EXTENDED EXERGY ANALYSIS OF THE NOVA SCOTIAN ECONOMY 2006

by

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Abstract

Human societies may be modeled as very large complex systems involving multiple flows of energy and materials between different sectors. Traditional exergy analysis methods are inadequate for the analysis of such systems because they do not take non-energetic flows into account. Extended exergy analysis (EEA) allows for the inclusion of exergetic equivalents of such non-energetic quantities as labor, capital and the costs of environmental remediation. It is also possible within an EEA context to evaluate the efficiency of domestic household energy use with respect to the rest of the economy by considering labor as an output from all households. In this work, extended exergy analysis is conducted to characterize the extraction, conversion, and end use of energy and materials in the Nova Scotian economy in 2006.

The economy is divided into seven sectors reflecting the organization of economic data reported by Statistics Canada. The agriculture, industry, tertiary, domestic, natural resource extraction, energy conversion, and transportation sectors are each modeled according to their characteristic material and energy fluxes.

A model of the structural connectivity of the economy in terms of exchanges between sectors is constructed using economic data generated by Statistic Canada. Equivalent values of exergy are computed for each flow of energy and material using exergy conversion factors found in the literature. Energy, exergy, and extended exergy efficiencies are calculated for each sector of the economy of Nova Scotia and compared with those of Norway, China, Italy, and the UK to identify similarities and differences between the composition and performance of sectors around the world.

List of Abbreviations and Symbols Used

A: Abroad sector

Ag: Agriculture sector

BoC: Bank of Canada

c : relative concentration (%)

CIMTD: Canadian International Merchandise Trade Database

Co: Conversion sector

Do: Domestic sector

DoA: Department of Agriculture

DNR: Department of Natural Resources

E: Environment sector

e: exergy (J)

ee: extended exergy (J)

EEA: Extended Exergy Analysis

Ex: Extraction sector

$\Delta\tilde{g}_f^0$: Gibbs function

GJ: gigajoule

H: enthalpy (J)

HAAE: Human Activity And the Environment (StatsCan report)

In: Industry sector

J: joule

LHV: Lower Heating Value

m: mass (kg)

NAICS: North American Industry Classification System

NIST: National Institute of Standards and Technology

NPRI: National Pollutant Release Inventory

NRCan: Natural Resources Canada

P: pressure (bar or Pa)

PJ: petajoule

S: entropy (J/°K)

StatsCan: Statistics Canada

T: temperature (°K)

TJ: terajoule

Te: Tertiary sector

Tr: Transportation sector

U: internal energy (J)

V: volume (m^3)

v: system velocity (m/s)

z: system height (m)

β: exergy factor

$\tilde{\varepsilon}^0$: molar chemical exergy

μ : chemical potential (J/kg)

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Chapter 1: Introduction

1.1 Background

1.1.1 Exergy

The location and degree of inefficient use of energy is a primary factor in the design and performance evaluation of any system. Rising energy costs shift economic design criteria from the initial investment to life cycle cost assessments, which require a more robust method of performance evaluation. To assess the effectiveness of energy utilization, a realistic measure of the efficiency of energy utilization must be applied. Exergy analysis provides a true measure of the efficiency of energy utilization through the application of both the first and second laws of thermodynamics. Exergy analysis answers the questions of where, why, and how much available work is lost to inefficiency in a system. The quantity "exergy" is the capacity to do work, calculated in relation to a defined baseline or zero level. Exergy has been defined by Szargut as follows (Szargut 1988):

> *"Exergy is the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes, involving interaction only with the abovementioned components of nature."*

Work is a useful final product derived from the expenditure of energy resources. Work is used to pump water, to create electricity, and power machines. It is made available in many forms, through the height difference of water held back by a hydroelectric dam, through high pressure, high temperature steam in a turbine/generator system. In these examples, the available work is depleted when the water level behind the dam drops to the level in front, and when the steam has condensed to liquid near the ambient temperature. When the system has reverted to the steady state of the surrounding environment, it can no longer perform work. Unlike energy, exergy is exempt from the law of conservation. Every real process involves irreversibilities that cause exergy to be lost (or destroyed), leading to a reduction in the useful effects of the process or to an increase in the amount of energy required to achieve the same effects (Szargut 1988). This is the basis of exergy analysis for energy systems. Exergy analysis can indicate the possibility of improving the thermodynamic performance of a particular process, however; only an economic analysis can indicate the desirability of undertaking that improvement.

In this work, exergy analysis is applied to the provincial economy of Nova Scotia for the year 2006. The approach of this work is similar to the classical application of exergy efficiency analyses; however, there are practical considerations that must be added to the analysis when dealing with human societies. The Nova Scotian economy is modeled as a very large complex system in order to analyze patterns of energy production and consumption. The system is assumed to be at steady state and the input and output flows between sectors of the economy are expressed in units of exergy (J).

1.1.2 Exergy Analysis

The methods of exergy analysis for thermal and other energy systems are well developed in the literature (Szargut 1988), and (Kotas 1985) and are not reproduced in this work. Exergy analyses of economic systems are less familiar but have been performed for countries like Canada (Rosen 1992), the United States (Reistad 1975), Norway (Ertesvåg and Mielnik 2000), and others. The availability of detailed statistical information on the national energy balance makes these analyses possible, though they are not common. The analysis of the United States for 1970 was the first, and only considered the flows of energy carriers for final use in the society (Reistad 1975). Wall (1977) devised a method of accounting for all types of material and energy flows in his analysis of Sweden, including harvested food and wood, ores and minerals, and the products of these raw materials. It is Wall's approach that is followed (though modifications are made where necessary) in the exergy analysis described in this work.

1.1.3 Extended Exergy Analysis

Exergy analysis is completely satisfactory from a thermodynamic perspective, but for the analysis of a system that involves large flows of non-energetic quantities (such as a national or provincial economy), it is necessary to develop a basis for evaluating these externalities. Extended exergy analysis (EEA) assigns a value to labour, capital, and the costs of environmental remediation of waste within a system based on the total physical exergy of materials and energy input to the system and a reference abundance of the quantity in question. In this way, a valuation in which kJ/kg are consistently equivalent to kJ/$ or kJ/hour is developed (Sciubba 2001) and applied to a system to quantify the externalities that are excluded from an exergy analysis.

Extended exergy analysis has been applied in recent years to a number of national and regional economies, including the province of Siena, Italy (Sciubba 2008), Norway (Ertesvåg 2005), and the UK (Gasparatos et al. 2009). These applications provide guidance for the application of the extended exergy analysis to the economy of Nova Scotia. In each case, the economy is divided into seven sectors: transportation, agriculture, extraction, conversion, tertiary, domestic and industry. The surrounding environment is represented as a separate sector, and other countries or regions with which the country in question might exchange mass flux, energy, capital, or labour, are represented as a sector as well.

In the analysis of the province of Siena, Italy (Sciubba 2008), extended exergy accounting is applied at the provincial level. A division of seven economic sectors is used, with an eighth sector representing the rest of Italy included. An important difference between this application and those that precede it (Wall 1977), (Reistad 1975) is that all inputs to the domestic sector are accounted for as having been "filtered" through the commercial sector first. Of note is the presence of a significant geothermal energy industry in the province of Siena, the heat from which is accounted for in the extraction sector. Accordingly, the environmental cost of remediation is much lower in the conversion sector for geothermal power than it would be for fossil fuel based energy conversion processes. Siena is found to have a relatively large flow of capital compared to its consumption of exergetic resources, indicating that the importance of the commercial sector in terms of exergetic consumption is greater than that of the industrial sector. Labour is found to have a high exergetic value overall (253 MJ/hour) (Sciubba 2008), affecting the efficiency of all sectors but particularly the domestic sector. It is clear from the calculated exergy and extended exergy usage values that the inclusion of the flows of capital, labour, and environmental remediation has a drastic effect on all sectors of the economy. Different sectors are capable of using capital and labour in different ways and with vastly different efficiencies. In particular, the domestic sector has a very low efficiency in terms of both exergy and energy. This can be explained by the fact that this sector does not produce appreciable amounts of energy, and is almost entirely reliant on high quality energy as an end user.

In his analysis of the Norwegian economy for the year 2000, Ertesvåg (2005) builds on a previous exergy analysis of the Norwegian economy for the year 1995 (Ertesvåg and Mielnik 2000) to apply extended exergy accounting. This is an approach also used by Gasparatos et al. (2009) in their analysis of the UK economy for the year 2004. Both of these analyses follow the approach described first by Wall (1977) for the exergy analysis and the extension to non-energetic quantities described by Sciubba (2001).

1.1.4 Economic Indicators of the Economy of Nova Scotia in 2006

The gross domestic product (GDP) of a country or region represents an aggregate of the total economic production for the specified time period. GDP provides not only an indication of the market values of goods produced within an economy but also a measure of growth when compared quarterly (or annually).

In 2006, Nova Scotia's GDP grew at a rate of 0.9%, similar to the growth rate in the previous four years. This is below the national average GDP growth in the same year of approximately 2.8%. The Nova Scotia GDP had grown at a lower rate than the national average for four years; between 2003 and 2006. This growth rate is attributed to a drop in manufacturing and forestry output compared to previous years, as well as a decline in natural gas and oil production. Corporate profits and export activity also contracted in 2006 following several years of growth. Sharp growth in business investment in non-residential construction, along with steady residential construction growth contributed positively to the GDP growth rate (NS Finance 2007). The distribution of GDP between the Agriculture, Extraction, Conversion, Industry, Transportation, and Tertiary sectors is shown in Figure 1, out of a total of $25.9 billion dollars.

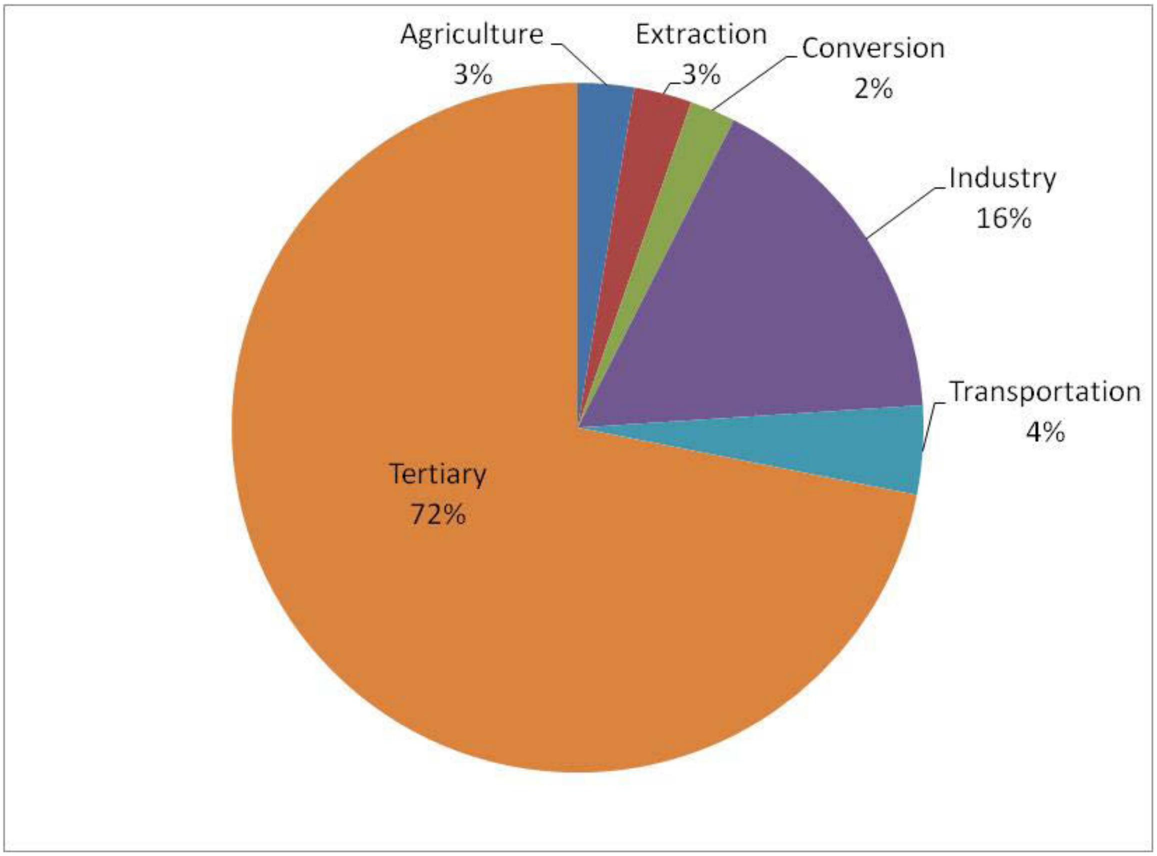

Figure 1- GDP distribution between sectors of the Nova Scotian economy, 2006.

The official energy balance of Nova Scotia is reported by Statistics Canada in the Report on Energy Supply and Demand (Energy Supply Demand 2007). The energy flows into and out of the Nova Scotian economy, as well as the relative share of end uses for 2006 are shown in Figure 2.

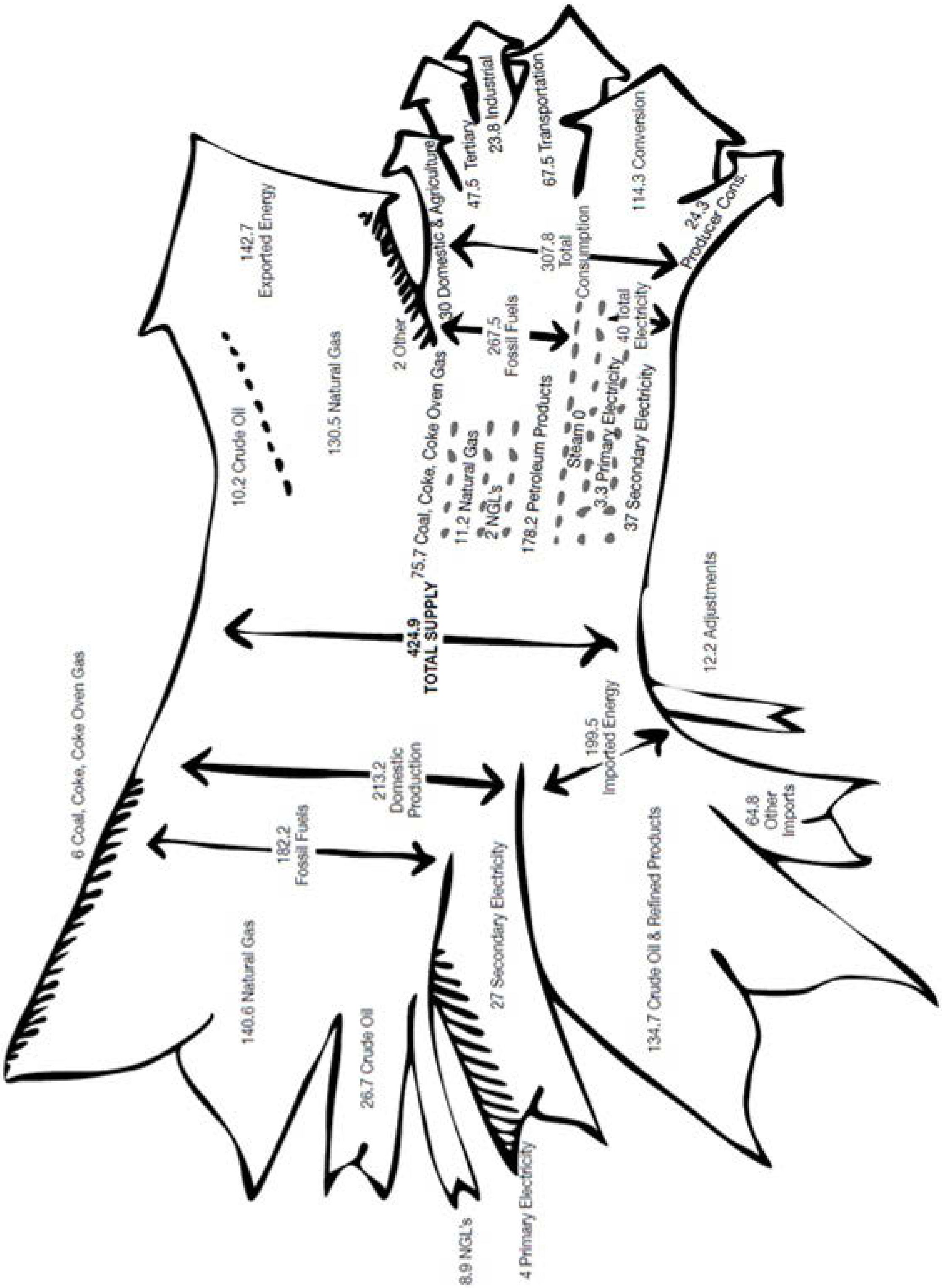

Figure 2 - Energy flows of the Nova Scotian economy 2006 (PJ).

1.2 Objective

The objective of this work is twofold:

- An exergy analysis of the material and energy fluxes transferred between economic sectors in Nova Scotia for 2006.
- An extended exergy analysis including the non-energetic fluxes of labour and capital transferred between economic sectors in Nova Scotia for 2006.

An exergy analysis of the economic sectors of Canada for the year 1986 was published by Rosen (1992), but this analysis did not include any attempt to quantify the exergetic value of non-energetic quantities like labour and capital, and did not consider the question of waste materials deposited in the environment. This is the first exergy (and extended exergy) analysis of the Canadian economy at the provincial level and serves as a guide for future analyses.

Chapter 2: Methodology

The procedures described below are the result of applying a methodology developed for exergy analysis of very large complex systems (Sciubba 2008) to the provincial economy of Nova Scotia. The underlying principles are the same, although some minor accounting changes are described. The purpose of this accounting is to determine the efficiency with which each sector of the economy consumes natural resources, capital, labour, and energy carriers and produces products, capital, and other quantities.

2.1 Calculation of Exergy

The exergy of a system (e_{sys}) can be described in terms of physical (e^{PH}), kinetic (e^{KN}), potential (e^{PT}), and chemical (e^{CH}) exergy (Sciubba 2008). The calculation of the total exergetic content of a system is as follows (Sciubba 2008), (Tsatsaronis 2007), and (Sciubba 2001):

$$e_{sys} = e^{PH} + e^{KN} + e^{PT} + e^{CH} \qquad (1)$$

$$e^{PH} = (U_i - U_0) + p_0 \cdot (V_i - V_0) - T_0 \cdot (S_i - S_0) = (H_i - H_0) + T_0 \cdot (S_i - S_0) \qquad (2)$$

$$e^{KN} = \frac{1}{2} \cdot m \cdot (v_i - v_0)^2 \qquad (3)$$

$$e^{PT} = m \cdot g \cdot (z_i - z_0) \qquad (4)$$

$$e^{CH} = \sum_i (\mu_i c_i - \mu_0 c_0) \qquad (5)$$

Where subscript 0 refers to the state of the reference environment.

Physical exergy is an extensive property relative to the reference state (Sciubba 2001). Chemical exergy is a measure of the deviation between the chemical composition of the system and the reference environment (Tsatsaronis 2007). The kinetic and potential components of exergy are neglected for the purposes of the extended exergy analysis (Sciubba 2001). The types of activities evaluated in an extended exergy analysis of a system like the economy of a province generally do not require quantification in terms of kinetic and potential exergy. These quantities are difficult to define in the context of an exergy balance of an economic sector (since they do not add any useful information to the analysis).

The total exergy of a s tream (the sum of the physical and chemical components of exergy) can be increased or decreased through thermal, mechanical, or chemical interaction with other systems. The final value of physical exergy of the stream reflects both the quantity (variation in enthalpy) and quality (variation in entropy and chemical potential) of the energetic interactions (Sciubba 2001). Exergy is an additive quantity, meaning that individual contributions from interactions can be summed. This allows for the total exergetic value of the stream after independent interactions with energetic systems to be expressed in units of exergy, provided these interactions are expressed in their equivalent exergetic values. Exergy can be transferred between systems and destroyed by irreversibilities within systems. Exergy is ultimately accounted for in an exergy balance (Moran 1994).

2.1.1 Reference environment

The potential for doing work exists whenever a system at a state different from that of the environment is brought into communication with the environment. Absent interference from other influences, the system and the environment will eventually arrive at an equilibrium state, known as the "dead state". At the dead state, the conditions of thermal, chemical, and mechanical equilibrium are satisfied and there is no opportunity to develop work between the two systems. The exergy of the system at its original state is the maximum theoretical work obtainable as it interacts to equilibrium with the environment. The idealized model of the environment (the reference environment) has several characteristics:

- It is in stable equilibrium, and all parts are at rest relative to each other.
- No chemical reactions can occur between separate components.
- It acts as an infinite system or reservoir, whether as a sink or source for heat and mass.
- Its intensive state remains unchanged (temperature, pressure, and chemical potentials remain constant) regardless of the amount of energy and mass transferred.

In other words, the reference environment is regarded to be a simple compressible system, infinitely large in extent, and uniform in temperature and pressure. The natural environment does not possess these theoretical characteristics, as it is most certainly not in stable equilibrium and is not infinitely large. Although it is possible to define a tailored reference environment for any particular application, this approach generally does not produce appreciably more accurate results (Sciubba 2008). Accordingly, for the purposes of this study, the standard reference environment of Szargut (1988). is used:

Pressure P_0 = 1.01325 bar

Temperature T_0 =298.15 K

This is the standard state used by Szargut (1988) for the calculation of thermo-chemical data. P_0 and T_0 may be considered to be standardized environmental parameters. From the assumption that all parts of the reference environment are at standard temperature and pressure and are in mutual equilibrium, chemical exergy values have been calculated for reference substances from all different parts of the environment (i.e. the atmosphere, the oceans and other bodies of water, and the Earth's crust).

Gaseous components are assumed to behave as an ideal gas at standard temperature and pressure. Values of standard molar chemical exergy are given for most chemical elements and a wide selection of common chemical compounds in Szargut (1988). For compounds not listed in available tables, the molar chemical exergy can be calculated from the values of chemical exergy of the constituent elements and the appropriate value of the Gibbs function of formation:

$$\tilde{\varepsilon}^0 = \Delta\tilde{g}_f^0 + \sum e_{el}^0 \quad (6)$$

Where $\Delta\tilde{g}_f^0$ is the standard molar Gibbs function of formation and e_{el}^0 is the standard chemical exergy of the constituent elements per mol of compound.

2.1.2 Choice of Control Volume

In traditional exergetic analyses, the control volume is drawn such that it only encloses the process under investigation. Fluxes are accounted for as they cross the control volume boundaries between the process and the environment and other processes. Exchanges of mass and energy that occur within the control volume are hidden from the analysis.

Extended exergy analysis necessarily includes an expansion of the control volume over traditional analysis. The boundaries must be sufficiently large to allow effluent from the process to exit the boundary at a state of zero physical exergy (i.e. with similar composition to the reference environment.). This is accomplished by including the immediate surroundings of the process and effluent treatment in the control volume. An effluent stream can then be said to cause zero impact on the environment as it will be in thermodynamic equilibrium with the reference state before being discharged into the environment.

Similarly, the control volume must include the portion of the environment from which resources and minerals are extracted. Due to the chemical similarity of the composition of many minerals (and other resources) to that of the surrounding environment, detailed knowledge of the composition of the extraction site is required in order to compute the physical exergy. If the composition of the resource at the extraction site is known, then the chemical portion of the physical exergy can be computed based on the resource's chemical composition, physical state, and the Gibbs energy of formation of its constituents. If the resource is chemically indistinguishable from the reference state, then the chemical portion of the physical exergy will be equal to zero.

2.2 Extended Exergy Accounting

The Extended Exergy Accounting (EEA) method incorporates some elements of existing exergy analysis methods like life-cycle analysis, cumulative exergy analysis, emergy (or embodied energy) analysis, and complex systems analysis (Sciubba 2001). 'Extended' refers to the inclusion of previously neglected non-energetic quantities such as labour, capital, and environmental remediation costs in the analysis. Equivalent exergetic values are assigned to these flows within a system for the purposes of accounting.

In any real process, the exergy input always exceeds the exergy output due to irreversibility (exergy destruction) in the system (Sciubba 2003). Any particular material or product stream has an exergetic value given by the sum of its physical and chemical exergy. Added to this is the sum of all net exergetic inputs, direct and indirect, received from all processes applied to the stream, as well as the exergetic equivalents of capital, labour and environmental remediation costs. Irreversibilities are debited from this sum as exergy destruction (Sciubba 2001).

Once all flows of material and energy, labour and capital have been identified and assigned equivalent exergetic values, the system or sector conversion effectiveness (ε_P), which is given by Sciubba (2003 and 2008) can be computed:

$$\varepsilon_P = \frac{ee_{O1}}{\sum_j ee_{I,j}} \quad (1)$$

The extended exergetic cost (c_P) is simply the reciprocal of the conversion effectiveness, such that:

$$c_P = \frac{\sum_j ee_{I,j}}{ee_{O1}} \quad (2)$$

Where ee_{O1} is the total extended exergy of the output and $ee_{I,j}$ is the sum of the equivalent exergetic inputs required to create the output.

2.2.1 The Effect of the Choice of the Time Window on the EEA

When performing an analysis such as the EEA, it is required to define the time period of the accounting. The accounting balance sheet will be affected by the inclusion of more or fewer exergy flows depending on the time period chosen. For example, when choosing a time scale for the biodegradability of effluent in the environment, environmental regulations prescribe a certain time interval for the effects of the effluent to be buffered by the surrounding environment. Extending the time interval of the analysis may decrease the exergetic value of the cleanup costs; however, this approach blurs the definition of ‘zero environmental impact’. Shortening the time interval of the analysis may lead to increased unnecessary costs in the exergetic balance of the process, because it fails to incorporate the buffering capacity of the biosphere.

Decisions on the scale of the time interval for exergy analysis must be made on a case by case basis. For the analysis of complex systems such as a country or region, it is convenient to use the time scale of one year, as most of the relevant statistics are published on an annual basis.

2.2.2 A general model for the application of EEA to Nova Scotia

In the EEA method for a nation or other large social system, the society is broken down into seven sectors to be included in the control volume. This is assumed to be a suitable disaggregation layer as it in cludes the five traditional economic sectors (Tertiary, Industry, Transportation, Agriculture, Domestic) as well as a sector representing the activity involved in the extraction of natural resources, and a sector representing the totality of energy conversion processes (Sciubba 2008). These two sectors, along with the agricultural sector, are largely responsible for societal exchanges of mass and energy with the environment.

The choice of the geographical boundaries of a country or province as the system boundary for exergy analysis is a matter of convenience, as statistical data are available on a geographical basis. Major inputs to the system include commodities and energy carriers that are imported, harvested and extracted, or otherwise harnessed from the environment. Major outputs of the system are products, materials, goods, and services that are consumed or exported.

The seven sectors correspond to the reporting methodologies by which Statistics Canada collects economic data, making them convenient for application to the EEA. Outside of the control volume are the environment (earth's crust, atmosphere, oceans, and the natural environment) and other nations, including the Atlantic Region and the rest of Canada. Transfers of mass and energy between sectors are classified as fluxes. Fluxes between sectors (such as labour, waste, products, capital, natural resources, heat discharges) are assigned equivalent exergetic values according to the ratio of energy to exergy as established in the literature for each type of flux.

A model of the economic activity that takes place within the Nova Scotian society is realized in this work as a series of linked data sheets. Exergy balances for each sector of the society are tabulated in separate sheets and linked together to complete the picture.

The extended exergy of each sector is calculated after the initial exergy analysis has been completed.

Each exergy flux between two sectors is represented by a flux category (see section ***2.2.4***) and a subscript listing the originating sector followed by the destination sector. For example, a flux of petroleum products from the Conversion sector to the Transportation sector is represented as $R_{co,tr}$, a flux of waste from the Domestic sector to the Tertiary sector is represented as $P_{do,te}$, and so on.

Equivalent exergetic fluxes of the same type with the same destination and origin are summed for the analysis of each sector. For example, flows of matter from the extraction sector to the conversion sector include natural gas, coal, and crude oil, among other quantities. There may be several different types of coal or grades of oil produced by the extraction sector. At this level of disaggregation, the exergetic value of the particular flow of matter is the sum of the exergetic values of the different types of fuel that combine to make up the term reported by statistical agencies as "coal". These sums are tabulated on s eparate, linked data sheets. All flows are similarly disaggregated as is appropriate, according to the complexity of the composition of any particular flow.

