THE UNIVERSITY OF CALGARY

A SOFT ENERGY SUPPLY AND DEMAND MODEL FOR ALBERTA

by

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A Master's Degree Project

Submitted to the Faculty of Environmental Design

In partial fulfillment of the Degree of

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A SOFT ENERGY MODEL FOR ALBERTA

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ABSTRACT

A Soft Energy Model for Alberta

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In this Master's Degree Project, a soft energy model of energy supply and demand in Alberta is developed to assess the potential for both reducing energy demand and increasing the contribution of income energy while maintaining a rising standard of living.

This is done from three main areas of investigation: 1) an examination of the context within which energy policy planning and decision-making takes place 2) an exploration of the relationship between energy policy and modelling 3) an evaluation of a sample of existing energy models.

Potentials for reducing energy demand in the domestic, commercial, transportation and industrial sectors are discussed and the structure of the model of these four sectors is described. Four supply sectors corresponding to energy quality types are also discussed.

Three scenarios are simulated on the model. In one, historically low energy prices, subsidies of capital energy sources, and penalties on income ones are maintained. This leads to high demand based largely on capital energy. In another the price of energy equals the cost of production and in the third, prices increase gradually. In the latter two scenarios, per capita demand drops between 1976 and 2026 and energy supply is met by income sources.

Three major conclusions were reached. First, energy intensities of end-use devices can be greatly reduced.

Second, income sources of energy can meet almost all of Alberta's energy demand in 2026.

Third, the use of income energy and the efficient use of energy will be inhibited unless institutional obstacles are removed and ignorance is reduced.

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INTRODUCTION

Canada is at a critical cross-road. The country's heavy dependence on dwindling, capital sources of energy cannot be sustained [1]. Technologies, policies and plans that minimise the vulnerability of the energy system must be developed and implemented. The path which Canada chooses to achieve this goal will have far reaching implications not only for the energy system but also for the entire Canadian economy and social structure.

Two possible paths are widely discussed: a hard path and a soft path. The hard path relies on the rapid expansion of centralised, large-scale, "high" technologies, especially in the form of electricity produced from nuclear energy and oil produced from oil sands. The soft path, on the other hand, relies on income energy sources, which to the greatest extent possible are diverse, flexible, matched in scale and in geographical distribution to end-use needs and have energy quality that is matched with its end use. These two paths lead to different technical, social, and political societal systems.

The purpose of this investigation is to explore the soft path alternative for Alberta. Through the development of a computerised model of energy supply and demand in Alberta, energy demand reduction measures and income energy technologies which bring about the transition to an income energy-based economy are studied.

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[1] Capital energy sources are finite in quantity and cannot be replaced once used. In contrast, income energy sources are regenerative and are limited by rate of use rather than supply.

The model is developed from three main areas of investigation. First, an examination is made of the context within which energy policy planning and decision making take place. This involves a delineation of human needs, societal goals, and energy goals both generally and as they apply to Alberta and Canada. Second, the relationship between energy policy and modelling is explored. The concept of models is defined and mental and formal models are discussed. Third, a sample of existing energy models is evaluated.

The Alberta soft energy model follows the convention of soft path analyses in that it begins with a study of the demand sector and options for reducing demand. Once demand has been determined, supply is allocated to meet demand according to a set of priorities. The demand sectors include domestic, commercial, industrial and transportation uses; the supply sectors include portable fuels, electricity, process heat and low temperature heat for use primarily within buildings. Each is discussed with reference to some of the alternatives now available for improving its energy efficiency.

Three scenarios are generated. In the first, present trends are continued. Energy remains very cheap until the turn of the century and then begins to rise. Capital sources of energy are subsidised and disincentives which discourage the use of income sources are maintained. In the second scenario, energy prices (and hence demand) are determined by actual production costs and the disincentives against income energy sources are removed, allowing them to compete fairly. In the third scenario, energy prices rise gradually to two to four times their current price. Incentives for capital energy are removed by the turn of the century and by 2026 there are charges for the social costs associated with capital energy sources.

The study concludes with a summary of the model-based research into future energy supply and demand in Alberta. Areas in need of further research are identified and some of the implications of the model for energy policy are presented.

1. ENERGY AND ENERGY POLICY

Energy is an essential ingredient for maintaining all life on Earth. Humans use energy in two broad ways: to power their internal metabolics and to power their external metabolics. That is, energy is used to power our bodies and our technological system. Food is the fuel of our bodies and must be of a certain quality and chemical composition. Energy for our technological system need not be of a certain type although some sources are more convenient or cheaper than others.

In recent years, it has been realised that the energy sources which have been used to power the technological system are non-renewable: they are being used at a faster rate than they are being created. What society has been doing is using its "capital" energy not its "income" energy and the reserves are declining. This situation has been referred to as "we're running out of energy" and the "energy crisis."

It must be pointed out that we certainly are <u>not</u> running out of energy. Earth receives 15.8 trillion EJ of solar radiation each year [2]. Only about 0.05 per cent of this total is used each year from the fossil and fissile reserves (Gabel 1980). Thus, we are running out of conveniently located, easily extractable fossil (and to a lesser extent fissile) fuels. This is not to understate the importance of the current situation, but rather is intended to place it in context.

Whether or not we are facing an energy crisis depends on how one defines "crisis." Humans are certainly facing a condition of instability

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[2] 15 800 000 000 000 000 000 000 000 000 joules or 1.5 x 10^{17} kWh per year (Gabel 1980).

which will lead to a decisive change in the energy system. A crisis can be defined as a "time for a decision". It is definitely time to make a decision on energy matters, to be concerned with energy policy.

1.1 The Context of Energy Policy

Energy (except as food) is not something of end-use concern. People do not really care about energy; they care about the life-support that energy makes possible [3]. This life support includes food, shelter, health and medical care, education, recreation, transportation and communication (Brown 1976). Energy policy, like energy, is not an end in itself but a means to an end. Energy policy-making is a means of setting energy goals, and energy goals are either a subset of, or a means of, obtaining societal goals. Ultimately, societal goals are designed to facilitate each member of the society to meet his or her needs.

1.1.1 Human needs

Two kinds of human needs can be identified: physiological (survival) needs and psychological (socio-cultural) needs. These two broad categories of human needs can be disaggregated and hierarchically organised. Laszlo (1974) summarised needs as follows:

- physiological needs (food, air, water, behavioural space, etc.)

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[3] For example, The energy industries' objectives are to survive as corporations and to turn a profit.

- safety needs (protection from weather, other species, and other humans)
- need to belong and love needs (family and social group membership)
- esteem needs (having the respect of oneself and one's peers in society)
- self-actualisation needs (fulfilling one's potentials in one's private and public capacities)
- cognitive needs (understanding one's relations to society and comprehending order in nature and the cosmos)
- aesthetic needs (perceiving beauty and order in experience)

In this hierarchy, higher needs require that the primary needs be met first.

1.1.2 Societal goals

In democracies, societal goals are formulated to help satisfy human needs. Jackson (1976) has suggested that there are eight goals for government:

- self-preservation (national sovereignty)
- human development
- freedom and human rights
- the just society
- democratic process (participation)
- stability and progress
- diversity
- the holistic view (a. the environment, b. the future) [4]

[4] Although it might be considered as a component of some of the other goals, such as stability and progress, a third component of the holistic view should be made explicit: c. the

1.1.3 Energy goals

From the consideration of human needs and societal goals, energy goals begin to emerge, as discussed in Gabel (1980), and Craig (1978) [5].

1.1.3.1 Sufficiency

The energy system should provide energy sufficient for life-support. All life support systems require an energy input. For example, the Canadian food system uses energy for fertilizers, pesticides, seeding, harvesting, shipping, storing, processing and preparing food. Likewise, all other life support systems have a need for energy.

1.1.3.2 Equity

It is not sufficient that there be enough energy for each individual but each individual must also have access to the energy that he or she needs. It follows from this that there must be some mechanism for distributing energy and/or energy harvesting artifacts and information.

1.1.3.3 Environmental harmony

The energy system should be designed to yield low (or no) negative environmental impacts. There should be minimal topographical, geological, hydrological, physiographic, limnological, meteorological, soil, vegetation, and wildlife disturbances. In addition, the energy system should minimise the use of land, water, air and space. Solid,

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rest of the planet.

[5] These goals are consistent with the energy goals of most individuals, however, each person's individual values, experiences and perspectives determines how much importance is placed on each goal. In addition, different contexts will lead to different ways of expressing these goals.

liquid, gaseous and heat wastes should also be minimised.

1.1.3.4 Sustainability and adaptability

The energy system should always be sustainable and it should be responsive and adaptable to both long and short term changes in demand, the availability of energy sources, and technologies. Implicit in this goal is that the system be flexible and therefore, not dependent on one source of energy. The system should be able to utilise a diversity of sources (i.e. don't put all your eggs in one basket). To be sustainable and adaptable, there must be back-up systems and emergency reserves.

1.1.3.5 Coercion

It is desireable to minimise or eliminate coerced human action. Energy system planners should never forget that the "meta-goal" is to allow human needs to be met. Using coerced labour is in conflict with this goal and is therefore to be avoided.

1.1.3.6 Safety

Another energy goal is to ensure that the energy system is safe to build, operate, maintain, and recycle. It should be safe to both workers within the energy system and consumers. Redundant safety systems are required.

1.1.3.7 Coordination

Parts of the energy system should be compatible. It is essential that the energy system be coordinated with other systems which attempt to achieve societal goals.

1.1.3.8 Manageability

The system should not be too complex to be controlled. Feedback systems should be included so that the system, as well as its interactions with other systems, can be monitored and managed.

1.1.3.9 Resource use

The energy system should minimise the use of energy within itself as well as its use of materials, humans and money. That is, the system should be thermodynamically and economically efficient.

1.1.4 Energy policy

Clearly, there is a discrepancy between the present state of the energy system and the preferred state which would exist if all the goals outlined above were being satisfied. Energy policy planning is done to narrow this discrepancy by formulating strategies to alter the energy system so that it will align more closely with specified goals.

1.1.4.1 Compatibility of goals

It is impossible to develop a strategy which will completely bridge the goals gap because of the inherent nature of systems; it is impossible to minimise or maximise all variables in a system at the same time. For example, it is clearly impossible to minimise material, human and energy uses in the energy system. The minimum use of these is zero and thus, there would be no energy system left. The real concern, therefore, is keeping all the variables within acceptable ranges. However, there are critical thresholds which cannot be exceeded (at least not on a continuous basis). For example, there is considerable discussion in the scientific community about the so-called carbon dioxide problem. Our energy use is increasing the concentration of carbon dioxide in the atmosphere, and it is believed by some scientists that this may increase the temperature of the atmosphere and thereby result in climatic change. A team from the University of East Anglia has predicted that droughts may occur over much of the United States, most of Europe and Russia, and Japan, while precipitation increases are expected over India and the Middle East (Gribbin 1980). If these researchers are correct, the impacts on the agriculture system could be devastating. This prediction suggests that a critical threshold for carbon dioxide levels may be exceeded and that the system must be modified so that the carbon dioxide variable is maintained within an acceptable range.

Determining what the acceptable levels or ranges are for each variable is an extremely difficult problem. In some cases, there is a wide divergence of opinion on what the acceptable ranges are, based on different analyses of the data, different values or both. For example, in the carbon dioxide-climate debate, there is an order of magnitude difference in the estimated temperature change which results from doubling the concentration of carbon dioxide in the atmosphere (Idso 1980). Energy policy development is the process of weighing these arguments and determining what ranges are acceptable. Therefore energy policy cannot be value free or objective.

The problem is further complicated by variables which may stay within acceptable ranges for so long that they are ignored and/or forgotten. If this situation persists, the variable may eventually be excluded from the paradigm [6]. Since the paradigm, in part, determines what is seen and what is not, the variable eventually may not even be considered. The environment (and the energy problem itself) are recent examples of this exclusion. Very few people thought much about the environment (or energy) until it was suddenly realised that human activities were approaching or exceeding critical limits. The environmental movement was a result of such a situation.

1.2 The Canadian Situation

1.2.1 Needs of Canadians

Canadians, being human, have human needs. However, these are manifested differently because of Canada's particular combination of climate, geography, culture, history, size, population and demography, landscape and ecology, and resources.

1.2.2 Goals of Canada

It is difficult to determine the goals of any society. However, some statements of goals are made by political parties, government organisations, and parliament. The Economic Council of Canada (1974) identified two goals of Canadian society; well-being and equity [7]. The areas of concern associated with these two goals included economic

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[6] See the discussion in Section 2.1.1 on mental models.
[7] The Economic Council suggested that well-being be measured by the extent to which individual needs are met.

matters [8], social rights and national identity, health, information, training and education, and natural and man-made environments.

Laszlo (1978) refers to a 1970 federal policy statement which identifies six Canadian goals: economic growth, sovereignty and independence, peace and security, social justice, quality of life and a harmonious natural environment. Highest priority was given to economic growth, social justice and quality of life policies.

At the time of the Club of Rome study of international goals, Laszlo (1978) suggested that Canadian goals were in a transitional state. The traditional view of economic growth as a means of obtaining goals showed signs of giving way to an awareness of the reality of serious global social, environmental and energy issues. Suggestions for goal modifications brought about by this new awareness were put forward by Pierre Elliot Trudeau, the Science Council of Canada, the Churches and others.

In recent years, the emphasis has shifted back somewhat towards the traditional goals of the economic growth paradigm.

1.2.3 Canadian energy goals

Gander and Belaire (1978) describe the energy goal of the federal government clearly:

> "...to ensure that Canadians achieve a sufficient measure of sustainable self-reliance in energy to ensure satisfactory

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[8] Economic matters include employment, consumption and production, and incomes and assets.

economic performance and enhanced individual and social well-being..."

1.3 The Situation in Alberta

1.3.1 Goals of Alberta

Alberta has the same basic goals as Canada although the emphasis is slightly different because of the unique perspective of Albertans, Alberta's geography, degree of industrial and social development, and because of politics. Alberta has a strong commitment to expanding its industrial base (in a quantitative sense) and this is reflected in its enthusiastic support for petrochemical and oil sands development.

1.3.2 Energy goals of Alberta

Energy goals in Canada are in a very large part dependent on Alberta. Alberta produces 86.5 per cent of the nation's petroleum, 84 per cent of its natural gas and 42 per cent of its coal (EMR 1978).

However, Alberta does not have stated explicit energy goals. Energy has been considered so abundant in the province that there has been little apparent need for energy planning. Alberta's concern with energy and the activities of the energy industries has been to use them as a means to develop the province's economy; this is an economic concern, not an energy one. Only the utilities seem to have any real concern for energy; it is their responsibility to provide sufficient energy on demand. Evidence of the provincial government's attitude is reflected in its belief that Albertans should benefit from the resources of the province and in its consequent subsidies of energy prices in the province [9]. If the government was genuinely concerned with energy, this "benefit" would go into other areas (such as home insulation or public transit) which would reduce energy use and which would give the greatest reward to the most, rather than the least, frugal user.

In spite of government subsidies of energy prices, some energy demand reduction programmes are still cost effective and are being instituted in various government departments and agencies under the coordination of the Energy Conservation Branch of Alberta Energy and Natural Resources (AENR 1980). In addition, the Alberta government is involved with some joint federal/provincial programmes including public information programmes and the Solar and Wind Energy Research Program which is funded by the Alberta/Canada Energy Resources Research Fund. Although the list of projects is quite extensive, it still represents a minor commitment to energy demand reduction and income energy. The Energy Conservation Branch shares less than five per cent of the total AENR budget with four other branches: The Resource Information and Renewable Resource Branch, The Financial Analysis Branch, The Computing Branch, and The Research Information Branch (AENR 1979a).

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[9] Market prices are lower than reference costs. The difference between reference cost and market price is referred to as the consumption subsidy. The Canadian average market price of oil (which is higher than the Alberta market price) is only 62 per cent of the reference cost. The ratio for natural gas is between 0.44 and 0.53 depending on the sector, and for electricity in Calgary, the ratio is less than 0.62 (EMR 1979). If environmental and other social costs are internalised, these subsidies would be greater still.

The government attitude is also reflected by the comments of provincial energy minister, Merv Leitch, on the solar and wind study by Wiggins (1978). In an interview with Canadian Renewable Energy News, Leitch said:

> "In my view, it makes better sense to direct the funds towards resolving Canada's vulnerability. ... It would look a little silly if we came up with a technological breakthrough (in solar and wind power) which reduced the value of our immense hydrocarbon resources" (Morton 1979).

Morton reports that the study has been shelved.

2. ENERGY MODELLING

In order to formulate energy policy to achieve the energy goals of a society, it is necessary to have some understanding of and insight into how the energy system works. In order to understand how the energy system works, it is necessary to be able to describe it. However, there are as many different descriptions of the energy system as there are people to describe it.

The energy system is an arbitrary component of the economic system which in turn is an arbitrary component of a yet larger system and so on recursively to the largest system (by definition), the Universe. Abstractions of the energy system, based on reality, are constructed through mental processes. What is included or excluded from this abstraction is dependent upon the describer's knowledge, experience, discipline, culture and other factors (Maruyama 1974). This abstraction, this representation of reality, is a model. Thus, a model, as used here, is some representation of a system, not, as is the painter's model, the thing to be represented.

Design or action is essential to humans who are constantly involved in modifying their environment. In order to be effective, humans must inventory, reflect and judge; all these activities require models. Jantsch (1975) defines a model as any static or dynamic concept which is supposed to represent, predict, prescribe or simulate structures and processes of reality. Models which were used in the past and which are now obsolete are now recognised as myths (Kuhn 1970). Our present perspective sometimes obscures the fact that our actions are based on myths. It is clear that models and myths are interwoven. When a model becomes effective as a basis for further design or action it becomes a myth (Jantsch 1975). All actions occur within the framework of a model and against the background of a myth.

2.1 Types of Models

There are various types of models. A model which is built in one's head is referred to by many names: world view, paradigm, or mental model. Other types of models are more familiar, including physical and mathematical models.

2.1.1 Mental models

Mental models are the most common type of model although they are probably least recognised as models. Human brains are well adapted to associating words and ideas and are good at relating objects in space. However, they have some noteworthy limitations.

The first limitation is that the brain of each individual is limited in its capacity and ability. Humans find it impossible to predict the behaviour of a small interactive servo-mechanism with a handful of variables once feedback is introduced (Beer 1975); the dynamics of a system as complex as the energy system, considered as a whole, are quite literally beyond comprehension. Beer (1975) asserts that the human brain only has the capability to discriminate over a scale of nine in any dimension.

Another limitation of mental models is that they tend to be ill-defined. As Hofstadter (1979) states:

> "Fantasy and fact intermingle very closely in our minds, and this is because thinking involves the manufacture and manipulation of complex descriptions, which need in no way be tied down to real events or things. Their purposes are often unclear and the modeller changes the contents and assumptions of the model both unknowingly and constantly."

The assumptions used in mental models are unclear, both to the modeller and to others, and there is no explicit statement of what information and experience is included. This makes it almost impossible to review the generation of the model.

Mental models are also limiting because they are hard to communicate. This is in part a consequence of their inadequate definition. Verbal descriptions are often, if not always, incomplete and may easily be misinterpreted.

In addition, mental models cannot be manipulated effectively. They are not good at dealing with dynamic systems that have feedback. Forrester (1968) has suggested that conclusions are not solved for but rather are drawn from analogy and this accounts, in part at least, for the "counter-intuitive" results yielded by his systems dynamic models.

Mental models have another problem: they cannot ever be completely debugged, either in the genotype or the phenotype. Obsolete models cannot be erased. Once some erroneous information is introduced, it is almost impossible to remove it from the brain [10].

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[10] R.B. Fuller has demonstrated how this is reflected in our language. In spite of 500 years of evidence to the contrary, we still say that we "see" the sun rise as if the sun revolved around Earth. Another example is Walter Cronkite's

At the genotypic level, Koestler (1967) suggests that our brains have a "schizophysiology" built into them. Inadequate coordination between the 'old brain' and the 'new brain' made the human instinct (built in models) and intellect (model building ability) fall out of step. In such situations, the mental model may suggest taking actions which are completely contrary to what is really needed. Beer (1975) suggests that we do not manage the world but that we manage a surrogate world. We are managing our mental models of the world and their inadequacy is primarily responsible for our current crises.

2.1.2 Formal models

A formal model might be thought of as any non-mental model. It is a model that has been externalised. By externalising this activity, it, like other functions externalised, may have its range and capabilities extended. Physical models are familiar to everyone. The architect's model helps one to visualise space and arrangement. Children have their imagination and play supported by models of babies and trucks.

Within the policy sciences, mathematical models have come to play an important role. In a mathematical model, all the structures and relationships of the system which are modelled are represented by numbers, equations and functions. This allows the model to be more specific than mental models (though not necessarily more accurate) and it allows it to be implemented on a computer which can be used to determine the consequences of the model within a matter of minutes.

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reference, during the lunar landings, to dust being thrown up into the "air" by the lunar rover.

By modelling the system in mathematical terms, the modeller is forced to make all his or her assumptions explicit. In addition, the model must be put in an organised framework. This permits easier communication of the model and permits the results to be easily duplicated.

Mathematical models can be built which are much more complex than any mental model could be. Furthermore, this more complex model can be worked through logically and coherently. This can help uncover counter-intuitive results and promote deeper understanding.

There are problems with mathematical models, however. Perhaps the key problem is the language they use, a language unfamiliar to the average person. The use of mathematical and computer programming languages gives a scientific aura to the models which may lead to unrealistic expectations. Koreisha (1979) points out the importance of demystifying the modelling process. Mathematical models are easy to misuse and their misuse can have harmful effects.

The utility of mathematical models should be judged by comparing them to mental and descriptive models, not by making reference to their predictive capability. Even if their predictions are imprecise, they may still be useful in organising an information base and in guiding decisions.

2.2 Model complexity

Determining how complex a model should be involves finding a balance. As Einstein said, "Things should be as simple as possible and no simpler." On the one hand, a model should be complex enough to be reasonable. On the other hand, it should be simple enough to be constructable and useable. Very large models may not be too helpful because they may contain too much that is not understood and not substantiated (Koreisha 1979).

Small models necessarily involve making simplifying assumptions which may lead to distorted or erroneous conclusions. The two most obvious of these simplifying assumptions are exclusion and aggregation.

No model can include everything. However, it is possible that important aspects of the system may be excluded. For example, the World3 model (Meadows 1974) which was popularised in *The Limits to Growth* has been harshly criticised for considering all nations as an aggregated whole, in spite of their great diversity.

Aggregation, like exclusion, is an important and necessary simplifying assumption but it must be used carefully and with discretion. Aggregating, or lumping together, various factors makes the model easier to construct but may obscure important variations.

2.3 Modelling Energy Supply and Demand

2.3.1 Energy demand modelling

Until quite recently, long term energy forecasts were done by what might be termed the GDP/primary energy law. It was assumed that primary energy demand would grow at the same rate as the Gross Domestic Product. This assumption has now been proven false.

In place of this type of forecast, a new type rapidly gained ground. It involves the breaking down of energy demand into sectors and then projecting energy demand for each sector. Forecasts within each sector are based on historical relationships between energy use and growth, often as econometric equations, and these are used to project for higher energy prices, technical advances and the effects of conservation policies.

Energy, Mines and Resources Canada employs this technique (EMR 1977b). Their model will be discussed briefly as an example of the type of energy modelling that is widely practised today.

2.3.2 Modelling energy supply

Energy supply modelling has two components: determining the required capacity for ensuring that demand can be met and determining the availability of energy resources. Determining the required capacity is a relatively straightforward task, assuming the demand and its temporal distribution are known. Determining the availability of energy sources is considerably more difficult, in part because evaluating the potential of each energy source is not done in the same way, and in part because of uncertainties. Many disciplines are required to evaluate supply including economics (since available energy is a function of price), engineering (since available energy is a function of the technology available to harvest or extract it), and geology, biology, climatology and hydrology (since available energy is a function of geology, climate, water flow and biological productivity) (Manne 1979).

At present, since most supply analyses consider fossil sources of supply, the reserves of coal, oil and natural gas are usually estimated. There are three main approaches to assessing fossil reserves: volumetric analysis, geological analysis, and analysis based on drilling results (Uhler 1977).

2.3.3 Modelling energy supply and demand in Canada

Energy Mines and Resources (EMR) and the National Energy Board (NEB) are responsible for estimating energy supply and demand in Canada. The NEB does this partly as a result of hearings into the matter at which all parties are welcome to participate. EMR does its work in-house. The NEB's work on energy supply and demand has historically been quite weak. Helliwell (1979) has described their demand analysis prior to their 1975 Report as "impossible." In addition, he argues that their supply analysis has switched back and forth between high and low estimates for no logical reason. Until early 1976, EMR's demand analysis was also quite inadequate.

While the NEB was working on their 1975 Report, an econometric model of energy demand was being built at EMR, the first results of which were published in 1976. This model represented a big jump forward in demand analysis. Forecasts were lower, in part because some consideration finally was given to the demand inhibiting effect of higher prices and a standard was set for documentation and quantitative analysis that the NEB felt pressure to adopt.

The EMR model was and is an econometric model. Econometric modelling is an approach to modelling in which the equations in the model describe the relationship of demand to the price of energy, other economic variables such as Gross Domestic Product (GDP), and some physical parameters such as population. The equations are determined using statistical techniques on historical data.

All available data on the relationship of energy demand and price of energy were determined when energy prices were falling in real terms. In addition, the range over which the price varied is not very wide and certainly does not include either present or expected energy prices. If these statistically derived constants are used for the forecasting of future energy prices, which are outside the range for which the constants were derived, a statistical error will be committed, the severity of which increases as the distance from the range is increased. EMR made some attempt at trying to correct this by treating estimates of price elasticities as variable parameters rather than as constants in a series of sensitivity analyses.

Another simplifying assumption which should be considered is the effect of time lags. In the EMR models, most of the estimated projection equations are static; the full effect of responses to price changes are felt immediately. This was corrected to some extent by using a set of judgemental price response coefficients.

Aggregation within the EMR model is another serious concern. Although the model is disaggregated into five regions and twelve separate fuels, the twelve sectors considered [11] are highly aggregated. For example, only two types of industry are considered, iron and steel and non-iron and steel.

2.3.4 Summary of demand and supply modelling

Energy demand modelling is in a transitional period. Although the current approach, in which demand is forecast by sector, is a great improvement over the GDP/primary energy approach and has resulted in lower forecasts, Leach (1979) has pointed out that this type of modelling is still unable to deal with the full complexity of the energy system and it says nothing about the form of the energy system. Energy demand is almost treated as an absolute over which there is little control. Future energy demand is not treated as though it is something which is planned but rather as something which can be forecast. However, there are so many variables that all forecasts must, in spite of any mathematical rigour, be considered as highly speculative. They

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[11] These are: domestic, commercial, industrial, road transport, air transport, marine transport, energy supply industries, non-energy use and fossil fuels used to produce electricity.

are primarily based on past lifestyles, past technologies and often past rates of growth.

