University of Alberta

The Development of a Framework for the Assessment of Energy Demand-based Greenhouse Gas Mitigation Options for Alberta's Agriculture Sector

by

Marziyeh Bonyad

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of requirements for degree of

Master of Science

in

Engineering Management

Department of Mechanical Engineering

Spring 2014
Edmonton, Alberta

To my parents and husband, for their love and support

Abstract

Due to rapid economic expansion, Alberta's energy sector has witnessed an upsurge in energy consumption and greenhouse gas (GHG) emissions. The agriculture sector in Alberta ranks second among the Canadian provinces in terms of energy consumption in the agricultural sector nationally. The current research uses the Long range Energy Alternatives and Planning (LEAP) model to develop a framework to assess the future trends of energy demand and associated GHGs for Alberta's agriculture sector. This framework helps in the assessment of various GHG mitigation options associated with energy consumption. Based on current growth rates of energy supply and demand, a business-as-usual scenario was developed for the years 2009-2050. Following this, various GHG mitigation scenarios were developed to assess the economic feasibility of energy efficiency improvement and GHG-reduction options. GHG abatement cost curves were developed to determine the marginal costs ($/tonne of GHG reduced) for all the GHG mitigation scenarios.

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Amit Kumar, for his guidance and advice, and for showing me how to become a researcher. This thesis would not have been possible without his insights and expertise.

I would also like to acknowledge with much appreciation Dr. Mohammad Khakbazan, a scientist of agricultural economics in Agriculture and Agri-Food Canada, for guiding this study with his experience. I am thankful to The Canadian Agricultural Energy End-Use Data and Analysis Center (CAEEDAC), Statistics Canada, and Natural Resources Canada for providing me access to their reports and databases.

I am greatly thankful to Ms. Veena Subramanyam and Dr. Deepak Paramashivan for helping and advising me in my research. Further, I am also thankful to my other colleagues and friends at the Sustainable Energy Research Lab — Saeidreza Radpour, Mahdi Vaezi, Patrick Miller, Azadeh Seif, Ali Talaei, Babatunde Olateju, and Babkir Ali — for useful discussions and for making a friendly and vibrant research environment.

I would like to express my gratitude to my family for their endless love and support.

Table of Contents

List of Tables

List of Figures

Acronyms & Abbreviation

CDN	Canadian dollar
CFLs	Compact fluorescent lamp
CFM	Cubic feet of air per minute
CH_4	Methane
cm	Centimeter
CO_2	Carbon dioxide
CRF	Capital recovery factor
CSE	Cost of saved energy
DFO	Diesel fuel oil
DOE	Department of Energy
EIA	Energy Information Administration
ERCB	Energy Resources Conservation Board
eq	Equivalent
EI	Energy intensity
FEI	Final energy intensity
EUI	Energy use intensity
ft	Feet
g	Gram
GDP	Gross domestic product
GHG	Greenhouse gas
GW	Gigawatt
GT	Gigatonne
HPCP	High-pressure centre pivot
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
KJ	Kilojoule
Km	Kilometer
KW	Kilowatt

KWh	Kilowatt hour
kT	Kilotonne
LEAP	Long-rang Energy Alternatives Planning
L	Liter
LFO	Light fuel oil
LHV	Lower heating value
LPCP	Low-pressure centre pivot
LPG	Liquefied petroleum gas
m	Meter
M	Million
MJ	Megajoule
mm	Millimeter
MT	Million tonne
MW	Megawatt
MWh	Megawatt hour
NEB	National Energy Board
NEV	Net energy value
NG	Natural gas
N_2O	Nitrous oxide
NPV	Net present value
PJ	Petajoule
SCO	Synthetic crude oil
SEI-B	Stockholm Environment Institute at Boston
Sq ft	Square feet
Tcf	Trillion cubic feet
TED	Technical and environmental database
TFP	Total factor productivity
T	Tonne
TJ	Terajoule
W	Watt
WEAP	Water Evaluation and Planning

Chapter 1. Introduction

1.1 Background

Global warming caused by greenhouse gas (GHG) emissions is an important environmental issue facing the world today. Increased emissions of GHGs trap radiation from the sun and warm the planet's surface. The rate of increase in GHGs is caused by increased human activities that not only introduce new sources of GHG emissions but also either reduce or completely destroy natural emission sinks such as forests. Globally, among all the GHGs, the principal emission is carbon dioxide (CO_2), which has one of the largest global warming potentials and is primarily emitted through energy consumption (EPA, 2013). From 2000 to 2011, energy-related emissions in the world increased by an average of 2.5% annually (BP, 2012). In 2011, about 34 billion tonnes of CO_2 were energy-related, and 90% of those were emitted from the combustion of fossil fuels (Olivier et al., 2012). The electricity generation sector is the world's largest source of carbon dioxide emissions, followed by the industry, forestry, and agriculture sectors (EPA, 2013).

In the agriculture and forestry sectors, CO_2 emissions from deforestation, land clearing for agriculture, the management of agricultural soils, livestock farming, and biomass burning account for more than 30% of global GHG emissions annually (EPA, 2013; Vermeulen et al., 2012). In fact, the agriculture sector is one of the significant contributors to worldwide GHG emissions (Smith et al., 2007). Globally, the average annual GHG emissions in agriculture from the crop and livestock subsectors are increasing at the rate of about 60 MT CO_2 equivalent per year due to population growth and changing diets (Smith et al., 2007).

GHG emissions in the Canadian Energy Sector – An Overview

Canada is one of the world's five largest energy producers and stands ninth among the top GHG emitters from fuel combustion in the world (EIA, 2013). Canada's economy is relatively energy intensive compared to other industrialized countries (Environment Canada, 2012). In 2011, Canada's energy consumption increased by 3.8% (7,945 petajoules) compared to the year before, and is largely fueled by petroleum, as well as natural gas and hydroelectricity (Statistics Canada, 2011a). The growth of energy consumption in Canada causes the growth of total national GHG emissions. The total Canadian GHG emissions were 702 million tonnes of CO_2 in 2011 (Environment Canada, 2013). GHG emissions increased by roughly 17% from 1990 to 2011 (EIA, 2013). In Canada, the largest contributor to GHG emissions is the energy sector, which includes power generation, transportation, and other fugitive sources. Transportation contributes 27% of Canada's total GHG emissions, while stationary sources such as electricity generation, space heating, fossil fuel industries, manufacturing, construction, and mining account for 44% and the agricultural sector for 12% (Goverment of Alberta, 2003; Government of Canada, 2012).

Energy Consumption and GHG emissions in Alberta

Energy consumption and its related GHG emissions are not evenly distributed among Canadian provinces. Alberta, followed by Ontario and Quebec, accounts for most of the energy consumed in Canada (Statistics Canada, 2011a). According to Statistics Canada, energy consumption in Alberta has had the largest increase of all the provinces (Statistics Canada, 2006). Alberta's energy use and GHG emissions profile are separated according to the residential, commercial, industrial, agriculture, and transportation sectors. The industrial sector consumes more than 50% of the total energy in Alberta (Natural Resources Canada, 2012a). Alberta's transportation sector is the second highest energy consumer, and the residential, commercial, and agriculture sectors account for a quarter of Alberta's total energy use (Natural Resources Canada, 2012a).

The largest source of GHG emissions in Alberta is from stationary fuel combustion, which accounts for about 85% of all provincial emissions (Goverment of Alberta, 2013). Alberta produces 48.5% of total reported GHG emissions in Canada, which is mostly due to the province's large energy industry and the production of electricity from coal-fired power plants (Goverment of Alberta, 2013). Since the focus of the current study is on the agricultural sector, the energy consumption in the agricultural sector in Canada and in Alberta will be discussed hereunder.

According to Natural Resources Canada, the five provinces that consumed the most energy in the agriculture sector in 2009 were Saskatchewan, Alberta, Ontario, Manitoba, and Quebec (Natural Resources Canada, 2012b). Energy use on farms for each province is based on their major farm operations. The energy use by all provincial agricultural sectors in Canada is represented by Table 1-1, which shows that Alberta, Ontario, and Saskatchewan account for most of the energy consumed in the agriculture sector.

Table 1-1: Canada's energy consumption in provincial agricultural sectors (in petajoules)

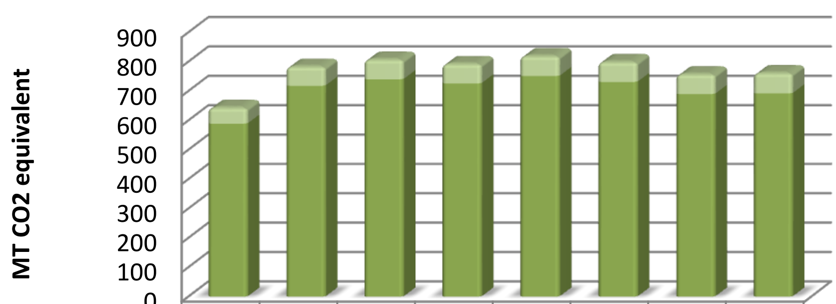
Energy use (PJ)	1990	2006	2007	2008	2009	2010
Canada	194.2	222.3	227.4	231.1	203.5	238.5
Newfoundland and Labrador	0.5	0.4	0.4	0.4	0.4	0.5
Prince Edward Island	1.4	1.7	1.8	1.7	2.0	2.2
Nova Scotia	2.5	3.5	3.9	3.6	2.8	4.1
New Brunswick	1.9	2.3	2.6	2.5	3.3	4.8
Quebec	18.6	27.9	28.9	28.9	27.0	30.7
Ontario	38.2	50.5	47.7	48.4	42.5	56.4
Manitoba	20.3	22.8	22.6	23.4	17.9	17.9
Saskatchewan	50.0	44.3	50.7	50.0	53.9	55.0
Alberta	51.1	55.4	53.1	56.4	42.0	47.9
British Columbia	9.6	13.0	14.9	14.8	11.6	17.8
Territories	0.0	0.4	0.9	0.9	0.4	1.1

Source: (Natural Resources Canada, 2012b)

Moreover, Alberta's agriculture sector accounts for the second largest source of emissions in the Canadian agricultural sector after Saskatchewan (Natural Resources Canada, 2012a).

Alberta's agricultural energy consumption reflects the use of fossil fuels, electricity, natural gas, and propane at the end-use level, e.g., drying, on-farm operations, irrigation, etc. (Heaps et al., 1998; Natural Resources Canada, 2012c). However, fossil fuels dominate the energy use in Alberta's agriculture sector and account for more than 70% of Alberta's agricultural energy demand (Natural Resources Canada, 2012c). In addition, Alberta's agriculture industry is faced with the need to increase energy inputs into all the agricultural operations due to the growth of farm mechanization and population (OTA, 1992; Statistics Canada, 2006). This increase is measured in terms of energy value, energy requirement, and corresponding GHG emissions.

Overall, GHG emissions from crops, pasture, and livestock production account for 9% of the nation's total GHG emissions, while farm fuel and agri-food processing account for 3% (Environment Canada, 2011; Goverment of Alberta, 2003). Thus, it is anticipated that all provincial agriculture industries will contribute in Canada's GHG reduction endeavors. The trend of Canada's GHG emissions in the agriculture sector is shown in Figure 1-1.



	1990	2000	2005	2006	2007	2008	2009	2010
Agriculture	54	65	67	66	68	68	67	69
NATIONAL GHG TOTAL	589	718	740	726	751	731	690	692

Figure 1-1: Canada's GHG emissions trends (Environment Canada, 2011)

According to Natural Resources Canada, Alberta's agriculture sector accounts for the second largest GHG emissions in Canadian agriculture. The majority of Alberta's agricultural GHG emissions are emitted through diesel and gasoline consumption, which are responsible for 90% of all agricultural emissions (Natural Resources Canada, 2012c). Industrial agriculture uses fossil fuels in machinery and petroleum-based agrochemicals, which cause GHG emissions in Alberta's agriculture sector. In fact, Alberta's agricultural sector accounts for about 20-25% of Canada's agricultural energy consumption and contributes 30% of the total of Canada's agricultural GHG emissions. These figures emphasize the need to improve energy efficiency and GHG mitigation in Alberta's agricultural sector (Goverment of Alberta, 2003; Natural Resources Canada, 2012b).

The agricultural industry has several opportunities to reduce GHG emissions. It is in the unique position of being able to capture atmospheric carbon by growing crops and storing the carbon in the soil (Goverment of Alberta, 2005). Agricultural soils can be a source as well as a sink of CO_2 by emitting and then storing the CO_2 (Smith et al., 2008). Moreover, it is possible to reduce GHG emissions in agriculture by growing crops and raising livestock more efficiently by improving management of farm operations and on-farm energy use and assessing all GHG mitigation options and rapidly changing the industry so that it operates sustainably. On-farm GHG emission assessments are necessary to identify where and how much GHGs are being emitted by agricultural processes. GHG emission management in agriculture is highly associated with energy management of farm operations, which have a large potential for reducing GHG emissions.

As efforts to mitigate climate change increase, many studies recognize agriculture as a source of emissions as well as an opportunity for mitigation. The main GHGs released by agricultural operations are CO_2, CH_4 ,and N_2O (Smith et al., 2008). Most of the carbon dioxide is released through microbial decay (e.g., soil organic matter) and through the burning of plant litter (Janzen, 2004 ; Smith et al., 2004). Methane is mainly generated in livestock farms, where organic materials decompose in oxygen-deprived conditions such as stored manures, and where rice is grown under flooded conditions (Mosier et al., 1998). Nitrous oxide is produced by the microbial transformation of nitrogen in soils (Oenema et al., 2005; Smith & Conen, 2004).

Several agricultural practices can potentially mitigate GHG emissions. For instance, the flows of carbon and nitrogen in agricultural ecosystems (e.g., livestock management) can be managed more efficiently. GHG emissions can be displaced by using crops and residues from agricultural lands as a source of bioenergy (clean energy) to be replaced by fossil fuels (Smith et al., 2008).

A study on GHG mitigation in Danish agriculture shows the feasibility of substantially reducing GHG emissions and energy use by 50-70% in agricultural operations by 2050 over a 60-year period beginning in 1990 (Dalgaard et al., 2001). The study suggested that reductions are possible through managing manure and fertilisers, optimizing animal feeding and cropping practices, and changing land use through more organic farming and afforestation and by growning energy crops. The study also suggested that these reductions could deliver surplus bioenergy for use in other sectors (Dalgaard et al., 2001).

In addition, energy use and GHGs emitted in agricultural operations are related to each other. Directly and indirectly, energy is necessary for agricultural operations. Agricultural production like cropping requires large amounts of fuel, fertilizers, pesticides, etc., while livestock uses energy directly through machinery and indirectly through production of the feed crops (Tewari, 1990).

The majority of energy modeling in agriculture studies is not recent, and most of the research is based on outdated technologies. Most of the studies in the agriculture sector have focused on only one of the two aspects: energy or GHG emissions. However, these two aspects should be considered together. Moreover, earlier studies of energy and GHG emissions in agriculture do not consider the current state of technology, and the links made between new technologies and the possibilities of energy use and GHG reduction are limited. Nor has the cost-effectiveness of mitigation been assessed. In order this fill the gap in knowledge, this research focuses on both direct energy consumption and GHG emissions, and it models energy demand and GHG emissions based on several mitigation scenarios over a planning horizon. This study also estimates the cost benefit of GHG mitigation scenarios to provide an overall view of the feasibility of implementing the GHG mitigation scenarios.

In order to develop a long-term energy planning and forecasting model, a generic energy demand and supply assessment tool is needed. Energy supply-demand models generally have a demand module responsible for handling all the energy demand sectors, subsectors, end-uses and devices. These models also have a transformation or conversion module that deals with the conversion of primary energy to a secondary energy. Some of these transformation modules have capabilities to forcast future energy supply and demand and develop a mitigation scenario followed by a cost-benefit analysis. Several energy-environment models have been used and developed to analyze energy supply and demand for various regions and countries. MARKAL, LEAP, MESSAGE, ReEDs, and EnergyPlan are the common energy-environment models for these purposes (IIASA, 2012; Lund, 2007; NREL, 2012; Seebregts et al., 2001; Stockholm Environment Institute, 2013). In this study, LEAP model was selected and the rationale is described in subsequent sections.

Thoughtful implementation of energy-efficiency improvement plans in the agricultural industry will help reduce a farm's energy demand and GHG emissions substantially. The agricultural sector can make a significant contribution to meeting energy demand and GHG emission reduction plans when farm land is used as a GHG emissions sink and as a source of biofuel. Interdependencies of energy management in agriculture can affect the energy consumption and its GHG mitigation potential in four principal ways:

- By improving energy efficiency in agricultural operations, e.g., in farm machinery and farm transportation, space heating, space cooling, lighting, equipment, irrigation, drying, etc.

- By replacing fossil fuels in farm machinery and vehicles with renewable energy, e.g., biodiesel, ethanol.
- By removing emissions through the capture of carbon in soils, pastures, or trees.
- By reducing emissions through improved feeding efficiency, manure management, or tillage management, e.g., conservation tillage.

1.2 Objectives of the current study

The overall objective of this research is to understand the energy use in Alberta's agriculture sector and develop energy efficiency scenarios through use of the Long range Energy Alternatives and Planning System model (LEAP). The specific objectives of this research are:

- The development of energy end use and energy intensity of equipment through the development of an energy demand tree for Alberta's agricultural sector.
- The development of a baseline scenario for an energy demand pattern in Alberta's agricultural sector for a study period of 42 years from 2009 to 2050 in the LEAP model.
- The identification and assessment of energy-efficiency opportunities in Alberta's agriculture sector.
- The assessment of various GHG mitigation scenarios for Alberta's agriculture sector and a simulation of each scenario in the LEAP model for the study period.
- The assessment of the cost-effectiveness of each GHG mitigation scenario in Alberta's agriculture sector.
- The development of abatement cost curves for Alberta's agricultural sector for the GHG mitigation scenario to show the GHG abatement cost and the extent of the cumulative GHG mitigation of each scenario over a long-term planning horizon.

1.3 Scope of the current study

Energy demand modeling for any energy demand sector including the agriculture sector follows different approaches that vary in terms of model, starting time horizon, and the type of questions the model is designed to answer. In this study, the LEAP model focuses on the period from 2009 to 2050 and is used to forecast future energy demand and assess proposed GHG mitigation scenarios.

Data collection on energy demand

In Alberta's agriculture sector energy model, a lot of publically available data issued by provincial and federal agencies (e.g., Statistics Canada) were used to develop baseline data for the model. Moreover, macro-economic assumptions for Alberta's agriculture sector were used to project the energy demand for the baseline scenario for the study period of 42 years.

Data collection of emissions

LEAP's Environmental Database (TED) has been used as the main source of GHG emission data for Alberta's agriculture energy model (Stockholm Environment Institute, 2011). However, some of the emissions factors that are not available in TED were developed externally using earlier published reports produced by many institutions (e.g., the Intergovernmental Panel on Climate Change (IPCC), the National Renewable Energy Laboratory (NREL), etc.).

The development of various GHG mitigation scenarios

The GHG mitigation scenarios for Alberta's agriculture energy sector focus on improving energy efficiency and using various renewable energy sources for agricultural applications.

Analysis of cost-effectiveness of GHG mitigation scenarios and the development of a GHG mitigation cost curve

Typically, detailed cost-benefit analyses can be conducted to identify which GHG mitigation scenarios are financially attractive in a particular region (Stockholm

Environment Institute, 2011). In Alberta's agricultural sector energy model, a cost-benefit analysis for each GHG mitigation scenario was developed to evaluate the incremental cost of each scenario compared to the reference scenario. Further, two economic methods were used to assess the cost of each mitigation scenario: the cost of saved energy and the activity cost available in the LEAP model. Eventually, GHG abatement cost curves were developed to determine the relative cost per tonne of GHG mitigated in a particular time frame.

1.4 Organization of the thesis

This thesis contains five chapters as well as a table of contents, a list of tables, a list of figures, a list of abbreviations, a bibliography, and appendices.

Chapter 1 provides the background, objectives, scope and limitations of the study and is followed by a literature review.

Chapter 2 describes the structure of the LEAP model, the key assumptions, and the detailed modeling methodology. The chapter also discusses the output results of the model for Alberta's agriculture energy demand and energy conversion sector along with the overall environmental results for the base year and reference scenario.

Chapter 3 contains descriptions of various GHG mitigation scenarios for Alberta's agriculture sector. The methodology of developing various mitigation scenarios as well as their input data and assumptions is described. This chapter discusses the approaches used to develop GHG mitigation scenarios and reviews the outcomes of each GHG mitigation scenario.

Chapter 4 describes the development of the cost-benefit analysis for each GHG mitigation scenario proposed in chapter 3. This chapter discusses the results of the cost-benefit analysis and offers a comprehensive assessment of energy efficiency improvement opportunities by estimating the abatement costs of GHG mitigation for each GHG mitigation scenario. Cost curves are presented that compare the abatement costs of each mitigation scenario with the reference scenario.

Chapter 5 discusses the conclusions and recommends several ideas for related future work.

Following these concluding chapters are several appendices. Appendix A and Appendix B present detailed lists of the data used in this thesis and the results for energy demand and baseline, followed by GHG mitigation input and output data. Appendix C contains some details of the cost-benefit analysis of GHG mitigation options. Appendix D shows reductions in several GHG emission factors achieved by the proposed mitigation scenarios. Appendix E consists of conversion factors used in this study and miscellaneous information that was useful in conducting the current research.

Chapter 2. Energy Sector Modeling of Alberta's Agricultural Sector using LEAP

2.1 Introduction

Alberta has the second largest agricultural land area in Canada. According to the 2006 census, there were 49,431 farms in the province with a total of 52 million acres, which represents 31.3% of the total Canadian farm land (Statistics Canada, 2009). There is an increasing demand for energy in the agricultural sector in Alberta. Alberta's agriculture sector is the second largest agricultural sector in Canada after Saskatchewan's and emitted 2.5 MT of CO_2 in 2009. This figure emphasises the importance of reducing agricultural energy consumption in the overall Canadian GHG mitigation action plan (Natural Resources Canada, 2012a).

According to Alberta's 2008 Climate Change Strategy, by 2050 the GHG emissions in all provincial group activities (e.g., industrial, transportation, commercial, residential and agricultural activities) should be reduced by 12% to comply with the long-term development of energy efficiency and conservation (Goverment of Alberta, 2008a). Alberta's energy vision is moving towards a clean energy future, innovation and new technology, wise energy use, and sustained economic prosperity (Goverment of Alberta, 2008b).

However, all of the provinces' energy action plans face critical challenges, namely, meeting the increased energy demand, ensuring a secure economical energy supply in the future, and protecting the environment (Goverment of Alberta, 2008b). Thus, the energy action plan should have a comprehensive model that accounts for both energy supply and demand and other factors that may affect energy use. For example, in the agriculture sector, energy use is related to agricultural production activities, farm type, and production practices. The complexity of these factors, their relationship with each other, and energy action plan goals require a model that accounts for macroeconomics, supply-demand scenarios, resource use and their transformation, and environmental effects.

In the current research, the Long range Energy Alternatives Planning System (LEAP) was used to develop a comprehensive model to simulate current energy consumption and future energy demand for Alberta's agriculture sector. Based on this model, several alternative scenarios were developed and compared in terms of their potential to reduce energy consumption and GHGs. Moreover, the model can be used to investigate energy efficiency improvement opportunities in Alberta's agricultural operations, resulting in cost savings, energy conservation, and reduced GHG emissions. The model is intended to help Alberta's agriculture sector to reduce energy input per unit of production by comparing various energy-efficient technologies and implementing long-term energy strategies and plans.

2.2 LEAP modeling tool

The LEAP model – an energy-environmental modeling tool – was developed by the Stockholm Environment Institute at Boston (SEI-B). LEAP is used for a bottom-up type accounting framework to develop prediction models for energy systems, abatement costs, and environmental impact. LEAP uses an integrated database called the Technology and Environment Database (TED) to describe a wide range of energy technologies including existing technologies, current best practices, and next generation devices. In a LEAP model, a TED database describes technical characteristics, costs, and environmental impacts of different energy technologies. A model developed using LEAP can be used to analyze energy policies, assess GHG mitigation potential, and assess costs of GHG mitigation (Stockholm Environment Institute, 2011). LEAP is an integrated modeling tool that develops an energy demand section by using existing data for a base year and the TED database. Furthermore, LEAP can analyze and forecast the data from resources to final end use for a long period of time (e.g., 20-50 years) (Stockholm Environment Institute, 2011). LEAP is a powerful tool to track energy consumption, production, and resource derivation.

2.2.1 Methodology of modeling in LEAP

The LEAP model is built considering both the demand and supply side of the energy sector. A demand side assessment can be bottom-up, end-use accounting, top-down macroeconomic modelling (Stockholm Environment Institute, 2011).

LEAP can create various models for different energy systems by using its special data structures. In other words, the methodology of LEAP is based on using a built-in database and input data to simulate the different alternative scenarios of energy demand and supply in each sector. These scenarios can be defined either for the energy sector or a non-energy sector such as GHG emissions or cost in a particular region.

LEAP consists of four modules: 1) the demand module, which represents the end-use energy data and details of both primary and secondary fuel, 2) the transformation module, which is responsible for the process of converting the primary fuel to the secondary fuel, 3) the resource module, which performs the accounting of all the primary and secondary fuels, and 4) the TED module for the accounting of the emissions factors of the primary and secondary fuels. Figure 2-1 shows the LEAP model framework.

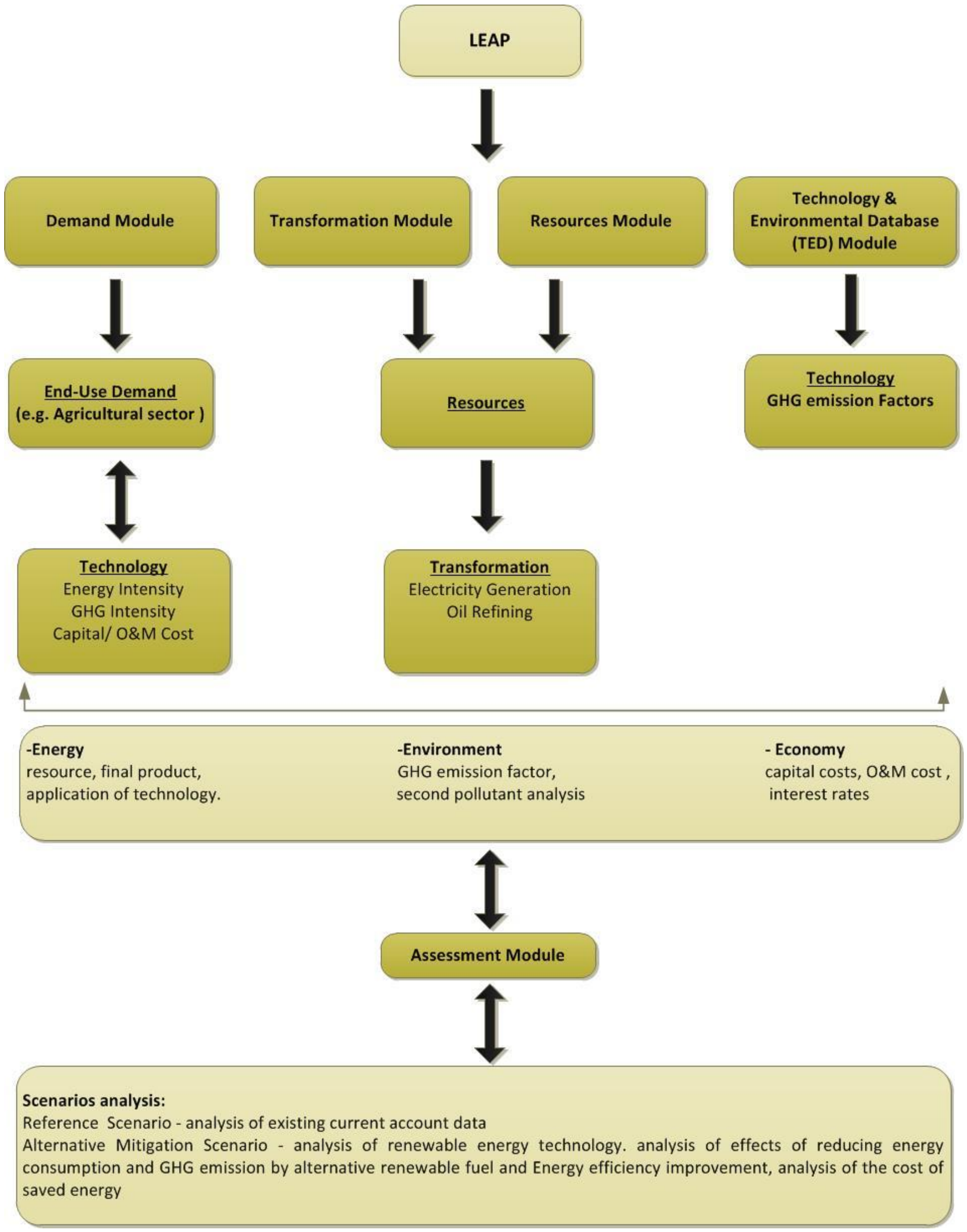


Figure 2-1: LEAP model framework

The LEAP model has a hierarchical tree structure with four key features: the key assumptions, the energy demand module, the energy transformation module, and the energy resource module. All data in these four sections are supported by the Technology and Environmental Database. In addition, the cost-benefit analysis in LEAP is a key indicator for performing a cost analysis of an energy system. A cost-benefit analysis gives a good perspective on creating an action plan for reducing energy consumption and GHG emission.

2.2.2 Key assumptions

The key assumptions category is the first branch in LEAP and includes macroeconomic, demographic, and time-series variables (e.g., GDP, population, income, consumption, investment, etc.). The key assumptions data can be used and referenced in the energy demand, energy transformation, and resources modules. Furthermore, these data play the role of intermediate variables for the energy model.

In the base year for Alberta's agriculture energy model, i.e., 2009, all data and variables in the key assumptions category were obtained from the following federal and provincial agencies: Statistic Canada (Statistics Canada, 2012), Natural Resources Canada (Natural Resources Canada, 2012c), the National Energy Board (NEB, 2012), The Canadian Agricultural Energy End Use Data and Analysis Centre (CAEEDAC, 2000), and the Government of Alberta's Agriculture and Rural Development Department (Goverment of Alberta, 2012a).

2.2.3 The energy demand module

The second branch in the LEAP model is energy demand, which is structured by four levels: sectors, subsectors, end uses, and devices. Each of these levels can be created either by energy, environmental emissions, or cost data depending on data availability and reliability. The typical approach for creating these levels is to break down all the data into subsections (e.g., end use and devices).

The energy analysis always commences with the demand module in LEAP since it is a demand-oriented model. The results of the demand module give the preliminary estimation of the energy consumption of various fuels.

2.2.4 The energy transformation module

The transformation module is an intermediate process between the energy demand and resources modules and simulates the conversion of energy forms from primary resources and imported fuels to secondary fuels. The energy lost during the distribution of fuels is measured in this section. In the case of Alberta's agricultural energy model, the transformation module includes power generation, Alberta oil refining, crude oil production, synthetic crude oil production, crude bitumen production, and coal mining. The transformation module was developed earlier in other research work (Subramanyam, 2010). The focus of this thesis is predominantly on the development of the agricultural sector demand module.

2.2.5 The energy resource module

The resource module functions like a database that holds the data on the availability of primary resources, which typically consist of fossil fuel and renewable resources. In addition, the module holds the data on the cost of indigenous production and imports and exports of primary and secondary fuels.

In order to determine how a fuel should be handled in the model analysis, the module categorises the fuel into primary resources or secondary fuels; these may include fossil resources, renewable resources, biomass resources, secondary fuels, and electricity.

The type of data entered for each of fuels mentioned above depends on whether they are fossil or renewable fuels. The total available reserve of the resource and the annual energy available from the resource are entered. Using the input data, the resource module automatically estimates the consumption and production of fuels individually for each sector. An automatic update of the list of fuel information in the LEAP model is triggered whenever fuels from the demand and transportation modules are added or deleted.

2.2.6 The Technology and Environmental Database (TED)

TED is a built-in, dynamic database in the LEAP model that includes environmental emissions of different fuels used in the energy demand and supply sectors, as well as the emission factors of different processes. The TED database consists of a wide range of energy technologies including but not limited to existing technologies, current best practices, and next generation devices (Stockholm Environment Institute, 2011).

TED is user friendly, which means the user can edit and supplement its core database with various regional data. TED has extensive information for describing the technical characteristics, costs, and environmental data that come from various resources such as the data developed and found in developing countries. In addition, the TED section includes the characteristics of various pollutants such as CO, CO_2 equivalents, CO_2 biogenic, non-biogenic, CH_4, NO_X, and SO_X.

In addition, some complementary data have been added to TED using reference reports produced by many institutions such as the Intergovernmental Panel on Climate Change (IPCC, 2010), the U.S. Department of Energy (US-DOE, 2012a), and the International Energy Agency (IEA, 2011). For Alberta's agricultural energy model, all data in TED are adapted from Canadian and U.S. emissions data for agricultural activities based on the availability of data.

2.2.7 Cost benefit in LEAP

A cost-benefit analysis is based on the costs of resources but does not directly provide the final price of energy to the consumer (Stockholm Environment Institute, 2011). Instead, LEAP is used to perform cost-benefit analyses on alternative scenarios, i.e., to compare two scenarios with similar economic assumptions such as population, GDP growth rates, etc., to arrive at the best possible alternative.

The cost estimates of an energy model may include demand cost (e.g., total cost, cost of saved energy based on alternative scenarios, and costs per activity), transformation capital cost, transformation operation and maintenance cost, the cost of primary resources including the cost of importing fuels and the benefit from exporting fuels, and other costs such as pollutant emission costs and the costs of administrating efficient improvement programs. The cost-benefit analysis in LEAP is shown in Figure 2-2 (Stockholm Environment Institute, 2011).

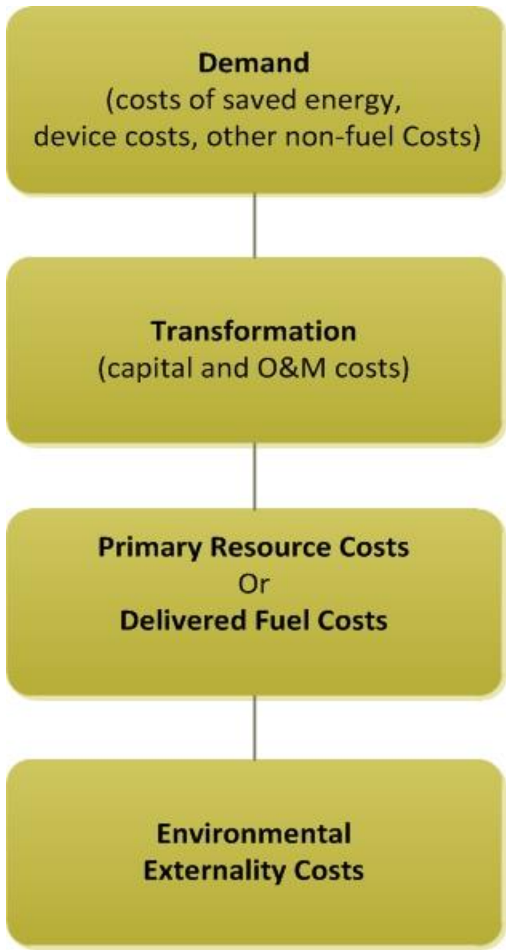


Figure 2-2: Cost-benefit analysis in LEAP

By default, LEAP estimates the incremental energy costs compared to the baseline scenario of a model by counting the fuel cost when the fuel is imported or exported or when fuel is extracted from primary resources.

2.3 Objective and Methodology

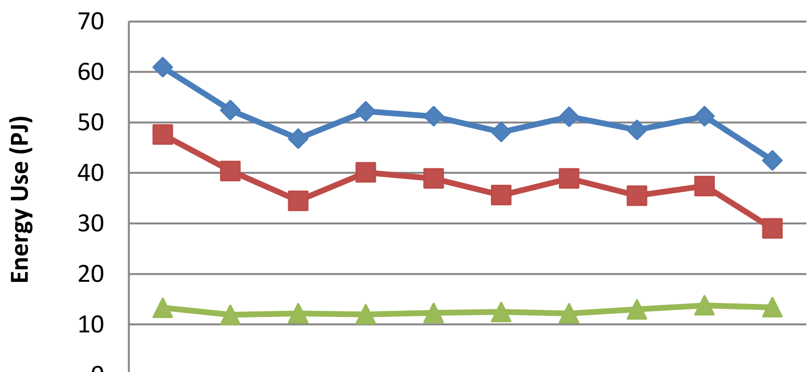
The objective of this research consists of developing Alberta's agriculture energy demand model using LEAP to analyze energy demand, GHG emissions, and cost of saved energy. The ultimate aim of this research is to create various GHG mitigation scenarios that introduce alternative options for fuel and technologies that reduce energy consumption and GHG emissions and to estimate abatement costs for each scenario.

In order to develop Alberta's agriculture sector energy demand model, all the agricultural activities and their end uses were identified. Afterwards, data were collected from federal and provincial agencies such as Statistics Canada's Energy division (Statistics Canada, 2012), Natural Resources Canada (Natural Resources Canada, 2012c), the National Energy Board (NEB, 2012), the Canadian Energy Research Institute (CERI, 2012), the Canadian Agricultural Energy End Use Data and Analysis Centre (CAEEDAC, 2000), the Government of Alberta's Agriculture and Rural Development Department (Goverment of Alberta, 2012a), and Agriculture and Agri-Food Canada (AAFC, 2012). Subsequently, a model was developed for the base year, 2009, using the gathered data. After establishing and validating the base year model, the reference or business-as-usual scenario was developed for a period of 42 years (from 2009 to 2050) based on the current energy situation and the growth rate of agriculture productions, population, and GDP. The reference scenario represents the amount of energy demand and supply over the study period.

The scenarios and data for energy demand were developed using a bottom-up approach based on end-use energy consumption, transformation, and resources. In other words, the model has a hierarchical tree structure for each energy demand and supply section. The energy demand tree for Alberta's Agricultural sector is divided by sectors and subsectors. Each of these sections is modeled according to their specific energy consumption, end-use fuels, and environmental loading factors related to energy demand, transformation, and resources. The model is described in detail in the following sections.

2.4 Input data and analysis in LEAP

Alberta’s energy use profile in agriculture is classified into two types of energy: direct and indirect. Direct energy sources include motive and non-motive fuels, and indirect sources include fertilizer, pesticides, and other inputs. Gasoline and diesel fuel oil (DFO) are classified as motive energy, and all other energy sources (i.e., electricity, natural gas, propane) are considered non-motive energy (Natural Resources Canada, 2012c). The majority of fuel consumption in Alberta’s agricultural sector is diesel fuel oil (DFO), motor gasoline, electricity, natural gas, and propane (LPG). DFO provides close to half of the total energy consumed in Alberta's agricultural sector (Natural Resources Canada, 2012c). In 2009, the agriculture energy use was dominated by motive energy use (about 70%) and the remainder was non-motive energy (Natural Resources Canada, 2012c). The trend of Alberta’s agriculture energy use over a ten-year period is shown in Figure 2-3.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total Energy Use(PJ)	60.9	52.4	46.8	52.2	51.2	48.1	51.1	48.5	51.2	42.5
Motive Energy Use	47.6	40.4	34.5	40.1	38.9	35.6	38.9	35.5	37.4	29
Non- Motive Energy use	13.3	11.9	12.2	12	12.3	12.5	12.2	13	13.8	13.4

Figure 2-3: Alberta’s agriculture sector energy use from 2000 to 2009 (Natural Resources Canada, 2012c)

Figure 2-3 shows that Alberta’s agriculture sector energy consumption decreased by 30 per cent between 2000 and 2009, from 60.9 PJ to 42.5 PJ. Moreover, motive energy consumption decreased by 39 per cent, and non-motive energy consumption increased by 0.75 percent between 2000 and 2009, which indicates that the decrease of total energy consumption was mainly due to a decrease in motive energy.

Alberta's agriculture sector energy consumption declined in 2009 as energy demand fell in all major sectors of the economy (Natural Resources Canada, 2012c). The gross domestic product (GDP) of the agriculture sector in Alberta in 2009 fell by 20% from 2008 (Goverment of Alberta, 2010). A decrease in the total amount of product and GDP is perhaps the main reason for the reduction in energy consumption in Alberta's agriculture sector in 2009 (Goverment of Alberta, 2010; Natural Resources Canada, 2012c). Several factors may be responsible for the overall decrease in motive energy use including energy efficiency improvement caused by enhanced technologies. However, the noticeable drop in motive energy use from 2008 to 2009 was mainly due to the cold winter and dry spring, which caused a significant decrease in agriculture production output and corresponding energy consumption (Goverment of Alberta, 2010).

2.4.1 The demand sector – base case

The demand module in Alberta's agriculture sector is made up of the total direct energy consumption in farm activities. Alberta's agriculture demand module is divided into three subsectors: crops, livestock, and "other" (i.e., other farm products and activities). Crops are classified by grain and oilseed, fruit and vegetable, and greenhouse and nursery. Cattle, hog, poultry and eggs, and dairy were classified under the livestock category.

Alberta's agriculture demand sector is modeled based on availability of all end-use energy data in the province of Alberta and in Canada. This study used the most recent data for energy use and GHG emissions reported by Statistics Canada and Natural Resources Canada (Natural Resources Canada, 2012c; Statistics Canada, 2012). Alberta's agriculture demand module is presented in Figure 2-4. The module illustrates the demand tree including the main sectors and their subsectors. The main sector is cascaded into device and end use. Each subsector was broken down into end-use level. Each end use was segregated by various types of primary and secondary fuels.

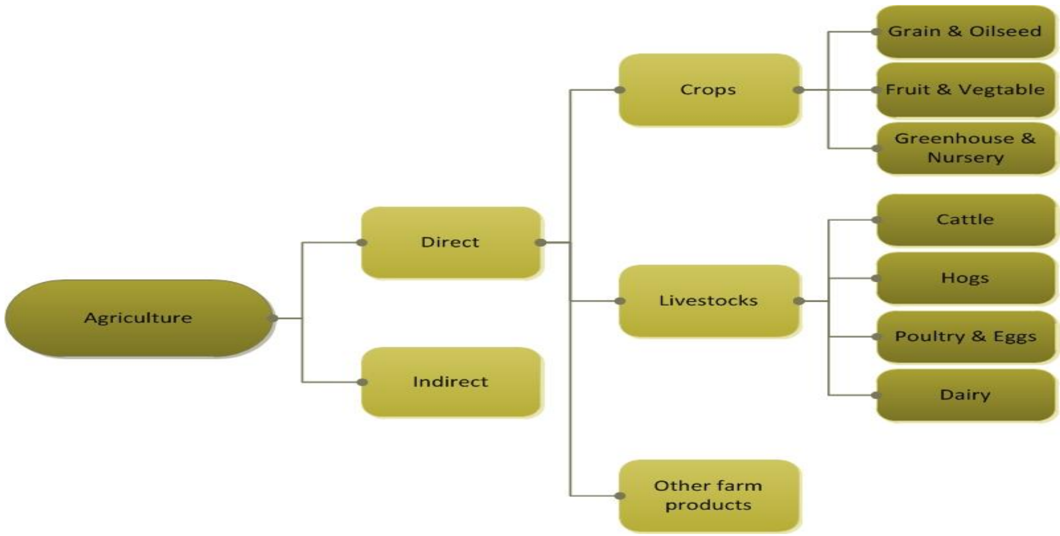


Figure 2-4: Alberta's agriculture sector energy demand tree

The methodology for providing a descriptive analysis of on-farm energy use is based on an earlier study completed for Natural Resources Canada (Khakbazan, 2000).

The on-farm energy use model was developed based on farm type, energy type, and use type. Farm type includes grain and oilseed, fruit and vegetable, greenhouse and nursery, cattle, hog, poultry and eggs, dairy, and "other." The "other" depends on the type of farm activities in each province; in Alberta, "other" was found to be predominantly grain and oilseed, and cattle (Khakbazan, 2000). The "other" section end-use activities include:

- The drying of grain
- The baling of hay
- The cultivation of crops

Energy type includes diesel, gasoline, natural gas, electricity, and liquid petroleum gas or propane (LPG). Figure 2-5 illustrates the type and the amount of energy use in Alberta agriculture in 2009.

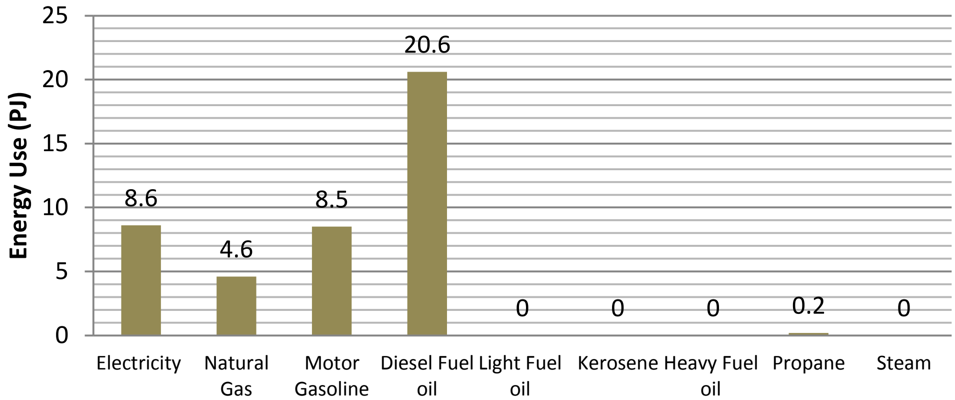


Figure 2-5: All types of energy use in Alberta's agriculture sector in 2009 (Natural Resources Canada, 2012c)

In Alberta's agriculture energy model, the usage type includes farm machinery, farm transport (farm trucks), non-farm, heat and light, and other uses. The farm machinery category includes the common equipment used in Canadian and Albertan agricultural activities: tractors, grain combines self-prop, swathers, mower conditioners, and balers.

Alberta's agriculture and food products include grains and oilseed, fruits and vegetables, meat and dairy products. Figure 2-6 represents the developed demand tree in a crop section and its subsection, grain and oilseed. The crop section is divided into three subsectors (i.e., grain and oilseed, fruits and vegetables, and greenhouse and nursery), and each subsector is broken down into its own device and end use. The other two subsectors in the crops section are shown in Figures A-1and A-2 in Appendix A.

Livestock is the second most prominent sector in Alberta agriculture. This sector, along with the details up to end-use activities in one of its subsectors, cattle, is shown in Figure 2-7. The remaining subsectors in livestock are shown in Figures A-3, A-4, and A-5 in Appendix A. The last section in Alberta agriculture, "other," is shown in Figure 2-8.