2.2.3 Sector Definitions

The economic activity included in each sector is listed below. It should be noted that the accounting for each sector includes the import/export and transport of any raw materials or goods related to the sector activity and labour, capital and environmental remediation inputs and outputs. The activities, inputs, outputs, and main sources of data for each sector in Nova Scotia are listed in Table 1.

- **Extraction (Ex)** – includes all mining activities related to mineral extraction and processing, as well as oil and natural gas extraction and related activities.
- **Conversion (Co)** – includes transformation of raw materials into fuels and energy as well as primary electricity production from solar, wind, hydro, tidal, and geothermal sources.
- **Industry (In)** – includes all construction and manufacturing industries.

- **Transportation (Tr)** – includes transportation of goods and passengers by rail, air, land, and sea and related activities, as well as warehousing of goods.
- **Tertiary (Te)** – includes all activities related to the service sector - wholesale and retail trade, information and cultural industries, finance, real estate, insurance, rental and leasing, professional, scientific, and technical services, administration and support for waste management and remediation activities, educational services, health care and social assistance, arts, entertainment and recreation, accommodation and food services, non-profit institutions and the government sector.
- **Agriculture (Ag)** – includes crop and animal production, forestry and logging, fishing and aquaculture, hunting and trapping, and related support activities.
- **Domestic (Do)** – includes all households.

Table 1 - Activities, inputs, outputs, and main sources of data for each sector of the economy in Nova Scotia.

Sector	Major Activities	Main Inputs	Main Outputs	Data Sources
Ex	Oil and gas extraction (on- and off-shore), coal mining, extraction of ores and minerals	Energy carriers, primary resources	Primary resources	Report on Energy Supply and Demand in Canada
Co	Heat and power plants, including coal and oil/natural gas, as well as hydro, wind, solar, and geothermal, energy carrier production	Recycled waste, natural resources, energy carriers	Primary resources, secondary resources, thermal discharge	Report on Energy Supply and Demand in Canada
In	All industrial and manufacturing activities, excluding food processing and energy industries	Natural resources, products, resources, and energy carriers	Products, waste	Statistics Canada, Canadian International Merchandise Trade Database
Te	Private and public sector services, including trade, commerce, finance, real estate, construction, schools, hospitals, hotels and tourism, entertainment, municipal engineering	Energy carriers, natural resources, and products	Labor and products	Report on Energy Supply and Demand in Canada, Provincial and Territorial Economic Accounts Review, The Input-Output Structure of the Canadian Economy
Ag	Agriculture, fisheries (including fish farming), forestry, hunting, and related food processing industries. Food retail is included in Te sector	Petroleum products, electricity, and other energy carriers, natural resources	Natural resources	NS Department of Agriculture

Sector	Major Activities	Main Inputs	Main Outputs	Data Sources
Do	Households	Products, energy carriers, natural resources	Labor, waste	Provincial and Territorial Economic Accounts Review, Report on Energy Supply and Demand in Canada, CANSIM tables.
Tr	Commercial transportation services of people and goods .	Energy carriers	Products, waste, and thermal discharge	Report on Energy Supply and Demand in Canada
E	The natural environment (earth's crust, oceans, atmosphere)	Thermal discharge and waste	Resources	Human Activity and the Environment
A	The rest of Canada and Abroad	Exports to other provinces and countries	Imports from other provinces and countries	The Input-Output Structure of the Canadian Economy, Canadian International Merchandise Trade Database

2.2.4 Flux Definitions

Following the approach of Wall (1977), exergy conversion efficiency is calculated by only considering output fluxes that are transferred between sectors to be useful. The accounting is done on this basis, such that output fluxes from conversion processes (like space heating and lighting) are not classified as outputs unless they are subsequently transferred between sectors. As such, products that are considered "final use" in a sector are accounted for in trash or discharge fluxes, with a corresponding drop in exergy content – caused by the destruction of exergy as the product is consumed.

Each flux is categorized according to the following:

- **R** - resources, primary (fossil fuels, solar, wind, minerals, metals, geothermal, hydraulic) and secondary (products from petroleum refining, mineral- and metal working), and electric energy.
- **N** - natural resources (agricultural products, wood, natural fibers, livestock, fish, game).
- **P** - products (products and services generated by In, Tr, and Te-sectors).
- **T** - trash fluxes (organic and inorganic waste materials) deposited in the environment.
- **D** - discharge (combustion gases, thermal discharge including radiated heat), waste heat and mass spread in the environment at low temperature.

- **W** – Human work hours, labour
- **C**– Capital

Monetary flux, i.e. capital (C) is defined as (Sciubba 2008):

$$ee_{Cap} = \frac{e_{in,society}}{M2} \tag{3}$$

$$C = ee_{Cap} \cdot C_{in} \tag{4}$$

Where e_{in} is the total exergy influx to the society, and *M2* is the reference amount of currency available in the society, a term known to economists as "broad money", which is defined by the Bank of Canada (BoC 2011) as:

> ***"M2 (gross):*** *Currency outside banks plus bank personal deposits, bank non-personal demand and notice deposits; less interbank deposits; plus continuity adjustments."*

In other words, the value of capital in terms of the exergy per monetary unit of the society is the ratio of the total exergy consumption to the monetary circulation within that society. This flux is measured in J/$, and can be converted to a value of capital in any particular sector (*C*) by multiplying ee_{Cap} by the capital influx to that sector (C_{in}).

Similarly, labour flux (W) is defined as (Sciubba 2008):

$$W = n \times \frac{e_{in,society}}{n_{tot}} \tag{5}$$

Where *n* is the flux of work-hours into a particular sector, n_{tot} is the total amount of work-hours generated in the entire system, and e_{in} is the total exergy influx to the society. This calculation is useful when it is the exergetic value of labour in a particular sector that is under investigation. If instead the primary resource value of labour over the entire society is desired, then the total number of work hours generated in the Domestic sector ($n_{workhours,Do\ sector}$) is used:

$$ee_{Lab} = \frac{e_{in,sector}}{n_{workhours,Do\ sector}} \tag{6}$$

The exergetic cost of environmental remediation is computed by the addition of a real or virtual effluent treatment process downstream of every production flux under investigation, such that the physical exergy of each effluent is reduced to zero before being returned to the environment; i.e. the reference state. Each treatment process requires material, energy, capital, and labour that must be accounted for under the principles of the EEA method (Sciubba 2008 and 2003).

2.3 Equivalent Exergy Value of Fluxes

All fluxes of material and energy are assigned exergetic values according to the established literature; for example mechanical, waterfall, electrical and other energy flows have energy values equivalent to their exergy content (Ertesvåg 2005). The exergy content of commonly used chemical fuels, seen in Table 2, is given by the ratios of exergy to energy calculated in the literature by Szargut (1988) and De Meester et al. (2006). The ratios for chemical fuels are based on the lower heating value (LHV), which corresponds to the standard of reporting of most national statistical agencies, including Statistics Canada. The exergy factors for fuel wood are also based on LHV, as wood generally contains ~20% moisture.

Exergy values for metals and minerals are similarly found in the literature, most notably in tables provided by Szargut (1988) (see Appendix A). It is suggested in the literature that food and fodder be assigned an exergetic value equivalent to their nutrient energy, mostly due to a lack of a better model (Sciubba 2008), (Ertesvåg 2005).

Table 2 - Ratio of exergy content to energy content for some hydrocarbon fuels.

Energy Carriers	Ratio
Coal	1.06
Coke	1.05
Crude oil	1.08
Gasoline	1.07

Energy Carriers	**Ratio**
Diesel oil	1.06
Kerosene	1.07
Fuel oil	1.06
LPG	1.06
Other petroleum products	1.06
Natural gas	1.04

Chapter 3: Exergy Analysis

3.1 The Agriculture Sector in Nova Scotia

According to the North American Industry Classification System (NAICS), the agriculture industry in Nova Scotia includes establishments primarily engaged in the growing of crops, the raising of animals, nursery and floriculture production, aquaculture, and Christmas tree production (NS Finance 2007). These establishments are categorized as farms for the purposes of the census, and include greenhouse operations and fur farms. Also included are establishments that are primarily engaged in providing essential support services to the activities listed previously.

In this work, the forestry industry is presumed to fall under the agriculture sector and therefore includes the production of Christmas trees. Likewise, the fishing and aquaculture industries are categorized as part of the agriculture sector as they involve the harvesting of natural resources for input to the economy. In 2006, there were 5,095 farm operators and approximately 10,400 fishers in Nova Scotia, accounting for $684.2 million of GDP, 11% the goods-producing sectors of the economy, and approximately 3% of the total economy (NS Finance 2007). Figure 1 presents the main activities of the Agriculture sector, including the inputs and outputs and their origins and destinations.

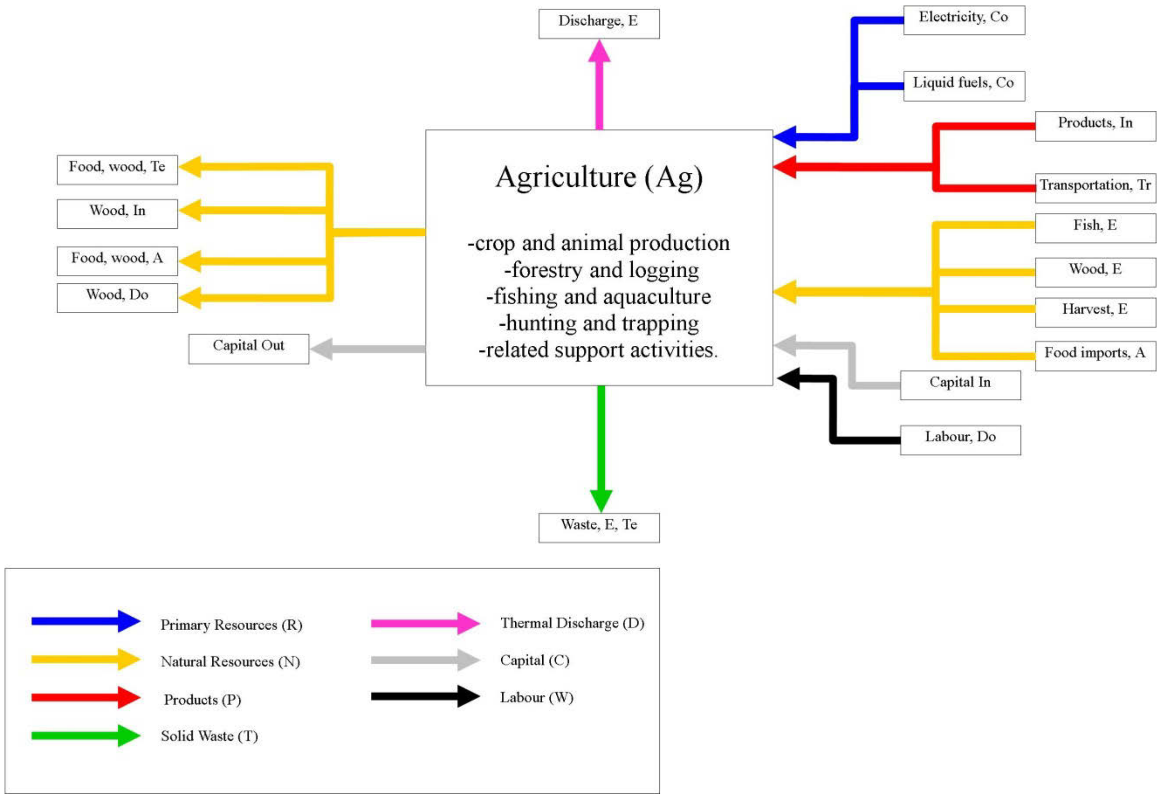

Figure 3 - Agriculture sector flux origins and destinations.

Information on the agriculture industry is gathered every five years by Statistics Canada and is reported in The Census of Agriculture. Fortunately for this work, The Census of Agriculture was undertaken in 2006 and data from that report is included in the Nova Scotia Statistical Review (NS Finance 2007).

3.1.1 The Farming Industry in Nova Scotia and Farm Products

A wide range of data is collected every five years, including the number and type of farms, the operating expenses and receipts, and information on the production of these establishments. In 2006, 3,795 farms were counted in Nova Scotia, with a total area of 995,942 acres (NS Finance 2007). Approximately three quarters of the farm area is concentrated in the North Shore region (48.1%) and the Annapolis Valley region (28.3%). 48.9% of this land is used for Christmas tree production (woodlands and wetlands included), 28.9% is used for crop production, 7.8% is used as natural land for pasture, 5.8% in tame or seeded pasture, and 0.3% as summerfallow land. The remaining 8.1% is classified as “other land”, which may comprise part of a farm establishment but not contribute directly to the farm production (roads, drainage areas, parking, etc.) (NS Finance 2007). Irrigation is not widely employed in Nova Scotia. Figure 2 shows the agricultural land use in Nova Scotia relative to the total amount of agricultural land.

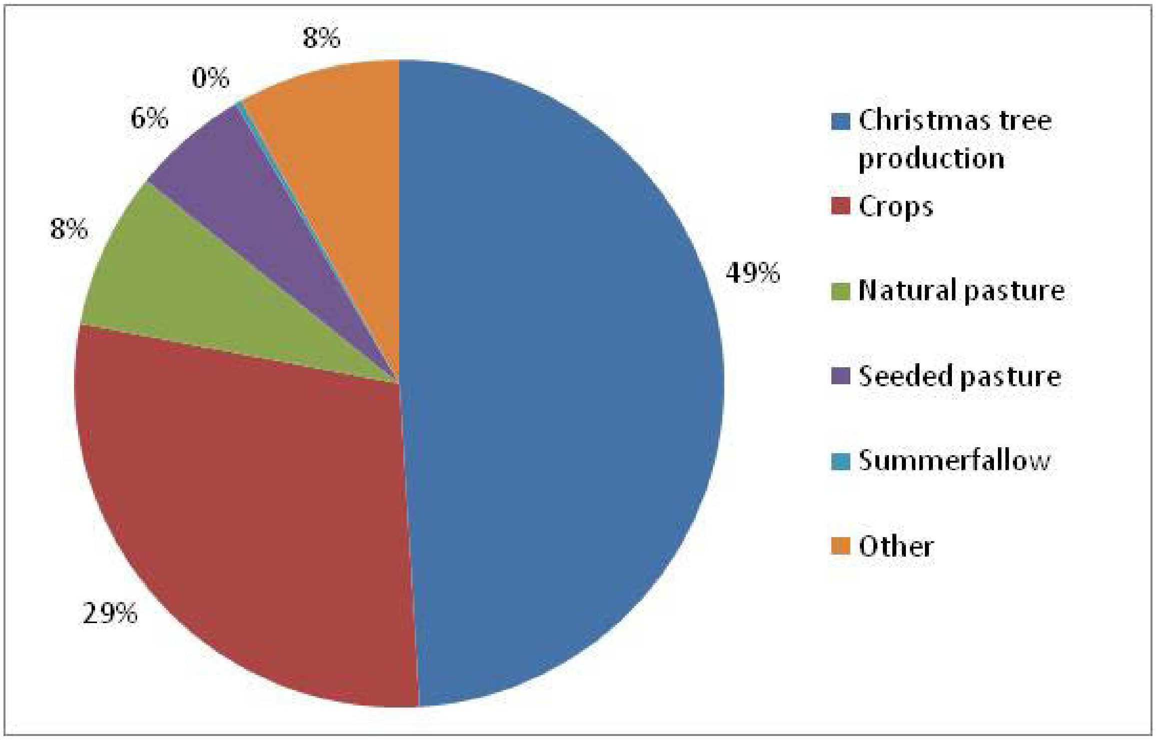

Figure 4 - Agricultural land use in Nova Scotia from a total of 995,942 acres (NS Finance 2007).

Total farm cash receipts are reported for 2006 as $447.6 million, a decline of 2.6% over the same data in 2005. Of that total, cash receipts for the sale of forest products (Christmas trees and maple products) are reported as $22.2 million. $303.2 million is from the sale of livestock and products; $107.7 million is from the sale of crops; $1.6 million is crop insurance payments from the insurance industry, and $12.8 million is from payments from the government (NS Finance 2007).

The products of farming activity in Nova Scotia include crops like grains, fruits and vegetables, and ornamental plants, and animal products like beef, pork, poultry, milk, eggs, and fish (from aquaculture). The greenhouse industry largely produces vegetables and ornamental plants but these natural resources have negligible energy and exergy contents. Production statistics for each year are available from the Statistics Canada and the NS Department of Agriculture (NS DoA 2011).

3.1.1.1 Farming Product Energy and Exergy Contents

Tabulated experimental data on the specific exergy content of individual foods and other agricultural products is not available in the literature. Similar exergy analyses have used estimates of per-capita production and consumption for calculating the exergy contents of food-based fluxes (Chen 2009), (Gasparatos et al. 2009). In these analyses, the equivalent exergetic value of any particular food-based flux is based on the average acreage used to produce the resource in question and reported values of per-capita consumption. As the production statistics for each commodity are readily available from Statistics Canada through the Nova Scotia Department of Agriculture (NS DoA 2006), the actual amounts produced are used here to determine the exergy content of the agriculture sector flows.

The exergy content of food products produced by the agriculture sector was assumed to be roughly equivalent to their nutrient energy content according to Gasparatos et al. (2008). The nutrient energy content of each product was retrieved from the US Department of Agriculture's Nutrient Data Laboratory (US DoA 2011).

3.1.1.2 Exergy Fluxes into and out of the Farming Industry

The main inputs to the farming industry include fuels, electricity, fertilizer, minerals, seeds, fodder for animals, and pesticides. The most common fuels used are gasoline and other petroleum products like diesel fuel oil (NS Finance 2007). Many farms use small amounts of renewable resources like biomass as a fuel source, but as these resources are generated and consumed within the sector without being transferred to another sector they are not accounted for under this analysis.

The agriculture sector as a whole consumes both electricity and liquid fuels sourced from the conversion sector. Diesel fuel oil is used extensively in farm machinery and equipment and light fuel oil is frequently used to heat outbuildings and spaces for animals (NS Finance 2007). Electricity is mainly used for the operation of equipment and lighting. Equivalent exergy values of each type of fuel were calculated using LHVs sourced from Borgnakke (2009) and Gasparatos (2008) and equivalent exergy factors sourced from Szargut (1988) and Gasparatos (2008).

Table 3 shows the consumption of various energy carriers within the agriculture sector, including the forestry and fishing industries. Diesel fuel oil makes up the largest portion of the refined petroleum product use within the sector at 2.13 PJ of energy. Fuel oil for heating makes up the second largest portion, at 0.75 PJ, and gasoline is third at 0.31 PJ, for a total of 3.19 PJ of energy. 0.21 PJ of electricity and 0.07 PJ of natural gas liquids (propane) make the total 3.47 PJ of total energy use for the sector, equivalent to 3.67 PJ exergy.

Table 3 - Agriculture sector energy carrier use energy and equivalent exergy (Energy Supply Demand 2006).

Energy Carrier	Energy (PJ)	Exergy (PJ)
NGL	0.07	0.07
Electricity	0.21	0.21
Refined petroleum products	3.19	3.38
Total	**3.47**	**3.67**

Detailed statistics on the extent of fertilizer use in Nova Scotia are not available from the Department of Agriculture, nor are statistics on the specific types of fertilizer used. What is available is information on the area of farmland to which fertilizer is applied. In 2006, this area was 81,917 ha (202,417 acres) (NS Finance 2007).

According to a 2004 Statistics Canada report on fertilizers and pesticides, sales of fertilizer in Atlantic Canada were split roughly equally between phosphates, potash, and nitrogen fertilizers (Korol 2004). The same report indicates that an assumption of a fertilizer intensity factor across all cropland for the Atlantic region of approximately 60 kg/ha is reasonable. The exergy contents of phosphate, potash, and nitrogen fertilizers are calculated as the equivalent exergy of P_2O_5, K_2O, and $(NH_4)_2SO_4$, respectively (Gasparatos et al. 2009), (Szargut 1988), with the total mass of fertilizer split equally between the three types. Table 4 shows the result of this calculation.

Table 4 - Fertilizers used by the farming industry and equivalent exergy values (Korol 2004).

Fertilizer Type	Mass (kg)	Specific Exergy (kJ/kg)	Equivalent Exergy (kJ)
Potash (K_2O)	1,638,340	0.00439	7,184
Phosphates (P_2O_5)	1,638,340	0.0001	163
Nitrogen (NH4·2SO4)	1,638,340	0.005	8,190
Total	**4,915,020**		**15,538**

The calculated equivalent exergy of fertilizer used in Nova Scotia is 15,538 kJ. This amount is negligible and has been excluded from the final transfer structure between sectors.

Approximately 329 tonnes of seed are imported annually for sowing crops grown by the farming industry in Nova Scotia. The vast majority (300 tonnes) is classified as grass seed by Statistics Canada, presumably for sowing wheat, barley, and oat crops (CIMTD 2007). The nutrient energy of wheat and barley seed is unavailable in the literature so the nutrient energy of flaxseed is used instead.

A significant portion of the farming sector is devoted to producing feed and fodder for animals of the same sector. Animal feed is not reported as a major export or import by Statistics Canada, therefore, in this analysis the hay and corn produced as animal feed is presumed to be consumed entirely within the agriculture sector. Equivalent exergy values for the production, import, export, and consumption of feed and seeds can be found in Table 5.

Table 5 - Amounts of feed and seeds input to the farming industry for 2006 (TJ equivalent exergy) (NS DoA 2006).

Commodity	Production (TJ)	Imports (TJ)	Exports (TJ)	Consumption (TJ)
Seed for sowing	0.00	7.00	0.00	7.00
Fodder corn	1067.00	0.00	0.00	1067.00
Tame hay	3027.00	0.00	0.00	3027.00
Total	**4094.00**	**7.00**	**0.00**	**4101.00**

Insecticides, herbicides, and fungicides are used every year on approximately half of the reporting farms in Nova Scotia, compared to approximately three-quarters of Canadian farms which deploy pesticides yearly (Korol 2004). Due to the unavailability of data on the amounts used and their specific chemical makeup, pesticide use has been neglected as an input to the farming industry in this work.

The main outputs of the farming industry are food products and a much less significant amount of furs, mainly for export (NS Finance 2007). Under this analysis, the equivalent exergy of fur products is neglected as it is insignificant compared to similar amounts of food products. However, the money generated by the sale of fur products domestically and abroad is accounted for under the exergy equivalent capital fluxes calculated for the Agriculture sector. Table 6 shows the production, import, and export of 15 major agricultural products of farming for 2006 in tonnes (except for eggs, which are reported in dozens).

Table 6 - Agriculture production (harvest), imports, and exports (tonnes) (NS DoA 2006).

Commodity	Production (tonnes)	Imports (tonnes)	Exports (tonnes)
Beef	12475	74	14
Pork	18830	24	2524
Lamb	335	51	0
Eggs (dozens)	18069000	15002	7541
Milk	101342	8	96
Chicken/Turkey/Fowl	37078	502	522
Potatoes	24766	156	218
Apples	43000	0	14276
Berries (Strawberries, blueberries, cranberries)	22837	651	12155
Wheat	14500	4228	9144
Oats	2900	7	42

Commodity	Production (tonnes)	Imports (tonnes)	Exports (tonnes)
Barley	5400	4141	0
Corn (for grain)	19000	3607	1
Seed	329	176	71

Table 7 shows the production, import, and export of these natural resources by their associated equivalent exergy values.

Table 7 - Agriculture production (harvest), imports, exports, and consumption, (TJ equivalent exergy).

Commodity	Production (TJ)	Imports (TJ)	Exports (TJ)	Consumption (TJ)
Beef	122.13	0.72	0.14	122.72
Pork	157.99	0.20	21.17	137.01
Lamb	3.41	0.52	0.00	3.93
Eggs	64.94	0.05	0.03	64.97
Milk	207.71	0.02	0.20	207.53
Chicken/Turkey/Fowl	333.70	4.52	4.70	333.52
Potatoes	82.22	0.52	0.72	82.02
Apples	93.74	0.00	31.12	62.62
Berries	52.45	1.49	27.92	26.03
Wheat	205.61	59.95	129.66	135.90
Oats	47.21	0.11	0.69	46.64
Barley	79.97	61.33	0.00	141.30
Corn (for grain)	68.40	12.99	0.00	81.38
Seed	7.35	3.93	1.59	9.69
Total human consumption (to Te sector)	**1526.84**	**146.35**	**217.93**	**1455.26**
Seed for sowing	*0.00*	*7.00*	*0.00*	*7.00*
Fodder corn	*1067.00*	*0.00*	*0.00*	*1067.00*
Tame hay	*3027.00*	*0.00*	*0.00*	*3027.00*

Commodity	Production (TJ)	Imports (TJ)	Exports (TJ)	Consumption (TJ)
Total harvest	**5620.84**	**153.35**	**217.93**	**5556.26**

The final column of Table 7 shows the consumption of these natural resources (production minus exports plus imports) that is accounted for as an N-flux from the Agriculture sector to the Tertiary sector. Note that the final three rows of Table 7 (in italics) are consumed within the Agriculture sector and do not form part of the N-flux to the Tertiary sector.

3.1.2 The Forestry Industry in Nova Scotia and Forestry Products

According to the NAICS, forestry industry includes establishments primarily engaged in the growing and harvesting of timber on a long production cycle of 10 years or more (NS Finance 2007). Thus, production of Christmas trees and other products with production cycles shorter than 10 years are considered part of the agriculture industry rather than the forestry industry (NS DoA 2011). However, since the entire forestry industry is included under the Agriculture sector in this work, Christmas tree production has been reclassified to the forestry industry along with maple product production.

Detailed forestry statistics for Nova Scotia are compiled by the Nova Scotia Department of Natural Resources (NS DNR 2010) while Statistics Canada reports a summary of the industry production (NS Finance 2007).

According to the guidelines followed by the Nova Scotia Department of Natural Resources and the National Forestry Database (NFD 2011), harvested wood is measured in net merchantable m^3, which is a measure of recently harvested (green) wood with an approximate moisture value of 50%. The forestry products produced in Nova Scotia include the following:

- **Logs -** Stem of a tree after it has been felled; the raw material from which lumber, plywood, and other wood products are processed.
- **Bolts -** Raw material used in the manufacture of shingles and shakes; short logs to be sawn for lumber or peeled for veneer.

- **Pulpwood -** Wood used to produce pulp used in the manufacture of paper products. Pulpwood is usually wood that is too small, of inferior quality, or the wrong species to be used in the manufacture of lumber or plywood.
- **Other industrial roundwood -** Including poles, pilings, and other products still in the round.
- **Firewood –** Wood used for domestic and recreational heating.
- **Fuelwood** - Wood salvaged from mill waste, cull logs, branches, etc. and used to fuel fires in a boiler or furnace.
- **Maple Products** – Includes syrup, sugar, taffy, and butter.
- **Christmas Trees** – Usually balsam fir, seasonal applications.

The wood harvest in Nova Scotia includes softwood and hardwood species. Softwood species are cone-bearing trees having needle- or scale-like leaves belonging to the botanical group Gymnospermae, while hardwood species have broad leaves that are usually shed annually and belong to the botanical group Angiospermae. In 2006, the total forestry production of all types of wood was 5,209,192 m^3. Of this total, softwood species made up 4,566,816 net merchantable m^3 corresponding to 87.7 % of the total production, while hardwood species made up the remaining 12.3%, i.e. 642,376 net merchantable m^3 (NS Finance 2007).

Softwood is processed in-province for a variety of uses, including lumber, plywood, and pulpwood, and exported for processing outside of the province. The hardwood harvest is primarily for use as firewood and pulpwood. In 2006, of the 5,209,192 m^3 production, 907,897 m^3 (17 %) was exported to other provinces or abroad, while 4,301,295 m^3 (83 %) was delivered to other sectors within the province (NS Finance 2007).

Exports of wood products include both raw wood and fabricated wood products. Fabricated products, produced by the industrial sector, are subdivided into lumber, wood pulp and similar pulp, paper and paperboard, and other wood fabricated materials. These are products that have been processed within the province, separate from the exports of raw wood, which include both interprovincial and international exchanges.

2006 marked the passage of an agreement between the United States and Canada on the subject of softwood lumber trade (NS Finance 2007). Since 2002, both countervailing and anti-dumping duties were imposed by the United States on Canadian softwood lumber imports. The dispute was resolved through the establishment of a system of variable, price-based export taxes and quota limits on the Canadian side. Maritime Provinces were excluded from these requirements, where they had previously been subject to an anti-dumping duty rate of 2.1 %. This agreement went into effect on October 12, 2006, and export statistics have been adjusted to reflect the change (NS Finance 2007).

