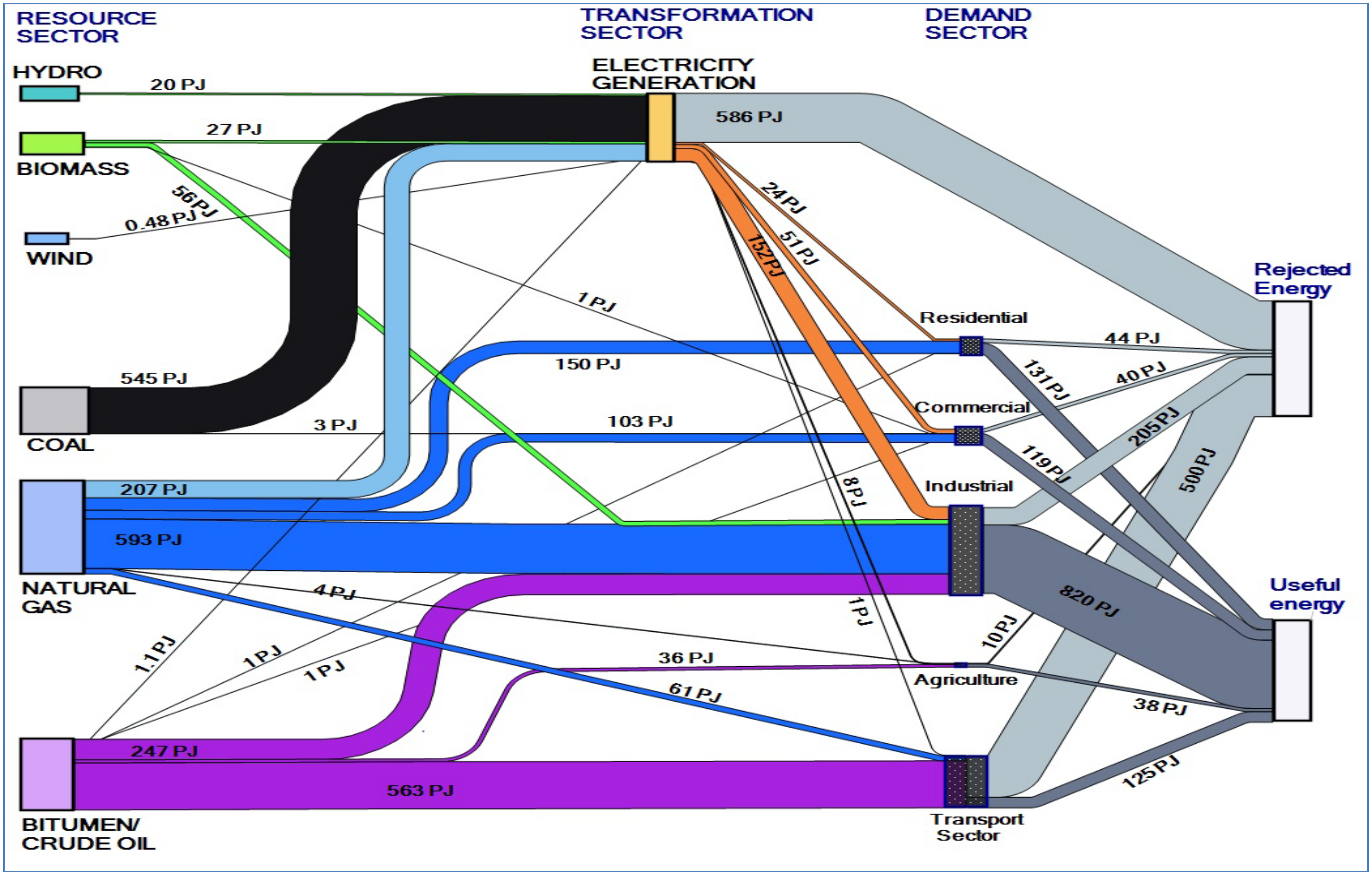

Figure E1: Alberta energy sankey diagram-without exports

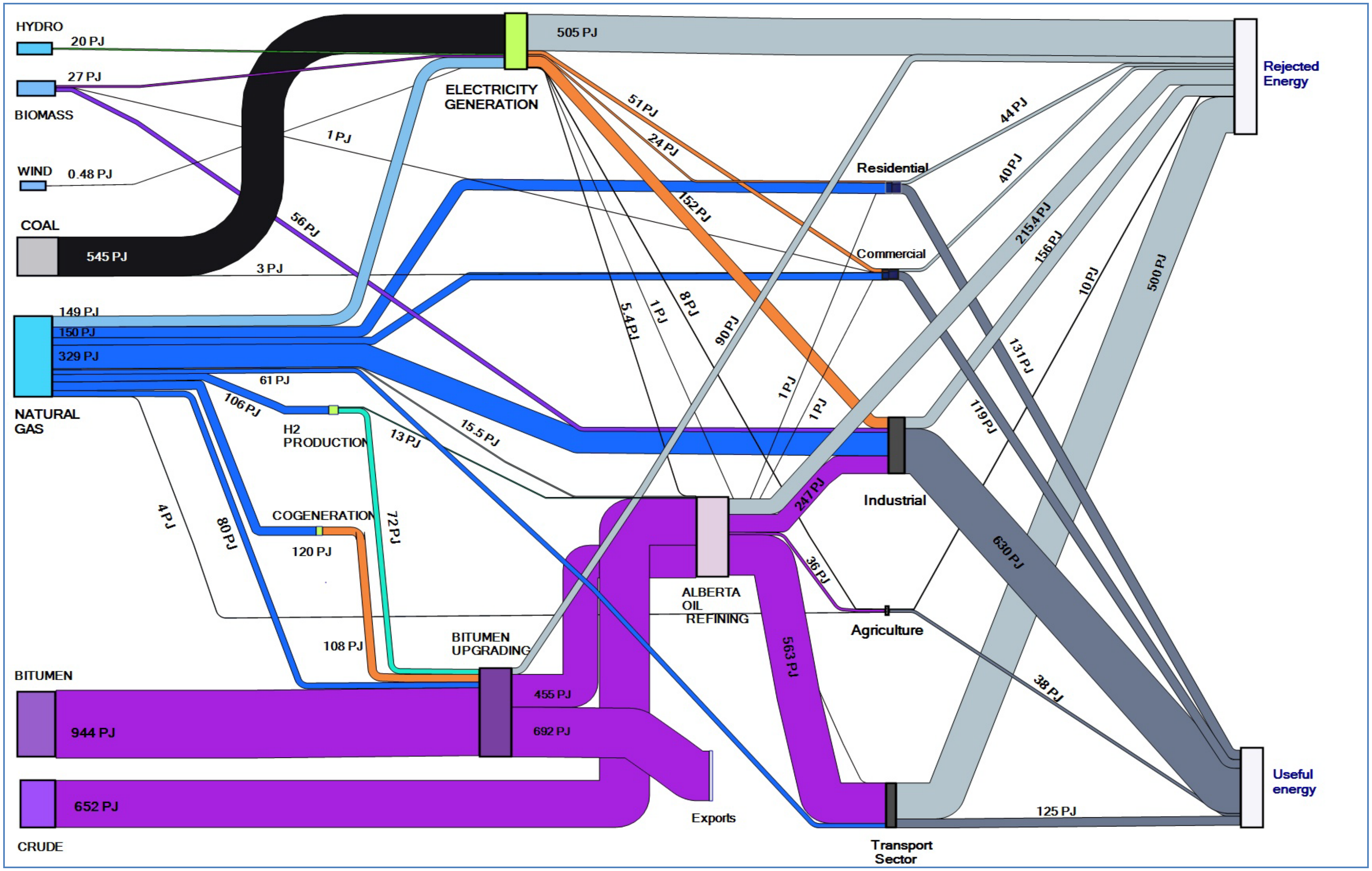

Figure E2: Alberta industrial sector energy flow sankey diagram

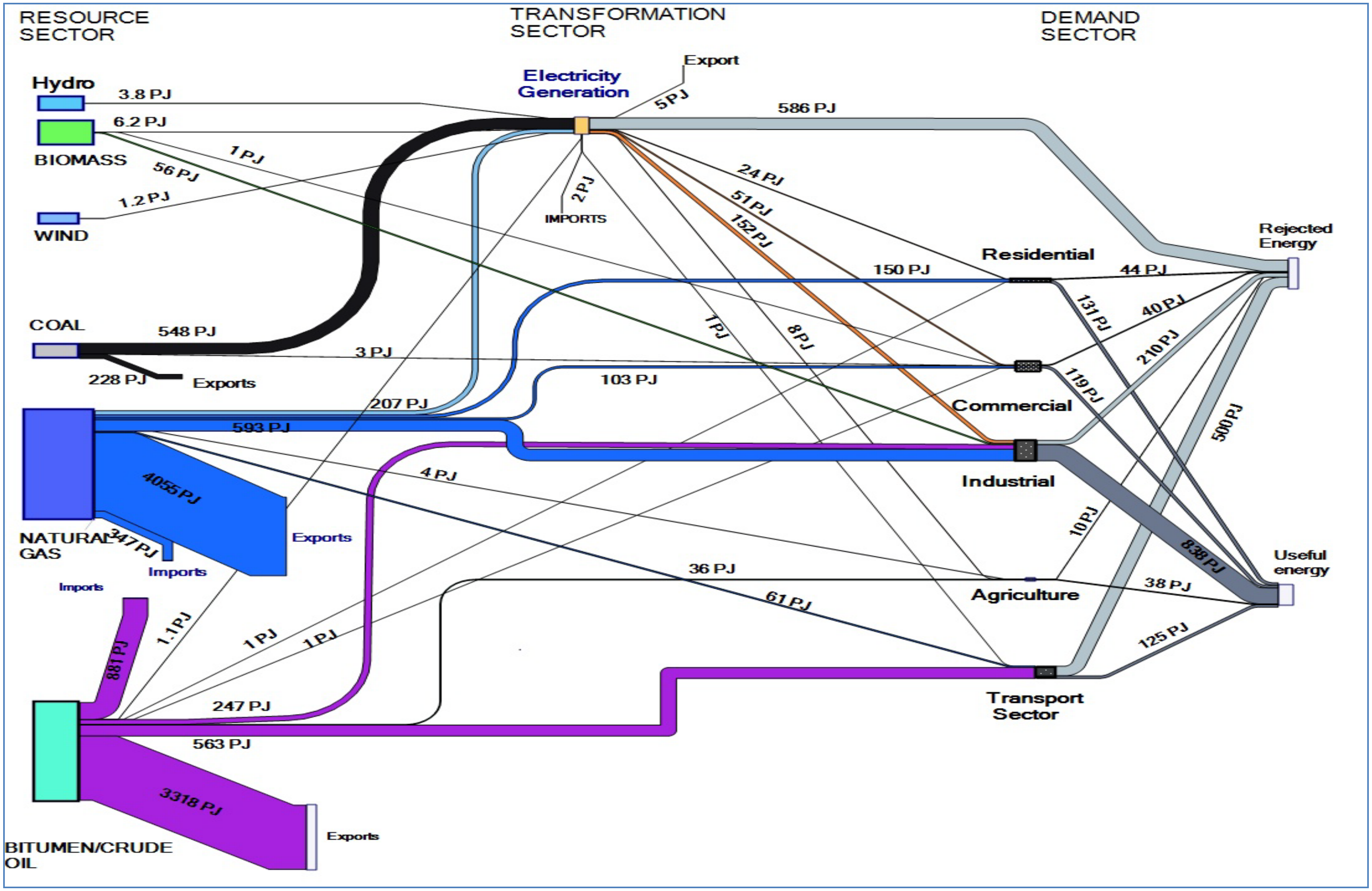

Figure E3: Alberta energy sankey with exports

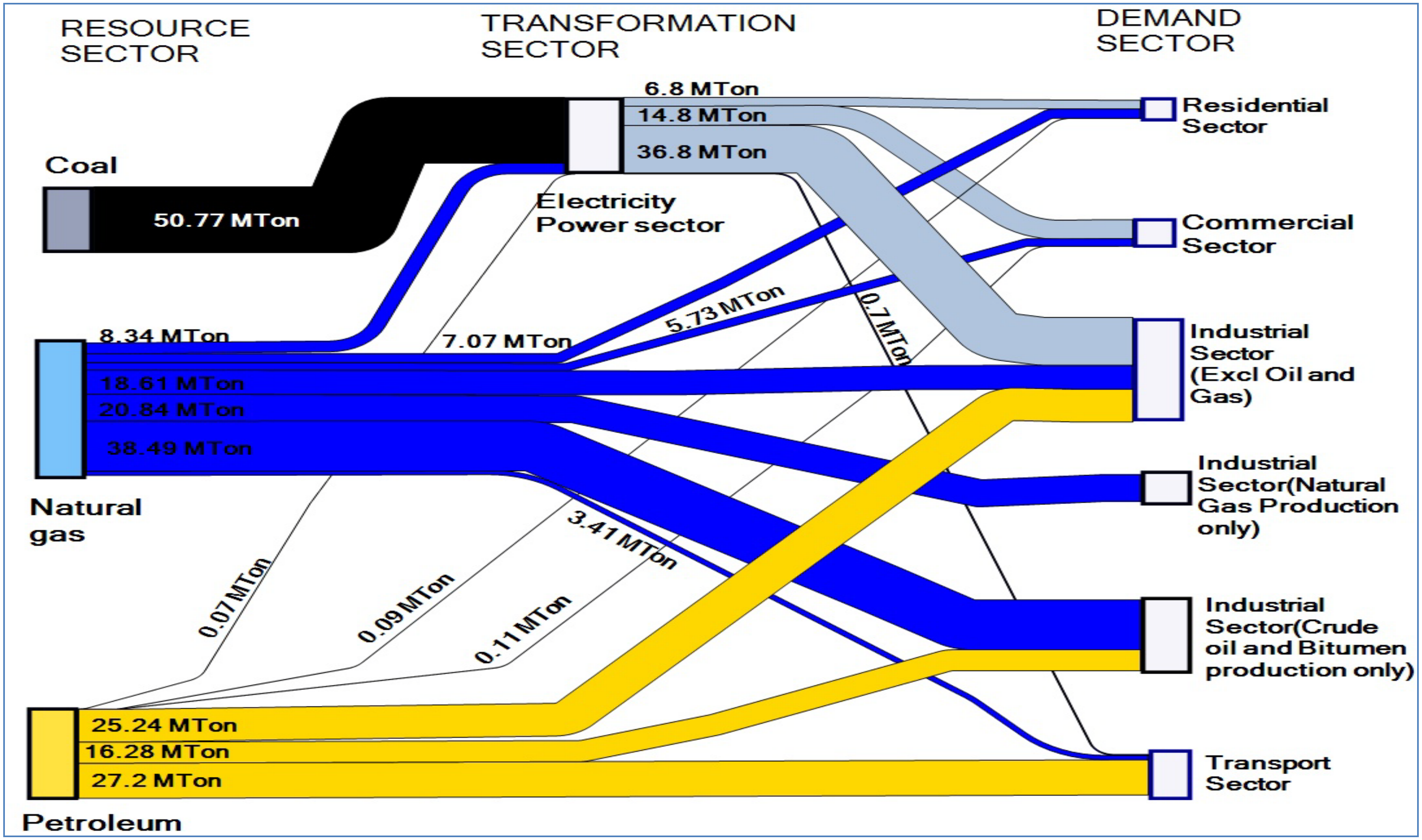

Figure E4: Alberta energy sector –emissions flow

The production of energy in the Province of Alberta involves the use of a large amount of water. Effective water management is a great challenge for Alberta and will continue to be a critical issue. To formulate a sustainable strategy for freshwater supply and utilization, it is necessary to understand how freshwater is allocated and used in Alberta. This study focuses on critically analyzing the water supply and demand for Alberta's different sectors. The primary objective of this study is to develop Sankey diagrams illustrating the water flow for key river basins and water utilization by different demand and supply sectors. This study analyzes surface and ground water separately. It also differentiates between water allocation and its use. As stated above, the base year for the study is 2005. Alberta is divided into seven major river basins or river systems, namely, the Peace, Athabasca, Hay, North Saskatchewan, South Saskatchewan, Beaver, and Milk river basins. Some of these are further divided into sub-basins. Overall, there are 17 identifiable river basins in Alberta. This study analyzes the water allocation and water use for each of these river basins and provides water flow Sankey diagrams it has developed. Water allocation represents the amount of water that licensees are entitled to take from surface or groundwater sources. On the other hand, water use is the portion of the licensed water that is expected to be consumed or lost. Water can be lost due to evaporation or seepage in the course of a process. The water demand sectors are referred to as: municipal, agricultural, commercial, petrochemical, industrial and others. Inventory data for the municipal and residential sectors was collected using the Water Use Reporting System (WURS) and Environment Canada's Municipal Water Use Database (MUD). Though water allocation is properly tracked, it should be noted that due to limitation of information, this analysis focuses only on licensed municipal water use. Wherever water use data was not available, it has been assumed to be equal to water allocation.