Energy supply modelling consists of two components: estimating available energy and matching production and distribution capacities to demand. Several methods are available for estimating the quantity of fossil reserves that are recoverable under a given set of economic conditions. Although these methods are being refined, at present, none are able to determine with high confidence the recoverable reserves available as a function of cost (Uhler 1977). In addition to improving the methods for estimating these fossil reserves, there is a need to assess the potential contribution which could be made to the energy sector by income energy sources as a function of cost. At present, this assessment is low on the list of priorities of governments and the energy industries.

In the past, it has been assumed that decisions based on economic criteria will lead to the achievement of societal and energy goals. However, this tacit assumption has come under attack in recent years. Hazel Henderson (1978b), one of the most eloquent critics of this assumption claims that the central fact is that the energy sector is part of the whole economy and the paradigm, the pattern by which we understand the world, has broken down for our whole system of economic mapping. She claims that social costs, such as unemployment, inflation, pollution and traffic accidents, are the only part of the Gross National Product (GNP) which is growing, and that these social costs are considered as gains, rather than as losses in economic vitality. Everytime there is a traffic accident, the GNP goes up!

The crises which we are facing today are evidence of the breakdown of our paradigm. A new paradigm is needed which can help us adapt to the rapidly changing conditions of Canadian society.

When societies or individuals face rapidly changing conditions, the two most likely responses are 1) to rigidify and redouble their efforts or 2) to reconceptualise their situation and redefine their problem (Henderson 1978c).

Within the energy sector, the first response is characterised by the development of nuclear energy [12] and possibly oil sands [13].

The second response is the one taken by soft energy planners.

2.4 The Soft Energy Approach

The soft energy approach was pioneered by Amory B. Lovins for several countries including Canada (Lovins 1976).

The soft energy approach does not look back at historical energy use patterns to perform the demand analyses. Instead, demand is built up sectorally and is dampened by detected saturations and energy demand lowering feedback mechanisms. The levels of energy using activities and their energy intensities are projected based on present capabilities and from these, the end-use energy demand is calculated. End-use energy is

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[12] Henderson (1978b) has described this approach as "a last, baroque elaboration of that old direction, no longer sustainable."

[13] There is some discussion of linking the two directly, using nuclear energy as a power source in developing Alberta's oil sands (Anon 1980).

converted to primary energy using the efficiencies of the energy sources chosen to meet the demand [14].

Most of the work on soft energy planning has been done long-hand until quite recently. Models which use approaches similar to the soft energy approach have been developed by Leach (1979), CONAES (1978) and Craig (1978).

2.5 The Alberta Soft Energy Model

The Alberta soft energy model developed herein consists of three types of components: services, their energy requirements by energy quality and quantity, and ways of meeting these energy requirements. The general structure of the model is presented in Figure 2-1. The level of services is specified exogenously and represents an increased standard of living. Many of these activity levels are based on those presented by the AERCB (1978): others are chosen to represent a significant

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[14] Primary energy measures the total energy input into the economy. Delivered energy measures the heat content of fuels purchased by final consumers and is always less than primary energy owing to conversion losses, distribution losses for electricity and fuel consumed by the energy supply industries. End-use energy measures the energy used to perform a given task after accounting for losses associated with extracting the heat content of fuels. For example, in a house which uses a natural gas furnace, end-use energy is the energy which actually goes to heat the house. Delivered energy is the heat content of the natural gas delivered to the house and is typically one third greater than the delivered energy (since natural gas furnaces are typically 75 per cent efficient). The primary energy associated with heating this house is even larger because it includes not only the heat content of the delivered gas but the energy it took to explore for the gas, to extract the gas from the ground, to transport it to a processing plant, to process it and to transport it to the consumer's house.

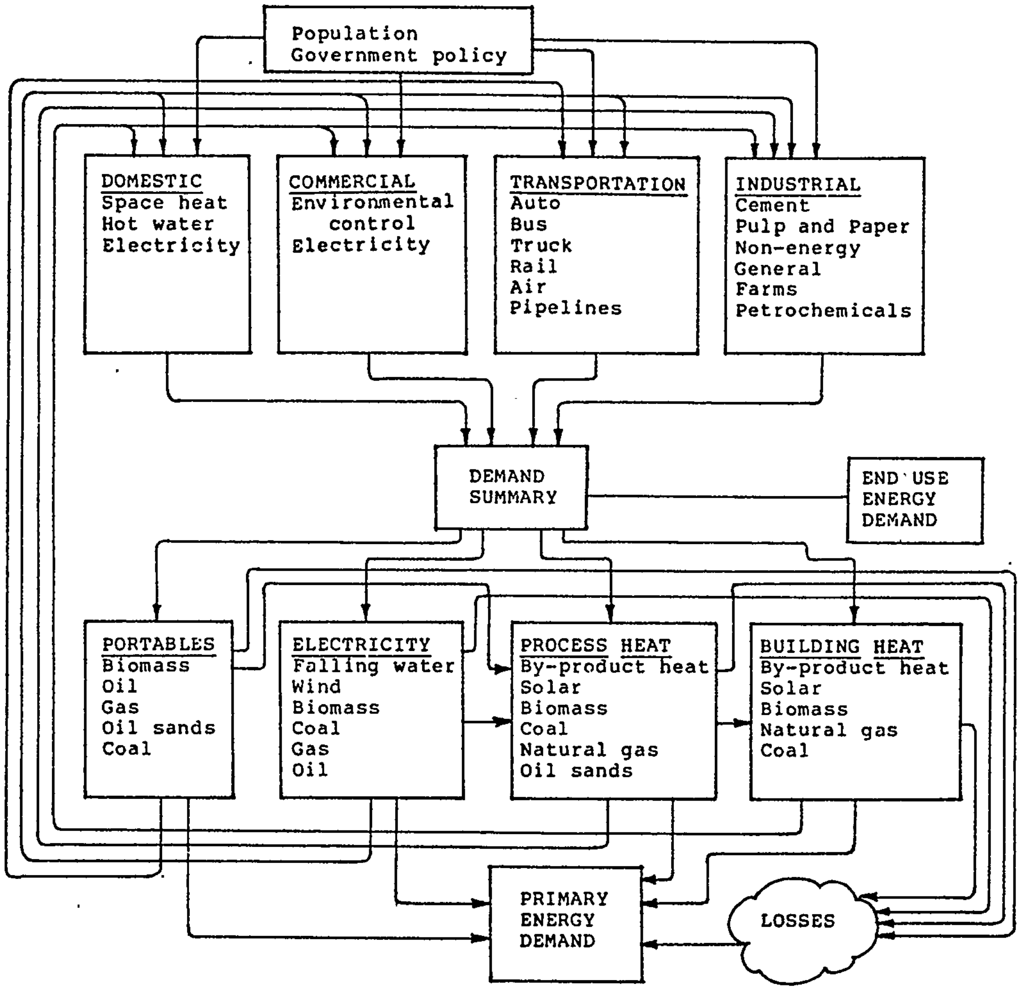

Figure 2-1. The Alberta soft energy model

increase in the per capita availability of services. These services, and their end-use energy demand are calculated in four sectors: domestic, commercial, industry, and transport [15]. Within each sector, end uses are specified according to four types of energy quality: portable fuels, electricity, high and medium temperature process heat, and low temperature heat. Each of these energy qualities has a supply sector which determines how much (if any) capacity must be built and

[15] For the transportation sector, end-use energy is taken as the delivered energy of the fuels used.

which sources are to be used, based on engineering costs, resource availability, and government policies.

Details of the structure and functioning of the model are given in Chapters 3 and 4.

3. ENERGY DEMAND IN ALBERTA

Within the Alberta soft energy model which has been developed for this project, end-use energy demand is determined for four sectors: the domestic sector, the commercial sector, the transportation sector and the industrial sector. Each of these in turn breaks down into subsectors.

3.1 The Domestic Sector

The domestic sector includes all houses and apartments. In 1976, the domestic sector accounted for about 15 per cent of Alberta's total energy use (AENR 1979b). This energy was used for five main purposes: water heating, cooking, operating electrical appliances, lighting, and space heating.

In order to determine energy consumption by the domestic sector, it is first necessary to know something about the domestic sector such as the population, the number of dwellings they live in, and the fraction of dwellings which are high density. Within the Alberta soft energy model, these are calculated in the domestic sector background housing characteristics subsector which is presented in Figure 3-1 [16]. As indicated by the variables which are within double circles in Figure 3-1, the population and the desired unit size are specified exogenously. The tables used are presented in Table 3-1.

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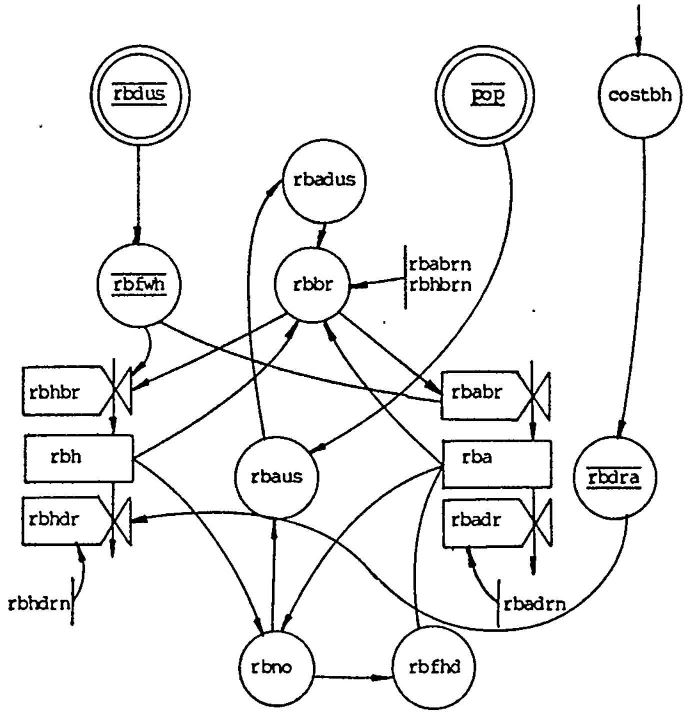
[16] The symbols used in Figure 3-1 and the other flow diagrams which follow are explained in Appendix D. A complete listing of the model is presented in Appendix A. The functions used are listed in Appendix B.



costbh	— cost of heat for buildings
pop	— population
rba	— number of apartment units
rbabr	— apartment unit building rate (units/a)
rbabrn	— normal apartment unit building rate (fraction/a)
rbadr	— apartment unit destruction rate (units/a)
rbadrn	— normal apartment unit destruction rate (fraction/a)
rbaus	— actual unit size (persons/unit)
rbadus	— ratio of actual to desired unit size (dimensionless)
rbbr	— building rate of dwelling units (units/a)
rbdra	— destruction rate accelerator (dimensionless)
rbdus	— desired unit size (persons/unit)
rbfwh	— fraction of population wanting houses
rbh	— number of houses
rbhbr	— house building rate (units/a)
rbhbrn	— normal house building rate (fraction/a)
rbhdr	— house destruction rate (units/a)
rbhdrn	— normal house destruction rate (fraction/a)
rbno	— total number of units

Figure 3-1. Domestic background housing characteristics subsector

Within the domestic sector, three types of energy demand are examined: electricity needs, space heating needs, and water heating needs. These needs are in turn distinguished according to whether the dwelling unit being considered is an apartment or a house [17].

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[17] A dwelling unit is defined as a housing facility for one family irrespective of the kind of building containing the unit.

Table 3-1. Exogenous variables for the domestic sector background housing characteristics subsector

Year	Population (millions)	Year	Desired unit size (pers/unit)
1976.	1.838	1976.	3.13
1986.	2.410	1981.	2.98
1996.	2.764	1986.	2.89
2006.	3.295	1991.	2.84
2016.	3.758	1996.	2.79
2026.	4.231	2001.	2.75

Notes: Population is from AERCB (1978) to 2006 after which it is extrapolated linearly. Desired unit size is given in persons/household and is from AERCB (1978). The value in 2001 is assumed to persist through 2026. Intermediary years are linearly interpolated by the functions "table" and "tabhl" (see Appendix B).

The electricity needs are projected by examining existing demand in Alberta, and considering the changing saturation of various appliances and their increasing efficiencies.

Space heating needs are considered in two ways. Existing houses can be "retrofitted" or upgraded so that their energy intensity is reduced. New dwellings requiring much less energy are cost-effective given present energy prices and even greater savings are considered feasible for the future when prices will be higher.

Water heating needs are projected by looking at present demand for hot water and incorporating the effect of changing household sizes [3], improvements in the efficiency of water heaters, and the potential for

[3] Household size is expected to drop from 3.13 persons per household to 2.75 persons per household by 2001 (AERCB 1978).

reducing the demand for hot water.

3.1.1 Water heating

Heating water currently uses 10 to 20 GJ/unit/a in Alberta (Ross 1980). Clothes and dish washers are large users of hot water and their market saturation is expected to increase between now and 2026 as presented in Table 3-2.

Table 3-2. Saturations of hot water using appliances

Year	Saturation of Dish washers (%)	Saturation of Clothes washers (%)
1976	36.9	73.2
1986	62.1	90.6
1996	75.4	91.5
2006	86.2	92.2
2016	87.4	92.7
2026	87.4	92.7

Notes: Saturations are the percentage of all homes with the indicated appliance from Calgary Power (1979) to 2006. The last year of the Calgary Power forecast is 2009 and the saturations in that year are assumed to persist through 2026.

Considerable improvements in the efficiency of the water heating system are possible. These can be accomplished by setting the thermostat at 60 degrees Celsius (instead of 70 degrees Celsius), annual maintenance, and monthly draining of sediments (OEC 1975). Insulating hot water pipes can also reduce the demand on the water heater. A good insulating jacket for the hot water tank can reduce heat loss by 80 per cent

(OEC 1975).

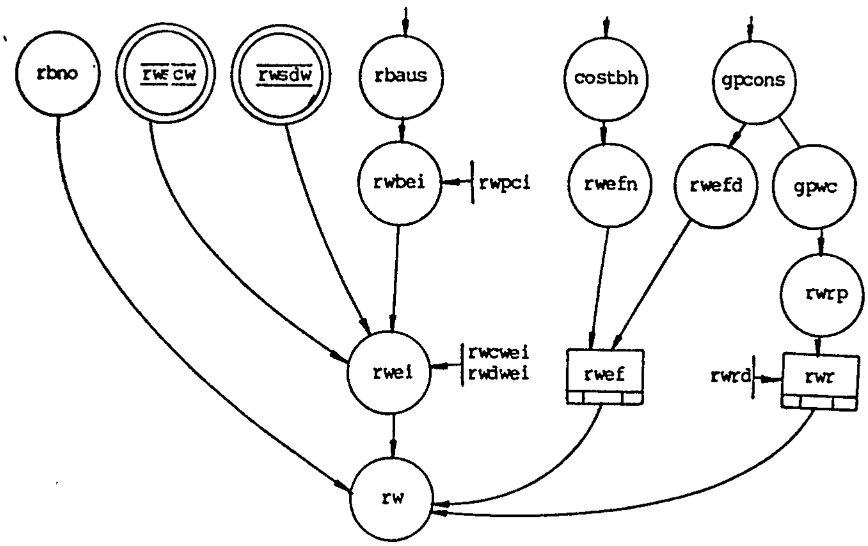
Substantial reduction in hot water use can be achieved with very little effort and/or cost. Aerators, flow controls, spray taps and self-closing mixing valves installed in faucets can all reduce water use by 50 to 75 per cent (Farallones 1979). Shower heads with flow restrictors can reduce water flow by 50 to 80 per cent with no reduction in pressure or "quality of the showering experience." All of these "technological fixes" are cost-effective. In fact, B.C. Hydro distributed shower flow restrictors to 300 000 households free of charge (Toller 1980). These 2.5 cent washer-like devices reduce water use by up to 40 per cent. Lifestyle changes hold potential for great savings with no capital investment [4].

The model of the Alberta domestic water heating subsector is presented in Figure 3-2.

3.1.2 Electricity demand

Albertans use electricity in their homes to operate appliances and lights. In 1979, each house used approximately 23.8 GJ/a and each apartment unit used 14.3 GJ/a. This is broken down by end use in Table 3-3. Calgary Power expects this use to increase according to the index in Table 3-4. In spite of expected increases in the saturation of existing appliances and the introduction of new appliances, there is

[4] Many of these lifestyle changes consist simply of using a container to hold water rather than letting it run. For example, using dishpans instead of running water to wash dishes can reduce use from 115 litres to 20 litres (Farallones 1979).



costbh	— cost of low temperature building heat ($/GJ)
gpcons	— year in which government policy towards conservation introduced
gpwc	— year in which government water conservation policy introduced
rbaus	— actual unit size (persons/household)
rbno	— number of domestic units
rw	— domestic water heating energy demand (PJ/a)
rwbei	— domestic water heating basic energy intensity (GJ/a/unit)
rwcwei	— domestic water heating energy intensity from clothes washers (GJ/a/unit)
rwdwei	— domestic water heating energy intensity from dish washers (GJ/a/unit)
rwef	— domestic water efficiency fraction (index, 1976=1.)
rwefd	— time to implement rwef (years)
rwefn	— new rwef
rwei	— domestic water energy intensity (GJ/a/unit)
rwpci	— domestic water energy intensity per capita (GJ/a/person)
rwr	— domestic water demand reduction (dimensionless)
rwrd	— time to implement water reduction measures (years)
rwrp	— domestic water demand reduction potential (dimensionless)
rwscw	— saturation of clothes washers (dimensionless)
rwsdw	— saturation of dish washers (dimensionless)

Figure 3-2. Domestic water heating subsector

still considerable scope for decreasing the demand for electricity from the values expected by Calgary Power. Nørgard's (1979) work on Danish appliances revealed that very substantial reductions in the energy intensity of appliances are possible. Some of these reductions are cost-effective at present energy prices, while others will be economic with higher prices. Table 3-5 indicates present and possible energy requirements for the more common electric appliances.

Table 3-3. Domestic electricity use in a house for 1976

Appliance	Appliance Energy Use (kWh/a)	Saturation (%)	Weighted Energy Use (kWh/a)
Refrigerator - frost free	1400	58	812
- manual	700	61	427
Electric range	900	78	702
Microwave oven	250	5	13
Furnace fan	400	100	400
Freezer	800	91	728
Dishwasher	250	22	55
Air conditioners	1000	4	40
Television	250	133	333
Electric Dryer	800	61	488
Automatic washer	80	72	58
Water heater	4500	17	765
Lighting	500	100	500
Block heater	300	153	459
Interior car warmer	500	47	235
Space heating	10000	2	150
Extra heating	300	19	57
Water pressure system	120	13	16
Miscellaneous			328
TOTAL			6416

Source: Calgary Power (1979).

Today, apartment units use only 60 per cent as much electricity as houses. Assuming this ratio holds, the potential use in 2026, as presented in Table 3-6, becomes 12 GJ/a for each house and 7.2 GJ/a for each apartment unit [5].

Inhibiting these reductions is the inertia resulting from all existing appliances (which have an average lifespan of 10 to 15 years (Nørgard 1979)). The lack of consumer awareness of life-cycle costs for

[5] This assumes that electricity prices exceed 15.18 $/GJ.

Table 3-4. Index of electricity use per household (1976=1.0)

Year	Index
1976.	1.00
1986.	1.18
1996.	1.31
2006.	1.42
2016.	1.45
2026.	1.45

Notes: The index is derived from Calgary Power (1979) energy use for appliances and their saturations. The index value indicated for 2016 and 2026 is the one calculated for 2009 (the last year of the Calgary Power forecast). The index is calculated excluding the use of heat pumps and electric cars.

appliances results in a lower demand for efficient appliances than would be indicated on economic grounds.

The electricity component of the Alberta model is presented in Figure 3-3. It is assumed that all new appliances meet the efficiency criteria presented by Nørgard (1979). The reduced use per dwelling unit is delayed because of the phasing out of old appliances. The resulting use per unit is multiplied by the number of houses. Since apartment dwellers use only 60 per cent as much electricity (on average) as those living in houses (in spite of bulk metering), the use per unit is multiplied by 60 per cent times the number of apartments to yield the total electricity use by apartments.

Table 3-5. Energy intensity of appliances

Appliance	Current Energy Use (kWh/a)	Possible Energy Use (kWh/a)	Future Energy Use (kWh/a)	Break-even Cost ($/GJ)
Refrigerator - frost free	1400	1400	229	14.26
- manual	700	700	115	14.26
Electric range	900	845	440	13.55
Microwave oven	250	250	250	5.60
credit from reduced range use	-300	-280	-147	13.55
Furnace fan	400	400	140	10.10
Freezer	800	800	145	12.02
Dishwasher	250	95	95	5.60
Air conditioners	1000	500	500	5.60
Television	250	130	130	5.60
Electric Dryer	800	800	166	15.18
Automatic washer	80	71	71	5.60
Water heater	4500	2250	2250	5.60
Lighting	500	350	350	5.60
Block heater	300	100	100	5.60
Interior car warmer	500	166	166	5.60
Space heating	10000	4200	4200	5.60
Extra heating	300	150	0	5.60
Water pressure system	120	100	100	5.60

Notes: Present energy intensities are from Calgary Power (1979). Refridgerator, range and electric dryer energy intensities possible with present prices ("possible energy use") and those possible with higher prices ("future energy use") are from Nørgard (1979) with proportional reductions based on the larger average appliance size in Alberta relative to Denmark. Furnace fan, freezer, lighting and television present possible and future are directly from Nørgard (1979). All costs are based on data given by Nørgard, an average appliance life of 7 years and a 0.10 real rate of return. Indicated break-even costs include the costs of lost waste heat used for space heating (60%) with the assumption that heat is 0.25 times as expensive as electricity. Where a cost of 5.60 $/GJ is indicated, the future energy intensity listed is cost-effective at present energy costs and/or appliance costs. The microwave credit is based on the assumption that the microwave oven will replace one third of range use.

(Continued next page)

Table 3-5. (Continued)

For automatic dishwashers and clothes washers, Nørgard indicates no additional cost to go from a higher energy intensity than is current in Alberta to the specified improved levels. The water heater energy intensity is based on a 50% reduction for the reasons discussed in the text for water heating. The reductions indicated as possible for block heaters, interior car warmers and extra heat are based on the use of a timer. Extra heat would be unnecessary in a well designed house with minimum air leakage. As discussed in the domestic space heating section of the document, space heating needs of 15 GJ/unit are reasonable and this level (4200 kWh) has been used for electric space heating. The same measures will also reduce air conditioning demand. This reduction has been conservatively estimated at 50%.

3.1.3 Space heating

Space heating is probably the area where the greatest waste occurs and it has received the greatest attention. In existing buildings, simple measures such as weather stripping, plugging cracks around doors and windows, and better furnace maintenance can significantly reduce energy use. Savings as high as 75 per cent have been obtained at little or no significant cost (Anon 1978b). More capital intensive improvements to the building shell are cost effective. In fact, many are the best investments that the average homeowner can make. The return on investment will often exceed the rates on even the highest interest bonds.

Robert Williams has metaphorically referred to these improvements in building shells as "drilling for oil and gas in our buildings" and he suggests that they are the cheapest ways of obtaining energy

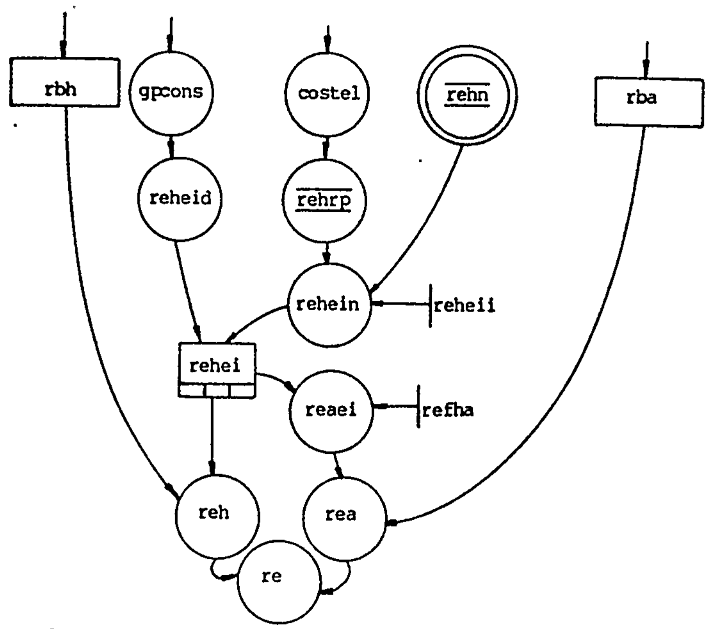
Table 3-6. Electrical appliance use for 2026 if electricity at 17 $/GJ

Appliance	Appliance Energy Use (kWh/a)	Saturation (%)	Weighted Energy Use (kWh/a)
Refrigerator - frost free	229	132	302
- manual	115	8	9
Electric range	440	92	406
Microwave oven	250	82	204
credit from reduced range use	-147	82	-120
Furnace fan	140	109	153
Freezer	145	90	131
Dishwasher	95	87	83
Air conditioners	500	4	20
Television	130	158	205
Electric Dryer	166	90	149
Automatic washer	71	93	66
Water heater	2250	19	429
Lighting	350	100	350
Block heater	100	149	100
Interior car warmer	166	53	87
Space heating	4200	0	0
Extra heating	150	0	0
Water pressure system	100	9	9
Miscellaneous	700		700
TOTAL			3332 kWh

(Harding 1979). He has estimated that to do so in the United States would be equivalent to acquiring oil for 2.30 $/GJ.

The average house in Alberta could have its space heating energy demand reduced from 152/ GJ/a to 70 GJ/a (Ross 1980). The retrofit potential of apartments is probably closer to 30 per cent since they are already more efficient. Thus the average apartment could reduce its space heating energy demand from 80 GJ/a to 55 GJ/a.

Within new dwellings, even greater savings are possible. For houses, the prototype is the Saskatchewan Conservation House in Regina



costel — cost of electricity ($/GJ)
gpcons — government policy towards conservation
rba — number of apartments
rbh — number of houses
re — domestic electric demand (PJ/a)
rea — domestic electric demand of apartments (PJ/a)
reaei — apartment's electrical energy intensity (GJ/a/unit)
refha — fraction of electricity used by apartments relative to houses (dimensionless)
reh — domestic electric demand of houses (PJ/a)
rehei — house's electrical energy intensity (GJ/a/unit)
reheii — initial (1976) rehei (GJ/a/unit)
reheid — time to implement a new rehei (years)
rehein — new rehei (GJ/a/unit)
rehn — normal domestic electric intensity of houses (index, 1976=1.)
rehrp — domestic electric reduction potential of houses (index, normal=1.)