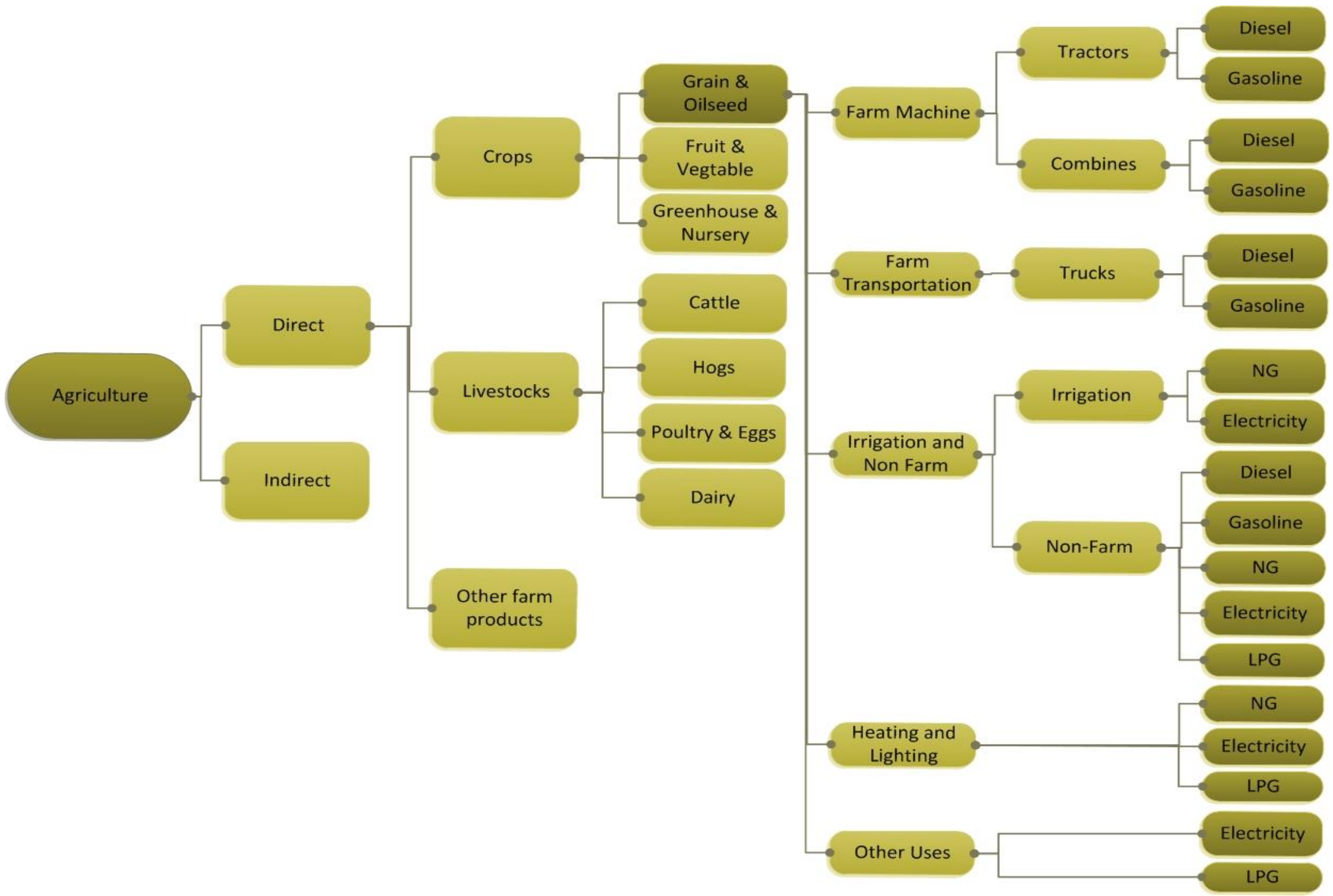


Figure 2-6: The crop subsector with grain and oilseed

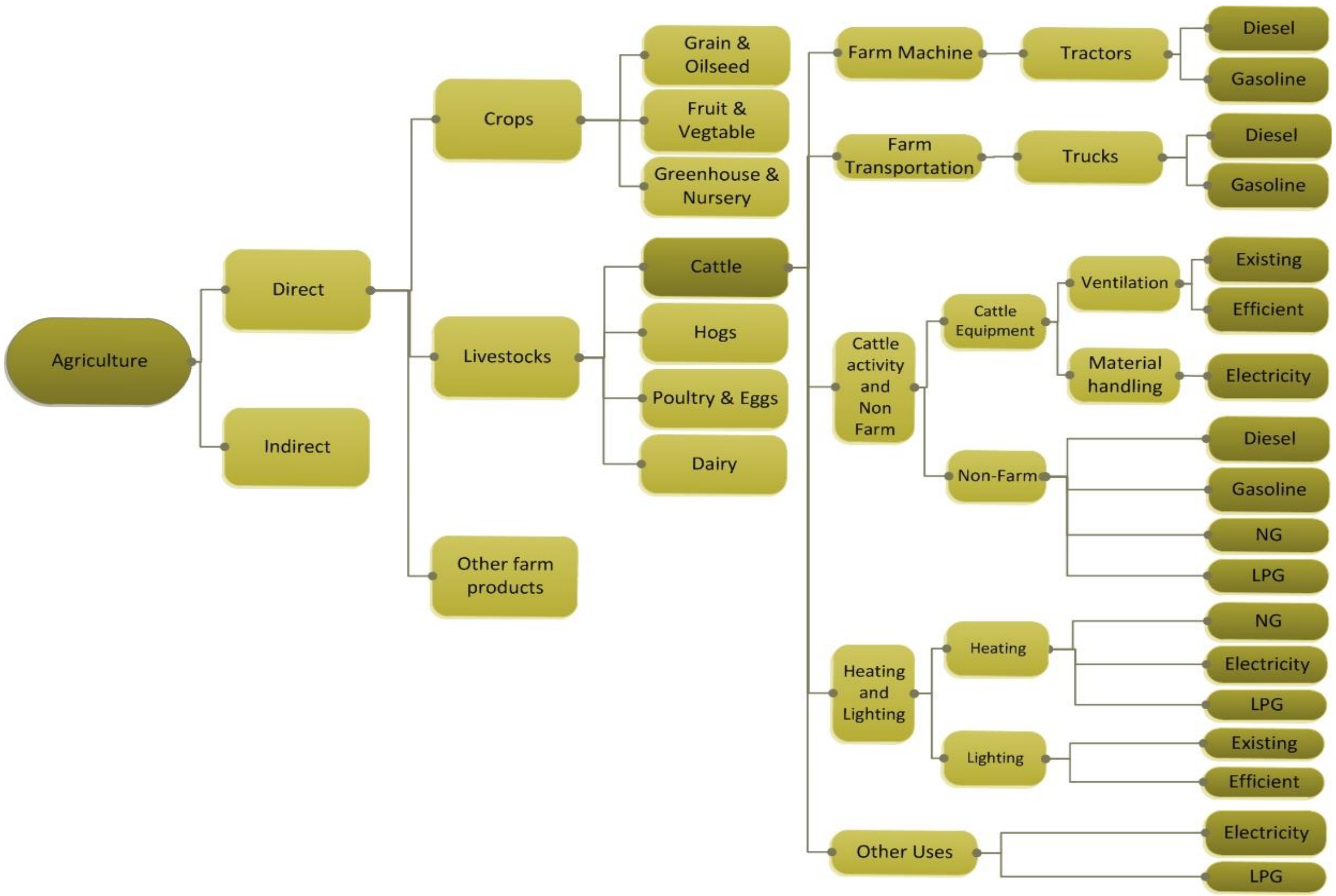


Figure 2-7: The livestock subsector with cattle

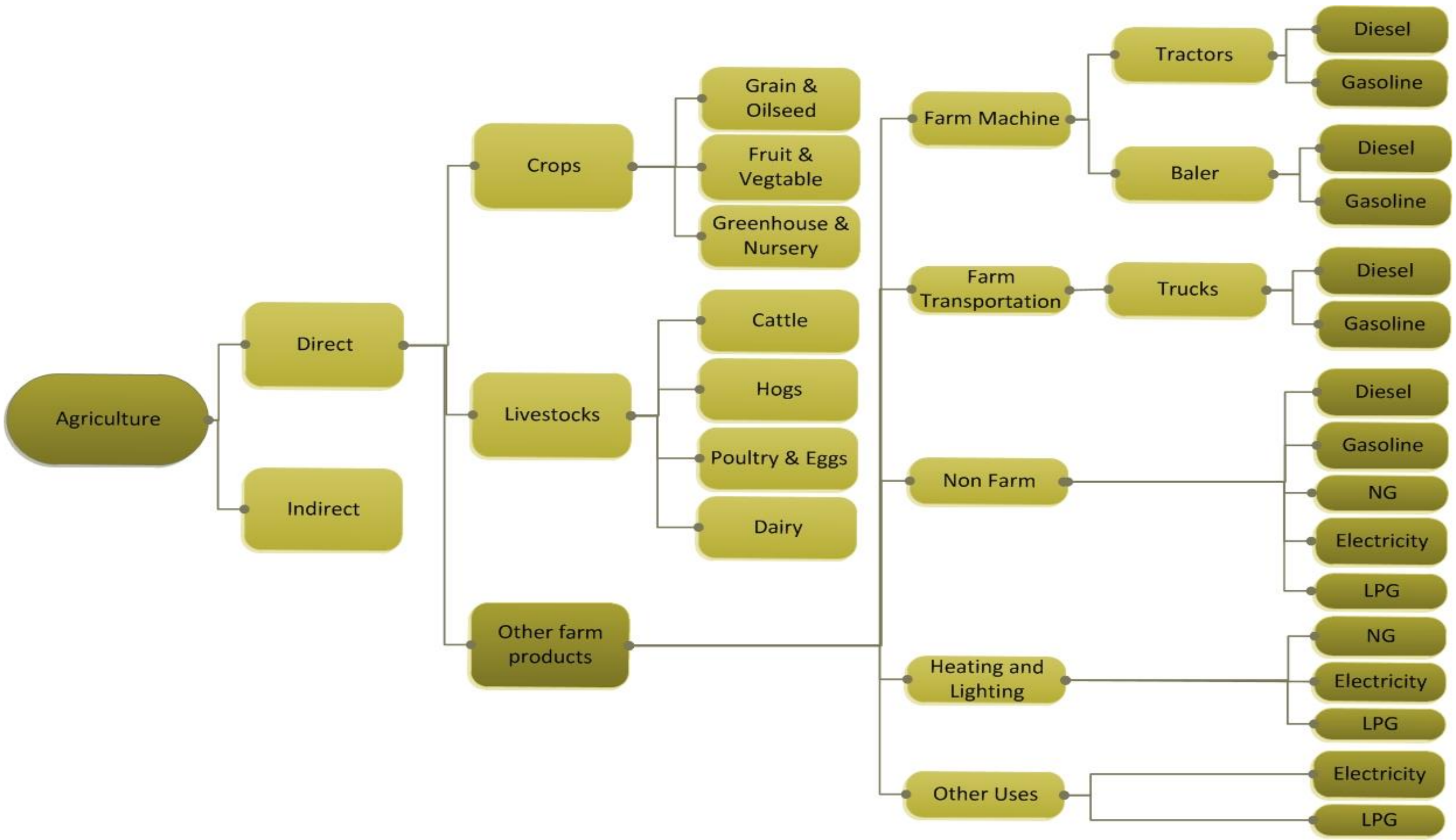


Figure 2-8: The "other" subsector

The demand tree for Alberta's agriculture sector consists of four key aspects: activity levels, final energy intensity, demand cost, and environmental loading factors. The activity levels include total production for each sector and its subsector, and the ratio of kilometer per tonne production of related sectors for farm transport activities. The final energy intensity consists of energy use intensity, which has an end-use energy demand expressed as per unit of the sector parameter, i.e., MJ/Km for farm truck and MJ/tonne for all other sectors. Table 2-1 illustrates the various parameters for Alberta's agriculture sector demand tree, which was derived from the provincial Agriculture Statistics Yearbook and Statistics Canada in 2009.

Table 2-1: Alberta's agriculture demand module for the base year 2009

Sector	Subsector	Characteristics	
Crop		14.85 million (tonne)[a],[b]	
	Grain & oilseed	14.81 million (tonne)[a],[b]	0.77 (km/T)[c]
	Fruits & Vegetables	20 thousands (tonne)[a],[b]	7.23 (km/T)[c]
	Greenhouse & Nursery	17 thousands (tonne)[a],[b]	14.7 (km/T)[c]
Livestock		3.57 million (tonne)[a],[b]	
	Cattle	2.72 million (tonne)[a],[b]	7.40 (km/T)[c]
	Hogs	61 thousands (tonne)[a],[b]	19.5 (km/T)[c]
	Poultry & eggs	106 thousands(tonne)[a],[b]	7.37 (km/T)[c]
	Dairy	678 thousands (tonne)[a],[b]	1.75 (km/T)[c]
Other		Production eq. Crop and	0.45(km/T)[c]

[a] Statistics Canada, 2012

[b] Agriculture Statistics Yearbook, 2009

[c] Kilometer per tonne is the unit of measure of farm transportation that represents the transportation of one tonne of product of each subsector over its total distance traveled.

For each type of energy, the share of energy use in Alberta's agriculture sector is provided by data from Natural Resources Canada (Natural Resources Canada, 2012c). In 2009, the share of energy use for gasoline, diesel, natural gas, electricity, and LPG were 20%, 48.4%, 10.9%, 20.2%, and 0.5%, respectively(Natural Resources Canada, 2012c). The total amount of energy consumption was 42 PJ in 2009 (Natural Resources Canada, 2012c). The share of each type of energy for a particular year of a ten-year period (2000 to 2009) is depicted in Table A-1 in Appendix A.

Each usage type (e.g., truck and auto, heat and light, farm machine, non-farm machine, and other) has a particular share of energy type in Alberta's agricultural sector and is given in Natural Resources Canada's report for the year 2000 (Khakbazan, 2000). For example, in Table 2-2 the share of gasoline in the farm truck section is 59% of the total gasoline used and the share of diesel is 8.7% of the total diesel used in Alberta's agriculture sector in 2009 (Khakbazan, 2000). However, electricity, NG, and LPG do not have any share in this category. The ten-year historical data of the usage and energy types are shown in Tables A-2 to A-10 in Appendix A.

Table 2-2: The amount of energy type (TJ) in various usage types in Alberta agriculture, in 2009

Usage type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm truck	4,961	1,770	0	0	0	6,731
Heat & Light	0	0	2,062	4,012	67	6,141
Farm machine	1,766	18,207	0	0	0	19,973
Non-Farm machine	1,682	370	2,520	3,341	57	7,970
Other uses	0	0	0	1,140	86	1,226
Total	8,409	20,347	4,582	8,493	210	42,041

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table 2-3 shows the total amount of product and total energy used for each farm activity (farm type) in 2009. These data were collected from Statistic Canada and Alberta's Agriculture Statistics Yearbook for 2009 and then calculated by using the share of energy used in each category based on Natural Resources Canada's data for 2000 (Khakbazan, 2000). The ten-year historical data of the total product and energy use are shown in Tables A-11 to A-19 in Appendix A.

Table 2-3: Total energy use and total product for particular farm types in 2009

Sector/subsector	Total product(Tonne)	Total energy(TJ)
Grain & oilseed	14,817,800	12,327
Dairy	678,814	1,678
Cattle	2,726,500	19,588
Hog	61,200	1,835
Poultry & eggs	106,746	1,188
Fruit & vegetable	20,276	301
Greenhouse & nursery	17,717	592
Other	14,855,806	4,530
Total	18,429,053	42,041

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012a; Statistics Canada, 2012)

Similarly, the share of energy used in each usage type within a farm type was collected from Natural Resources Canada's final report for the year 2000 (Khakbazan, 2000). For instance, the share of energy used in dairy activities is described as follows:

- Trucks consume 2.84% of the total energy used in Alberta's agriculture truck subsector
- Heat and light consume 6.22% of the total energy used in Alberta's agricultural heat and light subsector

- Farm machinery consume 3.98% of the total energy used in Alberta's agricultural farm machinery subsector
- The non-farm sector consumes 2.84% of the total energy used in Alberta's agricultural non-farm subsector
- The "other uses" subsector consumes 6.85% of the total energy used in Alberta's agricultural other uses subsector

The amount of energy use (in TJ) for this example and all of Alberta's agricultural categories are provided in Table 2-4.

Table 2-4: Total energy use (TJ) by farm use for a particular farm type in 2009

Sector/subsector	Trucks	Heat &light	Farm mach.	Non-farm mach	Other uses
Grain & oilseed	1,846	994	7,317	1,882	287
Dairy	191	382	795	226	84
Cattle	3,245	1,805	10,496	3,573	469
Hog	192	629	671	318	24
Poultry & eggs	126	730	146	155	30
Fruit & vegetable	24	43	134	76	24
Greenhouse/nursery	42	238	36	258	18
Other	1,065	1,318	378	1,480	289
Total	6,731	6,141	19,972	7,970	1,226

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012a; Statistics Canada, 2012)

In this study, the energy intensity of each usage type except farm trucks is calculated by dividing the total energy used (MJ) in that particular usage type by the total amount of production (tonnes). The energy intensity of farm trucks is calculated by dividing the total energy use by the amount of driven distance in kilometers. More details about how these energy intensities are calculated will be provided in the next section.

2.4.1.1 Energy intensity

In this study, input data were collected from various reports and CANSIM tables provided by Statistics Canada and Natural Resources Canada. Energy intensity is developed based on the averages of energy intensity over ten years (2000-2009) and projected for 42 years (2009-2050).

Many factors affect the energy intensity of on-farm activities, e.g., product, share of total output, energy price, technological advancement, capacity of farm, etc. The energy intensity for Alberta's agriculture model is calculated based on three main factors: the amount of energy used, the total product produced, and the total distance driven in each particular farm transport section. More precisely, energy intensity of all subsectors except the farm truck subsector is defined as the amount of energy used in a subsector to produce a unit of product in that subsector, which can be calculated by dividing the total energy use of the subsector by the total product produced in that particular subsector. For farm trucks, the energy intensity is defined as the overall amount of energy used for transporting a unit of production in the subsector, divided by the total distance traveled in kilometers for transportation. It is important to note that this energy intensity, called energy use intensity, is different from the energy intensity of the equipment advertised by manufactures. In the rest of this study the energy intensity refers to energy use intensity. The majority of the share of energy use in each farm type, usage type, and energy has been taken from Natural Resources Canada's data (Khakbazan, 2000). Indeed, the main assumption of this study is that all shares of energy use remain the same in all activities except farm machinery, farm transportation, and non-farm activities of the three main farm categories: grain and oilseed, cattle, and "other." It was found that farm machines are the largest agricultural energy consumption equipment followed by farm truck and non-farm machines.

2.4.1.2 Energy use in farm machines

Farm machinery in agricultural activities has a big role and accounts for the majority of energy consumption in farm activities. More than 50% of energy use in farm activities is from farm machinery (Khakbazan, 2000). But if we consider Alberta's agriculture sector as a whole, cattle farming has the highest total energy use for all end uses followed by grain and oilseed farming (Khakbazan, 2000).

According to Natural Resources Canada's data, the percentage of energy used in farm machinery for grain and oilseed, cattle, and other categories is about 91%, and the rest is spread over dairy, hogs, poultry and eggs, fruit and vegetable, and greenhouse and nursery (Khakbazan, 2000). Moreover, it can be safely assumed that the percentage of energy used by farm machinery in all other categories remains the same from the years 2000 to 2009. On the other hand, the percentage for the three dominant categories should be calculated dynamically throughout the model to achieve the best estimations. The following three sections describe how the percentage of energy use in farm machinery is calculated for grain and oilseed, cattle and "other."

a) Farm machinery energy use in grain and oilseed

The energy consumed in this category is proportional to the amount of product produced and yield (the dry volume of product produced in bushels per acre). However, the relationship between energy consumption and yield is the other way around. That is, yield is an indicator of how much product is produced per acre, thus the higher the yield, the less the farm machines need to move, which results in less energy use.

In order to put this premise into a mathematical formula, the year 2000 was set and the percentage of energy use for 2000 was taken from Natural Resources Canada's data as the base year for calculating the share of energy use in this section (Khakbazan, 2000). Afterwards, for the years following 2000, the share of energy use follows the equation:

$$percentage\ of\ energy_n = percentage\ of energy_{2000} \times \frac{product_n}{product_{2000}} \times \frac{yield_{2000}}{yield_n}$$

where n is the year.

This equation can also be derived using a different approach. As mentioned above, the energy use has a direct relation to the amount of production and has an inverse relation with yield. Thus, the energy use is related to the ratio of the amount of product produced divided by yield as shown below:

$$energy_n \approx \frac{product_{\ n}}{yield_n}$$

Therefore, the percentage of energy used in year n can be calculated by comparing the above ratio with the year 2000:

$$percentage\ of\ energy_n = percentage\ of\ energy_{2000} \times \frac{ratio_n}{ratio_{2000}}$$

Where $ratio_n$ is:

$$ratio_n = \frac{product_n}{yield_n}$$

If the percentage of farm machinery energy use in grain and oilseed is known for 2000, then the above formula can be used to calculate the percentage of farm machinery energy use in grain and oilseed for the following years. As mentioned earlier, the percentage of energy use in this category for the year 2000 compared to farm machine energy use in other categories is given in Natural Resources Canada's data (Khakbazan, 2000). Thus, one can calculate the percentage and total energy use for all other years.

After calculating the total farm machine energy use in the grain and oilseed subsector, the next step for calculating the energy intensity is to calculate the percentage of energy used by diesel or gasoline farm machinery. From Natural Resources Canada's data, we know how much diesel or gasoline is used in farm machinery. According to the Natural Resources Canada's report, 90.2% of energy use belongs to diesel farm machinery and the remaining 9.8% is used by gasoline farm machines (Khakbazan, 2000).

The farm machinery includes the variety of agricultural machines and equipment and has been divided into subsectors. The number of farm machine types (e.g., tractor, baler, combine) and their use in on-farm activities were taken from Statistics Canada's CANSIM table 004-0011 (Statistics Canada, 2011b). Using these data in combination with the unit energy use per type of farm machine, which is given in the Farm Machinery Custom and Rental Rate Guide, it is easy to calculate the percentage of farm machine type (MAFRI, 2012). For example, in grain and oilseed products, 80% of farm machine energy is consumed by tractors and their use, while the remaining energy is used by grain combines. Table A-20 in Appendix A shows the share and the type of farm machinery in other sections of Alberta agriculture. All of the data mentioned above and in Table A-20 are taken from Natural Resources Canada's data, the Farm Machinery Custom and Rental Rate Guide, and Statistics Canada (Khakbazan, 2000; MAFRI, 2012; Statistics Canada, 2011b).

b) Farm machine energy use for cattle

The energy intensity for this category is calculated as MJ per head count, where head count is the total number of cattle, and is converted to MJ/tonne to make it consistent with other energy intensities in Alberta's agricultural energy model. The percentage of farm machine energy use in this section is calculated by considering two factors: head count and the number of livestock slaughtered. One of the best possible ways to formulate these two factors is to calculate the ratio of the two and compare it with our base year. As explained in the previous section, the year 2000 was set as the base year and the percentage of energy use for this year is given by Natural Resources Canada's data (Khakbazan, 2000). Then, the percentage of energy use for the following years can be derived using the following formula:

$$percentage\ of\ energy\ used_n = \frac{ratio_n}{ratio_{2000}}$$

where n is the year, and $ratio_n$ is calculated by:

$$ratio\ _n = \frac{number\ of\ head\ count_n}{number\ of\ slaughtered_n}$$

c) Farm machine energy use in the "other" subsector

This section corresponds to "other" activities (e.g., cultivation, baler, the grain etc.) in the grain and oilseed category, thus the same procedure that is used in grain and oilseed was adopted to calculate the percentage of energy use here.

In Alberta's agriculture sector, the type of farm machine depends on on-farm activities. The main operating farm machines in the "other" section are the cultivator tractor and baler with shares of 89% and 11%, respectively. The share of energy use for all farm machine types in the "other" section depends on two factors: the number of farm machines and the unit energy use per farm machine. The total number of tractors and balers is given in Statistic Canada's CANSIM table 004-0011, and the unit energy use per tractor and baler is given in the Farm Machinery Custom and Rental Rate Guide (Khakbazan, 2000; MAFRI, 2012; Statistics Canada, 2011b). During our study we found that the tractor is the most common farm machine used in all other sections (i.e., fruit and vegetable, greenhouse and nursery, cattle, hogs, poultry and eggs, dairy).

2.4.1.3 Energy use in the non-farm subsector

The method for calculating the share of energy use in the non-farm subsector of each category is very similar to that used for farm machinery. According to Natural Resources Canada's data, more than 87% of energy used in non-farm is consumed in three categories: grain and oilseed, cattle and "other." Thus, the same procedure as was used in farm machinery was followed in which the percentage of non-farm energy use in grain and oilseed, cattle, and "other" was calculated dynamically to achieve the best estimation. However, the percentage of the rest of the categories was assumed to be constant across all years.

a) Non-farm energy use in the grain and oilseed and “other” subsectors

For the non-farm grain and oilseed and “other” categories, energy intensities were determined similarly to the method used to determine farm machinery energy use. In other words, the energy use of non-farm machinery is related to the amount of product produced and yield. The same procedure was used to calculate the percentage of farm machine energy use.

b) Non-farm energy use in cattle

The energy intensity of non-farm machinery was also calculated as MJ per head count where head count is the total number cattle. However, logically the percentage of energy used in this category can be only related to the total number of head. Therefore, the energy intensity is converted from MJ/head count to MJ/tonne. Similar to the previous sections, the year 2000 was chosen as the base year. The following formula shows how the percentage of energy use in year n can be derived from the percentage of year 2000.

$$percentage\ of\ energy_n = percentage\ of\ energy_{2000} \times \frac{head\ count_n}{head\ count_{2000}}$$

The non-farm subsector has different subsectors in crop and livestock. The crop subsector includes grain and oilseed, fruit and vegetable, greenhouse and nursery. It is further subdivided into two subsectors: irrigation and non-farm use. In the livestock section, non-farm is divided into various devices and end uses according to the type of product.

<u>Non-farm in crops</u>

Irrigation and non-farm use are the two subsectors in the crop subsector. Irrigation is one of the main-energy consuming activities in crop production. In Alberta’s agriculture sector, a low-pressure centre pivot (LPCP) and a high-pressure centre pivot (HPCP) with electric power pump are the primary irrigation methods (Goverment of Alberta, 2012b). According to the annual Alberta Irrigation Information report, electrical and natural gas irrigation are the most common types of irrigation system; 51% of agricultural land in Alberta was irrigated by electrical irrigation and 29.5% by natural gas irrigation (Goverment of Alberta, 2012b). Less than 4% of the energy use in irrigation in Alberta was diesel and LPG (Goverment of Alberta, 2012b). In our study, only electricity and natural gas were chosen under the irrigation branch; they cover 80% of the energy used for irrigation in Alberta.

The amount of energy used for irrigation for grain and oilseed, fruit and vegetable, and greenhouse and nursery depends on the acres irrigated on each subsector of crop section. However, data are limited for 2009, so we have assumed that the extent of irrigated land is same for both 2009 and 2011, as reported in Alberta's Agriculture Statistics Yearbook of 2011. Total acres irrigated in all three subsectors are shown in Table 2-5.

Table 2-5: Total acres irrigated in Alberta in 2011

Irrigated Farm Type	Irrigated Area (Acre)
Irrigation	1,241,411
Irrigated field crops	908,441
Irrigated hay and pasture	314,423
Irrigated vegetable	7,606
Irrigated fruit	638
Other irrigated areas (nursery, sod, etc.)	10,303

Source: (Goverment of Alberta, 2012, 2012b)

The average energy use for the electric pump in pressure centre pivot irrigation systems is 14.6 KWh per acre and the natural gas use is 0.30 GJ per acre (AG Canada, 2011).

Non-farm in livestock

The non-farm cattle and hog subsector is divided into two subsectors: cattle and hog activities and non-farm uses. Further, cattle and hog activities or equipment consists of ventilation and material handling devices powered by electricity. The non-farm poultry and eggs subsector consists of non-farm uses and poultry and eggs activities or equipment, which includes ventilation, material handling, and egg cooling systems. All end uses in poultry and eggs activities are driven by electricity.

The last section in the livestock category is dairy. The non-farm subsector dairy category is divided into two subsectors: dairy activities or equipment and non-farm uses. Ventilation, vacuum pump, manure handling, feeding equipment, and milk cooling are the dairy activity subsectors. The shares of electricity used in livestock activities or equipment are derived from a publication of Alberta's Agriculture and Rural Development Department and several other reports and studies (Goverment of Alberta, 2012a; Ludington & Johnson, 2003; Rhodes et al., 2009). Figure 2-9 shows the share of electricity use in Alberta's dairy section. Further, the shares of electricity use for other livestock activities or equipment are shown in Table A-21 in Appendix A.

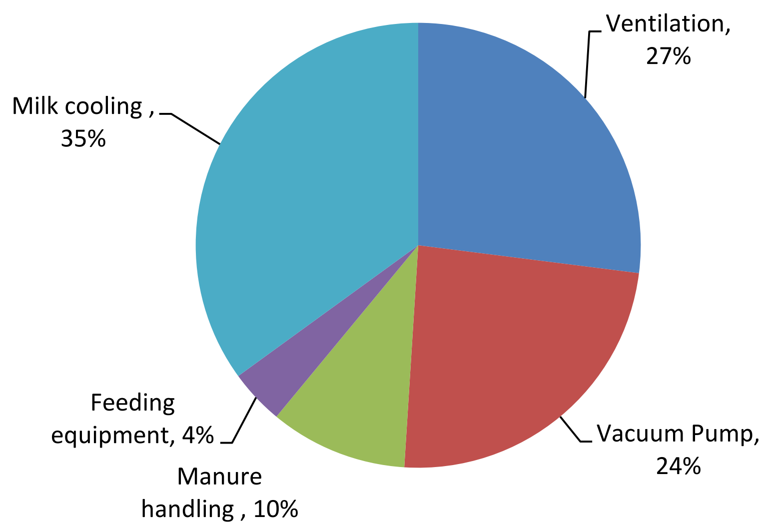


Figure 2-9: The shares of electricity use in Alberta's dairy subsector (Goverment of Alberta, 2012a; Ludington & Johnson, 2003; Rhodes et al., 2009)

2.4.1.4 Energy use in farm trucks

The crucial factor for improving agricultural productivity is farm transportation. Hence, the energy use in farm transport is one of the main components of energy consumption in all sections of the agriculture sector. The energy intensity of farm trucks is calculated as MJ per kilometer:

$$percentage\ of\ energy_n = percentage\ of\ energy_{2000} \times \frac{Kilometer_n}{kilometer_{2000}}$$

where n is the year.

The total number of kilometers driven by farm trucks is given in CANSIM table 405-0008 from Statistics Canada. In this table, trucks are divided into three categories: under 4.5 tonnes, between 4.5 to 15 tonnes, and over 15 tonnes. In Alberta's agriculture sector, the most common type of farm truck is assumed to be between 4.5 and 15 tonnes. This type of truck is chosen to represent the trucks used in farm transportation. Moreover, not all trucks between 4.5 to 15 tonnes are used in agriculture; thus, it was assumed that only between 10 and 20 percent of the total distance traveled by these types of trucks corresponds to farm activities

(Statistics Canada, 2010). It is assumed that in the base year (2000) only 16% of trucks were used for farm activities. This percentage is based on a report of truck activities in Canada (Transport Canada, 2003). It is a noteworthy observation that the percentage of kilometers driven in agriculture activities in a particular year is related to the ratio of energy use of farm trucks and the total kilometers driven in that year. One can use this information to compute the percentage of kilometers driven in farm activities for the years following 2000 based on the percentage for the year 2000. In other words, the increase in energy use of trucks in agriculture activities for a particular year suggests that the kilometers driven increased in that year; however, the percentage of the increase depends on the changes in kilometers driven in that year. The following formula is used to calculate the percentage of kilometres driven:

$$percentage_n = percentage_{2000} \times \frac{ratio_n}{ratio_{2000}}$$

where n is the year and $ratio_n$ is:

$$ratio_n = \frac{energy_n}{kilometer_n}$$

2.4.1.5 Energy use in the "other uses" subsector

Between 2000 and 2009, an average of 2.1% of the total energy used per year in Alberta's agriculture sector was consumed in the "other uses" subsector (Khakbazan, 2000). This amount of energy used was distributed among the eight categories (e.g., grain and oilseed, fruit and vegetable, greenhouse and nursery, etc.), which makes the energy used in each category negligible compared to the total energy use in that category. Thus, it is assumed that the percentage of energy used in each category in the "other uses" section is the same for the ten-year period 2000 to 2009. The share of energy use of all categories in the "other uses" section in 2000 is given in Natural Resource Canada's data (Khakbazan, 2000).

2.4.1.6 Energy intensity in heat and light

On average, 11% of the total energy used per year in Alberta's agriculture is consumed in the heat and light subsector (Khakbazan, 2000), which is considerably less than the energy used in other activities such as farm machinery, non-farm, and farm truck. Moreover, this amount of energy used was distributed among the eight categories in our model, which makes it even less important in the total energy use in the agriculture sector. The percentage of energy use of each category in the heat and light section, from 2000 to 2009, was assumed to be the same as the base year, i.e., 2000.

The energy use in the heat and light subsector in both the crop and "other" categories is less important than in livestock, thus the heat and light subsector of the crop and "other" sections have not been divided into subsections. The heat and light subsector in the livestock subsector is further studied under separate headings, namely the heating subsector and the lighting subsector. The share of energy use (i.e., electricity) in these two sections for the year 2000 is given in several reports and studies (Ludington & Johnson, 2003; Rhodes et al., 2009). All of the shares of energy use in lighting and heating in the livestock subsector are shown in Table A-22 in Appendix A.

2.4.1.7 Alberta agriculture's energy model and validation

In the previous sections, the approaches for calculating the energy intensities of various farm activities were discussed. Using these approaches, the energy intensities for the ten-year period 2000 to 2009 were calculated. Afterwards, the agriculture sector energy model for Alberta was developed by taking the average of the energy intensities as the final energy intensities. The model estimates the energy use of each year by taking the amount of production and the kilometers driven in that year as the input and calculating the average energy intensities through them using a bottom-up approach of estimation.

In order to validate the model, the energy use and GHG emissions estimate for the years 2000 to 2009 from the LEAP model were compared to the actual energy use, taken from Statistics Canada and Natural Resources Canada, as shown in

Figure 2-10 and Figure A-6, respectively. As it can be observed from the figure, the model is capable of capturing the trend of energy use. For instance, there is a drop in energy use from years 2000 to 2002 and from 2008 to 2009, and the model's estimate closely followed the actual drop in the energy use. Moreover, the percentage difference between the estimated energy use and the actual energy use, called the estimated error, stays fairly low, with a maximum of 4% in the year 2000 and an average of 2%.

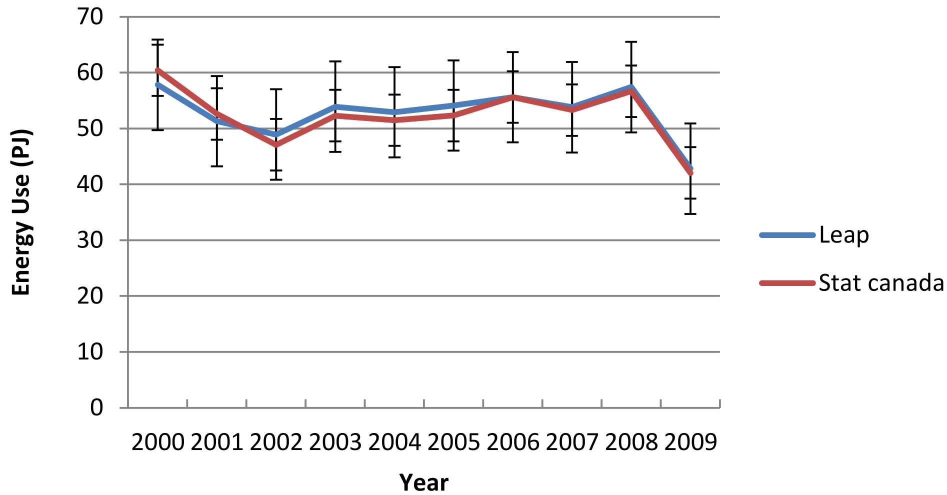


Figure 2-10: The ten-year energy-use trend in Alberta agriculture

2.4.2 Demand sector – reference case

2.4.2.1 Growth rate and outlook of energy: 2009-2050

In Alberta's agriculture model, the business-as-usual scenario is called the reference scenario and is developed for a 42-year period (from 2009 to 2050). The input data, the amount of production, and the total distance traveled of each year for the reference scenario for Alberta's agriculture energy demand are estimated based on Statistics Canada (Statistics Canada, 2012), Natural Resources Canada (Natural Resources Canada, 2012c), and Crops and Livestock Productivity Growth in the Prairies (Stewart et al., 2009).

a) Population growth rate in the province of Alberta

Alberta's population is expected to have a 1% growth rate annually based on reports from Natural Resources Canada and Statistic Canada (Natural Resources Canada, 2006; Statistics Canada, 2012). Thus, Alberta's population, which was 3.37 million at the beginning of this study, i.e. 2009, is expected to grow to 5.1 million by the end of study, 2050. Table 2-6 shows the population growth in Alberta during the study period.

b) Increase in GDP in the agricultural sector

The growth rate of GDP in Alberta's agriculture sector is expected to be 3% per year during the 42-year period from 2009 to 2050 (Natural Resources Canada, 2012a). By the end of study period the change in GDP is expected to be 11.5 million as shown in Table 2-6.

Table 2-6: Growth rate for Alberta's agriculture model reference case scenario (2009-2050)

Year	2009	2015	2020	2030	2040	2050
Population (million)	3.37	3.60	3.80	4.20	4.60	5.1
Agriculture (million CDN GDP)	3.41	4.10	4.70	6.30	8.50	11.5
Agriculture-crop (million tonne product)	14.85	17.5	20.1	26.6	35.1	46.3
Agriculture-livestock (million tonne product)	3.57	4.00	4.40	5.20	6.30	7.50

Source: (Natural Resources Canada, 2006; Statistics Canada, 2012; Stewart et al., 2009)

c) Increase in agricultural sector production

Output products in agriculture are one of the input data for Alberta's agriculture energy model. Thus, in order to estimate energy consumption for 42 years, the output productivity growth rate is needed for that period of time. It is important to note that output growth is different from total factor productivity (TFP) growth. Output growth is the total increase in the output, whether the increase is caused by input growth or any other factor. However, TFP growth is the output growth that is not caused by input growth (Stewart et al., 2009). More precisely, TFP growth is caused by technical changes, scale effects, and changes in the degree of efficiency (Stewart et al., 2009). Technical changes refer to advancement in physical technologies and innovation in the knowledge base. Scale effects refer to the fact that under some circumstances the additional increase in output requires "less than proportional increase in input" (Stewart et al., 2009). Finally, changes in the degree of efficiency are changes in which resources are used more efficiently by using the present knowledge (Stewart et al., 2009).

There was an exhaustive study on calculating the output growth rate and the TFP growth rate in the prairie provinces between 1940 and 2004 (Stewart et al., 2009). In addition, the paper calculated the crops and livestock growth — either the output growth or the productivity growth — separately, because the growth between these two sections may vary significantly (Stewart et al., 2009). In general, the growth in agriculture output is different in the crop and livestock sections. The overall output growth in Alberta agriculture was 2.81% and 1.84% for crop and livestock, respectively, during the historical 60-year period (Stewart et al., 2009).

For our estimate of energy consumption in the next 42 years, it is assumed that the output growth will follow the same pattern, meaning that the output growth rate stays the same. Consequently, the historical growth rate mentioned in the previous paragraph is used for the next 42 years (2009 to 2050) for modeling Alberta's agriculture energy demand.

2.4.3 The transformation sector

In the LEAP model, the transformation sector simulates the process of converting and transporting energy types from the withdrawal of imported fuel or primary resources all the way to end-use fuel consumption, i.e., using fuel for energy generation or fuel combustion.

The general structure of a transformation analysis consists of one or more processes that are subdivided into input and output processes. Each process represents one of the three following procedures: the conversion of energy from one type to another, the transmission of energy, and the distribution of energy. Each process should have the characteristic data of that procedure such as capacities, efficiencies, capacity factors, capital cost, and operating and maintenance costs (Stockholm Environment Institute, 2011).

In transformation module, the final secondary fuel production is controlled by the final requirement set (e.g, domestic and export requirement set) determined by the demand program and the transformation efficiency of the process. Hence, the imported fuel is always controlled by the transformation module.

Moreover, the efficiency of each process can be determined by the following ratio:

$$Efficiency\ of\ a\ process = \frac{E_{output\ fuels}}{E_{feedstock\ fuels}}$$

where $E_{output\ fuels}$ and $E_{feedstock\ fuels}$ is the total energy content of all output fuels and feedstock fuels produced respectively (Stockholm Environment Institute, 2011).

2.4.3.1 The transformation sector in Alberta's agriculture model

Alberta's agriculture energy model is an energy demand model, where the transformation module mostly consists of energy conversion sectors such as electricity generation, oil refining, crude oil production, and coal mining. Each of these processes may include one or more feedstock fuel (e.g., natural gas, coal, crude oil) and optionally one or more auxiliary fuel. All these fuels are used during the production of some secondary fuel. In feedstock fuels, the fuels convert within the process itself, and the output fuel is the final demand of the demand sector excluding the transmission losses. The transformation sector for Alberta's agriculture model was borrowed from an earlier study (Subramanyam, 2010).

2.4.4 The resource sector

Alberta's agriculture resource sector consists of two major resources: primary resources and secondary fuels. The data for resources that are either produced domestically or imported are stored under the primary resources.

In Alberta's agriculture sector model, the base year reserves of fossil fuels and the maximum annual available yield of renewable energy are specified under the resource sector. The input data along with their details are described in the following sections.

2.4.4.1 Primary resources

The primary resources in Alberta's agriculture sector model consist of the base year (2009) reserve, addition to reserve, resource imports and exports, and the cost of related data.

2.4.4.2 Secondary resources

In Alberta's agriculture sector energy model, the secondary fuels (e.g., electricity, steam, gasoline, diesel, etc.) specified by the transformation and demand sectors are included in the secondary resource sector. Secondary fuels are used by all end users in Alberta's agriculture sector.

2.4.5 Environmental inputs and emission factors

The LEAP model has been used to estimate the emissions of major pollutants in the reference scenario. The environmental emission factors are built in the Technology and Environmental Database (TED). TED was used for data on environmental holding.

2.4.5.1 Environmental data inputs for the demand sector

TED has an extensive industry technology list, and each technology has detailed data on emissions per unit of fuel consumed. In the energy demand sector, TED has various technology lists for fuel and electricity that are the end use of different sectors: households and services, industry, transport, and agriculture. Each sector includes several subsectors, as described below:

- The households and services sector, which is further classified into cooking, lighting, appliances, water heating, building shells, space conditioning, and other end uses.
- The industry sector with subsectors such as iron and steel, aluminum, cement, paper and pulp, chemicals, and rural industries.
- The transport sector, classified into four major modes: road, rail, air, and water
- The agriculture sector, consisting of water pumping and farm machinery.

In Alberta's agriculture sector energy model, the environmental data and demand side technology information for farm machine and farm truck were derived from the agriculture and transport sectors of TED. IPCC Tier 1 and Tier 2 default emission factors of the agriculture sector were used for the heating and irrigation sector and farm machinery, respectively. IPCC Tier 1 default emission factors of the road transport sector are used for the farm transport.

2.4.5.2 Environmental data inputs for the transformation and resource sectors

The energy transformation data were represented as different technologies lists in TED with the capability of customization based on the region. For example, by default LEAP has a set of data for emission factors from South Africa in the case of oil refining. However, for Alberta's agriculture sector energy model, TED was changed based on data from Canadian refineries.

In the energy model for agriculture in Alberta, the environmental input data for the demand sector were developed in this study as discussed in the previous section; however, the environmental input data for the transformation and resource sectors were borrowed from the earlier study (Subramanyam, 2010).

2.5 Results and discussion

2.5.1 Demand sector

The end-use energy consumption data in Alberta agriculture clearly illustrate the demand patterns of energy. Figure 2-11 shows the distribution of primary and secondary energy consumption by end uses in Alberta's agriculture sector in 2009.

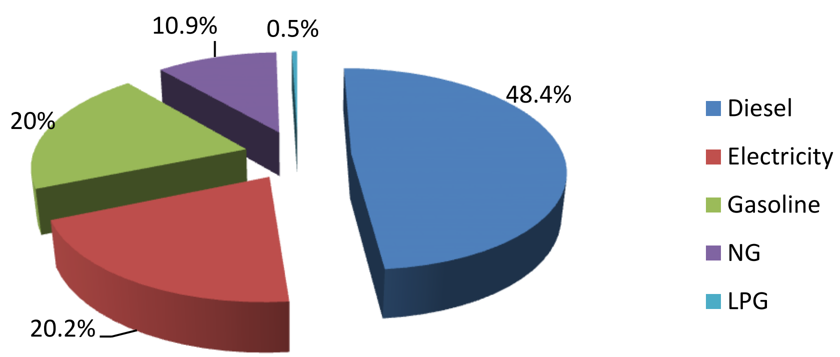


Figure 2-11: The distribution of primary and secondary energy in Alberta agriculture, 2009

2.5.1.1 Energy demand – base case

The energy demand model for Alberta's agriculture sector developed in this study is based on agricultural production and operation. The overall energy demand of Alberta's agriculture sector energy model for the base year 2009 developed by LEAP is shown in Table 2-7.

Table 2-7: Alberta energy demand — base case

Demand sector/subsector	Base year 2009 (TJ)
Agriculture-Crop	14,201
Agriculture-Crop-Grain & Oilseed	13,351
Agriculture-Crop-Fruit &Vegetable	191
Agriculture-Crop-Greenhouse & Nursery	660
Agriculture-Livestock	24,164
Agriculture-Livestock- Cattle	19,426
Agriculture-Livestock-Hog	1,571
Agriculture-Livestock- Poultry & Eggs	1,237
Agriculture-Livestock-Dairy	1,929
Agriculture-Other	4,254
Total Alberta Agriculture	42,618

As developed by the LEAP model

In the 2009 LEAP model, diesel fuel oil and motor gasoline had the highest use at 23.4 PJ and 6.9 PJ, respectively. The remainder of energy use in Alberta agriculture is divided between electricity at 5.9 PJ, natural gas at 6.1 PJ, and LPG at 0.3 PJ. Table 2-8 shows the details of primary and secondary fuels in the various demand sectors.

Table 2-8: Alberta's agriculture energy demand – base case fuel use (TJ)

Sector/subsector	Diesel	Electricity	Gasoline	LPG	NG
Crops	9,096	1,512	1,907	66	1,620
Grain & Oilseed	8,930	1,255	1,770	56	1,340
Fruit & Vegetable	94	34	31	2	30
Greenhouse & Nursery	72	223	106	8	250
Livestock	13,624	3,114	4,069	131	3,226
Cattle	11,672	2,028	3,489	90	2,147
Hog	683	320	214	11	343
Poultry & Eggs	217	443	117	15	445
Dairy	1,051	322	249	16	291
Other	708	1,281	910	56	1,298
Total	23,427	5,906	6,886	253	6,145

As developed by the LEAP model

a) Crops

Within the crop subsector, grain and oilseed consume most of the energy, with a total energy demand of 13.4 PJ for the year 2009 as shown in Table A-23 in Appendix A. The fruit and vegetable category has the second highest energy consumption followed by greenhouse and nursery. The details of energy demand for these two subsectors are given in Tables A-24 and A-25 in Appendix A.

b) Livestock

Within the livestock subsector, the cattle subsector has the highest energy demand, 19.4 PJ out of total 24.2 PJ, for the base year 2009. After the cattle subsector, dairy, followed by the hog subsector and the poultry and egg subsector have 1.9 PJ, 1.6 PJ, and 1.2 PJ energy demand, respectively. The details are given in Tables A-26 to A-29 in Appendix A.

c) "Other"

The total energy demand for the "other" subsector is 4.3 PJ. The details of energy consumption in "other" are given in Table A-30 in Appendix A.

2.5.1.2 Energy demand - reference scenario

According to Crops and Livestock Productivity Growth in the Prairies, the overall productivity in agriculture in Alberta grew at a rate of 1.56% per annum (Statistics Canada, 2012; Stewart et al., 2009). However, this growth rate does not indicate the individual growth rate of crops and livestock. Moreover, the results of growth rates for the past 60 years imply that the productivity growth of crops is considerably higher than that of livestock (Stewart et al., 2009). Thus, in the agriculture model for Alberta, the growth rate of agricultural products is taken from the trend of the past 60 years, 2.8% in crop and 1.8% in livestock (Stewart et al., 2009).

The overall growth in the agriculture energy demand in Alberta is expected to increase from 42.6 PJ to 108.5 PJ over the 42-year period from 2009 to 2050, as shown in Table 2-9. Consequently, it is expected that the consumption of all types of energy will increase during this period. More precisely, the consumption of diesel, the fuel used most in agriculture, is expected to grow from 23.4 PJ in 2009 to 59.3 PJ in 2050. Motor gasoline consumption is expected to increase from 6.89 PJ in 2009 to 17.37 PJ in 2050, while the consumption of electricity and NG will increase from 5.9PJ and 6.14 to 15.27 PJ and 15.9 PJ, respectively.

Table 2-9: The overall growth rate in energy demand in agriculture in Alberta (PJ)

Sector/subsector	2009	2020	2030	2040	2050
Crops	14.20	19.26	25.41	33.53	44.23
Grain & Oilseed	13.35	18.11	23.89	31.52	41.59
Fruit & Vegetable	0.19	0.26	0.34	0.45	0.59
Greenhouse & Nursery	0.66	0.89	1.18	1.56	2.05
Livestock	24.16	29.53	35.44	42.52	51.03
Cattle	19.43	23.74	28.49	34.19	41.02
Hog	1.57	1.92	2.30	2.76	3.32
Poultry & Eggs	1.24	1.51	1.81	2.18	2.61
Dairy	1.93	2.36	2.83	3.40	4.07
Other	4.25	5.77	7.61	10.04	13.25
Total	42.62	54.56	68.46	86.10	108.51

As developed by the LEAP model

2.5.1.3 Environmental module results for Alberta agriculture

2.5.1.3.1 Base case

In the base year 2009, total emissions from the agriculture sector in Alberta were about 2.58 MT of CO_2 eq. The CO_2 equivalents originate mainly from diesel, gasoline, and natural gas. Overall emissions from oil products (diesel and gasoline) in the demand sector in agriculture are about 2.22 MT of CO_2 eq. Farm machinery and farm transportation emit most of the GHG emissions. Table 2-10 shows the overall GHG emissions for the energy demand in agriculture from various types of energy for the base year 2009.

Table 2-10: The overall GHG emissions in agriculture in Alberta for various energy types (MT CO_2 eq.) in 2009

Sector/subsector	Diesel	Gasoline	LPG	NG
Crops	0.67	0.13	0.00	0.09
Grain & Oilseed	0.66	0.12	0.00	0.07
Fruit & Vegetable	0.01	0.00	0.00	0.00
Greenhouse & Nursery	0.01	0.01	0.00	0.01
Livestock	1.01	0.29	0.01	0.18
Cattle	0.86	0.25	0.01	0.12
Hog	0.05	0.02	0.00	0.02
Poultry & Eggs	0.02	0.01	0.00	0.02
Dairy	0.08	0.02	0.00	0.02
Other	0.05	0.06	0.00	0.07
Total	1.73	0.48	0.01	0.34

As developed by the LEAP model

2.5.1.3.2 Reference scenario

The GHG emissions in Alberta's agriculture sector are expected to increase due to production increases in different sectors of the demand module as well as increases in primary and secondary fuel consumption. Based on the LEAP model for the agricultural sector in Alberta, GHG emissions are expected to increase from 2.58 MT of CO_2 in 2009 to 6.55 MT of CO_2eq in 2050. As with the base case scenario, most of the GHG emissions come from the farm machinery and farm transportation subsectors.