Based on the collection of the inventory data, total surface and ground water allocation for Alberta was 9,251,640 dam^3 and 311,546 dam^3, respectively for the year 2005. In contrast, total surface and ground water use was 3,208,858 dam^3 (35% of allocation) and 103,835 dam^3 (33% of allocation), respectively, for the same year (Alberta Environment, 2007).

Based on the study it was found that Bow, Oldman, Athabasca and North Saskatchewan river basins are the most utilized basins in terms of water use. Figures E5 and E6 are Sankey diagrams showing water allocation and use for all the river basins of Alberta. The Agricultural sector uses the most water, followed by the industrial and municipal sectors. For the Bow river basin, the agricultural sector is the heaviest user followed by the municipal sector. For the Athabasca river basin, the petrochemical sector is the heaviest water user followed by the industrial sector. For the North Saskatchewan river basin the industrial sector is uses the most water.

The results of this study indicates that the Bow, Oldman, Athabasca, North Saskatchewan and Red Deer river basins are highly utilized in terms of water use. In 2005, these rivers had water allocations of 2,597,898, 2,292,402, 849,629, 1,996,840, and 372,833 dam^3, respectively. On the other hand, 44.33%, 49.77%, 32.14%, 9.82% and 56.34% of the allocated water was used from the respective basins by the different sectors. Although compared to other major river basins, very little water was allocated (62,361 dam^3) from the Milk river basin, 87.94% of what was allocated was used.

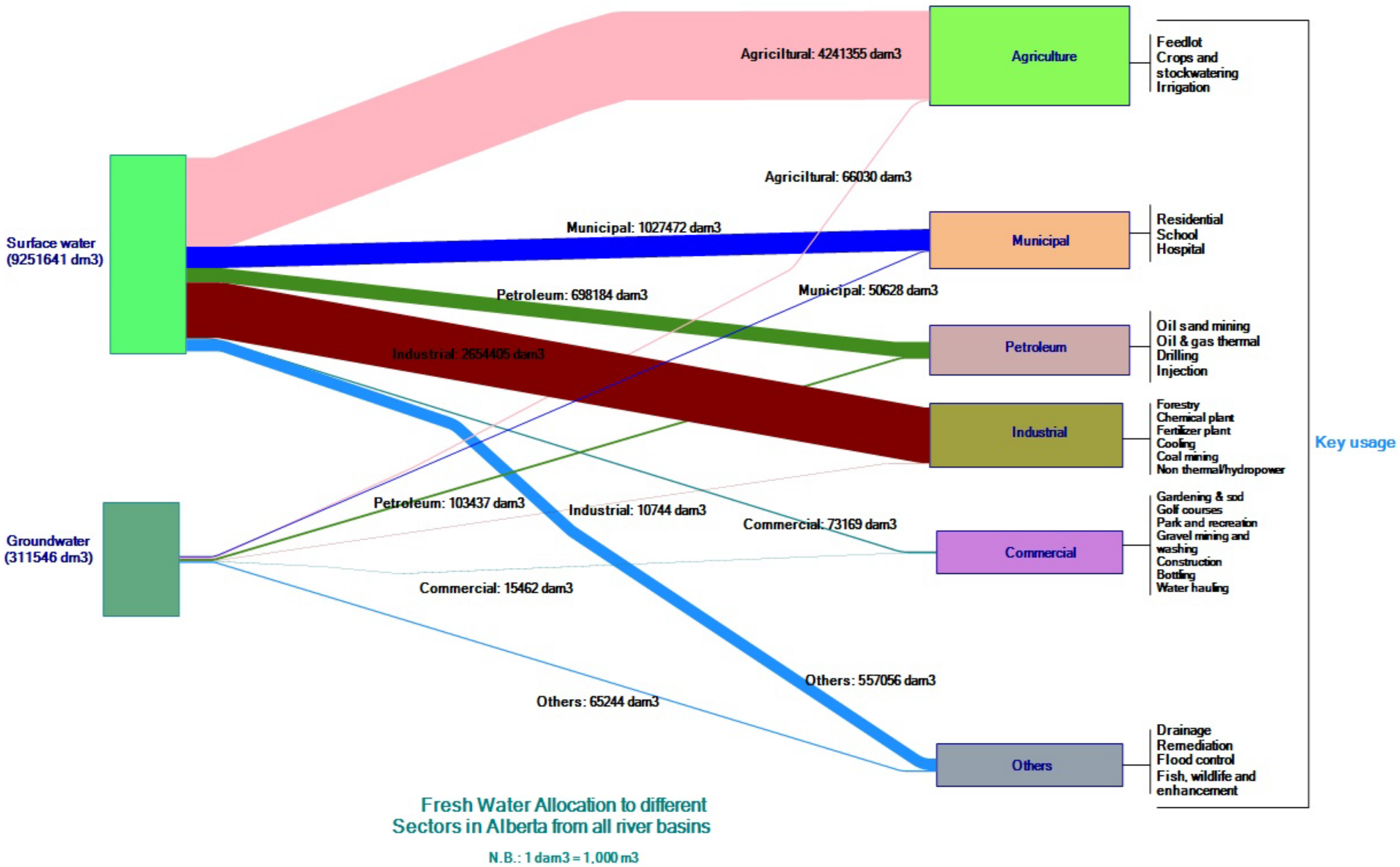

Figure E5: Sankey diagram of water allocation in Alberta (all river basins)

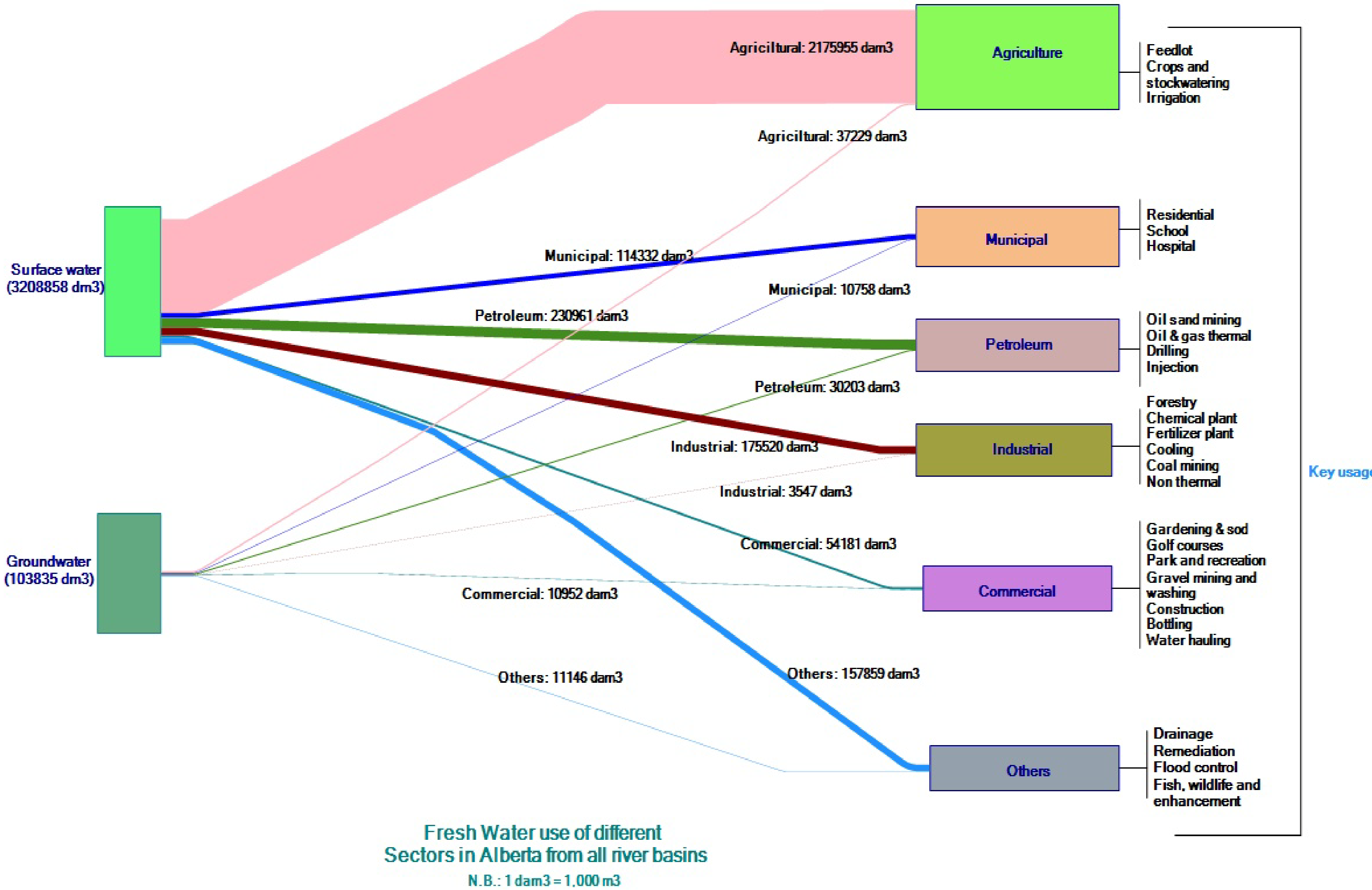

Figure E6: Sankey diagram of water use in Alberta (all river basins)

Summary

The current project was funded by Alberta Innovates – Energy and Environment Solutions (AI-EES) and the Department of Energy – Government of Alberta (DOE-GOA). Using *LEAP* this project developed a data intensive and Alberta specific energy planning and forecasting tool. This project has been of assistance in developing a preliminary energy and environment modeling capability for Alberta. This model developed along with the database and infrastructure could be used by different government agencies and departments when making policy decisions and assessing of energy projects. This model helped in developing Sankey flow diagrams involving energy and emission flow which critically increases understanding of Alberta's energy sector. Preliminary GHG mitigation scenarios have also been developed using the *LEAP* model. On-going support for this energy and environmental systems modeling is still needed, and could be provided through development of a *centre for energy and environmental systems engineering*. This would assist in further developing and maintaining Alberta's energy and environment modeling capability. It would further the training of energy and environment personnel allowing them to apply a systems approach to this area.

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1. Introduction

The energy sector plays a major role in Alberta's economy; both directly and indirectly contributing to GDP, income, and employment as well as the total revenue of the province. As a result, overtime, energy sector has an enormous impact on the macroeconomic scenario of Alberta. Alberta's growth has been associated with environmental impacts making Alberta the highest greenhouse gas (GHG) emitter, the source of about 40% of Canada's emissions. The threat of climate change can be effectively countered by mitigating GHG emissions. The options for combating climate change are: improvement of the efficiency of energy consuming systems, like lighting and appliances, improvement of the efficiency of process equipment in the industrial sector, improvement of the fuel efficiency of vehicles and improvement of the efficiency in the supply sector through reducing the energy intensity of the primary energy conversion process. Sequestration of emitted GHGs by using carbon capture and storage technology can be used in various energy sectors; switching over to low or no-carbon fuels such as biodiesel and bioethanol is an option for the transportation sector; and incorporation of renewable energy into the electricity generation sector.

To develop technologically feasible options for GHG mitigation in the Province of Alberta it is necessary to critically understand the flow of energy and emissions. Using various energy-environmental models would assist policy makers in formulating and implementing energy sector related policies. This can be achieved by using various energy-environmental models. Canada is a large consumer of energy. In 2002, it, along with the United States, was the highest energy consumer 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, and an economy partly based on energy-intensive industries (mining, forestry, petrochemical, pulp and paper, aluminum smelters, refining, and steel manufacturing) account for Canada's high energy consumption (Alberta Electricity System Operator, 2005; Ménard, 2009). Table 1 gives the details of the total domestic energy production in Canada for the years 2005 and 2007.

Table 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 2. According to the International Energy Agency (IEA), the United States and Canada are the largest consumers of energy in the world on a per capita, consuming each year almost 200 GJ per person – the equivalent of 5,000 litres (or 32 barrels) of crude oil. This is approximately twice the per capita energy consumption seen in other countries who are members of the 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 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 Canada's 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 and the total revenue of the province. The major spur to Alberta's economy has come from the production and processing of oil and gas. The indirect impact of this has been on the development of other sectors catering to the energy sector and the generation of large government revenues. That is why the energy sector can be said to have an impact on the macroeconomic scenario of Alberta over the long term.

The province of Alberta is the largest hydrocarbon base in North America. Each year Alberta produces 5 trillion cubic feet (Tcf) of natural gas, 250 million barrels of conventional oil, 500 million barrels of bitumen, and more than 30 million tonnes of coal. The capacity of electricity generation is more than 12,000 MW, and demand is growing at twice the rate of the rest of Canada (Government of Alberta, 2008a). According to Statistics Canada, Alberta is Canada's largest 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, its per capita energy consumption increased by 11%. A large part of the increase in total energy consumption was a result of increased industrial activity (Ménard, 2009). As shown in Figure 1-1, in 2003 Alberta's per capita energy consumption was 0.85 terajoule. This is much higher than the Canadian national average of 0.33 terajoule. A large portion of the total primary energy being produced is exported; the details of this are given in Table 3. About 80% of the energy produced is being exported, and the per capita energy consumption figures include this large export number.

Table 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 (million m^3)	112	27	88
Natural gas equivalent (billion m^3)	168	23	109

Alberta's rate of growth is expected to remain at 2.7% annually for the period 2005 to 2020 (Natural Resource Canada, 2006a). The conversion of natural resources into energy or fuel requires considerable understanding of the dynamics of energy pathways and the uncertainties associated with them. It is expected there will be massive investments in developing and implementing new technologies, infrastructure projects, renewable and non-renewable resources. Alberta's growth will be significantly influenced by its growth in the fossil fuel sector. This could also have associated environmental consequences that could make the development of right policies and regulatory frameworks challenging.

The most of all these challenges is indiscriminate greenhouse gas (GHG) emissions. Alberta's GHG emissions are about 40% of the total of Canada (Alberta Electricity System Operator, 2005; Alberta Environment, 2008). This has led to a lot of pressure being put on Alberta to develop an environmentally friendly path of energy production, and thereby reduce its carbon footprint. Canada's current and projected GHG emissions are shown in Figure 1. In order to achieve the targets set by the federal government, different GHG mitigation strategies need to be initiated. Because it is the largest GHG emitter among Canada's provinces, Alberta needs to find GHG mitigation options and evaluate them in terms of their extent of abatement and their abatement cost.

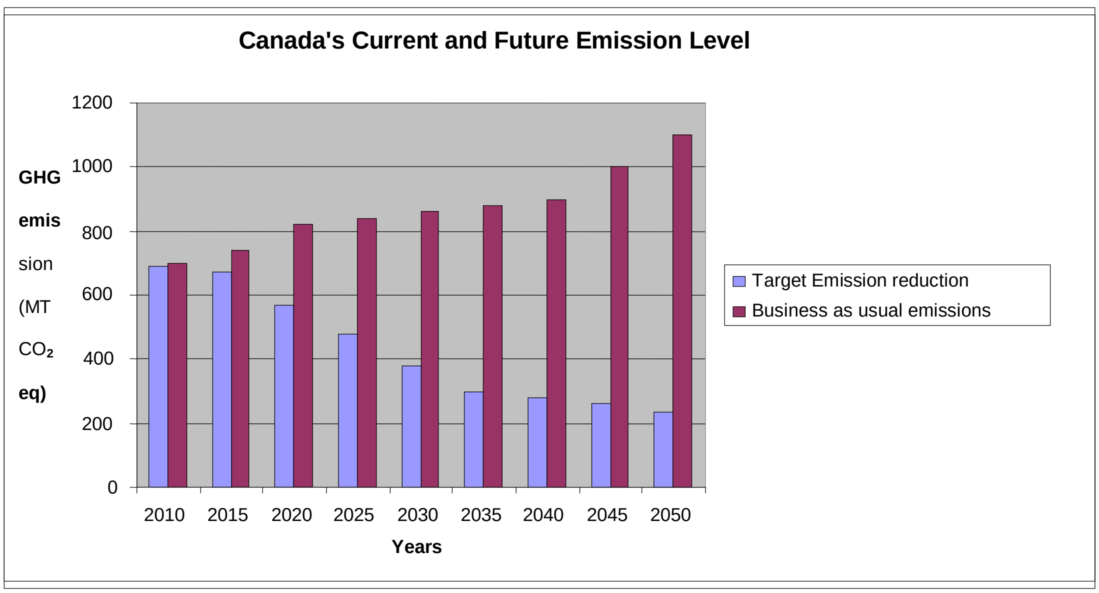

Figure 1: Government of Canada's current and future GHG emission levels and targets [derived from (NRTEE, 2009)].