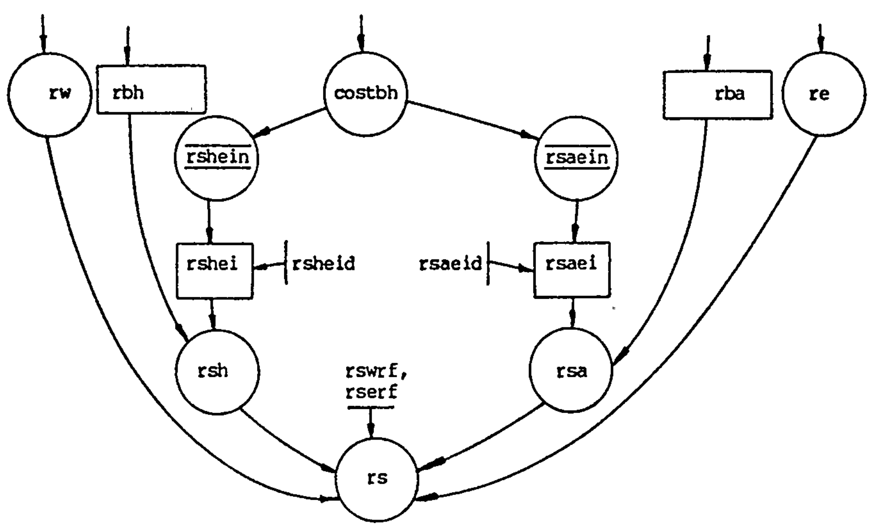
Figure 3-3. Domestic electric subsector

(Anon 1979). This 185 m^2 home uses only 5.1 GJ/a, after deducting 14.2 GJ passive solar gain, 4.6 GJ of human gain, and 19.6 GJ of electric appliance gain from the gross heat loss. This reduction in energy demand is accomplished at a cost of only 3500 dollars and is cost effective at energy prices only slightly higher than today's [6]. Applying the same techniques to smaller dwellings and multiple family dwellings could be expected to decrease their space heating energy needs

[6] Assuming a house life of 25 years, 3500 dollars at an interest rate of 0.1/a and energy savings of (152-5.1) GJ/a, the breakeven end-use energy price is 2.62 $/GJ. This corresponds to a delivered price for natural gas of 1.97 $/GJ (assuming furnace efficiency is 0.75).

by even greater amounts (due to shared walls and the greater fraction of gross heat gain made by solar, human and electric appliance gain). Apartment buildings could be designed to eliminate any need for space heating using the same techniques (Ross 1980).

Within the Alberta soft energy model, energy intensities for space heating of houses and apartments are determined from the price of low temperature heat, and these are phased in with a five year lag time. Waste heat from hot water, appliances and lights reduces the low temperature heat demand. The organisation of these variables within the model is diagrammed in Figure 3-4.

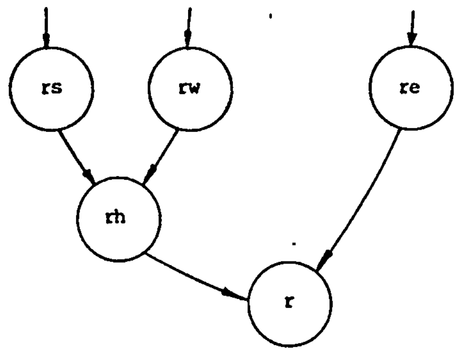


costbh	— cost of building heat ($/GJ)
rba	— number of apartments
rbh	— number of houses
re	— domestic electric demand (GJ/a)
rs	— domestic space heating demand (GJ/a)
rsa	— space heating demand of apartments (PJ/a)
rsaei	— energy intensity of apartments (GJ/unit/a)
rsaeid	— time to implement a new energy intensity (years)
rsaein	— energy intensity of new apartments (GJ/unit/a)
rsh	— space heating demand of houses (PJ/a)
rshei	— energy intensity of houses (GJ/unit/a)
rsheid	— time to implement a new energy intensity (years)
rshein	— energy intensity of new houses (GJ/unit/a)
rswrf	— water heat recoverable fraction (dimensionless)
rserf	— electricity recoverable fraction for space heat (dimensionless)
rw	— domestic water heating demand (PJ/a)

Figure 3-4. Domestic space heating subsector

3.1.4 Total domestic energy demand

After determining the individual components of the domestic energy sectors, these are summed, as shown in Figure 3-5.



r — total domestic energy demand (PJ/a)
re — total domestic electricity demand (PJ/a)
rh — total low temperature heat demand (PJ/a)
rs — total domestic space heat demand (PJ/a)
rw — total domestic water heat demand (PJ/a)

Figure 3-5. Domestic energy use

3.2 The Commercial Sector

About 16 per cent of all energy utilised in Alberta is used within the commercial sector (AENR 1979b). This energy is employed largely to operate environmental control equipment in buildings. Commercial buildings include a wide variety of uses. Statistics Canada defines as commercial all those users that are billed under "commercial" rates by utility companies. These are office complexes, retail and wholesale facilities, institutional facilities and light industry. Apartment buildings with bulk metering are sometimes included in the commercial sector, but in this study these are considered in the domestic sector.

Energy use in commercial buildings is generally rationalised on a unit area of floor space. However, even after such rationalisation, there is still a large range of energy use, even among buildings of the same type (Ross 1978;Stein 1977). In the survey of buildings in Calgary undertaken by the Faculty of Environmental Design, specific energy needs [7] varied from 11 W/m^2 to 577 W/m^2 with an average value of 98 W/m^2 (Ross 1978). Ken Cooper, chief architect for Canada Square Corporation, has estimated the average specific energy use of office buildings in Calgary at 65 W/m^2 (Peters 1979). A reasonable estimate of average specific energy needs of all commercial buildings in Alberta is 80 W/m^2. Of this need, only 19 per cent is for electricity (AERCB 1978).

Through better design and management, some new buildings are being built that have much lower specific energy needs. Gulf Canada Square in Calgary has a specific energy need of 12.9 W/m^2, and is clearly cost-effective at existing prices (Peters 1979) [8].

Older buildings can implement management and/or retrofit programmes and thereby reduce their energy demand by 25 to 50 per cent (Ross 1978). For example, in a study for the Grande Prairie school system, it was found that a saving of 25 per cent of the electricity use was possible with no capital investment (Ross 1979).

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[7] Specific energy need is the annual average energy use rate per unit of floor area.

[8] The building's design has been criticised by Jim McKellar, an architect in the Faculty of Environmental Design at the University of Calgary. He claims that it is not meeting the level of energy efficiency claimed by Gulf Canada. Employees within the building have complained of wide fluctuations in internal temperatures from the low teens to the mid-twenties (Salus 1980). These problems do not indicate an inherent problem with the design of energy efficient commercial buildings.

These improved energy performances of existing buildings and the much more energy efficient new buildings are incorporated into the model of the commercial sector, as presented in Figure 3-6. Commercial floor area per capita is assumed to grow from about 20 m^2 in 1976 to 40.3 m^2 in 2026. Most of this growth is assumed to occur early in the simulation with initial growth at four per cent gradually declining to 0.75 per cent by 2016. Also, pre-1976 building stock gradually declines to one half of its total in 1976. However, what buildings remain are retrofitted, the extent to which is dependent upon energy prices.

New buildings are all designed for a 12 W/m^2 specific energy need. As the price rises, new buildings eventually drop their specific energy need to 9 W/m^2. Within the model (as in the real world) government policy can shorten the lag time between price increases and the time of retrofitting the building.

As the buildings use less energy, the fraction of the total electricity need to total energy need increases. The assumed ratio is presented in Figure 3-7 [9].

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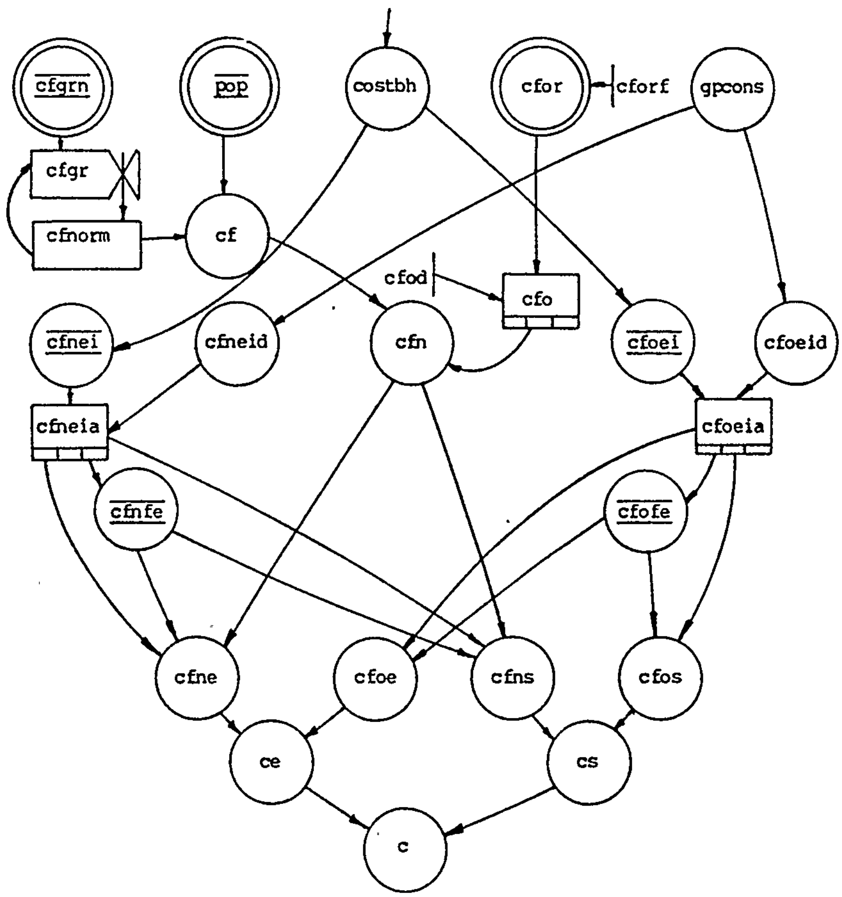
[9] Figure 3-7 is a graphical representation of the table used to determine cfnfe and cfofe in Figure 3-6. Like all other variables which look up values in a table function (and which are underlined and overlined in the diagrams), intermediate variables are linearly interpolated. For more details on table functions, see the listing of the functions "table" and "tabhl" in Appendix B. The actual values used in this and other tables are included in the model listing which can be found in Appendix A.



c — commercial energy use (PJ/a)
ce — commercial electric energy use (PJ/a)
cf — commercial floor area (m^2)
cfneia — actual new commercial floor energy intensity (W/m^2)
cfgr — commercial floor area growth rate
cfgrn — commercial floor area per capita normal growth rate
cfn — commercial floor area new (m^2)
cfne — new commercial buildings electric demand (PJ/a)
cfnei — new commercial buildings energy intensity (W/m^2)
cfneid — time to change cfnei to cfei (years)
cfnfe — new commercial fraction electric (dimensionless)
cfnorm — normalised commercial floor area (m^2/capita)
cfns — new commercial space conditioning energy need (PJ/a)
cfo — old commercial floor area (m^2)
cfod — life of commercial buildings (years)
cfoe — electric demand of old commercial buildings (PJ/a)
cfoei — energy intensity of old commercial buildings (W/m^2)
cfoeia — actual cfoei
cfoeid — time for cfoei to replace cfoeia (years)
cfofe — fraction of energy use in old buildings which is electric
cfor — ultimate old commercial buildings remaining (m^2)
cforf — final remaining commercial floor area (m^2)
cfos — space conditioning energy needs of old commercial buildings (PJ/a)
costbh — cost of building heat ($/GJ)
cs — commercial space conditioning needs (PJ/a)
gpcons — year of implementing government conservation policy
pop — population

Figure 3-6. Commercial energy use sector

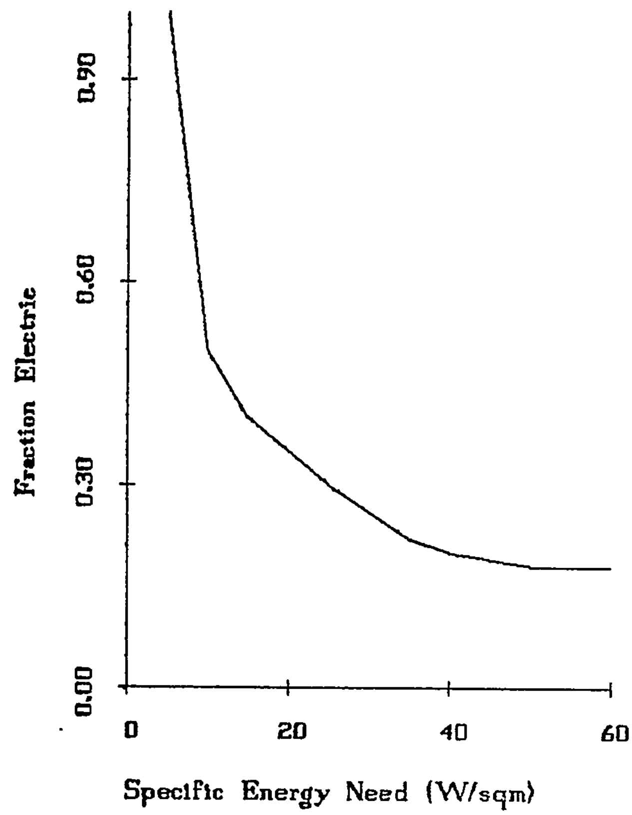


Figure 3-7. Fraction of energy demand which is as electricity at varying specific energy needs

3.3 The Transportation Sector

The transportation sector includes all horizontal modes of transport. Elevators and escalators are included as components of the commercial, domestic or industrial sectors. The modes considered within the model of the transportation sector are: air passenger, air freight, rail passenger, rail freight, automobiles, buses, trucks, and pipelines. The 1977 energy demand for each of these is presented in Table 3-7.

Table 3-7. Transportation demand in 1977

Passenger

Mode	Demand km/a/cap	Intensity MJ/seat/km	Load %	Total Energy PJ/a
Auto urban	4000	2.5	32.5	60.0
Auto inter-city	7900	1.4	60.0	35.0
Bus urban	170	1.1	60.0	0.6
Bus inter-city	250	0.5	60.0	0.4
Air	2500	2.2	55.0	18.7
Rail	125	0.7	40.0	0.4

Freight

Mode	Demand t-km/a/cap	Intensity MJ/t/km	Total Energy PJ/a
Truck urban	1800	5.1	17.1
Truck inter-city	3100	1.8	10.5
Air	40	29.8	2.1
Rail	35000	0.4	26.5

Notes: All travel demands (except passenger rail) are derived from the other columns and rounded. Passenger rail is from StatsCan (1978) and is the national average for 1975. Energy intensities are from EMR (1977a) and are the lowest values when a range is given in order to discount the effect of load factors which are here considered separately. Energy intensities of automobiles are based on the average fuel rating of 18.8 litres/100 km (23.5 litres/100 km urban, 13.5 litres/100 km inter-city) divided by four seats. Load factors for auto travel are based on American average occupancies of 1.3 out of 4.0 for urban transportation (1/2 rush hour at 1.2, half other at 1.4) and 2.4 out of 4 for inter-city transportation (Hayes 1977). Air and rail load factors are estimated from StatsCan (1978). AERCB (1978) has estimated total road energy demand at 123.5 PJ/a in 1977. Ross (1980) attributes 95 PJ to auto use in 1976. If this level persisted into 1977, 28.6 PJ/a would remain for trucks and buses. This is assigned according to the ratios in EMR (1977a). Air and rail totals are from AERCB (1978,p.5-56). Air is assumed to be 90% passenger, 10% freight. Rail passenger energy demand is calculated from the other three rail columns and rail freight demand is the difference between total rail and rail passenger. The population in 1977 is taken as 1.9 million (AERCB,1978).

3.3.1 Automobile transport

As is clear from Table 3-7, automobile transport is by far the greatest transportation energy user. It is also one of the least energy efficient. In the 'typical' car, only about 11 per cent of the fuel burned goes into useful work at the wheels (Leach 1979). The rest of the energy in the fuel goes to the exhaust (33%), cylinder cooling (29%), air pumping (6%), piston ring friction (3%), other friction (5%), accessories (2.5%), transmission (1.5%), axles (1.5%), braking (3.5%) and coasting and idling (4%).

There are several ways that the energy demand for automobiles can be reduced over varying time frames. In the near term, better driving habits can make a difference. These include making as few abrupt movements with the gas pedal as possible, combining trips, avoiding rush hours, car pooling and highway driving at 90 km/h instead of 100 or 110 km/h. These and other good driving habits, which are described in The Car Mileage Book (OEC 1977) can reduce fuel use in the automobile subsector by 3 to 5 per cent (Leach 1979).

By timing city traffic signals to correspond to traffic flows, idling time can be reduced, as can traffic congestion, accidents, and driver frustration (Anon 1975). The City of Calgary is in the process of installing traffic detectors in roads, which when connected to a central computer, will monitor traffic circulation and adjust signal timing accordingly. This system is likely to save a significant amount of gasoline.

Keeping automobiles in better tune can reduce fuel consumption. A test of car maintenance undertaken by Champion Spark Plug Company found that an average saving of 9 per cent could be realised (OEC 1977).

Some improvements in fuel economy can be made in existing cars through retrofitting. Possible retrofit measures include installing special carburetors designed for efficiency (5%-10%), devices which level out fuel pulses from the pump (10%-20%), thermostatically controlled electric cooling fans, and radial tires (2.5%) (Anon 1980a).

In the medium term, old cars can be replaced by smaller cars that use less energy. In fact, government guidelines dictate improved fuel economy for new cars and it is primarily the smaller car approach that was chosen by the automobile manufacturers to meet these guidelines. Automobiles produced in 1980 must have a fleet average gasoline fuel economy of 11.7 litres/100 km and this will be reduced to 8.56 litres/100 km in 1985 (EMR 1977a). Higher fuel prices and/or waiting lines at service stations are likely to encourage a shift to more energy efficient vehicles. Within this time frame, public transit could be improved in the larger cities and auto use discouraged by high parking rates and special lanes for buses and full cars.

Over longer periods, car design can be improved to reduce fuel consumption. Curtis (1980) claims that improvements in fuel consumption from the engine alone could reach 20 per cent and another 20 per cent could be reduced with a modern transmission system. Grey estimates that the fuel use of American cars could be reduced by 67 per cent by measures other than weight reductions (Leach 1979). In addition, urban areas could be designed to decrease the need for automobile use and make public transit more economical and convenient. Higher density developments result in shorter distances between sources and destinations. This is reflected in the lengths of road required by different types of dwellings as reported by the Real Estate Research Corporation (1974) and reproduced in Table 3-8.

Table 3-8. Relationship between housing density and road length (100 units)

	Length of Arterial Streets (m)	Length of Collector Streets (m)	Length of Minor Streets (m)	Total Street Length (m)
Single family conventional	1830	2135	14325	18290
Single family clustered	1675	5260	6705	13640
Townhouse clustered	1525	4115	3050	8690
Walk-up apartments	1145	2670	1370	5185
High-rise apartments	730	1480	520	2730

Reference: Real Estate Research Corporation (1974) p.147

Even for the same type of dwelling, different planning approaches can result in significant reductions in required road length and travel demand. When shorter distances are traversed, walking and bicycling become more feasible. With shorter roads for the same population, mass transit becomes more economical and convenient, since the frequency of service can be increased.

Urban automobile transport is considerably less efficient than inter-city automobile travel and the travel demand for the two is determined by different factors. As a result, the two are considered separately.

In both modes, fuel economy (and hence energy intensity) is determined by either the price of portable fuels or government standards.

Figure 3-8 presents the modelled structure of the automobile transportation subsector.

3.3.2 Air transportation

Air transportation used 21.3 PJ in 1977 (AERCB 1978). Of this amount, 19.2 PJ is assumed to be for passenger transport and 2.1 PJ for freight transport [10]. Typical energy intensities for a jet are 2.2 MJ/km/person for passenger transport and 29.8 MJ/km/t for freight transport (EMR 1977a).

Fuel consumption can be reduced by about 20 per cent in 1990 by continuing the shift towards single-class seating, by ensuring increased load factors and by expected technical improvements to the existing fleet (EMR 1977a). The Boeing 757's which will be introduced in late 1980 are 17 per cent more efficient than existing jets (Leach 1979).

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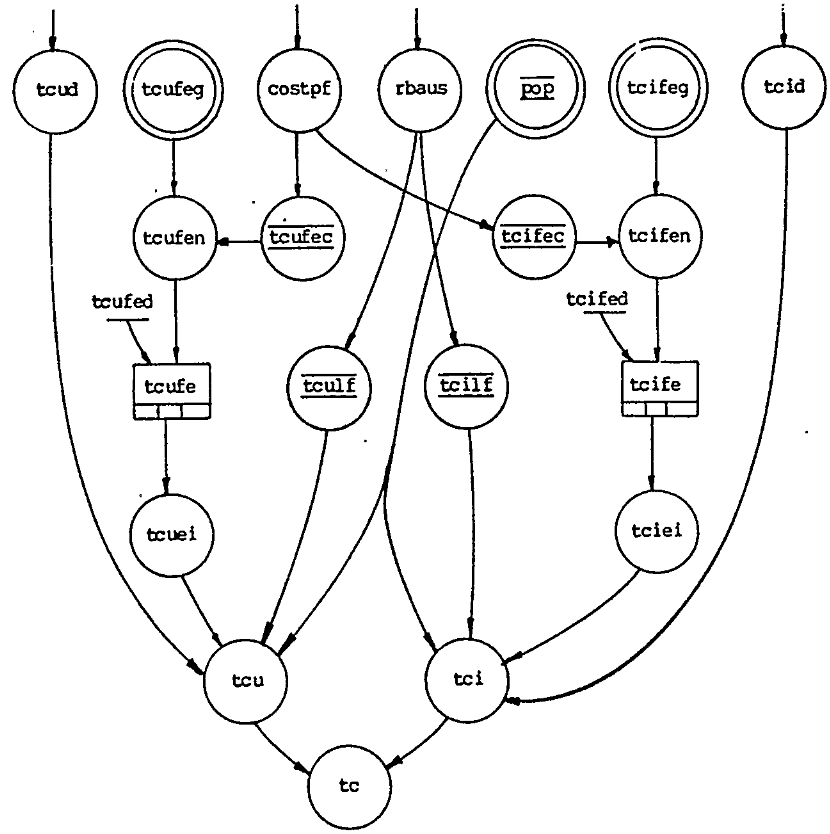
[10] This corresponds with the distribution in California (Craig 1978).



costpf — cost of portable fuels (\$/GJ)
pop — population
rbaus — actual unit size (persons/household)
tc — automobile energy demand (PJ/a)
tci — inter-city automobile energy demand (PJ/a)
tcid — inter-city automobile travel demand (km/a/capita)
tciei — inter-city automobile energy intensity (MJ/km)
tcife — inter-city automobile fuel economy (L gasoline/100 km)
tcifec — tcife from cost (L gasoline/100 km)
tcifed — time to implement a new fuel economy level (years)
tcifeg — tcife from government policy (L gasoline/100 km)
tcifen — tcife of new automobiles (L gasoline/100 km)
tcilf — inter-city automobile load factor (persons/vehicle)
tcu — urban automobile energy demand (PJ/a)
tcud — urban automobile travel demand (km/a/capita)
tcuei — urban automobile energy intensity (MJ/km)
tcufe — urban automobile fuel economy (L gasoline/100 km)
tcufec — tcufen from cost (L gasoline/100 km)
tcufed — time to implement a new fuel economy level (years)
tcufeg — tcufen from government policy (L gasoline/100 km)
tcufen — tcufe for new cars (L gasoline/100 km)
tculf — urban automobile load factor (persons/vehicle)

Figure 3-8. Automobile transport subsector

BOAC expects that its next generation of aircraft will have an energy consumption which is 50 per cent lower than that of current aircraft due to improved wing and engine design (Anon 1978c). (Anon 1978c; Leach 1979), This new twice-as-efficient fleet will probably begin to be introduced around 1990.

At present, as shown in Table 3-7, the average Albertan travels about 2 500 km/a by air. This is likely to increase. However, trips are likely to be longer because higher fuels prices are forcing airlines to consider abandoning short haul routes (Simaluk 1980). In addition, each Albertan has about 40 t-km of freight transported by air.

The model of the air passenger subsector incorporates a 20 per cent improvement in efficiency introduced over a one to two year period by the time liquid fuels reach 7 $/GJ. By that time, it is also assumed that load factors will increase from 55 per cent to 75 per cent. The new fleet of efficient aircraft is introduced beginning in 1990.

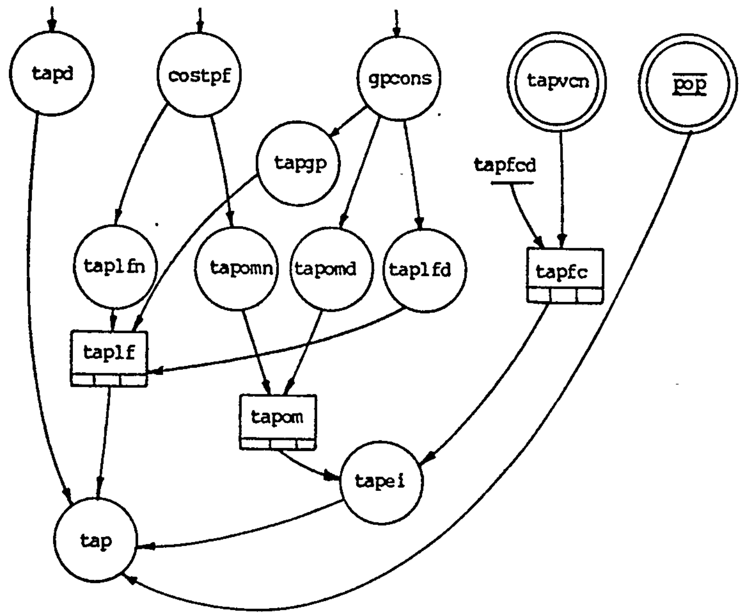
The improved efficiency of existing aircraft and the introduction of the new fleet of efficient aircraft occur concurrently in the air freight subsector.

The two air transport subsectors are outlined in Figure 3-9 and Figure 3-10.

3.3.3 Rail transport

In 1976, rail transportation used 26.9 PJ, all of which was derived from oil (AERCB 1978). Of this amount, 0.4 PJ was for passenger transport and 26.5 PJ was for freight transport.