3.1.2.1 Wood Product Energy and Exergy Contents

The energy content of wood varies largely with moisture content. While energy content of bone dry wood fuel is between 18-22 GJ/t, energy content of wood fuel with 20% moisture (air dry) is about 15 GJ/t (Wall 1977). As the moisture content increases, the energy content decreases. For example, energy content of wood with 50% moisture is about 7.6 GJ/t (Ertesvåg 2005).

Due to the large variation in the energy content of wood with moisture, and to a lesser extent the species, it is not practical to attempt deriving specific exergy values for the different varieties of wood products. In their analysis of the exergy conversion in the Japanese and Italian societies, Wall (1990) and Wall, et al. (1994) use a value of 8.0 GJ/m^3 for specific exergy of wood, consisting primarily of soft wood species. Considering that softwood species have a density of about 500 kg/m^3 on a dry basis, 8.0 GJ/m^3 specific exergy is equivalent to about 16 GJ/ton, which is close to the 17 GJ/ton value used by Ertesvåg and Mielnik in the exergy analysis of the Norwegian society (Ertesvåg and Mielnik 2000). Therefore, a specific exergy of 16 GJ/ton is used for wood in this work. Similarly, based on the work of Wall, (1986), a specific exergy value of 17 PJ/Mton is used for paper.

3.1.2.2 Exergy Fluxes into and out of the Forestry Industry

The forest product output from the forestry industry is represented as exergy fluxes from the Agriculture sector to the Industrial, Tertiary, Abroad, and Domestic sectors.

The total equivalent exergy transferred from one sector to another is tabulated according to the classification methods of the EEA as a resource, natural resource, product, waste, or thermal discharge. The main equivalent exergetic outputs of the forestry industry are in the form of forest products, which are classified as a natural resource.

Exergy inputs to the forestry industry include fuels and energy carriers, electricity, steam, and biomass in the form of wood. A total of 0.24 PJ equivalent exergy of energy carriers are transferred to the forestry industry from the Conversion sector. This amount is accounted for under the total input of energy carriers to the Agriculture sector. Wood liquors (effluents) are produced and burned within the industry to generate process heat for the production of products such as wood pulp. Under the EEA, these energy carriers are not accounted for separately on the balance sheet of the sector as they are intermediate products arising from the production of other commodities. Waste paper is assumed to be collected by the tertiary sector and transferred to the Industry sector for processing.

Exports of wood products, which include both crude and fabricated materials, are accounted for as a flux from the Agriculture sector to the Abroad sector, which includes both interprovincial and international exchanges. Raw wood exports are represented by a flux from the Agriculture sector to the Abroad sector, while exports of fabricated products are represented by a portion of the exergy flux from the Industry sector to the Abroad sector.

Fuel production (under the classification fuelwood, as opposed to firewood) from the forestry industry is a by-product of production processes. Accordingly, the volume of fuelwood created by the industry rises and falls with the overall volume of production. This creates storage and transportation problems as the supply can fluctuate year to year, and fuels such as sawdust and wood shavings are difficult to transport and store. As a response to this problem, many facilities use the by-products of production in the generation of process heat and, occasionally, electricity. Similar to the treatment of wood liquors, this in-sector energy and energy carrier production is not accounted for under the EEA as there is no transfer of exergy between sectors.

The equivalent exergetic value of all forest products transferred from the Agriculture sector is equal to the equivalent exergetic value of the total production of the forestry industry for one year:

$$5.21\, Mm3\; x\; 8.0\, PJ/Mm3 \;=\; 41.67\, PJ \qquad (1)$$

Table 8 shows the volume, energy and equivalent exergy of all forestry products transferred from the Agriculture sector by destination for 2006.

Table 8 - Transfer of forestry products from the Ag-sector for 2006 by destination.

Category	Volume (m^3)	Energy (PJ)	Exergy (PJ)	Destination
Industrial roundwood	907,897	6.66	7.26	A sector
Industrial roundwood, fuelwood	4,281,002	31.42	34.25	In sector
Forest products (C.trees)	358	0.00	0.00	Te sector
Firewood	19,935	0.15	0.16	Do sector
Total	**5,209,192**	**38.23**	**41.67**	

3.1.3 The Fishing Industry in Nova Scotia and Fish Products

According to the NAICS, the fishing industry in Nova Scotia is comprised of establishments engaged in the commercial harvesting of finfish, shellfish, and other marine animals from their natural habitats. This is distinct from the aquaculture industry, which involves the cultivation of marine organisms. Information on the fishing industry is collected by the Department of Fisheries and Oceans and combined with export and financial information from Statistics Canada. Information on the aquaculture industry is collected by the Nova Scotia Department of Agriculture (NS Finance 2007)

Major ports for the fishing industry in Nova Scotia include Lunenburg, Yarmouth, Lower West Pubnico, and Meteghan. The primary products of the fishing industry are pelagic fish like mackerel and herring, ground fish like haddock and halibut, and shellfish like lobster and scallops. There are also a variety of secondary products like seals, fish roes, and seaweed. By far the most lucrative product is lobster, and shellfish in general, most of which are exported regionally and abroad. Nova Scotia exports of fish and fish products are valued at $957 million for 2006, making them the second largest export product group at 18.8% of the value of all exports (CIMTD 2011).

3.1.3.1 Fish Product Energy and Exergy Contents

Information on the nutrient energy content of the products of the fishing industry is retrieved from the US Department of Agriculture's Nutrient Data Laboratory (US DoA 2011). Totals of the three classifications of products (finfish, shellfish, and misc.) are used to estimate nutrient energy content. The "misc." classification is presumed to be entirely fish roe for simplification. The nutrient energy content of raw Atlantic haddock is used to represent the equivalent exergy of ground fish, the nutrient energy content of raw Atlantic herring is used to represent the equivalent exergy of pelagic fish, and the nutrient energy content of raw farmed Atlantic salmon is used to represent the equivalent exergy of farmed finfish. A combined estimate of the nutrient energy of raw molluscs is used to represent the equivalent exergy of shellfish.

3.1.3.2 Exergy Fluxes into and out of the Fishing Industry

The inputs to the fishing industry include a small amount of fuel (accounted for under the total input energy carriers to the Agriculture sector in Table 3) and imported pelagic and ground fish.

The output of the fishing industry and the output of the aquaculture industry are combined and assigned equivalent exergetic values based on the process described above. Table 9 shows the total production, imports, exports and calculated final consumption (production minus exports plus imports) of seafood from the fishing and aquaculture industries for Nova Scotia in 2006. The majority of fish products are exported from the province fresh, while the majority of imports are generally frozen fillets.

Table 9 - Fishing and aquaculture industries production, imports, exports, and consumption (PJ).

Fish classification	Production (PJ)	Imports (PJ)	Exports (PJ)	Consumption (PJ)
Finfish	0.65	0.09	0.09	0.66
Shellfish	0.38	0.00	0.20	0.18
Misc.	0.00	0.00	0.00	0.00
Total	**1.04**	**0.10**	**0.29**	**0.84**

3.1.4 Exergy Fluxes into and out of the Agriculture Sector

The main inputs to this sector are natural resources harvested from the environment and energy carriers. The main outputs of this sector are natural resources transferred to other sectors and exported.

Table 10 summarizes the exergy inputs and outputs of the Agriculture sector as a whole. The total input to this sector is 49.6 PJ energy and 53.2 PJ exergy. The total output of this sector is 34.1 PJ energy and 37.0 PJ exergy. As mentioned previously in section **2.2.2**, each flux is represented by the flux type (R for resources, N for natural resources, P for products, etc.) and a subscript denoting first the originating sector followed by the destination sector.

Table 10 – Energy and exergy balance sheet, Agriculture sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
$R_{co,ag}$	3.47	3.67	Energy carriers
Natural Resources			
$N_{e,ag}$	38.23	41.67	Wood
$N_{e,ag}$	5.62	5.62	Harvest
$N_{e,ag}$	1.04	1.04	Fish
$N_{a,ag}$	0.25	0.25	Harvest, fish imports
Products			
$P_{tr,ag}$	0.13	0.14	Cargo services

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
P in,ag	0.57	0.59	Metals, minerals, etc
TOTAL INPUT	**49.31**	**52.98**	
OUTPUT			
Natural Resources			
N ag,in	31.42	34.25	Wood
N ag,do	0.15	0.16	Wood
N ag,te	2.30	2.30	Food, forest products
N ag,a	0.25	0.25	Harvest, fish, wood exports
Products			
P ag,te	0.02	0.02	Diverted waste
TOTAL OUTPUT	**34.13**	**36.97**	

3.2 The Extraction Sector in Nova Scotia

Under the EEA, the extraction sector is made up of the mining and oil and gas industries, defined in Canada under the North American Industry Classification System (NAICS) (Input Output 2006). It consists of establishments primarily engaged in extracting naturally occurring substances and minerals (solids, liquids and gases). This sector includes oil and gas extraction, mining (including well operations, quarrying, and pre-processing at the mine site), and associated support activities for the above (including exploration and development and associated contract or fee-based activities (Input Output 2006). In this work coal extraction is treated as part of the oil and gas industry as it involves the production of an energy carrying fuel. Figure 5 presents the main activities of the Extraction sector, including the inputs and outputs and their origins and destinations.

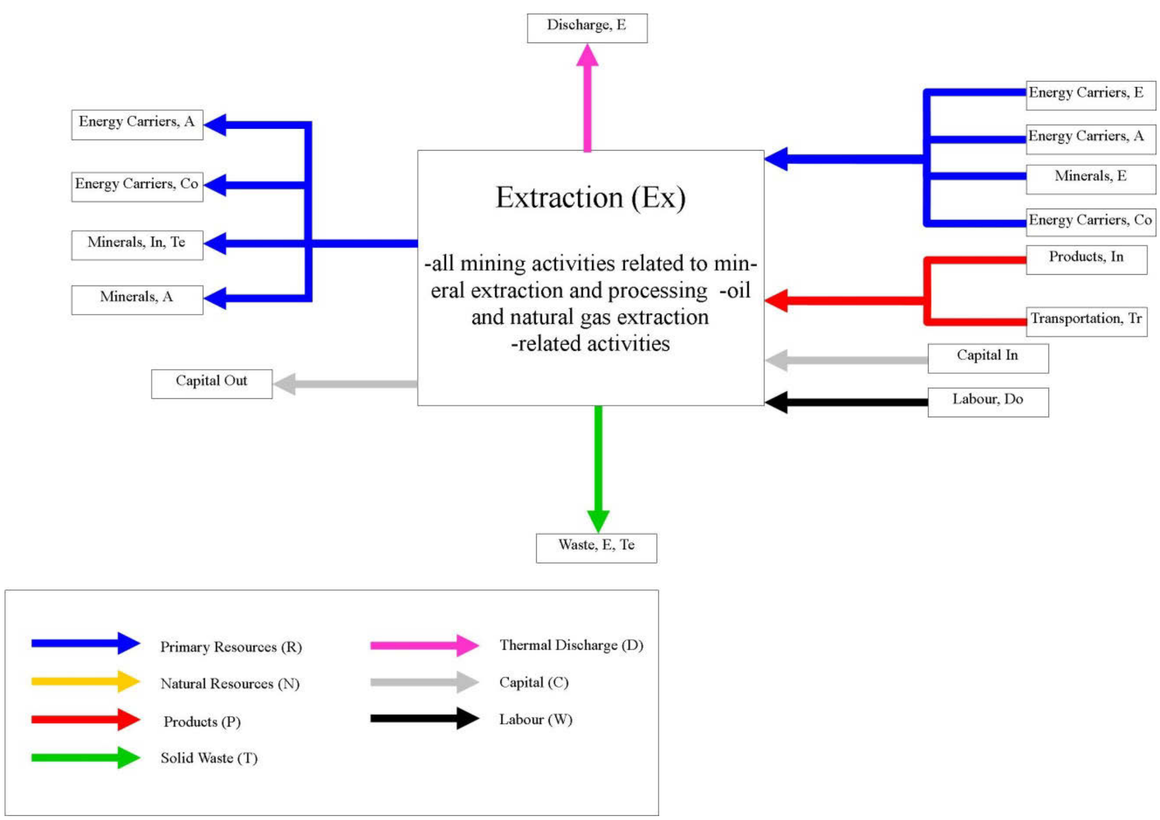

Figure 5 - Extraction Sector flux origins and destinations.

The GDP of this sector in 2006 was $704.2 million, a decline of 10% over the previous year (NS Finance 2007). This sector represented 2.7% of the total GDP of the province in

2006, and $161.0 million in wages and salaries (NS Finance 2007). For the oil and gas industries, Statistics Canada reported employment of 3400, paying total wages of $109.4 million (NS Finance 2007). For the mineral industries, Statistics Canada reported 31 establishments paying total wages of $51.6 million in 2006 (NS Finance 2007). Employment sustained by the total activity in the mineral industries was 1,046 full time jobs (NS Finance 2007).

3.2.1 Mineral Extraction Industry in Nova Scotia

Nova Scotia produces a variety of industrial minerals, including gypsum and anhydrite (usually mined together), salt, lead, zinc, quartz and silica sand, limestone, aggregates, and coal (NRCan 2008). In 2006, 85.2% of all gypsum produced in Canada was mined in Nova Scotia (approximately 8 million tons) (NS Finance 2007). All of this gypsum is exported to the United States for use in wallboard production. There are two salt mining operations in the province producing approximately 1 million tons of raw and refined salt products, which is about 10% of the total Canadian production (NS Finance 2007). Lead and zinc production for 2006 was negligible; however, exploration activities took place at a number of locations throughout the province (NRCan 2008). Quartz mining operations resumed in 2006; the companies involved stockpiled their production inventory for processing in early 2007 (NRCan 2008). Nova Scotia is also a significant producer of stone, with nearly 14 million tons quarried in 2006 (NS Finance 2007). A surface coal mining operation in Cape Breton continued in 2006; the company plans to extract a total of approximately 1.6 million tons over 7 years (NS Finance 2007).

3.2.1.1 Mineral Production

The exact production numbers for minerals in Nova Scotia are no longer reported by the Department of Natural Resources, and have not been since 2003. However, the values of these minerals are reported (NS DNR 2008), and are shown in Table 11. Production amounts for products are estimated where possible from the Canadian Minerals Yearbook (NRCan 2008) and the Nova Scotia Statistical Review (NS Finance 2007), based on average commodity prices for 2006. Exergy contents of these minerals are quite low as they are similar in composition to the reference environment (Kotas 1985).The production mass of anhydrite is included in the gypsum production mass.

As of the writing of this report there is a pilot project in Cape Breton to replace some amount of the coal burned to produce electricity with peat, however for 2006 the mass of peat produced in Nova Scotia is not known. It is assumed in this work that all of the salt production is transferred to the Industry sector for processing.

Table 11 – Value, mass, and equivalent exergy of production for minerals in Nova Scotia for the year 2006 (NS DNR 2008).

Mineral	Value of Production ($,000)	Produced (kt)	Exergy (J)
Anhydrite	2,038	x	-
Barite	596	0.497	7.20E+09
Limestone	3,626	257	2.60E+09
Clay	x	x	-
Gypsum	108,525	7,740	3.80E+14
Peat	x	x	-
Salt	55,631	978	2.88E+13
Silica	x	x	-
Sand and Gravel	10,800	4,243	1.20E+14
Stone	76,096	13,643	3.60E+14
Barite, Limestone, Clay, Silica	12,256	x	-
Total	**269,568**	**-**	**8.89E+14**

3.2.1.2 Mineral Product Energy and Exergy Contents

All of the mineral products extracted in Nova Scotia have a zero or negligible energy value except for peat. Peat prices are negotiated between the producer and end-user and are subject to privacy considerations along with the production amounts. Only the value of peat transactions is reported in the principal statistics of the mineral extraction industry. Due to a lack of information, the peat harvest has been excluded from the final accounting of total mineral production energy and exergy contents. Table 12 shows the standard chemical exergies of the minerals extracted in Nova Scotia for the year 2006.

Table 12 - Standard chemical exergies of commonly extracted minerals in Nova Scotia (Szargut 1988).

Substance	Common Name	Standard Chemical Exergy (kJ/mol)
$BaSO_4$	Barite	3.4
$CaCO_3$	Limestone (Aragonite)	1.0
$CaSO_4 \cdot 2H_2O$	Gypsum	8.6
NaCl	Salt	14.3
SiO_2	Quartz	1.9

All of the mineral products extracted in Nova Scotia (excluding peat) have extremely low values of standard chemical exergy. Though massive quantities of gypsum and anhydrite are extracted every year, their combined value of equivalent exergy is only 0.38 PJ. Similarly, the amounts of stone, sand, and gravel extracted every year yield (if they are assumed to have similar standard chemical exergies to quartz) only 0.48 PJ exergy equivalent. Salt production yields an exergy value of 0.029 PJ. Barite production yields 7.2 GJ exergy equivalent, and limestone production yields 2.6 GJ exergy equivalent. The rest of the minerals yield negligible exergy values, giving a final value for the exergy of extracted minerals of 0.89 PJ.

3.2.2 Oil and Gas Industry in Nova Scotia

In 2006, natural gas was Nova Scotia's single largest exported commodity (NS Finance 2007). The sole natural gas project in Nova Scotia in 2006 was the Sable Offshore Energy Project, which had been in operation since 1999 (ExxonMobil 2010). The Deep Panuke field was allowed to proceed in 2006; however, there was no exploration activity related to that project in 2006 (NS Finance 2007).

3.2.2.1 Production of Energy Carriers

The term "energy carriers" refers to primary resources that are classified as fuels. In particular, they are coal, oil and natural gas. Some energy carriers are produced by the conversion sector in the form of refined petroleum products, but this section deals only with the production of crude oil, natural gas, and coal by the extraction sector. Crude oil in this case refers to pentane plus condensates, crude bitumen and synthetic crude as well as conventional crude. Table 13 shows the flows of these energy carriers into and out of the extraction sector for the year 2006. Energy values are calculated based on conversion factors provided by Statistics Canada for the year 2006 (Energy Supply-Demand 2006). Production figures are measured at a "net yield" level, meaning after exchanges in a refinery have taken place.

3.2.2.2 Coal

2173 kT of coal flows through the Nova Scotian extraction sector in 2006 (Energy Supply-Demand 2006). Of this figure, 0.2 kT are produced in the province with the rest being imported from abroad. An adjustment to this figure is made on the order of 378 kT, most likely due to accounting and reporting errors at the source, making a final figure of 2551 kT of coal available as a resource in the Extraction sector (NS Finance 2007). All of the coal is transferred to the conversion sector and almost all is converted to electricity while a small amount is eventually used in the manufacturing industries (Energy Supply-Demand 2006). Coal mined in Nova Scotia is of a type called Canadian Bituminous. Imported coal has been converted to an equivalent energy value of Canadian Bituminous by Statistics Canada.

3.2.2.3 Oil

698 ML of oil are produced in Nova Scotia in 2006 (Energy Supply-Demand 2006). Added to this are 3517 ML of imported oil and 993 ML of oil transferred from within the Atlantic region to Nova Scotia. 266 ML of the oil produced in Nova Scotia are exported outside the Atlantic region for a total figure of availability of 4943 ML. The amount of oil transformed into electricity is unknown to Statistics Canada for the reference period in question (Energy Statistics Handbook 2009), however for the purposes of this analysis it can be assumed that virtually all of the oil is transferred to the conversion industry for conversion into refined petroleum products.

3.2.2.4 Natural Gas

3683 GL of natural gas are produced in Nova Scotia in 2006 (Energy Supply-Demand 2006). Most of this gas (3418 GL) is transferred from Nova Scotia to the surrounding region as an exported resource (NS Finance 2007). Adjustments are made to this figure on the order of 4 GL due to stock adjustments and 36 GL due to other adjustments (Energy Supply-Demand 2006). 304 GL of natural gas are therefore available within the extraction industry as a resource in 2006 (Energy Statistics Handbook 2009). Of this, 143 GL are consumed by the producers, providing an energy discharge to the environment equivalent to the energy content of the consumed gas (Energy Statistics Handbook 2009).

Table 13 - Flows of energy carriers within the extraction sector of Nova Scotia, 2006.

Fuel	**Coal**		**Natural Gas**		**Crude Oil**	
	kT	**TJ**	**GL**	**TJ**	**ML**	**TJ**
Produced	0	6	3,683	140,603	698	26,751
Imported	2,173	64,808	.	.	3,517	134,783
Exported	0	0	.	.	-266	-10,178
Inter-regional Transfer	0	0	-3,418	-130,498	993	38,063
Stock Variation	0	0	-4	-150	x	x
Other Adjustments	378	10,936	36	1,362	x	x
Availability	**2,551**	**75,750**	**304**	**11,618**	**4,943**	**189,419**
Producer Consumption	0	0	143	5,467	.	.

3.2.2.5 Oil and Gas Product Energy and Exergy Contents

Computing the exact chemical exergy content of each individual energy carrier can be a difficult and tedious task. If the mass fractions and the atomic ratios of H_2, C, O_2, and N_2 are known, then the exergy factor (β), which is the ratio of standard chemical exergy content to net calorific energy content, can be computed for an energy carrier using one of the following equations (Szargut 1988):

Gaseous hydrocarbons:

$$\beta = 1.0334 + 0.0183\ \frac{H}{C} - \ 0.0694\frac{1}{N_C} \quad (1)$$

Liquid hydrocarbons:

$$\beta = 1.0406 + 0.0144\ \frac{H}{C} \quad (2)$$

Solid hydrocarbons:

$$\beta = 1.0435 + 0.0159\ \frac{H}{C} \quad (3)$$

Bituminous coal, lignite, coke, peat:

$$\beta = 1.0437 + 0.1896\ \frac{z_{H_2}}{z_C} + \ 0.0617\frac{z_{O_2}}{z_C} + \ 0.0428\frac{z_{N_2}}{z_C} \quad (4)$$

Wood:

$$\beta = \frac{1.0412+0.2160\frac{z_{H_2}}{z_C} - 0.2499\frac{z_{O_2}}{z_C}[1+0.7884\left(\frac{z_{H_2}}{z_C}\right)] + 0.0450\frac{z_{N_2}}{z_C}}{1-0.3035(\frac{z_{O_2}}{z_C})} \quad (5)$$

Where N_C is the mean number of carbon atoms in the molecule, z_X is the mass fraction of a given element, and H/C is the atomic ratio of hydrogen to carbon in the substance. It is impractical to compute the exact chemical exergy content for each individual energy carrier from these equations due to the lack of information on the exact chemical makeup of any given substance. Exergy factors that are used throughout this work were computed for commonly used fuels and can be found in Table 14. The substance used to represent petroleum products is gasoline as it is the most common petroleum product (Energy Supply Demand 2007). Diesel and other fuel oils have an almost identical exergy factor so 1.06 is used to convert to equivalent exergy for any petroleum product in this work. The only natural gas liquid (NGL) produced in Nova Scotia is propane so it is used to compute the exergy factor for NGLs (Energy Supply Demand 2007).

Table 14 - LHV and exergy factors for commonly used fuels.

Fuel	LHV	Exergy factors
Coal	26.0 GJ/t	1.06
Coke	29.8 GJ/t	1.05
Crude oil	43.4 GJ/t	1.06
Petroleum products	43.6 GJ/t	1.06
Natural gas	35.6 MJ/m3	1.04
NGLs	45.9 GJ/t	1.08
Electricity	–	1.00

The extraction sector uses energy carriers from the Conversion sector as well. Table 15 lists the input energy carriers and their equivalent exergy, calculated by multiplying the energy content of the respective energy carrier by the appropriate exergy factor.

Table 15 - Energy and equivalent exergy of total energy carriers input to the Extraction sector (Energy Supply Demand 2007).

Energy Carrier	Energy (PJ)	Exergy (PJ)
NGL	0.04	0.04
Electricity	0.15	0.15
Refined petroleum products	2.43	2.58
Total	**2.62**	**2.77**

3.2.3 Exergy Fluxes into and out of the Extraction Sector

The main inputs to this sector are resources (energy carriers and minerals) extracted from the environment and energy carriers. The main outputs of this sector are the transfer of those resources to the conversion sector for processing.

Table 16 summarizes the exergy inputs and outputs of the Extraction sector as a whole. The total input to this sector is 419.3 PJ energy and 446.5 PJ exergy. The total output of this sector is 412.0 PJ energy and 438.9 PJ exergy.

Table 16 – Energy and exergy balance sheet, Extraction sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
R e,ex	0.01	0.01	Domestic coal production
R a,ex	75.75	80.30	Imported coal
R e,ex	26.75	28.89	Domestic oil production
R a,ex	172.85	186.67	Imported oil
R e,ex	140.58	146.20	Domestic NG production
R co,ex	0.15	0.15	Electricity
R e,ex	-	0.89	Domestic minerals production
R co,ex	2.43	2.58	Refined petroleum products
R co,ex	0.04	0.04	NGL
Products			
P tr,ex	0.13	0.14	Cargo services
P in,ex	0.59	0.61	Industry products
TOTAL INPUT	**419.27**	**446.47**	
OUTPUT			
Resources			
R ex,co	75.75	80.30	Coal to Conversion sector
R ex,a	10.18	10.99	Exported oil
R ex,co	189.42	204.57	Oil to conversion sector
R ex,a	130.50	135.72	Exported NG
R ex,co	6.15	6.39	NG to conversion sector
R ex,in	-	0.03	Minerals to industrial sector
R ex,a	-	0.38	Minerals exported
R ex,te	-	0.48	Minerals to tertiary sector
Products			
P ex,te	0.02	0.02	Diverted waste
TOTAL OUTPUT	**412.01**	**438.88**	

3.3 The Conversion Sector in Nova Scotia

Under the EEA, the conversion industry in Nova Scotia includes establishments primarily engaged in the generation of electricity from any source as well as establishments primarily engaged in the transformation of liquid fuels into refined petroleum products. The NAICS has separate classifications for these industries; electricity generation is considered to be a utility industry while refinery activity is considered to be part of the trade industry. In this work, the conversion industry is defined as establishments and facilities primarily engaged in either electric power generation or petroleum refining activities and facilities primarily engaged in providing essential support services to those industries. Information on the industries of the Conversion sector is collected by Statistics Canada and released on an annual basis as a report under the title "Supply and Demand of Primary and Secondary Energy" (Energy Supply Demand 2007). Figure 6 presents the main activities of the Conversion sector, including the inputs and outputs and their origins and destinations.

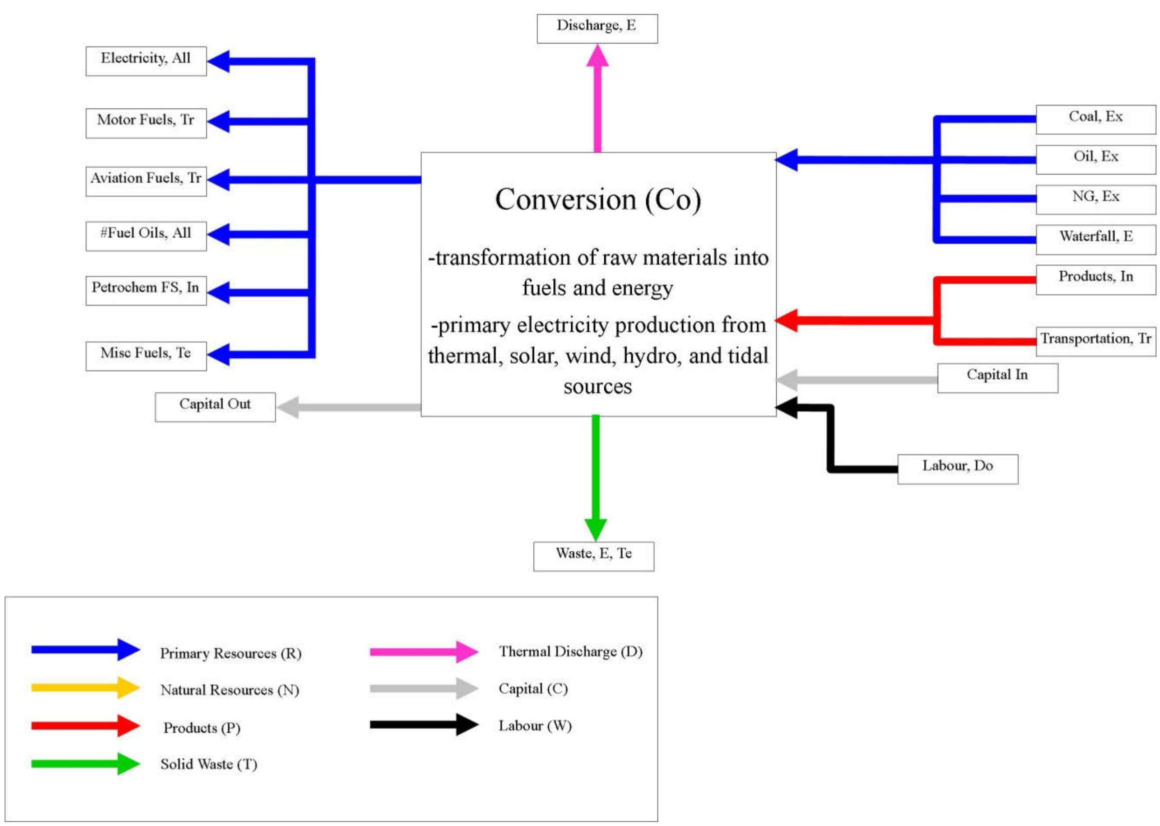

Figure 6 - Conversion Sector flux origins and destinations.