Recently, Alberta's electricity consumption has grown by an average of 5% per year. The Alberta Electricity System Operator (AESO) forecasts that peak demand will grow by an average of 2.2% per year for the next 20 years (Alberta Electricity System Operator, 2005). The basis for the increasing in electricity demand and energy forecast is Alberta's economic outlook, which remains strong. Figure 3 gives the outlook for upstream energy demand in the coming years**.** The oil and gas industries have a major impact on Alberta's economy and that demand is projected to increase more rapidly than in previous decades. This is a result of the growth taking place in the oil and gas industry and other service sectors of Alberta.

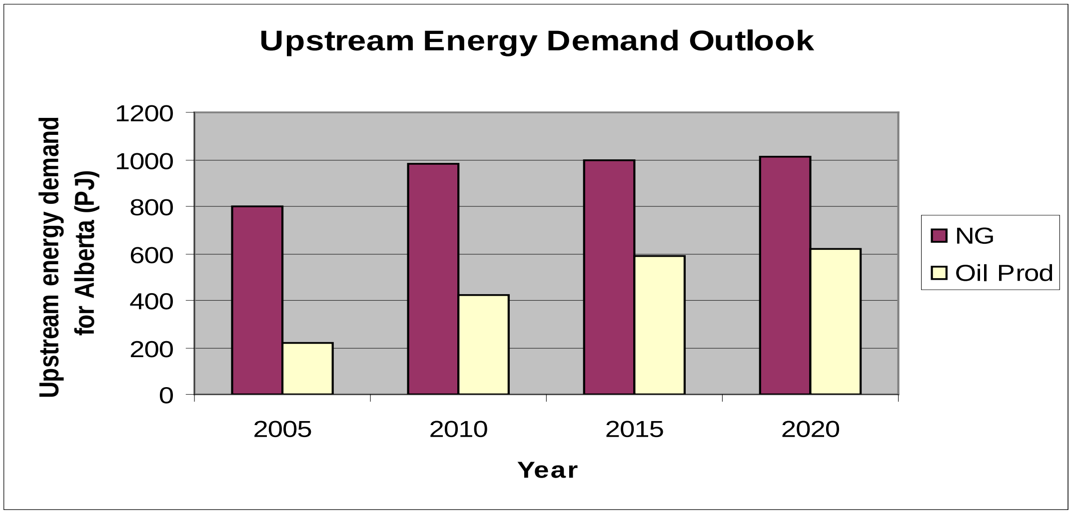

Figure 2: Projected upstream energy demand for Alberta [derived from (Natural Resource Canada, 2006a)].

In 2005, which is the base year for 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 the 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, communications, and manufacturing.

In order to develop a long term energy policy, 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 for a country/region. These are used in projecting the energy supply-demand mix and the associated costs and emissions over a long term planning horizon. Some of these models have been developed and used to analyze the 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 a number of published studies: *International Resource Group, Washington* (International Resource Group, 2010), *Estimating Canada's Greenhouse Gas policies* (Jaccard and Rivers, 2007), *Energy Environmental Modeling 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). This research uses 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 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.

It is necessary to critically understand the flow of energy and emissions in the Province of Alberta, in order to assist policy makers in formulating and implementing policies related to Alberta's energy sector. The overall objective of this research is to use the existing knowledge base to develop a long term energy forecasting and planning model for Alberta which can be used to analyze the flow of energy and emissions over a planning horizon. The details are given in subsequent sections. This research will also assist in assessing the impact on the energy industry of policy decisions made by the Alberta Government.

This report presents the summary of a thesis done as part of this project. The thesis is attached in the Appendix.

2. The Key Objectives of the Study

The adequate and reliable supply of energy is a prerequisite of economic development. As the demand for energy grows along with 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 an Alberta-specific energy forecasting and planning model which could assist in formulating energy policies and evaluating them in terms of the potential for GHG mitigation and cost effectiveness. Following are the key objectives of this research.

- Development of a base year energy demand and supply scenario in *LEAP* for the Province of Alberta.
- Development of a Sankey diagram of energy flow for Alberta for the base year.
- Development of CO_2 emissions estimates in the form of a Sankey diagram identifying major 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 several GHG mitigation scenarios for the Province of Alberta based on discussion with Government of Alberta representatives, and development of these scenarios in *LEAP* for the above study period.
- Estimation, using *LEAP*, of the amount of GHG mitigation made possible by the implementation over the study period of each of the identified mitigation scenarios.

3. Scope and Limitations of the Study

The modeling of energy supply and demand patterns is highly dependent on the demographic and macroeconomic situations involved.

Collection of data on energy demand and supply - Baseline data for a period of 25 years was developed for this study using the different outlook data projected by Natural Resources Canada. The data were further validated in detailed discussions with various provincial organizations like the Energy Resources Conservation Board (ERCB, 2009), Natural Resource Canada (NR Canada, 2008b), the National Electricity Board (NEB, 2008), Statistics Canada Multidimensional Tables (Statistics Canada, 2009), the Canadian Association of Petroleum Producers (CAPP, 2009), and Environment Canada (Environment Canada, 2010), among others. The energy supply and demand projections for the base year are based on key macro economic assumptions for Alberta which have been considered taking into account the provincial and federal government data projecting them. The detailed data are presented in a thesis given in the Appendix.

Data Collection of data on emissions - The emissions data were developed based on existing conditions and technology in Alberta. Most of the emissions factors were taken from *LEAP*'s Environmental Database (TED) (Stockholm Environment Institute, 2006). These emissions factors are developed in accordance with the Intergovernmental Panel on Climate Change (IPCC). Some emissions factors not available through *LEAP*'s TED were developed externally using various sources including the literature and discussions with experts. The detailed data are presented in a thesis given in the Appendix.

Development of Sankey diagrams depicting the flow of energy and emissions – An energy flow diagram known as a Sankey diagram has been generated for 2005 which is the base year of this study. Detailed Sankey and energy balance diagrams for other years have not been generated for this report, but the model is able to generate Sankey diagrams for any year within the planning horizon.

Development of different GHG mitigation scenarios - GHG mitigation scenarios for the Alberta's energy sector are based on various assumptions regarding the penetration in Alberta of new technology, i.e. renewable power generation, supercritical and ultra supercritical coal plants, and IGCC plants. Details are given in subsequent sections. Our present estimates are are preliminary and are currently being evaluated further under another project titled "*Development of Best Economic Option for GHG Mitigation in Alberta*". These scenarios are being developed using inputs from Alberta Innovates - Energy and Environment Solutions (Alberta Innovates, 2010).

The baseline data for this study was developed using various outlook data projected by Natural Resource Canada, Statistics Canada Multi-dimensional Tables, the National Energy Board (NEB), the Canadian Association of Petroleum Producers (CAPP), and Environment Canada, among others. The energy supply and demand data are also in accordance with provincial reports and databases from Energy Resources and Conservation Board (ERCB), Alberta Electric System Operator (AESO), ad Alberta Environment, among other sources. The data are presented in a thesis given in the Appendix.

The emissions database has been developed for Alberta specific technology and conditions using IPCC Tier 1 and Tier 2 emissions factors as available in the environmental database of the *LEAP* model. In order to develop GHG mitigation scenarios, several existing reports from the National Round Table on the Environment and the Economy (NRTEE) and the Office of Energy Efficiency (OEE- Natural Resources Canada) have also been used. As well, various scenarios have been developed based on input from and discussions with Alberta Innovates and the Department of Energy, Government of Alberta.

4. Methodology

4.1 *LEAP* as a modeling tool

The 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, and estimates its abatement costs and environmental impact. It is a demand driven program. The data can be built starting with the demand sector then moving on to the supply and resource sectors. *LEAP* model can be used to analyze data over a medium to long term user-defined planning horizon (e.g. 30 to 50 years).

Modeling an energy scenario is highly data intensive but *LEAP* has a framework to handle the data on energy flow characteristics from reserves to final end-use.

LEAP consists of four modules as detailed below.

- The demand module contains the details regarding the end-use energy demand for both primary and secondary fuel.
- The transformation module handles data on the conversion of primary fuel to secondary fuel.
- The resource module keeps an account of all the primary and secondary fuel in consideration.
- The Technology and Environment Database (TED) is the module which keeps a detailed account of all the emissions from the primary and secondary fuels.

Detailed information regarding energy sector modeling for Alberta using *LEAP* is given in Appendix A (Chapter Two of the thesis).

4.2 Development of sankey diagrams

Sankey diagrams are a specific type of diagram in which the width of the arrows is proportional to quantity of the flow. Software called "e!Sankey" was used to develop Alberta energy and emissions flow Sankey. Diagrams depicting Alberta energy and emissions are characterized by supply and demand sectors that give details of primary resources, transformations to secondary resources and demand for primary and secondary resources according to sector. These also characterize the total useful and rejected energy in the entire scheme. This study's Sankey diagrams were developed using final energy and emissions flow data generated by *LEAP* for 2005. Figure 3 shows the methodology used in developing the energy flow Sankey diagrams for Alberta. Figure 4 shows the methodology used in developing the emissions flow Sankey diagram for Alberta.

4.3 Development of reference scenarios

The reference scenario is the business as usual scenario for all the sectors. In this scenario, the growth rate and energy intensity of energy consuming devices and sectors accurately represent the province's current situation; there is no additional change in any policy or technological advancement built into the model. This scenario constitutes the baseline for developing different mitigation scenarios.

4.4 Development of GHG mitigation scenarios

Mitigation scenarios depict 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 created which are referred as GHG mitigation scenarios. Mitigation scenarios are the quantified projection of how GHG emissions can be reduced with respect to a baseline scenario by means of technological changes, prevailing macroeconomic conditions, and available policy options which are incorporated into the system. Figure 5 shows the methodology for developing GHG mitigation scenarios for Alberta.

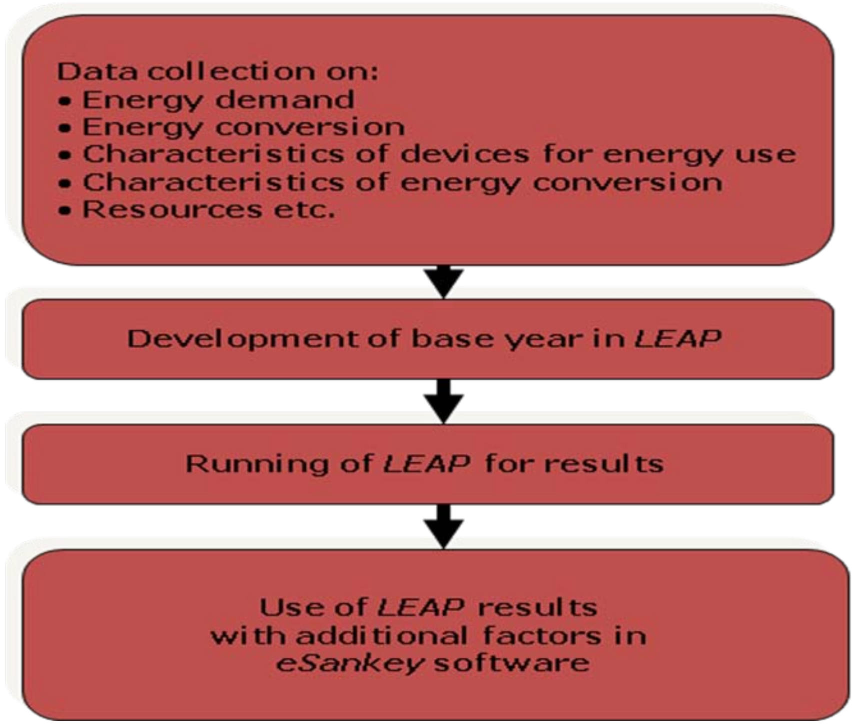

Figure 3: Methodology for development of energy flow Sankey diagrams for Alberta

Figure 4: Methodology for development of emission flow Sankey diagram for Alberta

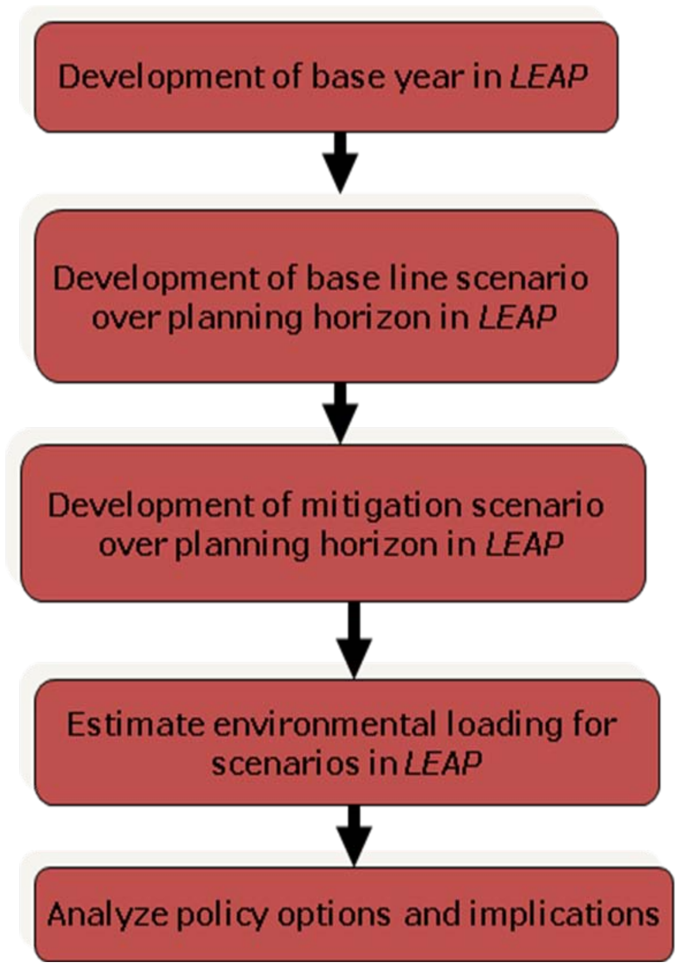

Figure 5: Methodology for the development of GHG mitigation scenarios for Alberta

5. Results and Discussion Based on *LEAP* Model

5.1 Energy demand Sector

5.1.1 Base year

Figure 6 shows Alberta's energy demand tree. All sectors are further subdivided up to the device level as shown in Figure 6 for the residential sector. Details are given in Appendix A – Chapter Two of the thesis. Table 4 gives Alberta's overall energy demand for the base year, 2005, as developed by *LEAP*; It is 2,273 PJ. Nine key modules were developed for the transformation sector using *LEAP*. These included transmission and distribution, electricity generation, natural gas and coal bed methane, Alberta oil refining, crude oil production, synthetic crude oil production, crude bitumen production, NGL production and coal mining. Alberta's electricity generation sector included all the current operating power plant and power plants planned for the future. The *LEAP* model for Alberta includes the detailed characteristics of each power plant and other transformation module components. The details are given in Appendix A – Chapter Two of the thesis.

5.1.2 Reference scenario

The overall energy requirement for 2005 and the growth in Alberta's energy demand sector over the 25 year study period is projected to be from 2,274 to 3,496 PJ as shown in Table 5. The rate of increase in the demand for energy is attributed to an increase in industrial sector intensity because the Alberta mining and petrochemical industries are expected to grow at a faster pace than other sectors. The commercial and household demands for energy are also shown to increase in the business as usual case over this 25 year period. Energy demand in the household sector is expected to grow from 175 PJ in the base year to 287 PJ in 2030. For the same period energy demand in the commercial and institutional sector is expected to grow from 159 to 307 PJ; whereas, in the transport sector, it is expected to grow from 367 to 582 PJ. The details on the parameters used in developing the baseline scenario are given in the Appendix A (Chapter Two of the thesis).