Fortunately, because of its relatively low energy intensity, rail transport still dominates the freight transport sector as is clear in

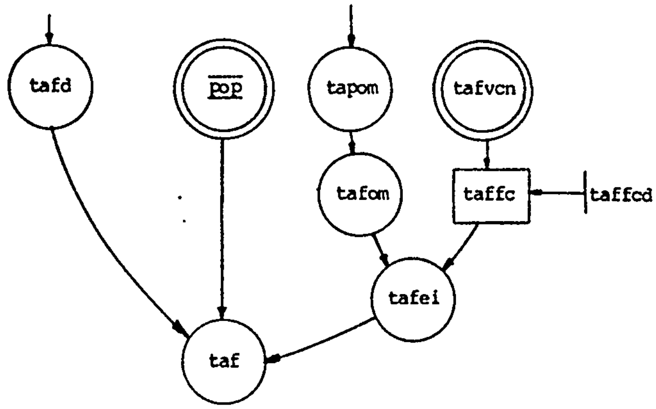


costpf — cost of portable fuels ($/GJ)
gpcons — year government policy on conservation introduced
pop — population
tap — air passenger transportation energy demand (PJ/a)
tapd — air passenger travel demand (km/a/capita)
tapei — air passenger energy intensity (MJ/km)
tapfc — air passenger vehicle fleet characteristics (MJ/km)
tapfcd — time to replace jets (years)
tapgp — government policy for jet load factors (dimensionless)
taplf — air passenger load factor (dimensionless)
taplfc — air passenger load factors indicated by cost (dimensionless)
taplfd — time to implement new load factors (years)
taplfn — new tablfc (dimensionless)
tapom — air passenger vehicle operation and maintenance index (1976=1.)
tapomd — time to implement new operation and maintenance practises (years)
tapomn — new tapom indicated by costpf (1976=1.)
tapvcn — tapfc from cost (MJ/km)

Figure 3-9. Air passenger transport subsector

Table 3-7. Today's freight trains are highly efficient in their use of energy. They are built to careful, rugged specifications and are powered by efficient engines. Trains carry large loads which are usually maximised to the requirements and design of the engine. In fact, the energy intensity of trains has decreased since 1950 (Clark 1975).

Despite the high energy efficiency of freight trains, there are still some modest savings which can be attained. These have been estimated at 10 per cent [11] by CONAES (1978) and at 15 per cent by



pop — population
taf — air freight energy demand (PJ/a)
tafd — air freight demand (t-km/a/capita)
tafei — air freight energy intensity (MJ/t/km)
taffc — air freight fleet characteristics (MJ/t/km)
taffcd — time to replace the fleet (years)
tafvcn — air freight fleet characteristics from cost (MJ/t/km)
tafom — air freight operation and maintenance practises index (1976=1.)
tapom — air passenger operation and maintenance practises index (1976=1.)

Figure 3-10. Air freight transport subsector

Leach et al (1979).

The passenger rail situation is not nearly so sanguine. Inter-city passenger rail service in Alberta has deteriorated in recent years and is plagued with obsolete equipment, low load factors, infrequent service, high prices and low priority access to rail lines. This occured in spite of its potentially low energy intensity [12]. The United Kingdom is developing a 240 km/h Advanced Passenger Train which is expected to have a fuel consumption 20 to 30 per cent lower than

[11] In scenario II, when oil is 12.79 $/GJ and electricity is 25 $/GJ (1975 US$).

[12] There is some conflict in the literature as to whether trains or buses are the most efficient. The discrepancy comes from whether or not the energy cost of the highway is included. In a soft energy society, it is quite conceivable that extensive networks of divided highways would give way to more modest roads for local use which could make inter-city train transportation the most efficient passenger transport mode. See, for example, Swan (1980).

conventional inter-city trains (Leach 1979). This type of vehicle may be well suited to the 300 km Calgary-Edmonton line which was the fourth heaviest travelled air route in Canada in 1975. Airline passage between the two cities in 1975 was 421 300 passengers (StatsCan 1978). An Edmonton-based lobby group, Transportation 2000, is trying to get work started on just such a system but government reaction has been less than enthusiastic (Anon 1980b).

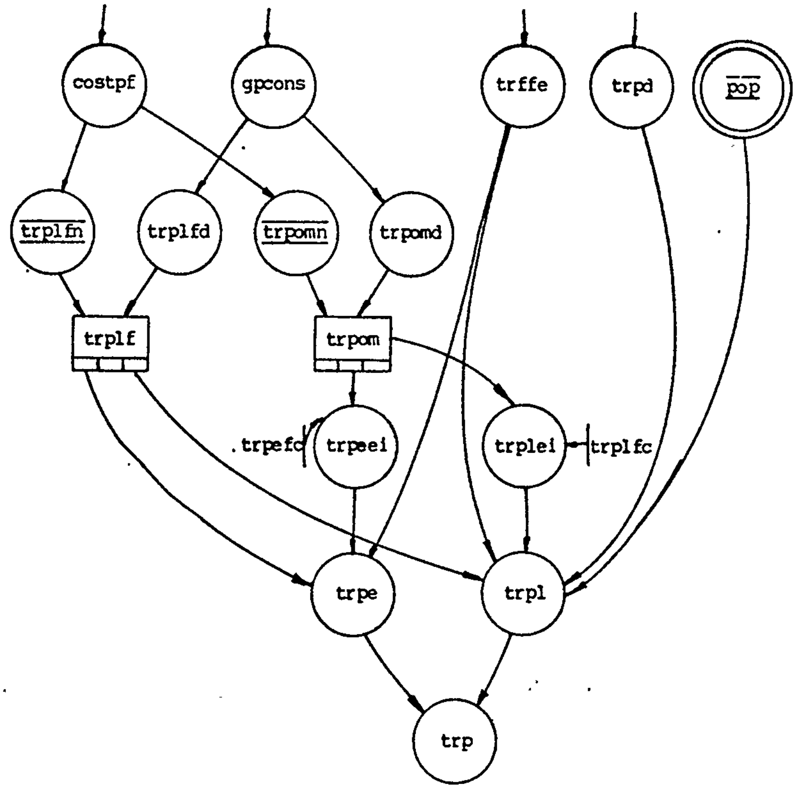
The model of the rail transport subsectors considers the electrification of rail lines, increases in efficiency with higher prices and changes in demand for transportation services over time. The structure of the subsector is presented in Figure 3-11 and Figure 3-12.

3.3.4 Non-automobile road transport

Two types of non-automobile road transport are considered; trucks and buses. Each of these is distinguished according to whether it is urban or inter-city.

Buses are generally considered to be the most energy efficient of the motorised passenger transport options widely available. In Canada, urban transit, which is primarily by bus, has increased modestly over the last decade but inter-city and rural passenger bus transit has decreased dramatically (StatsCan 1978).

Energy savings are possible due to driver education and better maintenance (3%), improved engines (5%), and closer matching of engine size to load and improvements in transmission, rolling resistance,

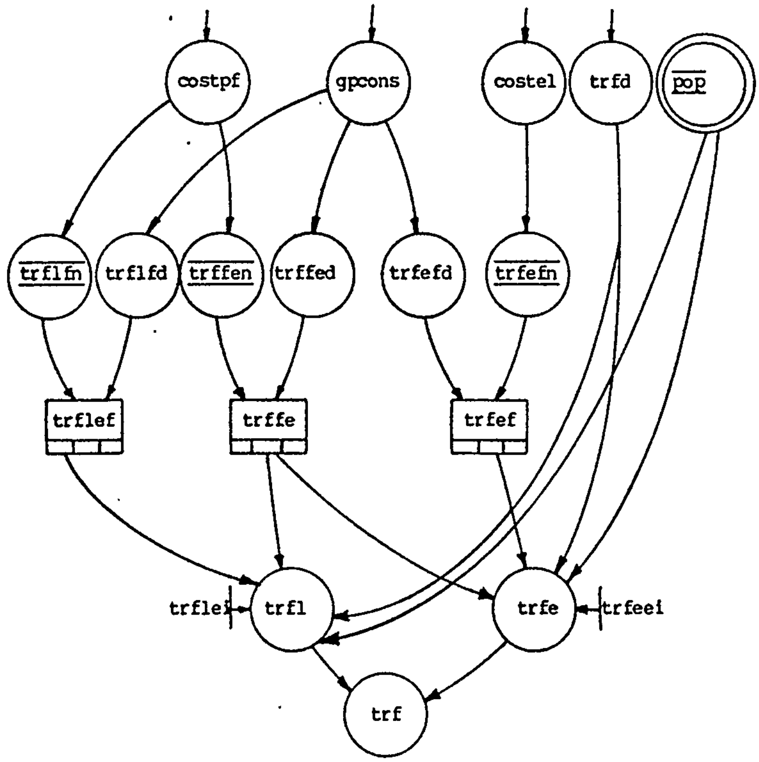


costpf — cost of portable fuels ($/GJ)
gpcons — year government conservation policy implemented
pop — population
trffe — rail freight fraction electric (dimensionless)
trp — rail passenger energy demand (PJ/a)
trpd — rail passenger travel demand (km/a/capita)
trpe — rail passenger electric demand (PJ/a)
trpeei — energy intensity of electric passenger trains (MJ/km)
trpefc — rail passenger fleet characteristics (MJ/km)
trpl — rail passenger liquid fuels demand (PJ/a)
trplei — energy intensity of liquid fuelled passenger trains (MJ/km)
trplf — rail passenger load factor (dimensionless)
trplfc — rail passenger fleet characterisitcs (MJ/km)
trplfd — time to implement a new load factor (years)
trplfn — new trplf
trpom — rail passenger operation and maintenance practises index (1976=1.)
trpomd — time to implement a new trpom (years)
trpomn — new trpom

Figure 3-11. Structure of the rail passenger sub-sector of the model

lubricants, etc. (7%-10%) (Leach 1979).

Increasing load factors can also play an important role. As mentioned in the consideration of automobiles, higher density development can make bus service more feasible and convenient.



costel	— cost of electricity ($/GJ)
costpf	— cost of portable fuels ($/GJ)
gpcons	— year of implementation of government policy on conservation
pop	— population
trf	— rail freight energy demand (PJ/a)
trfd	— rail freight transport demand (t-km/a/capita)
trfe	— rail freight electricity demand (PJ/a)
trfeei	— electric rail freight energy intensity (MJ/t/km)
trfef	— rail freight efficiency index (1976=1.)
trfefd	— time to implement improved efficiencies (years)
trfefn	— new trfef (1976=1.)
trffe	— rail freight fraction electric (dimensionless)
trffed	— time to electrify rail freight (years)
trffen	— new trffe (dimensionless)
trfl	— rail freight liquid fuel demand (PJ/a)
trflef	— liquid rail freight efficiency index (1976=1.)
trflei	— liquid rail freight energy intensity (MJ/t/km)
trflfd	— time to implement improved efficiency in liquid rail (years)
trflfn	— new trflf

Figure 3-12. Structure of the rail freight transportation sub-sector

Rice (1974) has suggested that inter-city buses could increase their patronage by increasing their roominess. Although the theoretical maximum efficiency would be reduced, the actual efficiency (not to mention passenger comfort) would be increased. The popularity of the Calgary-Edmonton Red Arrow seems to support this contention [13].

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[13] The Red Arrow is a bus service running between Calgary and

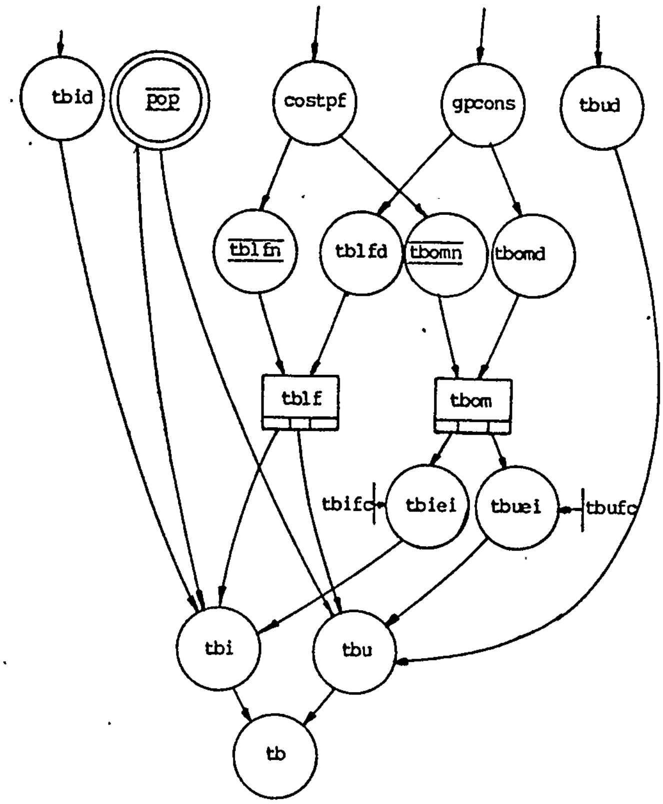
Truck transport used 22 per cent of all transportation energy in Canada in 1972 (EMR 1977a), but only carried about 12 per cent of all freight by mass in 1973 (StatsCan 1978). This further emphasises the higher energy intensity of trucks relative to rail (see Table 3-7).

Energy saving measures for trucks can lead to improvements in fuel economy of 35 per cent and greater (Kinley 1980). Manufacturers and researchers see the existing available savings as "the tip of the iceberg" (Kinley 1980). Energy, Mines and Resources Canada has estimated that truck and bus fuel consumption can be reduced by 18 per cent by 1990 through increased use of improved diesel engines and minor low-cost technical improvements (EMR 1977a). Other savings include aerodynamic add-ons (6%), radial tires for bulk haulers (10%), a declutchable fan (3%-5%), and a speed reduction of 15 km/h from 105 to 90 km/h (10%) (Kinley 1980).

The Canadian Trucking Association has recommended eliminating special delivery, consolidating routes, avoiding rush hour traffic, installing radio dispatch systems, and operating only full units both ways as measures to conserve energy in the truck transportation sector (Kinley 1980).

All of these measures are incorporated into the model. The two subsectors, as modelled, are presented in Figure 3-13 and Figure 3-14.

Edmonton in which there are fewer seats than normal for inter-city buses, seats have fold-down desks (like airplane seats) and there is beverage service.

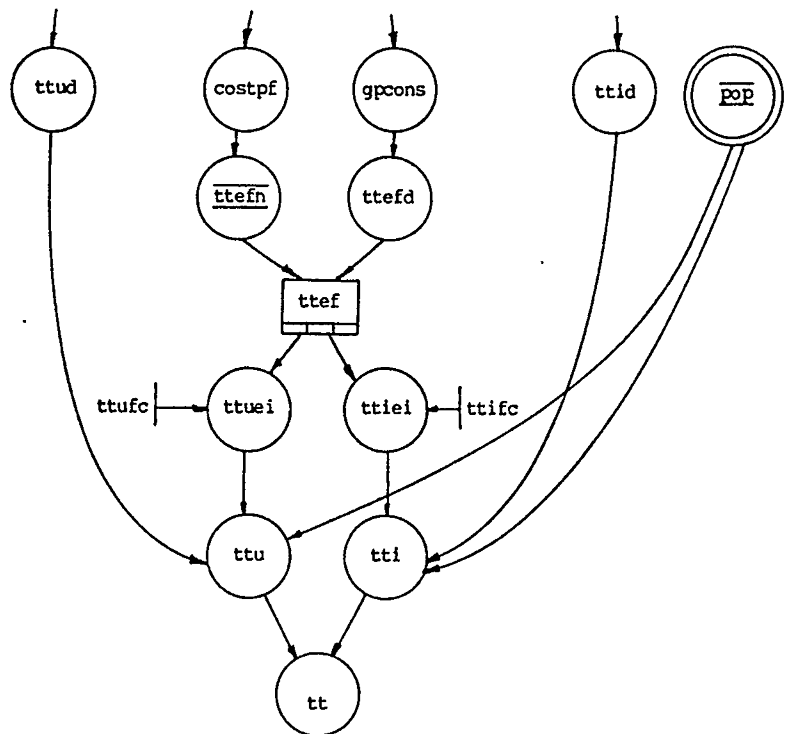


costpf	— cost of portable fuels ($/GJ)
gpcons	— year government conservation policy is implemented
pop	— population
tb	— energy use by buses (PJ/a)
tbi	— energy use by inter-city buses (PJ/a)
tbid	— inter-city bus travel demand (km/capita/a)
tbiei	— inter-city bus energy intensity (MJ/km)
tbifc	— inter-city bus fleet characteristics (MJ/km)
tblf	— load factor of buses (dimensionless)
tblfd	— time for tblfn to replace tblf (years)
tblfn	— new tblf
tbom	— bus operation and maintenance practises index (1976=1.)
tbomd	— time for tbomn to replace tbom (years)
tbomn	— new tbom
tbu	— urban bus energy use (PJ/a)
tbud	— urban bus travel demand (km/capita/a)
tbuei	— urban bus energy intensity (MJ/km)
tbufc	— urban bus fleet characteristics (MJ/km)

Figure 3-13. Structure of the bus transportation sub-sector

3.3.5 Pipeline transport

Pipelines are a very efficient means of transporting some types of freight. In Alberta, they are used primarily to transport oil and natural gas. In other areas, they are used to transport such diverse products as wheat, ketchup, and pulverised coal. In 1977, pipelines



costpf — cost of portable fuels ($/GJ)
gpcons — year in which government conservation policy is implemented
pop — population
tt — truck energy demand (PJ/a)
ttef — truck efficiency index (1976=1.)
ttefd — time to implement ttefn (years)
ttefn — new ttef
tti — inter-city truck energy demand (PJ/a)
ttid — inter-city truck transport demand (t-km/a/capita)
ttiei — inter-city truck energy intensity (MJ/t/km)
ttu — urban truck energy demand (PJ/a)
ttud — urban truck travel demand (t-km/a/capita)
ttuei — urban truck energy intensity (MJ/t/km)

Figure 3-14. Structure of the truck transportation sub-sector

used 26.3 PJ of natural gas and 1.7 PJ of electricity (AERCB 1978). Extrapolating energy demand for pipelines in a soft energy context is rather difficult because 80 per cent of the 1977 demand was used to move natural gas outside the province. Presumably, if Alberta chose to pursue a soft energy strategy, other provinces would as well, since many already face high energy prices and insecurity of supply. Thus, the pipeline flow may be reduced.

The Alberta soft energy model uses the AERCB's (1978) 1996 natural gas use for pipelines forecast as an ultimate demand and extrapolates the AERCB's electrical demand forecast without modification.

3.3.6 Transportation demand

Given the energy intensities of each mode of transport, the energy demand in the transportation sector can be determined if the transportation demand (in km/capita/a for passenger and t-km/capita/a for freight) and the modal split are known. The factors determining these differ depending on whether freight transportation, inter-city passenger transportation, or urban passenger transportation is being considered.

3.3.6.1 Freight transportation demand

At present, most of the manufactured goods used in Alberta are produced outside of Alberta and much of the resources extracted in Alberta are shipped outside of the province. As energy prices rise, it is likely that more manufacturing will occur within the province and that less resources will be exported. Higher energy prices will shift the economies of scale towards more localised production.

However, the gross mass of resources to be transported will probably increase because of the rising standard of living. This rate of increase is likely to decline as the economy shifts towards more service-oriented activities.

These two considerations suggest that the mass of freight transported will increase but it will, on average, be transported shorter distances as energy prices rise. Since trucks are the predominant form of urban freight transport, urban truck demand is likely to increase.

Higher energy prices are also likely to encourage a shift in inter-city freight transport from trucks to trains since the latter are significantly more energy efficient.

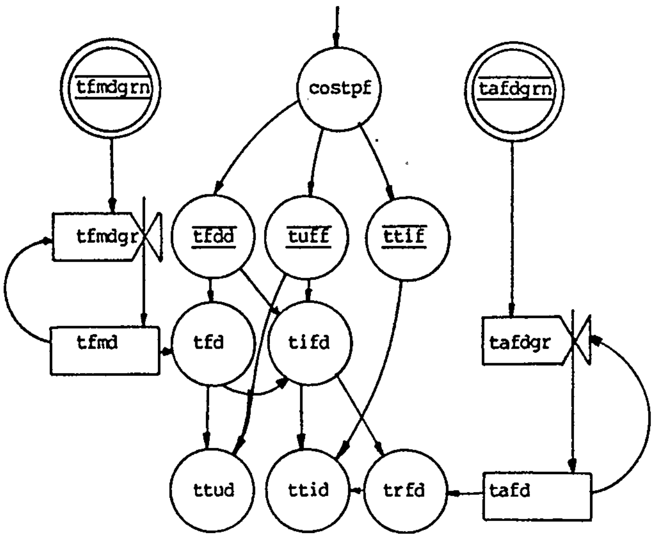
These considerations are included in the model of Alberta's transportation sector. "Normal" growth rates assumed in the Alberta soft energy model are presented in Table 3-9.

Table 3-9. Normal growth rates for the transportation sector (%/a)

Year	Freight		Passenger
	Air	Total	Inter-city
1976.	2.0	3.00	3.0
1986.	1.5	1.50	3.0
1996.	1.0	0.75	2.0
2006.	0.5	0.69	2.0
2016.	0.0	0.64	1.5
2026.	-1.0	0.60	1.5

Notes: Air freight growth rates are for mass times distance, total freight growth rates are for mass only. Passenger growth rates are for distance but are inhibited by high energy prices.

The freight transportation demand component of the model is presented in Figure 3-15.

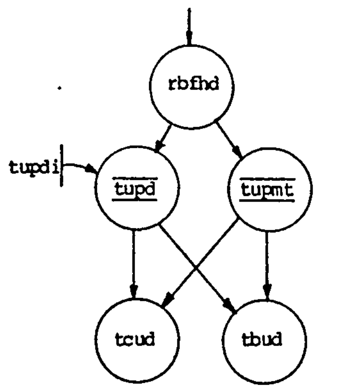


costpf — cost of portable fuels ($/GJ)
gdpgr — gross domestic product growth rate (dimensionless)
tafd — air freight transport demand (t-km/a/capita)
tafdgr — air freight transport demand growth rate (dimensionless)
tafdgrn — normal tafdgr
tfd — freight demand (t-km/a/capita)
tfdd — freight demand distance
tfmd — freight demand mass
tfmdgr — freight mass demand growth rate
tfmdgrn — normal tfmdgr
tifd — inter-city freight transport demand (t-km/a/capita)
trfd — rail freight transport demand (t-km/a/capita)
ttid — inter-city truck transport demand (t-km/a/capita)
ttif — fraction of truck transport which is inter-city (dimensionless)
ttud — urban truck transport demand (t-km/a/capita)
tuff — fraction of freight transport demand which is urban (dimensionless)

Figure 3-15. Model of freight transportation demand in Alberta

3.3.6.2 Urban passenger demand

As discussed above, the density of urban areas can play a significant role in both the distance to be travelled within a city and the fraction of the trips which occur by mass transit. These two considerations determine urban passenger transportation demand within the model of Alberta's transportation sector, according to the structure presented in Figure 3-16.



rbfhd — fraction of housing which is high density (dimensionless)
tupd — urban passenger transportation demand (km/capita/a)
tupdi — initial tupd
tupmt — fraction of urban trips on mass transit (dimensionless)
tcud — urban automobile demand (km/capita/a)
tbud — urban bus demand (km/capita/a)

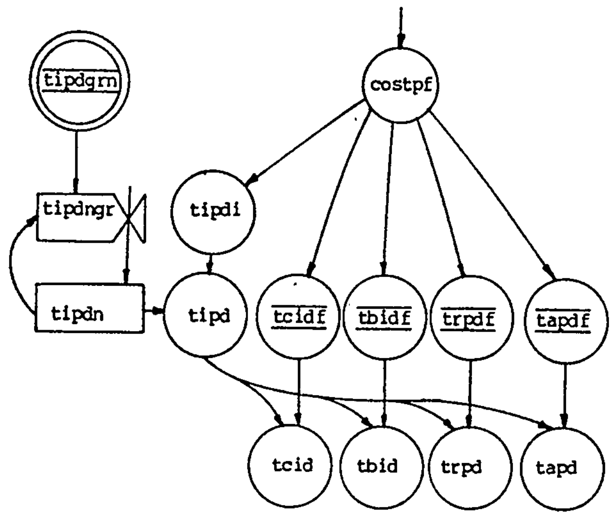
Figure 3-16. The urban passenger transportation demand component of the Alberta transportation sector model

3.3.6.3 Inter-city passenger transportation demand

Inter-city travel is expected to increase. However, as energy prices rise, other forms of entertainment are likely to become more attractive to the leisure traveller, and telecommunications are likely to replace some business travel. It has been estimated that 20 to 36 per cent of today's business trips could be replaced by telecommunications (Friedman 1980).

In addition, as the size of households (in persons/household) decreases, non-automobile modes of inter-city travel may be expected to increase. Short distances are more likely to be covered by bus or train than by airplane (Simaluk 1980).

These issues are included in the component of the Alberta transportation sector model dealing with inter-city passenger transportation demand, as diagrammed in Figure 3-17.



costpf — cost of portable fuels ($/GJ)
tapd — air passenger travel demand (km/capita/a)
tapdf — fraction of total inter-city travel by air (dimensionless)
tbid — inter-city bus travel demand (km/capita/a)
tbidf — fraction of total inter-city travel by bus (dimensionless)
tcid — inter-city automobile travel demand (km/capita/a)
tcidr — fraction of total inter-city travel by automobile (dimensionless)
tipd — intercity passenger travel demand (km/capita/a)
tipdgrn — normal growth rate of tipdn
tipdi — tipd inhibitor (dimensionless)
tipdn — normal tipd (km/capita/a)
tipdngr — tipdn growth rate (km/capita/a)
trpd — rail passenger demand (km/capita/a)
trpdf — fraction of total inter-city travel by rail (dimensionless)

Figure 3-17. Inter-city passenger transportation demand component of the model of the Alberta transportation sector

The "normal" (uninhibited) growth rates assumed for inter-city passenger transportation are presented on page 66 in Table 3-9.

3.4 The Industrial Sector

Using the classification of the Alberta Energy Resources Conservation Board (AERCB), ten categories of industry can be identified. These are: cement, petrochemicals, pulp and paper, farms, non-energy uses, general industry, oil sands and heavy oils, crude oil refineries, natural gas reprocessing plants, and coal mines. Of these ten, the energy demand associated with the last four will be directly dependent upon the total demand level and the energy sources used. For these reasons, and because the demand sectors have been concerned with end-use energy, these four will be considered within the supply sectors, rather than here. Each of the other six industrial sub-sectors will be considered individually.

3.4.1 The cement industry

The AERCB has projected that the demand for cement will increase from its current value of 1.27 Mt/a at a rate of 91 kt/a each year until 2006 (the end of its forecast period) (AERCB 1978). Its forecasted energy demand, cement demand and the energy intensity they imply is presented in Table 3-10.

Table 3-10. Demand for cement and energy for the cement industries

Year	Demand Mt	Intensity GJ/t	Gas PJ	Coal PJ	Electric PJ	Total PJ
1977	1.3	5.5	6.6	0.0	0.5	7.1
1981	1.7	4.5	5.0	1.7	0.9	7.6
1986	2.1	5.0	4.2	5.1	1.1	10.4
1991	2.6	5.0	0.0	11.8	1.2	13.0
1996	3.0	4.5	0.0	11.8	1.7	13.5
2001	3.5	4.4	0.0	13.5	1.9	15.4
2006	3.9	4.4	0.0	15.2	2.0	17.2

Source: AERCB (1978).