3.3.1 Electricity Generation Industry

Virtually all (97.9%) of Nova Scotia's electric power was generated by the public utilities in 2006. Industrial producers accounted for the remaining 2.1%. Nova Scotia Power Inc. operates a combined generating capacity of 2,293 MW. Approximately 55% of this capacity is coal-fired. Oil and natural gas-fired facilities make up an additional 28%, and hydro, wind, and biomass conversion comprise the remaining 17% of capacity.

In Nova Scotia in 2006 there were five thermal plants, three combustion turbines, one tidal barrage, and thirty-three hydroelectric plants – one large facility (230 MW) at Wreck Cove and thirty-two smaller installations (NPCC 2007).

In 2006, 11,340,829 megawatt hours of electrical energy were generated from all sources in Nova Scotia (NS Finance 2007). 89.9% of this energy was generated by conventional steam processes, while hydro generation accounted for 9.2% of the total. The remaining 0.9% was generated by combustion turbines burning natural gas. This electricity supplies all other sectors of the economy. A summary of the electric power generation for 2006 in PJ is shown in Table 17.

Table 17 - Electricity production 2006 by process.

Conversion Method	Production (MWh)	Equivalent Exergy (PJ)
Conventional Thermal	10,193,807	36.70
Hydroelectric	1,041,183	3.75
Combustion Turbine	105,839	0.38
Total	**11,340,829**	**40.83**

Megawatt hours of electricity are converted to equivalent exergy by converting between units of energy, MWh to PJ. The fuels converted into electricity in the preceding processes are listed in Table 2 (Energy Supply Demand 2007). There is a small disagreement between these figures (equivalent total exergy of conventional thermal plus combustion turbine generation is 37.08 PJ in Table 17 vs 38.61 PJ in Table 18) due to differences in reporting and the exclusion of wood liquor and pulping waste as a fuel source for conversion to electricity under the EEA. The figures in Table 18 are used in this work as they form part of the official energy balance of Canada (Demers 2011).

Table 18 - Fossil fuels transformed to electricity 2006.

Generating Fuel	Output Electricity (GWh)	Energy (TJ)	Exergy (PJ)
Coal	8,996	32.39	34.33
Natural gas	387	1.39	1.45
Diesel/light fuel oil	75	0.27	0.29
Heavy fuel oil	666	2.40	2.54
Total	**10124**	**36.45**	**38.61**

3.3.2 Petroleum Refining Industry

There is a single petroleum refining facility in Nova Scotia. This facility is owned by Imperial Oil and produces refined petroleum products for domestic sale and export with a production capacity of 82,000 barrels of crude oil per day (NS Finance 2007). The main products are motor gasoline, diesel fuel, heating oil, aviation fuels, and asphalt.

3.3.2.1 Petroleum Products Energy and Exergy Contents

Most of the production from this refinery in 2006 was sold in Nova Scotia and the other Atlantic provinces. Data on t he production amounts and exports of each product is confidential, but Imperial Oil is required to release the domestic sales of these refined petroleum products on an annual basis (NS Finance 2007). Table 19shows a summary of the domestic sales of refined petroleum products for 2006.

Table 19 - Refined petroleum production for 2006 (NS Finance 2007).

Fuel	Production (m^3)	Energy (PJ)	Exergy (PJ)
Aviation	227,798	8.29	8.86
Motor	1,985,852	68.83	73.65
Heating	1,287,011	49.78	52.77
Asphalt	97,073	4.32	4.57
Petrochem feedstock	58,216	2.05	2.17
Misc fuels	109,898	4.25	4.51
Petroleum coke	164,016	7.30	7.66
Total	**3,929,864**	**144.81**	**154.19**

Each of these products has been converted to an equivalent exergy value according to the standard chemical exergy of organic compounds found in the literature (Szargut, 1988) and (Kotas, 1995), for a total of 154.2 PJ. There is some small disagreement between these figures and those reported in the Report on Energy Supply and Demand (144.8 PJ energy vs. 141.5 PJ energy) due to differences in reporting. For the purposes of this work the figures from the Report on Energy Supply and Demand are taken as correct.

3.3.3 Exergy Fluxes into and out of the Conversion Industry

The main inputs to the Conversion sector are fuels from the Extraction sector and waterfall energy from the Environment sector. Values of energy are converted to equivalent exergy using the exergy conversion factors found in the literature (Gasparatos et al. 2009). Losses of 15% for the conversion of waterfall energy to electric energy are assumed for hydroelectric generation in the manner suggested by Ertesvåg (2000). The inputs to the Conversion sector are summarized in Table 20.

Table 20 - Summary of energy and exergy inputs of energy carriers to the Conversion sector.

Energy Carrier	Input Energy (PJ)	Equivalent Exergy (PJ)
Coal	75.47	80.00
Natural Gas	3.22	3.34
Oil	30.48	32.92
Waterfall Energy	4.31	4.31
Total	**113.48**	**120.57**

The main outputs of the Conversion sector are electricity and refined petroleum products which are delivered to every other sector of the economy. The total disposition of energy carriers delivered to all other sectors is shown in Table 21 in natural units. The Conversion sector is not included as there is no transfer of energy carriers into the sector.

Table 21 - Energy use, final demand for all sectors except Conversion (Energy Supply Demand 2007).

Sector	NG (GL)	NGL (ML)	Electricity (GWh)	Steam (kT)	Refined Petroleum Products (ML)
Agriculture	-	2.8	58.9	-	89.5
Extraction	-	1.5	40.2	-	62.8
Industry	42.5	15.7	3119.2	458.4	104.7
Transportation	24.1	3.3	6.3	-	1832.5
Tertiary	10.5	92.1	3164.2	-	892
Domestic	-	41.1	4011.3	-	297.3
Total	**77.1**	**156.5**	**10400.1**	**458.4**	**3278.8**

Table 22 summarizes the exergy inputs and outputs of the Conversion sector as a whole. The total input to this sector is 276.2 PJ energy and 296.2 PJ exergy. The total output of this sector is 171.2 PJ energy and 178.4 PJ exergy.

Table 22 – Energy and exergy balance sheet, Conversion sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
R ex,co	75.75	80.30	Coal
R ex,co	6.15	6.39	Natural gas
R ex,co	189.42	204.57	Oil
R e,co	4.31	4.31	Waterfall energy
Products			
P in,co	0.47	0.48	Metals, minerals, etc
P tr,co	0.10	0.11	Cargo services
TOTAL INPUT	**276.19**	**296.16**	
OUTPUT			
Resources			
R co,ex	2.62	2.77	Energy carriers
R co,ag	3.47	3.67	Energy carriers

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
R co,tr	69.58	73.73	Energy carriers
R co,te	46.58	48.73	Energy carriers
R co,in	21.96	21.66	Energy carriers
R co,do	27.01	27.79	Energy carriers
Products			
P co,te	0.02	0.02	Diverted waste
TOTAL OUTPUT	**171.24**	**178.36**	

3.4 The Industry Sector in Nova Scotia

Under the EEA, the Industry sector is made up of the manufacturing industries but excludes petroleum refining activities and activities that are classified to other sectors. The NAICS definition of the manufacturing industry includes establishments primarily engaged in the physical or chemical transformation of materials or substances into new products (finished or semi-finished) and related activities, such as the assembly of component parts of manufactured goods, blending of materials and finishing by dyeing, heat treating, plating, and similar operations. It is important to note that, in this work and under the NAICS definition, the manufacturing industry specifically excludes activities that are classified to other sectors, such as the post-harvest activities of agricultural establishments. Figure 7presents the main activities of the Industry sector, including the inputs and outputs and their origins and destinations.

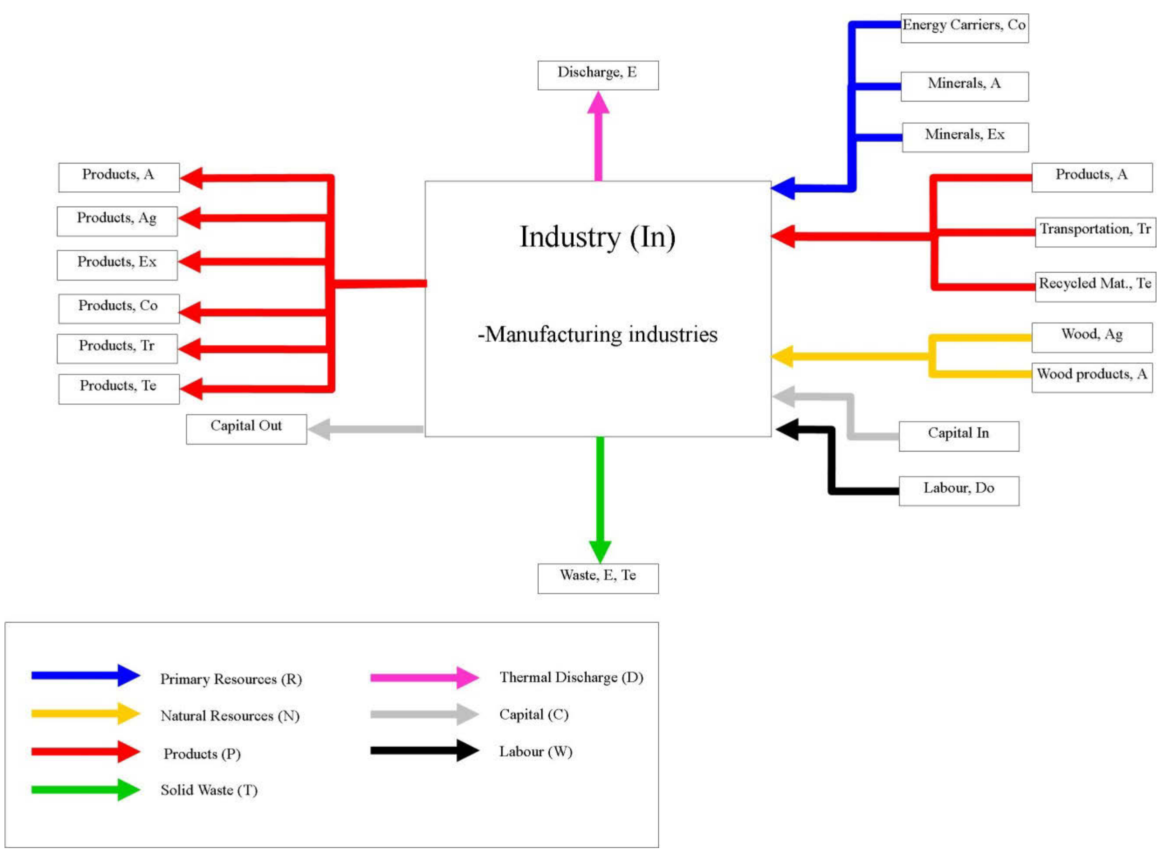

Figure 7 - Industry Sector flux origins and destinations.

In this work, the Industry sector is subdivided into the wood, pulp, and paper manufacturing industries and other industries, which includes vehicle manufacturing, chemical industries, which include the production of rubber and plastic products, mineral products, cement manufacturing, metal fabrication, foundries and grain industries.

The total GDP of the Industrial sector in 2006 was $2,616.3 million, representing 10.1% of the total GDP of the province. Wages and salaries in the manufacturing industries accounted for $1,487 million. Employment sustained by the total activity in the Industry sector was 39,100 persons.

3.4.1 Industry Product Energy and Exergy Contents

The output of the Industry sector largely consists of products which are consumed by the other sectors of the economy and exported outside the province. Information on the export of these products is retrieved from the Canadian International Merchandise Trade Database (CIMTD 2011). Information on the products and natural resources imported for industrial use is also retrieved from this database. These products and natural resources are divided into five general categories: Wood and related products pulp and paper products, fabricated metals, mineral products, and plastics and rubber.

3.4.1.1 Estimation of Industry Production

Wood and related products are items such as finished wood products that are the output of sawmills and related facilities. Lumber, particle board, veneer, and the like are included in this category. Pulp and paper is a mixed category of intermediate products like wood pulp and finished paper products. Fabricated metals are items of ferrous and non-ferrous metals that are not classified as scrap under the Canadian International Merchandise Trade Database. The only mineral products tracked in this work are related to cement production (Portland cement and clinker) as no other statistically significant products are produced in Nova Scotia. Plastics and rubber products produced in Nova Scotia include sheets and fabricated products of polyethylene, polystyrene, and other common plastics, and natural rubber imported for use in the pneumatic tire manufacturing industry.

The principal production statistics of industry in Nova Scotia are unavailable on a mass or volume basis. Analysis of the Input-Output Structure of the Canadian Economy (Input Output 2006) reveals the value of each commodity that is produced, transferred between sectors, and exported. A ratio of the export value to the value transferred between sectors was calculated for each commodity. Using the detailed data on the value and mass or volume of exported commodities found in the Canadian International Merchandise Trade Database, an estimation of the domestic consumption (that is, the mass or volume of industrial products transferred to the Tertiary sector from the Industry sector) is calculated for each of wood and wood products, pulp and paper, fabricated metal products, cement, and plastic and rubber products. Table 23 lists the ratio of export value to transferred value for these five commodities for 2006.

Table 23 - Ratios for the estimation of domestic consumption of commodities (Input Output 2006).

Commodity	Export/Transfer value ratio
Lumber and wood	1.42
Pulp and paper	3.52
Fabricated metal	0.52
Cement	0.18
Rubber and plastic	4.07

It is not possible at this time to analyse the pneumatic tire manufacturing industry as all aspects of the production process used in Nova Scotia are protected by the Privacy Act. Energy use, materials consumption, and product composition are all unavailable for this industry. Although it is important to the economy of this province, the products of this industry have been neglected in this work for these reasons. Where possible, energy and materials import that are presumed to be consumed by the pneumatic tire manufacturing industry are included in the analysis of “other industries”. It is likely that the exergy efficiency of the chemical industry has been underestimated as the production of high-exergy products like pneumatic tires has been neglected from the output side of the balance sheet.

3.4.1.2 Calculation of Equivalent Exergy

The exergy contents of wood, pulp, and paper products are calculated by multiplying a given mass of wood, pulp, or paper by the specific exergy contents specified by Ertesvåg and Mielnik (2000) in the exergy analysis of the Norwegian society: 16 PJ/Mton for wood and 17 PJ/Mton for paper.

Plastics and Rubber products masses are also converted to equivalent exergy contents by multiplying by the specific exergy, however some of these organic chemicals (like PVC, polyisoprene, and polystyrene) are not listed in Szargut (1988) as common compounds. Their specific exergy is computed by adding the group contribution of standard chemical exergy of each type of bond that makes up the complete molecule. The structure of each of these molecules is found in the NIST Standard Reference Database (NIST 2011).

Petrochemical feedstock is an input from the Conversion industry and is assumed to have the same specific exergy as other petroleum products. An exergy factor of 1.06 i s multiplied by the energy content of the feedstock to obtain an equivalent exergy value.

The specific exergies of metals are found in Szargut (1988) and can be applied to fabricated metal products by mass. It is assumed that steel is 98% iron and 2% carbon for this calculation. Table 24 contains the calculated specific exergy contents of common materials encountered in this work.

Table 24 - Specific exergy contents of common materials (Szargut 1988).

Material	Specific Exergy Content (PJ/Mt)
Wood	16
Paper and Pulp	17
Iron	6.7
Steel	8.7
Aluminium	32.9
Polyethylene	48.5
Polyisoprene (rubber)	46.7
Polystyrene	43.4

Material	Specific Exergy Content (PJ/Mt)
Portland Cement	1

3.4.2 Industry Sector Consumption of Energy Carriers

Information on the energy consumption of each manufacturing industry was retrieved from the Office of Energy Efficiency's Comprehensive Energy Use Database (OEE 2011). This information is available on a regional basis by industry, so the relative contribution of each type of industry to the overall energy consumption was calculated and multiplied by the total energy input to the Nova Scotian Industry sector from the Conversion sector (19.9 PJ) assuming that the same fractions apply to Nova Scotia and Atlantic Canada. The energy consumption of each part of the Industry sector is presented in Table 25. It is clear from this breakdown that the metal, cement, and chemical manufacturing industries do not use significant amounts of energy on their own and are therefore included in the analysis of other industries.

Table 25 - Energy consumption by industry, Atlantic figures converted to Nova Scotia figures (OEE 2011).

Industry	Atlantic Energy Use by Industry (PJ)	NS Energy Use by Industry (PJ)	Fraction
Pulp and paper manufacturing	87.7	14.1	0.71
Metal manufacturing	0.1	0.0	0.00
Cement manufacturing	1.4	0.2	0.01
Chemical manufacturing	1.2	0.2	0.01
Other	33.3	5.4	0.27
Total	**123.7**	**19.9**	**1.00**

In order to convert energy use to equivalent exergy use in the usual way, the relative contribution of each type of energy carrier to any particular end use must be known. Detailed statistics on energy use by end use and energy carrier are not available for the

Industry sector in Nova Scotia. It is assumed that the relative proportion of energy carriers input to the sector as a whole is the same for each individual industry. The total amount of energy input to the Industry sector is presented in Table 26. The fraction of each type of energy carrier relative to this total is presented in Figure 8. It is noted that the equivalent exergy content of steam is lower than the energy content. The exergy content depends on the temperature and quality of the steam, but no such information is available for this quantity. A value of β_{steam} = 0.34 for the conversion of energy to equivalent exergy is used according to the analysis of energy use by industry done by Ertesvåg and Mielnik in the exergy analysis of the Norwegian society (Ertesvåg and Mielnik 2000).

Table 26 - Total input energy and equivalent exergy input from Co-sector to In-sector.

Energy Carrier	Energy (PJ)	Exergy (PJ)
Coal	1.17	1.24
Natural gas	1.62	1.69
NGL	0.40	0.43
Electricity	11.18	11.18
Steam	1.26	0.45
Refined petroleum products	4.31	4.57
Total	**19.94**	**19.55**

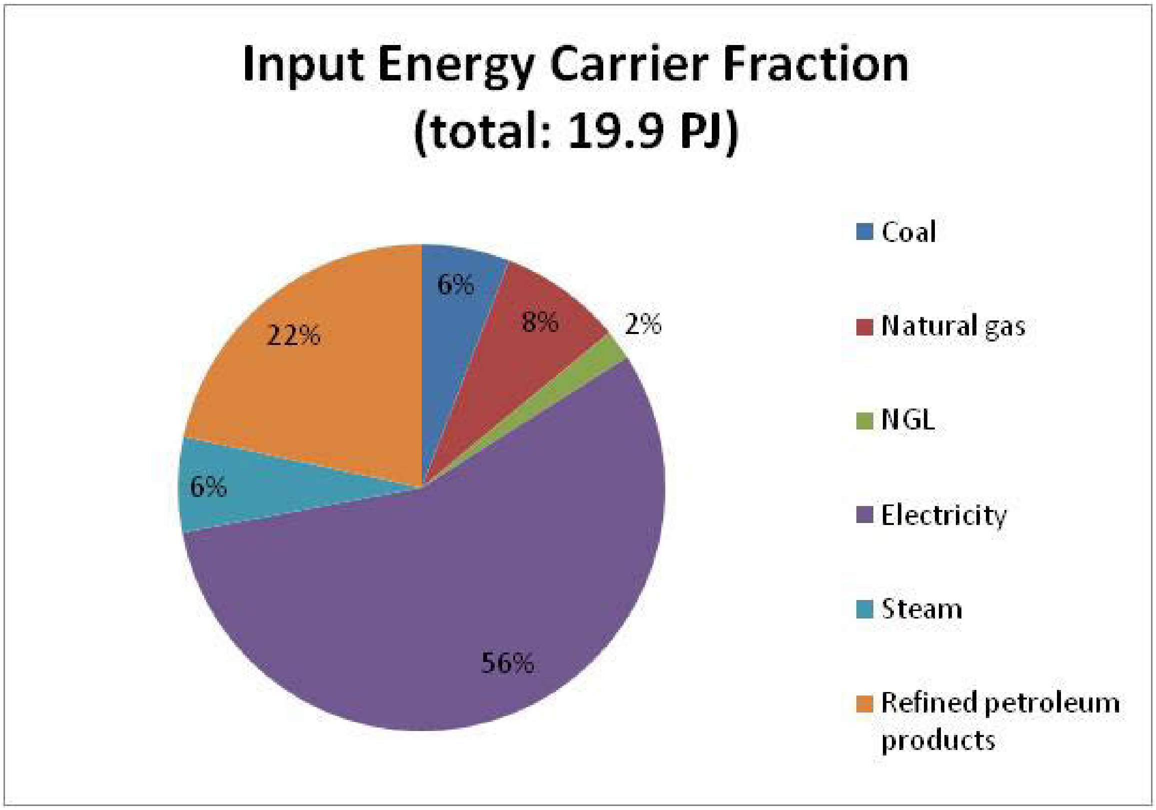

Figure 8 - Energy input to Industry sector by type of energy carrier.

Table 27 shows the resultant use of each energy carrier in PJ by industry according to the previously mentioned assumptions. The totals for each industry may not add up due to rounding.

Table 27 - Energy consumption (PJ) by industry and energy carrier, converted by relative fraction of input energy carrier.

Energy Carrier	Pulp and paper manufacturing	Other Industry
Coal	0.83	0.34
Natural gas	1.15	0.47
NGL	0.28	0.12
Electricity	7.91	3.26
Steam	0.89	0.37
Refined petroleum products	3.05	1.26

Energy Carrier	Pulp and paper manufacturing	Other Industry
Total	**14.10**	**5.82**

These energy figures are then converted to equivalent exergy values using the standard exergy factors and presented in Table 28. If data on the specific end use of each type of energy carrier were available it would be possible to calculate an exergy efficiency of each end use and obtain an exergy output for each quantity of energy carrier by end-use. In this way the output value of activities like space heating, lighting, and the use of motors could be quantified. This information is not available from Statistics Canada at this time; therefore the output exergy value of end-use activities is neglected in this work. However, from the analysis of industry in the UK (Gasparatos et al. 2009) and Norway (Ertesvåg 2005) their output value of is not expected to be above 15% of total input exergy.

Table 28 - Equivalent exergy consumption (PJ) by industry and energy carrier.

Energy Carrier	Pulp and paper manufacturing	Other Industry
Coal	0.88	0.36
Natural gas	1.19	0.49
NGL	0.30	0.13
Electricity	7.91	3.26
Steam	0.30	0.12
Refined petroleum products	3.23	1.33
Total	**13.81**	**5.70**

3.4.3 Exergy Fluxes into and out of the Industry Sector

The main inputs to this sector are natural resources from the Agriculture sector (wood for the wood, pulp and paper industries) and energy carriers. The main outputs of this sector are manufactured products to all other sectors.

Table 29 summarizes the exergy inputs and outputs of the Industry sector as a whole. The total input to this sector is 71.2 PJ energy and 74.6 PJ exergy. The total output of this sector is 64.8 PJ energy and 66.0 PJ exergy.

Table 29 – Energy and exergy balance sheet, Industry sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
R co,in	21.96	21.66	Energy carriers
R ex,in	-	0.03	Minerals
R a,in	-	0.02	Minerals imported
Natural Resources			
N ag,in	31.42	34.25	Wood
N a,in	9.23	9.85	Wood
Products			
P te,in	1.50	1.53	Recycled paper
P a,in	4.27	4.41	Metals, plastic
P tr,in	0.83	0.88	Cargo services
P te,in	1.95	1.95	Other recycled material
TOTAL INPUT	**71.16**	**74.58**	
OUTPUT			
Products			
P in,a	46.14	46.71	Metals, minerals, etc
P in,te	16.18	16.68	Diverted waste, products
P in,ag	0.57	0.59	Metals, minerals, etc
P in,ex	0.59	0.61	Metals, minerals, etc
P in,co	0.47	0.48	Metals, minerals, etc
P in,tr	0.91	0.94	Metals, minerals, etc
TOTAL OUTPUT	**64.85**	**66.00**	

3.5 The Transportation Sector in Nova Scotia

Under the EEA, the Transportation sector includes the shipping, trucking, air transport, pipeline, and warehousing industries, as well as those engaged in transporting passengers. This definition is consistent with that used by the NAICS, where the Transportation sector is defined as establishments primarily engaged in transporting passengers and goods by road, rail, water, and air, as well as pipelines, courier services, and warehousing and storage of goods (NS Finance 2006). Figure 9 presents the main activities of the Transportation sector, including the inputs and outputs and their origins and destinations.

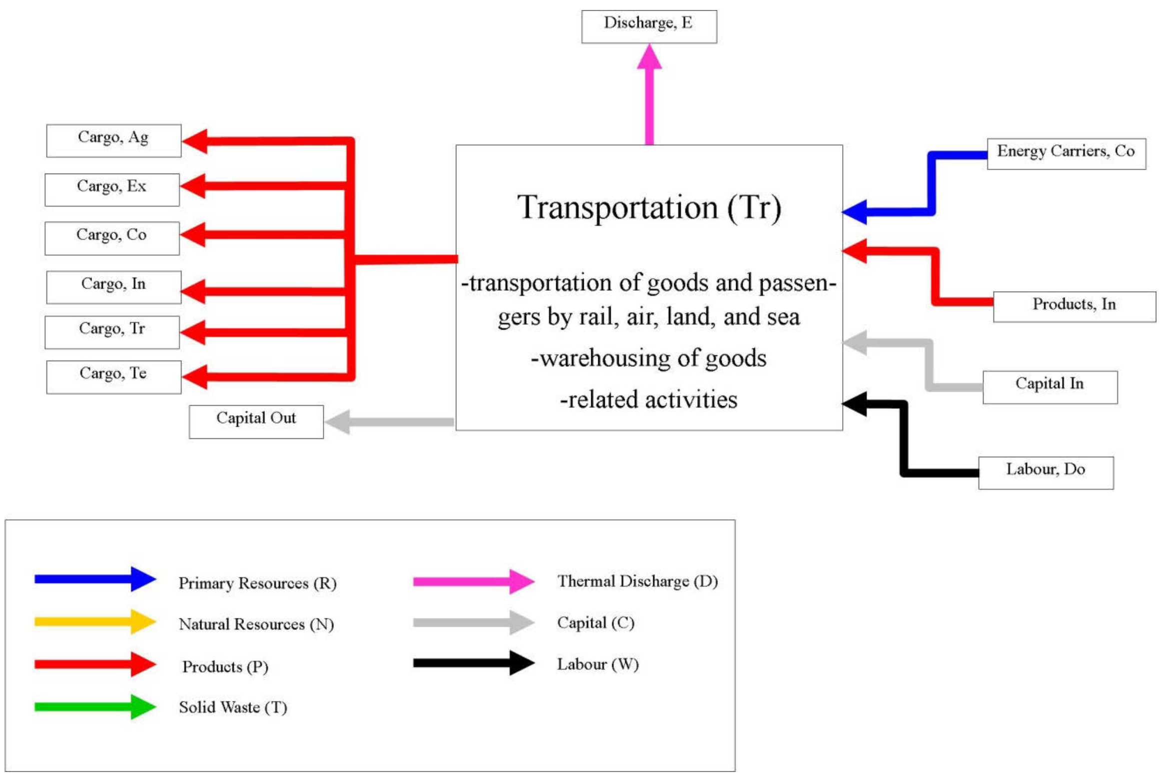

Figure 9 - Transportation Sector flux origins and destinations.