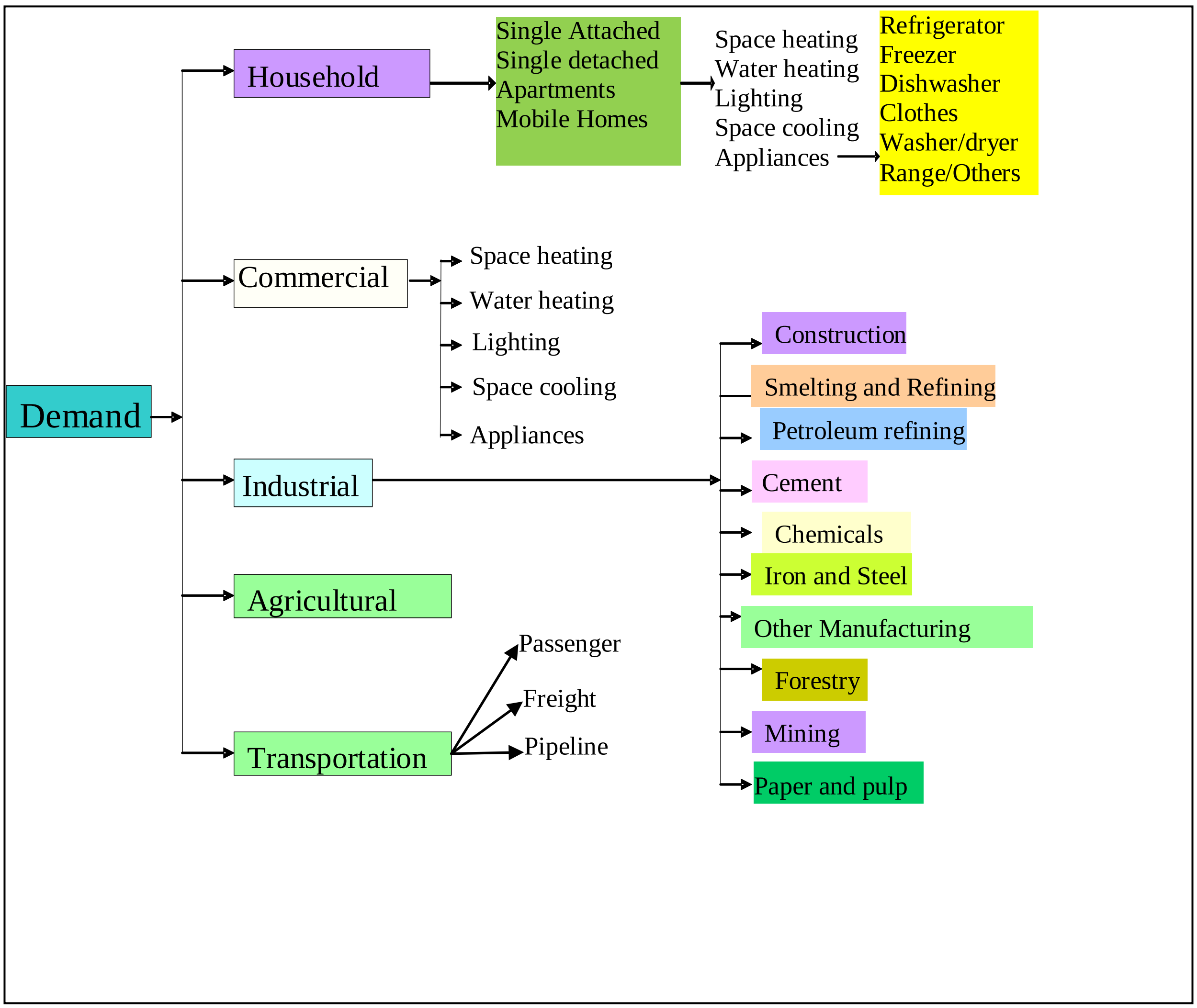

Figure 6: Alberta's energy demand tree as developed in LEAP

Table 4: Alberta energy demand for base year 2005 based on LEAP model

Sectors (PJ)	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

Table 5: Alberta energy demand – reference case scenario based on LEAP model

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

5.2 Overall emissions

5.2.1 Emissions demand sector

Table 6 shows Alberta's demand sector emissions in the reference scenario as developed in *LEAP*. These estimates of emissions were developed using the Technology and Environmental Database (TED) built into *LEAP*. Some emissions factors were developed externally and input into *LEAP* (e.g. emissions from oil sands). Emissions are expected to increase from 87 MT in 2005 to 149 MT in 2030. These CO_2 equivalents are mainly from the industrial sector, which is expected to nearly double its emissions from 41 to 74 MT. The details on the emissions from the demand sector are given in Appendix A (Chapter Two of the thesis).

Table 6: Alberta demand sector GHG emissions – reference case scenario based on *LEAP* model

Emissions (MT)	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

5.2.2 Emissions from transformation sector

In the transformation sector, GHG emissions from the energy conversion sector are expected to grow from 157 MT in 2005 to 323 MT of CO_2 equivalents in 2030, as shown in Table 7. Again the emissions factors for the transformation sector were developed using the *LEAP*'s Technology and Environmental Database. The details on the emissions from the demand sector are given in Appendix A (Chapter Two of the thesis).

Table 7: Alberta's transformation sector emissions – reference case scenario based on *LEAP* model

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	14.47	24.43	46.3	52.6	53.16	53.78

Sectors (MT of CO_2 eq)	2005	2010	2015	2020	2025	2030
production						
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

5.2.3 Overall Emissions

Alberta's total GHG emissions from the energy demand and transformation sectors are likely to increase from 2005's 244 MT (including the entire auxiliary fuel requirement) to 494 MT of CO_2 equivalents in 2030, as shown in Table 8.

Table 8: Overall emissions – reference case scenario based on *LEAP* model

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

5.3 Sankey diagrams of energy and emission flows

Alberta's Sankey diagrams were developed using the final energy demand and supply data obtained by *LEAP* for 2005. Alberta's Sankey diagrams give detailed energy flow patterns depicting primary and secondary energy consumption in the different demand sectors. The energy flow Sankey diagram also shows the total useful and rejected energy for the demand sector.

5.3.1 Sankey diagram for energy without exports

Figure 7 shows the basic Sankey diagram for energy flow Alberta's for the base year. This gives the details of energy flow from resource to transformation and utilization in the demand sectors. Coal, bitumen/crude oil and natural gas together represented about 96% of the total primary energy in 2005. As a percentage of the total primary energy consumed in Alberta, coal, bitumen/crude oil and natural gas contribute about 21%, 32% and 43%, respectively. Renewable energy sources including hydro, biomass and wind together contributed only 4% of the total primary energy. Nearly all coal was used to generate electricity. A major consumer of bitumen/crude oil is the transportation sector (about 66%). Figure 8 shows the Sankey diagram depicting the patterns of energy flow for Alberta's industrial sector.

5.3.2 Sankey diagram for energy with exports

Figure 9 shows the overall picture of Alberta's primary and secondary energy pathways 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 comparing flow data has been generated. About 72% of the net production of natural gas was exported in 2005, as was, about 58% of the net production of bitumen/crude.

5.3.3 Sankey diagram for emissions in Alberta energy sector

Figure 10 gives the details of Alberta's GHG emissions for the energy sector in megatonnes of CO_2 equivalents.

5.4 Mitigation scenarios developed in LEAP

In accordance with Alberta's focus on clean energy/technology, mitigation scenarios are created to identify the low GHG emissions pathways that are provided by well defined technology. The GHG mitigation scenarios presented here are preliminary; detailed work on this is in progress as part of other research by the authors. The details on assumptions affecting these scenarios are given in Appendix A. The estimates of GHG mitigation given here are specific to certain assumptions and could change with any variation in assumptions.

5.4.1 Residential sector

Two mitigation scenarios were developed for Alberta's residential sector. The first is in the lighting subsector and the second is in the appliance subsector. Both were modeled for improvement in efficiency. Results indicate that the overall energy demand reduction in 2030 is 11 PJ for efficient appliances and 3 PJ for efficient lighting. The total reduction in GHG for the appliance subsector is 1.72 MT of CO_2 equivalents per year by 2030, and for the lighting subsector it is about 0.5 MT of CO_2 equivalents per year by 2030. The assumptions affecting emissions from the demand sector are given in detail in Appendix A (Chapter Four of the thesis).

5.4.2 Commercial sector

Commercial sector GHG mitigation options are in lighting, water heating, auxiliary equipment and motors. We studied GHG mitigation due to the use of efficient lighting, high efficiency motors and efficient auxiliary equipment. The total mitigation possible is between 0.9 and 1.8 MT of CO_2 equivalents between 2015 and 2030. The assumptions affecting emissions from the demand sector are given in detail in the Appendix A (Chapter Four of the thesis).

5.4.3 Industrial sector

Industrial sector GHG mitigation scenarios have been developed for decreasing energy intensity in the oil and gas sector and for improving efficiency in other industrial sectors. This includes reducing the oil and gas sector's usage of auxiliary fuel. The total in demand reduction is estimated to be 340 PJ per year by 2030. The total GHG mitigation achievable is 46 MT of CO_2 equivalents per year by 2030. The assumptions affecting emissions from the demand sector are given in detail in Appendix A (Chapter Four of the thesis).

5.4.4 Transport sector

Alberta's transport sector mitigation scenarios are characterized by the inclusion of biofuels in the road and freight sector, and penetration of hybrid passenger cars into road subsector. The total GHG reduction in the transport sector attributable to the penetration of hybrid cars and biofuel is estimated to be 3.38 and 1.92 MT of CO_2 equivalents per year, respectively, by 2030.

The details on the assumptions affecting emissions from the demand sector are given in Appendix A (Chapter Four of the thesis).

5.4.5 Power sector

We have studied Alberta's power sector to evaluate different GHG mitigation options. The total estimated reduction by 2030 is 20 MT of CO_2 equivalents per year for a supercritical coal plant without CCS; with CCS the estimated reduction is about 21 MT of CO_2 equivalents per year. For the ultra supercritical coal plant option, the total estimated reduction by 2030 is 18 MT of CO_2 equivalents per year. With CCS incorporation the estimated reduction increases to approximately 69 MT of CO_2 equivalents per year by 2020. The IGCC coal plant scenario is based on the assumption that Alberta will have an IGCC coal plant facility by 2016; in this scenario it is assumed that all existing coal plants will be replaced by IGCC coal plants. The total GHG emissions reduction by 2030 is estimated to be 8 MT of CO_2 equivalents per year without a CCS plant and about 67 MT of CO_2 equivalents per year with a CCS plant. The assumptions affecting emissions from the demand sector are given in detail in Appendix A (Chapter Four of the thesis).

5.4.6 Oil and gas sector

The total GHG mitigation achievable with CCS incorporation in the production of crude bitumen production is 50 MT of CO_2 equivalents per year by 2030. In the case of bitumen upgrading (synthetic crude oil production) with CCS plants the total achievable GHG reduction is 27 MT of CO_2 equivalents per year by 2030. The assumptions affecting emissions from the demand sector are given in detail in Appendix A (Chapter Four of the thesis).

5.4.7 Inclusion of renewable energy in the Alberta power sector

Three renewable resources have been modeled in *LEAP* viz., wind, hydro and nuclear. The 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 and 18 MT of CO_2 equivalents, respectively, by the year 2030. The assumptions affecting emissions from the demand sector are given in detail in Appendix A (Chapter Four of the thesis).

There is a detailed study in progress on the development of GHG mitigation scenarios and the abatement cost for each scenario. It is being done by the authors as part of other research in the Department of Mechanical Engineering at the University of Alberta. The study considers a range of scenarios in detail. The scenarios presented in this report are preliminary and are being further modified.