Oil products, which include motor gasoline and diesel oil fuel, have the largest share in the total energy demand and contribute the maximum GHG emissions in Alberta's agriculture sector. During the 42-year study period, emissions come mainly from oil products in the reference scenario and are expected to almost double from 2.22 MT to 5.62 MT of CO_2eq. The details of GHG emissions in the reference scenario for each section of Alberta's agriculture sector are shown in Tables A-31, A-32, and A-33 in Appendix A.

2.5.2 Overall environmental results

2.5.2.1 GHG emissions – demand sector

The GHG emissions of Alberta's agriculture demand sector are expected to increase from 2.58 MT of CO_2 in 2009 to 6.55 MT of CO_2eq in 2050 in the reference scenario. The contribution of emissions for each Alberta agriculture demand sector is given in Table 2-11. Table A-34 in Appendix A shows the details of GHG emissions based on fuel use of Alberta's agriculture sector energy model.

Table 2-11: The overall growth rate in Alberta's agriculture emissions (MT CO_2 eq.)

Sector/subsector (MT CO_2 eq.)	2009	2020	2030	2040	2050
Crops	0.9	1.23	1.62	2.13	2.83
Grain & Oilseed	0.87	1.17	1.55	2.04	2.70
Fruit & Vegetable	0.01	0.01	0.02	0.03	0.03
Greenhouse & Nursery	0.03	0.04	0.05	0.06	0.09
Livestock	1.49	1.82	2.18	2.61	3.14
Cattle	1.24	1.51	1.81	2.18	2.61
Hog	0.09	0.10	0.13	0.15	0.18
Poultry & Eggs	0.05	0.06	0.07	0.09	0.11
Dairy	0.11	0.14	0.17	0.20	0.24
Other	0.19	0.26	0.34	0.45	0.60
Total	2.58	3.30	4.14	5.20	6.55

As developed by the LEAP model

2.5.2.2 GHG emissions – transformation sector

The GHG emissions from the energy conversion and transformation sector in Alberta are expected to increase from 24.74 MT of CO_2 in 2009 to 45.06 MT of

CO_2 eq in 2050. Table 2-12 shows the GHG emissions from Alberta's energy transformation sector in the reference case scenario.

Table 2-12: GHG emissions in the energy transformation sector reference scenario

Sectors (MT of CO_2 eq.)	2009	2020	2030	2040	2050
Electricity generation	1.55	1.69	1.74	2.18	2.84
NG and coal bed methane extraction	0	0	0	0	0
Alberta oil refining	6.56	6.7	6.86	7.06	7.31
Crude oil production	2.55	2.57	2.31	1.92	1.54
Synthetic crude oil production	0.02	0.08	0.13	0.18	0.22
Crude bitumen production	14.05	32.38	32.66	32.89	33.13
Coal mining	0.01	0.01	0.01	0.01	0.01
Total	24.74	43.42	43.70	44.25	45.06

As developed by the LEAP model

2.5.2.3 Total GHG emissions

Total GHG emissions from the energy demand and transformation sectors in the agricultural sector in Alberta are expected to increase from 27.32 MT of CO_2 in 2009 to 51.62 MT of CO_2 equivalents in 2050. These figures are shown in Table 2-13.

Table 2-13: GHG emissions in the agricultural demand and transformation sector – reference scenario for Alberta

Sectors (MT of CO_2 eq.)	2009	2020	2030	2040	2050
Demand	2.58	3.30	4.14	5.20	6.55
Transformation	24.74	43.42	43.7	44.25	45.06
Total	27.32	46.73	47.84	49.45	51.62

As developed by the LEAP model

In this chapter, the modeling methodology adopted to develop the end-use demand tree using the simulation tool LEAP was described. The structure and various modules of the LEAP model were explained. The demand tree for various end-use subsectors such as crops, livestock, and others under baseline and reference scenarios were shown. Eventually, the key results, based on the model's output, were presented. In chapter 3, the development of various GHG mitigation scenarios, along with the input data, key assumptions, and penetration rates of new technology for each scenario will be explained.

Chapter 3. Using the LEAP Model to Develop GHG Mitigation Scenarios for Alberta's Agriculture Sector

3.1 Introduction

The methodology for modeling energy demand in the agricultural sector in Alberta was presented in chapter two. It was shown that the developed model is capable of estimating energy consumption in the agriculture sector as well as the corresponding GHG emissions. The energy consumption and GHG emissions of the base year and the reference scenario were estimated using the model. In this chapter, various GHG mitigation scenarios for Alberta's agriculture sector will be introduced and evaluated using the model developed in the previous chapter.

Alberta's agriculture sector has the potential to provide the source of renewable biomass feedstock, which could contribute to reduce GHG emissions. In addition, the province of Alberta has a wealth of renewable energy resources including biofuel, wind, and hydro energies. According to the Government of Alberta, "it is in Alberta's best interests to be an aggressive early adopter of renewable energy" (Goverment of Alberta, 2008b).

Energy efficiency in the agriculture sector and rural regions has become a more prevailing nationwide problem. As part of Alberta's comprehensive GHG reduction obligations under its energy policy and strategies, the Government of Alberta has dedicated its focus on rural energy efficiency and taking measures to improve the efficiency of on-farm and ranch activities. Alberta's agriculture sector energy model developed in this study can contribute significantly by providing several alternative scenarios based on streamlining the implementation of GHG mitigation strategies.

The reductions in GHG emissions in Alberta's agriculture sector can be achieved by adopting novel tools, practices, and technologies. This chapter discusses the various GHG emission mitigation scenarios in Alberta's agriculture sector. The GHG emissions for various scenarios are estimated using Alberta’s agriculture sector emissions data, energy consumption, and the LEAP model.

Initially, a reference scenario was developed based on the business-as-usual situation. Afterwards, several GHG mitigation scenarios were developed based on the improvement of energy efficiency through implementation of various new technologies and renewable fuels in the Alberta’s agriculture sector. The total GHG emissions mitigation for each scenario is estimated and may serve as a guiding tool to develop best practices for energy demand side management in the agriculture sector. Based on technology penetration rates, scenarios are categorized into two types: slow technology penetration scenarios and fast technology penetration scenarios. Slow penetration scenarios assess the penetration of technologies from 2009-2050 assuming a slower rate of penetration per year; fast penetration scenarios assess the penetration of new technologies from 2009-2030 assuming a faster rate of penetration per year.

3.2 The development of a reference scenario for Alberta’s agriculture sector

A reference scenario, sometimes labelled as the baseline or the business-as-usual (BAU) scenario, includes all sectors and shows the effects of the current situation (e.g., energy intensities) on the trend of energy consumption based on specific assumptions of various growth factors. More precisely, the reference scenario is developed by assuming no additional changes in terms of policy and technology improvement (Stockholm Environment Institute, 2011). In the LEAP model, the effects of economic activities and technological choices on energy demand, environmental impacts, and primary energy resources are identified by the comparison of GHG mitigation scenarios with the reference scenario. The GHG mitigation scenarios are built based on a comprehensive accounting of environmental impacts and how energy is used, converted, and produced under a range of key assumptions, e.g., set of energy policies, macroeconomic conditions, population, and GDP growth.

3.3 The development of mitigation scenarios in the LEAP model

In the LEAP model, mitigation scenarios simulate and evaluate energy policy on meeting emissions reduction targets. They are compared against the backdrop of a reference scenario since it simulates the events taking place without any mitigation effort (Lazarus et al., 1998; Stockholm Environment Institute, 2012). Mitigation scenarios are self-consistent storylines of how an energy system might evolve over time and how GHG emissions can be reduced with respect to the reference scenario. The policy analysis in the LEAP model can create and evaluate alternate mitigation scenarios by comparing their energy requirements, environmental impacts, social costs, and benefits. The LEAP model can describe individual policy measures that can further be combined into alternative integrated scenarios. This approach can help to assess the marginal impact of an individual policy as well as the interactions that occur when multiple policies and measurements are combined (Lazarus et al., 1998).

GHG mitigation scenarios are estimated through two approaches: “bottom-up” and “top-down” (Stockholm Environment Institute, 2013). Bottom-up involves the comparison of an individual technology or a group of technologies called mitigation options based on the relative economic costs of achieving a unit of GHG reduction. Using this approach gives equal opportunities to both energy supply and demand side options. Cost curves can be used to identify promising mitigation options that can be combined into integrated mitigation scenarios (Lazarus et al., 1998; Stockholm Environment Institute, 2013). The bottom-up approach requires an accounting or modeling framework to assess the effects caused by mitigation options’ interactions to guarantee the consistency of energy, emissions, and cost analysis (Lazarus et al., 1998; Stockholm Environment Institute, 2013).

The top-down approach depends on economic models that “typically analyze the effect of carbon taxes on the behavior of energy consumers and producers and the resulting emission reductions and costs to national economies” (Lazarus et al., 1998; Stockholm Environment Institute, 2013). This approach uses the aggregate economic data and assumes the markets are efficient (Lazarus et al., 1998; Stockholm Environment Institute, 2013).

3.3.1 Creating and evaluating mitigation scenarios in LEAP

The process of developing a GHG mitigation scenario involves three steps: setting the scenario objective, identifying specific mitigation options, and combining these options in an integrated scenario (Lazarus et al., 1998; Stockholm Environment Institute, 2011).

3.3.1.1 Establishing objectives for mitigation scenarios

Setting the objective for a mitigation scenario is the main and first step of developing it. In the LEAP model, various objectives are possible in designing a mitigation scenario:

- GHG emission reduction targets,
- GHG mitigation options and their cost of emissions reduction per tonne,
- "No regrets" options, meaning only the economic options will be considered,
- Specific options or packages of options such as a renewable energies scenario.

Another important aspect in defining the scenario objective is setting targets for the potential global warming mitigation. For example, the objective could determine whether to reduce only CO_2 or all GHG emissions in a particular scenario or a combination of scenarios (Lazarus et al., 1998; Stockholm Environment Institute, 2011).

3.3.1.2 Selecting mitigation options to include in mitigation scenarios

Selecting mitigation options involves five steps: defining screening criteria, defining key parameters and considerations, identifying mitigation options, applying criteria and selecting final mitigation options, and estimating penetration rates (Lazarus et al., 1998; Stockholm Environment Institute, 2011).

The screening criteria determine whether a mitigation option should be included in the mitigation scenario or not. Indirect economic impacts, consistency with national environmental goals, and technology characterization are examples of screening criteria (Lazarus et al., 1998; Stockholm Environment Institute, 2012). The key parameters and considerations typically determine which costs and benefits, e.g., discount rates, should be included in the analysis. In identifying mitigation options, screening and (LEAP) scenario analyses are used to assess the relevance of potential options in the local situation based on their cost, performance, and emission characteristics (Lazarus et al., 1998; Stockholm Environment Institute, 2012). In applying criteria and selecting mitigation options, a set of screening criteria is used to rule out infeasible and undesirable options. The final step determines the penetration rate of selected mitigation options, i.e., the rate at which the select options can be implemented. The methodology used to adopt the penetration rate of the proposed scenarios in Alberta's agriculture sector energy model is discussed in section 3.4.

3.3.1.3 Construction of an integrated scenario

In this stage, the mitigation options identified in the previous section are combined to construct an integrated scenario. According to the report of methods for the assessment of mitigation options published by SEI-B (Lazarus et al., 1998), the construction of an integrated scenario consists of the following steps:

- Creating new demand and transformation scenarios.
- Creating an initial scenario by combining a set of mitigation options.
- Entering the mitigation options data chosen in the previous step into the LEAP model and calculating the results.
- Reviewing the results to make sure projected demands can be met with current energy supply capabilities.
- Repeating the previous steps until the targeted GHG reduction is met.

3.3.1.4 Evaluation of the results

A mitigation scenario is illustrated in the form of customized LEAP results tables and graphs. The efficiency improvements of a GHG mitigation scenario can be discussed by comparing its primary energy increase with the reference scenario. In addition, the input assumptions and data used to formulate the reference and mitigation scenarios should be presented (Lazarus et al., 1998; Stockholm Environment Institute, 2012).

3.3.1.5 Account for uncertainty

Any model that predicts future values may be prone to uncertainties. In the case of mitigation scenarios, the key inputs may be affected by many types of uncertainty; thus, a sensitivity analysis should be performed on mitigation scenarios, where the impacts of a range of assumptions for key inputs are tested (Lazarus et al., 1998; Stockholm Environment Institute, 2012).

3.3.1.6 Reviewing the impacts not captured by the LEAP analysis

As mentioned earlier, the "bottom-up" end-use approach is only capable of measuring the direct economic impacts of technologies, and if the data are provided, the approach can determine the costs of specific activities. However, the way the policy is implemented, i.e., through the choice of efficiency programs, import tariffs, or taxes, may result in a very different direct and indirect economic impact (Lazarus et al., 1998; Stockholm Environment Institute, 2012). Reviewing these impacts requires broad economic data and analysis that are beyond the scope of this study.

3.3.2 Penetration Rates

The market penetration rate of a new technology is the rate at which the new technology is adopted. In most cases, the penetration rate is not linear but varies in the different stages of the technology development. Typically, new technology deployment has four stages: the idea stage, the introduction of the new technology, the increase in acceptance of the new technology, and the mature technology stage (Packey, 1993). The new technology deployment starts with an idea, which later results in the introduction of the new technology. Afterwards, the awareness of the technology increases as the technology matures to the saturation stage (Packey, 1993).

There are various ways to forcast the penetration rate of a new technology. One of the common tools used to estimate the penetration rate is a diffusion model (Packey, 1993). There are four stages of market penetration, and diffusion models can be used during the latter three stages of new technology adoption: introduction, increasing acceptance of the new technology, and mature technology.

Technology diffusion is typically modelled as a sigmoid (S-shaped) curve over time. In the sigmoid curve, the rate of adoption begins slowly, speeds up, and finally slows down (Balachandra et al., 2010). There are different stages of a new technology diffusion — learning, growth, saturation, and decline — in the sigmoid curve (Balachandra et al., 2010).

In the sigmoid curve, the main assumption is that there is an upper limit to the growth of a new technology (Balachandra et al., 2010). The rate of adopting the new technology is slow at the learning stage and increases until it hits the upper limit at the saturation stage, and then starts to slow down afterwards as shown in Figure 3-2.

In Alberta's agriculture sector energy demand model, the penetration rate of new technologies was estimated using the S-curve model. Subramanyam et al. (2013) used earlier studies to evaluate different scenarios based on specific penetration rates of equipment (Subramanyam et al., 2013). In the current study, various efficiency improvement scenarios were developed based on three levels of penetration: low, medium, and high. The scenarios were also categorized with respect to the rate of the implementation of the efficient technologies over the study period. In the 2050 scenario or slow scenario, the maximum achievable penetration potential is expected to be achieved by 2050, whereas in the 2030 scenario or fast scenario, the maximum achievable penetration potential is assumed to be achieved by 2030. Table 3-1 shows the efficiency improvement scenarios categorized by both the level and rate of penetration.

Table 3-1: Categorization of efficiency-improvement scenarios

Scenario	Low penetration level	Medium penetration level	High penetration level
2050	Less than 15% by 2050	Between 50-70% by 2050	Up to 90% by2050
2030	Less than 15% by 2030	Between 50-70% by 2030	Up to 90% by2030

3.4 Development of mitigation scenarios for Alberta's agriculture sector

Alberta's energy strategies require a set of standards for energy consumption and for developing energy resources (Goverment of Alberta, 2008b). The provincial energy and GHG mitigation vision focusses on clean energy production, wise energy use, and sustained economic prosperity in all sectors (Goverment of Alberta, 2008b). Wise energy use refers to energy consumption with an emphasis on efficiency and conservation, while clean energy is about the development of more renewable energy, e.g., wind, solar, biomass, geothermal, and hydro. Moreover, crops and residues from Alberta agricultural lands can be used as a source of biofuel (e.g., ethanol and biodiesel).

In the agriculture sector, there are several opportunities for mitigating GHG emissions. For instance, replacing old farm machines with efficient ones can reduce energy consumption and corresponding GHG emissions. However, using alternative renewable fuels can be more effective options for GHG mitigation in Alberta's agriculture sector as will be discussed later. In this study, many practices are advocated to mitigate emissions through Alberta's agriculture sector energy model. The LEAP model is used to simulate the implementation of these various mitigation options in Alberta's agriculture sector and to forecast GHG emission reduction.

3.5 Mitigation Scenarios

In Alberta's agriculture sector energy model, various input data and assumptions are required to develop mitigation scenarios. The details for developing alternative mitigation scenarios are given in the following sections.

3.5.1 Mitigation scenarios for the livestock and poultry subsectors in Alberta - efficient lighting

Lighting is essential to increase productivity in the livestock and poultry subsectors. Moreover, by making small changes to lighting in livestock and poultry operations we can reduce energy consumption and cost. "A well-designed, energy-efficient lighting system means higher lighting levels, more performance, and more energy savings of 15% to 75%" (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a). The light output per lamp size (lm/W) is a key parameter in designing and selecting lighting systems (Clarke & Ward, 2006b). Typical lumen outputs used in lighting scenarios are shown in Table 3-2.

Table 3-2: General characteristics of light sources used for indoor lighting of livestock and poultry facilities

Lamp Type	Lamp Size (W)	Efficiency (Lumens/W)	Typical Lamp Life (hr.)
Incandescent	25-200	12.4-20	750-5,000
Fluorescent T8 (4 ft.)	32	88	20,000
Compact Fluorescent	5-57	50-80	10,000

Source: (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a)

Technically, each light type has specific characteristics, which are given in the following sections.

3.5.1.1 Incandescent

Incandescent lighting is the most common type of lighting used in the residential, commercial, and industrial sectors. Incandescent lamps have a much lower efficiency and operating life than other types of lighting. The old style incandescent lamps convert less than 5% of the energy into visible light, and the rest of the energy is wasted as heat (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2009). Incandescent lighting are quickly coated with dust, which results in even less light (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2009). Due to their inefficiency, incandescent light bulbs are gradually being replaced by efficient electric lights.

3.5.1.2 Fluorescent

Fluorescent lamps use 25-35% of the energy used by incandescent lamps to produce the same amount of light (US-DOE, 2012b). Moreover, they have long life cycles. Fluorescent lamps are the main light source in new livestock and poultry production units due to their high lighting quality. Typically, converting from incandescent to fluorescent bulbs will reduce energy use up to 75% (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a). In the livestock and poultry subsectors, there are two types of fluorescent systems: compact fluorescents lamps (CFLs) and tube fluorescents (T8).

3.5.1.3 Penetration of efficient lighting

The penetration rate of efficient lighting in the livestock and poultry subsectors is assumed to have reached a high penetration level by the end of the study period (Navigant Consulting Inc., 2012; Subramanyam et al., 2013). A high penetration rate is assumed to be 90% for new stock in both the slow and fast penetration scenarios (2050 and 2030 scenarios). Consequently, the penetration rate of existing lighting is expected to decrease to 10% at the end of the study period in both the slow and fast penetration scenarios. Table 3-3 illustrates the overall penetration rate of the scenario.

Table 3-3:Efficient lighting (CFLs and T8) penetration rates in the livestock and poultry subsectors as modeled in LEAP

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	90%	80%	50%	25%	10%
	Efficient stock	10%	20%	50%	75%	90%
Fast						
	Existing stock	90%	70%	10%		
	Efficient stock	10%	30%	90%		

3.5.2 Mitigation scenario 1 - Alberta agriculture – poultry and eggs subsector – efficient lighting (compact fluorescent lamps – CFLs)

Poultry farms and their process plants differ in size, layout, and degree of mechanization. Poultry farms require various degrees of lighting according to their production type (Clarke & Ward, 2006b). In mitigation scenario 1, the poultry farm lighting systems were reviewed, and energy use is reduced by replacing incandescent lamps with compact fluorescent lamps.

3.5.2.1 Input data and assumptions

In the base year 2009, it is assumed that 100% of bulbs used on poultry farms are incandescent. However, the use of incandescent bulbs is assumed to decrease to 90% by 2015. It is estimated that compact fluorescent lamps (CFLs) use about a third the energy of the existing bulbs (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a). As shown in Table 3-2, the maximum energy efficiency of CFL lamps is 80% while the maximum energy efficiency of incandescents is 20%; thus, switching to CFLs may achieve up to 60% energy savings (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a). Table 3-4 gives the details of final energy intensities of existing and efficient lamps.

Table 3-4: Energy intensity, poultry and eggs subsector efficient lighting scenario – compact fluorescent lamps (CFLs)

Subsector	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2030)	Energy intensity (MJ/T) (2050)
Poultry and Eggs			
Existing Stock	275.8	-	-
Efficient Stock	-	110.3	110.3

3.5.3 Mitigation scenario 2 – Alberta agriculture – poultry and eggs subsector – efficient lighting (T8 fluorescent tubes)

Fluorescent tubes are the second option for increasing energy efficiency in poultry farm lighting systems. Typically, the old standard incandescent lamps are being replaced by either T8 (1 in.) or T5 (0.6 in.) fluorescent tubes.

3.5.3.1 Input data and assumptions

This scenario assumed that incandescent bulbs are replaced with T8 fluorescent tubes. Efficiency of T8s is expected to be 88%, which has a high potential of energy savings (up to 68%), compared to incandescent bulbs (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a). The energy intensity of T8s is estimated to be 32% of the existing bulbs (Clarke & Ward, 2006b; Natural Resources Canada - OEE, 2011a). Table 3-5 compares the final energy intensities of existing and efficient lamps in the poultry and eggs subsector.

Table 3-5: Energy intensity, poultry and eggs subsector efficient lighting scenario – T8 fluorescent tubes

Subsector	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2030)	Energy intensity (MJ/T) (2050)
Poultry and Eggs			
Existing Stock	275.8	-	-
Efficient Stock	-	88.3	88.3

3.5.4 Mitigation scenario 3 – Alberta agriculture – dairy and cattle subsectors – efficient lighting (T8 fluorescent tubes)

The T8 fluorescent tube is an ideal energy efficient alternative to incandescent in dairy and cattle farm lighting systems. T8 fluorescents are four times more efficient than regular incandescent lights and last at least 20 times longer (Clarke & House, 2006). In the case of livestock subsector, there is a significant opportunity to make the lighting system more efficient by replacing incandescent lamps with T8 fluorescent tubes.

3.5.4.1 Input data and assumptions

This scenario is developed by replacing existing incandescent bulbs with T8 fluorescents. It is assumed that the energy intensity of T8 fluorescent tubes is 32% of the existing lamps (Clarke & House, 2006; Natural Resources Canada - OEE, 2011a). Table 3-6 gives the details of final energy intensities of existing and efficient lamps.

Table 3-6: Energy intensity, dairy and cattle subsector efficient lighting scenario – T8 fluorescent tubes

Subsector	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2030)	Energy intensity (MJ/T) (2050)
Cattle			
Existing Stock	40	-	-
Efficient Stock	-	13	13
Dairy			
Existing Stock	38	-	-
Efficient Stock	-	12	12

3.5.5 Mitigation scenario 4 – Alberta agriculture – hog (swine) subsector – efficient lighting (T8 fluorescent tubes)

As in the previous scenarios, this scenario assumed incandescent lamps are replaced with T8 fluorescent tubes in the hog subsector.

3.5.5.1 Input data and assumptions

The efficient lighting scenario for the Alberta's agriculture hog subsector was set up by replacing incandescent bulbs with T8 fluorescent tubes, which have 88% efficiency (Clarke & Chambers, 2006; Natural Resources Canada - OEE, 2011a). Consequently, this scenario is expected to improve energy savings by 68%. Table 3-7 shows the details of final energy intensities of both existing and efficient lamps.

Table 3-7: Energy intensity, hog subsector efficient lighting scenario – T8 fluorescent Tubes

Subsector	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2030)	Energy intensity (MJ/T) (2050)
Hog			
Existing Stock	829	-	-
Efficient Stock	-	265	265

3.5.6 Mitigation scenarios for Alberta's livestock subsector – efficient ventilation systems

Ventilation systems have a direct effect on animal productivity. Most livestock buildings are ventilated by mechanical fan systems (Clarke & Ward, 2006a). The majority of farm ventilation systems are designed to operate through the entire year (Clarke & Ward, 2006a). Ventilation systems consume a considerable amount of energy. Hence, a significant amount of energy can be saved in farm operations with the right ventilation system, proper size, use of energy-efficient fans, and proper maintenance (Clarke & Ward, 2006a).

In order to select the proper size and energy-efficient fans, one of the following should be considered:

- Cubic feet of air per minute per watt (CFM/W)
- Litres per second per watt (L/sec/W) in metric units

Energy efficiency is expressed as airflow per unit of input energy, or CFM/W (or L/sec/W). The L/sec/W or CFM/W rating is provided by the fan manufacturer as well as at least one of the independent test laboratories such as Bioenvironmental and Structural Systems (BESS) at the University of Illinois Agricultural Engineering Department and the Air Moving and Conditioning Association

(AMCA) for agricultural fans (Clarke & Ward, 2006a; Jacobson & Chastain, 1994).

3.5.6.1 Penetration of efficient ventilation systems

In the livestock and poultry subsectors, the penetration rate of the efficient fan is categorized as the medium level by the end of the study period. This assessment of the penetration rate is based on an earlier study (Navigant Consulting Inc., 2012; Subramanyam et al., 2013). In this scenario, the medium penetration rate is assumed for new efficient stock. The penetration rate is assumed to be 65% by the end of study period 2050 in the slow penetration scenario and 2030 in the fast penetration scenario. Table 3-8 illustrates the overall penetration rate of the scenario.

Table 3-8: Penetration rates, Alberta's livestock (dairy, cattle, and hogs) and poultry subsectors – efficient ventilation systems (fans)

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	95%	90%	75%	50%	35%
	Efficient stock	5%	10%	25%	50%	65%
Fast						
	Existing stock	90%	75%	35%		
	Efficient stock	10%	25%	65%		

3.5.7 Mitigation scenario 5 – Alberta agriculture – livestock subsectors (dairy, cattle and hog) – efficient ventilation systems (fans)

In the livestock subsector of Alberta's agriculture sector, there is a significant opportunity to make ventilation systems more efficient, which would in turn enhance production. In livestock farms, ventilation systems directly affect feed and mortality rates of animals. The careful choice of fans, the design of the ventilation system, and its maintenance are all critical factors for efficient operation in this subsector.

3.5.7.1 Input data and assumptions

In this mitigation scenario, it was assumed that current fans of livestock farms with the efficiency of 8.4 CFM/W are replaced by 18.6 CFM/W fans, which are 50% more energy efficient (Clarke & Ward, 2006a; Jacobson & Chastain, 1994). These assessment data are based on earlier studies for this scenario in Ontario (Clarke & Ward, 2006a). The final energy intensity is estimated to be reduced by up to 50% in both the slow and fast penetration scenarios. Table 3-9 gives the details of energy intensities of livestock ventilation systems considered for efficiency improvement.

Table 3-9: Energy intensity, livestock subsector efficient ventilation scenario – efficient fans

Subsector	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2030)	Energy intensity (MJ/T) (2050)
Cattle			
Existing Stock	250.4	-	-
Efficient Stock	-	125.2	125.2
Hog			
Existing Stock	1,094.5	-	-
Efficient Stock	-	547.2	547.2
Dairy			
Existing Stock	28.3	-	-
Efficient Stock	-	14.1	14.1

3.5.8 Mitigation scenario 6 – Alberta agriculture – poultry and eggs subsector – efficient ventilation systems (fans)

Ventilation rates control the environment of poultry buildings, the main parameter in poultry production. Ventilation systems improve the quality of indoor environment by removing the emissions from gas pollutants. This scenario studied GHG mitigation in Alberta poultry farms resulting from improvements in the energy efficiency of ventilation systems.

3.5.8.1 Input data and assumptions

In this scenario, it was anticipated that the existing fans, with an efficiency of 8.4 CFM/W, were replaced with fans with an efficiency of 18.6 CFM/W. The final energy intensity in this mitigation scenario declines to 50% by 2050 when existing fans are replaced with high-efficiency fans (Clarke & Ward, 2006a; Jacobson & Chastain, 1994; Navigant Consulting Inc., 2012). The assessment of this mitigation scenario was based on an earlier study done in Ontario (Clarke & Ward, 2006a). The details of final energy intensities are shown in Table 3-10.

Table 3-10: Energy intensity, poultry and eggs subsector efficient ventilation scenario – efficient fans

Subsector	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2030)	Energy intensity (MJ/T) (2050)
Poultry and Eggs			
Existing Stock	223	-	-
Efficient Stock	-	111	111

3.5.9 Mitigation scenarios for Alberta's farm machine subsector

Farm machinery consumes a large percentage of the energy used on a farm. The most common farm machines are a tractor, for tilling the fields and moving crops, a combine, and a baler (Brown & Elliott, 2005). The energy required to operate farm machinery is almost as high as the energy consumed in other agricultural subsectors. In Alberta's agriculture subsector, farm machinery accounts for almost half of the total energy used each year (Khakbazan, 2000). High use of farm machinery results in high use of fossil fuels; thus, farm machinery presents the largest opportunity for energy savings and GHG emission mitigation. There are several ways to increase the fuel efficiency of farm machinery, including upgrading to more energy-efficient machines and using renewable fuels such as biofuel.

3.5.10 Mitigation scenario 7 – Alberta agriculture – farm machine subsector – efficient diesel tractors

Tractors are used for various farm operations (e.g., soil tilling and plowing, seeding, moving, cultivating, etc.). Tractors are one of the most used and essential machines in agriculture (Janulevičius et al., 2013). Thus, tractors present one of the largest potential energy savings.

3.5.10.1 Input data and assumptions

The high-efficiency diesel tractor scenario was developed based on the Climate Action Plan adopted by the Yolo County Board of Supervisors (Government of Yolo County, 2011). According to the research in Yolo County's agricultural sector, 15-20% energy was saved by converting tractors from older models to those with Tier IV engines. The new tractor is 15-20% more fuel efficient (Government of Yolo County, 2011). In this scenario, the final energy intensity of tractors is assumed to be reduced by 20% by converting Tier III engines to the more efficient Tier IV engines. In order to evaluate and assess energy intensity improvements, fuel consumption estimates were obtained from the earlier study (Government of Yolo County, 2011). The data for final energy intensities of the scenario are shown in Table 3-11.

Table 3-11: Energy intensity, efficient diesel tractor scenario

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2030	Energy intensity (MJ/T) 2050
Grain and Oilseed			
Tractor	496	397	397
Fruit and Vegetable			
Tractor	4,698	3,758	3,758
Greenhouse and Nursery			
Tractor	3,026	2,421	2,421
Cattle			
Tractor	4,351	3,481	3,481
Hog			
Tractor	11,334	9,067	9,067
Poultry and Eggs			
Tractor	1,933	1,546	1,546
Dairy			
Tractor	1,606	1,285	1,285
Other			
Tractor	31	25	25

3.5.10.2 Penetration of efficient diesel tractors

The penetration level of the high-efficiency diesel tractor is expected to be from medium to high, i.e., to reach a maximum level of 79% by the end of the study period. This estimate is based on earlier studies and new vehicle manufacturers' fuel consumption guides (Government of Yolo County, 2011; Natural Resources Canada, 2012d, 2012e). In the LEAP model for Alberta agriculture, slow and fast penetration scenarios were developed based on a high penetration level, that is, the efficient stock reaching its maximum level of 79% by 2050 in the slow penetration scenario and 2030 in the fast penetration scenario. Given that diesel tractors make up 93% of tractors in Alberta agriculture in the base year, existing tractors are expected to decline to 14% by the end of the study period in both scenarios. Table 3-12 illustrates the overall penetration rate.

Table 3-12: Penetration rates, Alberta's farm machine subsector – efficient diesel tractor

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	93%	74%	28%	14%	14%
	Efficient stock	0%	19%	65%	79%	79%
Fast						
	Existing stock	70%	37%	14%		
	Efficient stock	23%	56%	79%		

3.5.11 Mitigation scenario 8 – Alberta agriculture - farm machinery subsector – biodiesel tractors

One way to mitigate GHGs emitted by farm machinery is to replace diesel fuel with biodiesel fuel, a "clean" fuel. Biodiesel is a renewable fuel made from biomass and can be blended with diesel to reduce the consumption of diesel. Biodiesel blends range from 2 to 20% (B2 to B20); however, in some experimental cases 100% biodiesel fuel was used (US-DOE, 2010). According to the US Department of Energy, biodiesel blends of 5-20% can be used without any engine modification (US-DOE-EERE, 2005). Most diesel engines can run on biodiesel fuel with the same amount of diesel fuel consumption (US-DOE, 2010). According to the US DOE, "biodiesel's physical properties are similar to those of petroleum diesel, but it is a cleaner-burning alternative" (US-DOE-EERE, 2013a). In very cold regions like Alberta, the lower biodiesel blend is the better option for improving the fuel efficiency of a biodiesel tractor (McLaughlin et al., 2009; Natural Resources Canada - OEE, 2011b).

3.5.11.1 Input data and assumptions

In LEAP, the biodiesel scenario considers blends of B5 to B20. In this mitigation scenario, the energy intensity of biodiesel tractors is assumed to be the same as that of diesel tractors. However, by using B5 and B20 a 20% reduction of CO_2 and a 2-5% reduction of CO and other hydrocarbon emissions, respectively, is anticipated (Subramanyam et al., 2013; US-DOE-EERE, 2008). Thus, the potential GHG mitigation of this scenario is expected to be up to 20%. In the LEAP model, various emissions factors are modeled based on the factors published by the US Department of Energy (US-DOE-EERE, 2008). The details of the final energy intensities for this scenario are given in Table B-1 in Appendix B.

3.5.11.2 Penetration of biodiesel tractors

Based on the availability and logistics of biodiesel fuel consumption in Alberta, a low to medium penetration rate is expected in this scenario, which has been estimated to reach the maximum level of 28% by the end of the study period. This estimate is based on an earlier study, new vehicle manufacturers' fuel consumption guides, and the projections of the World Energy Council on the global penetration levels of biofuel vehicles (Subramanyam et al., 2013; World Energy Council, 2012). The slow and fast penetration scenarios were developed in LEAP based on this penetration rate. The maximum penetration rate of 28% is achieved by 2050 in the slow penetration scenario and by 2030 in the fast penetration scenario. Considering that diesel tractors make up 93% of tractors in Alberta's agricultural sector, the existing stock levels are expected to decline to 65% by the end of the study period in both scenarios (Khakbazan, 2000). Table 3-13 illustrates the overall penetration rate in this scenario.

Table 3-13: Penetration rates, Alberta's farm machinery – biodiesel tractors

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	90%	83%	70%	65%	65%
	Efficient stock	3%	10%	23%	28%	28%
Fast						
	Existing stock	83%	70%	65%		
	Efficient stock	10%	23%	28%		

3.5.12 Mitigation scenario 9 – Alberta agriculture - farm machinery subsector – biodiesel combines

Most farms also have other diesel-powered equipment such as combines. A combine cuts and threshes grain. In the grain and oilseed subsector, the combine is a binder-type cutting device. The combine accounts for 20% of the total amount of energy used in the grain and oilseed farm machinery subsector (Khakbazan, 2000; Statistics Canada, 2011b). Therefore, replacing combines' diesel fuel with biodiesel could reduce CO_2 emissions by 20% (Subramanyam et al., 2013). In the biodiesel combine scenario, biodiesel was proposed as an alternative fuel to reduce GHG emissions.

3.5.12.1 Input data and assumptions

In this scenario, it is assumed that a biodiesel combine has the same energy intensity as the diesel engine combine and that the biodiesel combine could potentially mitigate GHGs by 20%. The details of final energy intensities for this scenario are given in Table B-2 in Appendix B.

3.5.12.2 Penetration of biodiesel combines

Similar to the biodiesel tractor scenario, the penetration levels of biodiesel fuel (B5-B20) combines are expected to be low to medium and reach the maximum level of 28% by the end of the period. The penetration rate was estimated based on new vehicle manufacturers' fuel consumption guides and the projections of the World Energy Council on global penetration levels of biofuel vehicles (World Energy Council, 2012). Considering diesel combines make up 93% of combines in Alberta's agriculture sector, the penetration rate of existing combines is expected to decline to 65% (Khakbazan, 2000). Table 3.14 illustrates the overall penetration rate.

Table 3-14: Penetration rates, Alberta farm machinery – biodiesel combines

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	90%	83%	70%	65%	65%
	Efficient stock	3%	10%	23%	28%	28%
Fast						
	Existing stock	83%	70%	65%		
	Efficient stock	10%	23%	28%		

3.5.13 Mitigation scenario 10 – Alberta agriculture – farm machinery subsector – biodiesel balers

Biodiesel is the best alternative renewable fuel for a baler. According to the US Department of Energy, the maximum mitigation from a biodiesel B20 blend baler is a 20% reduction in CO_2 and a 2-5% reduction in CO and other hydrocarbon emissions. However, the higher nitrogen percentage in biodiesel increases the NOx emissions (US-DOE-EERE, 2008).

3.5.13.1 Input data and assumptions

Under this scenario, it is assumed that baler diesel fuel is replaced with biodiesel by the end of the study period in both the slow and fast penetration scenarios. This mitigation scenario does not have any energy-saving potential due to the fact that the energy intensity of both biodiesel and diesel balers is the same. However, the scenario is expected to reduce the carbon dioxide emissions by 20% since burning biodiesel produces 20% less carbon dioxide than burning diesel (Subramanyam et al., 2013). The details of the final energy intensities of biodiesel balers are given in Table B-3 in Appendix B.

3.5.13.2 Penetration of biodiesel balers

The penetration rate for biodiesel tractors was adopted for biodiesel balers. Table 3-15 illustrates the overall penetration rate of the scenario based on the fact that diesel balers make up 93% of the combines in Alberta agriculture (Khakbazan, 2000).

Table 3-15: Penetration rates, Alberta's farm machinery subsector – biodiesel balers

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	90%	83%	70%	65%	65%
	Efficient stock	3%	10%	23%	28%	28%
Fast						
	Existing stock	83%	70%	65%		
	Efficient stock	10%	23%	28%		

3.5.14 Mitigation scenarios for Alberta's farm truck (farm transport) subsector

Trucking is vital to Alberta's agricultural economy. The farm truck subsector usually refers to local movement from farm to elevator or other local destinations. Farm trucks use approximately 17% of the total energy consumed in Alberta agriculture; thus, there is significant potential to reduce GHG emissions in this subsector (Khakbazan, 2000). Mitigation potentials are explored by using two different approaches: replacing existing farm trucks with efficient farm trucks and using renewable fuels.

3.5.15 Mitigation scenario 11 – Alberta agriculture – farm truck subsector – diesel trucks

According to the US Department of Energy "Only about 14%–26% of the energy from the fuel gets used to move the vehicle down the road and the rest of the energy is lost to engine and driveline inefficiencies or used to power accessories" (US-DOE-EERE, 2013b). A diesel engine, however, is more fuel efficient than gasoline engine of the same size (US-DOE-EERE, 2013c). According to the US DOE, an efficient diesel engine is about 30-35% more fuel efficient than a gasoline engine of the same size (US-DOE-EERE, 2013c). Today's diesel engine has the same emissions standards as a gasoline engine (US-DOE-EERE, 2013c). Hence, replacing gasoline engines with diesel engines was studied as a mitigation option.

3.5.15.1 Input data and assumptions

In this mitigation scenario, farm trucks that ran on gasoline were converted or upgraded to diesel engine. The energy intensity of a diesel engine was estimated to be two-thirds that of gasoline engine; thus, the maximum energy-saving potential in this mitigation scenario is 30-35% (US-DOE-EERE, 2013c). Moreover, in this scenario the GHG emissions produced in the farm truck subsector will decrease. Table 3-16 shows the average energy intensities of diesel and gasoline engines in the farm truck subsector.

Table 3-16: Energy intensity, farm diesel truck scenario

Subsectors	Energy intensity (MJ/Km)
Diesel truck	60.5
Gasoline truck	86.5

3.5.15.2 Penetration of diesel trucks

According to an earlier study, most of the new stock of high-efficiency vehicles on the market are in the high level penetration rate (Natural Resources Canada, 2012d, 2012e; Subramanyam et al., 2013). Therefore, the penetration rate of diesel engine trucks has been categorized as high with the maximum level of 85% reached by the end of the study period. In the LEAP model, the high penetration of the diesel truck is estimated to be 85% by 2050 in the slow penetration scenario and 85% by 2030 in fast the penetration scenario. In both scenarios, the gasoline truck stock is expected to decline to 15%. Table 3-17 illustrates the overall penetration rates.

Table 3-17: Penetration rates, Alberta's farm truck subsector – diesel trucks

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	68%	55%	30%	15%	15%
	Efficient stock	32%	45%	70%	85%	85%
Fast						
	Existing stock	68%	30%	15%		
	Efficient stock	32%	70%	85%		

3.5.16 Mitigation scenario 12 – Alberta agriculture – farm truck subsector – biodiesel trucks

Low-blend biodiesel fuel was chosen as a significant GHG mitigation option in Alberta's agriculture sector (Natural Resources Canada - OEE, 2012b).

3.5.16.1 Input data and assumptions

This scenario uses biodiesel with blends of B5 to B20 as an alternative fuel for diesel trucks. In the LEAP model, the final energy intensity of biodiesel trucks is assumed to be the same that of as diesel trucks. The details of energy intensities of this scenario are given in Table B-4 in Appendix B.

3.5.16.2 Penetration of biodiesel trucks

Based on new vehicle manufacturers' fuel consumption guides and the projections of the World Energy Council on global penetration levels of biofuel vehicles, the biodiesel truck penetration rate was categorized as low to medium (World Energy Council, 2012). In the LEAP model, both slow and fast penetration scenarios were developed based on the medium penetration level of up to 10% of efficient stock by the end of the study period. Consequently, the penetration rate of the existing diesel farm truck will decrease to 22% by the end of the study period, since the diesel trucks make up 32% of trucks in Alberta agriculture (Khakbazan, 2000). Table 3-18 illustrates the overall penetration rate.

Table 3-18: Penetration rates, Alberta's farm truck subsector – biodiesel trucks

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	30%	27%	24%	22%	22%
	Efficient stock	2%	5%	8%	10%	10%
Fast						
	Existing stock	30%	24%	22%		
	Efficient stock	2%	8%	10%		

3.5.17 Mitigation scenario 13 – Alberta agriculture – farm truck subsector – high-efficiency vehicle, diesel trucks (HEV)

The high-efficiency diesel engine can affect fuel consumption and GHG mitigation. Modern diesel engines use electronically controlled fuel injection that increases energy efficiency (Malloy & Lachapelle, 2012; US-DOE-EERE, 2003). According to the Fuel Consumption Guide published by Natural Resources

Canada and various guidelines for the energy efficiency of new vehicles and Energy-Guide rated vehicles, the average high-efficiency newer diesel trucks improve energy efficiency by 15-20% compared to older trucks (Natural Resources Canada, 2012d).

3.5.17.1 Input data and assumptions

Today's high-efficiency diesel engines are more powerful and durable and much more efficient than both the older diesel and gasoline engines. This mitigation scenario is developed to replace current diesel trucks with high-efficiency diesel trucks. In the LEAP model, the final energy intensity improvement caused by using the new engine is considered to be 20%. The details of energy intensities for this scenario are given in Table 3-19.

Table 3-19: Energy intensity, Alberta's farm truck subsector – HEV diesel truck scenario

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2030	Energy intensity (MJ/T) 2050
Grain and Oilseed			
Farm truck (diesel)	70.9	56.7	56.7
Fruit and Vegetable			
Farm truck (diesel)	60.5	48.4	48.4
Greenhouse and Nursery			
Farm truck (diesel)	60.5	48.4	48.4
Cattle			
Farm truck (diesel)	70.9	56.7	56.7
Hog			
Farm truck (diesel)	60.5	48.4	48.4
Poultry and Eggs			
Farm truck (diesel)	60.5	48.4	48.4
Dairy			
Farm truck (diesel)	60.5	48.4	48.4
Other			
Farm truck (diesel)	60.5	48.4	48.4

3.5.17.2 Penetration of HEV diesel trucks

The penetration rate for HEV diesel trucks is categorized as medium. In the LEAP model, the medium penetration rate of HEV diesel trucks was selected; up to 31.25% of existing diesel trucks (i.e., 10% of all trucks) will be converted to HEV diesel trucks by 2050 in the slow penetration scenario and by 2030 in the fast penetration scenario. The overall penetration rates for the HEV diesel truck scenario are shown in Table 3-20.

Table 3-20: Penetration rates, Alberta's farm truck subsector – HEV diesel trucks

Scenario	Penetration	2015	2020	2030	2040	2050
Slow						
	Existing stock	30%	27%	24%	22%	22%
	Efficient stock	2%	5%	8%	10%	10%
Fast						
	Existing stock	30%	24%	22%		
	Efficient stock	2%	8%	10%		

3.5.18 Mitigation scenario 14 – Alberta agriculture – farm truck subsector – ethanol trucks

Ethanol-blended gasoline is a renewable fuel; unleaded gasoline contains up to 10% ethanol. Ethanol burns more cleanly than gasoline or diesel fuel because it is produced from biomass, and it reduces GHG emissions such as carbon monoxide, particulate matter, and oxides of nitrogen (CRFA, 2010). The gasoline engine can run with up to 5-10% ethanol without any change in the engine, and some vehicles are specially manufactured to operate with up to 85% ethanol (Natural Resources Canada - OEE, 2012a).

3.5.18.1 Input data and assumptions

This scenario uses ethanol E85-base (85% ethanol) instead of gasoline. E85-base fuel is compatible with special engines only; thus the current gasoline engine should be replaced with the special engines. The energy intensity of ethanol-E85 of the farm truck is assumed to be the same as that of the gasoline truck (Natural Resources Canada, 2012a, 2012b; US-DOE-EERE, 2013d). However, the advantage of using ethanol compared to gasoline is the lower GHG emissions (Natural Resources Canada - OEE, 2012a). The emission factors used in the LEAP model are based on earlier studies (Subramanyam et al., 2013; Zhai et al., 2007). The details of final energy intensities for the ethanol engine are given in Table B-5 in Appendix B.

3.5.18.2 Penetration of ethanol trucks

The penetration rate of the ethanol fuel (E85) truck was categorized as low based on earlier studies and the estimates of the penetration levels of biofuel vehicles from the World Energy Council (Subramanyam et al., 2013; World Energy Council, 2012). In the LEAP model, both slow and fast penetration scenarios were developed based on a low penetration level. In the slow and fast penetration scenarios, the maximum penetration rate of 20% is achieved by both 2050 and 2030. Table 3-21 illustrates the overall penetration rate.

Table 3-21: Penetration rates, Alberta's farm truck subsector – ethanol truck

Scenario	Penetration	2009	2020	2030	2040	2050
Slow						
	Existing stock	68%	61%	51%	48%	48%
	Efficient stock	0%	7%	17%	20%	20%
Fast						
	Existing stock	68%	51%	48%		
	Efficient stock	0%	17%	20%		

3.5.19 Mitigation scenario 15 – Alberta agriculture – farm machine and farm truck subsectors – awareness programs for drivers

According to a case study conducted for New Zealand's Ministry for the Environment, those who drive farm machines and trucks can have a significant impact on fuel consumption and fuel efficiency in these subsectors. The education and awareness of farm drivers can bring about up to 15% fuel savings and fuel efficiency in forestry and agriculture (Maxwell & Rackley, 2010). Based on this case study's methodology of measuring fuel saving, the percentage of fuel savings is equal to the percentage of energy savings. For example, assuming that the consumption of 2 litres of fuel in farm machinery is equal to 46.6 MJ energy use, 15% fuel savings is equivalent to 0.30 liters of fuel savings or 6.99 MJ energy savings (Maxwell & Rackley, 2010).

In this scenario, a 100% penetration rate by the end of 2050 in drivers in the farm machine and farm truck subsectors having plans to improve their knowledge in these subsectors is assumed. In order to build this scenario, it is assumed that 15% fuel savings caused by drivers' education and awareness has gradually affected energy use during the study period (Maxwell & Rackley, 2010). The details of energy intensities of the farm truck and farm machines (e.g., combine, tractors, and balers) are shown in Table 3-22 and Table 3-23.

Table 3-22: Energy intensity, awareness programs scenario, Alberta agriculture – farm machinery subsector

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2050
Grain and Oilseed		
Farm machine-tractors (diesel)	496	422
Farm machine-tractors (gasoline)	709	602
Farm machine-combines (diesel)	124	105
Farm machine-combines (gasoline)	177	150
Fruit and Vegetable		
Farm machine-tractors (diesel)	4,698	3,993
Farm machine-tractors (gasoline)	6,711	5,704
Greenhouse and Nursery		
Farm machine-tractors (diesel)	3,026	2,572
Farm machine-tractors (gasoline)	4,323	3,674
Cattle		
Farm machine-tractors (diesel)	4,351	3,698
Farm machine-tractors (gasoline)	6,216	5,284
Hog		
Farm machine-tractors (diesel)	11,334	9,634
Farm machine-tractors (gasoline)	16,192	13,763
Poultry and Eggs		
Farm machine-tractors (diesel)	1,933	1,643
Farm machine-tractors (gasoline)	2,761	2,347
Dairy		
Farm machine-tractors (diesel)	1,606	1,365
Farm machine-tractors (gasoline)	2,295	1,951
Other		
Farm machine-tractors (diesel)	31	26
Farm machine-tractors (gasoline)	45	38
Farm machine-balers (diesel)	3.9	3.3
Farm machine-balers (gasoline)	5.5	4.7

The tractor is one of the most used and essential tools in Alberta's agriculture sector. Consequently, 80% of the total energy consumption in the farm machinery is from tractors (Statistics Canada, 2011b). Therefore, it is reasonable to assume that most of the energy savings in the scenario occurs in the farm machinery – tractor subsector and is shown in Table 3-22.