The total GDP of the Transportation sector in 2006 was $1,086.1 million, representing 4.2% of the total GDP of the province. Individual GDP contributions for all industries within the Transportation sector are unavailable at the provincial level for confidentiality reasons. From what is available, $258.3 million is attributed to the trucking industry and $584.8 million to the air, rail, water, and sightseeing industries, and support activities for transportation (NS Finance 2006). The remainder, $243 million can then be attributed to the remaining industries. Wages and salaries for the Transportation sector of $678.1 million represented 4.6% of the total wages and salaries in Nova Scotia (NS Finance 2006).

Road travel is the primary mode of transport in Nova Scotia for passengers and significant trucking activity facilitates trade with the rest of Canada and the United States. Roads and highways require major ongoing investments from the provincial and federal governments for maintenance and expansion. In 2006, the provincial government budgeted over $177 million in capital highway spending (NS Finance 2006). This spending paid for a variety of ongoing highway twinning projects and bridge upgrades and replacements.

There are numerous ports along the coast of Nova Scotia, including the large cargo ports at Halifax and the Strait of Canso. More than 38 million tons of cargo transited these two ports in 2006, in addition to the more than 100 cruise ships that visited Halifax and numerous car and passenger ferries at these and other ports around the province (NS Finance 2006).

Halifax International Airport is a regional hub for both cargo and passengers travelling within Canada and internationally. There are also two smaller airports located in Sydney and Yarmouth catering to passengers exclusively and several private airfields operated by clubs and serving private aircraft. 3.3 million people transited Nova Scotian airports in 2006, 3.2 million of them at Halifax, which also handled approximately 25,000 tonnes of cargo (NS Finance 2006).

There are over 800 kilometres of mainline railway track spread out across Nova Scotia (NS Finance 2006). In 2006, there were three federally regulated railways and two privately operated carriers under provincial jurisdiction. Most of the rail traffic was devoted to freight except for the VIA rail passenger service between Halifax and Montreal, with stops in Truro and Amherst.

3.5.1 Overall Exergy Efficiency of Transportation Services

The major useful output of the Transportation sector is the service of moving goods and passengers over a distance. The different modes of transport used within this sector are each associated with a first and a second law efficiency. The first law efficiency is defined as:

$$\eta = \frac{work}{energy\ input} \tag{1}$$

While the second law efficiency is defined as:

$$\psi = \frac{work}{exergy\ input} \tag{2}$$

Energy carriers have previously been assigned exergy factors (β) (See Table 14) for simple conversion from energy content to equivalent exergy. It follows that second law efficiency is also equivalent to:

$$\psi = \frac{\eta}{\beta} \tag{3}$$

Which is the first law efficiency divided by the exergy factor. In order to estimate the overall exergy output of the transportation services provided by the Transportation sector, a weighted mean overall exergy efficiency is calculated as (Ji 2006):

$$\psi_{overall} = \sum_{i,j}(\eta_i/\beta_j) \times Fr_{ij} \tag{4}$$

Where η_i is the exergy efficiency of the *i*th mode of transportation, β_j is the exergy factor of the *j*th energy carrier, and Fr_{ij} is the exergy fraction of the *j*th energy carrier used by the *i*th mode of transportation. Accordingly, Table 30 shows the consumption of energy carriers by mode of transportation measured in energy and equivalent exergy as well as the relative fraction of the consumed exergy (Energy Supply Demand 2006). The relative fraction of consumed exergy column is rounded; the exact numbers are used in the calculation of the overall exergy efficiency.

Table 30 - Consumption of energy carriers by mode of transportation.

Mode of Transport	**Fuel**	**Energy (TJ)**	**Exergy (TJ)**	**Fraction of total exergy consumption**
Cars	Gasoline	40.77	43.63	0.60

Mode of Transport	Fuel	Energy (TJ)	Exergy (TJ)	Fraction of total exergy consumption
	Diesel	5.42	5.74	0.08
Trucking	Gasoline	0.49	0.53	0.01
	Diesel	4.13	4.38	0.06
Marine	Diesel	4.39	4.66	0.06
	Heavy fuel oil	3.52	3.73	0.05
Aviation	Aviation turbofuel	8.49	9.09	0.12
Railroad	Diesel	1.33	1.41	0.02
Total		**68.55**	**73.16**	**1.00**

Table 31 shows estimated exergy efficiencies of the various modes of transportation, provided by Reistad (1975) for partially loaded vehicles in the United States in 1970. There have been significant improvements in the fuel economy of cars since 1970 as reported by the EIA, from approximately 14 mpg on average to 22 mpg (a 57% improvement) (EIA 2009) and the estimated operating efficiency has been updated to reflect that reality. The fuel economy of transport trucks has remained relatively unchanged over the same period (EIA 2009).

The fuel economy of aircraft has also improved significantly since the 1970's mainly due to advances in materials technology and load management, among other improvements (Peeters et al. 2005). The improvement in fuel economy is estimated at approximately 65% between 1971 and the early 2000's (Peeters et al. 2005), and the estimated operating efficiency used here has been updated to reflect that reality.

The fuel economy of marine modes of transportation has improved slightly since the 1970's due to changes in operating characteristics and trade patterns and improvements in engine construction (Endresen et al. 2007). The fuel economy improved over average sized fleets of ships by approximately 15% between the 1970 and the early 2000's (Endresen et al. 2007), and the estimated operating efficiency used here has been updated to reflect that change.

Mode of Transportation	Rated load efficiency	Estimated operating efficiency (1970)	Estimated operating efficiency (2006)
Cars	25%	15%	23.55%
Trucks	30%	25%	25%
Marine	-	15%	17.25%
Railroad	35%	28%	28%
Aviation	35%	28%	46.20%

Table 31 - Estimated exergy efficiencies for various modes of transportation (Reistad 1975).

The estimated operating efficiency is more representative of the reality of transport, as vehicles generally do not operate at their rated load. It is assumed that these efficiency estimates also apply to Canadian modes of transportation. Based on the data collected in Table 30 and Table 31, the overall exergy efficiency of the transportation services provided by the Transportation sector is calculated as:

$$\psi_{overall} = \left(\frac{23.5\%}{1.07}\right) \times 0.5963 + \left(\frac{23.5\%}{1.06}\right) \times 0.0785 + \left(\frac{25\%}{1.07}\right) \times 0.0072 + \left(\frac{25\%}{1.06}\right) \times 0.0599 + \left(\frac{17.5\%}{1.06}\right) \times 0.0636 + \left(\frac{17.5\%}{1.06}\right) \times 0.0510 + \left(\frac{28\%}{1.07}\right) \times 0.1242 + \left(\frac{46.2\%}{1.06}\right) \times 0.0193 = 22.40\% \quad (5)$$

As all of the fuels are refined petroleum products, exact exergy factors for gasoline (1.07), diesel (1.06), heavy fuel oil (1.06), and aviation turbofuel (1.07) are used rather than the generalized exergy factor of 1.06 assigned to refined petroleum products earlier in this work. The total exergy input to the Transportation sector that is used to provide transportation services is shown in Table 32.

Table 32 - Input of energy carriers to the Transportation sector from the Conversion sector (Energy Supply Demand 2007).

Energy Carrier	Energy (TJ)	Equivalent Exergy (PJ)
Natural gas	0.92	0.96
NGL	0.08	0.09
Electricity	0.02	0.02

Energy Carrier	Energy (TJ)	Equivalent Exergy (PJ)
Refined petroleum products	68.55	72.66[1]
Total	**69.58**	**73.73**

In addition to the refined petroleum products used to calculate the overall efficiency of the sector, there are also small amounts of natural gas, electricity, and propane transferred from the Conversion sector. As there is no listed mode of transportation consuming these energy carriers as fuels (Energy Supply Demand 2006), it is assumed that they are used within the Transportation sector in warehouses and support facilities for the purposes of heating, cooling, and lighting.

3.5.2 Exergy Fluxes Into and Out of the Transportation Sector

The overall exergy efficiency of the transportation services provided by the Transportation sector is multiplied by the total input of energy carriers used for that purpose to calculate the total equivalent exergetic output of transportation services:

$$22.40\% \times 73.16\ PJ = 16.39\ PJ \tag{6}$$

It is assumed that each sector of the economy requires transportation services, and that the share of transportation services used by each sector will correspond to its economic output, or GDP. The Domestic sector use of transportation services corresponds to the equivalent exergy fraction of refined petroleum products retailed at gas pumps for car transport and approximately 75% of air travel. The exergy output from the Transportation sector to all other sectors is summarized in Table 33. Some transportation services are consumed within the Transportation sector, amounting to approximately 1% of the total output.

Table 33 - Transportation service equivalent exergy output from the Tr-sector to all other economic sectors (TJ).

Services	Ag	Ex	Co	In	Te	Tr	Do	Total
Passengers	0.00	0.00	0.00	0.00	0.00	0.00	11.06	**11.06**

[1] This number differs slightly from the value in Table 30 due to rounding errors. The value in Table 30 is more precise so it is used in the calculation of the total equivalent exergetic output of transportation services.

Services	Ag	Ex	Co	In	Te	Tr	Do	Total
Cargo	0.14	0.14	0.11	0.88	3.83	0.22	0.00	**5.33**
Total	**0.14**	**0.14**	**0.11**	**0.88**	**3.83**	**0.22**	**11.06**	**16.39**

The main inputs to this sector are energy carriers (petroleum products like diesel, gasoline, fuel oils, and aircraft fuel) from the Conversion sector. The outputs of this sector are transportation services provided to all other sectors.

Table 34 summarizes the exergy inputs and outputs of the Transportation sector as a whole. The total input to this sector is 70.5 PJ energy and 74.7 PJ exergy. The total output of this sector is 15.24 PJ energy and 16.2 PJ exergy.

Table 34 – Energy and exergy balance sheet, Transportation sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
R co,tr	69.58	73.73	Energy carriers
Products			
P in,tr	0.91	0.94	Metals, minerals, etc
TOTAL INPUT	**70.48**	**74.67**	
OUTPUT			
Products			
P tr,ex	0.13	0.14	Cargo services
P tr,co	0.10	0.11	Cargo services
P tr,ag	0.13	0.14	Cargo services
P tr,in	0.83	0.88	Cargo services
P tr,te	3.61	3.83	Cargo services
P tr,do	10.44	11.06	Passenger services
TOTAL OUTPUT	**15.24**	**16.16**	

3.6 The Tertiary Sector in Nova Scotia

The Tertiary sector represents the largest share of the GDP of Nova Scotia at approximately 72%. This sector is made up of diverse economic activities, including wholesale, retail, finance, insurance, real estate, construction, public administration and institutions, and all other services that do not include transportation or industrial activities. Figure 10 presents the main activities of the Tertiary sector, including the inputs and outputs and their origins and destinations.

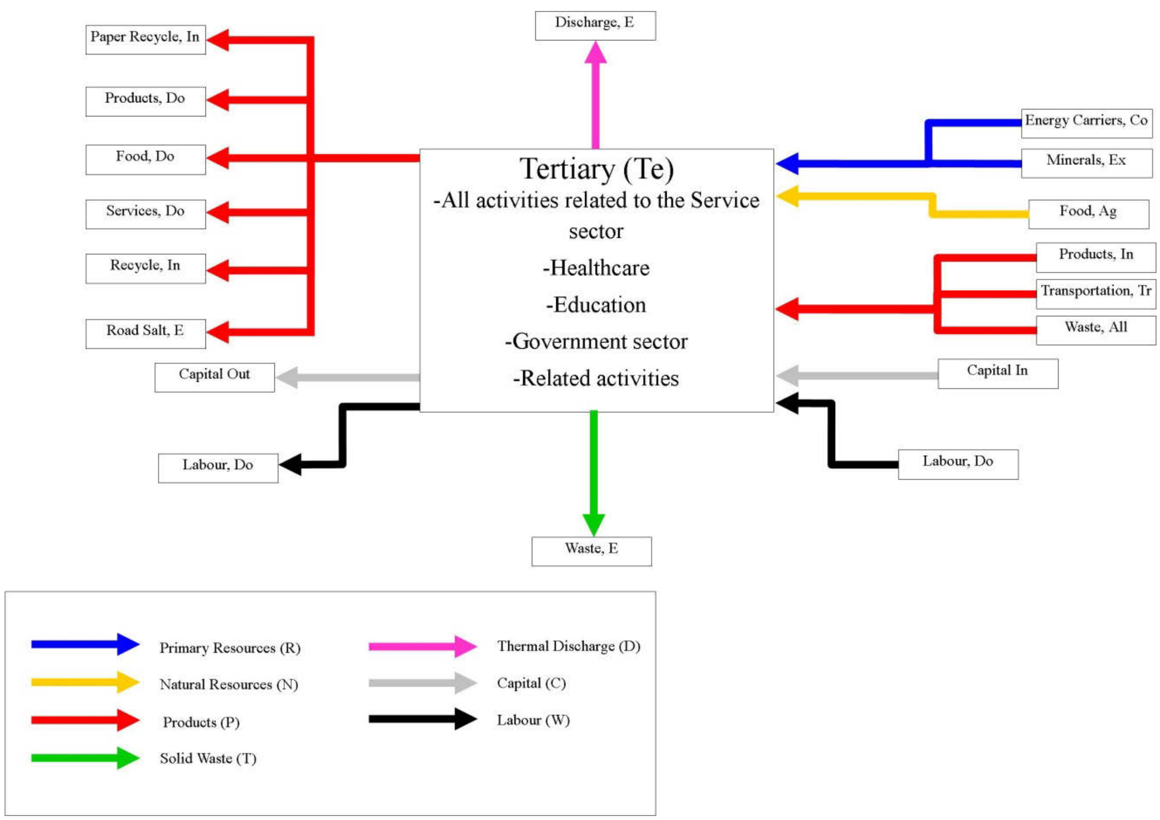

Figure 10 - Tertiary Sector flux origins and destinations.

The construction industry contributed $1,686 million to the total sector GDP of the sector total GDP $18,745 million and the FIRE sector (finance, insurance, and real estate) contributed the largest share at $5,399 million. Health care and social services contribute $2,236 million, education contributes $1,547 m illion, and public administration contributes $2,757 million. Wholesale and retail trade together contribute $2,916 million, and accommodation and food services, information and cultural industries, and professional, scientific, and technical services are also significant contributors to the overall GDP of this sector. (NS Finance 2007).

3.6.1 Tertiary Product Energy and Exergy Contents

The inputs and outputs of the Tertiary sector are dominated by labour and capital flows. However, there are quantifiable exchanges of materials and energy between this and other sectors. The Tertiary sector includes food service and retail establishments, so food imported and produced by the Agriculture sector is transferred to the Domestic sector via sale by the Tertiary sector. It is assumed that there is some loss and consumption in the transfer of food from Agriculture to Tertiary, estimated at 10% by Ertesvåg (2005). Other material inputs include asphalt from the Conversion sector to the construction industries, mineral products produced and imported by the Extraction sector, the products of industry, and diverted waste streams from all other sectors to the recycling industry. Diverted waste is collected by the Tertiary sector and transferred to the Industry sector for reprocessing. A loss of 10% between the gross input and output of diverted materials is estimated as suggested by Ertesvåg (2005). The equivalent exergy of all of these flows has been calculated in their respective originating sector.

As shown in Table 35, the input to the Tertiary sector from all energy carriers totaled 48.8 PJ of exergy (equivalent to 46.6 PJ of energy) (Energy Supply Demand 2007). The majority was contributed by electricity (11.4 PJ) and refined petroleum products (32.45 PJ). Natural gas and natural gas liquids made up the remainder. A summary of the energy carriers input to the Tertiary sector is given in Table 35.

Table 35 - Energy carriers input to the Tertiary sector from the Conversion sector (Energy Supply Demand 2007).

Category	Energy Carrier	Energy (PJ)	Exergy (PJ)	Fraction
Natural gas	Natural gas	0.40	0.42	0.01
NGL	Propane	2.33	2.52	0.05
Electricity	Electricity	11.39	11.39	0.23
Ref. petroleum products	Gasoline	1.98	2.12	0.04

Category	Energy Carrier	Energy (PJ)	Exergy (PJ)	Fraction
Ref. petroleum products	Kerosene	3.25	3.51	0.07
	Diesel	7.42	7.86	0.16
	Light fuel oil	15.07	15.97	0.33
	Heavy fuel oil	4.74	5.02	0.10
Total		**46.58**	**48.81**	**1.00**

These energy carriers are used in a variety of end-use applications within the sector. The precise end-uses of these energy carriers are not known for Nova Scotia, but data is available on the end-use of energy in the Tertiary sector for the whole of Canada (OEE 2011). It is assumed that the distribution of end-uses within the Tertiary sector of Nova Scotia is the same as the distribution of end-uses for the Tertiary sector of Canada. Table 36 shows this distribution and the resultant energy consumption for each activity.

Table 36 - Distribution of energy end-uses for Canada and Nova Scotia (OEE 2011), (Energy Supply Demand 2007).

End-Use	Canada Energy Use by End-Use (PJ)	Fraction	NS Energy Use by End-Use (PJ)	NS Exergy Use by End-Use (PJ)
Space heating	534.70	0.49	22.85	23.94
Water heating	98.20	0.09	4.20	4.40
Auxilary equipment	177.10	0.16	7.57	7.93
Auxilary motors	88.70	0.08	3.79	3.97
Lighting	108.30	0.10	4.63	4.85
Space cooling	74.80	0.07	3.20	3.35
Street lighting	8.30	0.01	0.35	0.37
Total	**1090.10**	**1.00**	**46.58**	**48.81**

There is value in providing services like space heating, hot water, and lighting to customers and employees of the service sector, patients and staff of hospitals, teachers and students in schools, and others. The equivalent exergy output of these activities for the Tertiary sector in Nova Scotia is estimated using end-use exergy efficiencies calculated by Gasparatos in the study of the UK economy (Gasparatos et al. 2009). This output is accounted for as a P-flux of services from the Tertiary sector to the Domestic sector. As the proportion of fuels used by the Nova Scotia for each end-use is different than that of the UK, a weighted average of exergy efficiencies is used to estimate the output of exergy from the use of energy carriers. The calculated exergy efficiencies of end-use activities for the Tertiary sector of the UK are shown in Table 37.

Table 37 - Exergy efficiency of end-use activities, UK Tertiary sector 2008 (Gasparatos et al. 2009).

End-Use	UK Exergy Efficiency (%)
Space heating and cooling	**6.40**
Electricity	6.50
Ref. petroleum products	5.70
Natural gas	6.40
Water heating	**7.00**
Electricity	8.10
Ref. petroleum products	3.50
Appliances	**18.50**
Electricity	18.50
Total	**12.30**

The end use activities of the Tertiary sector in Nova Scotia listed in Table 36 are aggregated to the classifications used in the study of the UK (Gasparatos et al. 2009) in Table 38.

Table 38 - Aggregated end-use activites, Nova Scotia Tertiary sector 2006.

Aggregated end use activity	Energy (PJ)	Exergy (PJ)	Fraction
Space heating and cooling	26.04	27.29	0.56
Water heating	4.20	4.40	0.09
Appliances	16.34	17.12	0.35

Considering the magnitude of exergy involved in these end-use activities, the exergy efficiencies reported in Table 37, though they do not accurately reflect the distribution of fuels used in Nova Scotia, are used here. The exergy output of appliances is calculated as:

$$18.5\% \times 17.12\ PJ = 3.1\ PJ \quad (1)$$

The exergy output of water heating is calculated as:

$$7\% \times 4.4\ PJ = 0.3\ PJ \quad (2)$$

The exergy output of space heating and cooling is calculated as:

$$6.4\% \times 27.29\ PJ = 1.7\ PJ \quad (3)$$

And the total exergy output to the Domestic sector from services provided by the Tertiary sector is 5.1 PJ.

3.6.2 Exergy Fluxes into and out of the Tertiary Sector

The main inputs to this sector are energy carriers from the Conversion sector, food from the Agriculture sector, and products from all sectors and the Industry sector in particular. The outputs of this sector are products transferred to the Domestic sector and diverted waste recycled to the Industry sector.

Table 39 summarizes the exergy inputs and outputs of the Tertiary sector as a whole. The total input to this sector is 68.5 PJ energy and 71.8 PJ exergy. The total output of this sector is 14.2 PJ energy and 14.6 PJ exergy.

Table 39 - Energy and exergy balance sheet for the Tertiary sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
R co,te	46.58	48.73	Energy carriers
R ex,te	-	0.48	Minerals
Natural Resources			
N ag,te	1.46	1.46	Food
Products			
P tr,te	3.61	3.83	Cargo services
P in,te	15.68	16.18	Diverted waste, products
P ex,te	0.02	0.02	Diverted waste
P ag,te	0.02	0.02	Diverted waste
P co,te	0.02	0.02	Diverted waste
P do,te	1.09	1.09	Diverted waste
TOTAL INPUT	**68.47**	**71.82**	
OUTPUT			
Products			
P te,in	1.50	1.53	Recycled paper
P te,do	4.59	4.74	Industry products
P te,do	1.31	1.31	Food
P te,do	4.81	5.05	Energy by services
P te,in	1.95	1.95	Other recycled material
P te,e	-	0.03	Road salt
TOTAL OUTPUT	**14.16**	**14.60**	

3.7 The Domestic Sector in Nova Scotia

Under the EEA, the Domestic sector includes all of the households physically located in Nova Scotia. The main inputs of this sector are energy carriers from the Conversion sector and services and products from the Tertiary sector. The main output of this sector is labour to all other sectors. Figure 11 presents the main activities of the Domestic sector, including the inputs and outputs and their origins and destinations.

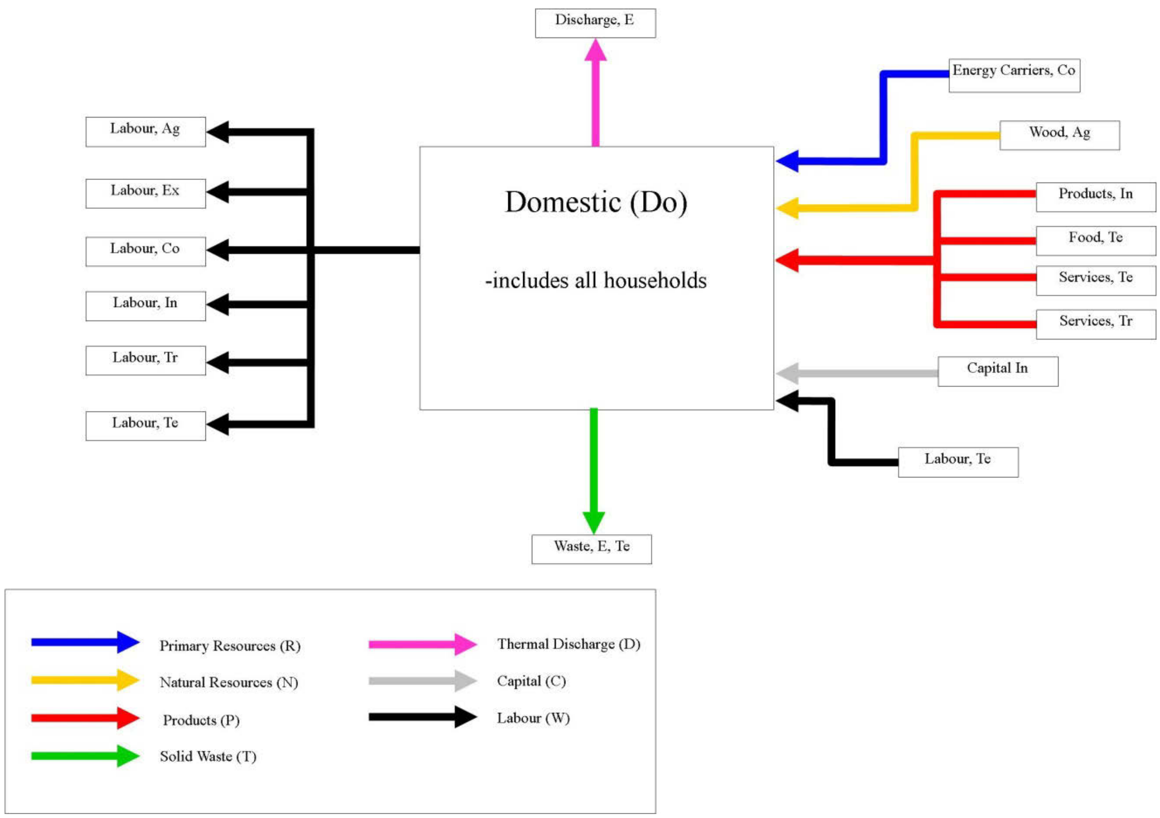

Figure 11 - Domestic Sector flux origins and destinations.

3.7.1 Exergy Fluxes into and out of the Domestic Sector

The main inputs to this sector are energy carriers from the Conversion sector, food from the Tertiary sector, and products from the Tertiary sector and Transportation sector. The output of this sector is only diverted waste for recycling.

Table 40 summarizes the exergy inputs and outputs of the Domestic sector as a whole. The total input to this sector is 48.3 PJ energy and 50.1 PJ exergy. The total output of this sector is 1.1 PJ of energy and the same of exergy.

Table 40 – Energy and exergy balance sheet for the Domestic sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
INPUT			
Resources			
R co,do	27.01	27.79	Energy carriers
Natural Resources			
N ag,do	0.15	0.16	Wood
Products			
P te,do	4.59	4.74	Industry products
P te,do	1.31	1.31	Food
P te,do	4.81	5.05	Energy by services
P tr,do	10.44	11.06	Passenger services
TOTAL INPUT	**48.31**	**50.10**	
OUTPUT			
Products			
P do,te	1.09	1.09	Diverted waste
TOTAL OUTPUT	**1.09**	**1.09**	

Chapter 4: Extended Exergy Analysis

4.1 Waste and Atmospheric Emissions

Most materials eventually end up as waste in one form or another. In Nova Scotia the majority of solid waste is deposited in landfills, while a significant minority (approximately 40%) is diverted for recycling purposes. Atmospheric emissions are regulated and monitored by Environment Canada. Since the available data is limited, in order to make a reasonable estimate of the waste generated by each sector of the Nova Scotian economy, a number of assumptions are made about the composition and sources of waste. These assumptions are explained in detail in the following section, but the resulting numbers should be used with caution. As the monitoring and auditing of waste streams improves, the information gathered will become easier to analyze.

4.1.1 Solid Waste

Detailed information on the source and destination of waste streams is not available at the Provincial level for any period of time. The total amount of waste (in tonnes) generated in Nova Scotia in 2006 is known, as well as the fractions of this waste that are either disposed of in public or private waste disposal facilities (deposited in the environment), or diverted to recycling facilities (HAAE 2009). This information can be found in Table 41 on a per capita and absolute basis.

Table 41 - Destination of waste streams (HAAE 2009).

Waste Stream	kg Per Capita	Total (tonnes)
Waste Disposed	428.2	401,670
Waste Diverted	294.2	275,983
Total Waste Generated	**722.4**	**677,653**

The sources of this waste are reported as either residential, construction and demolition waste, or a mixture of industrial, commercial, and institutional (HAAE 2009). Table 42 shows the amounts of waste reported by each of these sources for 2006.

Table 42 - Diverted and disposed waste by reporting source (tonnes) (HAAE 2009).

Sector	Diverted (tonnes)	Disposed (tonnes)
Residential	138,869	169,337
Industrial, Commercial, Institutional	85,851	185,867
Construction and Demolition	51,263	46,466
All Sources	**275,983**	**401,670**

For the purposes of this work, the full amount of residential waste is attributed to the Domestic sector. Waste reported from industrial, commercial, and institutional sources is divided among the Agriculture, Conversion, Industry, Tertiary, and Extraction sectors according to their relative share of GDP for the year 2006. Construction and demolition waste is attributed in full to the Tertiary sector in the fifth column, after the remaining waste is distributed between all of the sectors. Table 43 shows the relative share of diverted and disposed waste for each sector excluding the Domestic sector.

Table 43 - Waste disposal and diversion by sector according to relative share of GDP 2006.