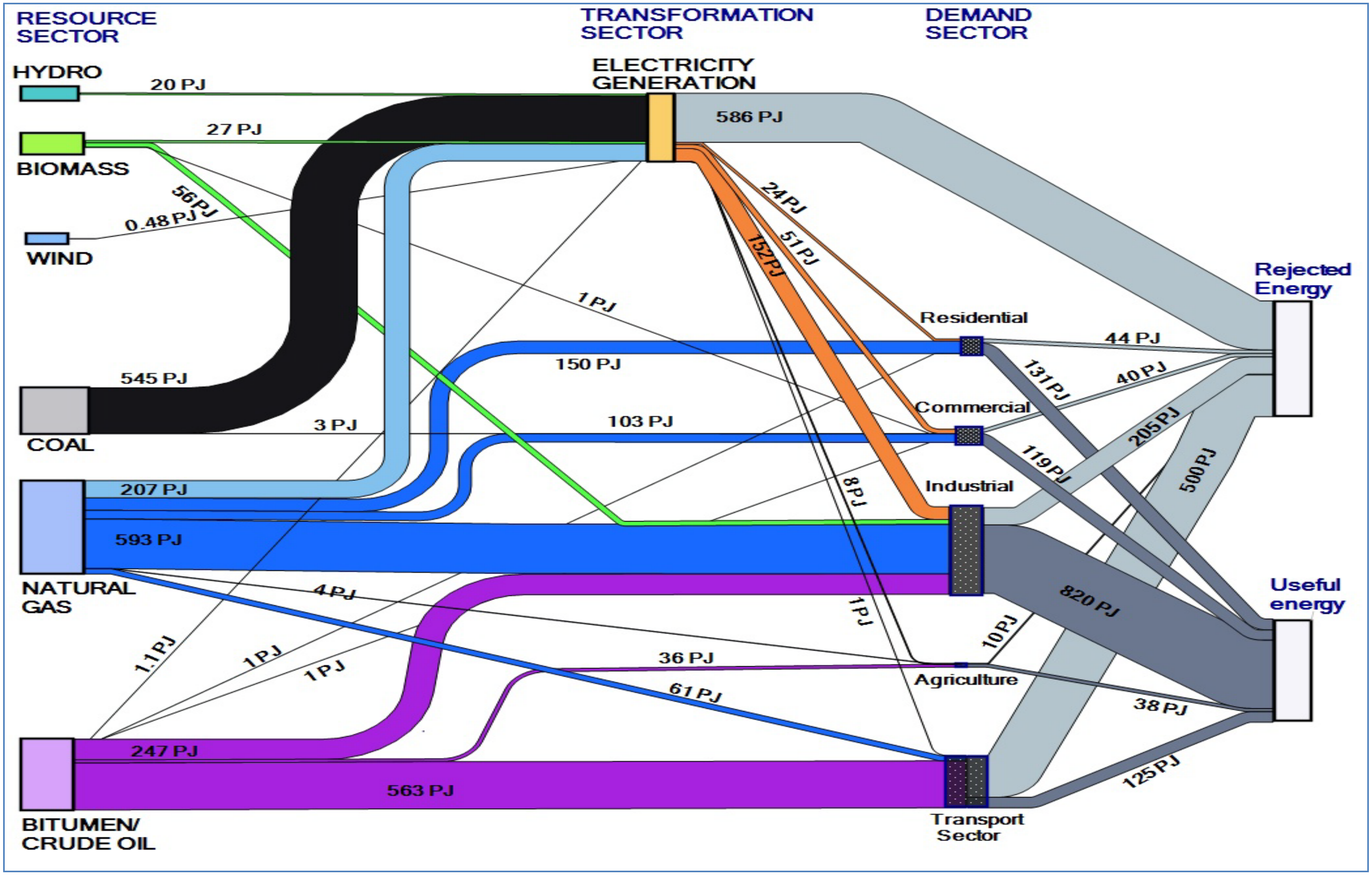

Figure 7: Alberta energy Sankey diagram-without exports

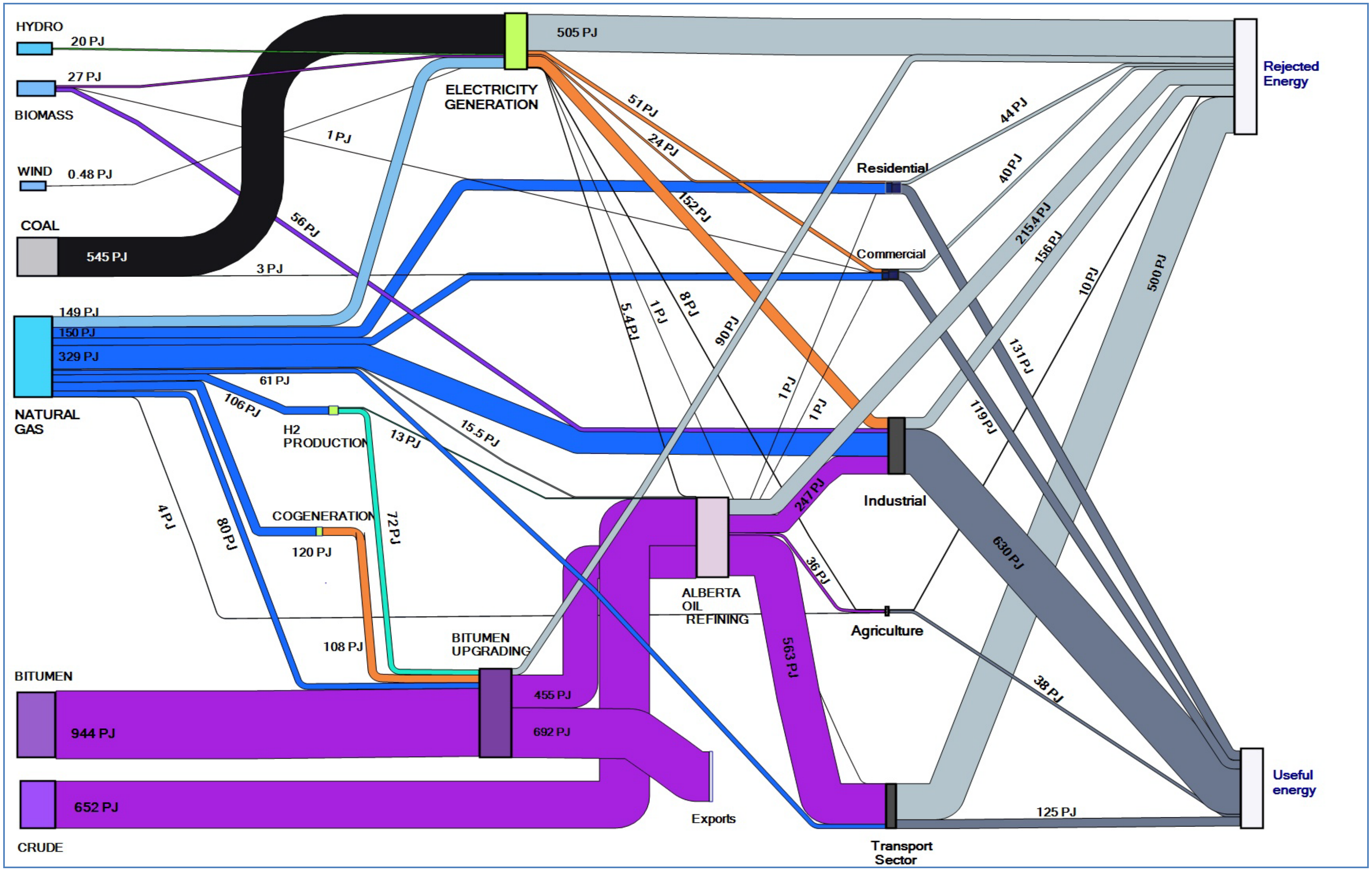

Figure 8: Alberta industrial sector energy flow Sankey diagram

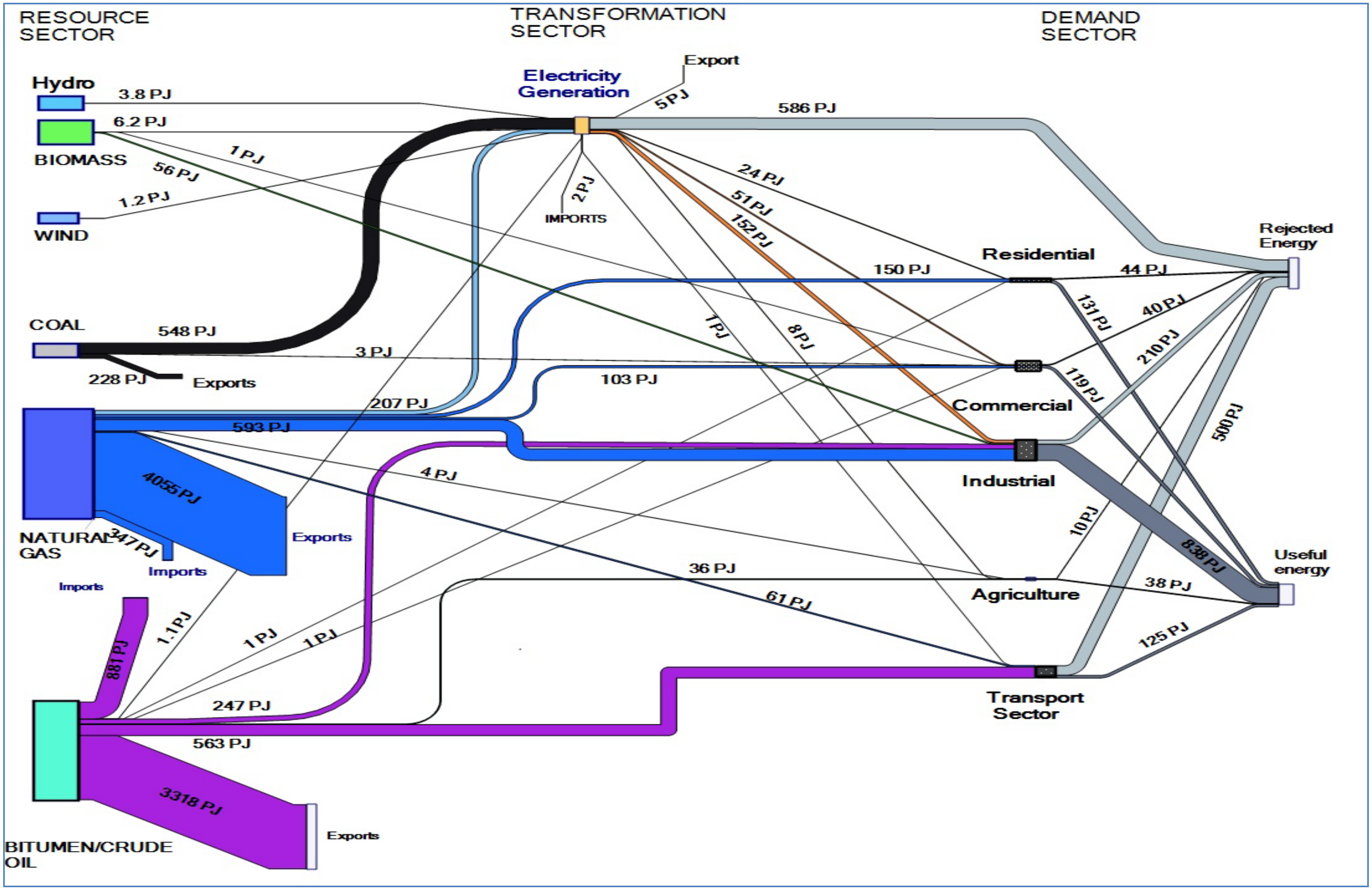

Figure 9: Alberta energy sankey with exports

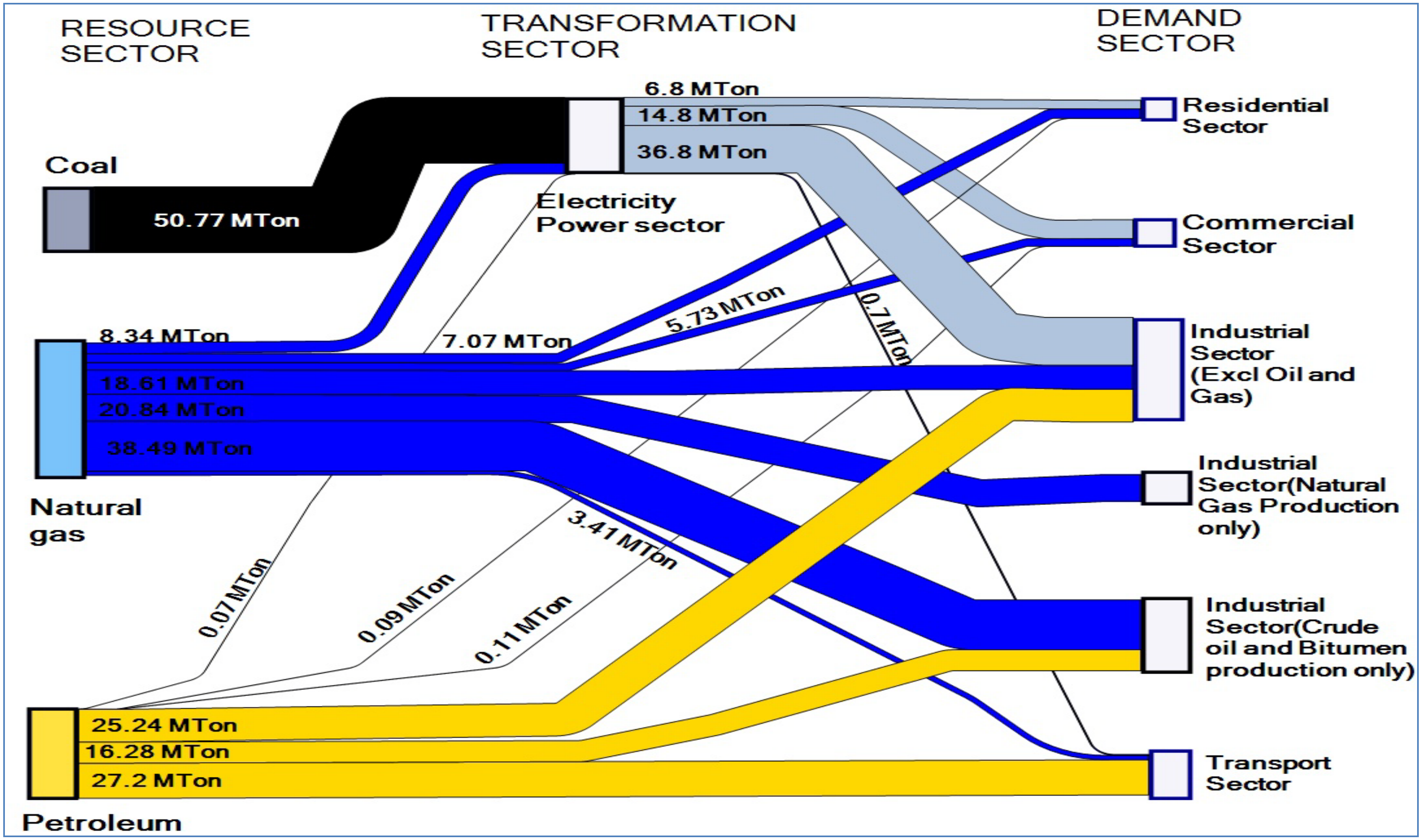

Figure 10: Alberta energy sector – emission flows

6. Development of Sankey Diagrams of Water Flows in Alberta

6.1 Background

The production of energy in the Province of Alberta is associated with the use of large amounts of water. Effective water management is a great challenge for Alberta and will continue to be a critical issue. To formulate a sustainable strategy for freshwater supply and utilization, it is necessary to understand the allocation and use of freshwater in Alberta. This study focuses on critically analyzing water supply and demand by the sector in Alberta. The key objective of this study is to develop Sankey diagrams showing water flow for different river basins and the utilization of water by different demand and supply sectors. These diagrams put a visual emphasis on the major water-use patterns in Alberta. This study focuses on analyzing surface and ground water separately. It also differentiates between water allocation and its use. The base year for the study is 2005.

6.2 River basins in Alberta

Alberta is divided into seven major river basins or river systems, namely: the Peace, Athabasca, Hay, North Saskatchewan, South Saskatchewan, Beaver and Milk river basins (Alberta Environment, 2010). Some of these are recognized as consisting of a number of significant sub-basins; for example, the South Saskatchewan river basin consists of the Red Deer, Bow, Oldman and South Saskatchewan sub-basins. Overall, there are 17 identifiable river basins in Alberta (Alberta Waterportal, 2010). These are shown in Figure 11. This study analyzes the water allocation and water use from each of these river basins and has developed water flow Sankey diagrams for these. Water allocation represents the amount of water that licensees are entitled to take from surface or groundwater sources. In contrast, water use is the portion of the licensed water that is expected to be consumed or lost. During a process water can be lost due to evaporation or seepage. These terminologies are further explained in Figure 12.

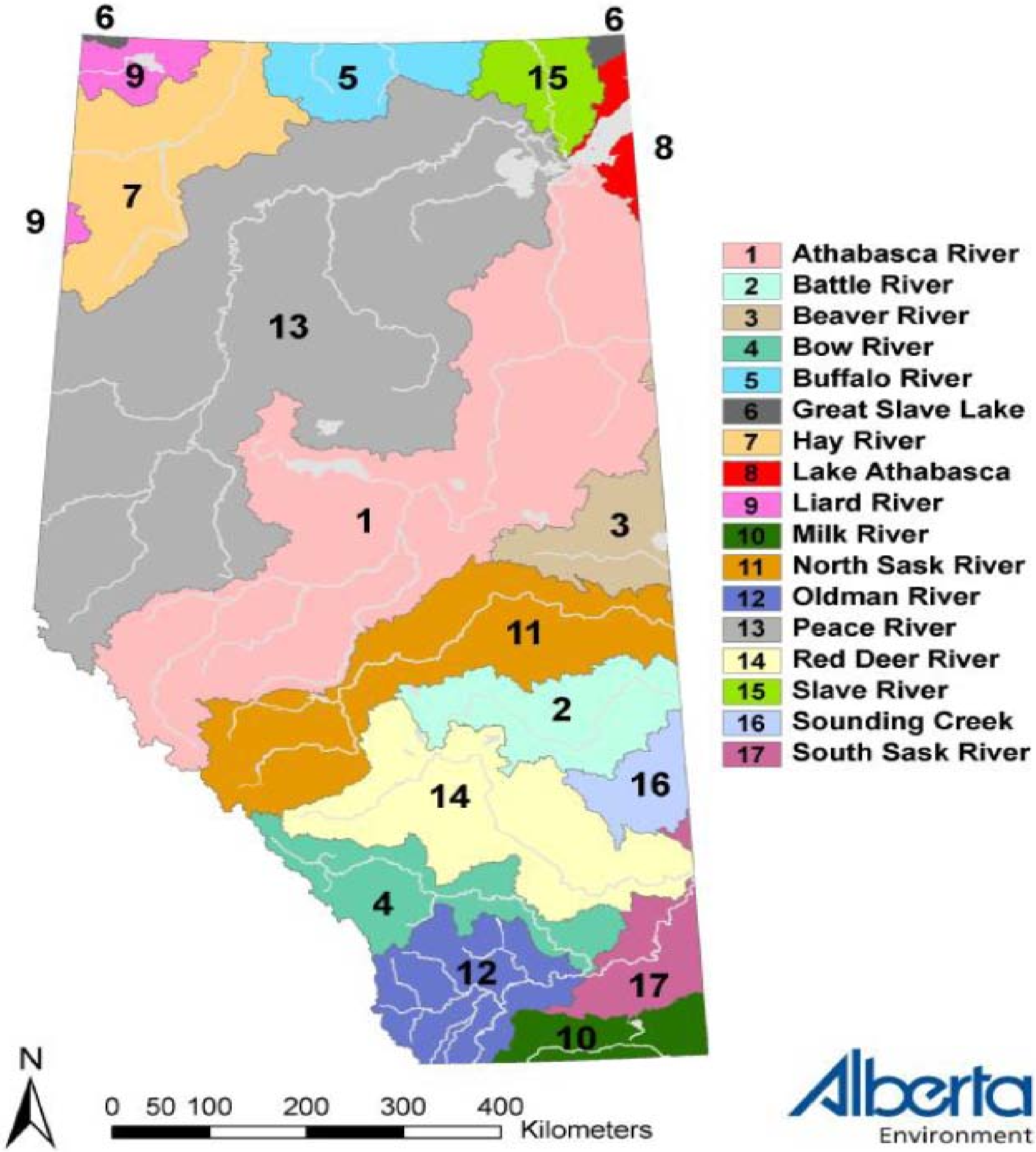

Figure 11: Alberta's river basins

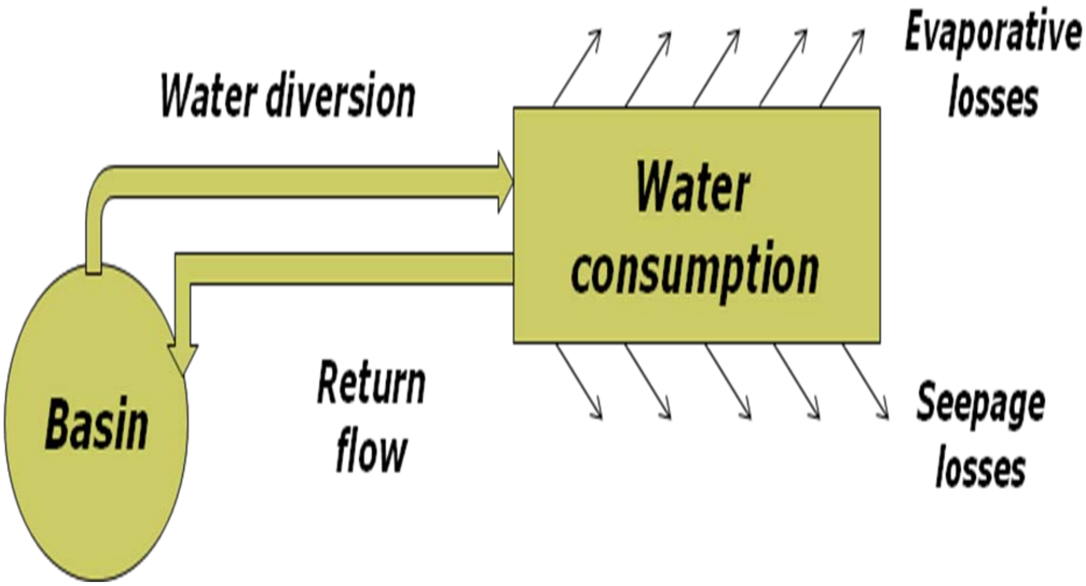

Figure 12: Water terminologies

6.3 Methodology for development of water flow sankey diagrams

The water demand sectors have been broken into six categories in this study. These are: municipal and residential, agricultural, commercial, petroleum, industrial and other. The demand sectors under each category are explained in Table 9. Inventory data was collected for water allocation and use in each category and then a systematic approach was followed to develop the Sankey diagrams depicted in Figure 13.