Table 3-23: Energy use intensity, awareness programs scenario, Alberta agriculture – farm truck subsector

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2050
Grain and Oilseed		
Farm truck (diesel)	70.9	60.3
Farm truck (gasoline)	101.3	86.1
Fruit and Vegetable		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Greenhouse and Nursery		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Cattle		
Farm truck (diesel)	70.9	60.3
Farm truck (gasoline)	101.3	86.1
Hog		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Poultry and Eggs		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Dairy		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Other		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5

3.5.19.1 Penetration rate

In this mitigation scenario, it is assumed that maximum energy savings will be achieved by creating awareness about energy efficiency among all the drivers (100%) by 2050. This penetration rate is applied on the energy intensity of all farm machinery and farm trucks. For instance, the penetration rate in 2015 is 25%, which implies that by 2015 the energy intensity of 25% of the farm machines and farm trucks is 15% lower than for other machines. This improvement can be presented as a 4% improvement in the energy intensity of all tractors and trucks in the particular year. Table 3-24 shows penetration rates and rates of energy intensity improvement for this scenario.

Table 3-24: Penetration rates and rates of energy intensity improvement, Alberta agriculture – awareness programs as modeled in LEAP

Year	2015	2020	2030	2040	2050
Penetration	25%	50%	80%	95%	100%
Rate of energy intensity improvement	4%	8%	12%	14%	15%

3.5.20 Mitigation scenario 16 – Alberta agriculture – farm machine and truck subsectors – regular maintenance

Regular maintenance and service including periodic replacement of farm machinery and truck parts (e.g., filters, belt, etc.) especially before and after harvest season can result in large energy savings (Firestine et al., 2007). Regular maintenance, optimum wheel slip, and properly lubricated farm machinery and equipment will result in fuel savings of up to 15% (Government of Yolo County, 2011; Maxwell & Rackley, 2010). Data of energy intensities for this scenario are shown in Table 3-25 and Table 3-26.

Table 3-25: Energy intensity, regular maintenance scenario, Alberta's agriculture sector –farm machine subsector

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2050
Grain and Oilseed		
Farm machine-tractors (diesel)	496	422
Farm machine-tractors (gasoline)	709	602
Farm machine-combines (diesel)	124	105
Farm machine-combines (gasoline)	177	150
Fruit and Vegetable		
Farm machine-tractors (diesel)	4,698	3,993
Farm machine-tractors (gasoline)	6,711	5,704
Greenhouse and Nursery		
Farm machine-tractors (diesel)	3,026	2,572
Farm machine-tractors (gasoline)	4,323	3,674
Cattle		
Farm machine-tractors (diesel)	4,351	3,698
Farm machine-tractors (gasoline)	6,216	5,284
Hog		
Farm machine-tractors (diesel)	11,334	9,634
Farm machine-tractors (gasoline)	16,192	13,763
Poultry and Eggs		
Farm machine-tractors (diesel)	1,933	1,643
Farm machine-tractors (gasoline)	2,761	2,347
Dairy		
Farm machine-tractors (diesel)	1,606	1,365
Farm machine-tractors (gasoline)	2,295	1,951
Other		
Farm machine-tractors (diesel)	31	26
Farm machine-tractors (gasoline)	45	38
Farm machine-balers (diesel)	3.9	3.3
Farm machine-balers (gasoline)	5.5	4.7

Table 3-26: Energy intensity, regular maintenance scenario, Alberta's agriculture sector – farm truck subsector

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2050
Grain and Oilseed		
Farm truck (diesel)	70.9	60.3
Farm truck (gasoline)	101.3	86.1
Fruit and Vegetable		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Greenhouse and Nursery		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Cattle		
Farm truck (diesel)	70.9	60.3
Farm truck (gasoline)	101.3	86.1
Hog		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Poultry and Eggs		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Dairy		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5
Other		
Farm truck (diesel)	60.5	51.4
Farm truck (gasoline)	86.5	73.5

3.5.20.1 Penetration rate

In this mitigation scenario, it is assumed that maximum energy savings is achieved by 2050 by performing regular maintainance. The assessment of penetration rates and rates of energy intensity improvement is similar to scenario - 16 and is shown in Table 3-27.

Table 3-27: Penetration rates for regular maintenance in Alberta's agriculture sector as modeled in LEAP

Year	2015	2020	2030	2040	2050
Penetration	25%	50%	80%	95%	100%
Rate of energy intensity improvement	4%	8%	12%	14%	15%

3.5.21 Mitigation scenario 17 - Alberta agriculture – farm machine and truck subsectors – tire pressure

One of the aspects of regular maintenance in farm machinery and farm trucks is controlling and checking the equipment manual as well as consulting the local tire distributor for the proper inflation information. Under or over-inflated tires affect not only fuel consumption but also maintenance costs. According to the case studies conducted for the Ministry for the Environment in New Zealand and California's Farm Bureau Federation, correctly inflated tires use 20% less fuel than tires that are under-inflated or over-inflated (CFBF, 2013; Lancas et al., 1996; Maxwell & Rackley, 2010). Table 3-28 and Table 3-29 show energy intensity details for this scenario.

Table 3-28: Energy intensity, tire pressure scenario, Alberta's agriculture sector – farm machine subsector

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2050
Grain and Oilseed		
Farm machine-tractors (diesel)	496	397
Farm machine-tractors (gasoline)	709	567
Farm machine-combines (diesel)	124	99
Farm machine-combines (gasoline)	177	142
Fruit and Vegetable		
Farm machine-tractors (diesel)	4,698	3,758
Farm machine-tractors (gasoline)	6,711	5,369
Greenhouse and Nursery		
Farm machine-tractors (diesel)	3,026	2,421
Farm machine-tractors (gasoline)	4,323	3,458
Cattle		
Farm machine-tractors (diesel)	4,351	3,481
Farm machine-tractors (gasoline)	6,216	4,973
Hog		
Farm machine-tractors (diesel)	11,334	9,067
Farm machine-tractors (gasoline)	16,192	12,954
Poultry and Eggs		
Farm machine-tractors (diesel)	1,933	1,546
Farm machine-tractors (gasoline)	2,761	2,209
Dairy		
Farm machine-tractors (diesel)	1,606	1,285
Farm machine-tractors (gasoline)	2,295	1,836
Other		
Farm machine-tractors (diesel)	31	25
Farm machine-tractors (gasoline)	45	36
Farm machine-balers (diesel)	3.9	3.1
Farm machine-balers (gasoline)	5.5	4.4

Table 3-29: Energy intensity, tire pressure scenario, Alberta's agriculture sector–farm truck subsector

Subsector	Energy intensity (MJ/T) 2009	Energy intensity (MJ/T) 2050
Grain and Oilseed		
Farm truck (diesel)	70.9	56.7
Farm truck (gasoline)	101.3	81
Fruit and Vegetable		
Farm truck (diesel)	60.5	48.4
Farm truck (gasoline)	86.5	69.2
Greenhouse and Nursery		
Farm truck (diesel)	60.5	48.4
Farm truck (gasoline)	86.5	69.2
Cattle		
Farm truck (diesel)	70.9	56.7
Farm truck (gasoline)	101.3	81
Hog		
Farm truck (diesel)	60.5	48.4
Farm truck (gasoline)	86.5	69.2
Poultry and Eggs		
Farm truck (diesel)	60.5	48.4
Farm truck (gasoline)	86.5	69.2
Dairy		
Farm truck (diesel)	60.5	48.4
Farm truck (gasoline)	86.5	69.2
Other		
Farm truck (diesel)	60.5	48.4
Farm truck (gasoline)	86.5	69.2

3.5.21.1 Penetration rate

The penetration rate of driver awareness in this scenario is assumed to reach the maximum level of 100% by 2050. This penetration rate is applied on the energy intensity of all farm machinery and farm trucks. Moreover, the penetration rate in

2015 is 25%, which implies that by 2015 the energy intensity of 25% of the farm machines and trucks is 20% lower than for other machines. This improvement can be presented as a 5% improvement in the energy intensity of all tractors and trucks. Table 3.30 shows the penetration rates for the educted driver.

Table 3-30: Penetration rates for Alberta's agriculture sector – tire pressure scenario as modeled in LEAP

Penetration	2015	2020	2030	2040	2050
Penetration	25%	50%	80%	95%	100%
Rate of energy intensity improvement	5%	10%	16%	19%	20%

3.6 Results and discussion

3.6.1 Results of the implementation of mitigation scenarios in Alberta's livestock and poultry lighting subsectors

The mitigation scenarios of Alberta's livestock and poultry lighting subsectors are developed by including efficient lighting and considering the penetration of efficient lamps in livestock and poultry operations. The results of the mitigation scenario for efficiency improvement confirm mitigation in both demand and transformation sectors. The details of energy demand for slow and fast penetration scenarios are given in Table 3-31 and Table B-6 (Appendix B), respectively.

Table 3-31: Alberta's livestock and poultry lighting subsector mitigation scenario – demand reduction – slow penetration scenario (2050)

Energy demand (PJ)	2009	2020	2030	2040	2050
Reference	42.62	54.56	68.46	86.10	108.51
Poultry lighting CFLs	42.62	54.56	68.45	86.07	108.48
Demand reduction (poultry lighting CFLs vs. reference)	0	0	-0.01	-0.02	-0.03
Poultry lighting T8	42.62	54.56	68.45	86.07	108.48
Demand reduction (poultry lighting T8 vs. reference)	0	0	-0.01	-0.03	-0.04
Dairy/Cattle lighting T8	42.62	54.54	68.39	85.97	108.34
Demand reduction (D/C lighting T8 vs. reference)	0	-0.02	-0.07	-0.12	-0.17
Swine lighting T8	42.62	54.55	68.44	86.05	108.45
Demand reduction (swine lighting T8 vs. reference)	0	-0.01	-0.03	-0.05	-0.07

As developed by the LEAP model

In the case of the poultry subsector scenarios, the energy savings in the T8 lighting scenario is 0.04 PJ, which is higher than in the CFLs lighting scenario in 2050. Thus, T8 fluorescent tubes are a better option for replacing incandescent lighting. The overall reduction in energy demand in the dairy and cattle lighting subsectors is 0.17 PJ in 2050. The reduction of energy demand in the swine lighting scenario is 0.07 PJ in 2050. Consequently, by replacing existing lights with T8s in the livestock and poultry lighting subsectors, the overall reduction in energy demand reaches 0.28 PJ in 2050. The total energy savings in these subsectors is in electricity use.

In the case of efficient lighting, T8 tubes have a more justified GHG mitigation than CFLs in the livestock and poultry subsectors, since the energy efficiency of fluorescent tube lighting is 8% higher than CFLs. The total energy transformation output after applying mitigation options for both slow and fast penetration scenarios is shown in Table 3-32 and Table B-7 (Appendix B), respectively.

Table 3-32: Alberta's livestock and poultry lighting subsector mitigation scenario – transportation output reduction – slow penetration scenario (2050)

Output (PJ)	2009	2020	2030	2040	2050
Output reduction (poultry lighting CFLs vs. reference)	0	-0.02	-0.04	-0.07	-0.11
Output reduction (poultry lighting T8 vs. reference)	0	-0.02	-0.05	-0.08	-0.13
Output reduction (D/C lighting T8 vs. reference)	0	-0.08	-0.21	-0.38	-0.58
Output reduction (swine lighting T8 vs. reference)	0	-0.03	-0.08	-0.14	-0.22

As developed by the LEAP model

The overall energy output reduction of efficient lighting scenarios using T8 tubes is 0.93 PJ by 2050. The total energy transformation output reduction is a result of lower electricity production requirements, corresponding decreased transmission and distribution losses, and less auxiliary fuel consumption.

The total GHG reduction in the livestock and poultry lighting subsectors, T8 fluorescent tubes scenario, is 0.05 MT of CO_2 equivalents by 2050. Details of GHG mitigation of the efficient lighting scenarios for slow and fast penetration case are given in Tables 3-33 and B-8 (Appendix B), respectively.

Table 3-33: Alberta's livestock and poultry lighting subsector mitigation – GHG reduction – slow penetration scenario (2050)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030	2040	2050
GHG reduction (poultry lighting CFLs vs. reference)	0	-0.001	-0.002	-0.004	-0.006
GHG reduction (poultry lighting T8 vs. reference)	0	-0.001	-0.003	-0.005	-0.007
GHG reduction (D/C lighting T8 vs. reference)	0	-0.005	-0.012	-0.021	-0.031
GHG reduction (swine lighting T8 vs. reference)	0	-0.002	-0.004	-0.008	-0.012

As developed by the LEAP model

The overall GHG reductions achievable for slow and fast penetration scenarios are shown in Figure 3-1 and Figure B-1 (Appendix B), respectively.

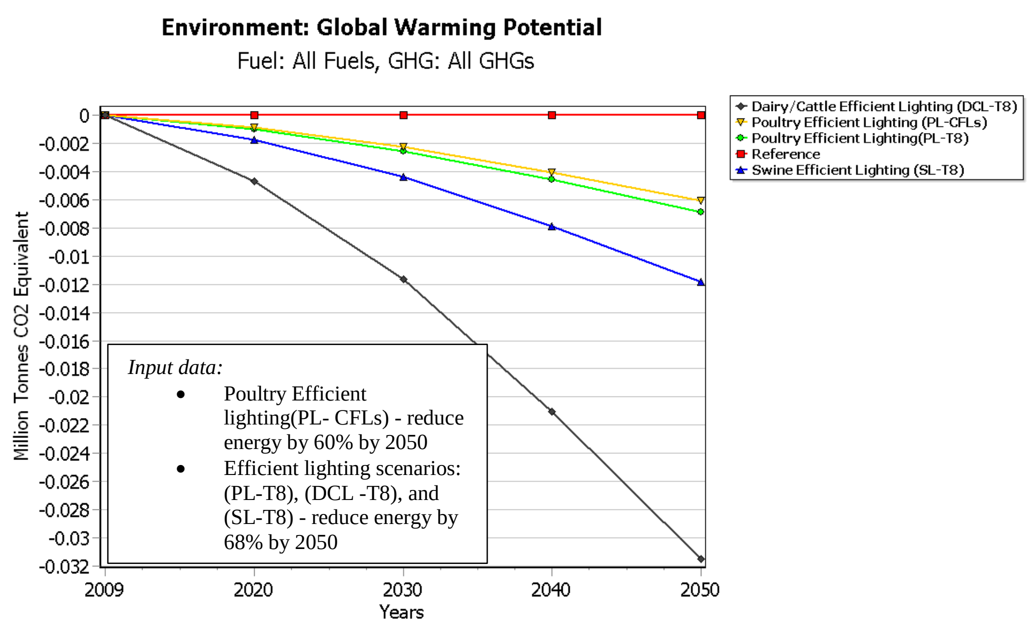


Figure 3-1: GHG mitigation in Alberta's livestock and poultry lighting subsector in the four mitigation scenarios in the slow penetration case (2050)

As shown in Tables 3-35 and 3-36, the efficient lighting mitigation scenarios for the livestock and poultry subsectors reduce energy demand by reducing electricity consumption, which in turn reduces transformation output, i.e., the electricity produced by natural gas and coal power plants. The reduction in electricity production results in lower GHG emissions. Figure 3-3 shows the total GHG mitigation in the scenarios caused by energy reduction in both demand and transformation sectors. The dairy and cattle subsector's efficient lighting scenario has the highest GHG mitigation, whereas the poultry efficient lighting-CFLs scenario has the lowest GHG mitigation.

3.6.2 Results of the implementation of mitigation scenarios in Alberta's livestock and poultry ventilation subsectors

The results of the mitigation scenarios indicate energy reduction in both demand and transformation sectors. In the efficient ventilation scenarios for both the livestock and poultry subsectors, there is a reduced demand for energy, and as a result transformation output is reduced. The efficient ventilation scenarios have a total energy demand reduction up to 0.54 PJ by 2050. Demand sector details for the slow and fast penetration scenarios are given in Table 3-34 and Table B-9 (Appendix B), respectively.

Table 3-34: Alberta livestock ventilation subsector mitigation – demand reduction – slow penetration scenario (2050)

Energy demand (PJ)	2009	2020	2030	2040	2050
Reference	42.62	54.56	68.46	86.10	108.51
Livestock ventilation	42.62	54.51	68.32	85.76	107.99
Demand reduction (livestock ventilation vs. reference)	0	-0.047	-0.141	-0.338	-0.528
Poultry ventilation	42.62	54.56	68.46	86.09	108.50
Demand reduction (poultry ventilation vs. reference)	0	-0.001	-0.004	-0.009	-0.015

As developed by the LEAP model

The results indicate the maximum reduction in energy demand in 2050 is 0.528 PJ through efficient ventilation in the livestock subsector; the reduction in energy demand for the poultry subsector, with efficient ventilation, is 0.015PJ in 2050. The overall energy conversion output reductions for both slow and fast penetration scenarios are given in Table 3-35 and Table B-10 (Appendix B), respectively.

Table 3-35: Alberta's livestock ventilation subsector mitigation – transportation output reduction – slow penetration scenario (2050)

Output (PJ)	2009	2020	2030	2040	2050
Output reduction (livestock ventilation vs. reference)	0	-0.176	-0.445	-1.072	-1.742
Output reduction (poultry ventilation vs. reference)	0	-0.005	-0.012	-0.030	-0.049

As developed by the LEAP mode

By 2050, the total reduction in GHG emissions in the livestock and poultry subsectors is 0.098 MT of CO_2 equivalents. The overall achievable GHG reduction in both the slow and fast penetration scenarios is shown in Table 3-36 and Table B-11 (Appendix B), respectively.

Table 3-36: Alberta's livestock ventilation subsector mitigation – GHG reduction – slow penetration scenario (2050)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030	2040	2050
GHG reduction (livestock ventilation vs. reference)	0	-0.010	-0.024	-0.059	-0.095
GHG reduction (poultry ventilation vs. reference)	0	0	-0.001	-0.002	-0.003

As developed by the LEAP model

Figure 3-2 and Figure B-2 show the total achievable GHG mitigation from both slow and fast mitigation scenarios.

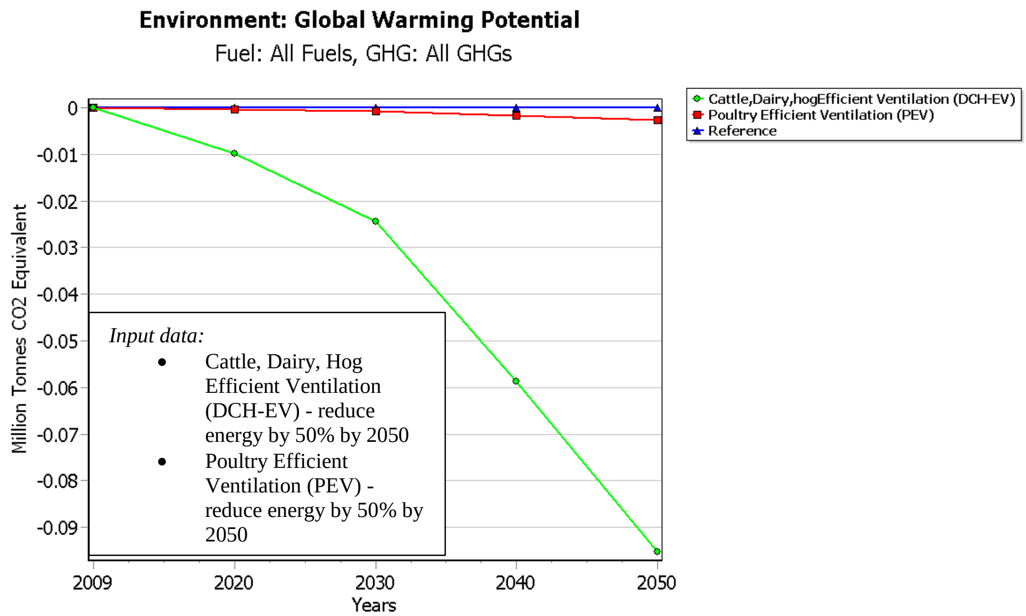


Figure 3-2: GHG mitigation in Alberta's livestock and poultry subsector ventilation section by two mitigation scenarios – slow penetration scenario (2050)

As it can be seen from Figure 3-2, GHG mitigation in the livestock subsector efficient ventilation scenario is significantly higher than that in the poultry subsector scenario, which is due to the fact that the energy demand in the livestock ventilation subsectors is much higher than in the poultry ventilation subsector. According to Table 3-39 and Table 3-40, reduction in energy demand in the livestock subsector is higher than in the poultry subsector. These reductions result in reductions in the transformation output (electricity output). It follows, then, that GHG emissions from the natural gas and coal power plants that provide the electricity used in the livestock efficient ventilation scenario are lower than in the poultry efficient ventilation scenario.

3.6.3 Results of implementing mitigation scenarios in Alberta's farm machine subsector

In Alberta's farm machine subsector, GHG mitigation scenarios were developed for tractors, combines and balers. These scenarios are characterized by the inclusion of efficient tractors and the assumed penetration of biodiesel into farm machinery (tractors, combines and balers). Four GHG mitigation options were developed to improve energy efficiency and mitigate GHGs through the use of efficient equipment and renewable fuels. All the data for energy demand of the four mitigation scenarios in both the slow and the fast penetration scenarios are given in Table 3-37 and Table B-12 (Appendix B), respectively.

Table 3-37: Alberta's farm machine subsector mitigation – demand reduction – slow penetration scenario (2050)

Energy demand (PJ)	2009	2020	2030	2040	2050
Reference	42.62	54.56	68.46	86.10	108.51
Efficient tractor	42.62	53.51	63.97	79.27	99.97
Demand reduction (efficient tractor vs. reference)	0	-1.05	-4.49	-6.82	-8.54
Biodiesel tractor	42.62	54.56	68.46	86.10	108.51
Demand reduction (biodiesel tractor vs. reference)	0	0	0	0	0
Biodiesel combine	42.62	54.56	68.46	86.10	108.51
Demand reduction (biodiesel combine vs. reference)	0	0	0	0	0
Biodiesel baler	42.62	54.56	68.46	86.10	108.51
Demand reduction (biodiesel baler vs. reference)	0	0	0	0	0

As developed by the LEAP model

The results indicate that for the efficient tractor scenario the overall reduction in energy demand in 2050 is 8.54 PJ. However, the rest of the scenarios, i.e., biodiesel tractor, biodiesel combine, and biodiesel baler, do not show any change in terms of energy demand. The total energy transformation output after implementing mitigation options for the both slow and fast penetration scenarios is shown in Table 3-38 and Table B-13 (Appendix B), respectively.

Table 3-38: Alberta's farm machine subsector mitigation – transportation output reduction – slow penetration scenario (2050)

Output (PJ)	2009	2020	2030	2040	2050
Output reduction (efficient tractor vs. reference)	0	-1.80	-4.49	-6.82	-8.54
Output reduction (biodiesel tractor vs. reference)	0	-4.74	-7.95	-12.09	-15.14
Output reduction (biodiesel combine vs. reference)	0	-0.43	-0.76	-1.22	-1.60
Output reduction (biodiesel baler vs. reference)	0	-0.01	-0.02	-0.04	-0.05

As developed by the LEAP model

The overall reduction in energy output is 25.33 PJ by 2050. The total reduction in energy conversion output results from a lower diesel production requirement and less auxiliary fuel consumption. Consequently, these mitigation scenarios show reduced GHG emissions in the farm machine subsector. The overall GHG mitigation of all scenarios in the farm machine subsector is estimated to be 2.27 MT of CO_2 equivalents. Details of achievable GHG mitigation for both slow and fast penetration scenarios are shown in Table 3-39 and table B-14 (Appendix B), respectively.

Table 3-39: Alberta's farm machine subsector – GHG mitigation – slow penetration scenario (2050)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030	2040	2050
Reference	27.32	46.73	47.84	49.45	51.62
Efficient tractor	27.32	46.63	47.44	48.84	50.85
GHG reduction (efficient tractor vs. reference)	0	-0.098	-0.405	-0.615	-0.770
Biodiesel tractor	27.32	46.47	47.13	48.37	50.26
GHG reduction (biodiesel tractor vs. reference)	0	-0.254	-0.711	-1.081	-1.353
Biodiesel combine	27.32	46.71	47.78	49.34	51.47
GHG reduction (biodiesel combine vs. reference)	0	-0.023	-0.068	-0.109	-0.143
Biodiesel baler	27.32	46.73	47.84	49.45	51.61
GHG reduction (biodiesel baler vs. reference)	0	-0.001	-0.002	-0.003	-0.005

As developed by the LEAP model

By 2050, the total reduction in GHG emissions in the efficient tractor scenario is 0.77 MT of CO_2 equivalents and in the biodiesel tractor and biodiesel combine scenarios is 1.353 and 0.143 MT of CO_2 equivalents, respectively. The results in the biodiesel baler scenario show that the GHG mitigation is 0.005 MT of CO_2 equivalents; this is lower than that of other farm machine mitigation scenarios, since the total energy consumption in the baler section is low. Figure 3-3 shows the trend of GHG mitigation for the four scenarios in Alberta's farm machine subsector.

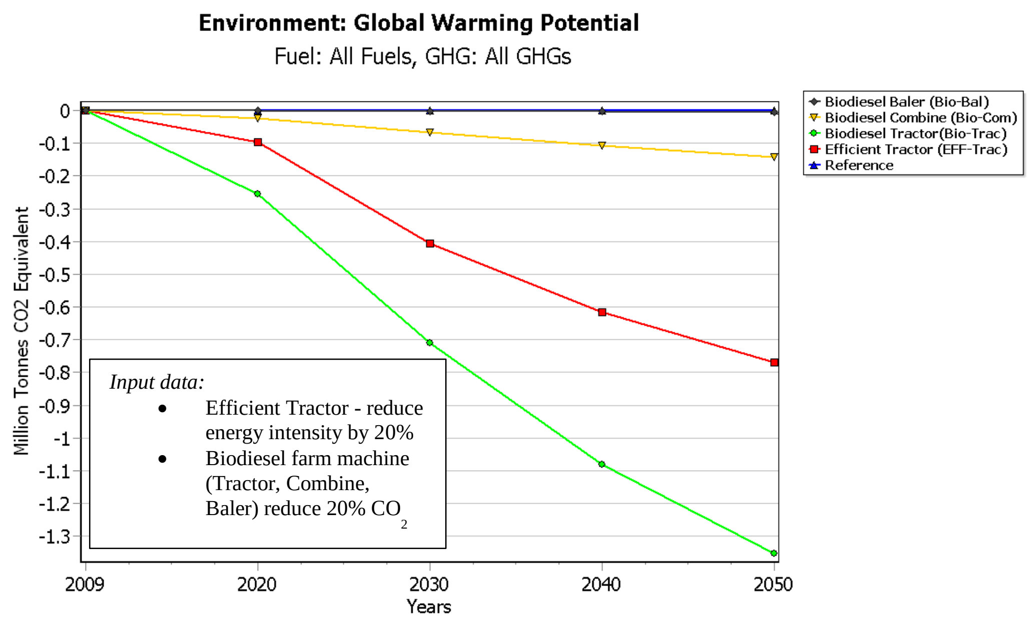


Figure 3-3: GHG mitigation in Alberta's farm machine section by four mitigation scenarios

Figure 3-3 shows that the biodiesel tractor scenario has the highest GHG mitigation in the farm machine subsector. In this scenario, the penetration of biodiesel consumption in tractors reduced transformation output and diesel requirement; further, biodiesel emits 20% CO_2 equivalent less than diesel. In this scenario, total diesel consumption is lower than in the efficient tractor scenario. However, in the efficient tractor scenario, GHG is mitigated by a 20% reduction in diesel consumption. Thus the biodiesel tractor mitigation scenario is more effective in terms of GHG mitigation than the efficient tractor scenario. The trend of GHG mitigation in the four mitigation scenarios for the period of 2009 to 2030 is shown in Figure B-3 in Appendix B.

3.6.4 Results of implementing mitigation scenarios in Alberta's farm truck subsector

Four GHG mitigation scenarios for Alberta's farm truck subsector were developed based on biofuel use and efficiency improvement of farm trucks. The overall reduction in energy demand achieved by applying each of the four mitigation options is shown in Table 3-40. The details of these mitigation options for the fast penetration scenario are given in Table B-15 in Appendix B.

Table 3-40: Alberta's farm transport subsector mitigation – demand reduction – slow penetration scenario (2050)

Energy demand (PJ)	2009	2020	2030	2040	2050
Reference	42.62	54.56	68.46	86.10	108.51
High Efficient diesel truck (HEV diesel truck)	42.62	54.52	68.38	85.98	108.36
Demand reduction (HEV truck vs. reference)	0	-0.037	-0.074	-0.116	-0.146
Diesel truck	42.62	54.36	67.71	84.78	106.85
Demand reduction (diesel truck vs. reference)	0	-0.20	-0.75	-1.32	-1.66
Biodiesel truck	42.62	54.56	68.46	85.10	108.51
Demand reduction (biodiesel truck vs. reference)	0	0	0	0	0
Ethanol truck	42.62	54.56	68.46	86.10	108.51
Demand reduction (ethanol truck vs. reference)	0	0	0	0	0

As developed by the LEAP model

The maximum demand reduction in the farm truck subsector is estimated to be 1.66 PJ for the diesel truck scenario in 2050. The total demand reduction for HEV diesel trucks is estimated to be 0.146 PJ in 2050. The demand reduction in biodiesel and ethanol trucks is estimated to be zero by 2050. As discussed in the biofuel farm truck scenarios, the reduction in fossil fuel energy demand is equivalent to the increase in ethanol and biodiesel fuel consumption. Total energy transformation output after the use of these mitigation options is given in Table 3-41 and Table B-16 (Appendix B).

Table 3-41: Alberta's farm truck subsector mitigation – transportation output reduction – slow penetration scenario (2050)

Output (PJ)	2009	2020	2030	2040	2050
Output reduction (HEV truck vs. reference)	0	-0.063	-0.074	-0.116	-0.146
Output reduction (diesel truck vs. reference)	0	-0.35	-0.75	-1.32	-1.66
Output reduction (biodiesel truck vs. reference)	0	-0.31	-0.37	-0.58	-0.73
Output reduction (ethanol truck vs. reference)	0	-0.63	-1.12	-1.65	-2.09

As developed by the LEAP model

For the HEV diesel, diesel truck, and biodiesel truck scenarios, the overall reductions in energy output are 0.146 PJ, 1.66 PJ, and 0.73 PJ, respectively, whereas the overall reduction in energy output in the ethanol truck mitigation scenario is 2.09 PJ in 2050. The total energy conversion output reduction is a result of lower diesel and gasoline production requirement, corresponding decreased transmission and distribution losses, and less auxiliary fuel consumption. The total GHG reduction in the farm truck subsector achieved by the penetration of HEV trucks, diesel trucks, and biofuel trucks is shown in Table 3-42 and Figure 3-4.

Table 3-42: Alberta's farm transport subsector mitigation – GHG mitigation – slow penetration scenario (2050)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030	2040	2050
Reference	27.32	46.73	47.84	49.45	51.62
High efficient diesel truck (HEV truck)	27.32	46.72	47.83	49.44	51.60
GHG reduction (HEV truck vs. reference)	0	-0.003	-0.007	-0.010	-0.013
Diesel truck	27.32	46.71	47.79	49.35	51.49
GHG reduction (diesel truck vs. reference)	0	-0.016	-0.056	-0.099	-0.125
Biodiesel truck	27.32	46.71	47.81	49.40	51.55
GHG reduction (biodiesel truck vs. reference)	0	-0.017	-0.033	-0.052	-0.065
Ethanol truck	27.32	46.72	47.81	49.40	51.55
GHG reduction (ethanol truck vs. reference)	0	-0.012	-0.033	-0.048	-0.061

As developed by the LEAP model

The details of these mitigation scenarios for the fast penetration scenario (ending in 2030) are given in Table B-17 and Figure B-4 in Appendix B.

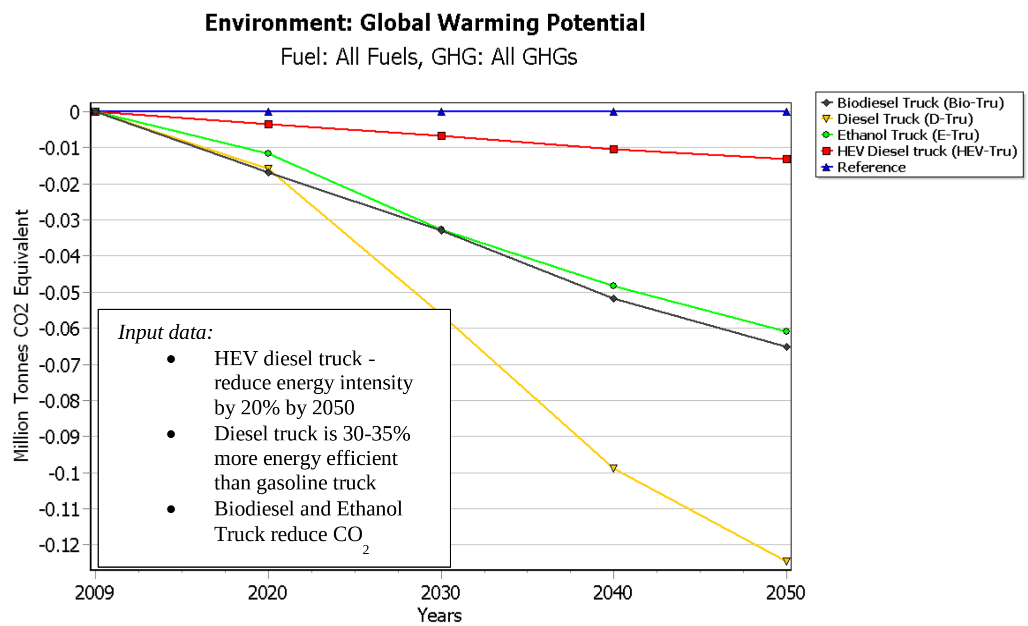


Figure 3-4: GHG mitigation in Alberta's farm transport subsector by four mitigation scenarios

The overall results of GHG reduction indicate that the diesel truck scenario is the best option to improve efficiency in the farm truck subsector, based on a switch from gasoline to diesel, which is 30-35% more efficient than gasoline. Moreover, GHG mitigation in the biodiesel truck scenario is slightly better than in the ethanol truck scenario. However, the difference in GHG mitigation is negligible, and other factors such as cost may be considered to favor one of the scenarios over the other. Finally, the HEV truck scenario has the lowest GHG mitigation in this category, due to its low penetration rate and low energy savings of only 20% compared to the diesel truck scenario.

3.6.5 Results of implementing mitigation scenarios (awareness programs for drivers, regular maintenance, tire pressure) in Alberta's farm machine and farm truck subsectors

In Alberta's agriculture sector, three scenarios were developed based on knowledge of operators: awareness programs for drivers, regular maintenance, and tire pressure. The results of the three scenarios confirm efficiency improvement in both energy consumption and GHG emissions. Table 3-43 shows the details of the energy demand sector in Alberta's farm machine and farm truck subsectors for slow penetration scenarios.

Table 3-43: Alberta's farm machine and farm truck subsector, mitigation scenarios (awareness programs, regular maintenance, tire pressure) – demand reduction

Energy demand (PJ)	2009	2020	2030	2040	2050
Reference	42.62	54.56	68.46	86.10	108.51
Regular maintenance	42.62	51.67	63.00	78.18	97.77
Demand reduction (regular maintenance vs. reference)	0	-2.89	-5.46	-7.92	-10.74
Awareness programs	42.62	51.67	63.00	78.18	97.77
Demand reduction (awareness programs vs. reference)	0	-2.89	-5.46	-7.92	-10.74
Tire pressure	42.62	50.97	61.25	75.34	94.27
Demand reduction (tire pressure vs. reference)	0	-3.60	-7.21	-10.75	-14.24

As developed by the LEAP model

In these mitigation scenarios, the results indicate that the maximum reduction in energy demand in 2050 is 14.24 PJ, achieved by the tire pressure scenario, followed by regular maintenance and awareness programs, with 10.68 PJ. The energy transformation output after use of mitigation strategies is given in Table 3-44.

Table 3-44: Alberta's farm machine and farm truck subsectors, mitigation scenarios, (awareness programs, regular maintenance, tire pressure) – transportation output reduction

Output (PJ)	2009	2020	2030	2040	2050
Output reduction (regular maintenance vs. reference)	0	-4.9	-5.5	-7.9	-10.7
Output reduction (awareness programs vs. reference)	0	-4.9	-5.5	-7.9	-10.7
Output reduction (tire pressure vs. reference)	0	-6.1	-7.2	-10.8	-14.2

As developed by the LEAP model

For the regular maintenance and awareness programs scenarios, the overall energy output reduction in 2050 is 10.7 PJ, whereas for the tire pressure mitigation scenario, the reduction is 14.2 PJ. The total energy conversion output reduction is a result of lower diesel and gasoline production requirement, corresponding decreased transmission and distribution losses, and less auxiliary fuel consumption. The overall GHG reductions are shown in Table 3-45.

Table 3-45: Alberta's farm machine and farm truck subsector, mitigation scenarios (awareness programs, regular maintenance, tire pressure) – GHG mitigation

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030	2040	2050
Reference	27.32	46.73	47.84	49.45	51.62
Regular maintenance	27.32	46.46	47.36	48.74	50.65
GHG reduction (regular maintenance vs. reference)	0	-0.27	-0.49	-0.71	-0.96
Awareness programs	27.32	46.46	47.36	48.74	50.65
GHG reduction (awareness programs vs. reference)	0	-0.27	-0.49	-0.71	-0.96
Tire pressure	27.32	46.40	47.20	48.49	50.34
GHG reduction (tire pressure vs. reference)	0	-0.33	-0.65	-0.96	-1.27

As developed by the LEAP model

In 2050, the total reduction in GHG emissions in the farm machine and farm truck subsectors is 1.27 MT of CO_2 equivalents according to the optimal tire pressure scenario, and in the regular maintenance and awareness programs scenarios the GHG emission reduction is 0.96 MT of CO_2 equivalents. Figure 3-5 shows the overall GHG reduction achievable in these mitigation scenarios.

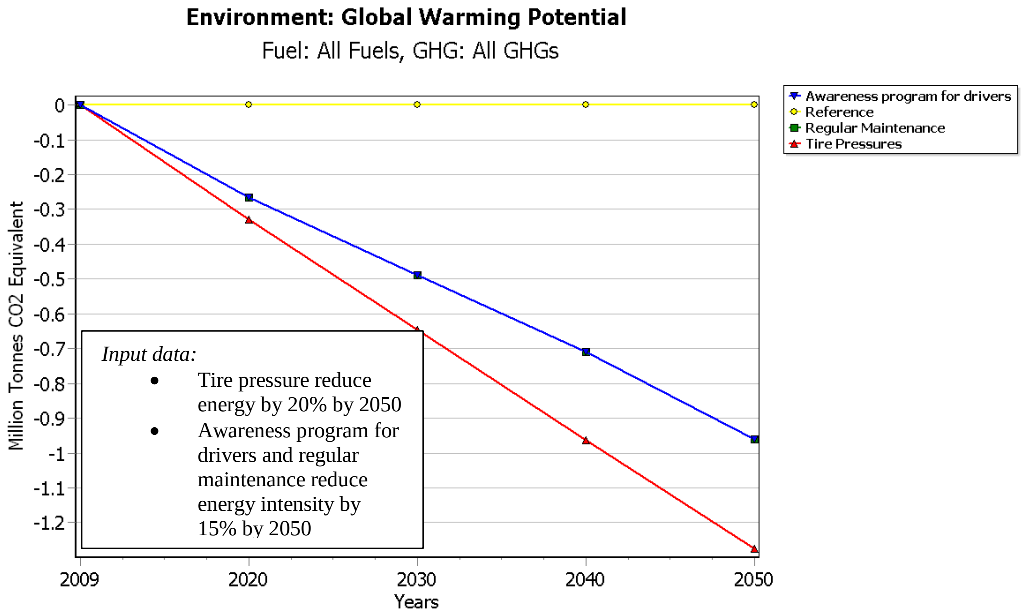


Figure 3-5: GHG mitigation in Alberta's farm machine and farm truck subsector by regular maintenance, awareness programs, and tire pressure scenarios

The overall GHG mitigation results demonstrate that in terms of reducing GHG emissions, checking tire pressure is more important than regular maintenance or awareness programs, based on the amount of energy saved by each scenario. As explained earlier, tire pressure reduces energy consumption by 20%, whereas regular maintenance and awareness programs scenarios reduce energy consumption by 15%. In addition, in both the general maintenance scenario and the scenario improving driver education and knowledge, GHG mitigation is the same.

3.6.6 Overall GHG reduction by various mitigation options in Alberta's agriculture sector

The overall GHG mitigation in the 17 mitigation scenarios is given in Table 3-46. The biodiesel tractor, tire pressure, and educated driver scenarios have a large potential for GHG mitigation, followed by the scenarios for regular maintenance, HEV diesel truck, and efficient tractor. The biodiesel tractor and tire pressure scenarios have a GHG mitigation potential of 1.353 MT of CO_2, and 1.275 MT of CO_2 by 2050.

Table 3-46: Summary of GHG mitigation scenarios projected for Alberta's agriculture sector in the slow penetration scenario (2050)

GHG Mitigation Option (MT of CO_2 eq.)	2020	2030	2040	2050
Livestock efficient ventilation	-0.01	-0.024	-0.059	-0.095
D/C efficient lighting (T8)	-0.005	-0.012	-0.021	-0.031
Biodiesel baler	-0.001	-0.002	-0.003	-0.005
Biodiesel combine	-0.023	-0.068	-0.109	-0.143
Biodiesel tractor	-0.254	-0.711	-1.081	-1.353
Biodiesel truck	-0.017	-0.033	-0.052	-0.065
Efficient tractor	-0.098	-0.405	-0.615	-0.77
Diesel truck	-0.016	-0.056	-0.099	-0.125
Ethanol truck	-0.012	-0.033	-0.048	-0.061
HEV diesel truck	-0.07	-0.337	-0.657	-0.92
Poultry efficient lighting (CFLs)	-0.001	-0.002	-0.004	-0.006
Poultry efficient lighting(T8)	-0.001	-0.003	-0.005	-0.007
Poultry efficient ventilation	0.000	-0.001	-0.002	-0.003
Swine efficient lighting	-0.002	-0.004	-0.008	-0.012
Awareness programs	-0.266	-0.489	-0.709	-0.961
Regular maintenance	-0.266	-0.489	-0.709	-0.961
Tire pressure	-0.330	-0.645	-0.962	-1.275

As developed by the LEAP model

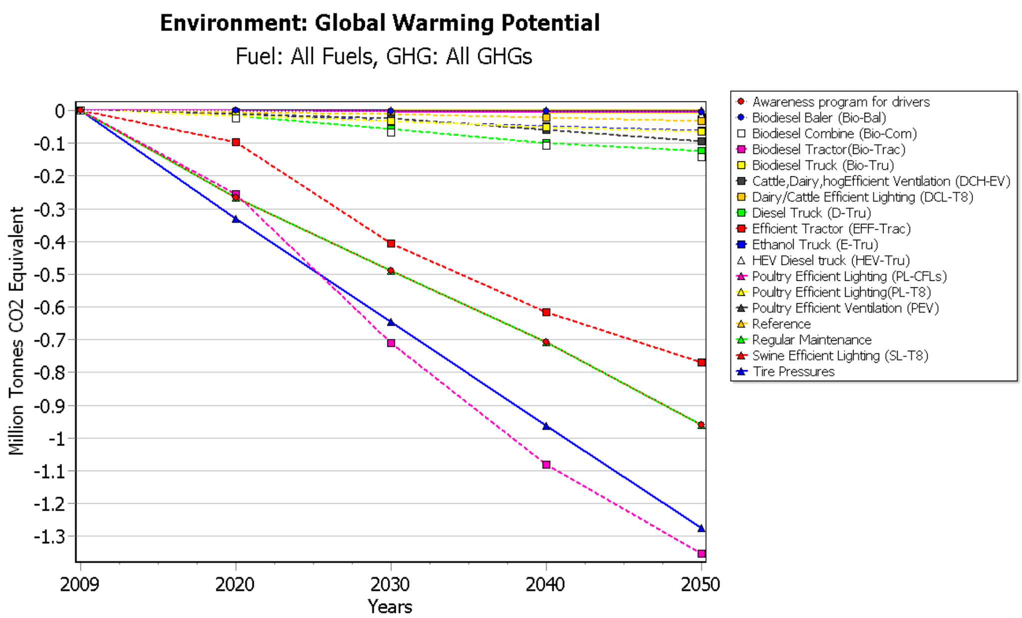


Figure 3-6: Overall GHG mitigation for all the mitigation scenarios for Alberta agriculture

The results of GHG mitigation for all scenarios discussed here are shown in Figure 3-6. In the farm machine and farm truck subsectors, both energy efficiency improvement and the renewable fuel scenarios have a higher potential of GHG mitigation compared to the lighting and ventilation subsectors of Alberta agriculture's energy demand sector.

In this chapter all proposed mitigation scenarios for Alberta's agriculture sector with their key assumptions were described, and the results of each scenario were shown in terms of the possibility of energy savings and GHG mitigation. However, to evaluate the overall performance of the mitigation scenarios, the cost of implementing each scenario should also be considered. Cost curves evaluate the relative costs per tonne of GHG mitigated in a particular time frame. In the next chapter, the cost benefit analysis and cost curve of each mitigation scenario will be discussed.

Chapter 4. GHG Mitigation Cost Curves for Alberta's Agriculture Sector

4.1 Introduction

In the previous chapter the main goal was to first identify GHG mitigation options associated with energy demand in Alberta's agricultural sector. GHG mitigation options are related to energy efficiency and renewable energy. The next goal was to estimate GHG mitigation potential and energy reduction for several options over the study period in slow and fast penetration scenarios. Various GHG mitigation scenarios were introduced, and the technology penetration rates for these scenarios, along with their corresponding GHG mitigation potential, were evaluated and compared with the reference scenario. However, in order to examine the feasibility of the scenarios, it is important to consider the abatement costs associated with them as well as their potential to mitigate GHG emissions. More precisely, the mitigation of GHG emissions requires studying past energy consumption and GHG emissions and both forecasting into a future time period and eventually applying techno-economic techniques to examine the cost-effectiveness of potential energy and GHG emission-reduction policies.

Performing a cost-benefit analysis is a common means of assessing the economic feasibility of projects and policies. The analysis can be used to compare benefits and costs of projects and policies before implementing them. In general, a cost-benefit analysis of emissions reductions is developed by estimating the abatement costs of both improving energy efficiency and of mitigating the environmental impacts.

In this chapter, a cost-benefit analysis is applied in the LEAP model to Alberta's agriculture sector to help assess GHG mitigation options. Afterwards, cost curves are developed in order to evaluate the relative cost-benefit of the various GHG mitigation scenarios.

4.2 Objective

Several GHG mitigation scenarios were developed in Alberta's agricultural sector to determine suitable options for the province. The objective of this study is to identify and assess all potential GHG mitigation options (in terms of million tonnes of CO_2 mitigated) and their abatement costs (dollar per tonne of CO_2 mitigated) in the energy demand side of Alberta's agriculture sector.

This objective was achieved by performing a cost-benefit analysis for different GHG mitigation options in Alberta's agriculture sector and developing cost curves to rank them. The Long range Energy Alternatives Planning Systems model (LEAP) was used in the analyses.

4.3 Methodology for developing GHG mitigation cost curves

A cost-benefit analysis option in the LEAP model was used to calculate the costs of each component of the energy system such as the capital, operating, and maintenance costs of using and purchasing the technologies in both the demand and transformation sectors. Other costs include costs of extracting primary resources and importing fuels and the benefits from exporting fuels (Stockholm Environment Institute, 2011). The cost-benefit analysis in the LEAP model helps to identify a range of policy scenarios and is not intended to determine financial viability. The analysis is a tool used to evaluate various options and technologies based on the availability of the technology in order to achieve sustainable development of a particular region. It is important to compare scenarios with similar economic assumptions.

In Alberta's agriculture energy subsector model, cost-benefit analyses of GHG mitigation scenarios were developed to evaluate the incremental costs of capital, operation, and maintenance for each of the proposed scenarios and to compare them with the reference scenario. In order to evaluate the relative cost-benefits of each mitigation scenario, cost curves were developed based on both the incremental costs and the GHG mitigation potential in each scenario.