Sector	GDP 2006 (millions $)	Fraction	Diverted by fraction (tonnes)	Total Diverted (tonnes)	Disposed (tonnes)
Agriculture	684.4	2.74%	2,351	2,351	5,089
Extraction	704.2	2.82%	2,419	2,419	5,237
Conversion	557.3	2.23%	1,914	1,914	4,144
Industry	4302.9	17.22%	14,780	14,780	78,464
Tertiary	18745.4	75%	64,387	115,650	139,398
Total	**24994.2**	**100%**	**85,851**	**137,114**	**232,333**

Also available is information on the relative composition of the diverted portion of this waste (HAAE 2009). Nova Scotia has the highest waste diversion rate in Canada, at 40.7% for 2006 (HAAE 2009). Due to a lack of detailed information on disposed waste, it is assumed that the composition of the disposed waste is the same as the composition of the diverted waste. The relative fraction of each diverted material is multiplied by the amount of disposed waste attributed to each sector to assign specific amounts of materials to the waste stream of each sector. Construction renovation, and demolition waste is attributed in full to the Industry sector. Table 44 shows the relative fraction of each material in the diverted waste stream.

Table 44 - Relative fractions of specific materials in the diverted waste stream.

Type of Waste	Diverted (tonnes)	Fraction
Newsprint	33,128	0.15
Cardboard/Boxboard	31,373	0.14
Mixed paper	8,592	0.04
Glass	1,511	0.01
Ferrous metals	2,962	0.01
Copper/Aluminum	x	-
Mixed metals	x	-
White goods	4,700	0.02
Electronics	0	0.00
Plastics	4,540	0.02
Tires	x	-
Organics	133,934	0.60
Other	1,808	0.01
Total	**275,983**	**1.00**

The equivalent exergies of solid waste fluxes are assumed to be equivalent to their respective LHVs (Sciubba 2008). The LHV of each type of waste is calculated from data in the PHYLLIS Database (PHYLLIS 2011). The net calorific values of newsprint, cardboard, mixed paper, and plastics are available as dry LHVs. The "Other" category of waste is assumed to be made up of textiles (as they were not otherwise listed) and assigned a general exergy value of 15 PJ/Mton. The equivalent exergies of glass and ferrous metals are calculated from Szargut (1988). Glass is approximated as consisting entirely of SiO_2 and ferrous metals are assumed to have the same standard chemical exergy of Fe. W hite goods, which refers to consumer appliances such as stoves, refrigerators, and air conditioners, are approximated as largely consisting of metal and assigned a general exergy value of 7.0 PJ/Mton (Ertesvåg 2005). Organic materials make up approximately half of all solid waste. These materials have high water contents (>50%) and are not listed in the PHYLLIS Database, making the estimation of a LHV difficult. It was assumed that these materials contain some exergy, and a v alue of 2 PJ/Mton is assigned as suggested by Ertesvåg (2005). Table 45 and Table 46 show the resultant equivalent exergy values for each type of solid waste by sector for the diverted and disposed waste streams respectively.

Table 45 - Equivalent exergy of diverted solid waste by material and sector.

Diverted Solid Waste (PJ)	**Ex**	**Co**	**Ag**	**In**	**Te**	**Do**	**Total**
Newsprint	0.01	0.01	0.01	0.04	0.31	0.37	0.74
Cardboard	0.01	0.01	0.00	0.03	0.25	0.30	0.60
Mixed paper	0.00	0.00	0.00	0.01	0.06	0.08	0.15
Glass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferrous metals	0.00	0.00	0.00	0.00	0.01	0.01	0.02
White goods	0.00	0.00	0.00	0.00	0.02	0.02	0.04
Plastics	0.00	0.00	0.00	0.01	0.10	0.12	0.25
Organics	0.00	0.00	0.00	0.02	0.14	0.17	0.33
Other	0.00	0.00	0.00	0.00	0.01	0.02	0.03
Total	**0.02**	**0.02**	**0.02**	**0.12**	**0.91**	**1.09**	2.17
Fraction	**0.8%**	**0.9%**	**0.7%**	**5.4%**	**41.9%**	**50.3%**	**100%**

Table 46 - Equivalent exergy of disposed solid waste by material and sector.

Disposed Solid Waste (PJ)	**Ex**	**Co**	**Ag**	**In**	**Te**	**Do**	**Total**
Newsprint	0.01	0.01	0.01	0.09	0.50	0.46	1.08
Cardboard	0.01	0.01	0.01	0.07	0.41	0.37	0.88
Mixed paper	0.00	0.00	0.00	0.02	0.10	0.09	0.22
Glass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferrous metals	0.00	0.00	0.00	0.00	0.02	0.02	0.04
White goods	0.00	0.00	0.00	0.00	0.03	0.02	0.06

Disposed Solid Waste (PJ)	**Ex**	**Co**	**Ag**	**In**	**Te**	**Do**	**Total**
Plastics	0.00	0.00	0.00	0.03	0.17	0.15	0.36
Organics	0.01	0.00	0.01	0.04	0.22	0.20	0.48
Other	0.00	0.00	0.00	0.00	0.02	0.02	0.05
Total	**0.04**	**0.03**	**0.04**	**0.25**	**1.46**	**1.33**	**3.16**
Fraction	**1.3%**	**1.0%**	**1.3%**	**7.9%**	**46.3%**	**42.2%**	**100%**

Diverted waste is accounted for under the EEA as a P-flux from the relevant sector to the Tertiary sector, while disposed waste is assumed to be deposited in the environment whether in a municipal landfill or treated and deposited in the ocean. The newsprint, cardboard, and mixed paper streams are assumed to be transferred to the Industry sector to be reprocessed by the pulp and paper industry. Disposed waste is accounted for under the EEA as a T-flux from the relevant sector to the environment. Each flux relating to solid waste is included in the balance sheet of the relevant sector as either an output P-flux to the Tertiary sector or and output T-flux to the environment. The balance sheet of Tertiary sector records each solid waste P-flux as an input.

As shown in Table 45, the total amount of waste deposited in the environment results in an equivalent exergy value of 3.2 PJ. 42% of this is generated in the Domestic sector, while the Tertiary sector generates 46% and the Industry sector generates 8% of the total. As shown in Table 46, the total amount of waste diverted to the Tertiary sector results in an equivalent exergy value of 2.2 PJ. Again, half of this is generated in the Domestic Sector, while the Tertiary sector generates 42% and the Industry sector generates 5%. The diverted waste that is generated within the Tertiary sector is not accounted for under the EEA as it is not transferred between two sectors.

4.1.2 Atmospheric Emissions

Detailed information on criteria air contaminants (such as NO_x, SO_x, and CO) is not available at the provincial level for the year 2006. The earliest available dataset is from 2009, so all of the information relating to pollutants other than greenhouse gases is from that year. Detailed information on greenhouse gases (CO_2, CH_4, and N_2O) is available from the Environment Canada National Pollutant Release Inventory (NPRI 2011) at the provincial level for 2006. Within the NPRI, criteria air contaminants are classified by source and measured in either tonnes or kg.

Included in the NPRI are estimates for the amount of particulate matter released each year, classified by particle size. The largest single source of particulate matter in Nova Scotia is dust from unpaved roads, making identification of the composition difficult. These contaminants are neglected in this work due to a lack of information on their specific composition. Sulphur oxides and nitrogen oxides are recorded generally as SO_x and NO_x. For the purposes of this work, these quantities are assumed to be entirely composed of SO_2 and NO_2 respectively. Similarly, volatile organic chemicals are recorded generally as VOC. For the purposes of this work, and in order to prevent an over-estimation of the contribution of this pollutant, the quantity of VOC is assumed to be entirely composed of acetone (C_3H_6O), which has a relatively low value of specific exergy.

The equivalent exergy of each pollutant is computed from specific chemical exergy values found in Szargut (1988) (see Appendix A). The organic molecules Benzo(a)pyrene, Benzo(*b*)fluoranthene, Benzo(*k*)fluoranthene, and Indeno(1,2,3-C,D)Pyrene are not listed as common compounds, so a specific exergy value for each is computed by adding the group contribution of standard chemical exergy of each type of bond that makes up these four compounds (see Appendix B). The structure of each molecule is found in the NIST Standard Reference Database (NIST 2011). Amounts of each pollutant are aggregated from the NPRI according to sector and converted to equivalent exergy. The results of these calculations are given in Table 47.

Table 47 - Equivalent exergy of atmospheric emissions by pollutant and sector (TJ).

Atmospheric Emissions By Sector (TJ)	**Ex**	**Co**	**Ag**	**In**	**Te**	**Tr**	**Do**	**Total**
SO_x	0.9	515.1	0.7	12.0	17.2	81.5	5.3	632.7
NO_x	1.1	22.9	0.2	2.4	1.3	50.7	1.8	80.4
VOC	29.2	73.1	68.2	76.5	371.6	413.7	260.5	1292.9

Atmospheric Emissions By Sector (TJ)	**Ex**	**Co**	**Ag**	**In**	**Te**	**Tr**	**Do**	**Total**
CO	2.0	20.7	2.2	20.9	2.19	1789.4	356.2	2193.8
NH_3	0.2	0.0	66.3	1.0	1.4	12.9	1.8	83.6
Pb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benzo(a)pyrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benzo(*b*)fluoranthene	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Benzo(*k*)fluoranthene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indeno(1,2,3-C,D)Pyrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greenhouse Gases (CO_2, CH_4, N_2O)	43.8	4352	221	396	1020	2569	478	9079
Total	**77**	**4984**	**359**	**509**	**1413**	**4917**	**1103**	**13362**
Fraction	**1%**	**37%**	**3%**	**4%**	**11%**	**37%**	**8%**	**100.0%**

Atmospheric emissions are accounted for under the EEA as D-fluxes from the relevant sector to the environment. Each flux relating to emissions is included in the balance sheet of the generating sector as a D-flux to the environment. D-fluxes have been placed on the Input side of the generating sector's balance sheet to reflect the fact that these compounds represent a cost to that sector.

The total amount of atmospheric emissions output to the environment results in an equivalent exergy value of 13.4 P J. The Transportation and Conversion sectors both generate around 37% of this total, while the Tertiary and Domestic sectors generate around 10% each. The Extraction, Agriculture, and Industry sectors each generate much smaller amounts to make up the balance.

4.2 Capital

The flux of capital from the Domestic sector to each of the other sectors is taken as the sum of the value of production (Input Output 2006), net subsidies (Input Output 2006), and depreciation (where available) (CANSIM(b) 2011). The value of production represents the total value of products output to all other sectors including exports. The net subsidies represent any financial support provided by any level of government. Depreciation (or the degradation of fixed capital) represents the renewal cost of capital assets or the value lost by any given sector, which under the EEA is analogous to a destruction of exergy. Table 48 shows the capital flux input to each sector from the Domestic sector. Cells marked with an “x” indicate that the information for that sector is unavailable due to the restrictions of the Privacy Act.

Table 48 - Capital input to each sector from the Domestic sector, current (2006) millions of dollars (Input Output 2006).

Sector	Value of production	Subsidies	Depreciation	Total
Extraction	1,708.7	64.6	x	1,773.3
Conversion	1,014.0	0.0	x	1,014.0
Agriculture	1,522.8	17.3	115.8	1,655.9
Industry	9,667.4	14.0	497.1	10,178.5
Transportation	3,160.7	74.1	x	3,234.8
Tertiary	40,796.4	142.6	1,652.4	42,591.4

The flux of capital from each sector into the Domestic sector was taken as the sum of the intermediate consumption of products and services by that sector (Input Output 2006), compensation of employees (Input Output 2006), net product taxes (Input Output 2006), return on investment to owners or other operating surplus (Input Output 2006), and any capital expenditures (CANSIM(a) 2011). Normally in economic analysis employees and owners are regarded as a part of the sector; in this work they are regarded to be a part of the Domestic sector, and accordingly all compensation flows from the originating sector to the Domestic sector. Table 49 shows the capital flux output of every sector to the Domestic sector.

Table 49 - Capital output from every sector to the Domestic sector, current (2006) millions of dollars (Input Output 2006).

Sector	Consump.	Taxes	Compensation	Other Op. Surplus	Capital Exp.	Total
Extraction	376.9	8.8	157.9	1,229.7	706.0	2,479.3
Conversion	421.1	53.1	132.8	407.0	x	1,014.0
Agriculture	818.9	34.7	482.3	204.2	258.7	1,798.8
Industry	7,005.2	54.0	1,707.5	914.7	668.8	10,350.2
Transportation	2,144.9	82.2	814.9	192.8	465.8	3,700.6
Tertiary	7,191.9	1,320.4	15,826.6	16,600.1	2,896.1	43,835.1

The equivalent exergy (E_C) of any given capital flux (C_{in}) is calculated by multiplying by the exergy influx to the entire economy (E_{in}) divided by the reference amount of money (C_{ref}):

$$E_C = C_{in} * \frac{E_{in}}{C_{ref}} \quad (1)$$

In previous extended exergy analyses done for Norway (Ertesvåg 2005), UK (Gasparatos et al. 2009), China (Chen 2009), and the province of Siena, Italy (Sciubba 2008), the reference amount of money used was the quantity M2, or broad money, which is the amount of currency in circulation outside of banks, plus bank personal deposits and non-personal demand and notice deposits (Bank of Canada 2009). It is not possible to use a precise value of this measure for the analysis of the Nova Scotian economy as it is not calculated or published for Nova Scotia by any entity. A value of M2 for Nova Scotia was estimated by multiplying the median of the 12 monthly values of M2 for 2006 for all of Canada (CANSIM(d) 2011) by the share of Nova Scotia's GDP relative to the total Canadian GDP (NS Finance 2007).

$$699{,}262.5\ million\ \$ \times 2.2\% = 15{,}256.06\ million\ \$ \quad (2)$$

The net exergy input to the Nova Scotian economy in 2006 is taken as the sum of all fluxes originating in either the environment or abroad (extracted, harvested, or imported) minus the total exports. This value is calculated as 316.01PJ; an account of these fluxes is given in Table 50. These fluxes are taken directly from the exergy balance sheets found in the preceding chapter for each sector.

Table 50 - Gross inputs and outputs to Nova Scotian economy 2006, calculated net input.

Fluxes	Energy (PJ)	Exergy (PJ)	Comments
R e,ex	0.01	0.01	Domestic coal production
R e,ex	26.75	28.89	Domestic oil production
R e,ex	140.58	146.20	Domestic NG production
R e,ex	-	0.89	Domestic minerals production
R e,co	4.31	4.31	Waterfall energy
N e,ag	38.23	41.67	Wood
N e,ag	5.62	5.62	Harvest
N e,ag	1.04	1.04	Fish
N a,ag	0.15	0.15	Food imports
N a,in	9.23	9.85	Wood
P a,in	4.27	4.41	Metals, plastic
R a,in	-	0.02	Minerals imported
R a,ex	75.75	80.30	Imported coal
R a,ex	172.85	186.67	Imported oil
R ex,a	10.18	10.99	Exported oil
R ex,a	130.50	135.72	Exported NG
R ex,a	-	0.38	Minerals exported
P in,a	46.14	46.71	Metals, minerals, etc
N ag,a	0.22	0.22	Food exports
EXTRACTED	**216.54**	**228.63**	
IMPORTED	**262.25**	**281.41**	
EXPORTED	**187.03**	**194.02**	
NET INPUT	**291.76**	**316.01**	

The exergy value of money in the Nova Scotian economy for 2006 is then calculated as:

$$316.01\ PJ\ \div 15{,}256.06\ million\ \$ = 20.71\ MJ/\$ \quad (3)$$

Which is close to the value designated by Sciubba (2008) for the province of Siena, Italy (18.18 MJ/USD). The capital inputs and outputs of each sector are converted to equivalent exergy using equation 1 and are presented in Table 51. These fluxes are included in the balance sheet for each sector under the Extended Exergy column.

Table 51 - Exergetic equivalents of capital flows for each sector of the economy (PJ).

Sector	Capital Input (PJ)	Capital Output (PJ)
Extraction	36.73	51.36
Conversion	21.00	21.00
Agriculture	34.30	37.26
Industry	210.84	214.39
Transportation	67.01	76.65
Tertiary	882.24	908.00
Domestic	396.09	-

4.3 Labour

Labour is considered to be an output from the Domestic sector to all other sectors. Labour statistics are recorded by Statistics Canada in terms of total hours worked for all jobs. The number of hours worked in all jobs is an estimate based on the annual average work hours for any given job and the average number of jobs in any given sector. This estimate includes the total number of hours that a person spends working whether paid or not. Regular and overtime hours, travel time, breaks, training, and brief work stoppage where workers do not leave their post are all included in this estimate (Statistics Canada 2011c). This estimate does not include time lost due to strikes, lockouts, or other long-term work stoppages, vacations or public holidays, or any type of leave, including maternity leave, sick leave, or leave for personal reasons (Statistics Canada 2011c). The total number of hours worked for all sectors in 2006 was 777.5 million hours. Table 52 shows the total number of hours worked by sector.

Table 52 - Total number of hours worked by sector (in thousands of hours) (CANSIM(c) 2011).

Sector	Hours (x1000)	Fraction
Extraction	6,102	0.01
Conversion	5,515	0.01
Agriculture	30,335	0.04
Industry	80,239	0.10
Transportation	40,809	0.05
Tertiary	614,456	0.79
Total	**777,456**	**1**

A major output of the Tertiary sector is labour associated with services. This labour is considered to be input to the Domestic sector in the form of food and accommodation services, health care and social assistance, education, arts, entertainment, and recreation services, information and cultural services, and public administration. The sum total of hours worked in these industries is approximately 45% of the total hours worked in the Tertiary sector. Table 53 shows the hours worked by industry for this labour output of the Tertiary sector.

Table 53 - Labour hours output from the Tertiary sector to the Domestic sector (in thousands of hours) (CANSIM(c) 2011).

Industry	Hours (x1000)
Health care and social assistance	80,758
Accommodation and food services	48,902
Arts, entertainment and recreation	13,906
Public administration	69,637
Information and cultural industries	14,580
Education services	44,049
Total	**271,832**

The equivalent exergy (E_W) of any given labour flux (W_{in}) is calculated by multiplying by the exergy influx to the entire economy (E_{in}) divided by the total number of work hours generated by the Domestic sector and input to all other sectors (W_{ref}) (Table 52):

$$E_W = W_{in} * \frac{E_{in}}{W_{ref}} \quad (1)$$

The same value of total exergy input to the Nova Scotian economy for 2006 is used for the calculation of the exergy value of labour as was used for the calculation of the exergy value of capital. The calculation of the exergy value of labour for the Nova Scotian economy in 2006 is then calculated as:

$$316.01\ PJ \div 777{,}456{,}000\ hours = 406.5\ MJ/hour \quad (2)$$

The labour inputs and outputs for each sector are converted to equivalent exergy using equation 1 and are presented in Table 54. These fluxes are included in the balance sheet for each sector under the Extended Exergy column.

Table 54 - Exergetic equivalents of labour flows for each sector of the economy.

Sector	Labour Input (PJ)	Labour Output (PJ)
Extraction	2.48	-
Conversion	2.24	-

Sector	Labour Input (PJ)	Labour Output (PJ)
Agriculture	12.33	-
Industry	32.61	-
Transportation	16.59	-
Tertiary	249.76	110.49
Domestic	110.49	316.01

4.4 Results of the Extended Exergy Analysis

4.4.1 Energy, Exergy, and Extended Exergy Balance Sheets

The following seven tables summarize the energy, exergy, and extended exergy input and output fluxes for each sector of the economy. Efficiency is calculated as the ratio of output value to input value for each of energy, exergy and extended exergy.

Table 55 - Energy, exergy, and extended exergy balance sheet for the Agriculture sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R co,ag	3.47	3.67	3.67	Energy carriers
Natural Resources				
N e,ag	38.23	41.67	41.67	Wood
N e,ag	5.62	5.62	5.62	Harvest
N e,ag	1.04	1.04	1.04	Fish
N a,ag	0.25	0.25	0.25	Harvest, fish imports
Products				
P tr,ag	0.13	0.14	0.14	Cargo services
P in,ag	0.57	0.59	0.59	Metals, minerals, etc
Discharges				
D ag,e		0.36	0.36	Atmospheric emissions
Work				
W do,ag			12.33	Labour
Capital			34.30	Capital

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
TOTAL INPUT	**49.31**	**53.34**	**99.97**	
OUTPUT				
Natural Resources				
N ag,in	31.42	34.25	34.25	Wood
N ag,do	0.15	0.16	0.16	Wood
N ag,te	2.30	2.30	2.30	Food, forest products
N ag,a	0.25	0.25	0.25	Harvest, fish, wood exports
Products				
P ag,te	0.02	0.02	0.02	Diverted waste
Waste				
T ag,e	0.04	0.04	0.04	Disposed waste
Capital			37.26	Capital
TOTAL OUTPUT	**34.17**	**37.01**	**74.27**	
Efficiency	**69%**	**69%**	**74%**	

Table 56 - Energy, exergy, and extended exergy balance sheet for the Extraction sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R e,ex	0.01	0.01	0.01	Domestic coal production
R a,ex	75.75	80.30	80.30	Imported coal
R e,ex	26.75	28.89	28.89	Domestic oil production
R a,ex	172.85	186.67	186.67	Imported oil
R e,ex	140.58	146.20	146.20	Domestic NG production

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
R co,ex	0.15	0.15	0.15	Electricity
R e,ex	-	0.89	0.89	Domestic minerals production
R co,ex	2.43	2.58	2.58	Refined petroleum products
R co,ex	0.04	0.04	0.04	NGL
Products				
P tr,ex	0.13	0.14	0.14	Cargo services
P in,ex	0.59	0.61	0.61	Industry products
Discharges				
D ex,e	5.48	5.70	5.70	Flared gas
D ex,e		0.08	0.08	Atmospheric Emissions
Work				
W do,ex			2.48	Labour
Capital			36.73	Capital
TOTAL INPUT	**424.75**	**452.25**	**491.46**	
OUTPUT				
Resources				
R ex,co	75.75	80.30	80.30	Coal to Conversion
R ex,a	10.18	10.99	10.99	Exported oil
R ex,co	189.42	204.57	204.57	Oil to conversion
R ex,a	130.50	135.72	135.72	Exported NG
R ex,co	6.15	6.39	6.39	NG to conversion sector
R ex,in	-	0.03	0.03	Minerals to industrial sector
R ex,a	-	0.38	0.38	Minerals exported
R ex,te	-	0.48	0.48	Minerals to tertiary sector

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
Products				
P ex,te	0.02	0.02	0.02	Diverted waste
Waste				
T ex,e	0.04	0.04	0.04	Disposed waste
Capital			51.36	Capital
TOTAL OUTPUT	**412.05**	**438.92**	**490.28**	
Efficiency	**97%**	**97%**	**99%**	

Table 57 - Energy, exergy, and extended exergy balance sheet for the Conversion sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R ex,co	75.75	80.30	80.30	Coal
R ex,co	6.15	6.39	6.39	Natural gas
R ex,co	189.42	204.57	204.57	Oil
R e,co	4.31	4.31	4.31	Waterfall energy
Products				
P in,co	0.47	0.48	0.48	Metals, minerals, etc
P tr,co	0.10	0.11	0.11	Cargo services
Discharges				
D co,e		4.98	4.98	Atmospheric emissions
Work				
W do,co			2.24	Labour
Capital			21.00	Capital

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
TOTAL INPUT	**276.19**	**301.14**	**324.39**	
OUTPUT				
Resources				
R co,ex	2.62	2.77	2.77	Energy carriers
R co,ag	3.47	3.67	3.67	Energy carriers
R co,tr	69.58	73.73	73.73	Energy carriers
R co,te	46.58	48.73	48.73	Energy carriers
R co,in	21.96	21.66	21.66	Energy carriers
R co,do	27.01	27.79	27.79	Energy carriers
Products				
P co,te	0.02	0.02	0.02	Diverted waste
Waste				
T co,e	0.03	0.03	0.03	Disposed waste
Capital			21.00	Capital
TOTAL OUTPUT	**171.27**	**178.39**	**199.40**	
Efficiency	**62%**	**59%**	**61%**	

Table 58 - Energy, exergy, and extended exergy balance sheet for the Industry sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R co,in	21.96	21.66	21.66	Energy carriers
R ex,in	-	0.03	0.03	Minerals
R a,in	-	0.02	0.02	Minerals imported
Natural Resources				
N ag,in	31.42	34.25	34.25	Wood

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
N a,in	9.23	9.85	9.85	Wood
Products				
P te,in	1.50	1.53	1.53	Recycled paper
P a,in	4.27	4.41	4.41	Metals, plastic
P tr,in	0.83	0.88	0.88	Cargo services
P te,in	1.95	1.95	1.95	Other recycled material
Discharge				
D in,e		0.51	0.51	Atmospheric Emissions
Work				
W do,in			32.61	Labour
Capital			210.84	Capital
TOTAL INPUT	**71.16**	**75.09**	**318.55**	
OUTPUT				
Products				
P in,a	46.14	46.71	46.71	Metals, minerals, etc
P in,te	16.18	16.68	16.68	Diverted waste, products
P in,ag	0.57	0.59	0.59	Metals, minerals, etc
P in,ex	0.59	0.61	0.61	Metals, minerals, etc
P in,co	0.47	0.48	0.48	Metals, minerals, etc
P in,tr	0.91	0.94	0.94	Metals, minerals, etc
Waste				
T in,e	0.25	0.25	0.25	Disposed waste
Capital			214.39	Capital
TOTAL	**65.10**	**66.25**	**280.65**	

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
Efficiency	**91%**	**88%**	**88%**	

Table 59 - Energy, exergy, and extended exergy balance sheet for the Transportation sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R co,tr	69.58	73.73	73.73	Energy carriers
Products				
P in,tr	0.91	0.94	0.94	Metals, minerals, etc
Discharges				
D tr,e		4.92	4.92	Atmospheric emissions
Work				
W do,tr			16.59	Labour
Capital			67.01	Capital
TOTAL INPUT	**70.48**	**79.58**	**163.18**	
OUTPUT				
Products				
P tr,ex	0.13	0.14	0.14	Cargo services
P tr,co	0.10	0.11	0.11	Cargo services
P tr,ag	0.13	0.14	0.14	Cargo services
P tr,in	0.83	0.88	0.88	Cargo services
P tr,te	3.61	3.83	3.83	Cargo services
P tr,do	10.44	11.06	11.06	Passenger services
Capital			76.65	Capital

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
TOTAL OUTPUT	**15.24**	**16.16**	**92.81**	
Efficiency	**22%**	**20%**	**57%**	

Table 60 - Energy, exergy, and extended exergy balance sheet for the Tertiary sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R co,te	46.58	48.73	48.73	Energy carriers
R ex,te	-	0.48	0.48	Minerals
Natural Resources				
N ag,te	1.46	1.46	1.46	Food
Products				
P tr,te	3.61	3.83	3.83	Cargo services
P in,te	15.68	16.18	16.18	Diverted waste, products
P ex,te	0.02	0.02	0.02	Diverted waste
P ag,te	0.02	0.02	0.02	Diverted waste
P co,te	0.02	0.02	0.02	Diverted waste
P do,te	1.09	1.09	1.09	Diverted waste
Discharges				
D te,e		1.41	1.41	Atmospheric emissions
Work				
W do,te			249.76	Labour
Capital			882.24	Capital
TOTAL INPUT	**68.47**	**73.23**	**1205.23**	

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
OUTPUT				
Products				
P te,in	1.50	1.53	1.53	Recycled paper
P te,do	4.59	4.74	4.74	Industry products
P te,do	1.31	1.31	1.31	Food
P te,do	4.81	5.05	5.05	Energy services
P te,in	1.95	1.95	1.95	Other recycled material
P te,e	-	0.03	0.03	Road salt
Waste				
T te,e	1.46	1.46	1.46	Disposed waste
Work				
W te,do			110.49	Labour
Capital			908.00	Capital
TOTAL OUTPUT	**15.63**	**16.06**	**1034.55**	
Efficiency	**23%**	**22%**	**86%**	

Table 61 - Energy, exergy, and extended exergy balance sheet for the Domestic sector, Nova Scotia 2006.