Inventory data for the municipal and residential sector was collected using the Water Use Reporting System (WURS) and Environment Canada's Municipal Water Use Database (MUD) (Environment Canada, 2001; Alberta Environment, 2006). Though the water allocation is properly tracked, it should be noted that due to lack of information, this analysis focuses only on the use of licensed municipal water. People owning or occupying land adjacent to surface water or under which groundwater exists can use up to 1.25 dam^3 without having to obtain a license (Alberta Environment, 2007). The number of such people and how much water they use for household purposes are unknown.

For irrigation, high quality information on actual diversions, the mix of crops being irrigated, the technology being used, and return flows for the 13 irrigation districts is available from Alberta Agriculture, Food and Rural Development (AAFRD), Alberta Environment (AENV), and the districts themselves (Alberta Environment, 2007). Since irrigation districts account for use of such a large amount of water in southern Alberta, their patterns of use are well known and documented. Thus, data on water allocation and use for this agricultural sector of Alberta is reliable and complete.

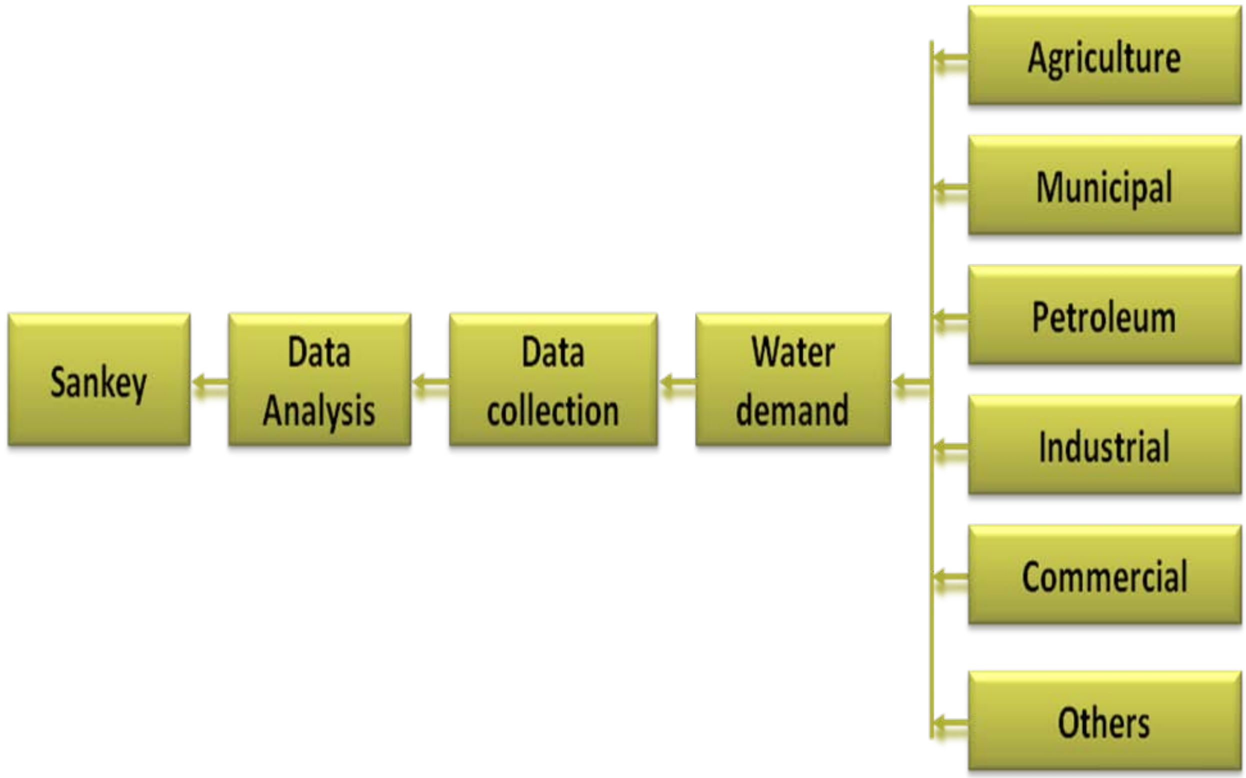

Figure 13: Methodology for development of sankey diagrams for water flows

The Alberta Energy and Utilities Board (EUB), Geowa Information Technologies Ltd. (Geowa), the Cumulative Environmental Management Association (CEMA) and AENV are the major sources of inventory data on oilfield injection and thermal extraction (Geowa Information Technologies Ltd., 2003; CEMA Surface Water Working Group, 2005). Water use information for gas and petrochemical plants was drawn from the WURS database provided by Alberta Environment (Alberta Environment, 2006). No data were available for drilling or other petroleum activities. For those activities having very little data or no data at all regarding water use, it was assumed that license holders were using 100 percent of their licensed consumption.

Estimates of actual water use by the industrial sector (for 2005) are based on data available in the WURS database and data provided by the major license holders (Alberta Environment, 2007). Wherever water use data was not available, use was assumed to be equal to allocation. As WURS contains no actual water use information for the commercial or other sectors, water use for these two sectors was assumed to be as specified in the licenses.

6.4 Key observations

To judge from the inventory data, the total allocation of surface and ground water in Alberta was 9,251,640 dam^3 and 311,546 dam^3, respectively, for 2005. Total surface and ground water use was 3,208,858 dam^3 (35% of allocation) and 103,835 dam^3 (33% of allocation), respectively, for the same year (Alberta Environment, 2007). Alberta's total water allocation and use from different river basins is given in Figures 14 and 15.

From our study it was found that the Bow, Oldman, Athabasca and North Saskatchewan river basins are the most utilized basins in terms of water use. The major river basins and their relative contribution to overall water use are described in Table 10.

Sankey diagrams for water allocation and use comprising all the river basins of Alberta are provided shown in Figures 16 and 17. The agricultural sector is the foremost water user, followed by the industrial and municipal sectors. Sankey diagrams for water use and allocation from some major river basins are presented in Figures 16-23. From the Bow river basin, the agricultural sector was the most water, followed by the municipal sector. The petroleum sector uses the most water in the Athabasca river basin, followed by the industrial sector. For the North Saskatchewan river basin the industrial sector is foremost user.

Table 9: Water consumers in different sectors in Alberta

Sector	Scope
Municipal and residential	Urban, villages, summer villages, towns, cities, hamlets, condominium/townhouses/mobile homes/complexes, hotels, motels, cooperatives, farmsteads, single/multi homes, colonies, Institution, senior/correctional centers, nursing/children's homes, hospitals, camps, Schools, training centers etc.
Agricultural	Feedlot, crops & stock watering, irrigation, traditional use
Commercial	Gardening, market gardens, sod and tree farms, golf courses, parks & recreation, gravel mining & washing, construction, bottling, water hauling, dust controls, abattoirs, bridge washing, hydro-seeding etc.
Petroleum	Oilsand mining, oil and gas thermal, oil & gas drilling, oil & gas plants, oil & gas – injection etc.
Industrial	Forestry, chemical plants, fertilizer plants, hydropower/ non-thermal operations, cooling, coal mining, other mining operations
Others	Drainage (gravel pits, mines), remediation, flood control, stabilization (lake level), fish, fish farms/hatcheries, storage reservoir for wildlife, wetlands and water conservation holdback

Based on this study it was found that the Bow, Oldman, Athabasca, North Saskatchewan and Red Deer river basins are highly utilized in terms of water use. For 2005, these rivers had water allocations of 2,597,898, 2,292,402, 849,629, 1,996,840, and 372,833 dam^3, respectively. This constitutes, 44.33%, 49.77%, 32.14%, 9.82% and 56.34% of the allocated water from their respective basins that was used by the different sectors. Although, compared with other major river basins, very little water was allocated (62,361 dam^3) from the Milk river basin, 87.94% of what was allocated was used.

Table 10: Water use from different Basins as a percentage of the total use in each sector

Sectors	Major rivers	Percentage (%)
Municipal	Bow	48
	Red deer	14
Agricultural	Bow	46
	Oldman	43
Commercial	Bow	38
	N. Saskatchewan	19
Petroleum	Athabasca	70
	N. Saskatchewan	12
Industrial	N. Saskatchewan	51
	Athabasca	13
Others	Oldman	32
	Peace/Slave	19

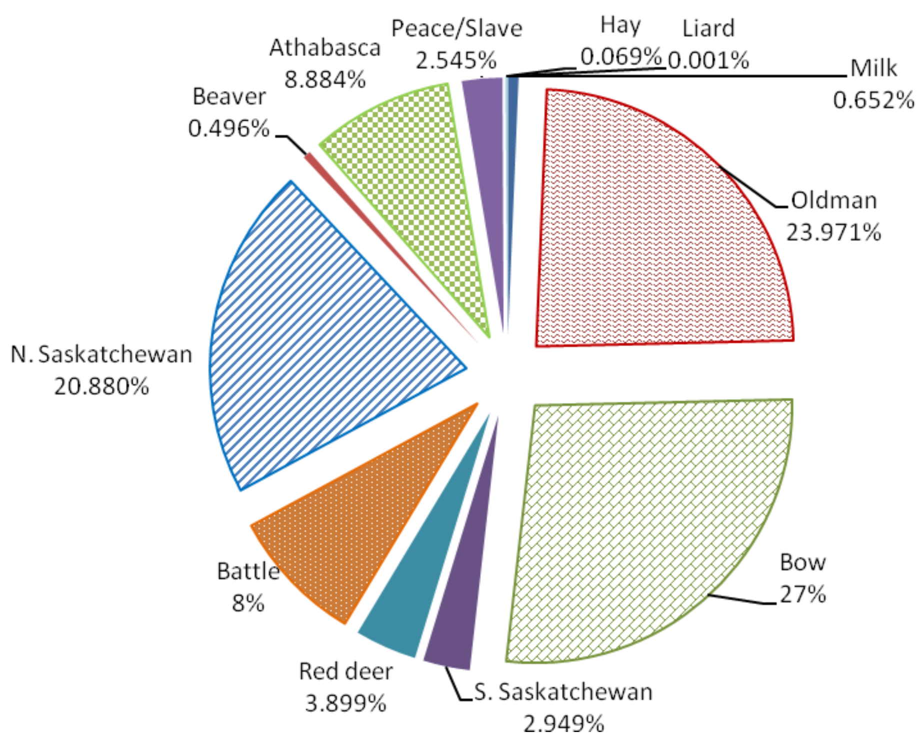

Figure 14: Summary of water allocation by river basin

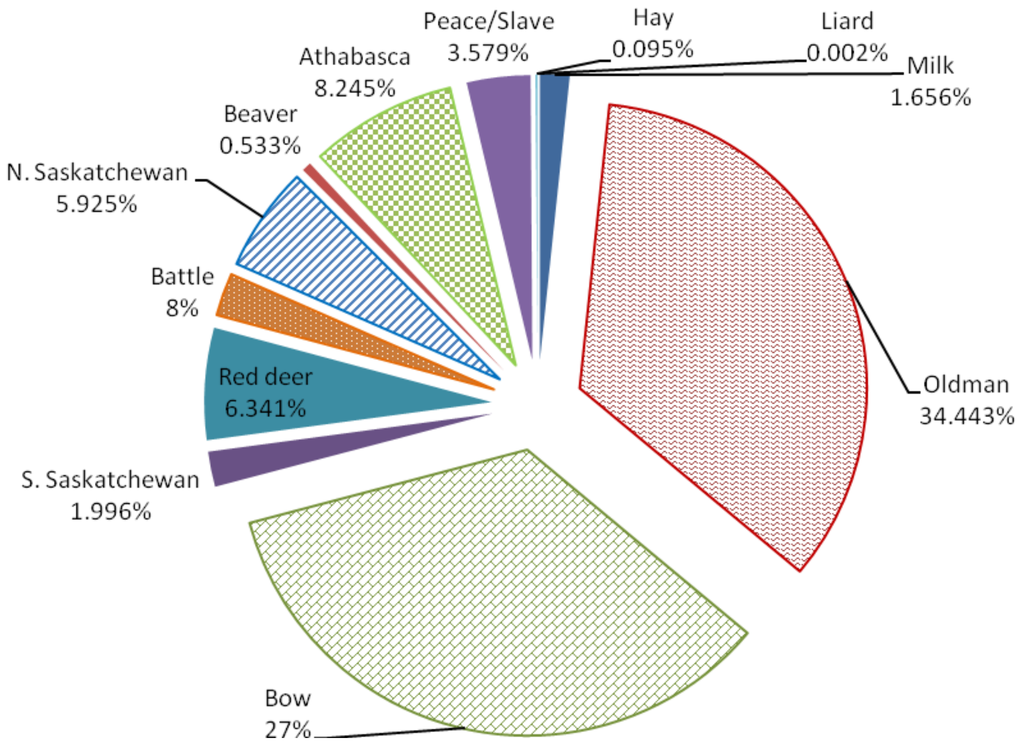

Figure 15: Summary of water use by river basin

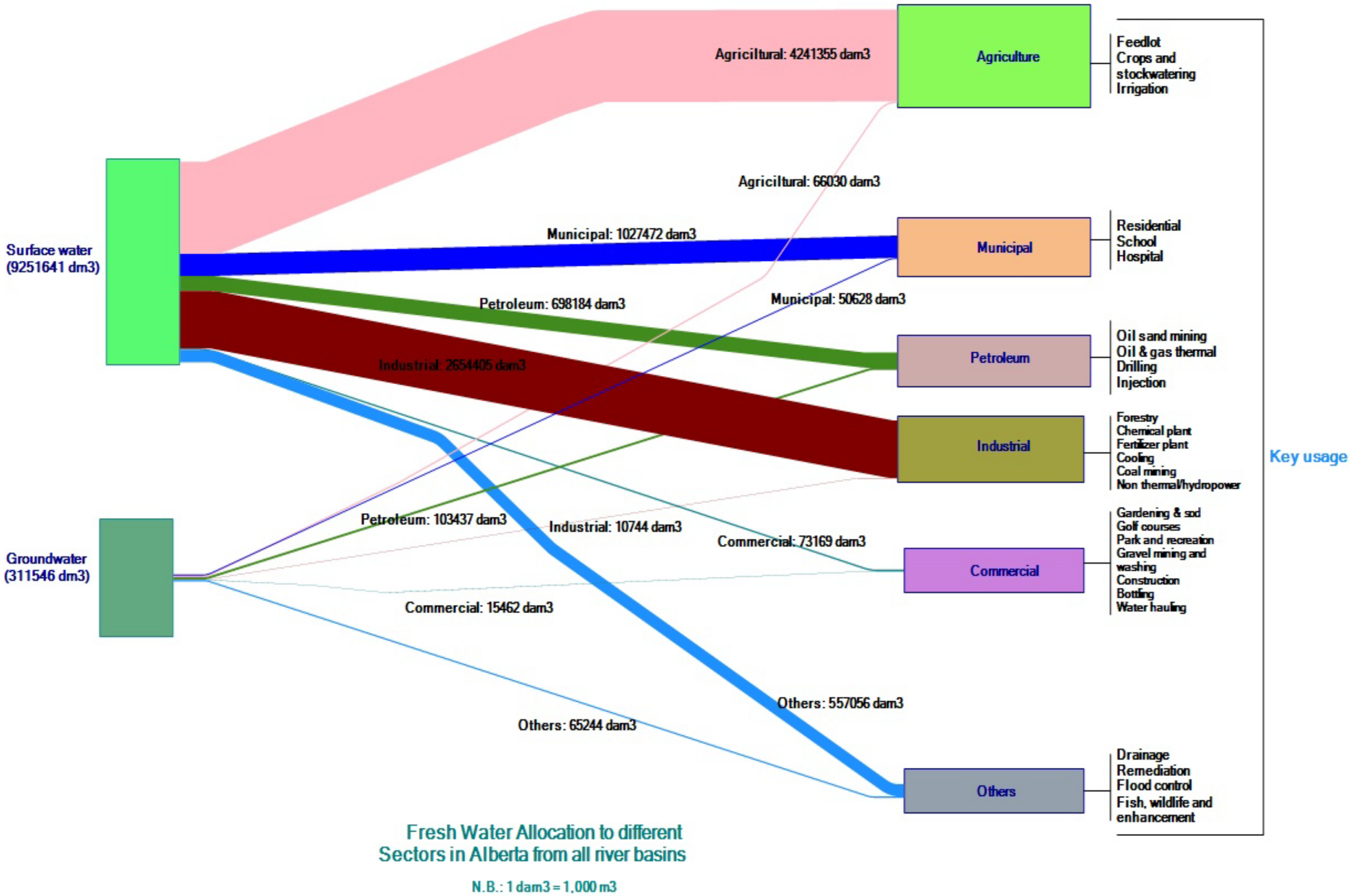

Figure 16: Sankey diagram of water allocation in Alberta (all river basins)