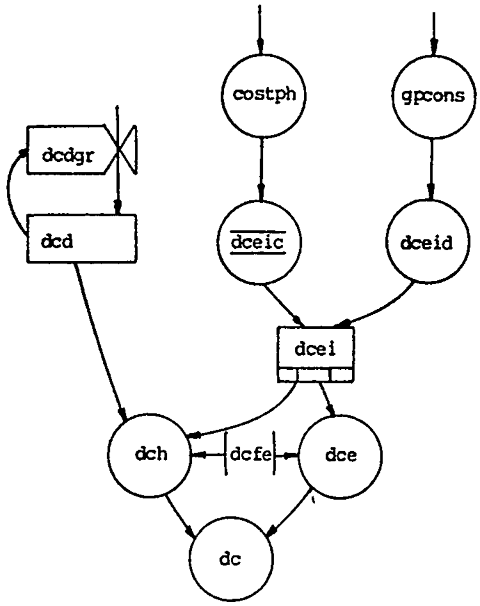
The lowest intensity of the seven years shown is 4.4 GJ/t.

A study of the cement industries in the Federal Republic of Germany, Italy, the United Kingdom, and the United States undertaken by the NATO Committee on the Challenges of Modern Society found a wide range of energy intensities (Leach 1979). One key factor determining the discrepancy was whether the wet or dry process was used; some dry processes are twice as efficient as the wet process. The Alberta forecast by the AERCB considered that new plants would use the dry process and some old plants would be converted from wet to dry. In spite of this, the energy intensity used by the AERCB is considerably greater than the FRG figure which was 3.8 GJ/t in 1976. The model assumes that the FRG figure is reached when energy prices are 2 $/GJ or more.

The model of the cement industry sub-sector is diagrammed in Figure 3-18.

3.4.2 The petrochemical industries

Petrochemical industries are classified in five categories by the AERCB (1978): ammonia, benzene, ethylene, methanol and others. These industries are a key element in Alberta's plans for industrial development and consequently, Alberta is expecting rapid development of petrochemical industries in the coming decades. Helliwell (1979) has suggested that economic pressures are likely to suppress the growth of these industries to a level considerably lower than that suggested by the AERCB. This is likely to be the result of several factors.



costph — cost of process heat ($/GJ)
dc — cement industry energy demand (PJ/a)
dcd — cement demand (t/a)
dcdgr — dcd growth rate (dimensionless)
dce — cement industry electricity demand (PJ/a)
dcei — cement industry energy intensity (GJ/t)
dceic — dcei from costph (GJ/t)
dceid — time to change dcei (years)
dcfe — fraction of demand which is electric (dimensionless)
dch — cement industry heat demand (PJ/a)
gpcons — year government conservation policy implemented

Figure 3-18. The cement industry model sub-sector

The first of these is the saturation of domestic demand at attractive prices, and restricted or cut-price export markets. OPEC, which is presently flaring some of its natural gas, could produce petrochemicals at 25 per cent of the Canadian cost because of the high opportunity cost of Canadian natural gas (Helliwell 1979).

Helliwell (1979) has suggested three reasons for Alberta's plans: to counter the federal petrochemical development in Sarnia, to broaden Alberta's industrial base, and to avoid export regulations. The first reason is clearly political.

The potential for petrochemicals to broaden the industrial base is small. Petrochemical industries are too capital-intensive to be the basis for balanced industrial development (Helliwell 1979). Whereas the average Canadian industry is 70 per cent labour and 30 per cent capital, petrochemical industries are typically 94 per cent capital and only 6 per cent labour.

The third reason Helliwell offers for Alberta's plans is to avoid export regulations. By processing the natural gas (or coal) to petrochemicals, the export control powers of the NEB are circumvented. The recent willingness of the NEB to increase exports undercuts this reason for petrochemical development.

Helliwell states that large scale petrochemical development is likely to stretch the province's borrowing powers to the limits, provide a situation in which there are more workers than available jobs, or both.

3.4.2.1 Ammonia

The AERCB expects the capacity for producing ammonia to more than double in the 1977 to 2026 period. The demand for ammonia includes both agricultural uses (which accounted for 85% of total demand in 1977) and industrial uses.

Ammonia is manufactured by the Haber process in which methane is steam reformed into hydrogen. Nitrogen is added to the hydrogen to produce ammonia. This process is very efficient, although some savings are still possible. Leach (1979) suggests that 2 to 3 GJ/t could be saved of the total specific energy demand of 47.6 GJ/t by using pure nitrogen instead of extracting it from air. If gas turbines are used for compressing the ammonia gas, another 2 to 3 GJ/t could be saved.

As Helliwell (1979) points out, the forecasted demand is inflated. The NEB analysis indicates that there will be an excess capacity of 65 per cent in 1985. If Alberta and/or Canada begins the shift to a sustainable energy system, it is reasonable to expect that the demand will be reduced from the level anticipated by the NEB. As Merrill (1976) and Commoner (1971) discuss, the present system with its dependence on fossil fuel based fertilizers cannot be sustained indefinitely. It is likely that a shift towards sustainability in the agricultural sector would occur in parallel to a shift towards a sustainable energy system.

There are several strategies that can be pursued which will decrease the demand for ammonia-based fertilizers including applying only as much fertilizer as can be used effectively by the crops and applying it at a time when the plants can use it before it volatises or leaches (Price 1979). Plants which fix their own nitrogen from the air can be planted in fields on a rotating basis [14]. Animal manures and sewage sludge can be used as fertilizers [15]. Genetic researchers are trying to develop species of corn and wheat which contain the nitrogen

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[14] This will reduce the yield of the non-nitrogen fixing crop by one-third (since it would only be planted two out of three seasons). However, some experiments have been done with inter-cropping, a process in which the legumes (which fix atmospheric nitrogen) are planted between the rows of other crops. In tests of inter-cropping, declines in yield ranged from zero to twenty per cent (Price 1979).

[15] Milwaukee bags its sewage sludge under the brand name "Milorganite" and sells it for fertilizer. In order to use these wastes more extensively, feedlot operations will have to be located closer to the point of application of the manure (Steinhart 1974).

fixing bacteria of the legumes [16]. Even if yields per unit area of land are reduced as a result of lower levels of nitrogen fertilizer use, global food problems need not necessarily worsen. Because of the law of diminishing returns [17], a more even distribution of less fertilizer may result in higher yields on a global basis (Gabel 1979). In addition, in the developing world, much of the existing demand for food results not from too little production but from post-harvest losses. If these losses could be eliminated, pressure to attain a high yield could be reduced.

More labour intensive agriculture could also reduce the demand for fertilizer [18]. If bioshelters (Todd 1980) become common for production of food or if commercial greenhouses are encouraged, ammonia demand might be expected to drop [19].

All these considerations hold potential for significant reductions in ammonia demand over the next 50 years.

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[16] It is conceivable that the use of these species could be practical within the next half century (Gabel 1979).

[17] The law of diminishing returns applies to fertilizer use and crop yields. For each unit increment of yield increase, more than one additional unit of fertilizer must be applied.

[18] Although increased labour intensity of the agricultural sector is somewhat unlikely, it is conceivable that more food will be produced (by labour intensive methods) in the domestic sector. Todd (1980) points out that in 1978 over one half of the householders in North America had some sort of a food garden. The trend towards producing (some of) one's own food appears to be increasing. Small plots using the French intensive biodynamic methods can increase yields four times over conventional agriculture without the use of any chemical fertilizers (Gabel 1979).

[19] Bioshelters, like ecosystems, cycle their nutrients and require minimal external inputs. Hydroponics, a system in which the waste of fertilizers can quite easily be minimised if not eliminated, is an attractive system for commercial food greenhouses.

Within the model, energy demand for the ammonia industry is determined from the demand for ammonia and the energy intensity of its production. The demand used is that projected by the AERCB reduced by the over-capacity forecast by the NEB. Demand is also inhibited by a shift to less chemically intensive agriculture: a shift which is dependent on energy prices. The energy intensity of ammonia production is based on existing energy intensities adjusted by the price response indicated by CONAES (1978) for chemical industries.

3.4.2.2 Ethylene

The AERCB has forecast the demand for ethylene considering Canadian demands, export demands and other ethylene plants in Canada. Its estimation of the demand differs from that of the National Energy Board which has estimated that capacity will exceed demand by 25 per cent in 1985.

Ethylene synthesis is an energy intensive process demanding 89.6 GJ/t (Helliwell 1979). There is some potential for reducing the energy demand, however. Leach (1979) has estimated possible savings at 25 per cent. CONAES (1978) has forecast an energy intensity drop of 22 per cent for energy at 7 $/GJ and 25 per cent at 9 $/GJ.

These considerations are incorporated into the soft energy model.

3.4.2.3 Benzene

The AERCB predicts that a world scale benzene plant will be built in Alberta to come on stream in 1982. Its forecast assumes a ten per cent improvement in the plant's efficiency by 2006. It is questionable that the plant will be built (because of the reasons discussed above). However, if it is built, greater improvements in its efficiency might be expected.

The CONAES (1978) scenarios relate changes in energy intensity to price changes. For the chemical industries, the Committee estimates energy intensities at 74 per cent (excluding feedstocks) of their 1976 equivalents for all the chemical industries [20]. The Committee's estimated savings are incorporated into the model.

3.4.2.4 Methanol

In Canada, 70 per cent of all methanol is used in the synthesis of formaldehyde which is used as a resin in the manufacture of adhesives for plywood and particle board (Egglestone 1979). Although there has been considerable discussion of using methanol as a transportation fuel, that consideration will be made within the supply sector. This section is only concerned with methanol used as a chemical. The AERCB has forecast energy demand by methanol manufacturers on the assumption that two world scale methanol plants will come on stream in Alberta in the early eighties.

The NEB forecasts of demand for methanol suggest that if Alberta Gas Chemicals proceeds with its plans for methanol plant development, there will be an excess capacity of 400 per cent by 1985. The model of the methanol industry assumes that capacity will only be increased to the level suggested by the NEB and that the CONAES efficiency

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[20] This is in the Committee's scenario with oil prices at 12.79 (1975 US$)/GJ.

improvements for the chemical industries will be applied.

3.4.2.5 Other petrochemicals

Petrochemical industries other than those discussed above are expected to undergo modest growth. These industries presently use 16.6 PJ/a in Alberta and this is expected to increase to 21.8 PJ/a in 1991 and to decrease slightly to 21.4 PJ in 2006 (AERCB 1978). In the model of this sub-sector, the CONAES energy intensity index is applied to the non-feedstock portion (which is about 70% of the total).

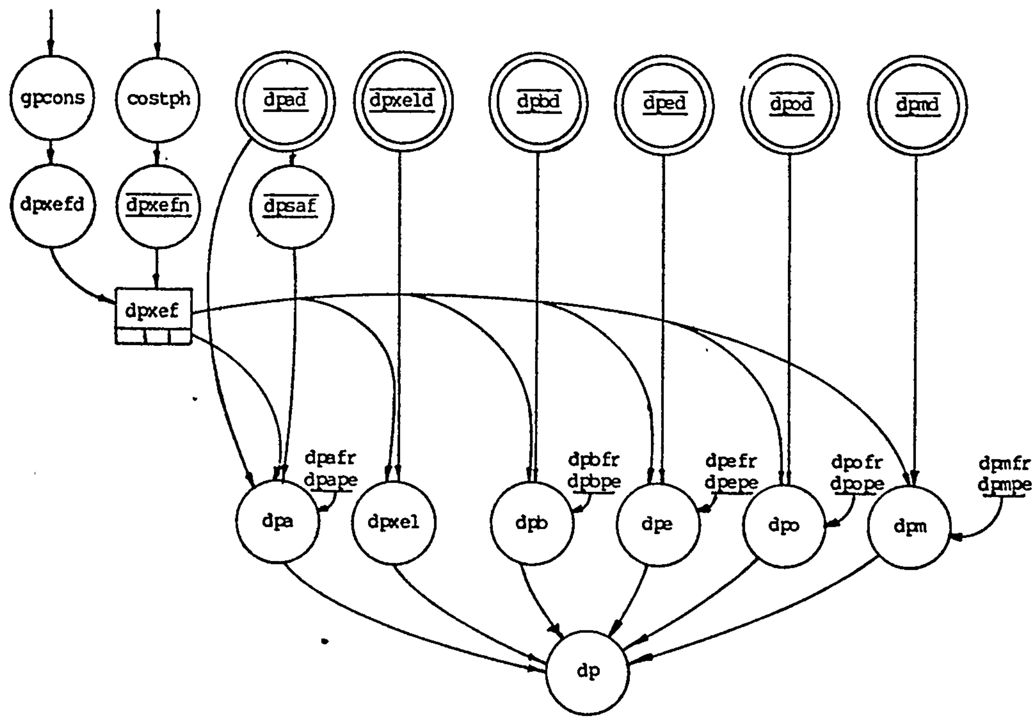
3.4.2.6 Electric demand

The AERCB evaluates the electricity demand of the petrochemical industries as an aggregate. The amount of electricity used is expected to rise from 3.1/ PJ/a in 1977 to 16.2 PJ/a by 2006. Given the possible savings and reduced production discussed above, it seems reasonable to assume that this demand could be decreased by 35 per cent.

The model of the petrochemical sub-sector is represented in Figure 3-19; the petrochemical demand levels are presented in Table 3-11.

3.4.3 Pulp and paper

Modest growth is expected in the pulp and paper industry with total energy demand rising from 6.1 PJ/a in 1977 to 8.5 PJ/a in 2006 (AERCB 1978). Extrapolating to 2026 gives an energy demand of 11.3 PJ/a, as indicated in Table 3-12.



costph — cost of process heat ($/GJ)
dp — petrochemical industry energy demand (PJ/a)
dpa — ammonia industry energy demand (PJ/a)
dpad — ammonia demand (t/a)
dpafr — ammonia feedstock requirement (MJ/t)
dpape — ammonia production energy (MJ/t)
dpb — benzene industry energy demand (PJ/a)
dpbd — benzene demand (t/a)
dpbfr — benzene feedstock requirement (MJ/t)
dpbpe — benzene production energy fraction (dimensionless)
dpe — ethylene industry energy demand (PJ/a)
dped — ethylene demand (t/a)
dpefr — ethylene feedstock requirement (MJ/t)
dpepe — ethylene production energy (MJ/t)
dpm — methanol industry energy demand (PJ/a)
dpmd — methanol demand (t/a)
dpmfr — methanol feedstock requirements (MJ/t)
dpmpe — methanol production energy (MJ/t)
dpo — other petrochemical industries energy demand (PJ/a)
dpod — other petrochemical demand (PJ/a)
dpofr — other petrochemical feedstock requirements (MJ/t)
dpope — other petrochemicals production energy fraction (dimensionless)
dpsaf — sustainable agriculture fraction (dimensionless)
dpxef — petrochemical efficiency factor (1976=1.)
dpxefd — time to change dpxef to dpxefn (years)
dpxefn — new dpxef
dpxel — petrochemical electricity demand (PJ/a)
dpxeld — petrochemical electricity demand (GWh/a)
gpcons — year in which government conservation policy is implemented

Figure 3-19. Model of the petrochemical industries' energy demand

The AERCB has considered some "conservation" as being applicable to the pulp and paper industry in the province. What the Board considered is the potential for using hog fuel to provide some of the energy demand

Table 3-11. Petrochemical demand levels

Year	Ammonia (Mt/a)	Ethylene (Mt/a)	Methanol (Mt/a)	Others (PJ/a)	Electricity (GWh/a)
1976.	0.98	0.82	0.37	2.9	860.
1986.	2.10	1.04	0.84	2.9	3260.
1996.	2.10	2.09	0.79	2.6	3980.
2006.	2.30	2.83	0.75	2.5	4500.
2016.	2.30	2.83	0.75	2.5	4600.
2026.	2.30	2.83	0.75	2.5	4700.

Notes: Demand levels are based on those indicated by the AERCB (1978) until 2006 and adjusted according to the discussion in the text. AERCB indicates a decline in energy demand in the last years of its forecast and therefore demands in 2006 are assumed to persist through 2026.

Table 3-12. "Normal" energy demand in the pulp and paper industry

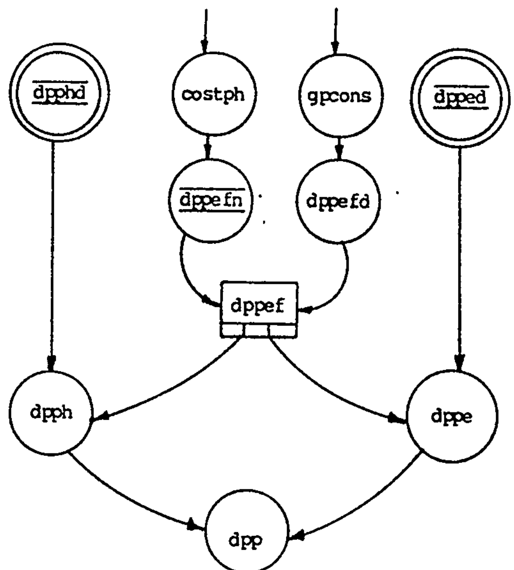
Year	Electricity (PJ/a)	Heat (PJ/a)
1976.	1.26	4.85
1986.	2.02	3.32
1996.	2.48	3.94
2006.	3.60	4.85
2016.	4.00	5.70
2026.	4.70	6.63

Notes: Pre-2007 data are from AERCB (1978) with an assumed efficiency of 85 per cent for converting delivered energy to heat. Values after 2006 have been extrapolated.

and this is not strictly demand reduction. Demand reducing measures are possible, however. Leach (1979) has suggested that radiowave drying could save 16 per cent of pulp and paper energy use. Estimates of total possible savings range from 22 per cent (Leach 1979) to 36 per cent

(CONAES 1978), and these are considered in the model.

The modelled structure of the pulp and paper industry sub-sector is presented in Figure 3-20.



costph — cost of process heat ($/GJ)
dpp — pulp and paper industry energy demand (PJ/a)
dppe — pulp and paper electricity demand (PJ/a)
dpped — initial dppe (PJ/a)
dppef — pulp and paper industry efficiency index (1976=1.)
dppefd — time for dppefn to become dppef (years)
dppefn — new dppef
dpph — pulp and paper heat demand (PJ/a)
dpphd — initial pulp and paper heat demand (PJ/a)
gpcons — year in which government conservation policy is implemented

Figure 3-20. Model of the pulp and paper industry sub-sector

3.4.4 Farms

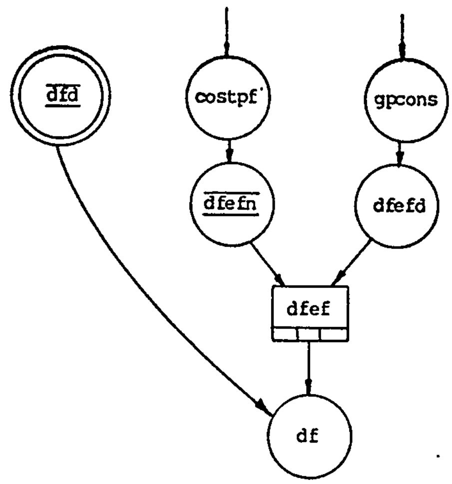
Energy use on farms is expected to increase slightly in the next decade from its current value of 53.9 PJ/a and then to decline to 50.8 PJ/a in 2006 (AERCB 1978). The AERCB has considered some potential for demand reduction, primarily through the use of minimum and zero tillage. These tillage methods can reduce energy demand by up to 35 per cent but the maximum acceptance expected by the AERCB will result in energy savings of only 19 per cent.

Other demand reduction measures could be introduced. A large fraction of farm energy is used to operate tractors which do not operate at peak efficiency. By combining separate operations (such as harrowing and planting), the number of passes the tractor must make over a field can be reduced and hence so can its energy demand (Hirst 1974). Some modifications to the tractor could result in significant savings. These include: cleaning or replacing the fuel injector and the air cleaners annually (10 to 15 per cent), better gear selection or transmission system (10 per cent), ballasting to limit wheel slip (15 to 20 per cent) and better maintenance of the engine and cultivation equipment (such as keeping blades sharp, 10 per cent). Leach (1979) has estimated that these measures could easily eliminate 40 per cent of the energy demand of tractors.

Figure 3-21 presents the structure of the model used to represent the Alberta farm sub-sector.

3.4.5 Non-energy industries

Non-energy industries produce diverse products such as asphalts, lubricating oils and greases and waxes. The AERCB expects quite rapid growth in these industries from 37.9 PJ/a in 1977 to 79.6 PJ/a in 2006. If growth continued at this rate, the demand in 2026 would be 111.6 PJ/a.



costpf — cost of portable fuels ($/GJ)
df — farm energy demand (PJ/a)
dfd — initial df (PJ/a)
dfef — farm efficiency index (1976=1.)
dfefd — time for dfefn to replace dfef (years)
dfefn — new dfef
gpcons — year in which government conservation policy is implemented

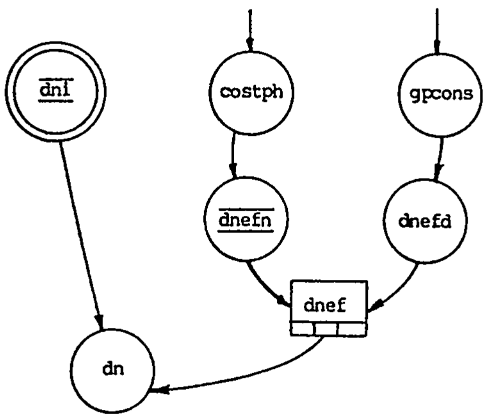
Figure 3-21. Model of the farm sub-sector

It is rather difficult to estimate potential savings on such a variety of industries as a group. CONAES has estimated potential savings for "other industry" at 43 per cent and this has been used in the model.

The structure of this sub-sector of the Alberta economy is diagrammed in Figure 3-22.

3.4.6 General industry

This is another high growth industry with demand rising from 68.2 PJ/a in 1976 to 208.9 PJ/a in 2006 (AERCB 1978). The Canadian Industry Energy Conservation Task Forces have set the conservation goals for this sub-sector at 10 to 15 per cent (CIECTF 1977) and these goals have been incorporated into the AERCB's forecasts. Applying the CONAES index for

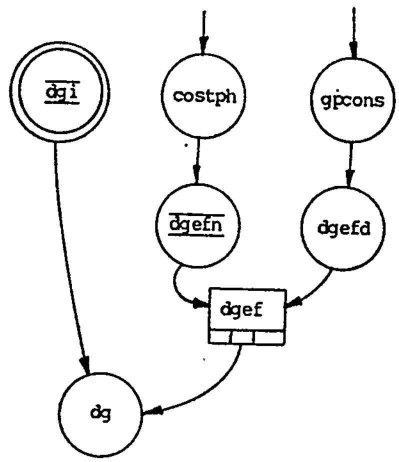


costph — cost of process heat ($/GJ)
dn — non-energy industry energy demand (PJ/a)
dni — initial dn (PJ/a)
dnef — non-energy industry efficiency index (1976=1.)
dnefd — time for dnefn to replace dnef (years)
dnefn — new dnef
gpcons — year in which government conservation policy is implemented

Figure 3-22. Model of the non-energy industry sub-sector

other industry again, potential savings could conceivably reach as much as 43 per cent, and this savings is reflected in the model.

Figure 3-23 represents the model of the general industry sub-sector.



costph — cost of process heat ($/GJ)
dg — general industry energy demand (PJ/a)
dgi — initial dg (PJ/a)
dgef — general industry efficiency index (1976=1.)
dgefd — time for dgefn to replace dgef (years)
dgefn — new dgef
gpcons — year in which government conservation policy is implemented

Figure 3-23. Model of the general industry sub-sector

3.5 Barriers to Reducing Energy Demand

From the discussion of the four demand sectors of the Alberta energy model, it is apparent that there is considerable scope for reducing energy demand. Although these measures are economic at the energy prices indicated, that is no assurance that the measures will be introduced. The reasons for this include ignorance, inertia, institutional obstacles and obstacles resulting from current approaches to energy planning.

Many users are unaware of the potential for improving the efficiency, both economic and thermodynamic of their energy use. This obstacle can be overcome, in part at least, by government information programmes. For example, the federal government now requires that all new automobiles and refrigerators be labelled with their rated fuel economy and energy use. Such measures are an effective method of informing the public on efficient energy use. Also, within the industrial sector, several governments, including the Alberta government, have introduced "energy buses" which go to industries to suggest more energy efficient ways of performing their tasks.

People may also be unaware that their individual efforts will have a significant effect on lowering energy demand. For example, an individual may think that turning off lights in his or her dwelling or office is not worth the effort since the energy use is so small. However, each individual must be made to understand that if everyone used energy wisely, the net result would be a substantial reduction in total energy use and demand.

Misinformation may hinder energy demand reduction as well. For example, it is a common misconception that conserving energy is an unpleasant task that leads to a more austere lifestyle. It should be made clear that the quality of life can be enhanced through energy demand reduction measures.

The second barrier to improved energy efficiency is the inertia resulting from the relatively long life of many energy using devices including buildings, automobiles, appliances and industrial equipment. It would be unwise both economically, and possibly on an energy basis, to replace all equipment just because it does not meet present performance standards. For some energy using equipment, it will simply be a matter of waiting for the old equipment to die off. However, it is more often the case that improvements in energy efficiency can be made now at a reasonable cost.

Another obstacle to reducing energy demand, perhaps the major obstacle to be overcome, is institutional barriers. These barriers take many forms including split incentives (when users of energy do not pay energy costs or when the person who pays the energy bill does not own the energy using equipment), tax structures which make energy use tax deductible, and low energy prices.

Institutional obstacles to efficient energy use must be attacked on many fronts. Energy prices should be raised to reflect actual costs. Subsidies to lower income persons can be given in other ways, if necessary. In addition to raising energy prices to reflect costs, other measures such as standards must be adopted to overcome split incentives.

Higher energy prices alone will not often force an apartment dweller to upgrade the performance of his or her unit since apartment dwellers rarely stay in the same unit long enough to recover their investment.

Processes in use for energy planning also inhibit the reduction of energy demand. Energy planning typically examines issues in short time frames, uses an incremental approach which emphasises the status quo and is based on forecasts, not designs. Energy demand is treated as an exogenous variable which cannot be altered to any significant extent. In fact, energy demand is something which is affected by government information programmes, energy use standards, and resource pricing policies.

If energy is to be used effectively, these four barriers must be confronted and policies must be designed to overcome them. Government information programmes can reduce both ignorance and inertia by ensuring that new energy using devices meet current efficiency levels. A user pays policy and efficiency standards are among the options for overcoming institutional barriers.

4. ENERGY SUPPLY IN ALBERTA

The supply section of the Alberta soft energy model consists of four sectors corresponding to the four types of energy quality needed: portable fuels, electricity, process heat, and low temperature heat.

4.1 Portable Fuels

Oil has a wide range of uses in Alberta. However, of the total 526 PJ consumed in 1977, only 158 PJ were used specifically in non-stationary applications where this high quality energy source is most appropriately used (AENR 1979b). For the most part, oil for stationary uses can be replaced by other fuels.

Only the transportation sector specifically requires the use of portable fuels and within the transportation sector there is the potential for some substitution of portable fuels by other energy types, in particular, electricity. Oil can also be replaced by other portable fuels. Methanol produced from any hydrocarbon source including biomass, coal or natural gas can be almost universally substituted for oil. Hydrogen can be produced from the electrolysis of water and can be used in any of three states to power vehicles: as a compressed gas, as a cryogenic liquid, or stored as a solid within metal hydrides. Oil or its derivatives can also be synthesised from coal and extracted from oil sands.