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
INPUT				
Resources				
R co,do	27.01	27.79	27.79	Energy carriers
Natural Resources				
N ag,do	0.15	0.16	0.16	Wood

Fluxes	Energy (PJ)	Exergy (PJ)	Extended Exergy (PJ)	Comments
Products				
P te,do	4.59	4.74	4.74	Industry products
P te,do	1.31	1.31	1.31	Food
P te,do	4.81	5.05	5.05	Energy by services
P tr,do	10.44	11.06	11.06	Passenger services
Discharges				
D do,e		1.10	1.10	Atmospheric emissions
Work				
W te,do			110.49	Labour
Capital			396.09	Capital
TOTAL INPUT	**48.31**	**51.20**	**557.79**	
OUTPUT				
Products				
P do,te	1.09	1.09	1.09	Diverted waste
Waste				
T do,e	1.33	1.33	1.33	Disposed waste
Work				
W do,ex			2.48	
W do,co			2.24	
W do,ag			12.33	
W do,in			32.61	
W do,tr			16.59	
W do,te			249.76	
TOTAL OUTPUT	**2.43**	**2.43**	**318.44**	
Efficiency	**5%**	**5%**	**57%**	

Table 62 shows the total extended exergy inputs and outputs by type of flux for all sectors of the economy. The total extended exergy loss (or destruction) for each sector is calculated as the difference between the input and the output.

Table 62 - Extended exergy fluxes of the province of Nova Scotia 2006, and extended exergy destruction by sector.

Flux	Ag	Ex	Co	In	Tr	Te	Do
Input							
R	3.92	445.72	295.57	21.71	73.73	49.21	27.79
P	48.58	0.75	0.59	8.77	0.94	21.65	22.15
N	0.00	0.00	0.00	44.10	0.00	1.46	0.16
W	12.33	2.48	2.24	32.61	16.59	249.76	110.49
C	34.30	36.73	21.00	210.84	67.01	882.24	396.09
Total Input	**99.1**	**485.7**	**319.4**	**318.0**	**158.3**	**1204.3**	**556.6**
Output							
R	0.00	438.86	178.34	0.00	0.00	0.00	0.00
P	0.02	0.02	0.02	66.00	16.16	14.60	1.09
N	36.96	0.00	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00	110.49	316.01
C	37.26	51.36	21.00	214.39	76.65	908.00	0.00
T	0.04	0.04	0.03	0.62	0.00	1.10	1.33
D	0.36	5.78	4.98	0.51	4.92	1.41	1.10
Total Output	**74.6**	**496.1**	**204.4**	**281.5**	**97.73**	**1035.6**	**319.5**
Extended Exergy Loss	**24.5**	**-10.4**	**115.0**	**36.5**	**60.53**	**168.7**	**237.2**

Chapter 5: Discussion

5.1 Discussion of Results

The energy and exergy analysis of the Nova Scotian economy following the principles of extended exergy accounting (Scuibba 2001) resulted in very high conversion ratios in the Extraction sector. This is mainly due to large amounts of natural gas produced and exported and large amounts of imported oil. The extended exergy balance sheet of the Extraction sector shows the domination of these two fluxes in the overall conversion of exergy.

The Agriculture sector analysis results in a relatively high conversion ratio of approximately 70% for energy and exergy and approximately 74% for extended exergy. The extended exergy balance sheet shows that this sector is producing large amounts of wood for transfer to the Industry sector, where it is processed into intermediate and final products for export and final consumption. A major loss of exergy in this sector is the low conversion efficiency of animals in converting feed to protein for human consumption. It is clear from this analysis that Nova Scotia is producing large amounts of food both for domestic consumption and export.

The Conversion sector analysis results in a relatively high conversion ratio of approximately 60% for energy, exergy, and extended exergy. The balance sheet of this sector is dominated by the conversion of domestically produced and imported oil into energy carriers like fuel oils, gasoline, and diesel. Coal is the main fuel source for electricity generation in Nova Scotia, which lowers the overall efficiency relative to countries like Norway, where the main source of electricity generation is hydropower (Ertesvåg 2005).

The Industry sector is dominated by the wood, pulp, and paper manufacturing industries. They are the single largest users of energy carriers and are efficient at converting raw wood into intermediate and final products for domestic consumption and export. The overall energy efficiency of this sector is approximately 92% due to the use of waste products for electricity and process heat generation. The exergy and extended exergy efficiencies are high as well, at approximately 88%. The Industry sector is capital-intensive, but also generates a large output of capital in the form of wages and compensation and return on investment.

The Transportation sector energy and exergy conversion ratios are low at approximately 20%. This is due to the large losses involved in converting liquid energy carriers to kinetic energy for the transportation of goods and passengers. Land transportation methods, and particularly cars, have the largest effect on lowering these conversion ratios as they completely dominate the use of energy carriers in this sector. The extended exergy conversion ratio is significantly higher, at approximately 57% owing to the high rate of return on capital investment.

The Tertiary sector analysis likewise results in low energy and exergy conversion ratios of approximately 20%. There are assumed to be small losses in the transfer of products from this sector to the domestic sector, but it is the relatively inefficient end-uses of energy like space heating and cooling that result in such low energy and exergy conversion ratios. The recirculation of waste materials from all other sectors to the Industry sector for reprocessing has the effect of raising these conversion ratios. The extended exergy conversion ratio is much higher at approximately 86%, representing the value of providing services to the Domestic sector in the form of labour and the high rate of return on capital investment.

The Domestic sector analysis results in very low energy and exergy conversion ratios of approximately 5%. Under the accounting principles followed in this work, this sector does not produce any products (besides waste) that can be quantified by their specific chemical exergy. The extended exergy conversion ratio is significantly higher, at approximately 57%. The labour input to this sector from the Tertiary sector and the large amount of input capital (in the form of wages and compensation) make a substantial contribution to raising this efficiency.

The balance sheets of each sector result in similar energy and exergy efficiencies. The main reason is that the fluxes dominating these analyses are generally products and resources for which the specific energy and specific exergy differs only slightly (for example there is an approximately 6% difference between the energy and exergy of any particular flux of refined petroleum products). The difference between these efficiencies is that while the energy is conserved and discharged to the environment, the exergy is destroyed through irreversibilities.

The extended exergy efficiencies calculated for each sector of the Nova Scotian economy are compared to those calculated for four other extended exergy analyses conducted in recent years for three European countries and China in Table 63. The year of data used in the analysis is found in the first row of Table 63, while the publication date for each is found in the caption.

Table 63 - Extended exergy efficiencies (%) by sector for recent analyses (Ertesvåg 2005), (Gasparatos et al. 2009), (Sciubba 2008), and (Chen 2009).

Sector	**Norway (2000)**	**UK (2004)**	**Siena, Italy (2000)**	**China (2005)**	**Nova Scotia, Canada (2006)**
Ex	94.5	91.4	33	88.3	**99**
Co	76.5	38.9	54	28.1	**61**
Ag	61.5	49.1	61	56.3	**74**
In	68.8	38.6	64	38.0	**88**
Tr	62.8	31.5	26	23.9	**57**
Te	74.6	80.0	85	54.9	**86**
Do	133.7	-	83	127.3	**57**

It is clear from Table 63 that the efficiency of similar sectors throughout the world varies considerably.

5.2 Discussion of Error

The production and import and export figures used in this work are taken from official Canadian statistical products generated by Statistics Canada and relevant reporting agencies. Different reports use different information gathering methods to estimate these figures, and each includes a m easure of statistical error. For example, the Report on Energy Supply and Demand (Energy Supply Demand 2007) published by Statistics Canada is the official energy balance of the country. The statistical difference between the availability and final demand of energy carriers is published as a fraction for each type of energy carrier. For Nova Scotia, this difference is zero for all energy carriers except refined petroleum carriers, where it is non-zero but suppressed due to the Privacy Act. The magnitude of production and use of refined petroleum products means that this difference would have to be substantial to have an effect on the energy or exergy conversion ratio for any sector, and so the influence of statistical error like this can be omitted.

Material fluxes of organic matter, like wood and food, are more difficult to account exactly. The moisture content of products and resources can vary substantially during storage and transport and so assumptions have been made about the moisture and energy contents of these fluxes. Exact reporting of the production mass or volume is not always available at the provincial level. This is not due to a lack of information or lax reporting standards, but rather the restrictions placed on Statistics Canada by the Privacy Act. The exact reason why a p articular figure is not publicly available is not reported. Where possible, estimates of production are made according the relative values reported as transfers between industries in the Input-Output Structure of Canada (Input Output 2007).

The exergy value of capital as calculated in this work is an estimate based on an assumption about the amount of currency available in the Nova Scotia economy in 2006. The measure suggested by Sciubba (2008) is broad money (M2) which is not published at the provincial level for Canada. However, the calculated value is close to that calculated for the extended exergy analysis of Siena, Italy (18.18 MJ/USD) (Sciubba 2008), another analysis at the provincial level, and that calculated for the extended exergy analysis of Norway (20.09 MJ/USD) (Ertesvåg 2005).

The exergy value of labour calculated for Nova Scotia is relatively high (406.5 MJ/hour compared to those calculated for other extended exergy analyses. This value was calculated as 253.0 M J/hour for Siena (Sciubba 2008), 248.3 M J/hour for the UK (Gasparatos et al. 2009), and 71.9 M J/hour for China (Chen 2009). Labour in Norway was calculated to have a value of 525.8 MJ/hour (Ertesvåg 2005) which is close to the value calculated for Nova Scotia. This relatively high value is explained for Norway as being a result of the large role played by the energy conversion and extraction industries. This explanation is satisfactory for Nova Scotia as well, Table 50 shows the large role played by energy carriers extracted and converted within this economy.

Chapter 6: Conclusions

6.1 Exergy Analysis

The objective of this work was twofold:

- An exergy analysis of the material and energy fluxes transferred between economic sectors in Nova Scotia for 2006.
- An extended exergy analysis including the non-energetic fluxes of labour and capital transferred between economic sectors in Nova Scotia for 2006.

The fluxes of materials and energy between sectors of the Nova Scotian economy are thoroughly accounted for 2006. T he efficiency of each sector is calculated and the performance with respect to exergy conversion and loss is discussed. The extended exergy efficiency of the Extraction sector was found to be 99.8%, the Conversion sector 61.5%, the Agriculture sector 74.1%, the Industry sector 88.2%, the Transportation sector 56.9%, the Tertiary sector 85.8%, and the Domestic sector 57.1%. These values are similar in many cases to those found for analogous sectors in other countries.

The value of capital in terms of extended exergy was found to be similar to the value found for European nations. The value of labour was found to be high, but not inexplicably so, as discussed in section 5.2 Discussion of Error.

The results of this study show a large dissipation of high quality energy (loss of exergy) for the majority of economic activities within the province. There is room for improvement on t hese measures through policies directed at raising the conversion efficiency, but it is not clear that an absolute increase in exergy (or extended exergy) conversion efficiency for all sectors is beneficial for the society at large. The variation of conversion efficiencies across countries presented in Table 63 suggests instead that there are multiple possible configurations of optimum efficiencies depending on the resources available and makeup of the economy.

6.2 Future Work

This is the first exergy (and extended exergy) analysis of the Canadian economy at the provincial level and serves as a g uide for future analyses. The procedure for other provinces will be similar depending on the availability of statistical data. The procedure for the analysis of the whole of Canada may prove to be more straightforward than analysis at the provincial level owing to the abundance and fewer restrictions placed on data at the country level of aggregation.

Future studies can build on t his analysis by inserting environmental remediation processes into the extended exergy analysis. In this work, only the specific chemical exergy of disposed waste and atmospheric emissions are considered as part of the extended exergy analysis. A theoretical process which brings the total exergy of each chemical compound or type of waste into equilibrium with the environment can be created, inserted where appropriate, and accounted for as an exergetic cost.

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Appendix A: Enthalpy of devaluation and standard chemical exergy of inorganic and organic substances (Szargut 1988)

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa

Substance	State	Molecular mass M	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
Ag	*s*	107.870	47.48	70.2
Ag_2CO_3	*s*	275.749	−17.38	115.0
AgCl	*s*	143.323	0	22.2
AgF	*s*	126.868	47.60	118.5
$AgNO_3$	*s*	169.875	−76.91	43.1
Ag_2O	*s*	231.739	63.91	57.6
Ag_2O_2	*s*	247.739	70.69	172.1
Ag_2S	*s*, α	247.804	787.79	709.5
Ag_2SO_4	*s*	311.802	104.50	139.6
Al	*s*	26.9815	930.69	888.4
Al_4C_3	*s*	143.959	4694.51	4588.2
$AlCl_3$	*s*	133.3405	467.18	444.9
Al_2O_3	*s*, α, corundum	101.9612	185.69	200.4
$Al_2O_3 \cdot H_2O$	*s*, boermite	119.9765	128.35	195.3
$Al_2O_3 \cdot 3H_2O$	*s*, gibbsite	156.0072	24.13	209.5
Al_2S_3	*s*	150.155	3313.81	2890.7
$Al_2(SO_4)_3$	*s*	342.148	596.80	529.7
Al_2SiO_5	*s*, andalusite	162.046	28.03	43.9
Al_2SiO_5	*s*, kyanite	162.046	25.94	45.1
Al_2SiO_5	*s*, sillimanite	162.046	0	15.4

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation $D°$, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
$Al_2Si_2O_5(OH)_4$	*s*, kaolinite	258.1615	68.25	197.8
$3Al_2O_3 \cdot 2SiO_2$	*s*, mullite	426.0536	630.11	618.8
Ar	*g*	39.948	0	11.69
As	*s*	74.9216	462.44	494.6
As_2O_5	*s*	229.8402	0	216.9
Au	*s*	196.967	0	15.4
AuCl	*s*	232.42	45.49	62.2
$AuCl_3$	*s*	303.326	123.09	155.5
AuF_3	*s*	253.962	246.46	437.3
Au_2O_3	*s*	441.932	−80.81	114.7
B	*s*	10.811	636.39	628.5
B_2O_3	*s*	69.6202	0	69.4
Ba	*s*, II	137.34	747.77	747.7
$BaCO_3$	*s*, II	197.35	−75.18	26.3
$BaCl_2$	*s*	208.25	48.69	61.3
BaF_2	*s*	175.34	−53.24	57.2
BaO	*s*	153.34	194.15	224.6
BaO_2	*s*	169.34	113.38	169.3
$Ba(OH)_2$	*s*	171.36	45.93	132.9
BaS	*s*	169.40	1012.88	901.9
$BaSO_4$	*s*, barite	233.40	0	3.4
Bi	*s*	208.980	286.94	274.5
Bi_2O_3	*s*	465.958	0	61.4
Bi_2S_3	*s*	514.152	2607.05	2237.3
Br_2	*l*	159.812	—	101.2
C	*s*, graphite	12.01115	393.509	410.26
C	*s*, diamond	12.01115	395.406	413.16
CCl_4	*l*	153.823	578.95	473.1
CN	*g*, cyano	26.01785	858.00	845.0
C_2N_2	*g*, cyanogen	52.0357	1096.14	1118.9
CO	*g*	28.0105	282.984	275.10
CO_2	*g*	44.0095	0	19.87
CS_2	*l*	76.139	1934.09	1694.7
Ca	*s*, II	40.08	813.57	712.4
CaC_2	*s*	64.10	1541.18	1468.3
$CaCO_3$	*s*, aragonite	100.09	0	1.0
$CaCO_3 \cdot MgCO_3$	*s*, dolomite	184.411	0	15.1
$CaCl_2$	*s*	110.99	178.21	87.9
CaF_2	*s*	78.077	0	11.4
$CaFe_2O_4$	*s*	215.77	161.07	104.0
$Ca_2Fe_2O_4$	*s*	271.85	321.00	194.7
$Ca_2Mg_5Si_8O_{22}(OH)_2$	*s*, tremolite	812.41	425.49	81.6
$Ca(NO_3)_2$	*s*	164.0898	−124.90	−18.1
CaO	*s*	56.08	178.44	110.2

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
$CaO \cdot Al_2O_3$	*s*	158.04	351.66	275.4
$CaO \cdot 2Al_2O_3$	*s*	260.00	541.71	460.4
$3CaO \cdot Al_2O_3$	*s*	270.20	716.72	500.6
$12CaO \cdot 7Al_2O_3$	*s*	1386.68	3415.71	2526.8
$CaO \cdot Al_2O_3 \cdot 2SiO_2$	*s*, anortite	222.038	273.92	218.3
$Ca(OH)_2$	*s*	74.09	69.04	53.7
$Ca_3(PO_4)_2$	*s*, α	310.18	0	19.4
CaS	*s*	72.14	1056.57	844.6
$CaSO_4$	*s*, anhydrite	136.14	104.88	8.2
$CaSO_4 \cdot 1/2H_2O$	*s*, α	145.15	83.16	12.1
$CaSO_4 \cdot 2H_2O$	*s*, gypsum	172.17	0	8.6
$CaSiO_3$	*s*, volastonite	116.16	90.24	23.6
Ca_2SiO_4	*s*, β	172.24	232.28	95.7
Ca_3SiO_5	*s*	282.32	424.94	219.8
Cd	*s*, ν	112.40	357.10	293.8
Cd	*s*, α	112.40	356.51	293.2
$CdCO_3$	*s*	172.41	0	40.6
$CdCl_2$	*s*	183.31	126.04	73.4
CdO	*s*	128.40	98.95	67.3
$Cd(OH)_2$	*s*	146.41	38.26	59.5
CdS	*s*	144.46	920.60	746.9
$CdSO_4$	*s*	208.46	149.24	88.6
$CdSO_4 \cdot H_2O$	*s*	226.48	84.79	80.6
Cl_2	*g*	70.906	160.44	123.6
Cl	*g*	35.453	201.90	87.1
Co	*s*, α, hexagonal	58.9332	297.06	265.0
$CoCO_3$	*s*	118.9426	−22.38	45.8
$CoCl_2$	*s*	129.839	144.96	118.8
CoO	*s*	74.9326	59.12	52.8
Co_3O_4	*s*	240.7872	0	38.2
$Co(OH)_2$	*s*, pink	92.9479	−0.86	50.7
CoS	*s*	90.997	942.27	792.2
$CoSO_4$	*s*	154.995	134.22	99.8
Cr	*s*	51.996	569.86	544.3
Cr_3C_2	*s*	180.010	2415.85	2372.0
Cr_7C_3	*s*	400.005	5007.63	4874.2
$CrCl_2$	*s*	122.902	361.91	311.9
$CrCl_3$	*s*	158.355	281.05	261.6
Cr_2O_3	*s*	151.990	0	36.5
Cs	*s*	132.905	362.68	404.4
CsCl	*s*	168.358	0	51.5
$CsNO_3$	*s*	194.910	−80.22	18.2
Cs_2O	*s*	281.809	407.75	521.8
Cs_2SO_4	*s*	361.872	30.53	127.0

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
Cu	*s*	63.54	201.59	134.2
$CuCO_3$	*s*	123.55	0	31.5
CuCl	*s*	98.99	144.57	76.2
$CuCl_2$	*s*	134.45	141.95	82.1
$CuFe_2O_4$	*s*	239.23	60.62	36.1
CuO	*s*	79.54	44.27	6.5
Cu_2O	*s*	143.08	234.56	124.4
$Cu(OH)_2$	*s*	97.55	−6.37	15.3
CuS	*s*	95.60	873.87	690.3
Cu_2S	*s*	159.14	1049.10	791.8
$CuSO_4$	*s*	159.60	155.65	89.8
Cu_2SO_4	*s*	223.14	377.15	253.6
D_2	*g*	4.02946	249.199	263.8
D_2O	*g*	20.02886	0	31.2
D_2O	*l*	20.02886	−45.401	22.3
F_2	*g*	37.9968	406.07	466.3
Fe	*s*, α	55.847	412.12	376.4
Fe_3C	α, cementite	179.552	1654.97	1560.2
$FeCO_3$	*s*, siderite	115.856	65.06	125.9
$FeCl_2$	*s*	126.753	230.77	197.6
$FeCl_3$	*s*	162.206	253.29	230.2
$FeCr_2O_4$	*s*	223.837	107.10	129.1
$Fe_{0.947}O$	*s*, wustite	68.8865	124.01	113.3
FeO	*s*	71.846	140.16	127.0
Fe_2O_3	*s*, hematite	159.692	0	16.5
Fe_3O_4	*s*, magnetite	231.539	117.98	121.6
$Fe(OH)_3$	*s*	106.869	−48.14	39.6
FeS	*s*, α	87.911	1037.54	885.6
FeS_2	*s*, pyrite	119.975	1684.72	1428.7
$FeSO_4$	*s*	151.909	209.11	173.0
FeSi	*s*	83.933	1249.42	1157.3
$FeSiO_3$	*s*	131.931	118.07	161.7
Fe_2SiO_4	*s*, fayalite	203.778	255.30	236.2
$FeTiO_3$	*s*	151.75	118.90	131.4
H_2	*g*	2.01594	241.818	236.1
H	*g*	1.00797	338.874	331.3
HCl	*g*	36.461	108.82	84.5
HDO	*g*	19.0213	0.21	18.8
HDO	*l*	19.0213	−44.38	10.0
HF	*g*	20.0064	52.82	80.0
HNO_3	*l*	63.0129	−53.19	43.5
H_2O	*g*	18.01534	0	9.5
H_2O	*l*	18.01534	−44.012	0.9
H_3PO_4	*s*	98.0013	−76.26	104.0

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
H_2S	*g*	34.080	946.61	812.0
H_2SO_4	*l*	98.077	153.25	163.4
He	*g*	4.0026	0	30.37
Hg	*l*	200.59	63.82	115.9
Hg_2CO_3	*s*	461.189	−12.39	179.8
$HgCl_2$	*s*	271.50	0	60.8
Hg_2Cl_2	*s*	472.09	22.86	144.5
HgO	*s*, red, orthorhombic	216.59	−27.01	57.3
HgS	*s*, red	232.65	731.08	674.8
$HgSO_4$	*s*	296.65	81.73	146.0
Hg_2SO_4	*s*	497.24	110.36	223.4
I_2	*s*	253.8088	—	174.7
K	*s*	39.102	356.63	366.6
$KAlSi_3O_8$	*s*, adularia	278.337	66.26	99.9
K_2CO_3	*s*	138.213	−43.58	85.1
KCl	*s*	75.555	0	19.6
$KClO_4$	*s*	138.553	6.67	136.0
KF	*s*	58.100	−7.77	62.2
KNO_3	*s*	101.1069	−135.90	−19.4
K_2O	*s*	94.203	350.04	413.1
KOH	*s*	56.109	52.72	107.6
K_2S	*s*	110.268	1024.40	943.0
K_2SO_3	*s*	158.266	300.47	302.6
K_2SO_4	*s*	174.266	4.62	35.0
K_2SiO_3	*s*	154.288	75.9	137.9
Kr	*g*	83.80	0	34.36
Li	*s*	6.939	328.10	393.0
Li_2CO_3	*s*	73.887	−166.33	70.1
LiCl	*s*	42.392	0	70.7
Li_2O	*s*	29.877	57.38	225.7
LiOH	*s*	23.946	−35.73	74.1
Li_2SO_4	*s*	109.940	−52.86	204.3
Mg	*s*	24.312	725.71	633.8
$MgAl_2O_4$	*s*, spinel	142.273	274.17	230.3
$MgCO_3$	*s*	84.321	23.43	37.9
$MgCl_2$	*s*	95.218	244.65	165.9
$MgFe_2O_4$	*s*	200.004	121.53	77.9
MgO	*s*	40.311	124.38	66.8
$Mg(OH)_2$	*s*	58.327	42.73	40.9
$Mg(NO_3)_2$	*s*	148.3218	−64.34	57.4
$Mg_3(PO_4)_2$	*s*	262.879	76.59	130.0
MgS	*s*	56.376	1105.11	901.6
$MgSO_4$	*s*	120.374	166.22	80.7
$MgSiO_3$	*s*	100.396	87.73	22.0

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
Mg_2SiO_4	*s*	140.708	188.35	74.9
$Mg_3Si_2O_5(OH)_4$	*s*, chrysolite	277.134	117.06	61.3
$Mg_3Si_4O_{10}(OH)_2$	*s*, talc	379.289	140.26	36.5
Mg_2TiO_4	*s*	160.52	231.48	134.3
Mn	*s*, α	54.9381	520.03	482.3
Mn_3C	*s*	176.82545	1958.20	1862.3
$MnCO_3$	*s*	114.9475	19.42	81.8
$MnCl_2$	*s*	125.844	199.18	165.4
$MnFe_2O_4$	*s*	230.630	118.36	121.4
MnO	*s*	70.9375	134.81	119.4
MnO_2	*s*	86.9369	0	21.1
Mn_2O_3	*s*	157.8744	81.09	89.4
Mn_3O_4	*s*	228.8119	172.26	171.6
$Mn(OH)_2$	*s*, amorphous	88.9528	66.47	107.3
MnS	*s*, green	87.002	1031.23	873.5
$MnSO_4$	*s*	151.000	180.20	142.4
$MnSiO_3$	*s*	131.022	110.08	102.3
Mo		95.94	745.09	730.3
Mo_2C		203.89	1838.88	1824.6
MoO_2	*s*	127.94	156.15	201.2
MoO_3	*s*	143.94	0	68.2
Mo_2S_3	*s*	288.07	3302.43	2891.2
MoS_2	*s*	160.068	1960.78	1723.1
N_2	*g*	28.0134	0	0.72
N_2, atmospheric	*g*	28.1541	0	0.69
NH_3	*g*	17.0305	316.62	337.9
NH_4Cl	*s*	53.491	249.43	331.3
NH_4NO_3	*s*	80.04348	118.08	294.8
$(NH_4)_2SO_4$	*s*	132.138	511.84	660.6
NO	*g*	30.0061	90.25	88.9
NO_2	*g*	46.0055	33.18	55.6
N_2O	*g*	44.0128	82.05	106.9
N_2O_4	*g*	92.0110	9.163	106.5
N_2O_5	*g*	108.0104	11.30	125.7
Na	*s*	22.9898	330.90	336.6
$NaAlO_2$	*s*	81.9701	128.40	151.7
$NaAlSi_2O_6 \cdot H_2O$	*s*, analcime	220.055	35.41	104.2
$NaAlSi_3O_8$	*s*, low albite	262.2245	72.75	105.5
Na_2CO_3	*s*	105.9891	−75.62	41.5
NaCl	*s*	58.443	0	14.3
$NaHCO_3$	*s*	84.0071	−101.94	21.6
NaI	*s*	149.8942	—	136.1
$NaNO_3$	*s*	84.9947	−135.62	−22.7
Na_2O	*s*	61.9790	243.82	296.2

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation $D°$, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
NaOH	*s*	39.9972	23.79	74.9
Na_2S	*s*	78.044	1014.84	921.4
Na_2SO_3	*s*	126.042	297.63	287.5
Na_2SO_4	*s*	142.041	0	21.4
Na_2SiO_3	*s*	122.064	11.31	66.1
$Na_2Si_2O_5$	*s*	182.149	13.28	67.6
Na_4SiO_4	*s*	184.043	151.45	256.6
Ne	*g*	20.183	0	27.19
Ni	*s*	58.71	239.74	232.7
Ni_3C	*s*	188.14	1180.09	1142.9
$NiCO_3$	*s*	118.72	−49.93	36.4
$NiCl_2$	*s*	129.62	94.85	97.2
NiO	*s*	74.71	0	23.0
$Ni(OH)_2$	*s*	92.72	−48.13	25.5
NiS	*s*	90.77	883.15	762.8
Ni_3S_2	*s*	240.26	1967.14	1720.2
$NiSO_4$	*s*	154.77	92.25	90.4
$NiSO_4 \cdot 6H_2O$	*s*, α, tetragonal, green	262.86	−266.75	53.6
O_2	*g*	31.9988	0	3.97
O	*g*	15.9994	249.17	233.7
O_3	*g*	47.9982	142.67	169.1
P	*s*, α, white	30.9738	840.06	875.8
P	*s*, red, triclinic	30.9738	822.49	863.6
P_4O_{10}	*s*, hexagonal	283.8892	376.21	825.3
Pb	*s*	207.19	305.64	232.8
$PbCO_3$	*s*	267.20	0	23.5
$PbCl_2$	*s*	278.10	106.67	42.3
PbO	*s*, yellow	223.19	88.32	46.9
PbO	*s*, red	223.19	86.65	45.9
PbO_2	*s*	239.19	28.24	19.4
Pb_3O_4	*s*	685.57	198.53	105.2
$Pb(OH)_2$	*s*	241.20	32.48	20.6
PbS	*s*	239.25	930.64	743.7
$PbSO_4$	*s*	303.25	111.12	37.2
$PbSiO_3$	*s*	283.27	70.88	31.2
Pb_2SiO_4	*s*	506.46	159.07	75.5
Rb	*s*	85.47	350.38	388.6
Rb_2CO_3	*s*	230.95	−33.90	152.4
RbCl	*s*	120.92	0	48.6
Rb_2O	*s*	186.94	370.60	491.3
S	*s*, rhombic	32.064	725.42	609.6
SO_2	*g*	64.0628	428.59	313.4
SO_3	*g*	80.0622	329.70	249.1
Sb	*s*, III	121.75	485.97	435.8