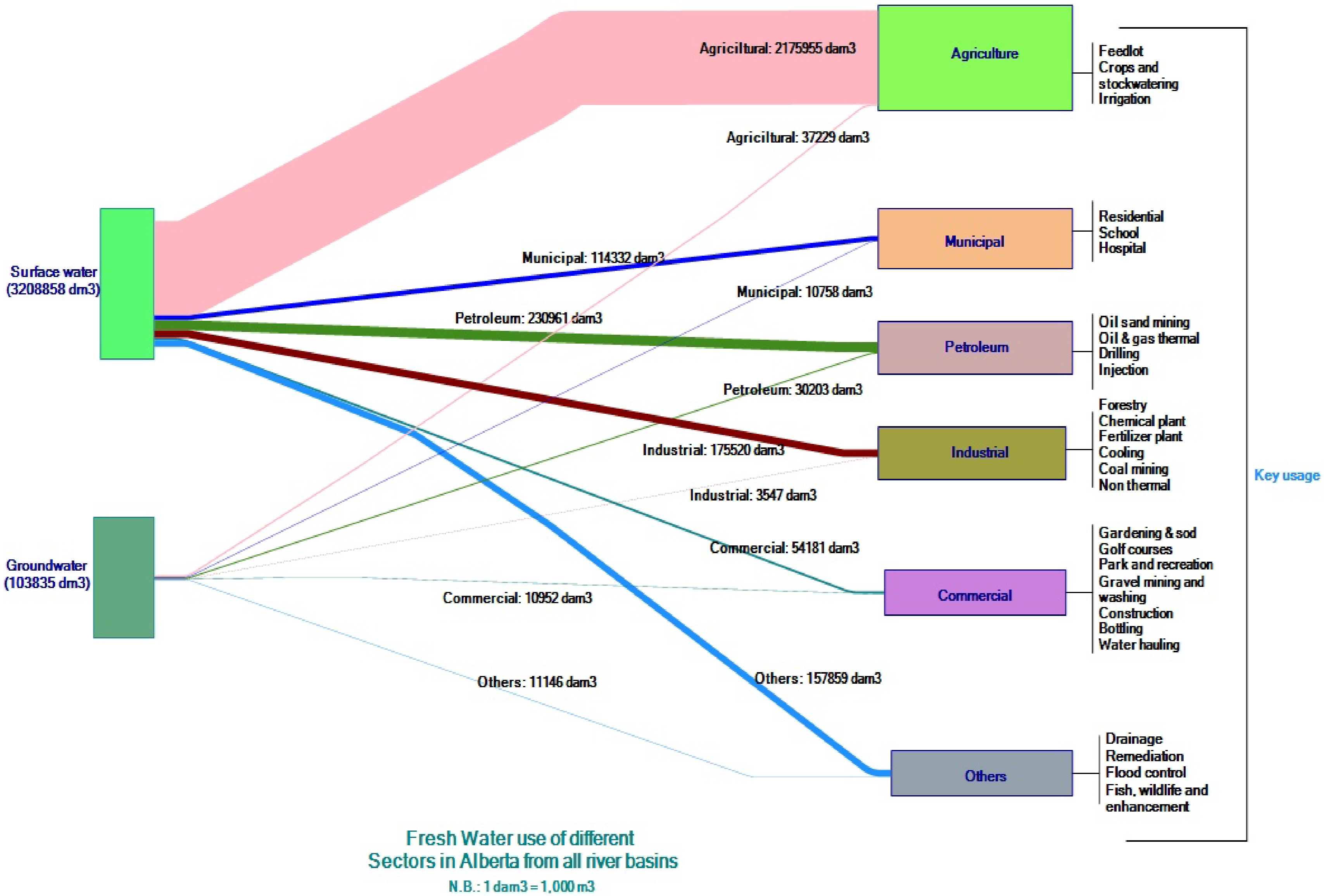

Figure 17: Sankey diagram of water use in Alberta (all river basins)