Cost curves help to assess each mitigation option by comparing techno-economic aspects of options and determining the relative cost per tonne of GHG mitigated for a particular time period. Cost curves represent the incremental abatement cost (dollar per tonne of CO_2) and GHG mitigation and compare the incremental costs of GHG mitigated in a particular scenario over the study period. The overall methodologies for developing cost curves in Alberta's agriculture sector are:

- Gathering data for energy demand and supply, energy end-use characteristics of devices, characteristics of energy supply and resources, cost of devices, and cost of operation and maintenance
- Developing base year data in LEAP
- Developing environmental emissions factors for each sector and subsector in LEAP using TED
- Developing a reference scenario in LEAP over a study period
- Developing mitigation scenarios in LEAP over the study period for both slow and fast penetration scenarios
- Calculating incremental costs for each scenario and comparing each scenario with reference scenario
- Estimating the difference in GHG mitigation between mitigation and reference scenario from LEAP
- Developing cost curves based on potential GHG mitigation options and abatement costs

In this study, the estimated incremental cumulative cost is calculated as the net present value (NPV) of the total discounted incremental cost over the study period in the slow penetration scenario (2009-2050) and the fast penetration scenario (2009-2030). All the costs are based on NPV in 2010. Afterwards, the estimated incremental cumulative cost of each mitigation scenario is compared to the reference scenario. The total cost and the incremental net present value for each scenario are developed based on a discount rate. In each scenario, the total discounted cash flow of the scenario is used to annualize capital cost, actual operation and maintenance costs (O&M costs), and fuel costs incurred due to the operation of the plant over the study period using the discount rate.

Cost curves for Alberta's agriculture sector are developed based on incremental abatement costs (dollar per tonne of CO_2 presented in y-axis) and GHG mitigation (million tonnes of CO_2 presented in x-axis) of each particular scenario compared to the reference scenario over the study period for both slow and fast penetration scenarios. A typical cost curve is shown in Figure 4-1. The height of the curve indicates the incremental cost of GHG mitigation and the width represents the total amount of GHG mitigated in a particular scenario. In Figure 4-1, each bar shows various GHG mitigation options.

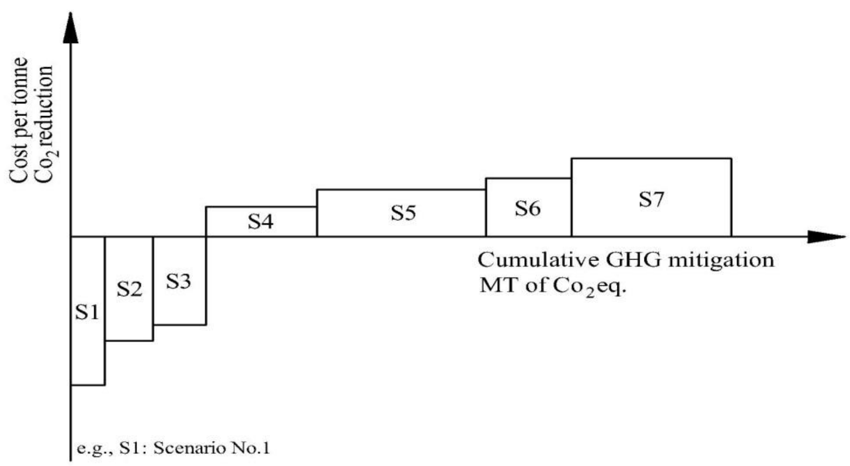


Figure 4-1: Typical cost curve showing incremental NPV of costs and the total mitigation in a particular scenario

4.4 Cost of saved energy

The cost of saved energy (CSE) is an expression of the cumulative costs of saving energy and the CSE method is commonly used to evaluate the economics of GHG emission reduction associated with the saved energy. The CSE method is used to measure the techno-economic costs involved in efficiency improvement and technology investment. Depending on the model characteristics, the CSE is the net cost of efficiency improvement divided by annual savings in energy or annual reduction in GHG emissions (Friedrich et al., 2009). The CSE can be presented either as $/GJ or $/KWh (Friedrich et al., 2009). In Alberta agriculture's energy demand model, the CSE was estimated for various energy efficiency improvement scenarios. In order to estimate the CSE for these scenarios, the discount rate in the LEAP model was set to 5%, and the life spans of different equipment were set to different values.

Developing and evaluating the cost of saved energy for different energy efficiency improvement scenarios require detailed analysis and assessment of the implementation of new technologies. In order to develop and estimate the CSE for different energy efficiency improvement scenarios for Alberta, current and future energy prices in Alberta (i.e. diesel, gasoline, and electricity prices) were used and are given in Appendix C.

In the biofuel scenarios in which gasoline and diesel fuel of farm machinery and farm trucks are replaced with ethanol and biodiesel fuel, an activity cost method instead of a CSE was applied to evaluate the actual demand costs of mitigation scenarios. The activity cost is based on operating and maintenance costs and the constancy of capital costs. The details of the activity costs are given in Appendix C.

4.5 Cost-benefit analyses of various mitigation scenarios

4.5.1 Mitigation scenario 1 – Alberta agriculture – poultry and eggs subsector – efficient lighting (compact fluorescent lamps – CFLs)

4.5.1.1 Input data and assumptions

The cost of installing and running an incandescent lighting system was compared to the cost of a compact fluorescent lamp system in one poultry farm building. In this mitigation scenario, several input data were required to estimate the cost of saved energy of the proposed lighting system. The assessment data and assumptions used for developing this scenario are based on an article on energy-efficient poultry lighting published by the Ontario Ministry of Agriculture, Food and Rural Affairs (Clarke & Ward, 2006b). It is assumed that the size the poultry barn was 224 ft. × 40 ft., total number of operating hours was 12 per day, and 54 lamps were required (Clarke & Ward, 2006b). The electricity price was based on the National Energy Board's forecast (NEB, 2011). Details of data used to estimate the CSE for efficient lighting in a poultry operation (CFLs) are given in Table C-2 in Appendix C.

4.5.2 Mitigation scenario 2 – Alberta agriculture – poultry and eggs subsector – efficient lighting (T8 fluorescent tube lighting)

4.5.2.1 Input data and assumptions

The same values as scenario 1 are assumed for the size of poultry barn and operating hours (Clarke & Ward, 2006b). The electricity price forecast is based on the National Energy Board's figures (NEB, 2011). Details of estimating the cost of saved energy for this scenario are given in Table C-3 in Appendix C.

4.5.3 Mitigation scenario 3 – Alberta agriculture – dairy and cattle subsector – efficient lighting (T8 fluorescent tube lighting)

4.5.3.1 Input data and assumptions

This scenario assumes the lighting system operates 18 hr/day and uses 30 incandescent 100 watt bulbs, which will be replaced by 20 T8 tubes. The electricity price is based on the National Energy Board's forecast (NEB, 2011). Details of estimating the cost of saved energy for this scenario are given in Table C-4 in Appendix C.

4.5.4 Mitigation scenario 4 – Alberta agriculture – hog (swine) subsector – efficient lighting (T8 fluorescent tube lighting)

4.5.4.1 Input data and assumptions

In the similar hog farm building, the capital cost of impleming an incandescent light system was compared with capital cost of a fluorescent tube system; these details are given in Appendix C. The total operating hours for a swine farm building is assumed to be 7 hours per day on average. The electricity price used to calculate the CSE was based on the National Energy Board's forecast (NEB, 2011). Table C-5 in Appendix C shows the details of estimating the cost of saved energy for this scenario.

4.5.5 Mitigation scenario 5 - Alberta agriculture - livestock (dairy, cattle, and hog) subsectors - efficient ventilation systems (fans)

4.5.5.1 Input data and assumptions

The total operating hours are assumed to be 8,760 hours per year for both existing and efficient fans. The electricity price used to calculate the CSE was based on the National Energy Board's forecast (NEB, 2011). Table C-6 in Appendix C illustrates the details of estimating the cost of saved energy for this scenario.

4.5.6 Mitigation scenario 6 – Alberta agriculture – poultry and eggs subsector – efficient ventilation systems (fans)

4.5.6.1 Input data and assumptions

This mitigation scenario assumes the total operating hours for each type of fan is 24 hours per day, and the electricity price used to calculate the CSE was forecast based on the National Energy Board's forecast (NEB, 2011). The details of estimating the cost of saved energy for this mitigation scenario are given in Table C-7 in Appendix C.

4.5.7 Mitigation scenario 7 – Alberta agriculture – farm machinery subsector – efficient diesel tractors

4.5.7.1 Input data and assumption

The cost of saved energy was estimated based on capital and operating costs of existing and efficient stock, discount rate, and the life-time of the tractor for incremental annualized capital cost. The diesel price used to calculate the CSE was forecast based on the National Energy Board's forecast (NEB, 2011). Table C-9 in Appendix C illustrates the details of data used for estimating the cost of saved energy.

4.5.8 Mitigation Scenario 8 – Alberta agriculture – farm machinery subsector – biodiesel tractors

4.5.8.1 Input data and assumptions

In this scenario, the activity cost was estimated. The capital costs for both diesel and biodiesel engines are assumed to be the same. This mitigation option does not offer any energy savings; however, the operating cost changes because diesel fuel is replaced by biodiesel fuel. Diesel and biodiesel prices used to calculate the activity cost were based on the National Energy Board's forecast (NEB, 2011). The details of estimating the activity costs are given in Table C-11 in Appendix C.

4.5.9 Mitigation scenario 9 – Alberta agriculture – farm machinery subsector – biodiesel combines

4.5.9.1 Input data and assumptions

Biodiesel, a renewable and clean fuel, has an effect on the operating fuel costs of combines compared to those of diesel combines. The activity costs were estimated similarly to those in scenario 8. The details of estimating activity costs are given in Table C-12 in Appendix C. Diesel and biodiesel prices used to calculate the activity cost were based on the National Energy Board's forecast (NEB, 2011).

4.5.10 Mitigation scenario 10 – Alberta agriculture – farm machinery subsector – biodiesel balers

4.5.10.1 Input data and assumptions

The activity costs were estimated based on operating costs. Diesel and biodiesel prices used to calculate the activity costs were based on the National Energy Board's forecast (NEB, 2011). The details of estimating activity costs are given in Table C-13 in Appendix C.

4.5.11 Mitigation scenario 11 – Alberta agriculture – farm truck subsector – diesel trucks

4.5.11.1 Input data and assumptions

Factors in this mitigation scenario were evaluated based on the estimated cost of saved energy. The CSE was estimated based on the capital and operating costs of diesel trucks and gasoline trucks. A discount rate and the life of the truck were applied to capital costs in order to estimate the incremental annualized capital cost. Based on the National Energy Board's figures, diesel and gasoline prices were forecast for estimating the cost of saved energy and are shown in Table C-15 in Appendix C (NEB, 2011).

4.5.12 Mitigation scenario 12 – Alberta agriculture – farm truck subsector – biodiesel trucks

4.5.12.1 Input data and assumptions

Activity costs were estimated in order to evaluate GHG mitigation costs. The capital costs and fuel consumption of both diesel and biodiesel trucks were assumed to be the same. However, the operating costs are different because fuel prices are different. Diesel and biodiesel prices used to estimate activity costs were based on the National Energy Board's forecast (NEB, 2011). Details of estimating the activity cost for this mitigation scenario are given in Table C-16 in Appendix C.

4.5.13 Mitigation scenario 13 – Alberta agriculture – farm truck subsector – high efficient vehicle (HEV diesel truck)

4.5.13.1 Input data and assumptions

The HEV diesel truck scenario was modeled based on efficiency improvement. The overall efficiency improvement of new high efficiency diesel trucks is 15-20% compared to older diesel trucks (Natural Resources Canada, 2012e; US-DOE-EERE, 2013e). The new trucks' efficiency was categorized as high based on the Fuel Consumption Guide published by Natural Resources Canada (Natural Resources Canada, 2012e). In the LEAP model, actual energy intensity improvements in HEV diesel trucks are up to 20% compared to older diesel trucks. In this scenario, the assessment and estimation of the cost of saved energy are based on earlier study (Subramanyam et al., 2013).

4.5.14 Mitigation scenario 14 – Alberta agriculture – farm truck subsector – ethanol trucks

4.5.14.1 Input data and assumptions

The GHG mitigation in the ethanol truck scenario is achieved by using ethanol instead of gasoline in farm truck activities. The energy intensity of the farm truck using E85 ethanol is assumed to be the same as that of the gasoline engine truck.

However, the advantage of using ethanol rather than gasoline is lower GHG emissions. In order to assess this mitigation scenario, activity costs were estimated based on operating costs. It is assumed that the overall energy intensity and capital costs of the ethanol truck are the same as those of the gasoline truck (Natural Resources Canada, 2012a, 2012b; US-DOE-EERE, 2013d). The emission factors used in the LEAP model are based on studies on combustion emissions for various flexi-fuel vehicles (Subramanyam et al., 2013; Zhai et al., 2007). Gasoline and ethanol prices used to estimate the activity costs were based on the National Energy Board's forecast (NEB, 2011). The activity costs were estimated in order to evaluate the scenario. The details of the estimates are given in Table C-18 in Appendix C.

4.6 Results and discussion

4.6.1 Scenario 1 slow and fast: Alberta agriculture – poultry and eggs subsector – efficient lighting (compact fluorescent lamps – CFLs)

4.6.1.1 Energy and emissions profile

In the slow penetration (2050) case of scenario 1, high-efficiency lighting (CFLs) in the poultry subsector, the LEAP model estimates a reduction of 0.6 PJ in electricity demand, which is equivalent to an average of 0.01 PJ/year savings in electricity. It is estimated that in this scenario, an average mitigation of 2.60 kT of CO_2 per year can be achieved.

In the fast penetration (2030) case of scenario 1, electricity is reduced by 0.1 PJ by 2030. This is equal to 0.009 PJ/year on average. The GHG mitigation is estimated to be 1.73 kT of CO_2 per year on average. The average GHG mitigation per year is higher in the slow penetration scenario because the changes are implemented over a longer period (40 versus 20 years). Overall details of GHG reduction potential are shown in Appendix D.

4.6.1.2 Cost assessment

The techno-economic model was used to assess the cost of saved energy for scenario 1 (efficient lighting in the poultry subsector – compact fluorescent lamps – CFLs). The CSEs are -$0.10/GJ (2010-2020), -$0.14/GJ (2020-2030), -$0.19/GJ (2030-2040), and -$0.26/GJ (2030-2040). All input data and details for obtaining the CSEs are shown in Appendix C.

4.6.1.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation in this scenario is shown in Table 4-1. The total emissions from the fast penetration for scenario 1 are 0.03 MT of CO_2 with -$1.67 million total discounted incremental cost. Accordingly, the result for cost per unit GHG mitigation is -48.31 ($/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-1: Summary of results for scenario 1 (efficient lighting in the poultry subsector – CFLs)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.10	0.03
Incremental NPV of costs (million $)	-2.96	-1.67
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	-28.45	-48.31

As developed by the LEAP model

4.6.2 Scenario 2 slow and fast: Alberta agriculture – poultry eggs subsector – efficient lighting (T8 fluorescent tube lighting)

4.6.2.1 Energy and emissions profile

In the slow penetration of scenario 2 (2050), high-efficiency lighting in the poultry subsector, the LEAP model estimates an average reduction of 0.02 PJ/year in electricity demand during the study period (2010-2050), which is equal to the total of 0.66 PJ electricity savings by 2050. It is estimated that in this scenario, an average mitigation of 2.95 kT of CO_2 per year can be achieved during the study period. In the fast penetration of scenario 2 (2030), the total reduction of electricity is 0.2 PJ during the study period (2010-2030), and the overall reduction in GHG emission is estimated to be 39.17 kT of CO_2 by 2030. The details of the GHG reduction potential are shown in Appendix D.

4.6.2.2 Cost assessment

The techno-economic model is used to assess the CSE for scenario 2 (efficient lighting in poultry subsector – T8 fluorescent tube lighting). The CSEs are -$0.01/GJ (2010-2020), -$0.05/GJ (2020-2030), -$0.10/GJ (2030-2040), and -$0.17/GJ (2040-2050). All input data and details for acquiring the CSE are shown in Appendix C.

4.6.2.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation for this scenario is shown in Table 4-2. The total mitigation from the fast penetration scenario is 0.04 MT of CO_2 with -$0.13 million of total discounted incremental cost. Accordingly, the result for cost per unit GHG mitigation is -3.41 ($/tonne of CO_2 eq.) in the 2030 scenario**.**

Table 4-2: Summary of results for scenario 2 (efficient lighting in the poultry subsector – T8)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.12	0.04
Incremental NPV of costs (million $)	-0.24	-0.13
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	-2.01	-3.41

As developed by the LEAP model

4.6.3 Scenario 3 slow and fast: Alberta agriculture – dairy and cattle subsectors – efficient lighting (T8 fluorescent tube lighting)

4.6.3.1 Energy and emissions profile

In the slow penetration of scenario 3 (2050), high-efficiency lighting in the dairy and cattle subsectors, the LEAP model estimates a total reduction of 3.03 PJ in electricity demand during the study period (2010-2050). It is estimated that in this scenario, an average mitigation of 0.54 MT of CO_2 can be achieved during the study period. In the fast penetration of scenario 3 (2030), the total reduction of electricity is 0.95 PJ by 2030 (2010-2030) and the overall GHG emission reduction is estimated to be 0.18 MT of CO_2 by 2030. Overall details of GHG reduction potential are shown in Appendix D.

4.6.3.2 Cost assessment

The techno-economic model is adopted to assess the CSE for scenario 3 (efficient lighting in the dairy and cattle subsector – T8 fluorescent tube lighting). The CSEs are -$0.08/GJ (2010-2020), -$0.12/GJ (2020-2030), -$0.17/GJ (2030-2040), and -$0.24/GJ (2040-2050). All input data and details for acquiring the CSE are shown in Appendix C.

4.6.3.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation for this scenario is shown in Table 4-3. The total emissions from the fast penetration scenario are 0.18 MT of CO_2 with -$4.90 million total discounted incremental costs. Accordingly, the cost per unit GHG mitigation is -$27.29 ($/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-3: Summary of results for scenario 3 (efficient lighting in the dairy and cattle subsector – T8)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.54	0.18
Incremental NPV of costs (million $)	-8.69	-4.90
Cost per unit GHG mitigation ($/tonne of $CO_{2\ eq.}$)	-16.07	-27.29

As developed by the LEAP model

4.6.4 Scenario 4 slow and fast: Alberta agriculture – hog (swine) subsector – efficient lighting (T8 fluorescent tube lighting)

4.6.4.1 Energy and emissions profile

In the slow penetration of scenario 4 (2050), high efficiency lighting in the hog subsector, the LEAP model estimates the total reduction of 1.14 PJ in electricity demand during the study period (2010-2050). It is estimated that in this scenario, an average mitigation of 0.20 MT of CO_2 by 2050 can be achieved. In the fast penetration of scenario 4 (2030), the total reduction of electricity is 0.36 PJ by 2030 (2010-2030) and the overall GHG emission reduction is estimated to be 0.07 MT of CO_2 by 2030. Overall details of GHG reduction potential are shown in Appendix D.

4.6.4.2 Cost assessment

The CSEs, as assessed by the developed techno-economic model, are -$0.08/GJ (2010-2020), -$0.12/GJ (2020-2030), -$0.17/GJ (2030-2040), and -$0.24/GJ (2040-2050). All input data and details for acquiring the CSEs are shown in Appendix C.

4.6.4.3 GHG abatement cost evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation in this scenario is shown in Table 4-4. The total emissions from the fast penetration scenario are 0.07 MT of CO_2 with -\$1.84 million total discounted incremental costs. Accordingly, the result for cost per unit GHG mitigation is -27.29 (\$/tonne of CO_2 eq.) in the 2030 scenario**.**

Table 4-4: Summary of results for scenario 4 (efficient lighting in the hog subsector – CFLs)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.20	0.07
Incremental NPV of costs (million \$)	-3.27	-1.84
Cost per unit GHG mitigation (\$/tonne of CO_2 eq.)	-16.07	-27.29

As developed by the LEAP model

4.6.5 Scenario 5 slow and fast: Alberta agriculture – livestock (dairy, cattle and hogs) subsectors – efficient ventilation systems (fan)

4.6.5.1 Energy and emissions profile

In the slow penetration of scenario 5 (2050), high efficiency ventilation in the livestock subsector, the LEAP model estimates the total reduction of 8.04 PJ in electricity demand during the study period (2010-2050), which is equal to an average 0.20 PJ/year electricity reduction. A reduction of 1.43 MT of CO_2 by 2050 is estimated. In the fast penetration of scenario 5 (2030), the average reduction of electricity is 0.16 PJ/year by 2030 (2010-2030) and the average GHG emission reduction is estimated to be 0.03 MT of CO_2 per year by 2030. Overall details of the potential of GHG reductions are shown in Appendix D.

4.6.5.2 Cost assessment

In scenario 2 (efficient ventilation in the livestock subsector – efficient fans), the CSEs, as assessed by the developed techno-economic model, are -\$0.46/GJ (2010-

2020), -\$0.66/GJ (2020-2030), -\$0.91/GJ (2030-2040), and -\$1.26/GJ (2040-2050). All input data and details for acquiring the CSE are shown in Appendix C.

4.6.5.3 GHG abatement cost evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-5. The total emissions from the fast penetration scenario are 0.60 MT of CO_2 with -\$210.77 million total discounted incremental costs. Accordingly, the cost per unit GHG mitigation is -353.90 (\$/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-5: Summary of results for scenario 5 (efficient ventilation in the livestock subsectors – efficient fans)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	1.43	0.60
Incremental NPV of costs (million \$)	-265.47	-210.77
Cost per unit GHG mitigation (\$/tonne of CO_2 eq.)	-185.39	-353.90

As developed by the LEAP model

4.6.6 Scenario 6 slow and fast: Alberta agriculture – poultry subsector – efficient ventilation systems (fans)

4.6.6.1 Energy and emissions profile

In slow penetration of scenario 6 (2050), high-efficiency ventilation in the poultry subsector, the LEAP model estimates the average reduction of 0.005 PJ/year of electricity demand during the study period (2010-2050). It is estimated that in this scenario, an average mitigation of 1.0 kT of CO_2 per year during the study period can be achieved. In the fast penetration of scenario 6 (2030), the total reduction of electricity is 0.004 PJ/year by 2030 (2010-2030) and the average GHG emission reduction is estimated to be 0.81 kT of CO_2 per year by 2030. The overall details of the potential of GHG reductions are shown in Appendix D.

4.6.6.2 Cost assessment

The techno-economic model was used to assess the CSE for scenario 2 (efficient ventilation in the poultry subsector – efficient fans). The CSEs are -\$0.93/GJ (2010-2020), -\$1.33/GJ (2020-2030), -\$1.83/GJ (2030-2040), and -\$2.53/GJ (2040-2050). All input data and details for acquiring CSEs are shown in Appendix C.

4.6.6.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-6. The total emissions from the fast penetration scenario are 0.02 MT of CO_2 with -\$13.53 million total discounted incremental costs. Accordingly, the cost per unit GHG mitigation is -834.69 (\$/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-6: Summary of results for scenario 6 (efficient ventilation in the poultry and eggs subsector – efficient fans)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.04	0.02
Incremental NPV of costs (million \$)	-18.28	-13.53
Cost per unit GHG mitigation (\$/tonne of CO_2 eq.)	-458.01	-834.69

As developed by the LEAP model

4.6.7 Scenario 7 slow and fast: Alberta agriculture – farm machinery subsector – efficient diesel tractors

4.6.7.1 Energy and emissions profile

In the slow penetration for scenario 7 (2050), efficient tractors in the farm machine subsector, the LEAP model estimates the average reduction of 4.14 PJ/year in diesel demand during the study period (2010-2050). It is estimated that in this scenario, an average mitigation of 0.4 MT of CO_2 per year during the study period can be achieved. In the fast penetration of scenario 7 (2030), the total reduction of diesel is 2.93 PJ/year by 2030 (2010-2030) and the overall GHG emission reduction is estimated to be 0.27 MT of CO_2 per year by 2030. The overall details of the potential of GHG reductions are shown in Appendix D.

4.6.7.2 Cost assessment

The CSEs, as assessed by the developed techno-economic model, are $1.74/GJ (2010-2020), -$1.27/GJ (2020-2030), -$2.07/GJ (2030-2040), and -$2.54/GJ (2040-2050). All input data and details for acquiring CSEs are shown in Appendix C.

4.6.7.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-7. The total emissions from the fast penetration scenario are 5.35 MT of CO_2 with $215.83 million total discounted incremental costs. Accordingly, the result for cost per unit GHG mitigation is 40.36 ($/tonne of CO_2 eq.) in 2030 scenario

Table 4-7: Summary of results for scenario 7 (efficient tractor)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	14.97	5.35
Incremental NPV of costs (million $)	312.03	215.83
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	20.84	40.36

As developed by the LEAP model

4.6.8 Scenario 8 slow and fast: Alberta agriculture – farm machinery subsector – biodiesel tractors

4.6.8.1 Energy and emission profile

In the slow penetration of scenario 8 (2050), biodiesel tractors, LEAP estimates a reduction in diesel demand of 5-20% per liter of biodiesel blend (B5-B20), which is equal to the liters of biodiesel added into the blend. However, the total energy demand in this scenario remains the same as the reference scenario. It is estimated that in this scenario, an average mitigation of 0.7 MT of CO_2 per year by 2050 can be achieved. In the fast penetration of scenario 8 (2030), there is no change in energy demand, as was found in the slow penetration of scenario 8; however, the average GHG emission reduction is estimated to be 0.5 MT of CO_2 per year by 2030. Overall details of the potential of GHG reductions are shown in Appendix D.

4.6.8.2 Cost assessment

The techno-economic model was used to assess total activity cost per tonne for scenario 8 (biodiesel tractors in the farm machine subsector). Activity costs are $1.98/tonne (2010-2020), $0.88/tonne (2020-2030), -$1.47/tonne (2030-2040) and -$3.82/tonne (2040-2050). All input data and details for acquiring activity cost are shown in Appendix C.

4.6.8.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-8. The total emissions from the fast penetration scenario are 10.25 MT of CO_2 with $195.92 million total discounted incremental costs. Accordingly, the result for cost per unit GHG mitigation is 19.12 ($/tonne of CO_2 eq.) in 2030 scenario

Table 4-8: Summary of results for scenario 8 (biodiesel tractors)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	27.31	10.25
Incremental NPV of costs (million $)	294.89	195.92
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	10.80	19.12

As developed by the LEAP model

4.6.9 Scenario 9 slow and fast: Alberta agriculture – farm machinery subsector – biodiesel combines

4.6.9.1 Energy and emission profile

For the slow penetration of scenario 9 (2050), biodiesel for combines, there are no changes in energy demand expected. The reduction of diesel demand is about 5-20% per liter of biodiesel (B5-B20) and is equal to the number of liters of biodiesel added into the blend; thus, the net energy demand remains the same. It is estimated that in this scenario, GHG emissions are reduced by 0.07 MT of CO_2 per year on average during the study period. In the fast penetration of scenario 9 (2030), the average GHG emissions reduction is estimated to be 0.05 MT of CO_2 per year by 2030. Overall details of the potential of GHG reductions are shown in Appendix D.

4.6.9.2 Cost assessment

The total activity cost per tonne, as estimated by the developed techno-economic model, are \$0.27/tonne (2010-2020), \$0.12/tonne (2020-2030), -\$0.20/tonne (2030-2040) and -\$0.53/tonne (2040-2050). All input data and the details for acquiring activity costs are shown in Appendix C.

4.6.9.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-9. The total emissions from the fast penetration scenario are 0.94 MT of CO_2 with \$12.05 million total discounted incremental costs. Accordingly, the result for cost per unit GHG mitigation is 12.83 (\$/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-9: Summary of results for scenario 9 (biodiesel combines)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	2.71	0.94
Incremental NPV of costs (million $)	18.31	12.05
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	6.75	12.83

As developed by the LEAP model

4.6.10 Scenario 10 slow and fast: Alberta agriculture – farm machinery subsector – biodiesel balers

4.6.10.1 Energy and emission profile

According to the LEAP model estimation, the slow penetration for scenario 10 (2050), biodiesel balers in the farm machine subsector, does not result in any reduction in the energy demand for either the slow or the fast penetration scenarios. However, the reduction in diesel demand is 5-20% per liter B5-B20 and is equivalent to the number of biodiesel liters added into blend. Consequently, the amount of diesel demand reduction is the same as the increase of biodiesel demand. However, it is estimated in this scenario that emissions could be reduced by 0.002 MT of CO_2 per year on average by 2050. In the fast penetration of scenario 10 (2030), the overall GHG emission reduction is estimated to be 0.001 MT of CO_2 per year by 2030. Overall details of the potential of GHG reductions are shown in Appendix D.

4.6.10.2 Cost assessment

The techno-economic model is adopted for assessing activity costs for scenario 10 (biodiesel balers in the farm machinery subsector). Activity costs are $0.3/tonne (2010-2020), $0.11/tonne (2020-2030), -$0.18/tonne (2030-2040) and -$0.49/tonne (2040-2050). All input data and details for acquiring activity costs are shown in Appendix C.

4.6.10.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-10. The total emissions from the fast penetration scenario are 0.03 MT of CO_2 with $13.42 million total discounted incremental costs. Accordingly, the result for cost per unit GHG mitigation is 453.57 ($/tonne of CO_2 eq.) in the 2030 scenario**.**

Table 4-10: Summary of results in scenario 10 (biodiesel balers)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.09	0.03
Incremental NPV of costs (million $)	20.40	13.42
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	238.61	453.57

As developed by the LEAP model

4.6.11 Scenario 11 slow and fast: Alberta agriculture – farm truck subsector – diesel trucks

4.6.11.1 Energy and emission profile

In the slow penetration for scenario 11 (2050), diesel trucks in the farm truck subsector, the LEAP model estimates the average reduction of 0.77 PJ/year in energy demand for the study period (2010-2050) and an average reduction in GHG emission of 0.06 MT of CO_2 per year for the same period. In the fast penetration of scenario 11, the average energy reduction of 0.50 PJ/year and the average GHG emission reduction of 0.04 MT of CO_2 per year by 2030 are estimated. Overall details of the potential of GHG reductions are shown in Appendix D.

4.6.11.2 Cost assessment

The techno-economic model is adopted to assess CSEs for scenario 11 (diesel trucks in the farm truck subsector). The CSEs are -$41.6/GJ (2010-2020), -

\$56.9/GJ (2020-2030), -\$57.8/GJ (2030-2040), and -\$58.1/GJ (2040-2050). All input data and details for acquiring the CSEs are shown in Appendix C.

4.6.11.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario is shown in Table 4-11. The total emissions from the fast penetration scenario are 0.76 MT of CO_2 with -\$328.35 million total discounted incremental costs. Accordingly, the costs per unit GHG mitigation are -429.86 (\$/tonne of CO_2 eq.) in the 2030 scenario**.**

Table 4-11: Summary of results in scenario 12 (diesel trucks)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	2.32	0.76
Incremental NPV of costs (million \$)	-921.06	-328.35
Cost per unit GHG mitigation (\$/tonne of CO_2 eq.)	-396.54	-429.86

As developed by the LEAP model

4.6.12 Scenario 12 slow and fast: Alberta agriculture - farm truck subsector - biodiesel trucks

4.6.12.1 Energy and emissions profile

The slow penetration for scenario 12, biodiesel trucks in the farm truck subsector, does not result in any reduction in energy demand. Emissions were estimated to be reduced by 0.03 MT of CO_2 per year on average during the study period (2010-2050), or by a total reduction of 1.34 MT of CO_2. In the fast penetration of scenario 12, the average emission reduction is estimated to be 0.02 MT of CO_2 per year for the period of 2010 to 2030. The overall details of the potential of GHG reductions are shown in Appendix D.

4.6.12.2 Cost assessment

The techno-economic model was adopted to assess the activity costs for scenario 12 (biodiesel trucks in the farm truck subsector). Activity costs are $0.09/Km (2010-2020), $0.04/Km (2020-2030), -$0.06/Km (2030-2040) and -$0.17/km (2040-2050). All input data and details for acquiring activity costs are shown in Appendix C.

4.6.12.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation for this scenario are shown in Table 4-12. The total emissions from the fast penetration scenario are 0.45 MT of CO_2 with $3.45 million total discounted incremental costs. Accordingly, the costs per unit GHG mitigation is 7.61 ($/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-12: Summary of results for scenario 12 (biodiesel truck)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	1.35	0.45
Incremental NPV of costs (million $)	5.88	3.45
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	4.36	7.61

As developed by the LEAP model

4.6.13 Scenario 13 slow and fast: Alberta agriculture – farm truck subsector – high-efficient vehicles (HEV diesel truck)

4.6.13.1 Energy and emissions profile

In the slow penetration for scenario 13, high-efficient trucks in the farm truck subsector, the LEAP model estimates the average reduction of 0.08 PJ/year in diesel demand for the study period (2010-2050). It is estimated that in this scenario, an average mitigation of 0.007 MT of CO_2 per year can be achieved. In the fast penetration for scenario 13, the average reduction of diesel is 0.05 PJ/year between 2010 and 2030 and the overall reduction in GHG emissions is estimated to be 0.004 MT of CO_2 per year by 2030. Overall details of the potential of GHG reductions are shown in Appendix D.

4.6.13.2 Cost assessment

The techno-economic model is adopted to assess the CSE for scenario 13 (HEV trucks in the farm truck subsector). The CSEs are -4$/GJ (2010-2030) and -5$/GJ (2030-2050). The estimates used in this scenario are based on an earlier study (Subramanyam et al., 2013).

4.6.13.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation of this scenario are shown in Table 4-13. The total emissions from the fast penetration scenario are 0.09 MT of CO_2 with -$3.53 million total discounted incremental costs. Accordingly, the costs per unit GHG mitigation are -38.75 ($/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-13: Summary of results for scenario 13 (HEV diesel trucks)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	0.27	0.09
Incremental NPV of costs (million $)	-10.24	-3.53
Cost per unit GHG mitigation ($/tonne of CO_2 eq.)	-37.83	-38.75

As developed by the LEAP model

4.6.14 Scenario 14 slow and fast: Alberta agriculture – farm truck subsector – ethanol trucks

4.6.14.1 Energy and emission profile

In scenario 14 for ethanol trucks in the farm truck subsector, the reduction in gasoline demand for both the slow and fast penetration scenarios is 15% per liter of E85, which is equal to the number of liters of ethanol added to the blend. However, the same percentage of ethanol is added into energy demand.

Consequently, the net energy demand for this scenario remains the same as in the reference scenario. The LEAP model estimates the average reduction in GHG emissions is 0.03 MT of CO_2 per year by 2050 (2010-2050). In the fast penetration of scenario 14, the average reduction in GHG emissions estimated to be 0.02 MT of CO_2 per year by 2030. The overall details of GHG reduction potential are shown in Appendix D.

4.6.14.2 Cost assessment

The total activity costs per kilometer, as estimated by the developed techno-economic model, are \$0.12/Km (2010-2020), \$0.06/Km (2020-2030), -\$0.07/Km (2030-2040), and -\$0.20/km (2040-2050). All input data and details for acquiring the CSE are shown in Appendix C.

4.6.14.3 GHG abatement costs evaluated as per the LEAP model

The summary of the incremental NPV of costs and of the total achievable GHG mitigation for this scenario are shown in Table 4-14. The total emissions from the fast penetration scenario are 0.41 MT of CO_2 with \$8.48 million total discounted incremental costs. Accordingly, the costs per unit GHG mitigation is 20.48 (\$/tonne of CO_2 eq.) in the 2030 scenario.

Table 4-14: Summary of results for scenario 14 (ethanol trucks)

Scenario	2050	2030
Total GHG mitigated (million tonnes or MT)	1.22	0.41
Incremental NPV of costs (million \$)	14.13	8.48
Cost per unit GHG mitigation (\$/tonne of CO_2 eq.)	11.61	20.48

As developed by the LEAP model

4.7 GHG mitigation in the 2050 and 2030 scenarios

Various GHG emission reductions are achieved in the slow penetration scenarios developed for Alberta's agriculture sector. The main GHG emissions from agriculture are nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). Table 4-15 gives the summary of GHG emission mitigation in the 2050 scenarios.

Table 4-15: Emissions reduction for the 2050 scenarios

Reduction by 2050 (thousand tonnes)	NOx	SO_2
Cattle, dairy, hog - efficient ventilation	-5.46	-33.09
Dairy/cattle efficient lighting (DCL –T8)	-2.06	-12.02
Biodiesel balers (Bio – Bal)	-0.03	-0.07
Biodiesel combines (Bio – Com)	-0.91	-2.17
Biodiesel tractors (Bio – Trac)	-9.15	-21.83
Biodiesel truck (Bio – Tru)	-0.45	-3.86
Efficient tractor (EFF – Trac)	-253.68	-11.87
Diesel truck (D – Tru)	-5.06	9.05
Ethanol truck (E – Tru)	-11.19	-3.78
HEV diesel truck (HEV – Tru)	-2.50	-0.78
Poultry efficient lighting (PL – CLFs)	-0.40	-2.31
Poultry efficient lighting (PL – T8)	-0.45	-2.62
Poultry efficient ventilation (PEV)	-0.15	-0.92
Swine efficient lighting (SL – T8)	-0.78	-4.51

As developed by the LEAP model

The reduction of GHG emissions in the fast penetration scenario in Alberta's agricultural sector is shown in Table 4-16. Details of total GHG mitigation are given in Appendix D.

Table 4-16: Emissions reduction for the 2030 scenario

Reduction by 2030 (thousand tonnes)	NOx	SO_2
Cattle, dairy, hog - efficient ventilation (DCH – EV)	-2.28	-8.27
Dairy/cattle efficient lighting (DCL - T8)	-0.69	-2.49
Biodiesel balers (Bio – Bal)	-0.01	-0.02
Biodiesel combines (Bio – Com)	-0.31	-0.74
Biodiesel tractors (Bio – Trac)	-3.40	-8.11
Biodiesel truck (Bio – Tru)	-0.15	-1.28
Efficient tractor (EFF – Trac)	-89.68	-4.20
Diesel truck (D – Tru)	-1.65	2.95
Ethanol truck (E – Tru)	-3.71	-1.25
HEV diesel truck (HEV – Tru)	-0.83	-0.26
Poultry efficient lighting (PL - CLFs)	-0.13	-0.48
Poultry efficient lighting (PL - T8)	-0.15	-0.54
Poultry efficient ventilation (PEV)	-0.06	-0.23
Swine efficient lighting (SL – T8)	-0.26	-0.94

4.8 GHG Mitigation Cost Curves for Alberta's Agricultural Sector

In Alberta agriculture, the abatement cost curves of the mitigation scenarios show GHG abatement costs and the cumulative GHG mitigation of the scenarios compared to the reference scenario. GHG mitigation options in Alberta's agriculture model are based on renewable resources and energy-efficiency improvements set out in the demand module. In the LEAP model, GHG mitigation options are separated into two scenarios based on the technology penetration rate: the slow penetration scenario and the fast penetration scenario. The slow and fast penetration scenarios were further categorized into two types of scenarios based on the overall achievable GHG mitigation results from the LEAP model: a moderate improvement scenario and an accelerated improvement scenario. The scenarios with total GHG mitigation up to 1 MT of CO_2 are put into the moderate improvement scenario, and the scenarios with more than 1 MT of CO_2 put into the accelerated improvement scenario.

4.8.1 GHG mitigation cost curves in the slow penetration scenario

The moderate improvement mitigation cost curve is shown in Figure 4-2. In the moderate improvement scenario, the total achievable GHG mitigation is lower than 1 MT of CO_2 in a particular scenario, and the abatement cost of mitigation is in the range of negative values to positive values. The efficiency improvement in efficient ventilation in the poultry subsector and the high-efficient diesel truck subsector yields negative abatement costs of -$458 and -$37/tonne of GHG mitigated with overall achievable GHG mitigations of 0.04 and 0.27 MT of CO_2, respectively, compared to the reference scenario. The GHG abatement cost in the poultry efficient lighting (CFLs) and the dairy and cattle efficient lighting (T8) scenarios are -$28 and -$16/tonne of CO_2 mitigated, and the overall potential of CO_2 mitigation in these scenarios is 0.10 and 0.54 MT of CO_2 over the study period. The scenario dealing with efficiency improvements in hog (swine) lighting (T8) and poultry lighting (T8) yields a negative mitigation cost of -$16 and -$2/tonne of GHG mitigation with a total GHG abatement potential of 0.20 MT and 0.12 MT of CO_2 over 40 years compared to the reference scenario. The biodiesel baler scenario has a very low overall GHG mitigation, 0.09 MT of CO_2 over the study period, and a high abatement cost, $238.61/tonne of CO_2 mitigated; thus, replacing diesel fuel with B5-B20 (i.e., blending 5-20% biodiesel) has not shown very significant GHG reduction in the baler subsector since the total energy consumption in that subsector is low.

Overall, efficient ventilation in the poultry subsector has the largest potential for cost savings (i.e., the height of the bar in the graph) and lowest potential for GHG mitigation (the width of the bar in the graph). The implementation of efficiency improvements in HEV diesel trucks and the implementation of efficient lighting in livestock and poultry have considerable energy cost savings compared to the reference scenario, and they have moderate GHG mitigation potential. However, the biodiesel baler has the largest incremental costs of GHG mitigation with a significantly low GHG mitigation, due to low energy consumption in the baler section.

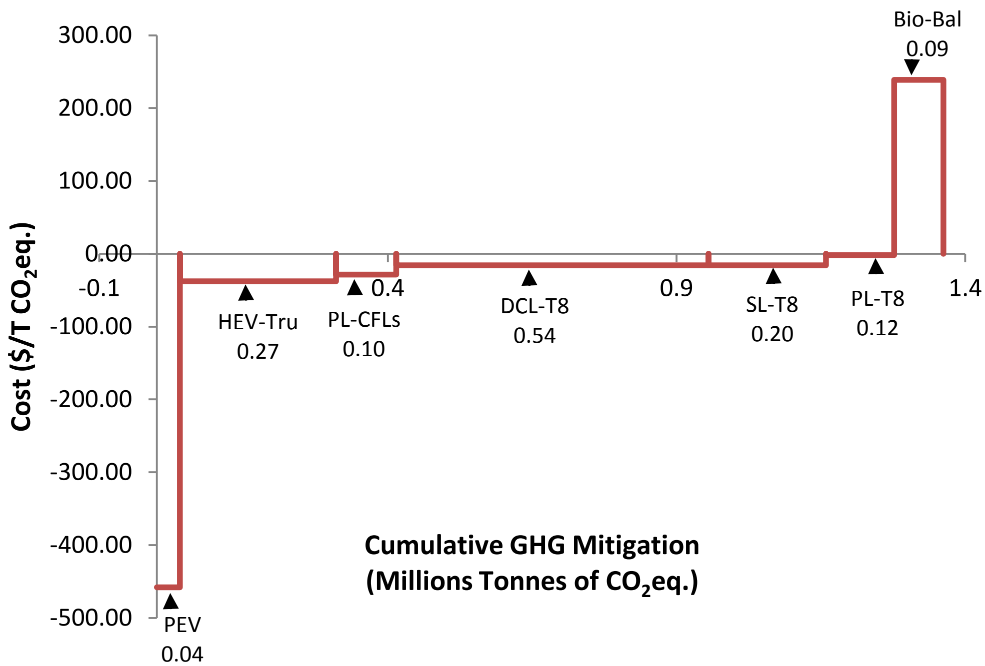


Figure 4-2: Moderate improvement mitigation cost curve for Alberta agriculture in the slow penetration scenario, 2010-2050 (based on NPV 2010)

The GHG mitigation cost curve for the accelerated improvement scenario is shown in Figure 4-3. In the accelerated improvement scenario, the total GHG mitigation achievable is higher than 1 MT of CO_2 and the abatement costs are in the range of negative and positive values. The GHG mitigation scenario in diesel truck and efficient ventilation for the livestock subsector has a negative mitigation cost, at -$396 and -$185/tonne of CO_2 mitigation with achievable GHG mitigation of 2.32 and 1.43 MT CO_2 by 2050, respectively. These two mitigation scenarios indicate large savings in terms of GHG emissions due to less fuel and electricity consumption. All the biodiesel truck, combine, and tractor scenarios have shown positive costs: the biodiesel truck and biodiesel combine scenarios have an overall GHG mitigation potential of 1.35 MT of CO_2 and 2.71 MT of CO_2, and abatement costs are \$4 and \$6/tonne of CO_2 mitigated by 2050, respectively. The biodiesel tractor scenario has a higher GHG mitigation, as tractor has the highest fuel consumption in Alberta's agriculture sector, 27.31 MT of CO_2 and abatement costs of \$10/tonne of CO_2 mitigated by 2050. Another biofuel scenario, ethanol truck, yields a positive cost of \$11/tonne of GHG mitigated with an overall achievable GHG mitigation of 1.22 MT CO_2 compared to the reference scenario. The GHG mitigation scenarios involving the use of efficient of tractors shows a high GHG mitigation, 14.97 MT of CO_2, and positive abatement costs of \$20/ tonne of GHG mitigation (indicating large cost saving and large CO_2 mitigation potential).

The implementations of diesel truck and efficient ventilation in the livestock subsector have both shown savings with negative GHG abatement costs. Therefore, they are economically attractive, but the potential of GHG mitigation is not extremely high. The biofuel farm machinery and farm truck as well as the efficient tractor categories show positive GHG abatement costs compared to the reference scenario in Alberta's agriculture sector. The potential of GHG savings is high, due to the fact that large volumes of energy are consumed in the farm machine and farm truck categories.

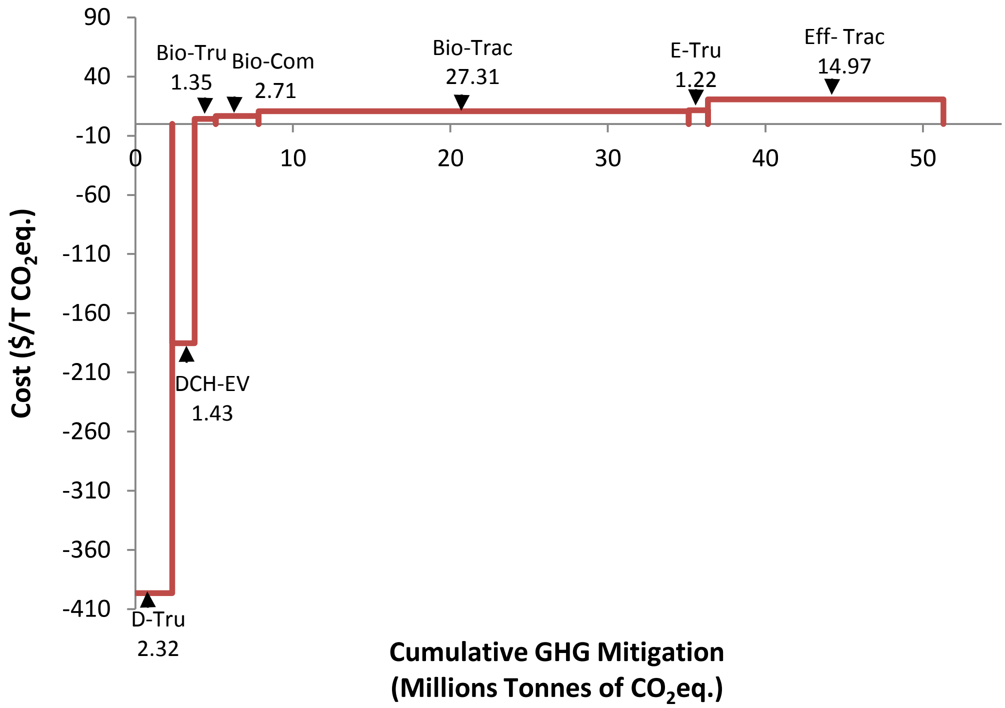


Figure 4-3: Accelerated growth mitigation cost curve for Alberta agriculture in the slow penetration scenario, 2010-2050 (based on NPV 2010)

4.8.2 GHG mitigation cost curves in the fast penetration scenario

The GHG mitigation cost curve for the moderate improvement scenario in the 2030 scenario is shown in Figure 4-4. The scenarios dealing with efficiency improvements in the poultry efficient ventilation, diesel truck, and livestock (dairy, cattle, and hog) efficient ventilation categories show high negative costs in the range of -$834, -$429, and -$353 per tonne of GHG mitigation with a total GHG mitigation potential of 0.02 MT, 0.76 MT, and 0.60 MT of CO_2, respectively, over 20 years. One of the key contributors to the high negative abatement cost for each scenario is the low GHG mitigation during the study period. However, the GHG mitigation scenarios involving efficient lighting for livestock and poultry and the use of high efficiency (HEV) diesel trucks show medium GHG abatement costs (indicating medium costs) and significant CO_2 mitigation potential. Accordingly, poultry – efficient lighting (CFLs), HEV diesel truck, dairy and cattle – efficient lighting (T8s), hog (swine) – efficient lighting, and poultry – efficient lighting (T8s) have negative abatement costs of -$48,-$38, -$27, -$27, and -$3 per tonne of GHG mitigation with a total GHG mitigation potential of 0.03 MT, 0.09 MT, 0.18 MT, 0.07 MT, and 0.04 MT of CO_2, respectively, over 40 years. All the biofuel scenarios show positive costs: the biodiesel truck, biodiesel combine, ethanol truck, and biodiesel baler scenarios have an overall GHG mitigation potential of 0.45 MT, 0.94 MT, 0.41 MT, and 0.03 MT of CO_2, respectively, by 2030. The abatement costs for four proposed biofuel scenarios are $7, $12, $20, and $453 per tonne of CO_2 mitigated, respectively.