All of these fuels are hydrocarbons (except hydrogen, although some analysts consider it C_0H_2) which are fairly easily stored and burned to produce energy.

4.1.1 Biomass

Of the five energy sources which are considered here for the production of portable fuels, biomass is the only one which is an income source. Biomass is a form of solar energy in which the energy radiated by the sun is stored in plants as complex organic molecules as a result of photosynthesis. Since photosynthesis extracts carbon dioxide from the atmosphere, no increase in the concentration of carbon dioxide in the atmosphere is anticipated from the combustion of biomass. Provided that the biological communities from which the biomass is harvested are not over-exploited, they will continue to provide a source of energy indefinitely.

There are many different forms of biomass in Alberta including wood, grain, human and animal waste products and municipal waste. Any or all of these could be processed into fuels suitable for use by transportation vehicles.

4.1.1.1 Wood

Four main sources of wood are potentially available for energy production in the province. These are: logging residues, mill residues, forests that are presently underexploited, and energy plantations.

When wood is harvested for lumber or pulp production, not all of the tree is taken. That part of the tree which remains could be harvested and processed to produce methanol through gasification and catalytic hydrogenation or ethanol through enzyme or acid hydrolysis [1].

Easily recoverable logging residues in Alberta have been estimated at 235 900 ODt/a (AENR 1978). New types of technology to gather branches and other types of residuals could increase the yield. The environmental consequences of removing these residues are mixed. Verhoeff (1978) suggests that removing these may result in increased soil erosion and resultant silt laden runoff and the loss of soil nutrients. Richards (1977) has indicated that leaving the residues is a fire hazard and hinders reforestation. The cost of harvesting these logging residues is quite reasonable. Bennington (1978) has estimated the cost at 1.23 to 2.46 $/GJ (1976 US$).

Mill residues are an even larger potential source of biomass in Alberta, totalling some 958 800 ODt/a (AENR 1978). In addition to being more abundant than easily collectible logging residues, they are cheaper. In fact, many mills now pay for disposal of these residues. If these residues were processed to methanol, about 13 PJ/a could be produced.

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[1] In gasification, thermochemical processes breakdown complex organic molecules into carbon monoxide and hydrogen (syngas). The syngas is then fed into a catalytic hydrogenation plant which, depending on the catalyst used, produces methanol or ammonia. Acid hydrolysis, which is used widely in the pulping industry, recovers sugar from the organic materials. This sugar can then be fermented to produce ethanol. In enzyme hydrolysis, fungi are used which produce an enzyme solution in a culture of cellulose. The solution is then used to hydrolyse the remaining cellulose feedstock to produce glucose which is fermented to produce ethanol.

Annual Allowable Cut (AAC) is the measure used to indicate how much timber can be harvested without exceeding sustainable yields and depleting forest reserves. In Alberta, present harvests are considerably less than the AAC, especially for hardwoods.

Finally, trees could be planted, nurtured and harvested specifically for energy production on "energy farms" or silviculture plantations. Such a scheme would involve intensive management of densely planted fast-growing species, such as poplar, on a short rotation (6 to 10 year) basis. Harvesting would be performed by a self-propelled harvester that cuts and chops the crop and delivers it to a dump wagon following the harvester.

InterGroup (1978) has estimated that the total forest biomass in Alberta suitable for processing into portable fuels could amount to 23.2 Mt in 2005. This is for wood with a harvesting cost of 44 $/ODt or less. If this forest biomass were converted to methanol using the simple gasification process, about 320 PJ could be produced. Within the Alberta soft energy model, it has been assumed that the maximum primary available energy from wood rises linearly from 100 PJ/a in 1976 to 400 PJ/a in 1986 to an ultimate potential of 800 PJ/a which is achievable in 1996.

4.1.1.2 Grain

Other plants, such as grains, can be used to produce ethanol. This is presently being done in MidWestern United States, where it is mixed with gasoline to produce "Gasohol". Grains could conceivably be grown for energy in Alberta. However, such a scheme should not be attempted without very careful analysis since the net energy production in this system is quite site specific (Hopkinson 1980) and relatively low [2]. As discussed in the consideration of ammonia and farms in the demand chapter, farms are now dependent upon fossil fuel inputs and are using techniques which are not sustainable. For this reason, crops other than wood have not been considered for energy production. It should be realised, however, that this decision is based upon a very cursory examination and more study is needed to determine the advantages and disadvantages associated with this potential energy source in Alberta.

4.1.1.3 Animal wastes

Animal wastes can be digested anaerobically to produce "biogas" which can be substituted for natural gas or used as a feedstock for catalytic hydrogenation to produce methanol. In the consideration of ammonia demand, it was suggested that animal wastes be used as a replacement for inorganic fertilizers. This is not in conflict with digesting these wastes since the anaerobic digestion process produces biogas, while leaving the nutrients in a sludge which can be used as a fertilizer. Where there are large concentrations of animals, manure can be collected and digested.

4.1.1.4 Human wastes

Humans, being animals, also produce waste which could be converted into

[2] Net energy produced is the amount of energy produced after the energy inputs have been subtracted from the gross energy content of the product, in this case ethanol. Note that a low net energy yield is not sufficient basis for rejecting a scheme because the energy output may be in a form which is more convenient.

fuel and fertilizer. The 2026 Alberta population is estimated at 3 295 000. On average, each person produces a quantity of waste sufficient to produce 130 MJ of methanol per year. Thus the maximum possible yield from this source would be 0.43 PJ in 2026. Smaller towns and villages would, however, find it uneconomic to process this waste into methanol and this reduces the potential yield. Even the larger cities (Calgary, Edmonton, Red Deer and Lethbridge) may find it too expensive to continue their present form of waste management.

A better solution might be the Clivus Multrum composting toilets from Sweden. With this type of toilet, each individual dwelling manages its own sewage, rather than being connected to a central waste treatment facility. In these composting toilets, human waste is aerobically decomposed in a container which is kept in the basement of the dwelling. Todd (1980) has estimated that each unit that uses this type of toilet, which is totally sanitary and produces no foul odours, saves the community 40 000 dollars [3]. A rich soil is also produced which can be used in gardens. This type of waste management also avoids the problems that some communities face as a result of using sewage sludge which has been mixed with industrial wastes as a fertilizer. For example, high levels of zinc and cadmium were found in lettuce grown in soils treated with Edmonton sludge (Edwards 1980).

Thus, energy could be extracted from human waste but it appears to be a sub-optimal solution to the management of these wastes. For this

[3] This assumes five persons per household. For the expected unit size of 2.75 persons/household in 2026, the community would save 22 000 dollars. The price of the units begins at 2300 $ (Adams 1980).

reason, sewage is not considered as a potential source of portable fuels.

4.1.1.5 Municipal wastes

Municipal wastes are in many ways like sewage. There is potential for producing portable fuels or electricity from municipal waste but it is also a sub-optimal solution (Heeney 1980). Only the organic component of the waste yields energy. The organic component is mostly paper for which recycling saves more energy than is gained by processing it into portable fuels (Love 1976). Food wastes are better disposed of in composting toilets where they help to increase the carbon ratio. The Clivus Multrum includes a disposal chute in the kitchen where food waste can be dropped into the composting toilet in the basement.

4.1.1.6 Biomass summary

Animal wastes can be used to produce a small quantity of portable fuels, however, because the potential of this and other sources of biomass is so limited, wood is the only source considered in the model for the production of portable fuels.

4.1.2 Natural gas

Natural gas is a very old form of solar energy. Organic matter buried in sediments undergoes changes that convert some of it into organic gases. Because it is under pressure from the weight of the land that covers it, it normally flows out on its own, so that it is inexpensive to process. Natural gas is the easiest fossil fuel to process, and it burns the hottest. However, the carbon oxides released when it is burned are not derived from recent photosynthesis and the carbon dioxide concentration of the atmosphere therefore may be increased. Heat will also be released which would not otherwise have entered the environment [4].

Since natural gas is being used at a much greater rate than it is being produced, it is a capital source of energy. Natural gas reserves in Alberta were estimated at 1.8 trillion m^3 as of year-end 1979 (Hull 1980). In energy terms, this is equivalent to 67 EJ. At present portable demand levels of 158 PJ/a, these reserves would last 400 years if used only for portable fuel needs within Alberta. However, considering all uses, the life index of natural gas reserves was set at 25.4 years at the end of 1979. This index is 1.9 years less than that set at the end of 1978 (Hull 1980).

Natural gas can be used directly to power transportation vehicle engines in compressed tanks or it can be converted into methanol, since liquid fuels are presently easier to handle.

4.1.3 Conventional oil

As mentioned, oil is currently the major fuel for portable fuel applications. Like natural gas, oil is a non-renewable fuel and has problems of carbon dioxide concentration increases, waste heat production, equity and non-sustainability. In addition, Canada's

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[4] The heat released when biomass is burned would have been released through normal decomposition.

addiction to oil, an increasing amount of which is derived from foreign sources, creates potential political and economic problems for the nation. According to David S. Bruce, President of the National Automotive Trades Association of Canada, closing the Persian Gulf to oil traffic will mean immediate gasoline rationing in Canada (Anon 1980d).

Recoverable reserves of conventional crude oil in Alberta were estimated to be 760 million m^3 as of year-end 1979 (Hull 1980). In energy terms, this much oil is equivalent to 29 EJ.

It is becoming increasingly difficult to obtain more oil. In 1978, the average well was 1.2 km deep compared with 0.99 km in 1977 (AENR 1979a). The costs of finding oil have increased significantly in recent years, as is evident in Figure 4-1, which is from Uhler (1979). This reflects the shift from a price elastic to a relatively price inelastic response. Earl Cook, the noted petroleum geologist and Dean of the College of Geosciences at Texas A & M, has said that raising the price five or ten times will result in some - but not alot - more oil and gas being produced (Henderson 1978a). Within the Alberta soft energy model, it is assumed that conventional oil production will never exceed 250 PJ/a (the maximum producible in 1986) and that the maximum production which could be developed will fall after 1986 to an ultimate of 100 PJ/a in 2026.

4.1.4 Oil sands

The oil sands are a potentially huge resource of fossil - and hence capital - energy. In place reserves have been estimated at 8260 EJ

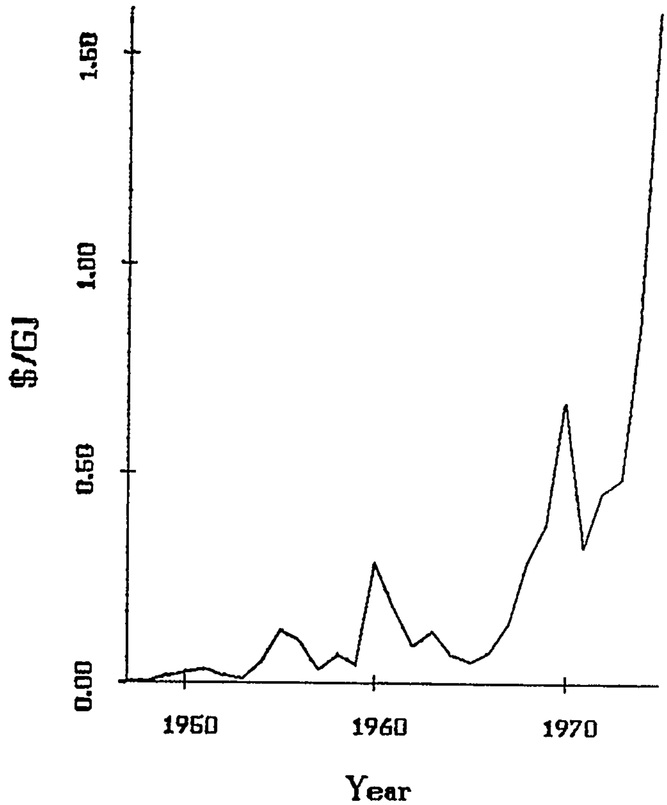

Figure 4-1. Costs of finding oil

(Mossop 1980). However, much of this is too difficult or expensive to recover. Energy, Mines and Resources has estimated recoverable reserves at 162 EJ (EMR 1977c).

Oil sands have a tar like consistency and are not recoverable by conventional oil recovery practises. The sands are processed by one of two types of technology; surface mining or in-situ retortion. To date, only surface mining has been developed commercially. In surface mining, the sands are mined and then heated to vapourise the oil and thus separate it from the sand.

With in-situ operations, the oil is separated in the ground. Esso plans to build an in-situ facility at Cold Lake in which steam is injected into closely grouped wells to make the oil flow and allow the wells to pump until a further steam injection is required.

Recent oil sands extraction sites have been developed as a result of three federal government actions; direct investment in Syncrude, tax concessions, and the guarantee of a market at world prices (Helliwell 1979). Helliwell suggests that the policies affecting oil sands development were formulated in great haste when rising costs threatened the Syncrude project in early 1975. Pratt (1976) has called oil sands development a giveaway to the private sector by the federal and Alberta governments. Helliwell (1979) refers to an economic analysis he did in 1976 that suggests that oil sands are, at best, only marginally cheaper than imported oil and that the tax, royalty and investment structures have resulted in a net transfer of funds from the federal government to the Alberta government and the industries.

The environmental consequences of oil sands development are quite significant. The two major impacts result from emissions of carbon dioxide and sulphur dioxide. Like other fossil fuels, synthetic crude oil from oil sands releases carbon dioxide when combusted. In addition, sulphur dioxide is released from the production and combustion of the crude oil. Sulphur dioxide reacts with water to produce sulphuric acid and is thus a major contributor to acid precipitation. In 1978, the Syncrude and Suncor oil sands plants emitted 147.4 t/d of sulphur dioxide, and this resulted in the worsening of sulphur dioxide pollution (White 1980). Until 1978, emissions had been declining.

4.1.5 Coal

Coal is another old form of solar energy (although not as old as oil), and it too is a capital energy source. Coal can also be processed into portable fuels; it can be either gasified or liquified. Germany synthesised oil from coal during World War II to power tanks and aircraft and South Africa uses the same German process today (Clark 1975).

Coal is a fairly abundant energy source in Alberta. The AERCB has estimated recoverable reserves at 12.2 Gt (AENR 1979a). Eighty per cent of this coal is sub-bituminous and the energy reserve is thus 245 EJ. Alberta currently uses slightly less than 500 PJ/a of coal, primarily to produce electricity (AENR 1979b).

4.2 Electricity

Electricity is a very high quality energy type which accounts for about 16 per cent of all energy requirements in Alberta. At present, the 200 PJ/a of electricity generated are from four sources: coal (69%), oil (1%), falling water (8%), and natural gas (22%) (AENR 1979b).

Like portable fuels, there are limited end uses which require electricity or which are most appropriately met by electricity. These include lighting, electronics, telecommunications, home appliances, electric railways, electrometallurgy and electrochemistry. Electricity can be produced from almost any energy source at varying degrees of economy and thermodynamic efficiency. The sources which are considered are falling water, wind, biomass, coal, oil, and natural gas. Falling water and wind drive turbines directly. The other sources are burned to produce steam or gases which are used to drive turbines.

4.2.1 Falling water

Falling water is an income energy source; the energy is solar energy since the Sun drives the hydrological cycle. Electricity is generated by converting the gravity pull of the falling water of rivers through turbines. By damming the river, the flow past the turbines can be regulated.

No air pollutants and no waste heat are produced from hydroelectric developments. However, water quality and quantity may be altered up and down stream with potential changes in dissolved gases, temperature, and water level (Verhoeff 1978). In addition, the pool of water behind the dam may cause physical, chemical, biological and microclimatic changes in the environment.

In 1977, 1530 GWh (5.5 PJ) of the electric end use energy requirements was met by falling water (AERCB 1978). The AERCB has forecast that two large hydroelectric developments will be built in the next quarter century to come on stream in 1991 and 2001. The total production of hydroelectric energy in 2001 is projected to be 50.4 PJ. If it is assumed that a third large project (4200 GWh/a) could be developed, the maximum annual generation of electricity from falling water is 65.5 PJ/a. This assumption is based on the AERCB's indication that there are a number of potential unexploited hydro sites in Alberta

(AERCB 1978).

4.2.2 Wind

Wind energy is also a form of solar energy since it is the Sun which heats the atmosphere. Uneven heating due to uneven cloud cover, latitude, albedo and other factors creates geographical variations in the density of the atmosphere which are unstable and lead to winds. By inserting turbines in the air currents, some of this energy can be harvested, either to perform mechanical work, such as pumping water, or to generate electricity.

Technologies for harnessing this income energy source are undergoing rapid development and costs associated with generating electricity from the wind have dropped dramatically in recent years. What was an expensive toy only a few years ago is now attracting the attention of utilities (Smith 1980). Wiggins (1978) states that wind electric generation could become competitive as early as 1982 in Lethbridge where wind speeds average 6.1 m/s. In Calgary, where wind speeds average 4.5 m/s, and in Edmonton which has average wind velocities of 3.9 m/s, he expects wind electric generation is expected to become competitive in 1988 and 1992, respectively.

A rough approximation of the wind electric energy potential in Alberta can be gained from a consideration of two regions: one south of High River, the other north of High River and south of Red Deer. If 6000 turbines, each with 90 m diameter blades, were installed and evenly distributed in each area, there would be less than one in every 10 km^2.

The electricity that could be generated by such a plan is greater than 120 PJ/a, as is shown in Table 4-1.

Table 4-1. Estimate of electric energy harvestable from wind

	Available energy ($GJ/m^2/a$)	Harvestable energy per machine (TJ/a)	Number of machines	Total harvestable energy (PJ/a)
Area I	2.360	15.24	6000	91.5
Area II	0.920	5.94	6000	36.0
TOTAL			12000	127.5

Notes: Machines are assumed to have 90 m diameter blades and to operate with a 0.33 capacity factor with 90% availability. The number of machines indicated represents less than one machine per 10 km^2 if evenly distributed over the area. Naturally, the machines could be packed much more tightly. Area I is roughly the part of Alberta south of High River; Area II, the area between Red Deer and High River. Available energy for the two areas assumes that Lethbridge and Calgary readings are typical for the respective areas. Areas north of Red Deer have not been considered because of low average wind velocities. Specific sites and/or higher prices of electricity may make wind energy harvesting in Northern Alberta economical.

Because wind velocities (and hence energy) fluctuate, some sort of storage is required. Small amounts, 15 per cent or less of the total capacity, can be allowed to float on the grid as a fuel-saver or can be peaked with hydro. Above this amount, to maintain reliability a more formal kind of storage is required. Storage processes include batteries, pumped water, compressed air, and flywheels. Within Alberta, old natural gas wells may be able to serve as a convenient reservoir for storing wind energy as compressed air.

4.2.3 Biomass

Organic materials, if not too wet, can be burned to produce gases and/or steam. Wood wastes are likely to be used to generate electricity in pulp and paper plants. However, if biomass plays a major role in the portable fuels sector then it would not be used for gas or steam production on a large scale unless the needs of the portable fuels sector had already been met.

4.2.4 Oil

At present, oil is used to generate one per cent of the electricity in Alberta (AENR 1979b). It is very unlikely that the use of oil to generate electricity will increase because of the costs, availability and range of alternatives. However, the AERCB does anticipate that oil will be employed in increasing amounts for on-site generation of electricity for operating oil sands plants.

4.2.5 Natural gas

Natural gas is currently used to generate 22 per cent of Alberta's electricity (AENR 1979b). The AERCB indicates that the use of natural gas to generate electricity is likely to decline in the future. However, it will be used increasingly for special purposes such as start-up and flame stabilisation in coal-fired plants.

Natural gas is an attractive fuel for generating electricity because it is clean burning and can be used in generators of various sizes from Fiat's 15 kWe TOTal Energy Module (Conley 1980) to much larger scale generators. The rising cost of natural gas is likely to make the generation of electricity from natural gas appear relatively expensive. However, this cost can be softened by using the waste heat from electricity generation either in industry or for district heating.

4.2.6 Coal

Coal is used to produce 69 per cent of all electricity in Alberta (AERCB, 1979b). Coal is relatively abundant and the technology for producing electricity from coal is proven. Conventional forecasts have coal playing an important role in electricity generation. This may change, however, if cheaper sources of electricity become available or for environmental reasons.

4.3 High and Medium Temperature Heat

The industrial sector demands process heat for many of its activities. This heat is needed at different temperatures by different industries. Steel melting, chemical industries, and cement industries require high temperature heat (>350 degrees Celsius) (Wiggins 1978). Most other industries require only low temperature (40 to 100 degrees Celsius) process heat. On an industry wide basis, 30 per cent of all process heat is used for water heating in the 40 to 100 degrees Celsius range, 20 per cent is used for air heating, and a substantial part of the remaining 50 per cent is used in the form of low pressure steam (Wiggins 1978).

These heat needs can be satisfied by several energy sources. Those considered in the Alberta soft energy model are by-product heat from electricity generation and portable fuels production, solar concentrating collectors, biomass, natural gas, coal and oil.

4.3.1 By-product heat

When electricity and portable fuels are produced, large amounts of heat may be generated, depending on the source. If this heat is recovered and used to meet either process or low temperature heat demands, the thermodynamic efficiency of the economy can be increased and energy resources can be conserved. Joseph Zanyk, energy chief at Dow Chemical of Canada Ltd., claims that the major obstacle to the widespread use of electrical co-generation (electrical generation with by-product heat recovery) is not economics. Rather, it is the poor attitude to the new energy sources displayed by industry and utilities (Toller 1979). Total cycle efficiency at the co-generating Dow chlor-alkali plant in Sarnia is 83 per cent; this constrasts with the conventional thermal power generation efficiency of 38 per cent. By-product heat can be used to meet process heat needs directly or can be employed for pre-heating if the waste heat has a lower temperature than the use being met.

Within the model of the process heat sector, by-product heat use is a function of the price of electricity and the total demand for process heat. The utilisation of by-product heat is never expected to exceed 35 per cent of the demand for medium and high temperature process heat.

4.3.2 Solar concentrators

Solar concentrators can be used to collect solar radiation and convert it into heat. Parabaloidal concentrators can produce heat in the 350 to 2000 degrees Celsius range. These devices are expensive, as is apparent from Table 4-2, and costs rise significantly with temperature because the degree of optical precision required increases.

Table 4-2. Costs of process heat (300^{o}C)

	Average Insolation W/m^2	Capital Cost \$/GJ/a	Operating Cost \$/GJ	End-use Cost \$/GJ
Fort Smith	125	80.14	2.10	10.60
Beaverlodge	139	72.07	1.94	9.59
Edmonton	146	68.59	1.87	9.15
Suffield	163	61.45	1.73	8.25

Notes: Retail price 118 \$/m^2 for 315^{o}, 0.44 First Law efficiency Winston collector; installation price 22 \$/m^2; 2% O&M, and 0.50 \$/GJ buffer storage (Lovins 1979, corrected for AB insolation). Life of equipment, 30 years, interest at 0.10/a constant 1976 dollars.

4.3.3 Biomass

Gases produced from biomass (biogas) can displace natural gas for process heat applications and wood can displace coal. The fluidised bed combustion of wood can produce high grade heat at efficiencies exceeding 80 per cent. In these combustors, a fluidised bed of some granular solid, usually sand, provides a heat reservoir and turbulent zone for combustion to take place. Many units are in operation and have been proven through experience (Levelton 1978).

4.3.4 Coal

Coal can also produce process heat and it is this source that the AERCB (1978) expects will meet much of their forecast energy demand in the industrial sector. Lovins (1977) has argued that the use of coal in fluidised bed reactors is an efficient and appropriate transitional energy technology which can later be replaced by income sources.

4.3.5 Natural gas

At present, natural gas is the dominant industrial fuel. Annual industrial energy use is over 180 PJ (AENR 1979b). Natural gas has many advantages including its clean combustion. However, supply constraints and rising costs are important limitations on its extended use.

4.3.6 Oil and oil sands

Industry presently uses about 85 PJ/a of oil (AENR 1979b). The AERCB (1978) has forecast that oil use will increase in the oil sands plants, for ethylene manufacture, crude oil refineries, non-energy and general industries. The availability of conventional oil and the cost of synthetic crude oil may place a damper on growth in oil use.

4.4 Low Temperature Heat

All remaining energy end uses require low temperature heat. Low temperature heat is used for space conditioning within buildings and as process heat in the industrial sector. Low temperature process heat is used in food processing plants, to spray dry food products, for alfalfa dehydration, industrial washing and drying, heat curing, solvent recovery and plastic molding (Wiggins 1978).

Seven sources of low temperature heat are considered: by-product heat from the other supply sectors, central solar installations, solar homes, central and distributed biomass systems, coal and natural gas.

4.4.1 By-product heat

Already, many processes utilise by-product heat for low temperature needs in Alberta, especially in the chemical and process industries (Wiggins 1978). There is potential for significant expansion in the use of waste heat for low temperature applications including district heating.

4.4.2 Solar systems

Hollands (1977) expected that 100 unit solar systems without backup systems would be able to compete economically with fully oil-fired systems in many Canadian cities in 1980. Similar economics apply to industrial low temperature process heat solar systems.

Houses can be designed with solar systems to meet some or all of their heat needs. Partial solar heating is the least expensive method of supplying heat on a $/GJ solar heat basis. However, the use of partial solar intensifies the seasonal peak of conventional energy because of the need for more peak capacity. Utilities have responded to this by charging users with partial solar systems higher prices.

Annual storage systems for individual dwellings are possible but are generally more expensive than neighbourhood systems because of higher storage costs. Hollands (1977) estimated that in 1980 individual house solar systems with annual storage would be competitive with oil at world prices for well-insulated homes throughout Canada.

4.4.3 Biomass

Wood can be used to generate low temperature heat at a wide range of scales from the individual dwelling to larger scale applications. In recent years, the use of wood burning stoves and furnaces has been regaining popularity. However, this popularity has been due more to aesthetic than to economic reasons.

Although burning wood will not likely increase the carbon dioxide concentration of the atmosphere since the carbon in wood is recently fixed carbon dioxide, particulate emissions from small scale combustion units could present a potential problem if installed in large numbers. In larger scale units, these emissions can be regulated. In addition, larger scale facilities can ensure more complete combustion and hence higher efficiency and lower cost.

4.4.4 Natural gas

Natural gas is the predominant source of heat in the domestic and commercial sectors in Alberta. These sectors consume 185 PJ/a (AENR 1979b). Natural gas is a convenient fuel for space heating since it is clean burning and easily and efficiently delivered (by pipe). Although there is currently a "surplus" of natural gas in Alberta, rising costs of exploration and development and the decreasing availability of supply as use increases in eastern Canada (at a rate likely to be greater than new reserves become available) may encourage a shift to other sources of space heat. At present, natural gas is considerably cheaper than oil on an enthalpic basis and this is expected to change, both as a result of government policy and the development of new industries which can use a range of fuels. This industrial flexibility will mean that increases in demand for oil, for example, may result in higher prices for all fuels.