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation $D°$, kJ/mol	Standard chemical exergy b^0_{ch}, kJ/mol
1	2	3	4	5
Sb_2O_3	*s*	291.50	263.07	251.2
Sb_2O_4	*s*	307.50	62.63	83.7
Sb_2O_5	*s*	323.60	0	52.3
Se	*s*, black	78.96	—	346.5
Si	*s*	28.086	910.94	854.6
SiC	*s*, α, hexagonal	40.097	1241.69	1204.6
$SiCl_4$	*l*	169.898	544.81	481.9
SiO_2	*s*, α, quartz	60.085	0	1.9
SiO_2	*s*, α, cristobalite	60.085	1.46	2.8
SiO_2	*s*, amorphous	60.085	7.45	7.9
SiS_2	*s*	92.214	2149.23	1866.3
Sn	*s*, I, white	118.69	580.74	544.8
Sn	*s*, II, gray	118.69	578.65	544.9
$SnCl_2$	*s*	189.60	416.08	386.4
SnO	*s*	134.69	294.97	289.9
SnO_2	*s*	150.69	0	29.1
SnS	*s*	150.75	1205.74	1056.1
SnS_2	*s*	182.82	1863.8	1604.6
Sr	*s*	87.62	826.34	730.2
$SrCO_3$	*s*	143.63	0	6.2
$SrCl_2$	*s*	158.53	157.93	72.6
SrO	*s*	103.62	234.30	170.2
SrO_2	*s*	119.62	191.96	140.4
SrS	*s*	119.68	1098.99	891.8
$SrSO_4$	*s*	183.68	98.66	7.1
Ti	*s*	47.90	944.75	906.9
TiC	*s*	59.91	1154.16	1136.7
TiO	*s*	63.90	425.14	418.5
TiO_2	*s*, rutile	79.90	0	21.4
Ti_2O_3	*s*	143.80	368.66	385.5
Ti_3O_5	*s*	223.70	375.10	413.2
TiS_2	*s*	112.03	2060.45	1875.9
U	*s*	238.03	1230.10	1190.7
UCl_3	*s*	344.39	577.35	550.1
UCl_4	*s*	379.84	499.39	475.2
UCl_5	*s*	415.30	536.93	513.6
UO_2	*s*	270.03	145.19	162.9
UO_3	*s*	286.03	0	43.9
U_3O_8	*s*	842.085	115.49	218.5
V	*s*	50.942	775.30	721.1
VC	*s*	62.953	1067.96	1032.6
VO	*s*	66.941	343.51	318.9
VO_2	*s*	82.940	57.74	61.9
V_2O_3	*s*	149.882	322.60	299.7

Table I Enthalpy of devaluation and standard chemical exergy of inorganic substances, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Substance	State	Molecular mass M	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
1	2	3	4	5
V_2O_5	*s*	181.881	0	32.5
W	*s*	183.85	842.87	827.5
WC	*s*	195.86	1195.84	1199.5
WO_2	*s*	215.85	253.18	297.5
WO_3	*s*	231.85	0	69.3
WS_2	*s*	249.98	2084.51	1796.6
Xe	*g*	131.30	0	40.33
Zn	*s*	65.37	419.27	339.2
$ZnCO_3$	*s*	125.38	0	23.9
$ZnCl_2$	*s*	136.28	583.93	93.4
$ZnFe_2O_4$	*s*	241.06	74.08	36.4
ZnO	*s*	81.37	70.99	22.9
$Zn(OH)_2$	*s*, β	99.38	19.18	25.7
ZnS	*s*, sphalerite	97.43	938.71	747.6
$ZnSO_4$	*s*	161.43	161.87	82.3
Zn_2SiO_4	*s*	222.82	112.74	17.8

Table II Enthalpy of devaluation and standard chemical exergy of organic compounds, T_n = 298.15 K, p_n = 101.325 kPa

Nos. on Figs. 3.16–3.18	Chemical formula	Name	State	Molecular mass	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
	1	2	3	4	5	6
—	CH_2	Methylene	*g*	14.02709	1032.9	1030.5
—	CH_3	Methyl	*g*	15.03506	889.9	900.5
		Aliphatic saturated hydrocarbons C_nH_{2n+2}				
1	CH_4	Methane	*g*	16.04303	802.33	831.65
2	C_2H_6	Ethane	*g*	30.07012	1427.79	1495.84
3	C_3H_8	Propane	*g*	44.09721	2045.4	2154.0
4	C_4H_{10}	*n*-Butane	*g*	58.1243	2658.4	2805.8
5	C_5H_{12}	*n*-Pentane	*g*	72.15139	3274.3	3463.3
			l		3247.2	3461.8
6	C_6H_{14}	*n*-Hexane	*g*	86.17848	3889.3	4118.5
			l		3857.6	4114.5
7	C_7H_{16}	*n*-Heptane	*l*	100.20557	4464.7	4761.7
8	C_8H_{18}	*n*-Octane	*l*	114.23266	5074.4	5413.1

Table II Enthalpy of devaluation and standard chemical exergy of organic compounds, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Nos. on Figs. 3.16–3.18	Chemical formula	Name	State	Molecular mass	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
	1	2	3	4	5	6
9	C_9H_{20}	*n*-Nonane	*l*	128.25975	5684.2	6064.9
10	$C_{10}H_{22}$	*n*-Decane	*l*	142.28684	6294.0	6716.8
11	$C_{11}H_{24}$	*n*-Undecane	*l*	156.31393	6908.6	7376.9
12	$C_{12}H_{26}$	*n*-Dodecane	*l*	170.34102	7518.8	8029.4
13	$C_{13}H_{28}$	*n*-Tridecane	*l*	184.36811	8129.0	8682.0
14	$C_{14}H_{30}$	*n*-Tetradecane	*l*	198.3952	8739.2	9334.5
15	$C_{15}H_{32}$	*n*-Pentadecane	*l*	212.42229	9349.4	9984.8
16	$C_{16}H_{34}$	*n*-Hexadecane	*l*	226.44938	9959.6	10639.7
		Cycloparaffins C_nH_{2n}				
17	C_3H_6	Cyclopropane	*g*	42.08127	1959.2	2043.2
18	C_4H_8	Cyclobutane	*g*	56.10836	2388.7	2516.2
19	C_6H_{12}	Cyclohexane	*g*	84.16254	3691.4	3914.3
			l		3658.3	3909.2
—	C_6H_{12}	Methylcyclopentane	*l*	84.16254	3673.5	3910.8
20	C_7H_{14}	Methylcyclohexane	*g*	98.18963	4295.5	4556.9
21	C_8H_{16}	Ethylcyclohexane	*g*	112.21672	4914.3	5228.5
			l		4873.8	5205.9
22	C_9H_{18}	*n*-Propylcyclohexane	*l*	126.24381	5483.3	5857.7
23	$C_{10}H_{20}$	*n*-Butylcyclohexane	*l*	140.2709	6094.3	6511.5
		Olefins (ethylenic hydrocarbons) C_nH_{2n}				
24	C_2H_4	Ethylene	*g*	28.05418	1323.1	1361.1
25	C_3H_6	Propylene	*g*	42.08127	1927.7	2003.9
26	C_4H_8	1-Butylene	*g*	56.10836	2542.9	2659.7
27	C_6H_{12}	1-Hexylene	*g*	84.16254	3772.9	3970.5
			l		3742.2	3967.9
28	C_7H_{14}	1-Heptylene	*g*	98.18963	4388.0	4625.5
			l		4338.5	4604.6
		Acetylene hydrocarbons C_nH_{2n-2}				
29	C_2H_2	Acetylene	*g*	26.03824	1255.6	1265.8
30	C_3H_4	Propyne	*g*	40.06533	1850.9	1899.5
31	C_4H_6	1-Butyne	*g*	54.09242	2465.6	2552.3
32	C_6H_{10}	1-Hexyne	*g*	82.1466	3696.3	3865.1
33	C_7H_{12}	1-Heptyne	*g*	96.17369	4311.4	4520.5
—	C_8H_{14}	1-Octyne	*g*	110.20078	4923.2	5170.3
—	C_9H_{16}	1-Nonyne	*g*	124.22787	5537.9	5825.1
		Diene hydrocarbons C_nH_{2n-2}				
—	C_3H_4	Propadiene	*g*	40.06533	1472.1	1523.8
—	C_5H_8	Pentadiene	*g*	68.11951	2789.2	2914.8

Table II Enthalpy of devaluation and standard chemical exergy of organic compounds, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Nos. on Figs. 3.16–3.18	Chemical formula	Name	State	Molecular mass	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b^0_{ch}, kJ/mol
	1	2	3	4	5	6
		Aromatic hydrocarbons (benzene derivatives)				
34	C_6H_6	Benzene	*g*	78.11472	3171.6	3303.6
			l		3137.7	3298.5
35	C_7H_8	Toluene	*g*	92.14181	3774.4	3943.4
			l		3736.4	3931.0
36	C_8H_{10}	Ethylbenzene	*g*	106.1689	4390.0	4598.8
			l		4347.7	4587.9
—	C_8H_{10}	*o*-Xylene	*l*	106.1689	4332.8	4573.1
37	C_9H_{12}	*n*-Propylbenzene	*l*	120.19599	4957.5	5249.1
38	$C_{10}H_{14}$	*n*-Butylbenzene	*l*	134.22308	5567.7	5892.0
39	$C_{16}H_{26}$	*n*-Decylbenzene	*l*	218.38562	9198.3	9700.8
		Solid hydrocarbons				
40	$C_{10}H_8$	Naphthalene	*s*	128.17526	4984.2	5255.0
41	$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	*s*	134.22308	5533.0	5880.0
42	$C_{11}H_{10}$	2-Methylnaphthalene	*s*	142.20235	5574.9	5881.4
43	$C_{11}H_{16}$	Pentamethylbenzene	*s*	148.25017	6131.6	6516.0
44	$C_{12}H_{18}$	Hexamethylbenzene	*s*	162.27726	6739.1	7171.0
45	$C_{14}H_{10}$	Anthracene	*s*	178.2358	6850.9	7218.1
46	$C_{14}H_{10}$	Phenanthrene	*s*	178.2358	6835.9	7201.8
47	$C_{14}H_{14}$	1,1-Diphenylethan	*s*	182.26768	7250.9	7665.9
48	$C_{18}H_{38}$	*n*-Octadecane	*s*	254.50356	11116.7	11937.4
49	$C_{19}H_{16}$	Triphenylmethane	*s*	244.33937	9579.7	10109.2
50	$C_{24}H_{18}$	1,3,5-Triphenylbenzene	*s*	306.41106	11850.1	12490.3
51	$C_{25}H_{20}$	Tetraphenylmethane	*s*	320.43815	12544.1	13231.6
		Organic compounds containing oxygen				
52	CH_2O	Formaldehyde	*g*	30.02649	519.4	538.4
53	CH_2O_2	Formic acid	*g*	46.02589	259.1	301.3
			l		213.0	291.7
—	CH_4O	Methanol	*l*	32.04243	638.4	718.0
54	C_2H_6O	Ethyl alcohol	*g*	46.06952	1278.2	1363.9
			l		1235.9	1357.7
55	C_2H_6O	Dimethyl ether	*g*	46.06952	1328.1	1419.5
56	C_2H_4O	Acetic aldehyde	*g*	44.05358	1105.5	1163.3
57	C_2H_4O	Ethyleneoxyde	*g*	44.05358	1220.5	1284.4
58	$C_2H_6O_2$	Ethylene glycol	*l*	62.06892	1058.6	1207.3
59	$C_2H_4O_2$	Acetic acid	*g*	60.05298	834.1	919.0
			l		786.6	908.0
60	C_3H_8O	Propylalcohol-2	*l*	60.09661	1830.6	1998.6
61	C_3H_6O	Acetone	*g*	58.08067	1690.9	1791.5
			l		1659.6	1788.5

Table II Enthalpy of devaluation and standard chemical exergy of organic compounds, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Nos. on Figs. 3.16–3.18	Chemical formula	Name	State	Molecular mass	Enthalpy of devaluation $D°$, kJ/mol	Standard chemical exergy b°_{ch}, kJ/mol
	1	2	3	4	5	6
62	C_4H_8O	Butylaldehyde-1	*l*	72.10776	2296.5	2463.3
63	C_4H_8O	Butylketone-2	*l*	72.10776	2264.1	2432.6
64	C_4H_4O	Furane	*g*	68.07588	2024.4	2118.8
			l		1996.7	2118.2
65	$C_4H_8O_2$	Butyric acid	*l*	88.10716	2018.8	2215.8
66	$C_4H_8O_2$	Ethyl acetate	*l*	88.10716	2073.6	2269.6
67	$C_5H_{12}O$	Amyl alcohol	*l*	88.15079	3060.7	3311.7
68	$C_5H_{12}O$	2-Methylbutanol-2	*l*	88.15079	3017.2	3275.7
69	$C_5H_{10}O$	Cyclopentanol	*l*	86.13485	2878.7	3109.7
70	$C_5H_6O_2$	Furfuryl alcohol	*l*	98.10237	2418.6	2687.7
71	$C_6H_{14}O$	Hexyl alcohol-1	*l*	102.17788	3668.9	3961.1
72	$C_6H_{12}O$	Cyclohexanol	*l*	100.16194	3465.4	3750.8
73	$C_7H_{16}O$	Heptyl alcohol-1	*l*	116.20497	4285.6	4619.2
74	C_7H_8O	Benzyl alcohol	*l*	108.14121	3563.4	3795.8
75	$C_4H_{10}O_4$	Erythrite	*s*	122.1219	1874.7	2193.0
76	$C_4H_6O_4$	Succinic acid	*s*	118.09002	1356.9	1609.4
77	$C_4H_4O_4$	Malonic acid	*s*	116.07408	1271.3	1495.7
78	$C_4H_4O_4$	Fumaric acid	*s*	116.07408	1249.1	1471.5
79	C_6H_6O	Phenol	*s*	94.11412	2925.9	3128.5
80	$C_6H_{14}O_6$	Dulcite	*s*	182.17488	2729.6	3196.3
81	$C_6H_{14}O_6$	Mannit	*s*	182.17488	2739.6	3204.8
82	$C_6H_{12}O_6$	α-D-Galactose	*s*	180.15894	2529.6	2928.8
83	$C_6H_{12}O_6$	L-Sorbose	*s*	180.15894	2544.6	2939.0
84	$C_7H_6O_2$	Benzoic acid	*s*	122.12467	3097.2	3343.5
85	$C_7H_6O_3$	Hydroxybenzoic acid	*s*	138.12407	2888.1	3151.2
86	$C_8H_4O_3$	Phthalic acid anhydride	*s*	148.11928	3173.8	3434.8
87	$C_8H_6O_4$	Phthalic acid	*s*	166.13462	3094.3	3412.6
88	$C_{12}H_{10}O$	Diphenyl ether	*s*	170.2129	5903.1	6282.4
89	$C_{12}H_{22}O_{11}$	β-Lactose	*s*	342.30254	5154.2	5988.1
90	$C_{12}H_{22}O_{11}$	Saccharose	*s*	342.30254	5166.2	6007.8
91	$C_{12}H_{24}O_{12}$	α-Lactose monohydrate	*s*	360.31788	5152.2	6043.3
92	$C_{12}H_{24}O_{12}$	β-Maltose monohydrate	*s*	360.31788	5173.2	6063.4
93	$C_{16}H_{34}O$	Cetyl alcohol	*s*	242.44878	9731.3	10493.9
94	$C_{16}H_{32}O_2$	Palmitin acid	*s*	256.43224	9290.3	10052.3
95	$C_2H_2O_4$	Oxalic acid	*s*	90.03584	202.7	368.7
		Organic compounds containing nitrogen and oxygen				
96	$C_2H_4N_4$	Dicyanodiamide	*s*	84.08098	1296.5	1477.4
97	$C_3H_6N_6$	Melamine	*s*	126.12147	1835.6	2120.5
98	$C_5H_5N_5$	Adenine	*s*	135.1291	2664.9	2941.0
99	$C_6H_4N_2$	2-Cyanopyridine	*s*	104.11218	3106.1	3246.9
100	$C_{12}H_{11}N$	Diphenylamine	*s*	169.22817	6188.1	6540.7

Table II Enthalpy of devaluation and standard chemical exergy of organic compounds, T_n = 298.15 K, p_n = 101.325 kPa (*Continued*)

Nos. on Figs. 3.16–3.18	Chemical formula	Name	State	Molecular mass	Enthalpy of devaluation D°, kJ/mol	Standard chemical exergy b^0_{ch}, kJ/mol
	1	2	3	4	5	6
101	CH_4ON_2	Urea	*s*	60.05583	544.7	689.0
102	$CH_6O_2N_2$	Ammonium urethane	*s*	78.06037	474.8	666.7
103	$C_2H_5O_2N$	Aminoacetic acid	*s*	75.06765	867.6	1049.5
104	$C_3H_7O_2N$	D,L-Alanine	*s*	89.09474	1462.4	1689.4
105	$C_4H_7O_4N$	L-Aspartic acid	*s*	133.10469	1445.2	1743.8
106	$C_4H_8O_3N_2$	L-Asparagine	*s*	132.11996	1749.9	2061.3
107	$C_4H_2O_4N_2$	Alloxan	*s*	142.07154	813.1	1053.8
108	$C_4H_7ON_3$	Creatinine	*s*	113.11989	2179.7	2440.6
109	$C_4H_9O_2N_3$	Creatine	*s*	131.13523	2123.1	2442.8
110	$C_4H_6O_3N_4$	Allantoin	*s*	158.11742	1580.0	1909.9
111	$C_5H_9O_4N$	D-Glutamic acid	*s*	147.13178	2047.9	2393.2
112	$C_5H_4ON_4$	Hypoxanthine	*s*	136.11383	2337.3	2602.4
113	$C_5H_4O_2N_4$	Xanthine	*s*	152.11323	2068.8	2361.7
114	$C_5H_4O_3N_4$	Uric acid	*s*	169.1206	1950.6	2289.1
115	$C_5H_5ON_5$	Guanine	*s*	151.1285	2385.2	2691.2
116	$C_9H_9O_3N$	Hypuric acid	*s*	179.17698	4014.3	4388.1
117	$C_{12}H_5O_{12}N_7$	1,3,5-Hexanitrodiphenylamine	*s*	439.21335	5397.2	6167.8
		Organic compounds containing sulfur				
118	C_2H_6S	Ethyl mercaptan	*l*	62.134	2164.9	2134.0
119	C_2H_6S	Dimethyl sulfide	*l*	62.134	2173.2	2145.4
120	C_3H_8S	Propyl mercaptan	*l*	76.161	2784.3	2794.7
121	C_3H_8S	Methylethyl sulfide	*l*	76.161	2783.6	2795.0
122	$C_4H_{10}S$	Butyl mercaptan	*l*	90.188	3386.2	3438.7
123	$C_4H_{10}S$	2-Methylpropyl mercaptan	*l*	90.188	3378.9	3434.3
124	$C_4H_{10}S$	Diethyl sulfide	*l*	90.188	3392.9	3446.3
125	$C_4H_{10}S$	Methylpropyl sulfide	*l*	90.188	3386.2	3442.6
126	C_4H_4S	Thiophene	*l*	84.140	2865.9	2847.0
127	$C_4H_{10}S_2$	Ethylbutyl disulfide	*l*	122.252	4117.1	4055.4
128	$C_5H_{12}S$	Amyl mercaptan	*l*	104.215	3994.8	4091.3
129	C_5H_6S	2-Methylthiophene	*l*	98.168	3374.5	3396.5
130	C_5H_6S	3-Methylthiophene	*l*	98.168	3376.1	3398.2
131	C_6H_6S	Thiophenol	*l*	110.179	3876.6	3916.1
132	$C_6H_{14}S_2$	Dipropyl disulfide	*l*	150.306	5336.5	5358.4
133	$C_6H_{10}O_4S_2$	Milk acid β,β′-dithiane	*s*	210.272	4053.1	4168.6
134	C_3H_7OSN	1-Cysteine	*s*	105.159	2219.3	2285.8
135	$C_6H_{12}O_4S_2N_2$	1-Cystine	*s*	240.302	4212.8	4415.5

Appendix B: Group contributions for enthalpy of devaluation and standard chemical exergy of organic compounds (Szargut 1988)

Table III Group contributions for enthalpy of devaluation and standard chemical exergy of organic compounds*

		Gases		Liquids	
No.	Group	D°, kJ/mol	b°_{ch}, kJ/mol	D°, kJ/mol	b°_{ch}, kJ/mol
1	2	3	4	5	6
1	$-\overset{\vert}{\underset{\vert}{C}}-$	398.57	462.77	403.54	462.64
2	$-\overset{\vert}{\underset{\vert}{C}}H$	509.77	557.40	485.75	545.27
3	$-\overset{\vert}{C}H_2$	614.91	654.51	607.38	651.46
4	$-CH_3$	713.47	747.97	715.35	752.03
5	$=\overset{\vert}{C}-$	440.53	513.35	443.16	473.02
6	$=\overset{\vert}{C}H$	551.86	576.31	535.08	569.95
7	$=CH_2$	660.26	678.74	680.26	675.68
8	$=C=$	543.04	554.23	539.28	559.21
9	$\equiv C-$	510.20	519.58	494.34	515.27
10	$\equiv CH$	625.37	630.28	623.86	634.34
11	$-\overset{\vert}{\underset{\vert}{C}}-$ (ring)	413.34	461.01	379.03	425.11
12	$-\overset{\vert}{\underset{\vert}{C}}H$ (ring)	522.78	561.37	468.76	543.05
13	$-\overset{\vert}{C}H_2$ (ring)	629.05	662.29	614.16	653.63
14	$=\overset{\vert}{C}-$ (ring)	442.71	466.41	—	—
15	$=\overset{\vert}{C}H$ (ring)	559.18	576.65	542.95	568.28
16	$\leftrightarrow C\langle$	414.22	436.03	416.14	435.03
17	$-C\langle$	415.47	440.00	426.22	436.45
18	$HC\langle$	528.26	549.91	519.93	547.15
19	$-O-$	−111.59	−89.11	−131.17	−86.52
20	$=O$	−246.86	−245.09	−91.46	—
21	$-O-$ (ring)	−117.42	−97.12	−126.27	−106.64
22	$O\langle$	−89.96	−83.59	−84.43	−73.13
23	$-OH\left(\text{to } -\overset{\vert}{\underset{\vert}{C}}-\right)$	−68.42	−165.48	−137.54	−80.08
24	$-OH\left(\text{to } -\overset{\vert}{\underset{\vert}{C}}H\right)$	−63.90	−66.78	−85.11	−52.59
25	$-OH\ (\text{to } -\overset{\vert}{C}H_2)$	−56.66	−42.89	−84.82	−51.34
26	$-OH\ (\text{to } -CH_3)$	−77.00	−25.52	−76.87	−33.97

Table III Group contributions for enthalpy of devaluation and standard chemical exergy of organic compounds* (*Continued*)

		Gases		Liquids	
No.	Group	D°, kJ/mol	b°_{ch}, kJ/mol	D°, kJ/mol	b°_{ch}, kJ/mol
1	2	3	4	5	6
27	$-OH\left(\text{to }-\overset{\vert}{\underset{\vert}{C}}H\text{ ring}\right)$	−65.16	−46.78	−70.47	−58.16
28	−OH (attached to aromatic)	−66.12	−52.01	81.64	−47.57
29	$-\overset{\vert}{C}=O$	262.38	293.87	231.58	281.36
30	$-\overset{H}{\overset{\vert}{C}}=O$	388.64	412.68	356.72	400.21
31	$-\overset{O}{\overset{\Vert}{C}}-O-$	65.69	108.30	35.90	101.15
32	$-\overset{O}{\overset{\Vert}{C}}-O-\overset{O}{\overset{\Vert}{C}}-$	296.94	382.66	244.81	362.70
33	$-\overset{O}{\overset{\Vert}{C}}-OH$	—	168.04	—	155.11
34	$-O-\overset{O}{\overset{\Vert}{C}}-H$	207.01	250.09	183.96	—
35	$-\overset{O}{\overset{\Vert}{C}}-$ (ring)	—	305.66	—	277.76
36	$-\overset{H}{\overset{\vert}{C}}=O$ (attached to aromatic)	382.87	415.07	379.60	410.21
37	$-\overset{\vert}{N}-$	97.03	142.05	64.60	131.09
38	$-\overset{\vert}{N}H$	181.49	213.38	137.18	195.56
39	$-NH_2$	258.43	290.20	235.43	284.39
40	$=\overset{\vert}{N}$	56.82	72.98	−103.43	—
41	$\equiv N$	24.18	23.06	0	29.97
42	$-\overset{\vert}{N}H$ (ring)	186.19	209.24	151.20	199.37
43	$-\overset{\vert}{N}H_2$ (attached to aromatic)	237.80	240.16	216.84	269.24
44	$-\overset{\vert}{N}H$ (attached to aromatic)	153.58	196.27	—	—
45	$-\overset{\vert}{N}-$ (attached to aromatic)	77.07	134.06	—	—
46	$N\begin{smallmatrix}\nearrow \\ \searrow\end{smallmatrix}$	69.08	81.68	72.34	83.33
47	$-NO_2$	−42.30	1.45	−58.32	12.16

Table III Group contributions for enthalpy of devaluation and standard chemical exergy of organic compounds* (*Continued*)

		Gases		Liquids	
No.	Group	D°, kJ/mol	b°_{ch}, kJ/mol	D°, kJ/mol	b°_{ch}, kJ/mol
1	2	3	4	5	6
48	–O–NO	–19.66	18.89	—	—
49	$-O-O_2$	–89.91	–89.77	–121.71	–23.88
50	–N=C–	585.26	592.73	551.97	584.03
51	N≡C–	516.93	527.50	510.53	522.14
52	–S–	761.07	636.88	741.74	642.32
53	–SH	862.06	724.36	848.67	732.26
54	=SO	692.04	553.78	696.47	566.88
55	$-\overset{\vert}{\underset{\vert}{S}}O$	660.53	562.95	686.39	—
56	$-\overset{\vert}{S}O_2$	439.87	373.78	414.68	—
57	–S– (ring)	764.08	633.45	755.42	687.25
58	$S^{\nearrow}_{\searrow}$	781.15	653.56	762.45	654.41
59	–F	–15.00	16.25	–8.85	34.70
60	–Cl	46.08	26.24	42.89	32.01
61	–F (attached to aromatic)	15.08	45.16	–8.85	34.70
62	–Cl (attached to aromatic)	46.08	26.24	42.89	32.01
†63	Ortho (1,2)	4.35	7.66	0.0	0.0
†64	Meta (1,3)	1.76	3.47	0.0	0.0
†65	Para (1,4)	1.26	4.60	0.0	0.0
†66	1,2,3 Position	12.89	20.08	0.0	0.0
†67	1,2,4 Position	9.05	13.60	0.0	0.0
†68	1,3,5 Position	6.28	14.27	0.0	0.0
†69	1,2,3,5 Position	14.06	26.94	0.0	0.0
†70	1,2,3,5 Position	12.80	23.93	0.0	0.0
†71	1,2,4,5 Position	12.38	24.27	0.0	0.0
†72	1,2,3,4,5 Position	17.99	35.36	0.0	0.0
†73	1,2,3,4,5,6 Position	19.66	62.34	0.0	0.0
‡74	3 Atom saturated ring	62.30	49.04	83.68	83.68
‡75	4 Atom saturated ring	50.84	43.76	87.82	82.30
‡76	5 Atom saturated ring	–50.38	–45.52	0.00	0.00
‡77	6 Atom saturated ring	–83.05	–61.25	–28.79	0.00
‡78	7 Atom saturated ring	–73.81	–46.32	—	—
‡79	8 Atom saturated ring	–72.59	–33.47	—	—
‡80	Pentene ring	–50.38	–45.52	0.00	0.00
‡81	Hexene ring	–83.05	–61.25	–28.79	0.00

*Recalculated from data of [71] to the reference levels adopted in this book. Reproduced by permission.

†Branching in aromatic.

‡Ring correction.