In summary, the implementation of efficiency improvements in poultry ventilation and livestock lighting and the implementation of diesel truck have considerable energy cost savings compared to the reference scenario, and they have low to moderate GHG mitigation potential. However, the implementation of high efficiency lighting (in both the livestock and the poultry subsectors) has negative GHG abatement costs with low energy cost savings. Therefore, the implementing of high efficiency lighting is economically attractive, but the potential of GHG mitigation is low. All biofuel scenarios have positive GHG abatement costs compared to the reference scenario, and they have moderate GHG mitigation potential. The biodiesel truck, biodiesel combine, and ethanol truck scenarios have positive abatement costs that are significantly lower than the biodiesel baler abatement costs. Therefore, the costs of implementing these three scenarios are significantly lower than those for the biodiesel baler scenario. Moreover, the GHG mitigation potential of these three scenarios is higher than for the biodiesel baler scenario (as illustrated by the wider bars), which makes them more attractive since lower investment results in higher GHG mitigations.

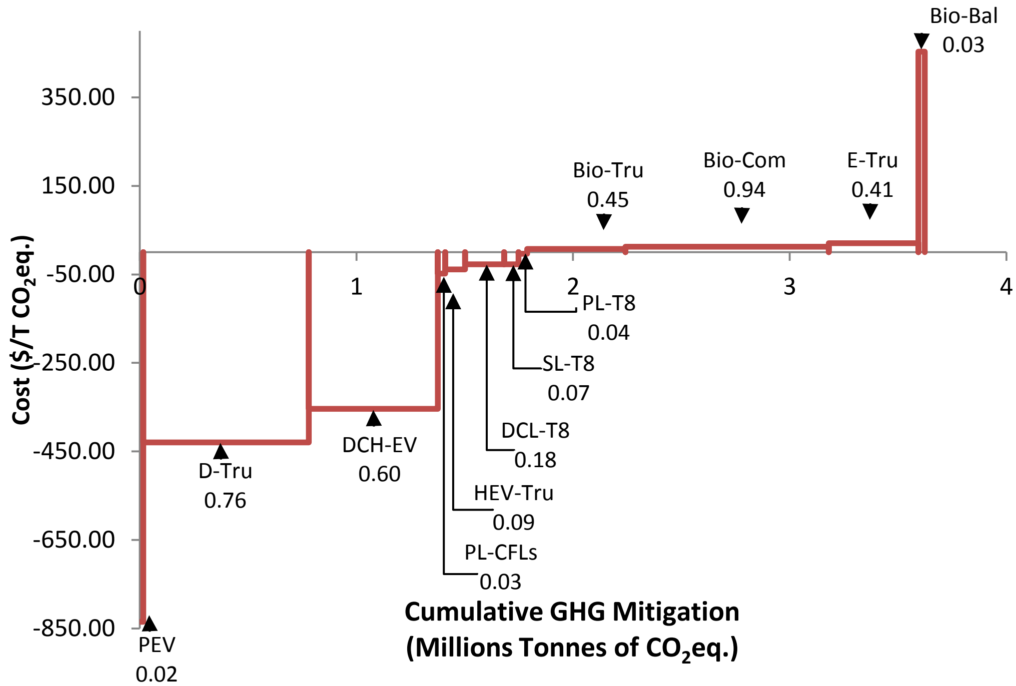


Figure 4-4: Moderate improvement mitigation cost curve for Alberta's agriculture sector in the fast penetration scenario, 2010-2030 (based on NPV 2010)

The GHG mitigation cost curve for the accelerated improvement scenario in the 2030 time period is shown in Figure 4-5. Only two scenarios with positive abatement costs in the fast penetration scenario are categorized in the accelerated improvement scenario: biodiesel tractor and efficient tractor. Biodiesel tractor and efficient tractor have a high GHG mitigation potential of 10.25 and 5.35 MT of CO_2 and abatement costs of $19.12 and $40.36/tonne of CO_2 mitigated, respectively. As the results indicate, the tractor category has a high potential of GHG mitigation in Alberta agriculture in both the efficiency improvement and renewable fuel scenarios. Despite the positive abatement costs that imply higher investment compared to the reference scenario, the scenarios may be desirable due to their significantly high potential for GHG mitigation.

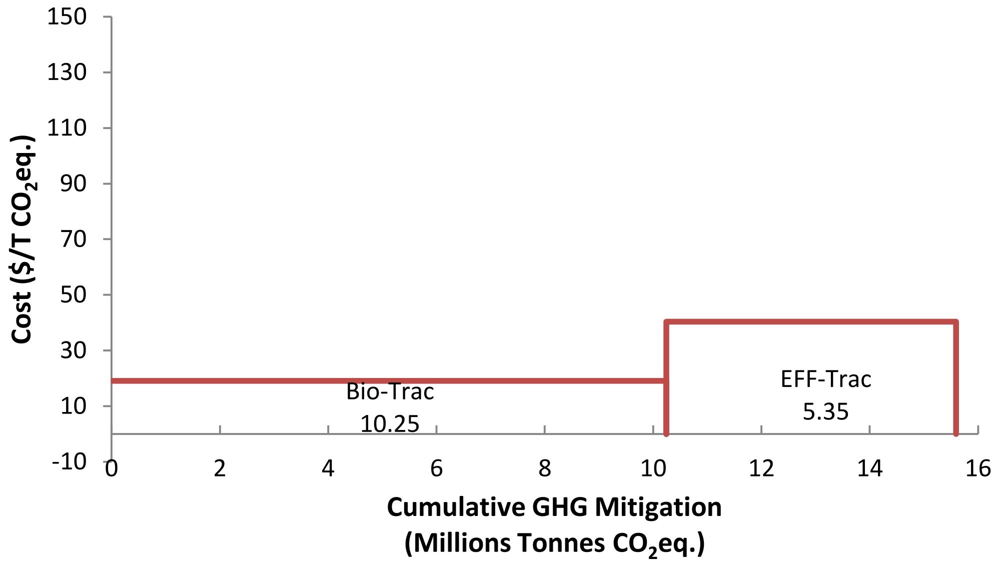


Figure 4-5: Accelerated growth mitigation cost curve for Alberta's agriculture sector in the fast penetration scenario, 2010-2030 (based on NPV 2010)

The results of the current study showed that the scenarios defined based on farm machine and farm truck, except for biodiesel baler, have significant potential to reduce GHG emissions in both the slow and fast penetration scenarios. The implementations of these scenarios either result in cost savings or require reasonable abatement costs that make them economically attractive. In contrast, the scenarios defined based on reducing electricity consumption in farm operations, i.e., the efficient lighting and ventilation scenarios, result in significant abatement cost savings. However, their GHG emission reduction is not considerable compared to the farm machine and farm truck scenarios.

In the current chapter, the cost of implementing each scenario was described and, to evaluate the relative abatement costs per tonne of GHG mitigated in each scenario, cost curves were developed for the study period.

Chapter 5. Conclusions and Recommendations for Future Work

5.1 Conclusions

Alberta's agriculture sector is the second largest consumer of energy and GHG emitter in Canada after Saskatchewan's agriculture sector. Analyses are required both to better understand future energy consumption and GHG emissions in Albert's agriculture sector and to help determine various GHG mitigation options. In the current study, energy demand in Alberta's agriculture sector was modeled and GHG emissions were analysed. Seventeen mitigation scenarios based on energy efficiency improvement and alternative biofuel energy were developed in order to evaluate and compare reference and mitigation scenarios. The key objectives of this research work included the development of an energy model for Alberta's agricultural sector and proposed GHG mitigation scenarios along with a cost-benefit analysis of GHG mitigation scenarios and comparison of the scenarios with the reference scenario. These objectives were achieved by using Long range Energy Alternatives Planning System (LEAP) as an energy-environment model. LEAP is an integrated modeling tool that was used to track energy consumption and GHG emissions for Alberta's agriculture sector. A reference case, also called the business-as-usual scenario, was developed for a study period of 42 years (2009-2050), as were various GHG mitigation scenarios. The GHG mitigation scenarios consist of various demand side management scenarios such as efficient lighting and ventilation in the livestock and poultry subsectors as well as energy efficiency improvements and the use of alternative biofuel energy in the farm machine and farm truck subsectors.

5.1.1 The development of Alberta agriculture's energy demand for 2009 in LEAP

In LEAP, the year 2009 was selected as the base year for Alberta's agriculture energy model, which covered energy demand as well as energy transformation sectors. The demand sector of the model consisted of three main sectors: crops, livestock, and “other.” These are the predominant end uses of primary and secondary energy in Alberta’s agriculture sector. According to the model output, in the base year the total energy produced in Alberta agriculture’s energy transformation sector was 2,155 PJ and the total energy consumed was 42.6 PJ in the demand sector. The majority of energy consumption was diesel at 23.4 PJ as well as gasoline at 6.9 PJ.

In the base year 2009, total GHG emissions from Alberta agriculture’s demand sector was 2.58 MT of CO_2 eq as per the model results from LEAP. The livestock subsector had the majority of GHG emissions, 1.49 MT of CO_2 eq. in 2009. Further, the cattle subsector was responsible for 83% of the total GHG emitted from livestock, 1.24 MT of CO_2 equivalents. Overall, the most GHG emissions were from combustion related to fossil fuel use in farm machine followed by farm truck, which were about 2.22 MT of CO_2 eq. Total emissions from the transformation sector were about 24.74 MT of CO_2 eq. The majority of GHG emissions in the transformation sector came from the crude bitumen production sector (14.05 MT of CO_2 eq.) followed by Alberta’s oil refining (6.56 MT of CO_2eq.).

5.1.2 The development of the reference scenario for Alberta’s agriculture sector

Initially, the reference scenario was created based on the current energy situation projected over the 42-year study period (2009-2050). Different factors, such as population, GDP, and product growth rate, were chosen as the basis for the development of the reference scenario for Alberta agriculture’s energy demand sector.

Over the 42-year study period, the energy demand was projected to grow from 42.6 PJ to 108.5 PJ. The increase in energy demand in the crop subsector was from 14 PJ to 44 PJ, while the livestock and “other” subsectors experienced increases from 24 PJ to 51 PJ and from 4 PJ to 13 PJ, respectively. Energy consumption in the crop subsector is expected to grow faster than in other subsectors in Alberta's agriculture sector due to the crop subsector's product growth rate. Overall fuel demand in Alberta's agriculture sector for the reference scenario is shown in Table 5-1.

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

Fuel Demand (PJ)	2009	2020	2030	2040	2050
Diesel	23.4	29.9	37.5	47.1	59.3
Electricity	5.9	7.6	9.6	12.1	15.3
Gasoline	6.9	8.8	11	13.8	17.4
LPG	0.3	0.3	0.4	0.5	0.7
Natural gas	6.1	7.9	10	12.6	15.9
Total	42.6	54.6	68.5	86.1	108.5

Diesel and gasoline dominate the fuel consumption in the reference scenario, diesel at 23.4 PJ and gasoline 6.9 PJ in the base year, and are projected to grow to 59.3 PJ and 17.4 PJ, respectively, in 2050.

Based on the rate of increase in primary and secondary fuel consumption in Alberta's agriculture sector, it is expected that the GHG emissions would increase from 2.58 MT of CO_2 eq. in 2009 to 6.55 MT of CO_2 eq. in 2050. The increased demand for energy in the farm machine and farm truck subsectors, along with the increase in the consumption of oil products, is expected to lead to an increase in GHG emissions in Alberta agriculture. GHG emissions from diesel and gasoline consumption are expected to grow from 2.22 MT in the year 2009 to 5.61 MT of CO_2 equivalents in 2050. Figure 5-1 shows the increase in GHG emissions in the demand sector based on fuel consumption in the reference scenario.

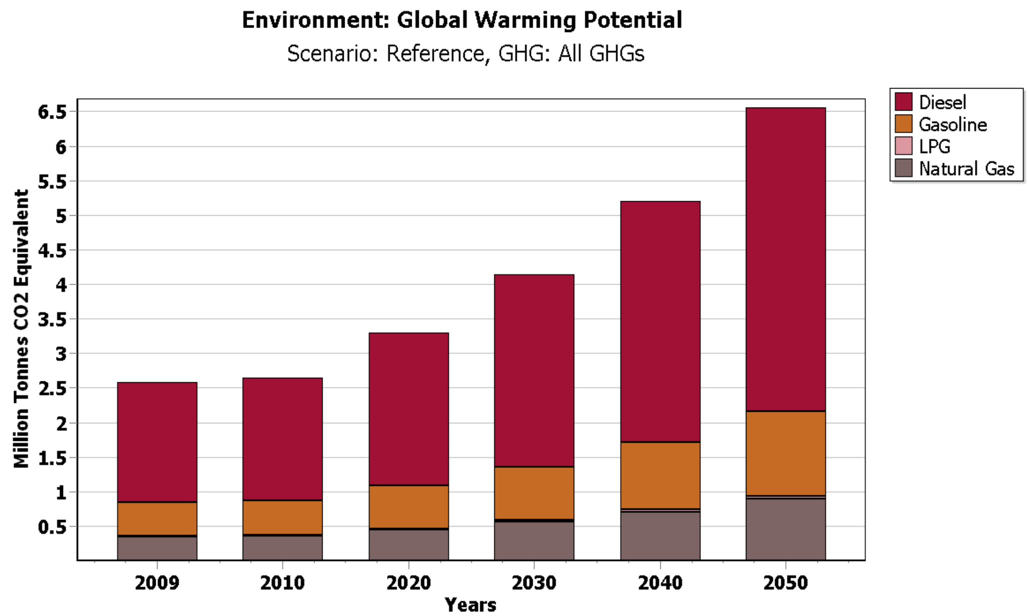


Figure 5-1: The increase in GHG emissions in the demand sector based on fuel consumption in the reference scenario

Based on the growth in energy consumption in the demand sector, emissions in the transformation sector are expected to grow from 24.74 MT of CO_2 in the base year to 45.06 MT of CO_2 equivalents in 2050. The overall increase of emissions in the transformation sector based on fuel consumption is shown in Figure 5-2.

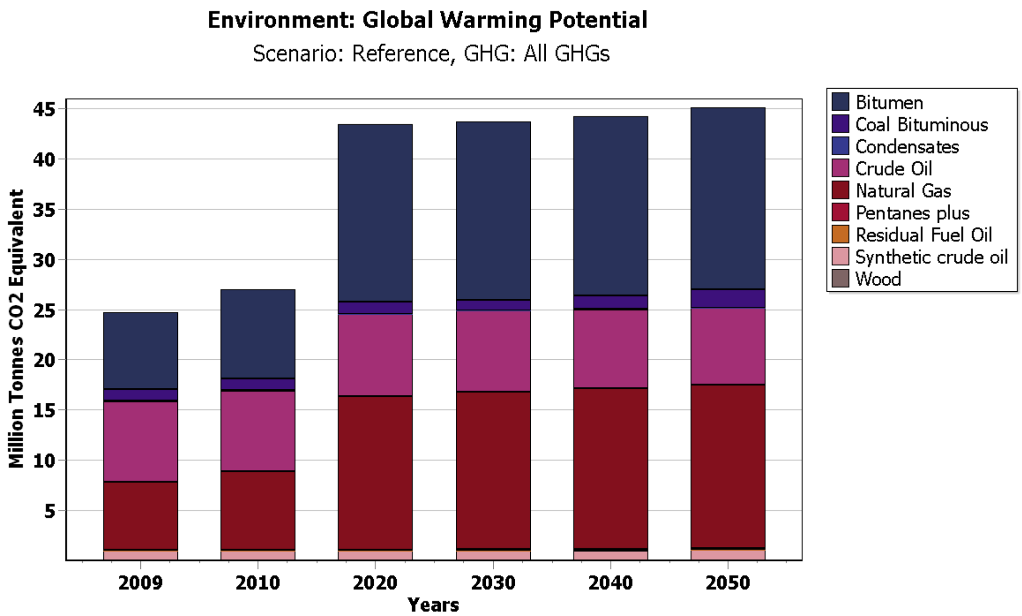


Figure 5-2: The increase in GHG emissions in the transformation sector based on fuel consumption in the reference scenario

The transformation sector in Alberta's agriculture energy model is based on seven subsectors: electricity generation, natural gas and coal methane extraction, Alberta oil refining, crude oil production, synthetic crude oil production, crude bitumen production, and coal mining. The large increase in GHG emissions in the transformation sector is due to crude bitumen production and oil refining. Figure 5-3 shows the increase in GHG emissions in the transformation sector based on its subsectors in the reference scenario.

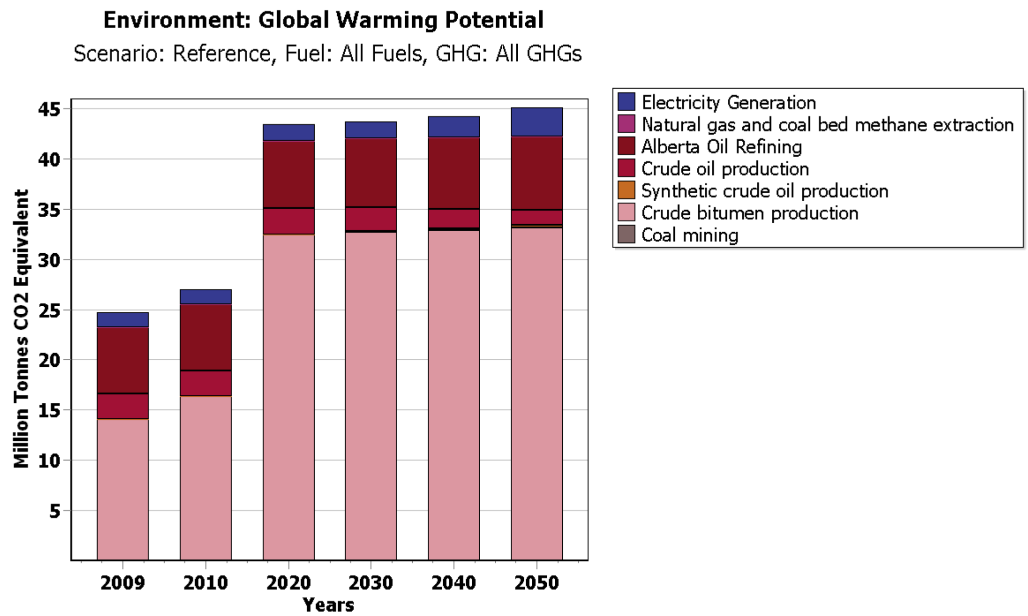


Figure 5-3: Increase in GHG emissions in the transformation sector based on its subsectors in the reference scenario

5.1.3 The development and analysis of GHG mitigation scenarios for Alberta's agriculture sector

In Alberta's agriculture energy model, various GHG mitigation scenarios were developed for the energy demand side based on efficiency improvements and the use of renewable energy in the energy portfolio. Mitigation scenarios were divided into two scenarios based on technology penetration: slow penetration (2009-2050) and fast penetration (2009-2030). To evaluate the scenarios in terms of overall energy reduction and GHG mitigation, the energy consumption of end uses such as farm machinery, farm truck, livestock and poultry lighting and ventilation was modeled. Table 5-2 gives the input data and assumptions used to develop GHG mitigation scenarios in Alberta's agricultural sector.

Table 5-2: Description of GHG mitigation scenarios for the agricultural sector

Scenario Number	Scenario Name	Scenario Details	Input Data for Energy Intensity and Penetration
Scenario 1	Poultry efficient lighting (PL–CFLs)	The assumption is that existing incandescent bulbs will be replaced by high–efficiency light, compact fluorescent lamps – CFLs.	Energy intensity improvement by 40%/ Max. penetration of 90% by 2030 or 2050
Scenario 2	Poultry efficient lighting (PL–T8)	The assumption is that existing bulbs (incandescent bulbs) are replaced by T8 fluorescent tubes. The existing bulbs, with 20% efficiency, will be replaced by T8s with 88% efficiency.	Energy intensity improvement by 32% (high efficiency light T8)/ Max. penetration of 90% by 2030 or 2050
Scenario 3	Dairy/cattle efficient lighting (DCL–T8)	The assumption is that all existing bulbs (incandescent bulbs) are replaced by T8 fluorescent tubes. The existing bulbs with, 20% efficiency, will be replaced by T8s with 88% efficiency.	Energy intensity improvement by 32% (high efficiency light T8)/ Max. penetration of 90% by 2030 or 2050
Scenario 4	Swine/ hog efficient lighting (SL–T8)	The assumption is that all existing bulbs (incandescent bulbs) are replaced by T8 fluorescent tubes. The existing bulbs, with 20% efficiency, will be replaced by T8s with 88% efficiency.	Energy intensity improvement by 32% (high efficiency light T8)/ Max. penetration of 90% by 2030 or 2050
Scenario 5	Cattle, dairy, hog efficient ventilation (DCH–EV)	The assumption is that current fans in livestock farms with the efficiency of 8.4 CFM/W are replaced by 18.6 CFM/W fans with 50% more energy efficiency.	Energy saving up to 50% (high efficiency fans)/ Max. penetration of 65% by 2030 or 2050

Scenario Number	Scenario Name	Scenario Details	Input Data for Energy Intensity and Penetration
Scenario 6	Poultry efficient ventilation (PEV)	The assumption is that fans currently used in the poultry and eggs subsector with the efficiency of 8.4 CFM/W are replaced by 18.6 CFM/W fans with 50% more energy efficiency.	Energy saving up to 50%/ Max. penetration of 65% by 2030 or 2050
Scenario 7	Efficient tractor (EFF–Trac)	In this scenario, the final energy intensity of tractors is assumed to be reduced by 20% by converting Tier III engines to the more efficient Tier IV engines.	Energy saving up to 20%/ Max. penetration of 79% by 2030 or 2050
Scenario 8	Biodiesel tractor (Bio – Trac)	In this mitigation scenario, the energy intensity of biodiesel tractors is assumed to be the same as that of diesel tractors. However, by using B5 and B20 a 20% reduction of CO_2 and a 2-5% reduction of CO and other hydrocarbon emissions, respectively, is anticipated	There is no energy saving; GHG mitigation with up to 20% reduction of CO_2 and a 2-5% reduction of CO/Max. penetration of 28% by 2030 or 2050
Scenario 9	Biodiesel combine (Bio – Com)	The assumption is that a biodiesel combine has the same energy intensity as the diesel engine combine and that the biodiesel combine could potentially mitigate GHGs by 20%.	There is no energy saving; GHG mitigation with up to 20% reduction of CO_2 and a 2-5% reduction of CO/Max. penetration of 28% by 2030 or 2050
Scenario 10	Biodiesel baler (Bio – Bal)	The assumption is that baler diesel fuel is replaced with biodiesel by the end of the study period in both the slow and fast penetration scenarios. The scenario is expected to reduce the carbon dioxide emissions by 20%.	There is no energy saving; GHG mitigation with up to 20% reduction of CO_2 and a 2-5% reduction of CO/Max. penetration of 28% by 2030 or 2050

Scenario Number	Scenario Name	Scenario Details	Input Data for Energy Intensity and Penetration
Scenario 11	Diesel truck (D – Tru)	In this scenario, the maximum energy-saving potential is 30-35% by replacing a gasoline truck with a diesel truck.	Energy saving up to 30%/ Max penetration of 85% by 2030 or 2050
Scenario 12	Biodiesel truck (Bio – Tru)	This scenario uses biodiesel with B5 to B20 blends as alternative fuels for diesel trucks. The final energy intensity of biodiesel trucks is assumed to be the same that of as diesel trucks.	There is no energy saving; GHG mitigation with up to 20% reduction/Max. penetration of 10% of total diesel truck (32%) by 2030 or 2050
Scenario 13	HEV diesel truck (HEV – Tru)	This mitigation scenario is developed to replace current diesel trucks with high-efficiency diesel trucks. In the LEAP model, the final energy intensity improvement caused by using the new engine is considered to be 20%.	Energy intensity improvement by 20%/ Max. penetration of 10% of total diesel truck (32%) by 2030 or 2050
Scenario 14	Ethanol truck (E – Tru)	This scenario uses ethanol E85-base 85% ethanol instead of gasoline. The advantage of using ethanol rather than gasoline is the lower GHG emissions.	Energy intensity of ethanol the same as the gasoline truck/Max. penetration of 20% by 2030 or 2050
Scenario 15	Awareness programs for drivers	It is assumed drivers' education and awareness has gradually affected energy use during the study period, with a 15% fuel savings.	Energy intensity improvement by 15%/Max. penetration of 100% by 2050
Scenario 16	Regular maintenance	In this scenario, by planning the regular maintenance of farm trucks and farm machines, it is assumed that 15% fuel savings during the study period would result.	Energy intensity improvement by 15%/Max. penetration of 100% by 2050
Scenario 17	Tire pressure	It is assumed that correctly inflated tires use 20% less fuel than tires that are under-inflated or over-inflated	Energy intensity improvement by 20%/Max. penetration of 100% by 2050

In the livestock and poultry subsectors, two types of efficient lamps were considered: compact fluorescent lamps (CFLs) and fluorescent tube lighting (T8s). The results showed that the implementation of efficient lighting (T8) in the mitigation scenario results in overall energy and GHG reductions in the amount of 4.82 PJ and 0.86 MT of CO_2 equivalents by 2050 and 1.51 PJ and 0.29 MT of CO_2 equivalents by 2030.

The efficient ventilation scenarios were developed in the livestock and poultry subsectors. The overall energy and GHG emission reductions are 8.26 PJ and 1.47 MT of CO_2 eq., respectively, by 2050 and 3.21 PJ and 0.62 MT of CO_2 eq., respectively, by 2030. Efficiency improvement in ventilation showed a high potential of energy and emission reductions in the livestock and poultry subsectors.

In the farm machinery subsector, two types of mitigation scenarios were developed: energy efficiency improvement and renewable energy use. In Alberta's agriculture sector, the farm machine subsector consumes the most energy and produces the most GHG emissions. Studies of the farm machine subsector predominantly considered the use of efficient tractors and biodiesel farm machines as the primary options for energy savings and GHG mitigation. Biodiesel farm machine scenarios showed the same energy consumption as the reference scenario, since the energy intensity of biodiesel and diesel were assumed to be the same in the model. These scenarios are attractive due to the reduction in GHGs emitted by biodiesel farm machinery. Among all the farm machines, the results indicated that the biodiesel tractor has the largest GHG mitigation potential, 27.31 MT of CO_2 equivalents by 2050 and 10.25 MT of CO_2 equivalents by 2030. Considering the maximum penetration level of efficient tractors in the farm machine subsector, the reduction in energy demand was about 7% compared to the reference scenario in both slow and fast penetration scenarios.

Mitigation options in the farm truck subsector were considered under energy efficiency improvement and renewable energy scenarios. Overall energy savings and GHG mitigation are higher in the case of converting gasoline trucks to diesel compared to using an efficient diesel truck, which results in about a 1.5% reduction in energy demand compared to the reference scenario. The biodiesel and ethanol truck scenarios showed the same energy consumption as the reference scenario since the energy intensity of biodiesel and ethanol are considered to be the same as diesel and gasoline, respectively. GHG mitigation in both the biodiesel and ethanol truck scenarios was more than 1 MT of CO_2 equivalents by 2050.

Three miscellaneous scenarios to study indirect ways of reducing energy consumption were developed; they were based on regular maintenance of farm equipment and awareness programs for drivers. These scenarios showed a 15-20% reduction in energy demand compared to the reference scenario. The majority of saved energy was mainly due to the enhanced knowledge of farm machine and farm truck operator, along with regular maintenance of farm equipment. This saved energy caused a significant GHG mitigation over the study period. The details of energy and GHG savings potential in Alberta's agricultural sector in both slow and fast scenarios are shown in Table 5-3.

Table 5-3: Summary of energy and GHG emissions for the 2030 and 2050 scenarios in the agricultural sector

Scenario	Energy Reduction –Cumulative by 2030 (PJ)	GHG Mitigation by 2030 (MT)	Energy Reduction –Cumulative by 2050 (PJ)	GHG Mitigation by 2050 (MT)
Poultry efficient lighting (PL – CFLs)	-0.17	-0.03	-0.6	-0.10
Poultry efficient lighting (PL – T8s)	-0.20	-0.04	-0.7	-0.12
Dairy/cattle efficient lighting (DCL – T8s)	-0.93	-0.18	-3.0	-0.54
Swine/ hog efficient lighting (SL – T8s)	-0.35	-0.07	-1.1	-0.20
Cattle/dairy/hog efficient ventilation (DCH – EV)	-3.13	-0.60	-8.1	-1.43
Poultry efficient ventilation (PEV)	-0.08	-0.02	-0.2	-0.04
Efficient tractor (EFF – Trac)	-58.62	-5.35	-165.8	-14.97
Biodiesel tractor (Bio – Trac)	0	-10.25	0	-27.31
Biodiesel combine (Bio – Com)	0	-0.94	0	-2.71
Biodiesel baler (Bio – Bal)	0	-0.03	0	-0.09
Diesel truck (D – Tru)	-10.06	-0.76	-30.9	-2.32
Biodiesel truck (Bio – Tru)	0	-0.45	0	-1.35
HEV diesel truck (HEV – Tru)	-0.99	-0.09	-3.0	-0.27
Ethanol truck (E – Tru)	0	-0.41	0	-1.22

5.1.4 Cost-benefit analysis and development of GHG mitigation cost curves for Alberta's agriculture sector

Fourteen GHG mitigation scenarios were developed for a cost-benefit analysis in Alberta agriculture's energy model. Abatement costs for various GHG mitigation scenarios were used to develop cost curves for both the slow and fast penetration scenarios. The cost curves helped to evaluate the relative costs per tonne of GHG mitigated in a particular time frame and gave insights into the techno-economic feasibility of the mitigation option under consideration. Further, based on the total GHG mitigation in both the slow and fast penetration scenarios, the mitigation scenarios were divided into two main categories: moderate improvement scenarios with GHG mitigation up to 1 MT of CO_2 and accelerated improvement scenarios with more than 1 MT of CO_2. The key conclusions from the cost-benefit analysis are summarized in the following paragraphs. Figures 5-4 and 5-5 show the cost curves for energy-efficiency improvement scenarios in Alberta's agricultural sector for 2050 and 2030, respectively. The base year for the study is 2009. Hence the cost curves in Figures 5-4 and 5-5 indicate the study period from 2009 to 2050 and from 2009 to 2030, respectively.

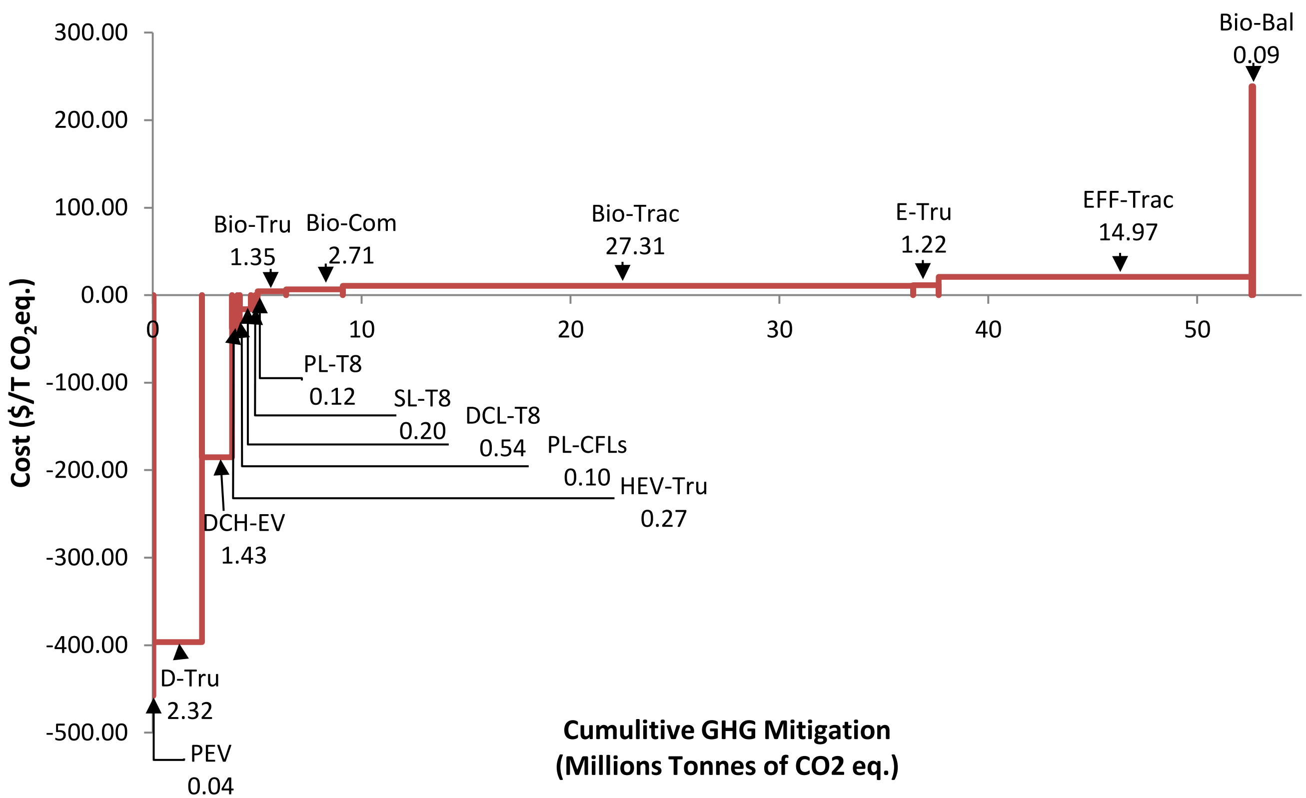


Figure 5-4: Cost curve for Alberta's agricultural sector, 2050 scenario, 2009-2050 (based on NPV 2010)

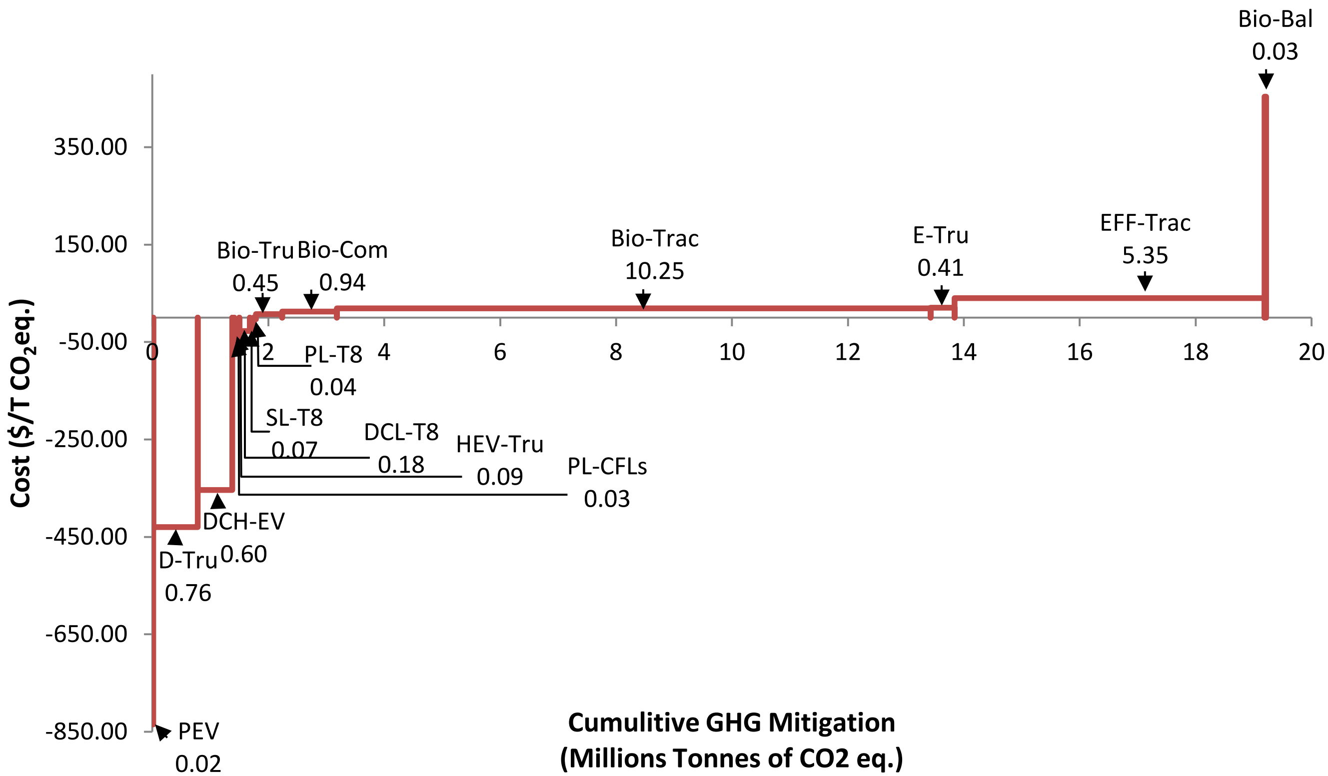


Figure 5-5: Cost curve for Alberta's agricultural sector, 2030 scenario, 2009-2030 (based on NPV 2010)

In the livestock and poultry lighting subsector, T8 fluorescent tube lighting has the largest potential for both GHG mitigation and cost savings. The total GHG mitigation achievable compared to the reference scenario for this technology was found to be 0.86 MT of CO_2 and 0.29 MT of CO_2 for the years 2050 and 2030, respectively, with overall GHG mitigation costs of -$34/tonne of CO_2 eq. and -$57/tonne of CO_2 eq. The implementation of T8 fluorescent tube lighting shows considerable energy cost savings but has very low GHG mitigation potential. Similarly, high efficiency lights are economically attractive, but GHG mitigation potential is low.

In the livestock and poultry ventilation subsector, the implementation of efficient ventilation showed high potential of both GHG mitigation and cost savings. Over the study period (2009-2050), the total achievable GHG mitigation was estimated to be 1.47 MT of CO_2 and the total GHG mitigation costs are projected to be in the range of -$458/tonne of CO_2 eq. and -$185/tonne of CO_2 eq., respectively, in the poultry and livestock subsectors. The GHG abatement costs in the slow and fast penetration scenarios are negative; however, the fast penetration scenario has higher cost savings and a lower rate of GHG mitigation. In short, efficient ventilation is economically attractive, with significant GHG mitigation potential.
Mitigation scenarios in farm machinery in both energy efficiency improvement and biodiesel fuel showed positive abatement costs as well as high GHG mitigation potential over the study period. As tractors are responsible for the majority of energy consumption in Alberta agriculture, the farm machinery subsector has the highest opportunity for GHG mitigation. Biodiesel and efficient tractors showed the highest GHG mitigation potential (27.31 MT of CO_2 and 14.97 MT of CO_2 over the study period, 2050) and a positive abatement cost ($10 and $20/tonne of CO_2 mitigated). It was observed that the slow penetration scenario has a higher GHG mitigation potential and lower abatement costs compared to the fast penetration scenario in the farm machinery subsector. In addition, the biodiesel combine and tractor, efficient tractor, and biodiesel baler

have positive GHG abatement costs. However, the GHG abatement costs of the biodiesel baler are significantly higher than the others, and the biodiesel balers have a low GHG mitigation potential. In contrast, the GHG abatement costs of biodiesel combines and tractors as well as efficient tractors are low, with considerable GHG mitigation potential, which makes this machinery economically attractive.

The high-efficiency diesel truck and diesel truck scenarios have negative GHG abatement costs in both the slow and fast penetration scenarios (e.g., -$37 and -$396/tonne of CO_2 mitigated by 2050) with a significant GHG mitigation potential of 0.27 MT of CO_2 and 2.32 MT of CO_2, respectively, under the 2050 scenario. The biofuel truck showed positive GHG abatement costs in both the slow and fast penetration scenarios. The overall GHG mitigation costs in the biodiesel and ethanol truck scenarios are projected to be in the range of $4 and $7/tonne of CO_2 eq., respectively, by 2050, while the maximum achievable GHG mitigation of the scenarios was found to be 1.35 MT to 1.22 MT of CO_2 under the year 2050 scenario. The energy efficiency improvement scenarios have the potential to save costs (negative GHG abatement costs), while the biofuel energy scenarios have positive abatement costs (justified positive GHG mitigation costs). Further, both mitigation scenarios showed modest GHG mitigation potential, which makes these scenarios economically attractive.

5.2 Recommendations for future work

This research developed an energy-environment model for Alberta’s agriculture sector through LEAP. The reference scenario and seventeen mitigation scenarios were developed to explore energy-efficiency options. Some recommendations for opportunities to expand the current study follow.

- This study was developed for the base year 2009. The year 2009 was chosen based on data available when the project was started in 2011.

Consequently, the base year should be updated within a year with more recent data.

- The model was developed based on direct energy use in Alberta's agriculture sector due to the availability of data and the role of direct energy use on farms. With the availability of more comprehensive data, this model could be extended to include indirect energy use, such as energy use in the distribution of fertilizers and pesticides.
- The WEAP model could be integrated with LEAP to estimate water use for various energy demand sectors (Stockholm Environment Institute, 2013a). Since the WEAP model operates water balance and can be applied to agricultural systems, WEAP could be used to simulate a broad range of water sources, e.g., natural and engineered water systems such as rainfall runoff, base flow, and groundwater (Stockholm Environment Institute, 2013a). Also, this model can simulate the pollution, water quality, vulnerability assessments, and change in ecosystem balance due to fertilizer and pesticide use.
- A mitigation scenario in the WEAP model can be further developed for cost-benefit analysis. The financial analysis module for Alberta agriculture allows farmers to investigate cost-benefit comparisons for projects (Stockholm Environment Institute, 2013a). Several suggested WEAP scenarios, such as water conservation, more efficient irrigation techniques, the mix of agricultural crop changes, and how land-use changes affect runoff farm land, can be studied in tandem with energy analysis scenarios in the LEAP model, and both can be integrated to get a holistic picture of the energy-water-climate nexus.

References

AAFC. (2012). Science Publications and Resources. Agriculture & Agri-Food Canada. Retrieved April 10, 2012, from http://www.agr.gc.ca/eng/science-and-innovation/science-publications-and-resources/?id=1196363731573

AG Canada. (2011). Cutting the energy cost of delivering irrigation water. Retrieved August 10, 2012, from http://www.agcanada.com/albertafarmer/2011/02/28/cutting-the-energy-cost-of-delivering-irrigation-water/

Balachandra, P., Nathan, H.S., & Reddy, S.B. (2010). Commercialization of sustainable energy technologies. *Renewable Energy, 35*(8), 1842–1851.

BFIN. (2013). Bioenergy Feedstock Information Network (BFIN). 2013, from https://bioenergy.ornl.gov/

BP. (2012). BP Statistical review of world energy June 2012 London, UK: BP p.l.c.

Brown, E., & Elliott, R.N. (2005). On-farm energy use characterizations. Retrieved April, 2013, from http://s3.amazonaws.com/zanran_storage/www.aceee.org/ContentPages/5425005.pdf

CAEEDAC. (2000). The Canadian agricultural energy end use data and analysis centre. Retrieved April 17, 2012, from http://www.usask.ca/agriculture/caedac/main/mpage.html

CERI. (2012). Publications. Canadian energy research institute. Retrieved March 18, 2012, from http://www.ceri.ca/

CFBF. (2013). Fuel efficiency on the farm. Retrieved March, 2013, from http://www.cfbf.com/issues/energy/flex.cfm

Clarke, S., & Chambers, R. (2006). *Energy Efficient Swine Lighting Factsheet*. Ontario Ministry of Agriculture and Food: Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/06-011.htm.

Clarke, S., & House, H. (2006). *Energy Efficient Dairy Lighting Factsheet*. Ontario Ministry of Agriculture and Food: Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/06-007.htm.

Clarke, S., & Ward, D. (2006a). *Energy-Efficient Mechanical Ventilation Fan Systems Factsheet*. Ontario Ministry of Agriculture and Food: Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/06-057.htm.

Clarke, S., & Ward, D. (2006b). *Energy Efficient Poultry Lighting Factsheet*. Ontario Ministry of Agriculture and Food: Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/06-009.htm.

CRFA. (2010). Canadian Renewable Fuels Association, Ethanol. Retrieved March 20, 2013, from http://www.greenfuels.org/en/resource-centre/ethanol.aspx

Dalgaard, T., Halberg, N., & Porter, J.R. (2001). A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture Ecosystems & Environment, 87*(1), 51-65. doi: Doi 10.1016/S0167-8809(00)00297-8

EIA. (2013). Country Analysis Brief Overview, Canada. U.S. Energy Information Administration. Retrieved August 20,2013, from http://www.eia.gov/countries/country-data.cfm?fips=CA

Environment Canada. (2011). Canada’s Emissions Trends. from http://www.ec.gc.ca/Publications/E197D5E7-1AE3-4A06-B4FC-CB74EAAAA60F/CanadasEmissionsTrends.pdf

Environment Canada. (2012). Canada’s Emissions Trends. from http://www.ec.gc.ca/Publications/253AE6E6-5E73-4AFC-81B7-9CF440D5D2C5/793-Canada's-Emissions-Trends-2012_e_01.pdf

Environment Canada. (2013). National Greenhouse Gas Emissions. 2013, from http://ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=FBF8455E-1

EPA. (2013). Global Greenhouse Gas Emissions Data. Retrieved August 30, 2013, from http://www.epa.gov/climatechange/ghgemissions/global.html

Firestine, N., Furrey, L., Aslin, C., Crivella, E., & Sautter, J.A. (2007). *The Farmer’s Handbook for Energy Self-Reliance: A Guide to Using Energy*

Efficiency, Biomass, and Renewable Energy on the Farm. South Royalton, VT: The Institute for Energy and the Environment.

Friedrich, K., Eldridge, M., York, D., Witte, P., & Kushler, M. (2009). *Saving energy cost-effectively: a national review of the cost of energy saved through utility-sector energy efficiency programs.* . Paper presented at the American Council for an Energy-Efficient Economy, Washington D.C.

Goverment of Alberta. (2003). Development of a Farm-Level Greenhouse Gas Assessment: Identification of Knowledge Gaps and Development of a Science Plan. Edmonton, Alberta: Alberta Agriculture Food and Rural Development,University of Alberta,.

Goverment of Alberta. (2005). Climate Change and Agriculture. Retrieved April 7, 2013, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl9706

Goverment of Alberta. (2008a). Alberta's 2008 Climate Change strategy from http://environment.gov.ab.ca/info/library/7894.pdf

Goverment of Alberta. (2008b). *Launching Alberta's energy future: provincial energy strategy*.etrieved from http://www.energy.alberta.ca/Org/pdfs/AB_ProvincialEnergyStrategy.pdf.

Goverment of Alberta. (2010). *Agriculture Statistics Yearbook 2009.* . Alberta Agriculture and Rural Development Retrieved from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13305.

Goverment of Alberta. (2012). *Agriculture Statistics Yearbook 2011* Edmonton, Alberta: Alberta Agriculture and Rural Development Retrieved from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex14115.

Goverment of Alberta. (2012a). Alberta Agriculture and Rural Development Department Retrieved April 17, 2012, from http://www.agric.gov.ab.ca/app21/rtw/index.jsp

Goverment of Alberta. (2012b). Alberta Irrigation Information 2011. Retrieved April 2013, from www.agric.gov.ab.ca

Goverment of Alberta. (2013). Report on 2011 Greenhouse Gas Emissions, Alberta Environment and Sustainable Resource Development:from http://www.environment.alberta.ca/02166.html

Government of Canada. (2012). Canada's Action on Climate Change,Greenhouse Gas Emissions. Retrieved August 30, 2013, from http://www.climatechange.gc.ca/default.asp?lang=En&n=21654B36-1

Government of Yolo County. (2011). *Yolo County Climate Action Plan: A Strategy for Smart Growth Implementation, Greenhouse Gas Reduction, and Adaptation to Global Climate Change*. Woodland, CA: Retrieved from http://www.yolocounty.org/Index.aspx?page=2004.

Heaps, C., Kemp-Benedict, E., & Raskin, P. (1998). Conventional Worlds: Technical Description of Bending the Curve Scenarios *PoleStar Series Report no.9.*

IEA. (2011). Environment. Retrieved April 10, 2011, from http://www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4139

IIASA. (2012). Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) Energy Modeling Framework, .

IPCC. (2010). The IPCC Assessment reports. Retrieved April 10, 2011, from http://www.ipcc.ch/index.htm

Jacobson, L.D., & Chastain, J.P. (1994). Fan Performanceand Efficiency for Animal Ventilation Systems. Retrieved March, 2013, 2013, from http://www.extension.umn.edu/distribution/livestocksystems/di0956.html

Janulevičius, A., Juostas, A., & Pupinis, G. (2013). Tractor’s engine performance and emission characteristics in the process of ploughing. *Energy Conversion and Management, 75*, 498-508.

Janzen, H.H. (2004). Carbon cycling in earth systems—a soil science perspective. *Agriculture, Ecosystems & Environment*(104), 399–417.

Khakbazan, M. (2000). Descriptive Analysis of On-Farm Energy Use in Canada: The Canadian Agricultural Energy End Use Data and Analysis Centre (CAEEDAC) from http://www.usask.ca/agriculture/caedac/pubs/Energy.PDF

Lancas, K.P., Upadhyaya, S.K., Sime, M., & Shafii, S.A. (1996). Overinflated Tractor Tires Waste Fuel , Reduce Productivity. *California Agriculture, 51*(2).