4.4.5 Coal

Low temperature heat is produced from coal in the same way as the production of medium and high temperature heat. For low density domestic applications, using coal would probably involve a district heating network.

4.5 Model Structure

Within the model, it is assumed that existing energy capacities will be used before new capacity is built and that these facilities will die off at rates dependent on the life of the technologies. The new capacity for each of the energy quality types comes from an evaluation of the "cheapest" source option. The cost of each source option is determined from the engineering costs, the availability of the sources, and the government policies towards environmental quality and income or capital resources. In some of the technologies there is a way of calculating for the reduction or escalation of costs with time. These rates are presented in Table 4-3 [5]. Within each energy quality section, the present installed capacity is compared to the demand for energy of that quality. If the capacity exceeds the demand, no new capacity is installed. If the capacity is less than the demand, new capacity is added and is installed in increments of about 320 MW until the demand is met using the "cheapest" sources [6].

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[5] Although the data presented in Table 4-3 have been used to generate the outputs presented in Chapter 5, the model is not dependent on these data. It can easily be modified to use other sets of economic data as they become available or seem more appropriate 1) for the specific task at hand, or 2) to the person using the model.

[6] The actual incremental unit used is 10 PJ/a.

Table 4-3. Energy costs and escalation rates

	Capital costs ($/GJ/a)	Operating costs ($/GJ)	Initial rate (%/a)	Time of rate change	Final rate (%/a)
Portable fuels sector					
Biomass	8.94	1.99	-2.0	2000	0.5
Conventional oil	1.34	2.65	6.1	1985	2.0
Oil sands	14.38	3.50	3.3	1985	3.3
Coal	4.80	3.50	6.4	1985	1.5
Natural gas	0.89	2.69	6.6	1985	2.0
Electric Sector					
Hydroelectric	30.24	0.21	1.0	1985	1.0
Wind	58.07	2.51	-2.0	2000	1.0
Biomass	36.00	8.14	-2.0	2000	0.5
Oil	15.00	3.00	18.0	1985	2.0
Natural gas	15.00	3.00	1.0	1985	2.0
Coal	17.35	3.28	6.4	1985	1.5
Wind storage	72.24	0.35	2.9	1985	2.5
Process heat sector					
Solar conc.	23.90	1.35	0.0	1985	0.0
Biomass	4.34	1.99	-2.0	2000	0.5
Coal	4.34	3.50	3.3	1985	0.8
Natural gas	1.16	0.89	6.6	1983	3.0
Oil sands	3.59	2.60	18.0	1978	1.0
Low temperature heat sector					
Small solar	32.46	0.10	0.0	1976	0.0
Large solar	18.55	0.10	0.0	1976	0.0
Large biomass	13.91	2.35	-2.0	2000	0.5
Small biomass	24.34	4.00	-2.0	2000	0.5
Coal	13.91	2.41	6.4	1985	1.5
Natural gas	4.64	1.35	6.6	1985	2.0

Table 4-3. (Continued)

Notes: Costs accelerate at the initial rate until the time of rate change, after which they accelerate at the final rate.

Portable fuels sector Capital and operating costs for biomass are average values for collection and bioconversion of farm and forestry wastes (Lovins 1978b). For conventional oil, capital costs are the historical value; operating costs are derived to yield the current refiner's wellhead cost (EMR 1979) and a 20 per cent premium is added to account for transportation and processing to appropriate fuels. Oil sands capital costs are for Cold Lake (Mossop 1980). Oil sands operating costs are derived to be the wellhead reference cost (EMR 1979) plus 20 per cent. Coal costs are for H-Coal liquefaction and do not include coal mining, refining or transportation (Verhoeff 1978). Natural gas operating costs are fuel costs only (1.35 $/GJ) and assume a 50 per cent conversion efficiency of natural gas to methanol. Rates of change are directly from fuel escalation rates in Bennington (1978) except for conventional oil for which Bennington's rate changes for oil electric are used. Biomass rates are those Bennington assigns to silviculture. All technologies in the portable fuels sectors are assumed to have 30 year lifetimes (except oil sands which has 25).

Electric sector Hydro and wind costs are directly from Verhoeff (1978). Biomass costs are from Verhoeff with fuel costs from the middle of the given range. Coal capital costs are for fluidised bed combustion of Western subbituminous coal (Verhoeff 1978). Coal operating costs are derived from an assumed delivered electricity cost of 5.60 $/GJ and a capital life of 20 years amortised at 0.12/a. Oil and natural gas costs approximate historical values. Wind storage costs are for pumped hydro (Verhoeff 1978); compressed air costs are lower (Villecco 1974). Rate changes for natural gas, oil and coal are those cited by Bennington for the "process heat sector"; biomass rates are those Bennington cites for the "synthetic products sector". (Continued next page)

Table 4-3. (Continued)

Process heat sector Solar capital costs are California costs from Verhoeff; doubling of costs in Alberta is assumed. Operating costs are taken as 5.5 per cent of capital costs. Biomass and coal costs assume a fluidised bed combustion unit which is four times as efficient at converting fuel to heat as it is at converting fuel to electricity and hence costs are one quarter of capital costs for a fluidised bed combustor for generating electricity. Fuel costs are assumed to be 1.69 $/GJ and 2.98 $/GJ for biomass and coal respectively with a first law conversion efficiency to heat of 0.85. Oil sands capital costs are one quarter of oil sands portable fuels capital costs. Natural gas and oil sands operating costs are estimated at 0.75 and 2.20 $/GJ respectively. Rates for biomass are silviculture synthetic fuels rates cited by Bennington (1978). Natural gas escalation rates are also those used by Bennington for the synthetic fuels sector. Oil sands rates are Bennington's rates for oil in the process heat sector and coal are one half of his rates for coal in that sector.

Low temperature heat Solar capital costs are the high end of the range cited by Lovins (1978b). Solar operating costs are also from Lovins (1978b) as are costs for coal. Large biomass is assumed to have the same capital costs as coal. Small biomass is assumed to have the same ratio to large biomass as small solar has to large solar. Biomass fuel costs are assumed to be 2.00 $/GJ delivered and converted to heat at 83 per cent and 50 per cent efficiencies for large and small scale units respectively. Natural gas costs are the lowest of the range of frontier costs cited by Lovins (1978b). Natural gas operating costs are 1.00 $/GJ delivered converted to end-use at 75 per cent efficiency.

4.6 Barriers to the Use of Income Energy

Income energy sources have significant potential in Alberta. The south of the province has one of the best wind fields in Canada; there are large areas of forest, significant hydroelectric potential, and much of the populated portion of the province has reasonable solar insolation. However, just as there are obstacles to improving the energy efficiencies of energy using devices, there are also obstacles to the development and use of income energy sources. Some of these obstacles are inertia, institutions and politics.

The present Alberta energy system is almost totally dependent on capital sources and there is a large investment in producing, processing and distributing equipment which cannot be abandoned immediately without dire consequences. In addition, not all of this equipment can be adapted easily to the use of income energy sources and there are a large number of individuals and institutions involved in the energy industries. Most of these industries have little or no experience with income sources of energy and therefore will likely adapt slowly to their introduction.

Institutional barriers also exist to significant development of income energy. A home owner who installs a solar collector has no guarantee that his neighbour will not build a tall building or plant a tree that will shadow the collector. In addition, capital energy sources receive government assistance such as research subsidies and tax credits which place income sources at an economic disadvantage.

Helliwell (1979) points out that it is institutionally easier for governments to encourage large scale rather than small scale energy developments, even though the long term pay-offs for the small scale projects may be greater. For example, projects such as Syncrude which require enormous amounts of capital depend upon unique relationships between government and industry to ensure the project's success. Because of the need for cooperation to resolve the economic and technical problems of the project, the institutional barriers are rapidly removed. These changes are expedited by the government since the project has a high public profile and the government can take credit for the project.

Removing institutional obstacles for small scale projects, on the other hand, is often a difficult and risky venture for governments. A government can do little more than establish a favourable climate through tax incentives and pricing policies, for example, to encourage small scale projects. These projects do not necessarily require close contact between government and industry and the industry, not the government, usually obtains visible public credit for the project.

Thus what is needed is a concerted effort to make small scale energy projects with high pay-offs more attractive to both industry and government. One way of doing this is to reward wise energy users, not energy wasters - to reward innovators, not laggards. Another is to enhance the cooperation, coordination and information exchange between government and industry to quickly remove obstacles to the rapid introduction of these projects.

Present trends suggest that income energy sources will, as most government analysts state, play a relatively minor role in Alberta's future. However, this is not inevitable or necessary. It is estimated that many sources of income energy would have cost advantages over their capital counterparts now if they were allowed to compete freely. A shift towards a sustainable energy system will require that either incomes be given subsidies equivalent to those given to capital energies or, preferably (from the demand and social efficiency perspective), that the removal of the subsidies for capital energy be carried out.

5. SCENARIOS AND THE SOFT ENERGY MODEL

This chapter discusses the results from the model for three scenarios for possible developments of the energy component of Alberta's energy future.

A scenario is a set of assumptions. A set of assumptions is used as an input to the model of energy supply and demand in Alberta. The results given by the model are therefore not a forecast of what will happen, but rather the consequences suggested by the model for the set of assumptions. By running the model with several scenarios, limitations and vulnerabilities of the model and/or the energy system can be determined. Within the context of soft energy planning, the role of scenarios is to determine what needs to be done to bring about a desired end state, or to test how effective a set of policies is likely to be at achieving some set of goals.

The first scenario is a continuation of present trends. Historically, energy prices were negligible and this scenario considers the effect of continuing this policy until the turn of the century. Income energy sources continue to be discouraged by such measures as increasing the property tax on a home with a solar collector. Capital energy sources are subsidised by government research, tax incentives and direct subsidy such that the consumer is neither encouraged to use energy wisely according to its real value nor attracted to non-subsidised income energy sources.

The second scenario is one in which engineering costs of energy systems are the key determinant of pricing policies and in which the subsidies for capital energy sources are gradually removed by 2001.

The third scenario represents a gradual shift towards a more sustainable energy future. Energy prices rise gradually beginning in 1976. Concurrently, subsidies are gradually removed from capital energy sources. Disincentives to the use of income energy sources are removed.

5.1 Business As Usual Scenario

This scenario assumes that current energy intensities will continue to apply until the turn of the century. As in all the scenarios, growth in population and standard of living is quite large.

5.1.1 Energy demand

5.1.1.1 The domestic sector

Under the "business as usual" scenario, total domestic end-use energy consumption grows by almost 150 per cent between 1976 and 2026. Electricity use almost triples in the same period. The dynamics of this use are presented in Figure 5-1. These rates are more rapid than the increase in population growth reflecting the shift to smaller household sizes (2.75 persons per household in 2000 compared with 3.13 in 1976), and the increased saturation of appliances in the marketplace.

5.1.1.2 Commercial energy demand

Growth in energy use within the commercial sector is also large with floor area per capita doubling from 20 m^2 to 40.3 m^2. The specific

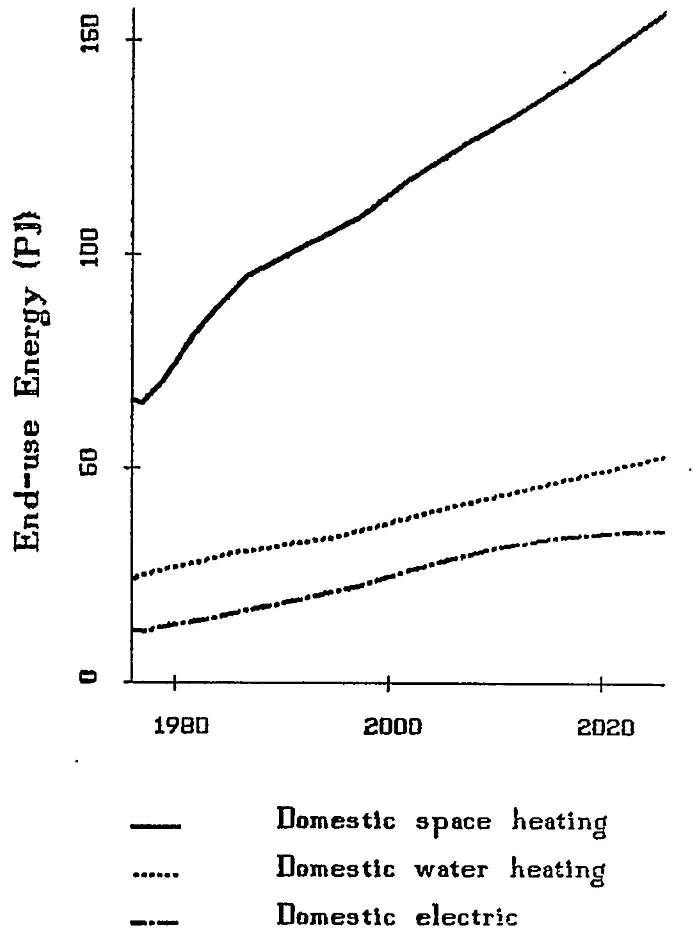

Figure 5-1. Energy demand in the domestic sector from the "business as usual" scenario

energy need stays constant at 85 W/m^2 and all growth is thus accounted for by increasing population and area per capita. Figure 5-2 indicates the pattern of use over time.

5.1.1.3 Transportation energy use

Because of the increase in the fraction of dwelling units which are apartments, urban passenger demand per capita steadily drops from 4200 km/a to 3800 km/a, as indicated in Table 5-1. Urban bus travel increases significantly, an effect also attributable to higher density

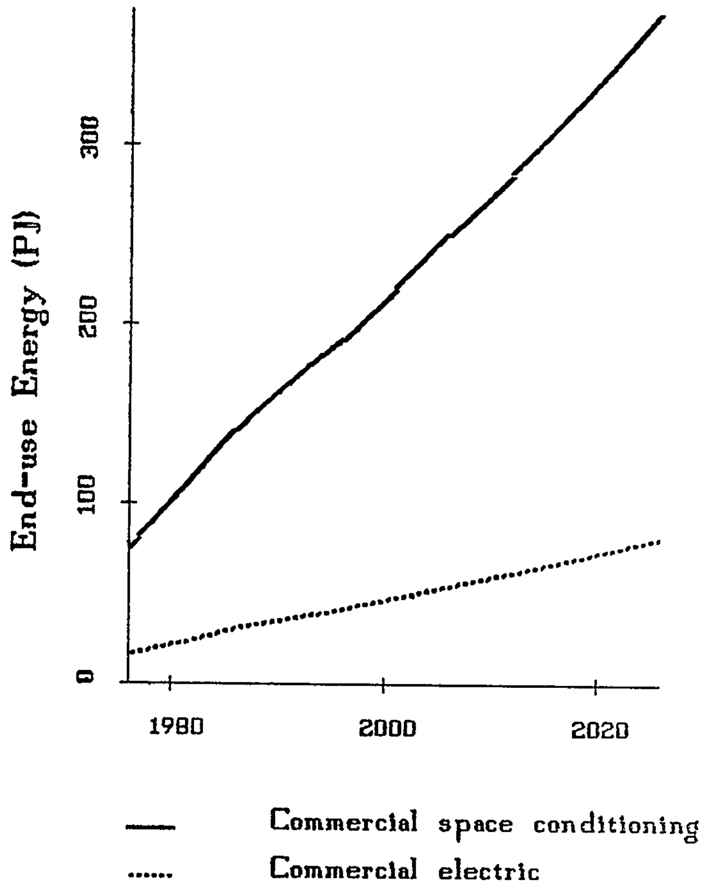

Figure 5-2. Energy demand in the commercial sector from the "business as usual" scenario

development.

Inter-city travel demand per capita almost triples with growth in all modes growing at almost the same rate. With the population more than doubling over the fifty year period, this indicates more than a 6 fold increase in inter-city passenger energy demand.

Freight transport demand per capita increases by approximately 50 per cent by 2011 and then gradually declines as prices rise and more localised production of goods is encouraged. As the price of portable fuels begins to rise, the efficiency of vehicles improves and this,

Table 5-1. Urban transportation demand and energy use from the business as usual scenario

Time	Total Demand km/cap/a	Auto Demand km/cap/a	Bus Demand km/cap/a	Auto Energy PJ/a	Bus Energy PJ/a
1976.	4211.	4043.	168.	27.6	0.6
1981.	4126.	3961.	165.	31.0	0.6
1986.	4056.	3879.	177.	26.2	0.8
1991.	3996.	3757.	239.	18.2	1.1
1996.	3943.	3651.	292.	15.5	1.5
2001.	3891.	3549.	342.	15.9	1.9
2006.	3849.	3469.	380.	16.7	2.2
2011.	3822.	3416.	406.	17.6	2.4
2016.	3802.	3378.	424.	18.5	2.5
2021.	3788.	3351.	436.	19.6	2.6
2026.	3777.	3332.	446.	20.3	2.6

coupled with the decreased demand for transport, results in lower energy demand in later years.

The energy use by the transportation sector is presented in Figure 5-3.

5.1.1.4 The industrial sector

The industrial sector demand is derived from the demand forecast by the AERCB (1978) and modified according to the demand reductions Section 3.4 discussed. In the "business as usual" scenario, efficiencies stay at the levels suggested by the AERCB. This results in rapid growth, especially by the petrochemical industries and general industry. This growth is illustrated in Figure 5-4.

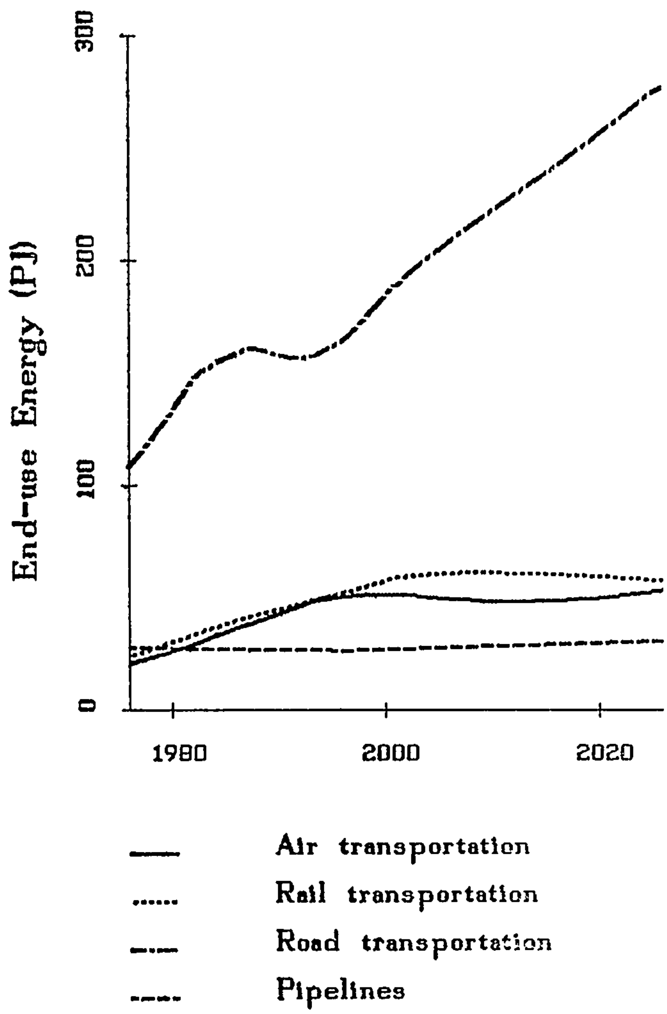

Figure 5-3. End-use energy demand in the transportation sector from the "business as usual" scenario

5.1.2 Energy supply

As in the other scenarios, energy supply in the "business as usual" scenario is determined by the energy production costs, their dynamics over time, and government policies towards incomes and capitals. In this scenario, it is assumed that capitals receive a 50 per cent subsidy and incomes receive a 100 per cent penalty.

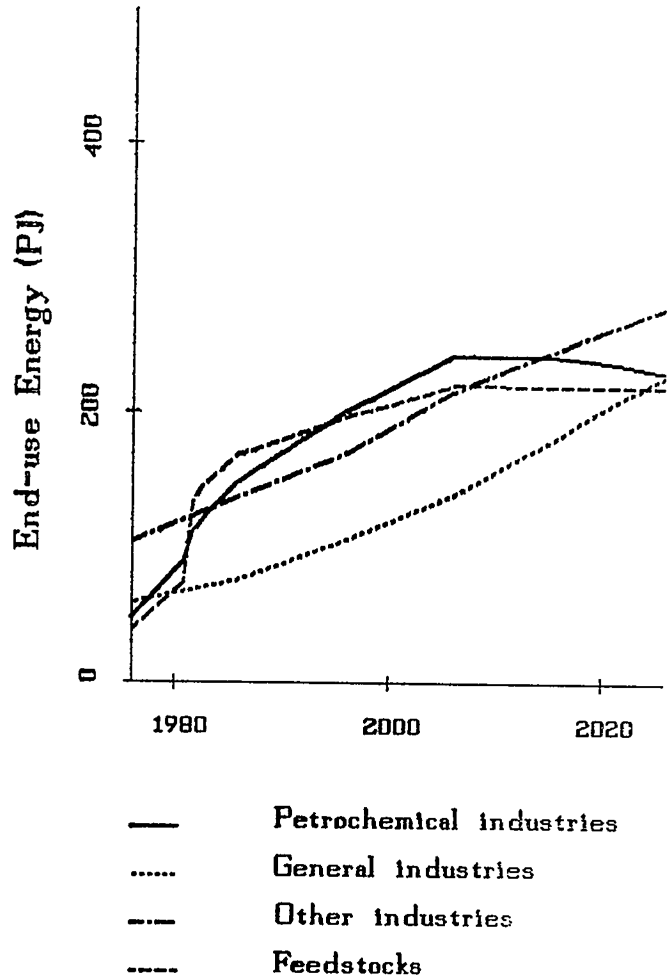

Figure 5-4. End-use energy demand in the industrial sector from the "business as usual" scenario

5.1.2.1 Portable fuel supply

Conventional oil continues to hold its monopoly position until 1987 when production begins to decline. The deficit is made up by natural gas which is converted into methanol at a cost of 3.69 $/GJ. The installed capacity of natural gas to methanol plants continues to grow until it reaches a maximum of 92.2 PJ/a (production) in 1998. In spite of a four fold cost disadvantage, (due to the 50 per cent capital energy subsidy and 100 per cent income energy penalty) portable fuels (methanol) from biomass increase until they become competitive with oil and methanol from natural gas in 1999. From 1999 until 2026, methanol from biomass gradually becomes the dominant source of portable fuels as shown in Figure 5-5.

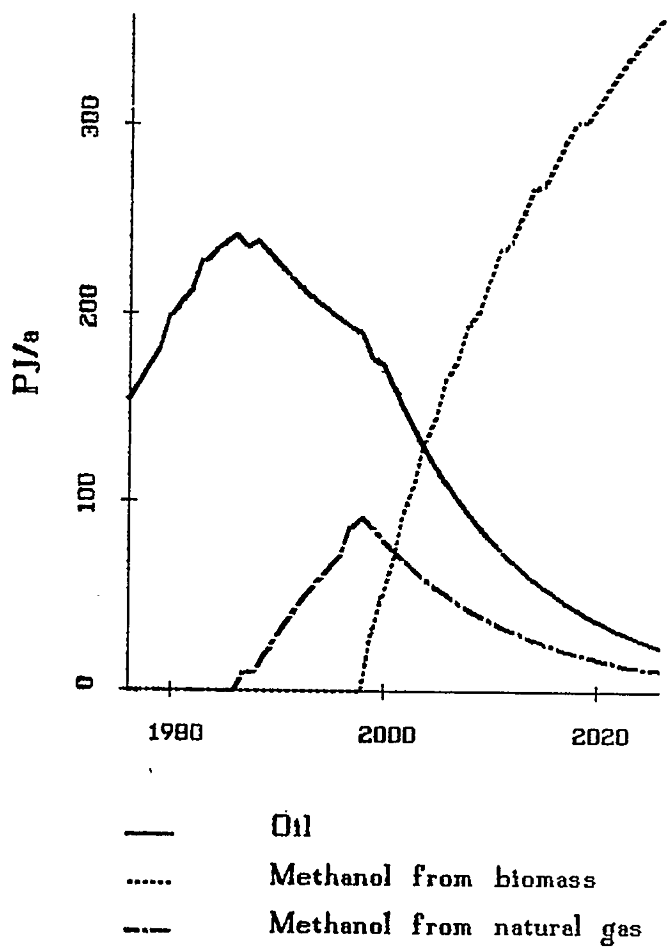

Figure 5-5. Production of portable fuels in the "business as usual" scenario.

The conversion of wood to methanol is a relatively inefficient process and the primary energy demand of the portable fuels sector thus grows quite quickly. Some of the waste heat generated from methanol production is recovered, however, for meeting heat needs.

5.1.2.2 Electricity supply

In the "business as usual" scenario, coal is the dominant energy source used to generate electricity, although the model suggests that natural gas would, based on price, be used to generate some electricity until a maximum production of electricity from natural gas of 46.1 PJ/a is reached in 1980. After 1980, electricity from natural gas declines as the equipment depreciates. In spite of the disincentives placed on income energy, electricity from hydroelectric plants is still reasonably priced and is developed to its maximum. The installed capacities are illustrated in Figure 5-6.

5.1.2.3 Process heat supply

Natural gas, the dominant source of process heat today, maintains its strong hold on the market throughout the entire 1976 to 2026 period in the "business as usual" scenario. With the pricing policies of this scenario (50% subsidy on capitals, 100% penalty on incomes), the two income sources, biomass and solar, are nowhere near competitive and are therefore not developed.

5.1.2.4 Low temperature heat supply

Within the low temperature heat supply sector, natural gas continues to have a strong hold on the market reaching a maximum installed production capacity of 495 PJ/a in 2012. By 2013, neighbourhood solar systems become competitive with costs of 2.50 $/GJ compared to natural gas at 2.69 $/GJ. By 2026, neighbourhood systems produce about 20 per cent of

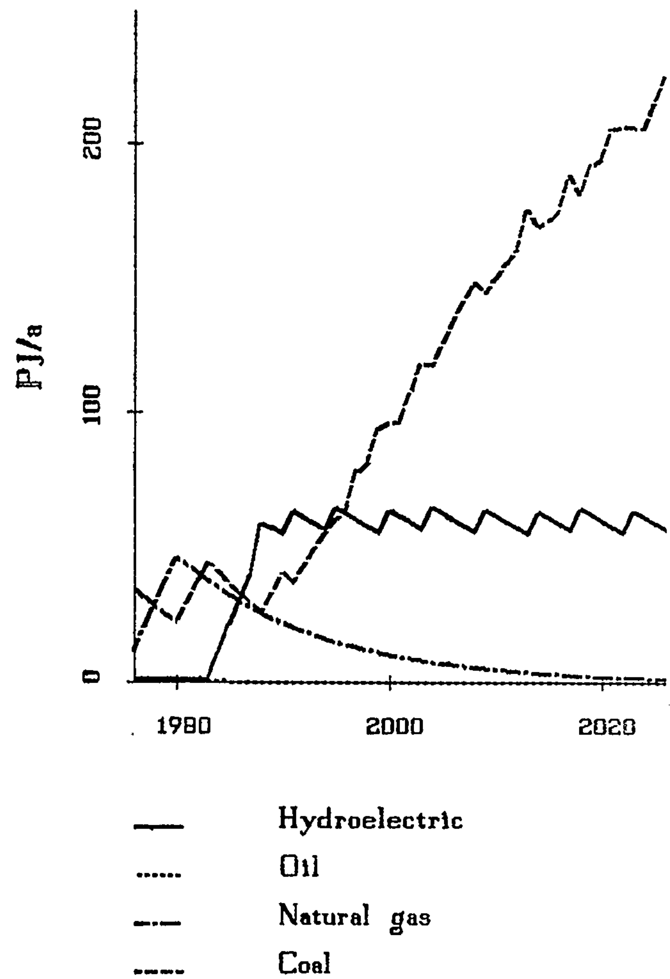

Figure 5-6. Installed electric capacity in the "business as usual" scenario

the low temperature heat supplied. The installed capacities of low temperature sources of heat are diagrammed in Figure 5-7.