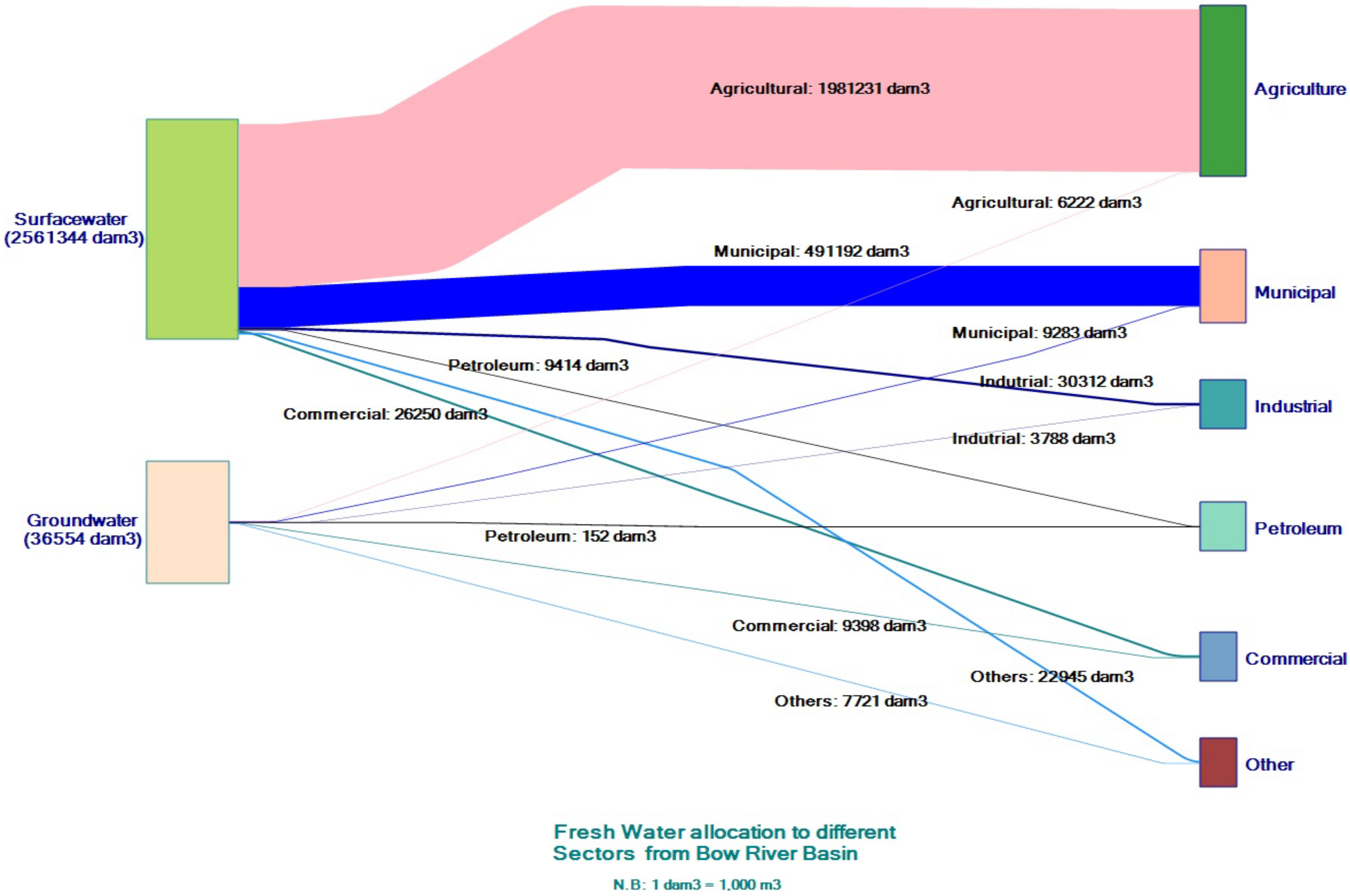

Figure 18: Sankey diagram for water allocation of Bow river basin

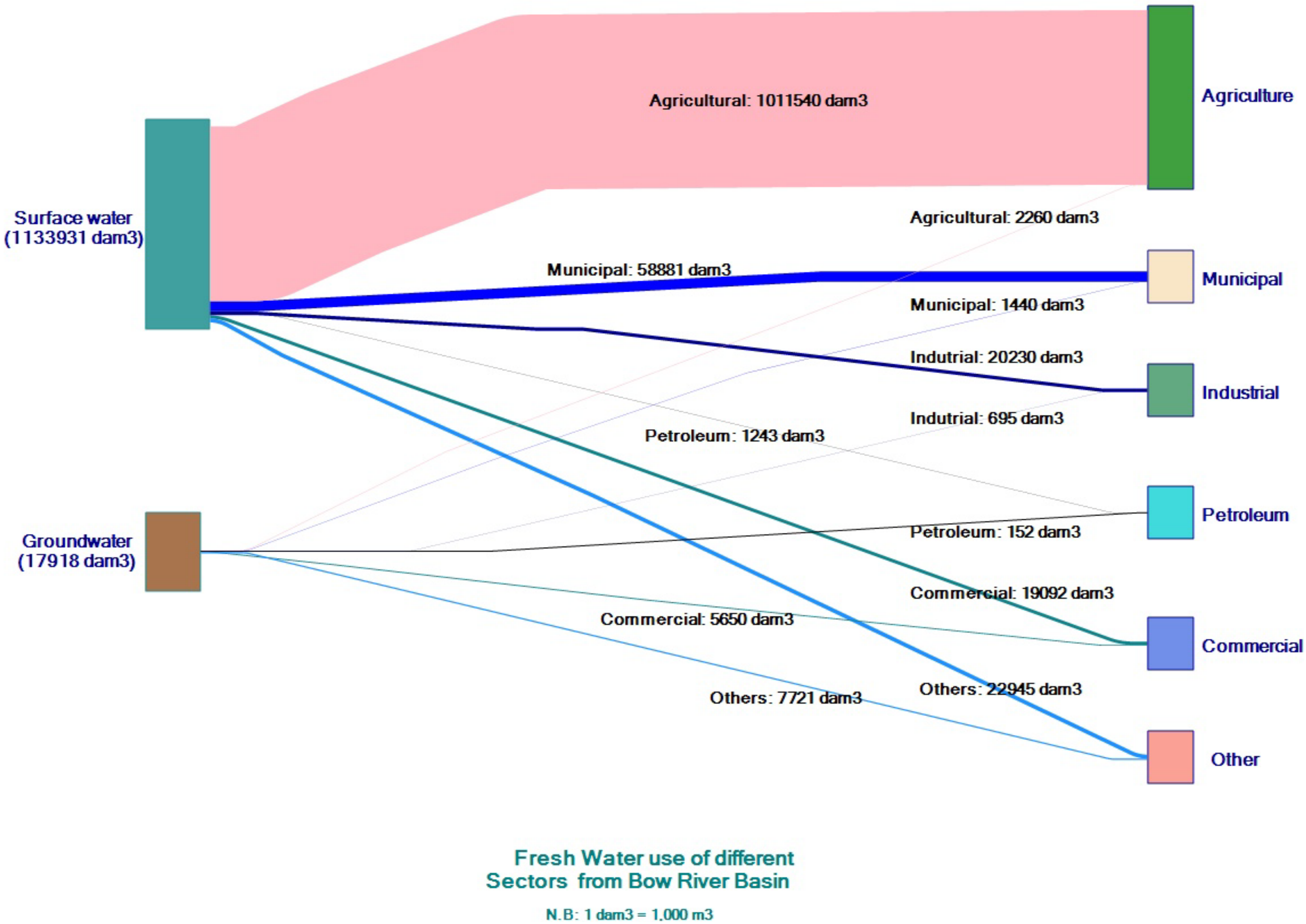

Figure 19: Sankey diagram for water use of Bow river basin

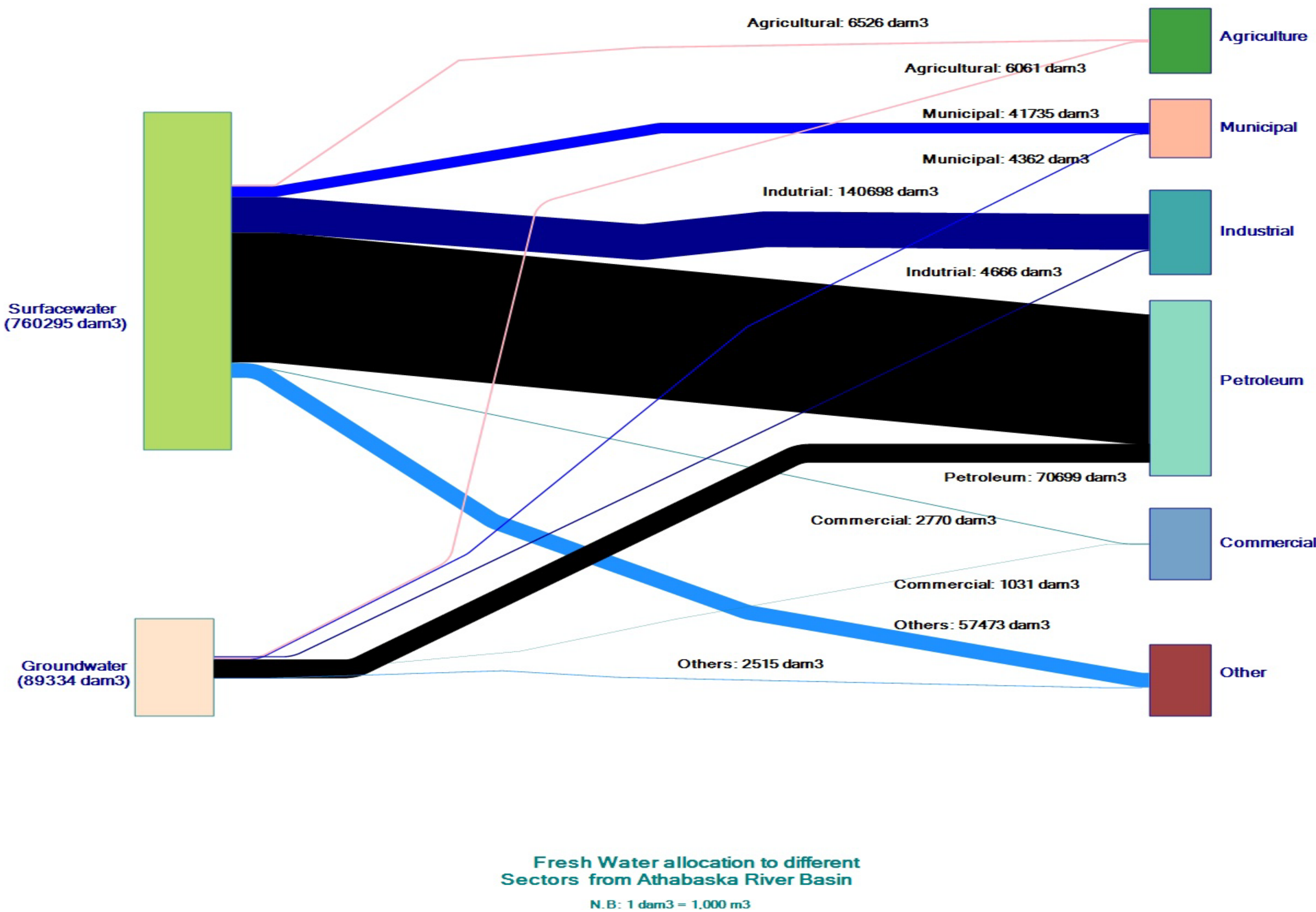

Figure 20: Sankey diagram for water allocation of Athabasca river basin

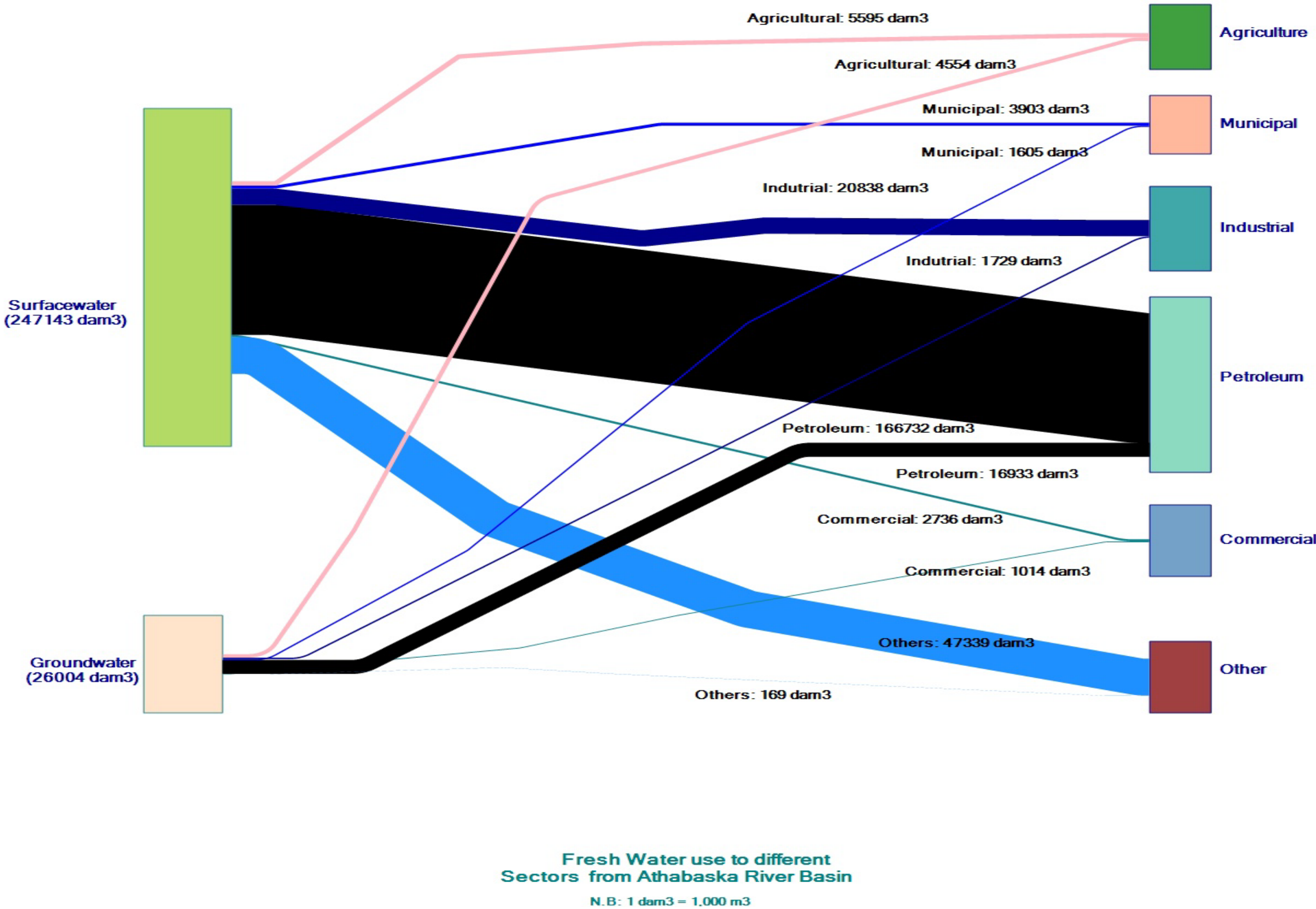

Figure 21: Sankey diagram for water use of Athabasca river basin

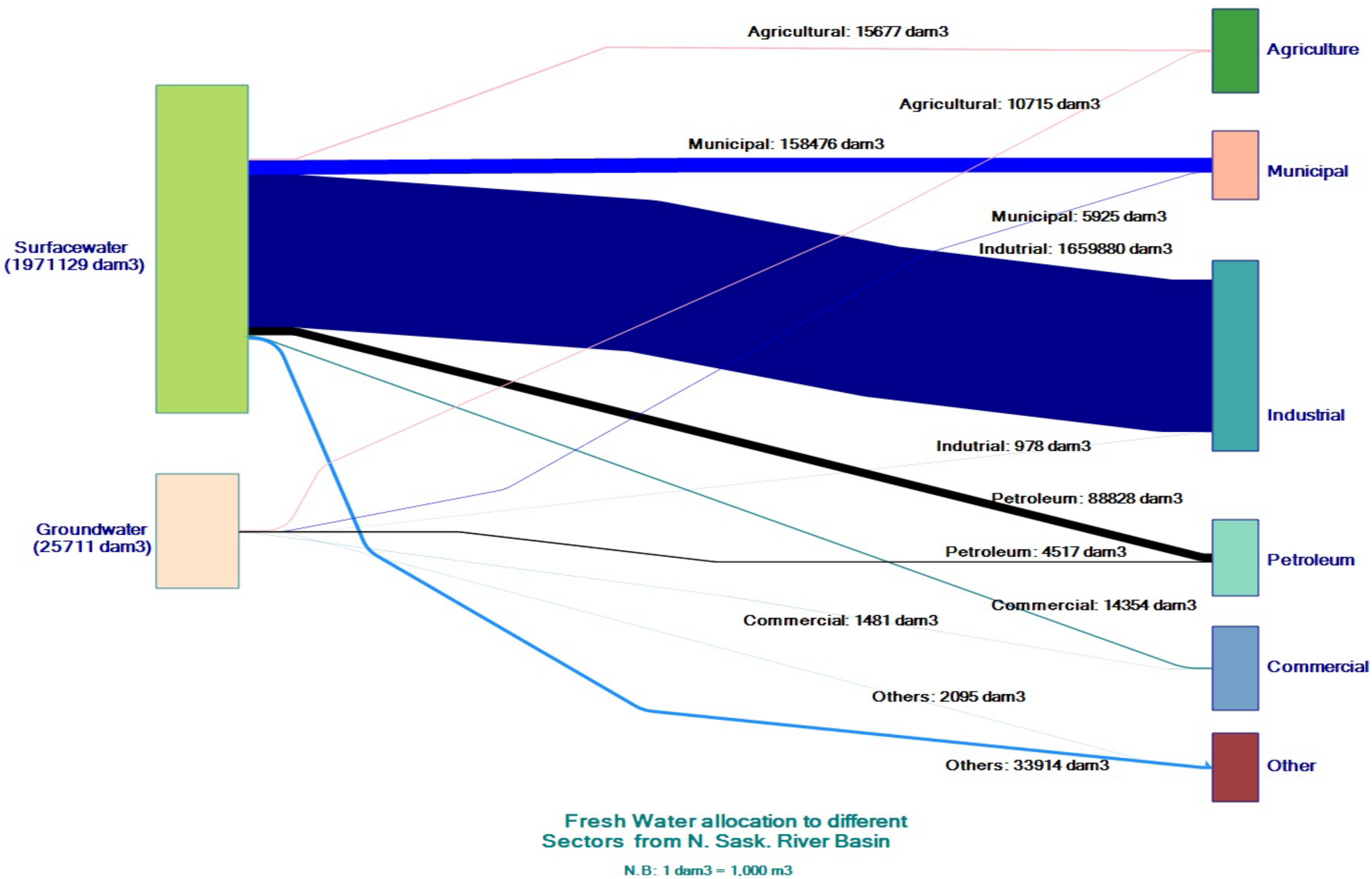

Figure 22: Sankey diagram for water allocation of North Saskatchewan River basin

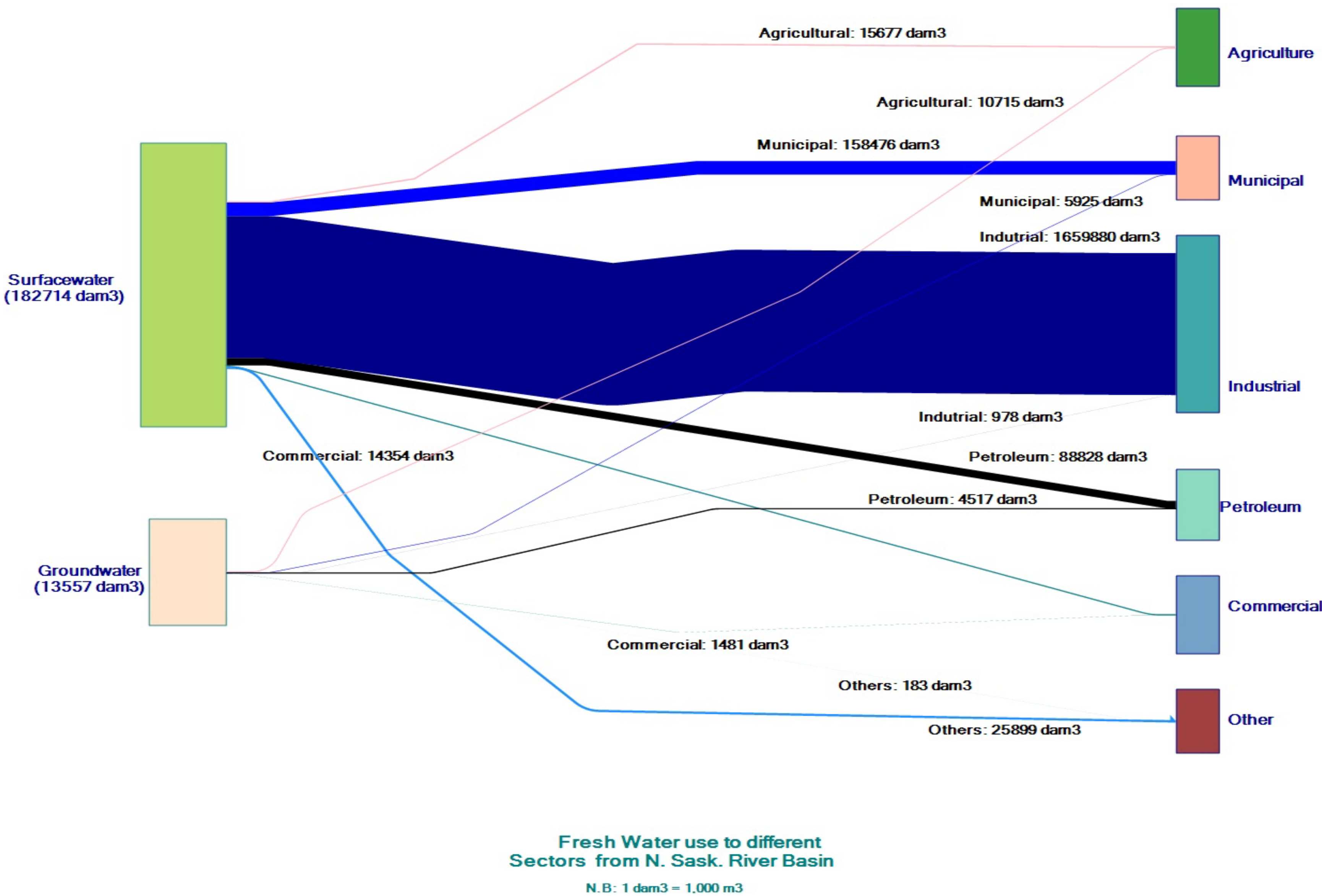

Figure 23: Sankey diagram for water use of North Saskatchewan River basin

7. Conclusions

The key objectives of this research were the development of an energy flow Sankey diagram, an emissions flow Sankey diagram, and greenhouse gas mitigation scenarios for the Province of Alberta. These objectives were achieved using the *Long Range Energy Alternative Planning Systems Model* (*LEAP*). The energy environment model that was developed using *LEAP* gives the details of Alberta's complete energy structure including all the major and minor energy users for the entire energy demand and supply sectors. A reference case called the business-as-usual scenario was developed for a study period of 25 years (2005-2030), as were a number of plausible GHG mitigation scenarios. These GHG mitigation scenarios encompass different demand side management scenarios such as efficient lighting and appliances in the residential and commercial sector, and supply side options such as renewable power generation.

In 2005 the total energy produced in Alberta was 10,643 PJ. For the same year, the demand for energy totaled 2,274 PJ from the energy demand sector; the remaining energy was transformed into secondary fuel in the transformation sector. This was used for electricity generation, bitumen production and upgrading and for meeting a non-energy–sector demand for energy which amounted to 2894 PJ. The total energy exported was 7,420 PJ that year. Alberta's emissions totaled 244 MT as modeled in LEAP.

Over the period of 2005-2030, the growth in demand for energy is expected to be between 2274 and 3496 PJ. The rate of increase in energy demand is attributed to increases in industrial sector intensity because Alberta's mining and petrochemical industries are expected to grow at a faster pace than other sectors.

A Sankey diagram for energy flow indicates that about 70% of the energy produced in Alberta is exported; the rest is used locally. About 50% of the energy used in the energy demand sectors constitutes rejected energy. Major GHG emitting sectors are the industrial sector - 67% followed by the transportation sector, with 20% of total emissions generated by Alberta's energy sector. Mitigation scenarios indicate that, industrial sector GHG mitigation options could potentially reduce emissions up to 45 MT per year by 2030. Supply side mitigation scenarios indicate that the power generation and oil sands sectors have a large GHG mitigation potential of up to 70 MT per year assuming CCS is incorporated.

8. Recommendations for future work

- The current project was funded by Alberta Innovates – Energy and Environment Solutions (AI-EES), and Department of Energy – Government of Alberta (DOE-GOA). This project developed a data-intensive and Alberta specific energy planning and forecasting tool using *LEAP*. Further, it has developed a preliminary energy and environment modeling capability. This model, along with the developed database and infrastructure, can be used by different government agencies and departments for making policy decisions and assessing different energy projects. A *centre for energy and environmental systems engineering* is needed to assist in the further development of Alberta's energy and environmental modeling capability and for training personnel in this area on using an energy and environment based systems approach.

- The study was conducted for the base year, 2005, because that was the most current data available when the project was started in 2007. The 2005 data will have to be replaced by more recent data, such as that for 2008.

- The current study developed preliminary estimates of GHG mitigation for different scenarios. These scenarios need to be further developed and GHG mitigations should be considered for the demand, supply and resource sectors. The development of these scenarios should be accompanied by the cost-benefit analyses. The abatement cost of each mitigation option should be developed for the demand, transformation and resource sectors.

- In its current form, Albert's version of the *LEAP* model does not have an optimization capability. This energy-environment planning model for Alberta can be further developed for use with the available database by including an optimization capability. Optimization models are typically used to generate least-cost configurations for energy systems, based on different limitations.

- Development of GHG mitigation scenario cost curves for the 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 would also help in understanding the extent of mitigation possible in different GHG mitigation scenarios over a study planning horizon.

- Energy sectors have consequences, not only in terms of GHG emissions but also in terms of water and land use. There has been very limited research on projected water and land requirements resulting from the use/supply parameters of different energy sectors. Because Alberta is a major energy producer, models in these areas need to be developed that have features specific to Alberta.

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APPENDIX

APPENDIX – A – Graduate Thesis with the detailed data and results