Lazarus, M., Heaps, C., & Hippel, D.V. (1998). Methods For Assessment of Mitigation Options. Retrieved August 20, 2012, from http://www.energycommunity.org/default.asp?action=47

Ludington, D., & Johnson, E.L. (2003). Dairy Farm Energy Audit Summary. Ithaca, New York: DLtech, Inc.

Lund, H. (2007). EnergyPlan, Advanced Energy Systems Analysis Computer Model, . from http://www.geni.org/globalenergy/library/technical-articles/generation/small-island-nations/Energy%20Plan/EnergyPLAN-Version7-December2007.pdf

MAFRI. (2012). *Farm Machinery Custom and Rental Rate Guide*. Manitoba: Government of Manitoba.

Malloy, G., & Lachapelle, M. (2012). *Gas, Hybrid and Electric: What You Need To Know - Canadian Automobile Association.* Retrieved from http://caa.ca/docs/eng/CAA_Engine_Technology_eBook_en.pdf

Maxwell, D., & Rackley, J. (2010). Energy Efficient Ways to Improve the Economic Bottom line of your Forest Harvesting Business. New Zealand: Energy Federation of New Zealand, .

McLaughlin, N.B., Deaville, D., Rosenblatt, D., Peden, R., Burtt, S.D., Patterson, B.S., & Smith, A. (2009). Biotractor: On-farm Evaluation of Biodiesel Use in Agricultural Equipment. Kemptville, Ontario: Agriculture and Agri-Food Canada, Ontario Soil and Crop Improvement Association, Environment Canada, UPI Energy LP, University of Guelph, .

Mosier, A.R., Duxbury, J.M., Freney, J.R., Heinemeyer, O., Minami, K., & Johnson, D.E. (1998). Mitigating Agricultural Emissions of Methane. *Climatic Change, 40*(1), 39-80.

Natural Resources Canada - OEE. (2009). Natural Resources Canada, Office of Energy Efficiency-Standard Incandescent Bulbs Retrieved March 19, 2013, 2009, from http://oee.nrcan.gc.ca/equipment/lighting/6642

Natural Resources Canada - OEE. (2011a). Natural Resources Canada, Office of Energy Efficiency-Lighting Retrieved March 19, 2013, 2011, from http://oee.nrcan.gc.ca/energy-efficient-products/lighting/15137

Natural Resources Canada - OEE. (2011b). Alternative Fuels. Retrieved March 19, 2013, from http://oee.nrcan.gc.ca/node/361

Natural Resources Canada - OEE. (2012a). Alternative fuel facts-Applications of Ethanol. Alternative Fuels Report. Retrieved March 19, 2013, from http://oee.nrcan.gc.ca/transportation/alternative-fuels/fuel-facts/ethanol/17571

Natural Resources Canada - OEE. (2012b). Government programs and Regulations. Biodiesel Fuel Report. Retrieved March 19, 2013, from http://oee.nrcan.gc.ca/transportation/alternative-fuels/fuel-facts/biodiesel/13900

Natural Resources Canada. (2006). *Canada's Energy outlook: The Reference Case 2006. Analysis and Modelling Division,*. (Cat. No.M144-126/2006E-PDF). Ottawa,: NR Canada.

Natural Resources Canada. (2012a). Average Retail Price of Regular Gasoline. - Energy Sources. Retrieved March 19, 2013, from http://www2.nrcan.gc.ca/eneene/sources/pripri/prices_bycity_e.cfm?PriceYear=0&ProductID=1&LocationID=66,8,39,17#PriceGraph

Natural Resources Canada. (2012b). *Understanding Gasoline Markets in Canada. Fuel Focus Report.* Ottawa: Natural Resources Canada.

Natural Resources Canada. (2012a). Comprehensive Energy Use Database. Retrieved April 16, 2012, 2012, from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/comprehensive_tables/list.cfm?attr=0

Natural Resources Canada. (2012b). Natural Resources Canada. Retrieved April 16, 2012, 2012, from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=agr&juris=ca&rn=3&page=4&CFID=28532856&CFTOKEN=4c1185d160d2fe68-1A045A21-F0C3-4FB4-A7322753A73498A3

Natural Resources Canada. (2012c). Natural Resources Canada. Retrieved April 16, 2012, 2012, from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=agr&juris=ab&rn=1&page=4&CFID=28532856&CFTOKEN=4c1185d160d2fe68-1A045A21-F0C3-4FB4-A7322753A73498A3

Natural Resources Canada. (2012d). *Fuel consumption Guide 2012*. Ottawa.

Natural Resources Canada. (2012e). OEE- Fuel consumption Rating. Retrieved April 16, 2012, from http://oee.nrcan.gc.ca/transportation/tools/fuelratings/ratings-search.cfm

Navigant Consulting Inc. (2012). Measures and assumptions for demand side management, Navigant Consulting and Ontario Energy Board. Toronto, Ontario

NEB. (2011). Canada's energy future: energy supply and demand projections to 2035. Retrieved March 10, 2013, from http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/2011/nrgsppldmndprjctn2035-eng.pdf

NEB. (2012). Canadian Energy overview – An energy market assessment Retrieved March 10, 2012, from http://www.neb-one.gc.ca/clf-nsi/rcmmn/hm-eng.html

NREL. (2012). Regional Energy Deployment System (ReEDS). Energy Analysis. from http://www.nrel.gov/analysis/reeds/related_pubs.html

Oenema, O., Wrage, N., Velthof, G.L., Groenigen, J.W., Dolfing, J., & Kuikman, P.J. (2005). Trends in Global Nitrous Oxide Emissions from Animal Production Systems. *Nutrient Cycling in Agroecosystems, 72*(1), 51-65. doi: 10.1007/s10705-004-7354-2

Olivier, J.G.J., Janssens-Maenhout, G., & Peters, J.A.H.W. (2012). Trends in global CO2 emissions: Institute for Environment and Sustainability (IES) of the European Commission's Joint Research Centre (JRC).

OTA. (1992). *Fueling Development: Energy Technologies for Developing Countries.* U.S. Congress, Office of Technology Assessment, Washington, DC.

Packey, D.J. (1993). Market Penetration of New Energy Technologies. Golden, Colorado: National Renewable Energy Laboratory.

Rhodes, N., Lung, P., & Leduc, P. (2009). Energy Use in Alberta Agriculture Literature Review. Humboldt, Saskatchewan.

Seebregts, A.J., Goldstein, G.A., & Smekens, K. (2001). Energy/Environmental Modeling with the MARKAL Family of Models,. 2001, from ftp://ftp.ecn.nl/pub/www/library/report/2001/rx01039.pdf

Smith, K.A., & Conen, F. (2004). Impacts of land management on fluxes of trace greenhouse gases. *Soil Use and Management, 20*(2), 255-263. doi: 10.1079/sum2004238

Smith, P., Field, C.B., & Raupach, M.R. (2004). Engineered biological sinks on land. *The global carbon cycle: integrating humans, climate and the natural world*, 479–491.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., . . . Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B-Biological Sciences, 363*(1492), 789-813.

Smith, P.D., Martino, Z.C., D. Gwary, H., Janzen, P., Kumar, B., McCarl, S., . . . Sirotenko. (2007). Climate Change 2007: Mitigation of Climate Change *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA.

Statistics Canada. (2006). Trends in energy consumption. Retrieved August 7, 2013, from http://www41.statcan.gc.ca/2006/1741/ceb1741_004-eng.htm

Statistics Canada. (2009). 2006 Census of Agriculture. Retrieved April 7, 2013, from http://www.statcan.gc.ca/ca-ra2006/analysis-analyses/alberta-eng.htm

Statistics Canada. (2010). CANSIM Table 405-0008 Canadian vehicle survey, vehicle-kilometres, by type of vehicle, province and territory. Retrieved April 7, 2012, 2012, from http://www5.statcan.gc.ca/cansim/a26

Statistics Canada. (2011a). Report on Energy Supply and Demand in Canada (Manufacturing and Energy Division, Trans.). Ottawa.

Statistics Canada. (2011b). Table 004-0011, Census of agriculture, selected farm machinery data, Canada and provinces every 5 years. Retrieved April 7, 2012, from http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0040011&paSer=&pattern=&stByVal=1&p1=1&p2=50&tabMode=dataTable&csid=

Statistics Canada. (2012). CANSIM Table. Retrieved April 7, 2012, from http://www5.statcan.gc.ca/cansim/home-accueil?lang=eng&p2=50&HPA

Stewart, B., Veeman, T., & Unterschultz, J. (2009). Crops and Livestock Productivity Growth in the Prairies: The Impacts of Technical Change and Scale. *Canadian Journal of Agricultural Economics, 57*, 379–394.

Stockholm Environment Institute. (2011). LEAP: Long-range Energy Alternatives Planning System user guide for version 2011. Retrieved April 20, 2012, from http://www.energycommunity.org/documents/LEAP2011UserGuideEnglish.pdf

Stockholm Environment Institute. (2012). Greenhouse Gas Mitigation Screening Exercise For LEAP and Excel Retrieved August 20, 2012, 2012, from http://www.energycommunity.org/documents/GHGScreening.pdf

Stockholm Environment Institute. (2013). An Introduction to LEAP. Retrieved August 20, 2012, 2012, from http://www.energycommunity.org/default.asp?action=47

Stockholm Environment Institute. (2013a). Water Evaluation And Planning system. Retrieved July 20, 2013, from http://www.weap21.org/index.asp?action=201

Subramanyam, V. (2010). *Development of Greenhouse Gas Mitigation Options for Alberta's Energy Sector.* (Master of Science), University of Alberta, Edmonton, Alberta.

Subramanyam, V., Paramashivan, D., Radpour, S., Shah, T., & Kumar, A. (2013). Identification of Best Energy-Efficiency Opportunities in Alberta's Energy Sector PHASE II. Edmonton, Alberta,: Alberta Innovates – Energy and Environmental Solutions (AIEES).

Tewari, D.D. (1990). Energy-price impacts modelling in the agriculture sector *Energy Economics*, *12*(2), 147–158.

Transport Canada. (2003). *Truck Activity in Canada*. Transport Canada.

US-DOE-EERE. (2003). Just the Basics: Diesel Engine. Retrieved August 20, 2012, from http://www1.eere.energy.gov/vehiclesandfuels/pdfs/basics/jtb_diesel_engine.pdf

US-DOE-EERE. (2005). Clean Cities, Biodiesel Blends Fact Sheet. Retrieved March 20, 2013, from http://www.nrel.gov/docs/fy05osti/37136.pdf

US-DOE-EERE. (2008). Clean Cities -Biodiesel Fact sheet. NREL and US Department of Energy. Retrieved August, 2012, from http://www1.eere.energy.gov/cleancities/

US-DOE-EERE. (2013a). Alternative Fuels Data Center. Retrieved March, 2013, from http://www.afdc.energy.gov/fuels/biodiesel.html

US-DOE-EERE. (2013b). Fuel Economy: Where the Energy Goes. Retrieved March 10, 2013, from http://www.fueleconomy.gov/feg/atv.shtml

US-DOE-EERE. (2013c). Diesel Vehicles. Retrieved March 10, 2013, from http://www.fueleconomy.gov/feg/di_diesels.shtml

US-DOE-EERE. (2013d). Alternative Fuels Data Center-Ethanol. Retrieved March, 2013, from http://www.afdc.energy.gov/fuels/ethanol.html

US-DOE-EERE. (2013e). Diesel Links. Retrieved March 10, 2013, from http://www.fueleconomy.gov/feg/diesellinks.shtml

US-DOE. (2010). Biodiesel Offers a Renewable Alternative. Retrieved April 20, 2012, from http://energy.gov/energysaver/articles/biodiesel-offers-renewable-alternative

US-DOE. (2012a). Environmental cleanup. Retrieved April 20, 2012, from http://energy.gov/environmental-cleanup

US-DOE. (2012b). Fluorescent Lighting Retrieved March, 2013 2012, from http://energy.gov/energysaver/articles/fluorescent-lighting

Vermeulen, S.J., Campbell, B.M., & Ingram, J.S.I. (2012). Climate Change and Food Systems. *Environment and Resources, 37*, 195-222. doi: 10.1146/annurev-environ-020411-130608

World Energy Council, I.C. (2012). Report : Global Transport Scenarios 2050. London.

Zhai, H., Frey, H.C., Rouphail, N.M., Gonçalves, G.A., & Farias, T.L. (2007). *Fuel consumption and emissions comparisons between ethanol 85 and gasoline fuels for flexible fuel vehicles*. Paper presented at the Proceeding of the 100th Annual Meeting of the Air & Waste Management Association, Pittsburgh, PA.

APPENDIX

Appendix A.

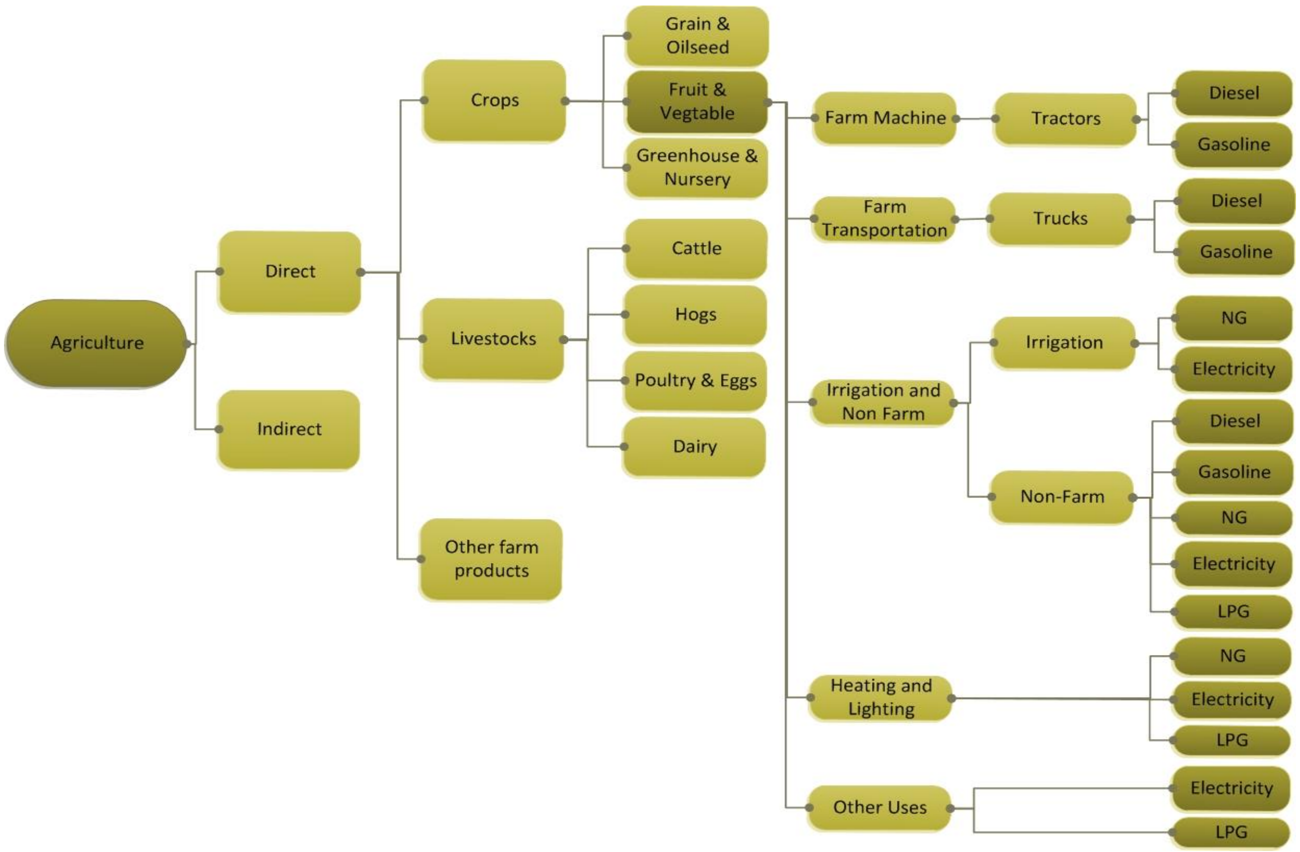


Figure A-1: The crop subsector with fruit and vegetable

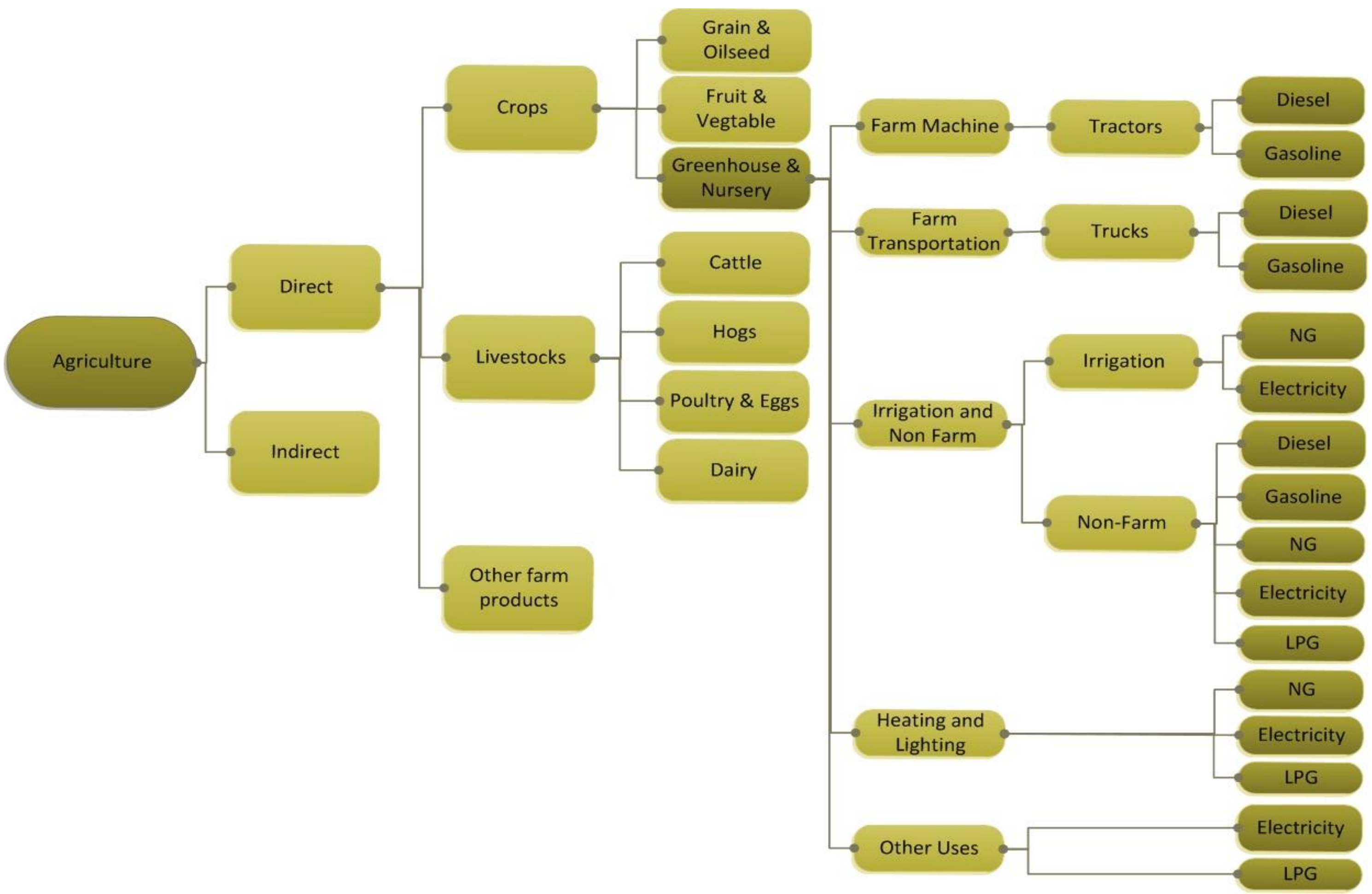


Figure A-2: The crop subsector with greenhouse and nursery

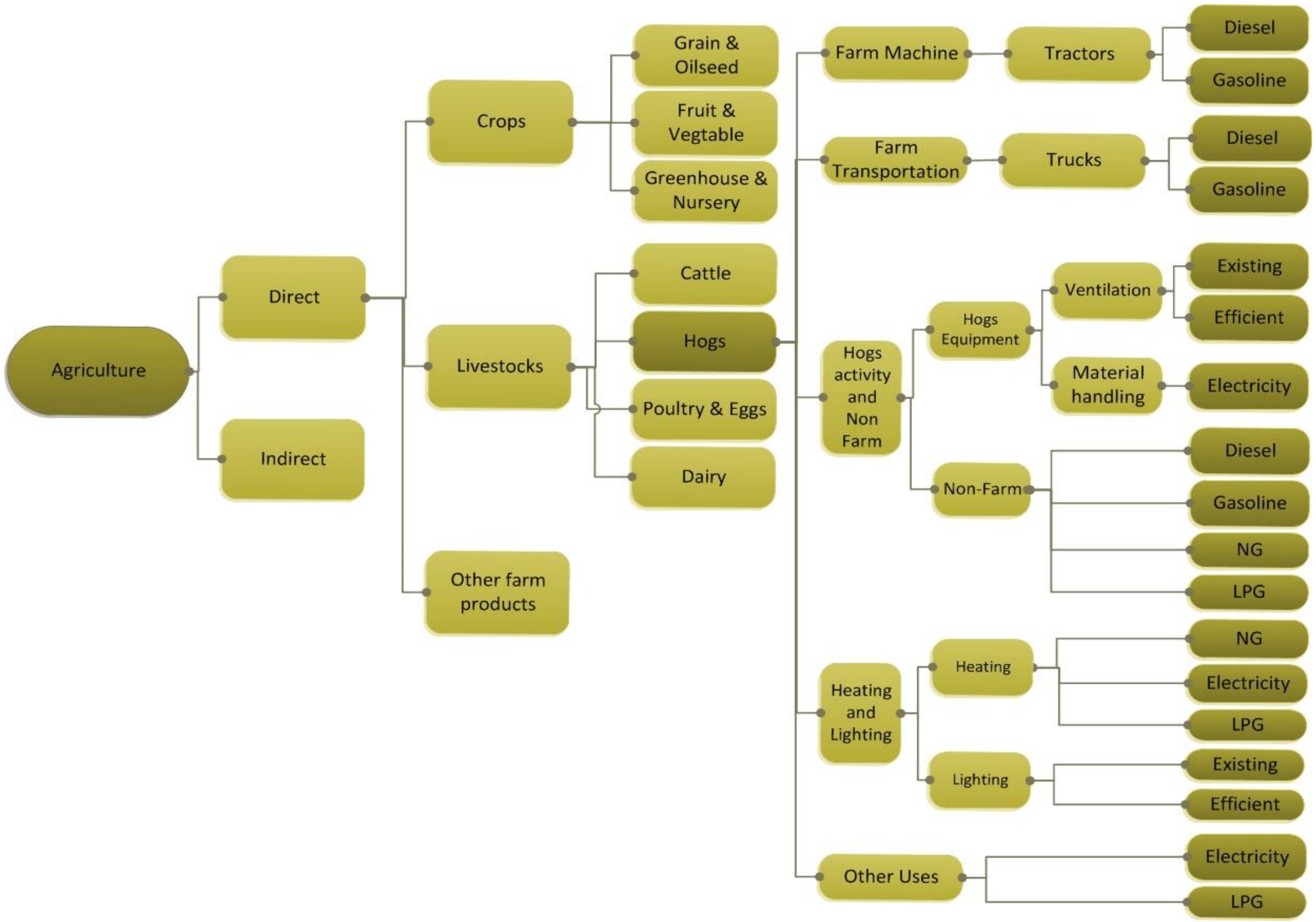


Figure A-3: The livestock subsector with hog

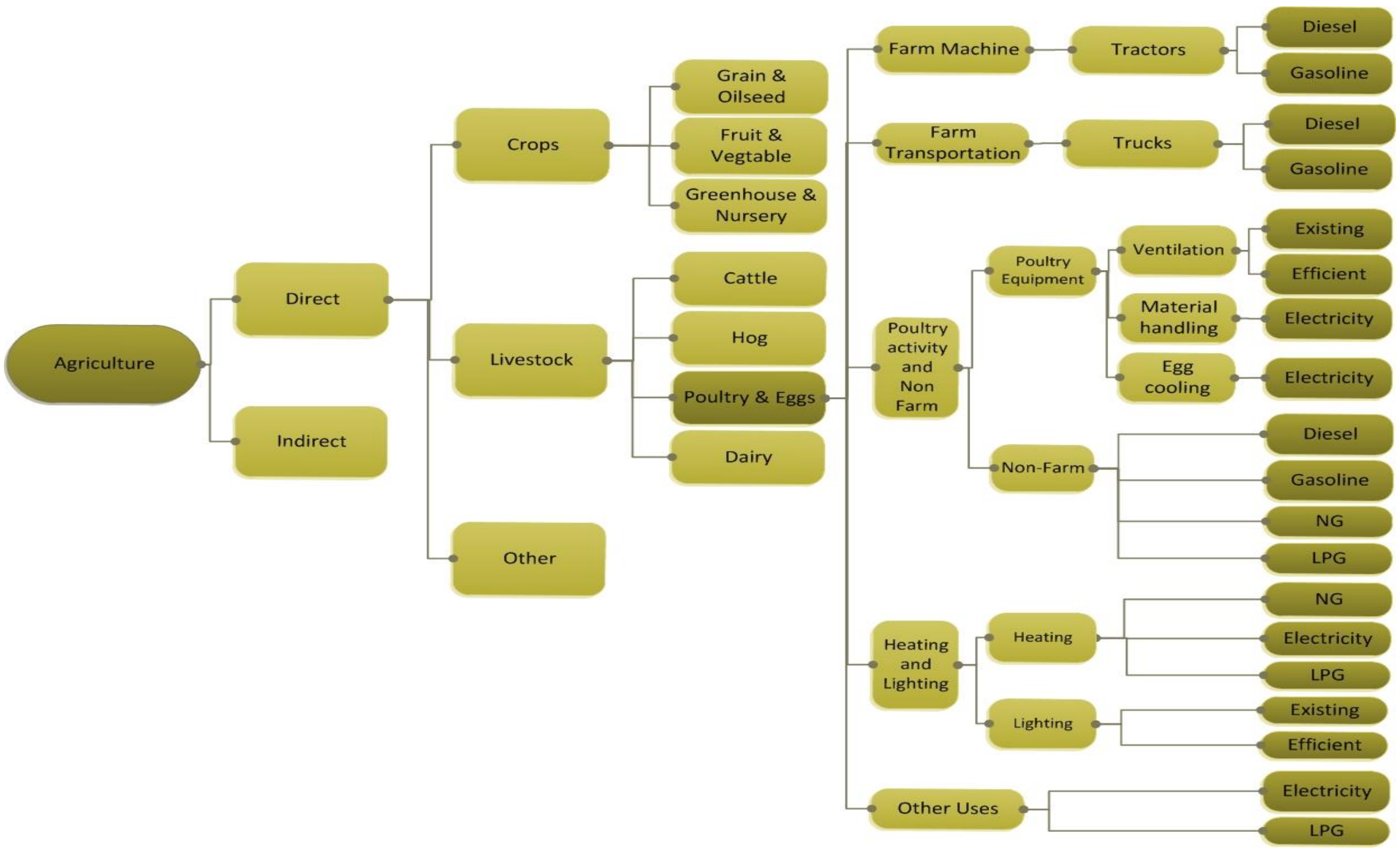


Figure A-4: The livestock subsector with poultry and eggs

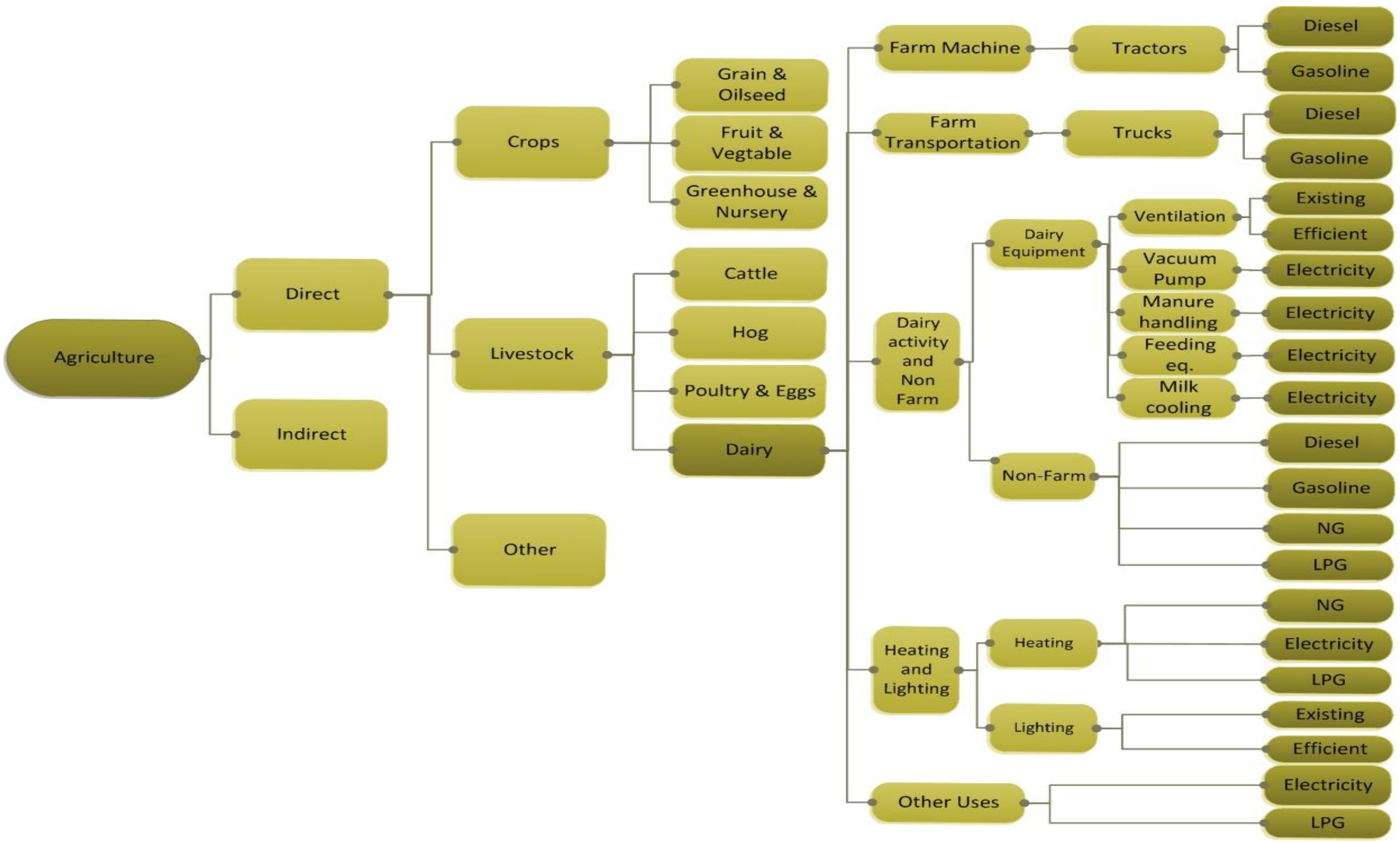


Figure A-5: The livestock subsector with dairy

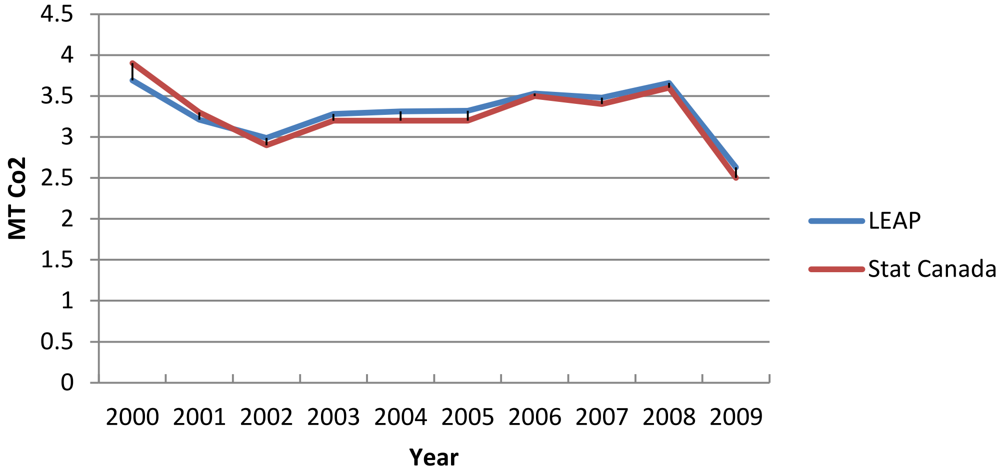


Figure A-6 : The ten-year GHG-emission trend in Alberta agriculture

Tables:

Table A-1: The share (%) of energy type for ten years of energy use in Alberta agriculture

Energy type	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Gasoline	21.2	21.7	28.3	29.4	26.1	27.8	27.0	23.0	22.5	20.0
Diesel	56.9	55.6	45.6	47.6	49.9	46.2	49.1	50.3	50.6	48.4
NG	10.4	9.5	11.3	9.3	9.1	9.1	8.1	10.2	10.8	10.9
Electricity	10.8	12.7	14.5	13.3	14.3	16.4	15.0	15.8	15.3	20.2
LPG	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.5	0.5

Source: (Natural Resources Canada, 2012c)

Table A-2: The amount of energy by type (TJ) in various uses in Alberta agriculture, in 2000

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	7647.39	3026.61	0.00	0.00	0.00	10674.00
Heat & Light	0.00	0.00	2861.35	3119.31	0.00	5980.67
Farm Machine	2721.95	31129.89	0.00	0.00	0.00	33850.85
Non-Farm Machine	2591.68	633.15	3497.21	2597.60	0.00	9320.30
Other Uses	0.00	0.00	0.00	886.20	0.00	886.20
Total	12961.68	34788.66	6358.56	6603.12	0.00	60712.00

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-3: The amount of energy by type (TJ) in various uses in Alberta agriculture, in 2001

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	6738.22	2545.82	0.00	0.00	0.00	9284.04
Heat & Light	0.00	0.00	2249.93	3157.53	0.00	5407.46
Farm Machine	2398.35	26183.89	0.00	0.00	0.00	28582.24
Non-Farm Machine	2284.14	532.51	2749.92	2629.42	0.00	8196.06
Other Uses	0.00	0.00	0.00	897.06	0.00	897.60
Total	11420.71	29262.28	4999.85	6684.01	0.00	52366.85

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-4: The amount of energy by type (TJ) in various uses in Alberta agriculture, in 2002

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	7860.95	1867.76	0.00	0.00	0.00	9728.71
Heat & Light	0.00	0.00	2394.02	3180.40	0.00	5574.42
Farm Machine	2797.96	19210.0	0.00	0.00	0.00	22007.96
Non-Farm Machine	2664.73	390.73	2926.02	2648.47	0.00	8629.95
Other Uses	0.00	0.00	0.00	903.56	0.00	903.56
Total	13323.64	21468.48	5320.04	6732.44	0.00	46844.60

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-5: The amount of energy by type (TJ) in various uses in Alberta agriculture, in 2003

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	9087.57	2169.57	0.00	0.00	0.00	11257.14
Heat & Light	0.00	0.00	2192.52	3291.62	0.00	5484.14
Farm Machine	3234.56	22314.20	0.00	0.00	0.00	25548.76
Non-Farm Machine	3080.53	453.87	2679.75	2741.09	0.00	8955.24
Other Uses	0.00	0.00	0.00	935.16	0.00	935.16
Total	15402.66	24937.64	4872.27	6967.87	0.00	52180.44

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-6: The amount of energy by type (TJ) in various uses in Alberta agriculture, in 2004

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	7927.41	2234.90	0.00	0.00	0.00	10162.31
Heat & Light	0.00	0.00	2108.11	3477.64	0.00	5585.74
Farm Machine	2821.62	22986.09	0.00	0.00	0.00	25807.71
Non-Farm Machine	2687.26	467.53	2576.57	2896.00	0.00	8627.36
Other Uses	0.00	0.00	0.00	988.01	0.00	988.01
Total	13436.28	25688.52	4684.68	7361.64	0.00	51171.12

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-7: The amount of energy by type (TJ) in various uses in Alberta agriculture, in 2005

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	8178.67	2266.38	0.00	0.00	0.00	10445.05
Heat & Light	0.00	0.00	1977.32	3731.40	0.00	5708.72
Farm Machine	2911.05	23309.88	0.00	0.00	0.00	26220.93
Non-Farm Machine	2772.43	474.12	2416.72	3107.31	0.00	8770.58
Other Uses	0.00	0.00	0.00	1060.10	0.00	1060.10
Total	13862.15	26050.38	4394.04	7898.81	0	52205.38

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-8: The amount of energy by type (TJ) in various use type in Alberta agriculture, in 2006

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	8400.84	2550.12	0.00	0.00	0.00	10950.97
Heat & Light	0.00	0.00	1877.18	3625.93	71.19	5574.30
Farm Machine	2990.13	26228.14	0.00	0.00	0.00	29218.28
Non-Farm Machine	2847.74	533.47	2294.33	3019.49	60.07	8755.10
Other Uses	0.00	0.00	0.00	1030.14	91.22	1121.35
Total	14238.72	29311.74	4171.50	7675.56	222.48	55620.00

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-9: The amount of energy by type (TJ) in various use type in Alberta agriculture, in 2007

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	7231.45	2332.02	0.00	0.00	0.00	9563.48
Heat & Light	0.00	0.00	2446.01	3977.52	119.37	6542.90
Farm Machine	2573.91	23985.00	0.00	0.00	0.00	26558.90
Non-Farm Machine	2451.34	487.85	2989.57	3312.27	100.72	9341.75
Other Uses	0.00	0.00	0.00	1130.02	152.94	1282.97
Total	12256.70	26804.87	5435.58	8419.82	373.03	53290.00

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-10: The amount of energy by type (TJ) in various use type in Alberta agriculture, in 2008

Use type/Energy type	Gasoline	Diesel	NG	Electricity	LPG	Total
Farm Truck	7521.62	2494.29	0.00	0.00	0.00	10015.90
Heat & Light	0.00	0.00	2753.68	4095.23	145.05	6993.95
Farm Machine	2677.19	25653.88	0.00	0.00	0.00	28331.07
Non-Farm Machine	2549.70	521.79	3365.60	3410.29	122.39	9969.77
Other Uses	0.00	0.00	0.00	1163.46	185.84	1349.31
Total	12748.50	28669.96	6119.28	8668.98	453.28	56660.00

Source: (Khakbazan, 2000; Natural Resources Canada, 2012c)

Table A-11: Total energy use and total product for particular farm types in 2000

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	15,298,500	20382.68
Dairy	657,292	2347.80
Cattle	2,965,200	27262.65
Hogs	76,728	2444.22
Poultry& Eggs	112,871	1362.16
Fruit & Vegetable	48,070	413.22
Greenhouse & Nursery	9,716	674.25
Other	15,356,297	5825.02
Total	19,168,377	60,712

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-12: Total energy use and total product for particular farm types in 2001

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	12,937,800	16131.81
Dairy	657,292	2031.80
Cattle	3,047,800	24995.85
Hogs	81,176	2124.19
Poultry& Eggs	124,764	1207.76
Fruit & Vegetable	48,685	358.47
Greenhouse & Nursery	18,624	597.65
Other	13,005,121	4919.32
Total	16916141	52366.85

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-13: Total energy use and total product for particular farm types in 2002

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	11,039,885	14212.15
Dairy	657,292	1805.93
Cattle	2,968,700	21715.34
Hogs	85,636	1950.52
Poultry& Eggs	107,065	1196.60
Fruit & Vegetable	27,347	321.44
Greenhouse & Nursery	16,523	609.20
Other	11,083,769	5033.42
Total	14902448.00	46844.60

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-14: Total energy use and total product for particular farm types in 2003

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	15,008,300	16657.73
Dairy	657,292	1996.04
Cattle	2,835,000	23665.64
Hogs	81,200	2117.41
Poultry& Eggs	95,272	1247.56
Fruit & Vegetable	28,955	353.64
Greenhouse & Nursery	15,796	632.56
Other	15,053,063	5509.86
Total	18721814.50	52180.4

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-15: Total energy use and total product for particular farm types in 2004

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	17,060,200	16043.98
Dairy	657,292	1975.88
Cattle	2,974,300	23607.20
Hogs	81,200	2093.30
Poultry& Eggs	86,647	1235.83
Fruit & Vegetable	44,085	350.16
Greenhouse & Nursery	14,220	620.34
Other	17,118,520	5244.42
Total	20917944.00	51171.12

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-16: Total energy use and total product for particular farm types in 2005

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	18,216,700	16484.61
Dairy	659,341	2017.02
Cattle	3,114,300	23921.86
Hogs	80,000	2135.00
Poultry& Eggs	98,714	1263.33
Fruit & Vegetable	48,762	357.60
Greenhouse & Nursery	15,160	633.31
Other	18,280,636	5392.66
Total	22,232,976	52205.38

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-17: Total energy use and total product for particular farm types in 2006

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	16,132,400	17846.40
Dairy	645,870	2146.07
Cattle	2,959,600	25567.45
Hogs	82,000	2236.96
Poultry& Eggs	98,462	1279.93
Fruit & Vegetable	43,440	379.59
Greenhouse & Nursery	14,414	637.03
Other	16,190,275	5526.57
Total	19976185	55,620

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-18: Total energy use and total product for particular farm types in 2007

Farm type	Total product (tonnes)	Total energy(TJ)
Grain & Oilseed	15,272,800	17106.38
Dairy	648,066	2088.80
Cattle	3,096,800	23760.95
Hogs	78,800	2233.98
Poultry& Eggs	88,558	1364.96
Fruit & Vegetable	31,909	372.56
Greenhouse & Nursery	19,006	682.62
Other	15,323,728	5679.73
Total	19,235,939	53290.00

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-19: Total energy use and total product for particular farm types in 2008

Farm type	Total product (tonnes)	Total energy (TJ)
Grain & Oilseed	19,156,900	19054.72
Dairy	678,985	2222.62
Cattle	2,805,600	24235.87
Hogs	66,800	2379.04
Poultry& Eggs	96,956	1453.90
Fruit & Vegetable	31,649	396.53
Greenhouse & Nursery	43,510	727.45
Other	19,232,071	6189.88
Total	22,880,400	56660.00

Source: (Goverment of Alberta, 2010; Khakbazan, 2000; Natural Resources Canada, 2012c; Statistics Canada, 2012)

Table A-20: The share (%) and type of farm machine in all of Alberta's agriculture sectors

Sector	Subsector	Type and Share of Farm Machine
Crop		
	Grain & Oilseed	Tractor (80%), Combine (20%)
	Fruits & Vegetables	Tractor (100%)
	Greenhouse & Nursery	Tractor (100%)
Livestock		
	Cattle	Tractor (100%)
	Hogs	Tractor (100%)
	Poultry & eggs	Tractor (100%)
	Dairy	Tractor (100%)
Other		Tractor (89%), Baler (11%)

Source: (MAFRI, 2012; Statistics Canada, 2012)

Table A-21: Electricity use (%) by primary system in livestock subsectors

System	Cattle	Hogs	Poultry & eggs	Dairy
Ventilation	74	89	47	27
Material handling	26	11	37	10
Vacuum pump	-	-	-	24
Feeding equipment	-	-	-	4
Milk cooling	-	-	-	35
Egg cooling	-	-	16	-
Total	100	100	100	100

Source: (Rhodes et al., 2009)

Table A-22: Electricity use (%) by heating and lighting in livestock subsectors

System	Heating	Lighting
Cattle	86	14
Hogs	78	22
Poultry and eggs	92	8
Dairy	86	14

Source: (Rhodes et al., 2009)

Table A-23: Alberta agriculture's energy demand – grain and oilseed subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	8551	0	920	0	0
Farm transport	261	0	791	0	0
Non-farm	119	599	59	16	883
Heat and Light	0	447	0	13	456
Other uses	0	209	0	27	0
Total	8930	1255	1770	56	1340

As developed by the LEAP model

Table A-24: Alberta agriculture's energy demand – fruit and vegetable subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	89	0	10	0	0
Farm transport	3	0	9	0	0
Non- farm	3	13	13	0	19
Heat and Light	0	11	0	0	11
Other uses	0	10	0	1	0
Total	94	34	31	2	30

As developed by the LEAP model

Table A-25: Alberta agriculture's energy demand – greenhouse and nursery subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	50	0	5	0	0
Farm transport	5	0	15	0	0
Non- farm	17	86	86	2	128
Heat and Light	0	122	0	3	123
Other uses	0	15	0	2	0
Total	72	223	106	8	250

As developed by the LEAP model

Table A-26: Alberta agriculture's energy demand – cattle subsector– base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	11033	0	1186	0	0
Farm transport	458	0	1390	0	0
Non-farm	182	923	913	26	1362
Heat and Light	0	779	0	22	784
Other uses	0	326	0	41	0
Total	11672	2028	3489	90	2147

As developed by the LEAP model

Table A-27: Alberta agriculture's energy demand – hog subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	645	0	69	0	0
Farm transport	23	0	70	0	0
Non-farm	15	75	74	2	111
Heat and Light	0	231	0	7	232
Other uses	0	15	0	2	0
Total	683	320	214	11	343

As developed by the LEAP model

Table A-28: Alberta agriculture's energy demand – poultry and eggs subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	192	0	21	0	0
Farm transport	15	0	46	0	0
Non- farm	10	51	50	1	75
Heat and Light	0	368	0	10	370
Other uses	0	24	0	3	0
Total	217	443	117	15	445

As developed by the LEAP model

Table A-29: Alberta agriculture's energy demand – dairy subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	1014	0	109	0	0
Farm transport	23	0	70	0	0
Non-farm	14	71	70	2	105
Heat and Light	0	185	0	5	186
Other uses	0	66	0	8	0
Total	1051	322	249	16	291

As developed by the LEAP model

Table A-30: Alberta agriculture's energy demand – "other" subsector – base year fuel use (TJ)

Subsectors	Diesel	Electricity	Gasoline	LPG	NG
Farm machine	486	0	52	0	0
Farm transport	129	0	393	0	0
Non- farm	92	469	465	13	694
Heat and Light	0	600	0	16	605
Other uses	0	211	0	27	0
Total	708	1281	910	56	1298

As developed by the LEAP model

Table A-31: The overall growth in GHG emissions in Alberta agriculture's crop subsector (MT of CO_2)

GHG emissions	2009	2020	2030	2040	2050
Carbon dioxide non-biogenic	0.89	1.21	1.60	2.11	2.78
Methane	0.01	0.01	0.01	0.01	0.02
Nitrous oxide	0.01	0.01	0.01	0.01	0.02
Total	0.90	1.23	1.62	2.13	2.82

As developed by the LEAP model

Table A-32: The overall growth rate in GHG emissions in Alberta agriculture's livestock subsector (MT of CO_2)

GHG emissions	2009	2020	2030	2040	2050
Carbon dioxide non-biogenic	1.47	1.79	2.15	2.58	3.10
Methane	0.01	0.01	0.01	0.02	0.02
Nitrous oxide	0.01	0.01	0.01	0.02	0.02
Total	1.49	1.82	2.18	2.61	3.14

As developed by the LEAP model

Table A-33: The overall growth rate in GHG emissions in Alberta agriculture's "Other" subsector (MT of CO_2)

GHG emissions	2009	2020	2030	2040	2050
Carbon dioxide non-biogenic	0.19	0.26	0.34	0.45	0.59
Methane	0.00	0.00	0.00	0.00	0.00
Nitrous oxide	0.00	0.00	0.00	0.00	0.00
Total	0.19	0.26	0.34	0.45	0.60

As developed by the LEAP model

Table A-34: Total emission - demand sector – fuel-based emissions (MT of CO_2)

Fuel	2009	2020	2030	2040	2050
Diesel	1.74	2.22	2.78	3.49	4.39
Gasoline	0.48	0.62	0.77	0.97	1.22
LPG	0.02	0.02	0.03	0.04	0.05
NG	0.34	0.44	0.56	0.70	0.89
Total	2.58	3.30	4.14	5.20	6.55

As developed by the LEAP model

Appendix B.

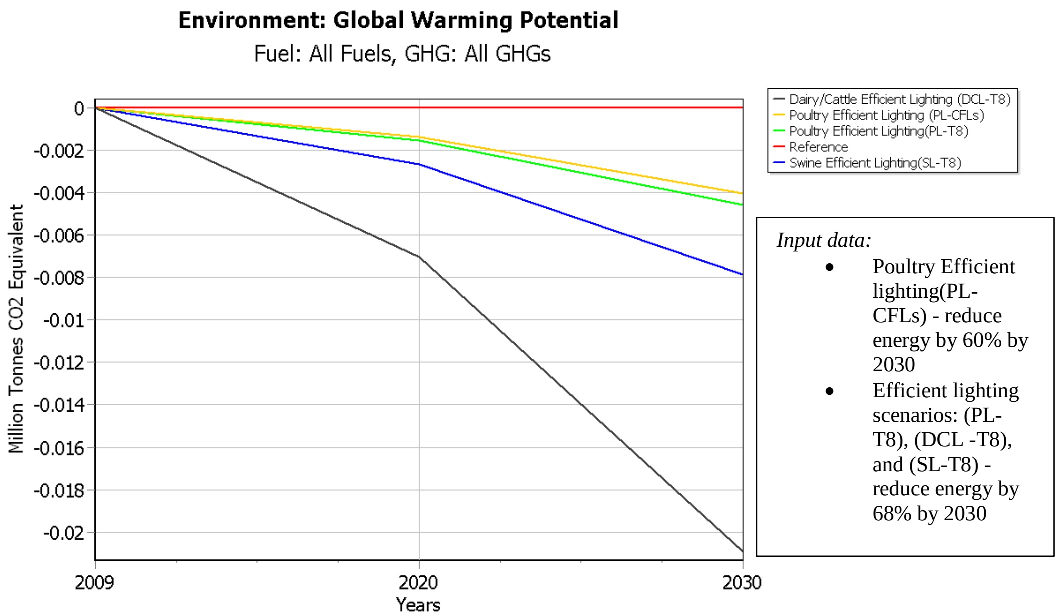


Figure B-1: GHG mitigation by 2030 in Alberta's livestock and poultry lighting subsector by four mitigation scenarios

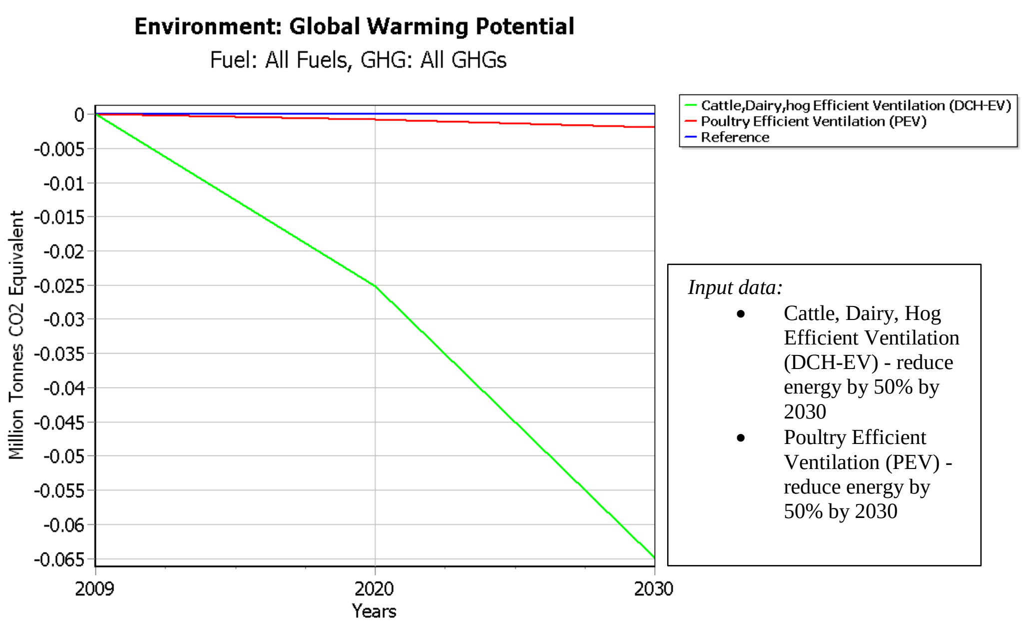


Figure B-2: GHG mitigation by 2030 in Alberta's livestock and poultry ventilation subsector by two mitigation scenarios

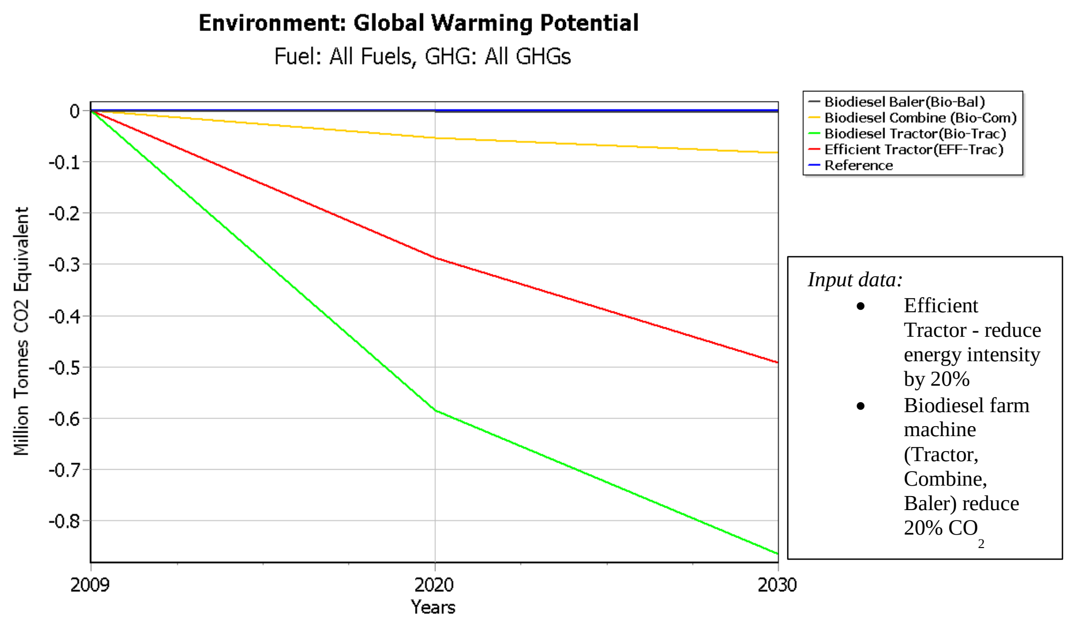


Figure B-3: GHG mitigation by 2030 in Alberta's farm machine subsector by four mitigation scenarios

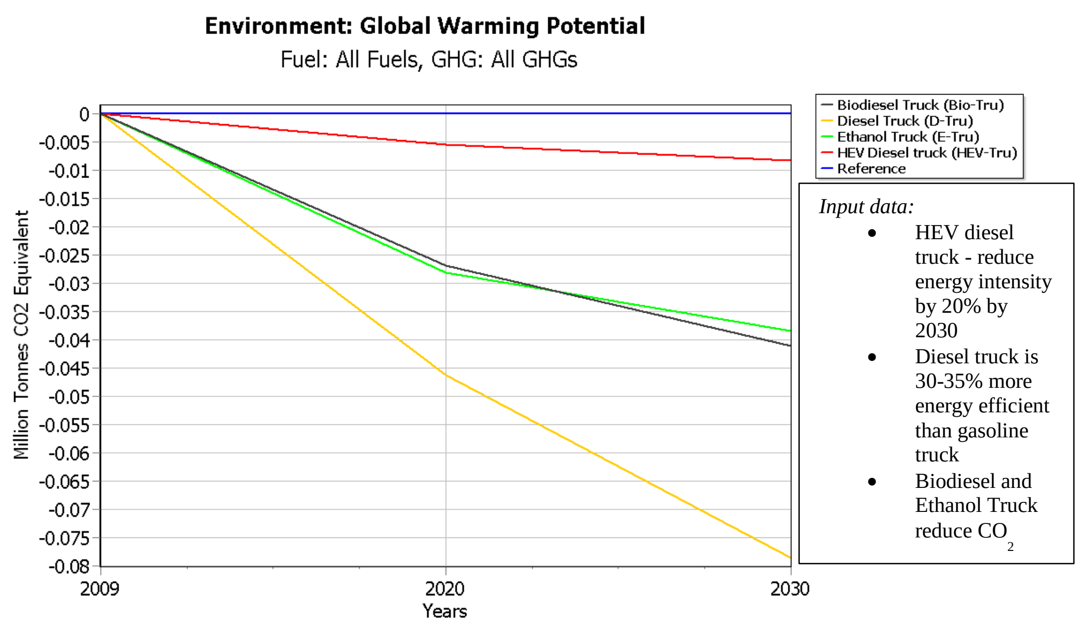


Figure B-4: GHG mitigation by 2030 in Alberta's farm transport subsector by four mitigation scenarios

Table B-1: Energy intensity in the biodiesel tractor scenario

Subsectors	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2050 (slow)-2030 (fast))
Grain and Oilseed		
Farm machine-tractors (diesel)	496	496
Fruit and Vegetable		
Farm machine-tractors (diesel)	4698	4698
Greenhouse and Nursery		
Farm machine-tractors (diesel)	3026	3026
Cattle		
Farm machine-tractors (diesel)	4351	4351
Hogs		
Farm machine-tractors (diesel)	11334	11334
Poultry and Eggs		
Farm machine-tractors (diesel)	1933	1933
Dairy		
Farm machine-tractors (diesel)	1606	1606
Other		
Farm machine-tractors (diesel)	31	31

Table B-2: Energy intensity in the biodiesel combine scenario

Subsectors	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2050 (slow)-2030 (fast))
Grain and Oilseed		
Farm machine combines (diesel)	124	124

Table B-3: Energy intensity in the biodiesel baler

Subsectors	Energy intensity (MJ/T) (2009)	Energy intensity (MJ/T) (2050 (slow)-2030 (fast))
Other		
Farm machine-balers (diesel)	3.9	3.9

Table B-4: Energy intensity in the biodiesel truck scenario

Subsectors	Energy intensity (MJ/km) (2009)	Energy intensity (MJ/km) (2050 (slow)-2030 (fast))
Grain and Oilseed		
Farm truck (diesel)	70.9	70.9
Fruit and Vegetable		
Farm truck (diesel)	60.5	60.5
Greenhouse and Nursery		
Farm truck (diesel)	60.5	60.5
Cattle		
Farm truck (diesel)	70.9	70.9
Hogs		
Farm truck (diesel)	60.5	60.5
Poultry and Eggs		
Farm truck (diesel)	60.5	60.5
Dairy		
Farm truck (diesel)	60.5	60.5
Other		
Farm truck (diesel)	60.5	60.5

Table B-5: Energy intensity in the ethanol truck scenario

Subsectors	Energy intensity (MJ/km) (2009)	Energy intensity (MJ/km) (2050 (slow)-2030 (fast))
Grain and Oilseed		
Farm truck (gasoline)	101.3	101.3
Fruit and Vegetable		
Farm truck (gasoline)	86.5	86.5
Greenhouse and Nursery		
Farm truck (gasoline)	86.5	86.5
Cattle		
Farm truck (gasoline)	101.3	101.3
Hogs		
Farm truck (gasoline)	86.5	86.5
Poultry and Eggs		
Farm truck (gasoline)	86.5	86.5
Dairy		
Farm truck (gasoline)	86.5	86.5
Other		
Farm truck (gasoline)	86.5	86.5

Table B-6: Alberta's livestock and poultry lighting subsector mitigation – demand reduction – fast penetration scenario (2030)

Energy demand (PJ)	2009	2020	2030
Reference	42.62	54.56	68.46
Poultry lighting - CFLs	42.62	54.56	68.44
Demand reduction (poultry lighting CFLs vs. reference)	0	-0.01	-0.02
Poultry lighting -T8	42.62	54.55	68.44
Demand reduction (poultry lighting T8 vs. reference)	0	-0.01	-0.03
Dairy/Cattle Lighting - T8	42.62	54.53	68.34
Demand reduction (D/C lighting T8 vs. reference)	0	-0.03	-0.12
Swine Lighting - T8	42.62	54.55	68.42
Demand reduction (swine lighting T8 vs. reference)	0	-0.01	-0.05

Table B-7: Alberta's livestock and poultry lighting subsector mitigation – transportation output reduction – fast penetration scenario (2030)

Output (PJ)	2009	2020	2030
Output reduction (poultry lighting CFLs vs. reference)	0	-0.02	-0.07
Output reduction (poultry lighting T8 vs. reference)	0	-0.03	-0.08
Output reduction (D/C lighting T8 vs. reference)	0	-0.13	-0.38
Output reduction (swine lighting T8 vs. reference)	0	-0.05	-0.14

Table B-8: Alberta's livestock and poultry lighting subsector mitigation – GHG reduction – fast penetration scenario (2030)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030
GHG reduction (poultry lighting CFLs vs. reference)	0	-0.001	-0.004
GHG reduction (poultry lighting T8 vs. reference)	0	-0.002	-0.005
GHG reduction (D/C lighting T8 vs. reference)	0	-0.007	-0.021
GHG reduction (swine lighting T8 vs. reference)	0	-0.003	-0.008

Table B-9: Alberta's livestock ventilation subsector mitigation – demand reduction – fast penetration scenario (2030)

Energy demand (PJ)	2009	2020	2030
Reference	42.62	54.56	68.46
Livestock ventilation	42.62	54.44	68.09
Demand reduction (livestock ventilation vs. reference)	0	-0.120	-0.378
Poultry ventilation	42.62	54.56	68.45
Demand reduction (poultry ventilation vs. reference)	0	-0.003	-0.010

Table B-10: Alberta's livestock ventilation subsector mitigation – transportation output reduction – fast penetration scenario (2030)

Output (PJ)	2009	2020	2030
Output reduction (livestock ventilation vs. reference)	0	-0.45	-1.19
Output reduction (poultry ventilation vs. reference)	0	-0.01	-0.03

Table B-11: Alberta's livestock ventilation subsector mitigation – GHG reduction – fast penetration scenario (2030)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030
GHG reduction (livestock ventilation vs. reference)	0	-0.025	-0.065
GHG reduction (poultry ventilation vs. reference)	0	-0.001	-0.002

Table B-12: Alberta's farm machine subsector mitigation – demand reduction – fast penetration scenario (2030)

Energy demand (PJ)	2009	2020	2030
Reference	42.62	54.56	68.46
Efficient tractor	42.62	51.46	63.00
Demand reduction (efficient tractor vs. reference)	0	-3.10	-5.46
Biodiesel tractor	42.62	54.56	68.46
Demand reduction (biodiesel tractor vs. reference)	0	0	0
Biodiesel combine	42.62	54.56	68.46
Demand reduction (biodiesel combine vs. reference)	0	0	0
Biodiesel baler	42.62	54.56	68.46
Demand reduction (biodiesel baler vs. reference)	0	0	0

Table B-13: Alberta's farm machine subsector mitigation – transportation output reduction – fast penetration scenario (2030)

Output (PJ)	2009	2020	2030
Output reduction (efficient tractor vs. reference)	0	-5.31	-5.46
Output reduction (biodiesel tractor vs. reference)	0	-10.91	-9.68
Output reduction (biodiesel combine vs. reference)	0	-0.98	-0.92
Output reduction (biodiesel baler vs. reference)	0	-0.03	-0.03

Table B-14: Alberta's farm machine subsector mitigation – GHG mitigation – fast penetration scenario (2030)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030
Reference	27.32	46.73	47.84
Efficient tractor	27.32	46.44	47.35
GHG reduction (efficient tractor vs. reference)	0	-0.29	-0.49
Biodiesel tractor	27.32	46.14	46.98
GHG reduction (biodiesel tractor vs. reference)	0	-0.59	-0.87
Biodiesel combine	27.32	46.68	47.76
GHG reduction (biodiesel combine vs. reference)	0	-0.05	-0.08
Biodiesel baler	27.32	46.73	47.84
GHG reduction (biodiesel baler vs. reference)	0	-0.002	-0.003

Table B-15: Alberta's farm transport subsector mitigation – demand reduction – fast penetration scenario (2030)

Energy demand (PJ)	2009	2020	2030
Reference	42.62	54.56	68.46
High efficient diesel truck (HEV diesel truck)	42.62	54.50	68.37
Demand reduction (HEV truck vs. reference)	0	-0.06	-0.09
Diesel truck	42.62	53.96	67.41
Demand reduction (diesel truck vs. reference)	0	-0.60	-1.05
Biodiesel truck	42.62	54.56	68.46
Demand reduction (biodiesel truck vs. reference)	0	0	0
Ethanol truck	42.62	54.56	68.46
Demand reduction (ethanol truck vs. reference)	0	0	0

Table B-16: Alberta's farm truck subsector mitigation – transportation output reduction – fast penetration scenario (2030)

Output (PJ)	2009	2020	2030
Output reduction (HEV truck vs. reference)	0	-0.10	-0.09
Output reduction (diesel truck vs. reference)	0	-1.02	-1.05
Output reduction (biodiesel truck vs. reference)	0	-0.50	-0.46
Output reduction (ethanol truck vs. reference)	0	-1.52	-1.32

Table B-17: Alberta's farm transport subsector mitigation – GHG mitigation – fast penetration scenario (2030)

GHG mitigation (MT of CO_2 eq.)	2009	2020	2030
Reference	27.32	46.73	47.84
High efficient diesel truck (HEV truck	27.32	46.72	47.84
GHG reduction (HEV truck vs. reference)	0	-0.01	-0.01
Diesel truck	27.32	46.68	47.77
GHG reduction (diesel truck vs. reference)	0	-0.05	-0.08
Biodiesel truck	27.32	46.70	47.80
GHG reduction (biodiesel truck vs. reference)	0	-0.03	-0.04
Ethanol truck	27.32	46.70	47.81
GHG reduction (ethanol truck vs. reference)	0	-0.03	-0.04

Appendix C.

Scenario – 1: Alberta Agriculture – poultry subsector – efficient lighting (compact fluorescent lamps – CFLs)

Assumptions:

One sample of poultry farm (building)

Total hours operating:	12 hr/day, 4380 hr/year
Total Kwh/year (incandescent bulbs):	7570 Kwh/year
Total Kwh/year (CFLs):	2840 Kwh/year
Number of fixtures (incandescent bulbs):	54
Number of fixtures (CFLs):	54
Efficiency of incandescent bulbs:	20%
Efficiency of CFLs:	80%
Difference in efficiency:	60%

i= Discount rate, 5%   n = Number of years (life of bulb), 4 years

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} = 0.282$$

Table C-1: Electricity price forecast for calculating the cost of saved energy

Electricity Price Forecast *	2010-2020	2020-2030	2030-2040	2040-2050
Cost considered ($/KWh)	0.11	0.15	0.2	0.27

*Based on forecast by the National Energy Board (NEB, 2011) and Identification of Best Energy-Efficiency Opportunities in Alberta's Energy Sector report (Subramanyam et al., 2013).

Table C-2: Cost of saved energy for scenario - 1

Years	Cost of new stock ($/B)	Cost of old stock ($/B)	Incremental annualized cost ($)	Saved energy (KWh/yr)	CSE ($/KWh)
Duration (2010-2020)	-	-	-	-	-0.10
Capital cost	1,000	860	39	4,730	-
Operating cost	312.4	832.7	-520	-	-
Duration (2020-2030)	-	-	-	-	-0.14
Capital cost	1,000	860	39	4,730	-
Operating cost	426	1,135.5	-710	-	-
Duration (2030-2040)	-	-	-	-	-0.19
Capital cost	1,000	860	39	4,730	-
Operating cost	568	1,514	-946	-	-
Duration (2040-2050)	-	-	-	-	-0.26
Capital cost	1,000	860	39	4,730	-
Operating cost	766.8	2,043.9	-1,277.1	-	-

Scenario – 2: Alberta Agriculture – poultry subsector – efficient lighting (T8)

Assumptions:

One sample of poultry farm (building)

Total hours operating:	12 hr/day, 4380 hr/year
Total Kwh/year (incandescent bulbs):	7570 Kwh/year
Total Kwh/year (T8):	2820 Kwh/year
Number of fixtures (incandescent bulbs):	54
Number of fixtures (T8):	27
Efficiency of incandescent bulbs:	20%
Efficiency of T8:	88%
Difference in efficiency:	68%

i= Discount rate, 5%   n = Number of years (life of bulb), 6 years

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} = 0.197$$

Electricity price forecast for calculating the cost of saved energy is shown in Table C-1.

Table C-3: Cost of saved energy for scenario - 2

Years	Cost of new stock ($/B)	Cost of old stock ($/B)	Incremental annualized cost ($)	Saved energy (KWh/yr)	CSE ($/KWh)
Duration (2010-2020)	-	-	-	-	-0.01
Capital cost	3,350	860	491	4,750	-
Operating cost	310.2	832.7	-523	-	-
Duration (2020-2030)	-	-	-	-	-0.05
Capital cost	3,350	860	491	4,750	-
Operating cost	423	1,135.5	-713	-	-
Duration (2030-2040)	-	-	-	-	-0.10
Capital cost	3,350	860	491	4,750	-
Operating cost	564	1,514	-950	-	-
Duration (2040-2050)	-	-	-	-	-0.17
Capital cost	3,350	860	491	4,750	-
Operating cost	761.4	2,043.9	-1,282.5	-	-

Scenario – 3: Alberta agriculture – dairy and cattle subsector – efficient lighting (T8)

Assumptions:

One sample of dairy /cattle farm (building)

Total hours operating:	18 hr/day, 6570 hr/year
Total Kwh/year (incandescent bulbs):	20126 Kwh/year
Total Kwh/year (T8):	5362 Kwh/year
Number of fixtures (incandescent bulbs):	30
Number of fixtures (T8):	20
Efficiency of incandescent bulbs:	20%
Efficiency of T8:	88%
Difference in efficiency:	68%

i= Discount rate, 5%   n = Number of years (life of bulb), 6 years

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} = 0.197$$

Electricity price forecast for calculating the cost of saved energy is shown in Table C-1.

Table C-4: Cost of saved energy for scenario - 3

Years	Cost of new stock ($/B)	Cost of old stock ($/B)	Incremental annualized cost ($)	Saved energy (KWh/yr)	CSE ($/KWh)
Duration (2010-2020)	-	-	-	-	-0.08
Capital cost	2,400	450	384	14,764	-
Operating cost	590	2,214	-1,624	-	-
Duration (2020-2030)	-	-	-	-	-0.12
Capital cost	2,400	450	384	14,764	-
Operating cost	804	3,019	-2,215	-	-
Duration (2030-2040)	-	-	-	-	-0.17
Capital cost	2,400	450	384	14,764	-
Operating cost	1,072	4,025	-2,953	-	-
Duration (2040-2050)	-	-	-	-	-0.24
Capital cost	2,400	450	384	14,764	-
Operating cost	1,448	5,434	-3,986	-	-

Scenario – 4: Alberta agriculture – hog (swine) subsector – efficient lighting (T8)

Assumptions:

One sample of hog farm (building)

Total hours operating:	7 hr/day, 2555 hr/year
Total Kwh/year (incandescent bulbs):	3106 Kwh/year
Total Kwh/year (T8):	766 Kwh/year
Number of fixtures (incandescent bulbs):	32
Number of fixtures (T8):	53
Efficiency of incandescent bulbs:	20%
Efficiency of T8:	88%
Difference in efficiency:	68%

i= Discount rate, 5%   n = Number of years (life of bulb), 6 years

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} = 0.197$$

Electricity price forecast for calculating the cost of saved energy is shown in Table C-1.

Table C-5: Cost of saved energy for scenario - 4

Years	Cost of new stock ($/B)	Cost of old stock ($/B)	Incremental annualized cost ($)	Saved energy (KWh/yr)	CSE ($/KWh)
Duration (2010-2020)	-	-	-	-	-0.08
Capital cost	500	120	75	2,340	-
Operating cost	84	342	-257	-	-
Duration (2020-2030)	-	-	-	-	-0.12
Capital cost	500	120	75	2,340	-
Operating cost	115	466	-351	-	-
Duration (2030-2040)	-	-	-	-	-0.17
Capital cost	500	120	75	2,340	-
Operating cost	153	621	-468	-	-
Duration (2040-2050)	-	-	-	-	-0.24
Capital cost	500	120	75	2,340	-
Operating cost	207	839	-632	-	-

Scenario – 5: Alberta agriculture – livestock subsector – efficient ventilation

Assumptions:

One sample of livestock farm (building)

- 100 animals for one farm
- 6000 square feet for 60 animals
- 5 fans for 6000 square feet and for 60 cows

Efficiency of fan A: 8.4 CFM/W

Efficiency of fan B: 18.6 CFM/W

i=Discount rate, 5% n= Number of years (life of fan), 10 years

CRF= $\frac{i(1+i)^n}{(1+i)^n-1}$ = 0.130

EOCS = [(AFR1 ÷ FE1) - (AFR2 ÷ FE2)] × AOH × ER × 0.001

$\text{EOCS}_{(2010-2020)}$ = [(9750 ÷ 18.6) - (9900 ÷ 8.4)] × 2880 × \$0.11 × 0.001

EOCS = electrical operating cost savings per year (in dollars/yr) when one fan is used compared to another.

AFR_1= airflow rate (L/s or CFM) of fan B, the fan with the lower efficiency, at the selected static pressure.

FE_B = fan efficiency (L/s/W or CFM/W) of fan B, the fan with the lower efficiency, at the selected static pressure.

AFR_A= airflow rate (L/s or CFM) of fan A, the fan with the higher efficiency, at the selected static pressure.

FE_A= fan efficiency (L/s/W or CFM/W) of fan A, the fan with the higher efficiency, at the selected static pressure.

AOH= average operating hours per year (h/yr) for the fan.

ER = electrical rate (dollars/kW-h) charged by the electrical supplier.

Electricity price forecast for calculating the cost of saved energy is shown in Table C-1.

Table C-6: Cost of saved energy for scenario - 5

Years	Cost of new stock ($)	Cost of old stock ($)	Incremental annualized cost ($/y)	Saved energy (KWh/yr)	CSE ($/KWh)
Duration (2010-2020)	-	-	-	-	-0.46
Capital cost	-	-	162	1,885	-
Operating cost	830	1,867	-1,037	-	-
Duration (2020-2030)	-	-	-	-	-0.66
Capital cost	-	-	162	1,885	-
Operating cost	1,132	2,546	-1,414	-	-
Duration (2030-2040)	-	-	-	-	-0.91
Capital cost	-	-	162	1,885	-
Operating cost	1,510	3,394	-1,885	-	-
Duration (2040-2050)	-	-	-	-	-1.26
Capital cost	-	-	162	1,885	-
Operating cost	2,038	4,582	-2,544	-	-

Scenario – 6: Alberta agriculture – poultry subsector – efficient ventilation

Assumptions:

One sample of poultry farm (building)

- 20000 birds one farm
- 1.5square feet for 1 bird
- 16 fans for every 16,000 sq ft
- 6 fans for 1500 sq ft and for 1000 birds

Efficiency of fan A: 8.4 CFM/W

Efficiency of fan B: 18.6 CFM/W

i=Discount rate, 5% n= Number of years (life of fan), 10 years

CRF= $\frac{i(1+i)^n}{(1+i)^n-1}$ = 0.130

EOCS = [(AFR1 ÷ FE1) - (AFR2 ÷ FE2)] × AOH × ER × 0.001

$EOCS_{(2010-2020)}$ = [(9750÷ 18.6) - (9900 ÷ 8.4)] × 2880 × $0.11 × 0.001

EOCS = electrical operating cost savings per year (in dollars/yr) when one fan is used compared to another.

AFR_1 = airflow rate (L/s or CFM) of fan B, the fan with the lower efficiency, at the selected static pressure.

FE_B = fan efficiency (L/s/W or CFM/W) of fan B, the fan with the lower efficiency, at the selected static pressure.

AFR_A = airflow rate (L/s or CFM) of fan A, the fan with the higher efficiency, at the selected static pressure.

FE_A= fan efficiency (L/s/W or CFM/W) of fan A, the fan with the higher efficiency, at the selected static pressure.

AOH = average operating hours per year (h/yr) for the fan.

ER = electrical rate (dollars/kW-h) charged by the electrical supplier.

Electricity price forecast for calculating the cost of saved energy is shown in Table C-1.

Table C-7: Cost of saved energy for scenario - 6

Years	Cost of new stock ($)	Cost of old stock ($)	Incremental annualized cost ($/y)	Saved energy (KWh/y)	CSE ($/KWh)
Duration (2010-2020)	-	-	-	-	-0.93
Capital cost	-	-	324	1,885	-
Operating cost	1,661	3,734	-2,073	-	-
Duration (2020-2030)	-	-	-	-	-1.33
Capital cost	-	-	324	1,885	-
Operating cost	2,265	5,091	-2,827	-	-
Duration (2030-2040)	-	-	-	-	-1.83
Capital cost	-	-	324	1,885	-
Operating cost	3,019	6,789	-3,769	-	-
Duration (2040-2050)	-	-	-	-	-2.53
Capital cost	-	-	324	1,885	-
Operating cost	4,079	9,165	-5,089	-	-

Scenario –7: Alberta agriculture – farm machine subsector – efficient diesel tractor

Assumptions:

Total Tractor: 155,808 Efficiency improvement: 20%

i=Discount rate, 5% n= Number of years (life of tractor), 15 years

CRF= $\frac{i(1+i)^n}{(1+i)^n-1}$ = 0.096

Capital cost new stock: $55,000 Capital cost old stock : $50,000

Table C-8: Diesel price forecast for calculating the cost of saved energy

Diesel Price Forecast *	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Cost considered ($/GJ)	29	30.45	31.97	33.6

*Based on forecast by the National Energy Board (NEB, 2011) and Identification of Best Energy-Efficiency Opportunities in Alberta's Energy Sector report (Subramanyam et al., 2013).

Table C-9: Cost of saved energy for scenario - 7

Years	Incremental annualized cost ($)	Saved energy (GJ/yr)	CSE ($/GJ)
Duration (2010-2020)	-	104	1.74
Capital cost	482	-	-
Operating cost	-301	-	-
Duration (2020-2030)	-	271	-1.27
Capital cost	482	-	-
Operating cost	-826	-	-
Duration (2030-2040)	-	429	-2.07
Capital cost	482	-	-
Operating cost	-1372	-	-
Duration (2040-2050)	-	590	-2.54
Capital cost	482	-	-
Operating cost	-1982	-	-

Scenario – 8: Alberta agriculture – farm machine subsector – biodiesel tractor

Assumptions:

Total Tractor: 155,808

Total production (tonne): 33284859

Tonne per tractor: 214

i=Discount rate, 5%   n= Number of years (life of tractor), 15 years

CRF= $\frac{i(1+i)^n}{(1+i)^n-1}$ = 0.096

Diesel price forecast for calculating the cost of saved energy is shown in Table C-8.

Table C-10: Biodiesel price forecast for calculating the cost of saved energy

Biodieseliesel Price Forecast *	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Cost considered ($/GJ)	31.61	31.61	30.03	28.5

*Based on forecast by the National Energy Board (NEB, 2011) and Identification of Best Energy-Efficiency Opportunities in Alberta's Energy Sector report (Subramanyam et al., 2013).

Table C-11: Activity cost for scenario - 8

Years	Cost of new stock ($/Tractor)	Cost of old stock ($/Tractor)	Incremental annualized cost ($/Tractor)	Activity cost ($/Tonne)
Duration (2010-2020)	-	-	-	1.98
Capital cost	55,000	55,000	0	-
Operating cost	5,110	4,688	421	-
Duration (2020-2030)	-	-	-	0.88
Capital cost	55,000	55,000	0	-
Operating cost	5,110	4,923	187	-
Duration (2030-2040)	-	-	-	-1.47
Capital cost	55,000	55,000	0	-
Operating cost	4,855	5,169	-314	-
Duration (2040-2050)	-	-	-	-3.82
Capital cost	55,000	55,000	0	-
Operating cost	4,612	5,427	-815	-

Scenario – 9: Alberta agriculture – farm machine subsector – biodiesel combine

Assumptions:

Total combine:	26,576
Total production (tonne):	33284859
Tonne per combine:	1252

i=Discount rate, 5%   n= Number of years (life of combine), 15 years

CRF= $\frac{i(1+i)^n}{(1+i)^n-1}$ = 0.096

Diesel and biodiesel price forecast for calculating the cost of saved energy are shown in Tables C-8 and C-10, respectively.

Table C-12: Activity cost for scenario - 9

Years	Cost of new stock ($/Combine)	Cost of old stock ($/Combine)	Incremental annualized cost ($/Combine)	Activity cost ($/Tonne)
Duration (2010-2020)	-	-	-	0.27
Capital cost	-	-	0	-
Operating cost	4,128	3,788	340	-
Duration (2020-2030)	-	-	-	0.12
Capital cost	-	-	0	-
Operating cost	4,128	3,977	151	-
Duration (2030-2040)	-	-	-	-0.20
Capital cost	-	-	0	-
Operating cost	3,922	4,176	-253	-
Duration (2040-2050)	-	-	-	-0.53
Capital cost	-	-	0	-
Operating cost	3,726	4,385	-658	-

Scenario – 10: Alberta agriculture – farm machine subsector – biodiesel baler

Assumptions:

Total baler:	32,191
Total production (tonne):	33284859
Tonne per baler:	1034

i = Discount rate, 5%   n = Number of years (life of baler), 15 years

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} = 0.096$$

Diesel and biodiesel price forecast for calculating the cost of saved energy are shown in Tables C-8 and C-10, respectively.

Table C-13: Activity cost for scenario - 10

Years	Cost of new stock ($/Baler)	Cost of old stock ($/Baler)	Incremental annualized cost ($/Baler)	Activity cost ($/Tonne)
Duration (2010-2020)	-	-	-	0.30
Capital cost	-	-	0	-
Operating cost	3,161	2,900	261	-
Duration (2020-2030)	-	-	-	0.11
Capital cost	-	-	0	-
Operating cost	3,161	3,045	116	-
Duration (2030-2040)	-	-	-	-0.18
Capital cost	-	-	0	-
Operating cost	3,002	3,197	-194	-
Duration (2040-2050)	-	-	-	-0.49
Capital cost	-	-	0	-
Operating cost	2,852	3,357	-504	-

Scenario – 11: Alberta agriculture – farm truck subsector – diesel truck

Assumptions:

Total Tractor: 135,752

Efficiency improvement: 30%

i= Discount rate, 5% n = Number of years (life of truck), 12 years

CRF = $\frac{i(1+i)^n}{(1+i)^n-1}$ = 0.113

Table C-14: Gasoline price forecast for calculating the cost of saved energy

Gasoline Price Forecast *	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Cost considered ($/GJ)	38	40	42	44

*Based on forecast by the National Energy Board (NEB, 2011) and Identification of Best Energy-Efficiency Opportunities in Alberta's Energy Sector report (Subramanyam et al., 2013).

Diesel price forecast for calculating the cost of saved energy is shown in Table C-8.

Table C-15: Cost of saved energy for scenario - 11

Years	Incremental annualized cost ($/Truck)	Saved energy(GJ/Truck)	Cost of saved energy($/GJ)
Duration (2010-2020)	-	-	-41.67
Capital cost	584	33	-
Operating cost	-1,991	-	-
Duration (2020-2030)	-	-	-54.90
Capital cost	584	143	-
Operating cost	-8,451	-	-
Duration (2030-2040)	-	-	-57.83
Capital cost	584	513	-
Operating cost	-30,256	-	-
Duration (2040-2050)	-	-	-58.18
Capital cost	584	735	-
Operating cost	-43,397	-	-

Scenario – 12: Alberta agriculture – farm truck subsector – biodiesel truck

Assumptions:

Total baler:	135,752
Total average (km) in base year2009:	42000000
Km per truck:	309

i= Discount rate, 5%   n = Number of years (life of truck), 12 years

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} = 0.113$$

Diesel and biodiesel price forecast for calculating the cost of saved energy are shown in Tables C-8 and C-10, respectively.

Table C-16: Activity cost for scenario - 12

Years	Cost of new stock ($/Truck)	Cost of old stock ($/Truck)	Incremental annualized cost ($/Truck)	Activity cost ($/Km)
Duration (2010-2020)	-	-	-	0.09
Capital cost	-	-	0	-
Operating cost	321	294	27	-
Duration (2020-2030)	-	-	-	0.04
Capital cost	-	-	0	-
Operating cost	321	309	12	-
Duration (2030-2040)	-	-	-	-0.06
Capital cost	-	-	0	-
Operating cost	305	325	-20	-
Duration (2040-2050)	-	-	-	-0.17
Capital cost	-	-	0	-
Operating cost	290	341	-51	-

Scenario – 13: Alberta agriculture – farm truck subsector – ethanol truck

Assumptions:

Total baler: 135,752

Total average (km) in base year2009: 42000000

Km per truck: 309

i= Discount rate, 5%   n = Number of years (life of truck), 12 years

$$CRF = \frac{i(1+i)^n}{(1+i)^n-1} = 0.113$$

Gasoline price forecast for calculating the cost of saved energy is shown in Table C-14

Table C-17: Ethanol price forecast for calculating the cost of saved energy

Ethanol Price Forecast *	2010-2020	2020-2030	2030-2040	2040-2050
Cost considered ($/GJ)	41.8	41.8	39.7	37.7

*Based on forecast by the National Energy Board (NEB, 2011) and Identification of Best Energy-Efficiency Opportunities in Alberta's Energy Sector report (Subramanyam et al., 2013).

Table C-18: Activity Cost for scenario - 13

Years	Cost of new stock ($/Truck)	Cost of old stock ($/Truck)	Incremental annualized cost ($/Truck)	Activity cost ($/Km)
Duration (2010-2020)	-	-	-	0.12
Capital cost	-	-	0	-
Operating cost	404	367	37	-
Duration (2020-2030)	-	-	-	0.06
Capital cost	-	-	0	-
Operating cost	404	387	17	-
Duration (2030-2040)	-	-	-	-0.07
Capital cost	-	-	0	-
Operating cost	384	406	-22	-
Duration (2040-2050)	-	-	-	-0.20
Capital cost	-	-	0	-
Operating cost	365	426	-62	-

Appendix D.

Table D-1: Emissions reduction based on fuel type for the slow penetration scenario

Reduction in 2050 (Thousand tonnes)	Diesel	Gasoline	LPG	NG
Cattle, dairy, hog – efficient ventilation	0	0	0	-33.3
Dairy/cattle efficient lighting (DCL – T8)	0	0	0	-11
Biodiesel balers (Bio – Bal)	-3.7	0	0	0
Biodiesel combines (Bio – Com)	-118.9	0	0	0
Biodiesel tractors (Bio – Trac)	-1122	0	0	0
Biodiesel truck (Bio – Tru)	-53.7	0	0	0
Awareness programs for drivers	-646.1	-138.3	0	0
Efficient tractor (EFF – Trac)	-633	0	0	0
Diesel truck (D – Tru)	284.6	-382.5	0	0
Ethanol truck (E – Tru)	0	-144.3	0	0
HEV diesel truck (HEV – Tru)	-10.74	0	0	0
Poultry efficient lighting (PL – CLFs)	0	0	0	-2.1
Poultry efficient lighting (PL – T8)	0	0	0	-2.4
Poultry efficient ventilation (PEV)	0	0	0	-0.9
Reference	0	0	0	0
Regular Maintenance	-646.1	-138.3	0	0
Swine efficient lighting (SL – T8)	0	0	0	-4.1
Tire Pressures	-861.4	-184.4	0	0

Table D-2: Emissions reduction based on fuel type for the fast penetration scenario

Reduction in 2030 (Thousand tonnes)	Diesel	Gasoline	LPG	NG
Cattle, dairy, hog – efficient ventilation	0	0	0	-25.87
Dairy/cattle efficient lighting (DCL – T8)	0	0	0	-8.34
Biodiesel balers (Bio – Bal)	-2.15	0	0	0
Biodiesel combines (Bio – Com)	-68.3	0	0	0
Biodiesel tractors (Bio – Trac)	-717.6	0	0	0
Biodiesel truck (Bio – Tru)	-33.87	0	0	0
Awareness programs for drivers	-330.6	-70.2	0	0
Efficient tractor (EFF – Trac)	-404.7	0	0	0
Diesel truck (D – Tru)	179.5	-241	0	0
Ethanol truck (E – Tru)	0	-91	0	0
HEV diesel truck (HEV – Tru)	-6.7	0	0	0
Poultry efficient lighting (PL – CLFs)	0	0	0	-1.6
Poultry efficient lighting (PL – T8)	0	0	0	-1.82
Poultry efficient ventilation (PEV)	0	0	0	-0.7
Reference	0	0	0	0
Regular Maintenance	-330.6	-70.2	0	0
Swine efficient lighting (SL – T8)	0	0	0	-3.1
Tire Pressures	-436.3	-93.2	0	0

Table D-3: Reduction in nitrogen oxide (NOx) based on fuel type for the slow penetration scenario

Reduction in 2050 (Thousand tonnes)	Diesel	Ethanol	Gasoline	LPG	NG	Biodiesel
Cattle, dairy, hog – efficient ventilation	0.0	0.0	0.0	0.0	-0.1	0.0
Dairy/cattle efficient lighting (DCL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel balers (Bio – Bal)	-0.1	0.0	0.0	0.0	0.0	0.1
Biodiesel combines (Bio – Com)	-2.4	0.0	0.0	0.0	0.0	2.4
Biodiesel tractors (Bio – Trac)	-22.7	0.0	0.0	0.0	0.0	22.7
Biodiesel truck (Bio – Tru)	-0.6	0.0	0.0	0.0	-0.1	0.6
Awareness programs for drivers	-12.8	0.0	-0.7	0.0	0.0	0.0
Efficient tractor (EFF – Trac)	-12.8	0.0	0.0	0.0	0.0	0.0
Diesel truck (D – Tru)	3.1	0.0	-3.3	0.0	-0.1	0.0
Ethanol truck (E – Tru)	0.0	0.8	-1.3	0.0	0.0	0.0
HEV diesel truck (HEV – Tru)	-0.12	0.0	0.0	0.0	0.0	0.0
Poultry efficient lighting (PL – CLFs)	0.0	0.0	0.0	0.0	0.0	0.0
Poultry efficient lighting (PL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Poultry efficient ventilation (PEV)	0.0	0.0	0.0	0.0	0.0	0.0
Reference	0.0	0.0	0.0	0.0	0.0	0.0
Regular Maintenance	-12.8	0.0	-0.7	0.0	0.0	0.0
Swine efficient lighting (SL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Tire Pressures	-17.1	0.0	-0.9	0.0	0.0	0.0

Table D-4: Reduction in sulfur dioxide (SO_2) based on fuel type for the slow penetration scenario

Reduction in 2050 (Thousand tonnes)	Diesel	Ethanol	Gasoline	LPG	NG	Biodiesel
Cattle, dairy, hog - efficient ventilation	0.0	0.0	0.0	0.0	0.0	0.0
Dairy/cattle efficient lighting (DCL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel balers (Bio – Bal)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel combines (Bio – Com)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel tractors (Bio – Trac)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel truck (Bio – Tru)	-134	0.0	0.0	0.0	0.0	0.0
Awareness programs for drivers	-64	0.0	-20	0.0	0.0	0.0
Efficient tractor (EFF – Trac)	0.0	0.0	0.0	0.0	0.0	0.0
Diesel truck (D – Tru)	713	0.0	-108	0.0	0.0	0.0
Ethanol truck (E – Tru)	0.0	0.0	-40	0.0	0.0	0.0
HEV diesel truck (HEV – Tru)	-26	0.0	0.0	0.0	0.0	0.0
Poultry efficient lighting (PL – CLFs)	0.0	0.0	0.0	0.0	0.0	0.0
Poultry efficient lighting (PL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Poultry efficient ventilation (PEV)	0.0	0.0	0.0	0.0	0.0	0.0
Reference	0.0	0.0	0.0	0.0	0.0	0.0
Regular Maintenance	-64	0.0	-20	0.0	0.0	0.0
Swine efficient lighting (SL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Tire Pressures	-86	0.0	-27	0.0	0.0	0.0

Table D-5: Reduction in nitrogen oxide (NOx) based on fuel type for the fast penetration scenario

Reduction in 2030 (Thousand tonnes)	Diesel	Ethanol	Gasoline	LPG	NG	Biodiesel
Cattle, dairy, hog – efficient ventilation	0.00	0.00	0.00	0.0	0.00	0.00
Dairy/cattle efficient lighting (DCL-T8)	0.00	0.00	0.00	0.0	0.00	0.00
Biodiesel balers (Bio – Bal)	-0.04	0.00	0.00	0.0	0.00	0.04
Biodiesel combines (Bio – Com)	-1.38	0.00	0.00	0.0	0.00	1.38
Biodiesel tractors (Bio – Trac)	-14.52	0.00	0.00	0.0	0.00	14.52
Biodiesel truck (Bio – Tru)	-0.37	0.00	0.00	0.0	0.00	0.37
Awareness programs for drivers	-6.56	0.00	-0.34	0.0	0.00	0.00
Efficient tractor (EFF – Trac)	-8.19	0.00	0.00	0.0	0.00	0.00
Diesel truck (D – Tru)	1.95	0.00	-2.09	0.0	0.00	0.00
Ethanol truck (E – Tru)	0.00	0.47	-0.79	0.0	0.00	0.00
HEV diesel truck (HEV – Tru)	-0.07	0.00	0.00	0.0	0.00	0.00
Poultry efficient lighting (PL – CLFs)	0.00	0.00	0.00	0.0	-0.01	0.00
Poultry efficient lighting (PL – T8)	0.00	0.00	0.00	0.0	-0.01	0.00
Poultry efficient ventilation (PEV)	0.00	0.00	0.00	0.0	0.00	0.00
Reference	0.00	0.00	0.00	0.0	0.00	0.00
Regular Maintenance	-6.56	0.00	-0.34	0.0	0.00	0.00
Swine efficient lighting (SL – T8)	0.00	0.00	0.00	0.0	0.00	0.00
Tire Pressures	-8.67	0.00	-0.45	0.0	0.00	0.00

Table D-6: Reduction in sulfur dioxide (SO_2) based on fuel type for the fast penetration scenario

Reduction in 2030 (Tonnes)	Diesel	Ethanol	Gasoline	LPG	NG	Biodiesel
Cattle, dairy, hog – efficient ventilation	0.0	0.0	0.0	0.0	0.0	0.0
Dairy/cattle efficient lighting (DCL-T8)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel balers (Bio – Bal)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel combines (Bio – Com)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel tractors (Bio – Trac)	0.0	0.0	0.0	0.0	0.0	0.0
Biodiesel truck (Bio – Tru)	-84.9	0.0	0.0	0.0	0.0	0.0
Awareness programs for drivers	-34.0	0.0	-10.6	0.0	0.0	0.0
Efficient tractor (EFF – Trac)	0.0	0.0	0.0	0.0	0.0	0.0
Diesel truck (D – Tru)	450	0.0	-68.4	0.0	0.0	0.0
Ethanol truck (E – Tru)	0.0	0.0	-25.8	0.0	0.0	0.0
HEV diesel truck (HEV – Tru)	-16.9	0.0	0.0	0.0	0.0	0.0
Poultry efficient lighting (PL – CLFs)	0.0	0.0	0.0	0.0	0.0	0.0
Poultry efficient lighting (PL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Poultry efficient ventilation (PEV)	0.0	0.0	0.0	0.0	0.0	0.0
Reference	0.0	0.0	0.0	0.0	0.0	0.0
Regular Maintenance	-34.0	0.0	-10.6	0.0	0.0	0.0
Swine efficient lighting (SL – T8)	0.0	0.0	0.0	0.0	0.0	0.0
Tire Pressures	-43.4	0.0	-14.0	0.0	0.0	0.0

Appendix E.

Capital recovery factor (CRF) is the ratio used to annualize the present value of receiving an annuity for a particular life time.

$$\text{CRF}= \frac{i(1+i)^n}{(1+i)^n-1}$$

where *n* is the number of annuities received, i is interest rate or discount rate

Conversion Factors

Acre = 0.404686 ha
m3 = cubic meter = 1000 litres = 220 gallons
MJ = megajoule = 10^6joules
GJ = gigajoule = 10^9joules
TJ = terajoule = 10^{12}joules
PJ = petajoule = 10^{15}joules
TJ = 28 852.7 litres of motor gasoline

Joule measurements and conversions

1 kilojoule = 1,000 joules
1 watt hour = 3,600 joules
1 kilowatt hour = 3.6 megajoules
1 megajoule = 1 million joules
1 terajoule = 1 million mega joules

Liquid fuel measurements and conversions:

Gasoline

1 gallon = 121.7 megajoules – LHV* 1 liter = 32.2 megajoules – LHV*
1 gallon = 131.9 megajoules – HHV* 1 liter = 34.8 megajoules – HHV*

Diesel fuel

1 gallon = 135.8 megajoules – LHV* 1 liter = 35.9 megajoules – LHV*
1 gallon = 146.3 megajoules – HHV* 1 liter = 38.7 megajoules – HHV*

Ethanol

1 gallon = 79.8 megajoules – LHV* 1 liter = 21.1 megajoules – LHV*
1 gallon = 89.3 megajoules – HHV* 1 liter = 23.6 megajoules – HHV*

Bio-diesel

1 gallon = 123.5 megajoules – LHV* 1 liter = 32.6 megajoules – LHV*
1 gallon = 133.1 megajoules – HHV* 1 liter = 35.2 megajoules – HHV*

LP Gas (liquefied petroleum gas – propane)

1 gallon = 88.1 megajoules – LHV* 1 liter = 23.3 megajoules – LHV*
1 gallon = 96.3 megajoules – HHV* 1 liter = 25.4 megajoules – HHV*

A complete table of conversion factors can be found in Statistics Canada's Energy Statistics Handbook.

* Energy contents are expressed as either high (gross) heating value (HHV) or lower (net) heating value (LHV) [derived from (BFIN, 2013)].