5.1.3 Scenario summary

In the "business as usual" scenario, growth in both end-use and primary energy demand is large, as shown in Figure 5-8. However, income energy sources, primarily biomass, still play a significant role, as

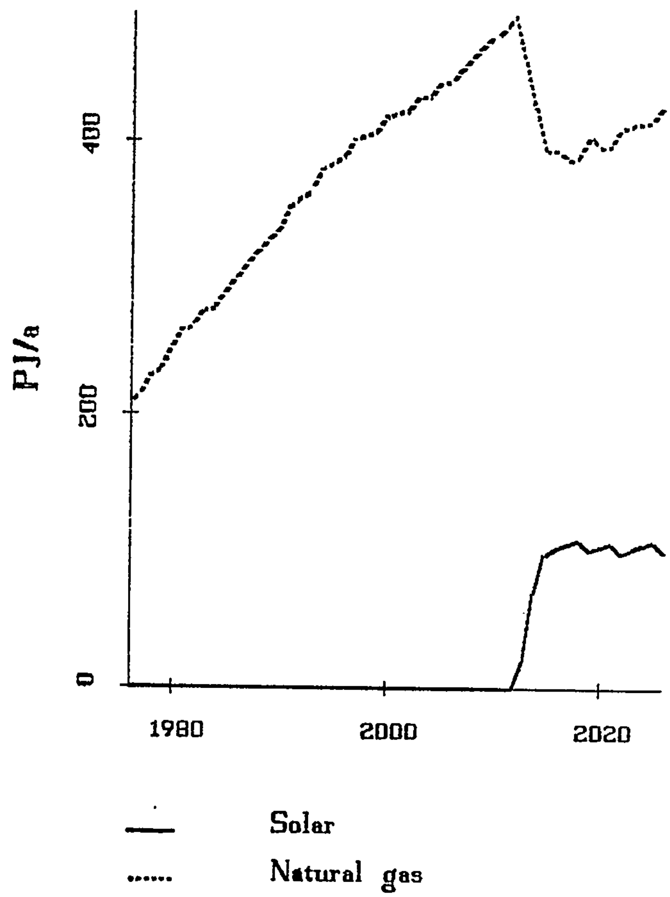

Figure 5-7. Installed capacities for supplying low temperature heat from the "business as usual" scenario

illustrated in Figure 5-9, although, coal is the dominant source of energy.

In many ways, this scenario represents a conventional energy forecast. However, it illustrates three areas of aggregation or exclusion. First, the model does not consider government policies towards specific fuels, although it does consider policies towards sources depending on whether they are income or capital.

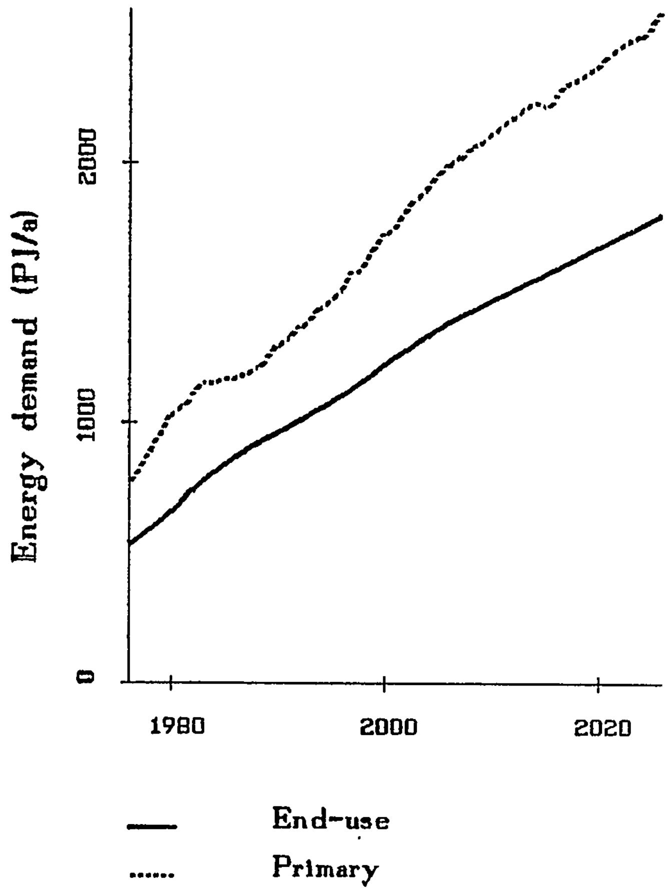

Figure 5-8. Energy demand in the "business as usual" scenario

Another consideration excluded from the model is a long term perspective when choosing energy sources. This results in two deviations from expected results, as presented in the media. Firstly, oil sands development does not occur when the model is run with this scenario and it is replaced by biomass development. Secondly, natural gas is used to generate electricity in the early years of the run, even though its cost advantage is fleeting.

The scenario also differs from "conventional forecasts" such as those of the AERCB (1978) in that demand for some goods and services

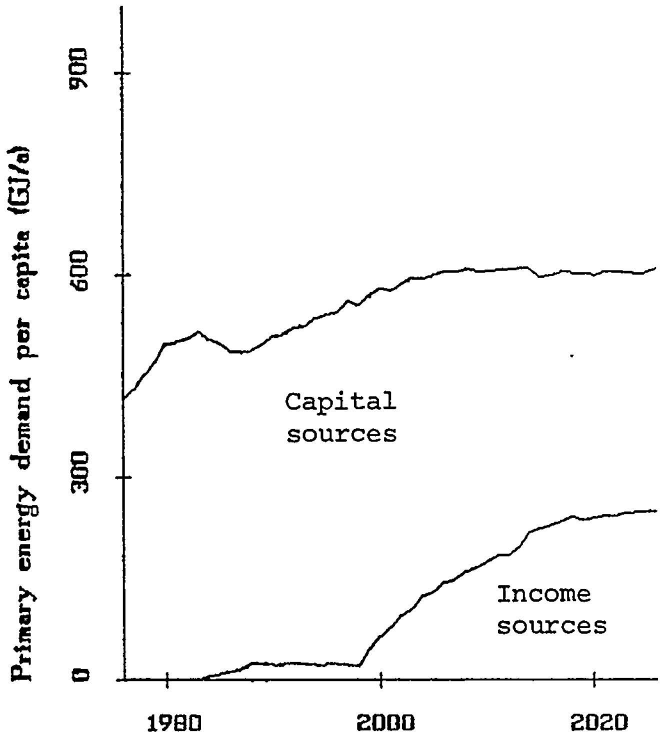

Figure 5-9. Primary energy demand per capita from the "business as usual" scenario

(especially petrochemicals) has been reduced.

This scenario suggests that maintaining present energy efficiencies until the turn of the century will result in a 3.4 fold increase in primary energy demand between 1976 and 2026. Coal, biomass and natural gas are the sources used to meet this demand.

5.2 Economic Efficiency Scenario

In this scenario, prices are allowed to float with the costs of energy production. However, initially, capitals are subsidised (to represent present conditions). These subsidies are gradually removed until they have been eliminated by 2026.

It should be pointed out that the phrase "economic efficiency" is being utilised in a very narrow sense. Costs of energy production are not necessarily "real" costs because they may exclude social and environmental costs, and ignore such issues as inter-generational equity problems. In a truly efficient economy, decisions would be based on these "real" costs as well as on the costs of production.

5.2.1 Energy demand

5.2.1.1 Domestic energy demand

Within the domestic sector, energy intensities fluctuate with energy prices. However, by 2026 there is a significant reduction in the energy intensities for space heating in houses and apartments.

Throughout the forecast period the domestic electricity demand increases. However, total demand for water heating rises until it reaches a maximum of 27.3 PJ/a in 1981 and then falls until 2014, with a slight rise to 2026. The space heat demand fluctuates over the forecast period in the direction of lower space heat demand. It goes from a maximum of 66 PJ/a in 1976 to 18.9 PJ/a in 2026 (see Figure 5-10).

5.2.1.2 Commercial energy demand

Commercial specific energy needs decline until the mid 1990's and then rise until the mid 2010's. In the final years, they fall slowly. These trends are presented in Figure 5-11.

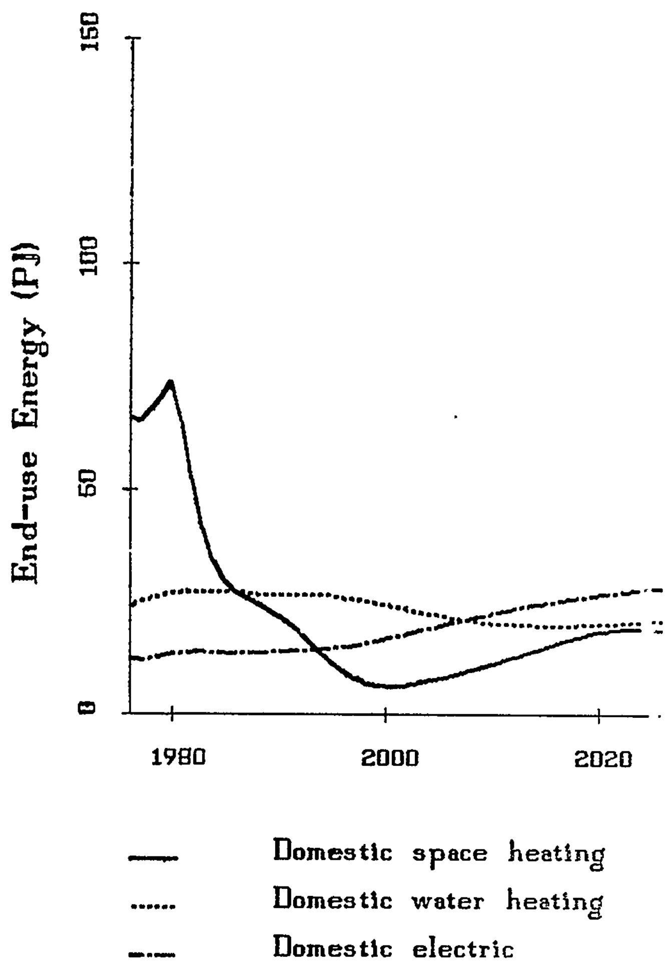

Figure 5-10. End-use energy demand by the domestic sector in the "economic efficiency" scenario

5.2.1.3 Transportation energy demand

As in the "business as usual" scenario, urban auto use declines as a result of higher density development whereas bus use increases. Energy use by cars rises after 1996 because of the rising population and market saturation of efficient automobiles. Urban bus energy rises throughout most years until a level more than four times higher than the original energy use (2.6 PJ/a in 2026, 0.6 PJ/a in 1976) is reached.

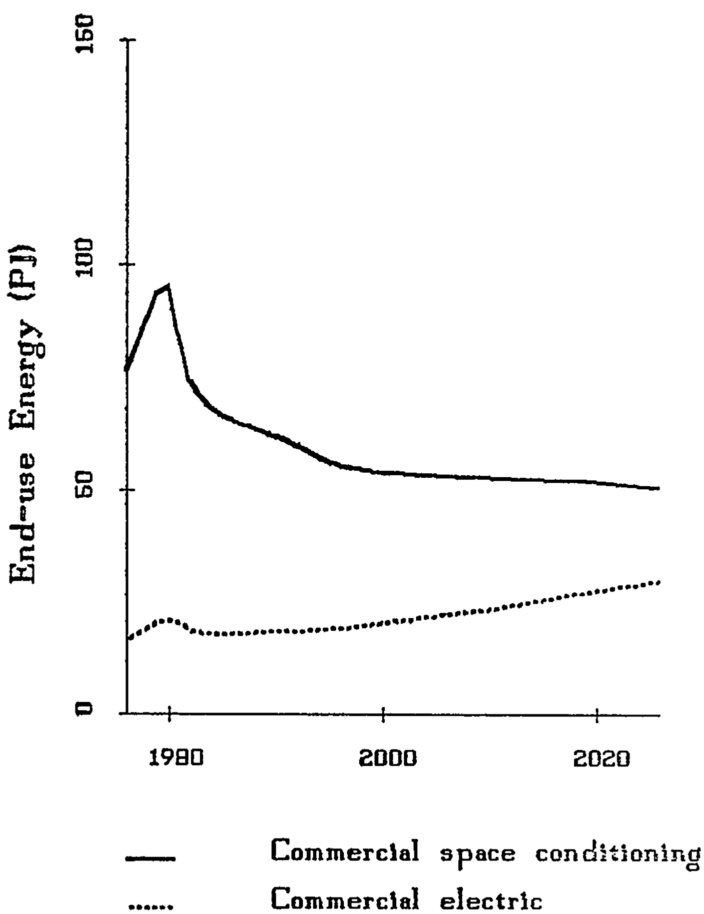

Figure 5-11. End-use energy demand by the commercial sector in the "economic efficiency" scenario

Inter-city passenger transportation increases significantly from 10 800 km/capita/a in 1976 to 30 400 km/capita/a in 2026. Automobiles lose their large share of the total demand in the first few decades but rapidly regain their large share as portable fuel prices drop.

The dynamics of the cost of portable fuels result in a shift to more localised production in the first few decades leading to increased urban truck use and decreased rail and inter-city truck freight transport demand. As energy prices fall, economies of scale once again favour larger production centres resulting in increased inter-city freight transport demand.

How energy use by transportation mode changes over time is illustrated in Figure 5-12.

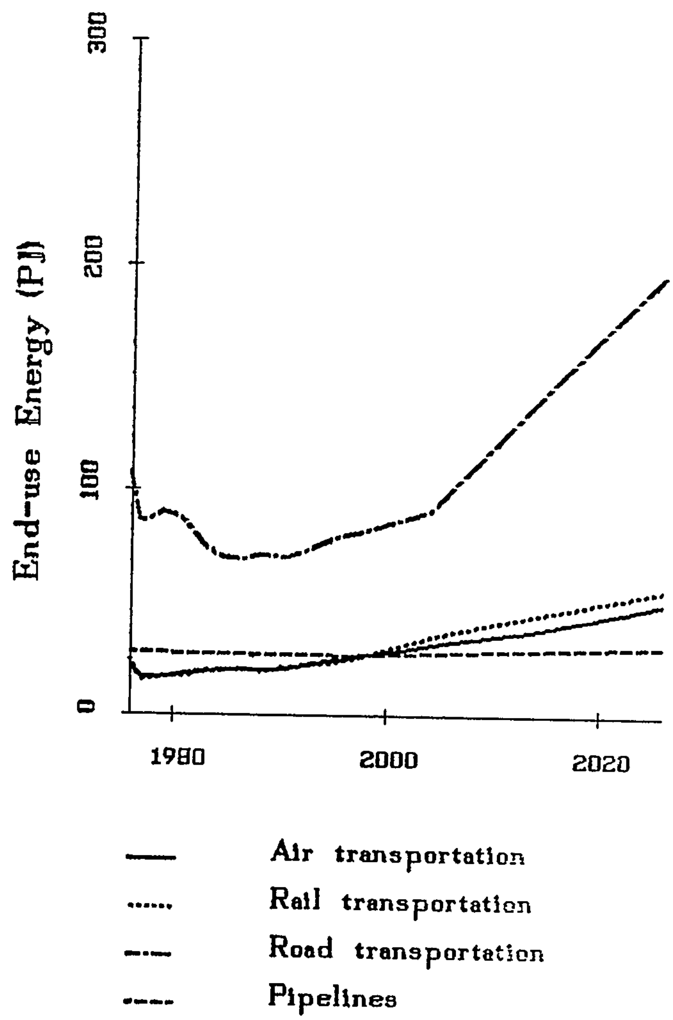

Figure 5-12. End-use energy demand by the transportation sector in the "economic efficiency" scenario

5.2.1.4 Industrial energy demand

As in the other two scenarios, industry undergoes rapid growth in the "economic efficiency" scenario. The efficiency of energy use fluctuates with energy costs but is generally shadowed by the large growth in production, which is illustrated in Figure 5-13.

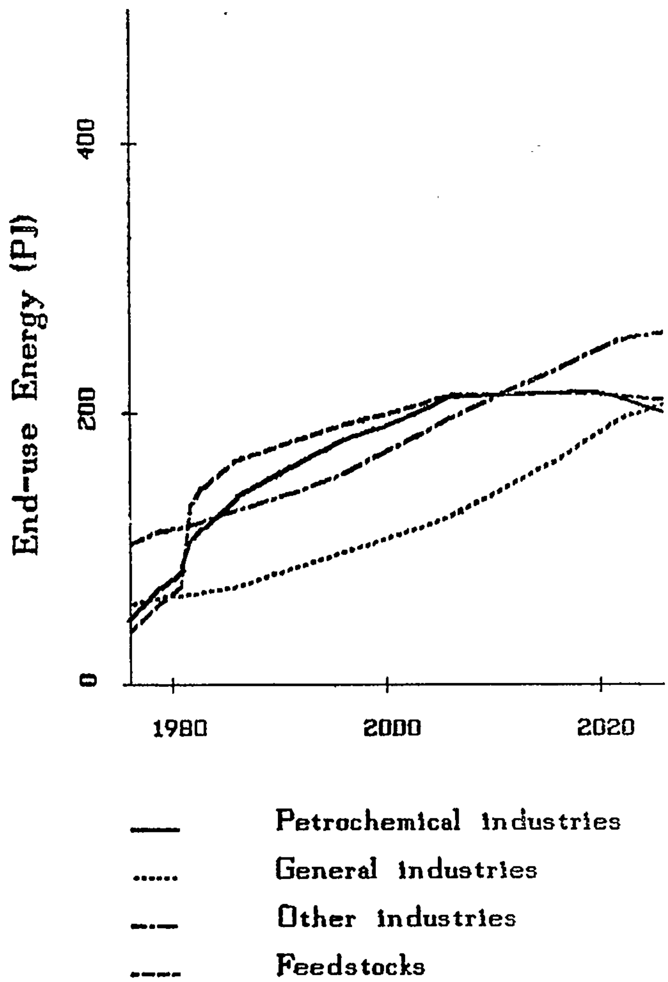

Figure 5-13. End-use energy demand by the industrial sector in the "economic efficiency" scenario

5.2.2 Energy supply

5.2.2.1 Portable fuels supply

In the portable fuels supply sector, oil, which at present meets almost all portable fuel needs, begins to be replaced by methanol from biomass in 1984. The domination of the portable fuels market by methanol from biomass commences in the early 1990's. By 2026, over 98 per cent of all portable fuels is methanol from biomass.

Although this means that Alberta will become less dependent on capital sources of energy, it also means that the efficiency with which portable fuels are produced will decrease. (The First Law efficiency of producing methanol from wood is between 0.4 and 0.5). This increases primary energy demand dramatically, although some of the 60 per cent of primary energy lost can be recovered and used for process heat or space heat needs. Figure 5-14 illustrates the shift to biomass and the increase in primary energy.

5.2.2.2 Electricity supply

In the "economic efficiency" scenario, coal loses its strong hold on electricity generation to natural gas, hydro, wind and biomass. Natural gas use peaks in 1979 and then drops off, too. By 2026, electricity from wind predominates, with natural gas and coal providing less than 1 per cent of the total electricity supply.

In contrast to the portable fuels supply sector, the ratio of primary to end-use energy in the electricity supply sector decreases as the use of wind and hydro increases. Installed electric capacity is

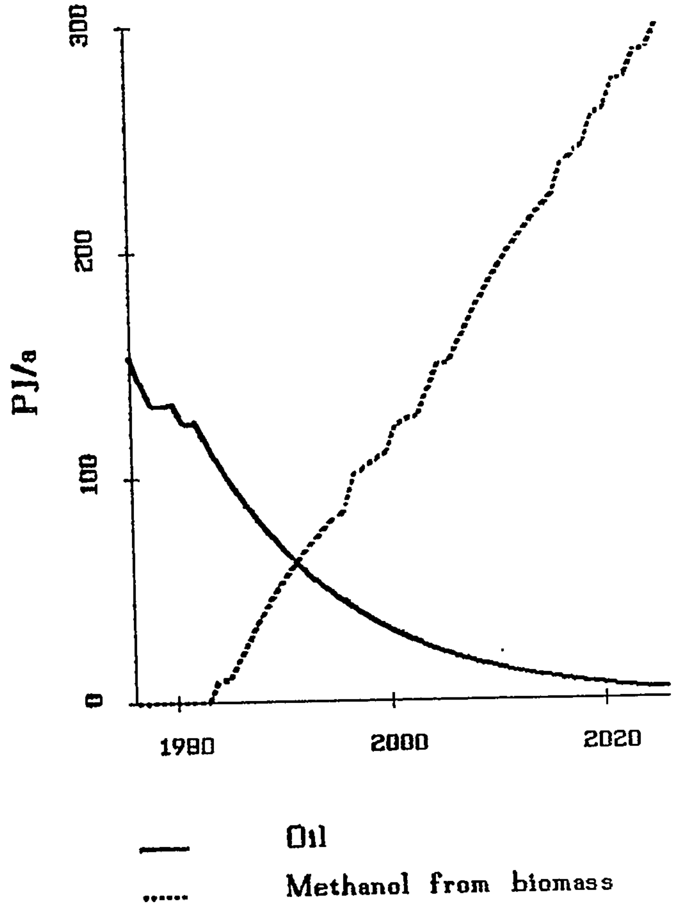

Figure 5-14. Production of portables fuels in the "economic efficiency" scenario

presented in Table 5-2.

5.2.2.3 High and medium temperature process heat supply

Until 1995, the use of natural gas for process heat increases. In 1996, however, biomass comes on stream and begins to overtake natural gas in 2003 as the major supply source. In 2017, solar process heat becomes cost-effective. By 2026, natural gas, biomass and solar process heat comprise appproximately equal shares of the total process heat supply.

Table 5-2. Installed electric capacity from the "economic efficiency" scenario (PJ/a)

Time	Hydro	Wind	Bio-mass	Oil	Gas	Coal	Total
1976.	1.6	0.0	0.0	0.5	11.2	35.0	48.3
1981.	11.3	0.0	0.0	0.3	33.4	19.7	64.8
1986.	47.5	0.0	0.0	0.2	22.8	11.1	81.6
1991.	58.4	10.0	0.0	0.2	15.5	6.2	90.3
1996.	57.5	35.3	0.0	0.1	10.6	3.5	107.0
2001.	56.7	61.8	0.0	0.1	7.2	2.0	127.7
2006.	55.7	89.7	0.0	0.0	4.9	1.1	151.5
2011.	64.9	99.5	0.0	0.0	3.3	0.6	168.4
2016.	63.9	93.6	19.3	0.0	2.3	0.3	179.4
2021.	63.1	99.5	31.7	0.0	1.6	0.2	196.1
2026.	62.4	103.6	40.2	0.0	1.1	0.1	207.3

5.2.2.4 Low temperature heat

Low temperature heat demand rises until 1980 and falls until 1997. However, it increases again to 2019 and then decreases to 2026. Neighbourhood solar systems and industrial solar systems begin to be used in 1987 but their potential is limited. Central biomass facilities and individual solar homes make up the deficit, as can be seen in Figure 5-15.

5.2.3 Scenario summary

In the "economic efficiency" scenario, total primary energy use almost doubles from 750 PJ/a to 1460 PJ/a. End-use energy demand goes from 530 PJ/a to 1100 PJ/a as illustrated in Figure 5-16. As shown in Figure 5-17, primary energy demand per capita undergoes an overall drop

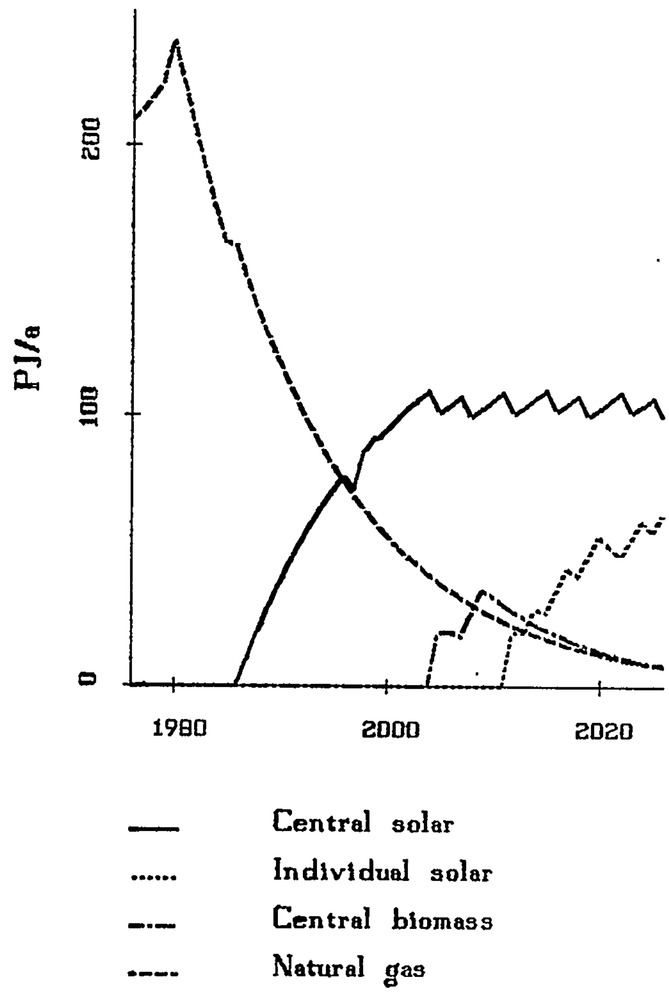

Figure 5-15. Production of low temperature heat in the "economic efficiency" scenario

from its present level but the proportion of primary energy coming from incomes increases dramatically. In 2026, incomes meet 91 per cent of primary energy demand. However by 2015, the potential contribution of many income sources has reached its peak and capital energy use begins to increase slightly.

Energy costs are moderate in 2015 (2.36 $/GJ for portable fuels, 6.93 $/GJ for electricity, 2.09 $/GJ for high and medium temperature

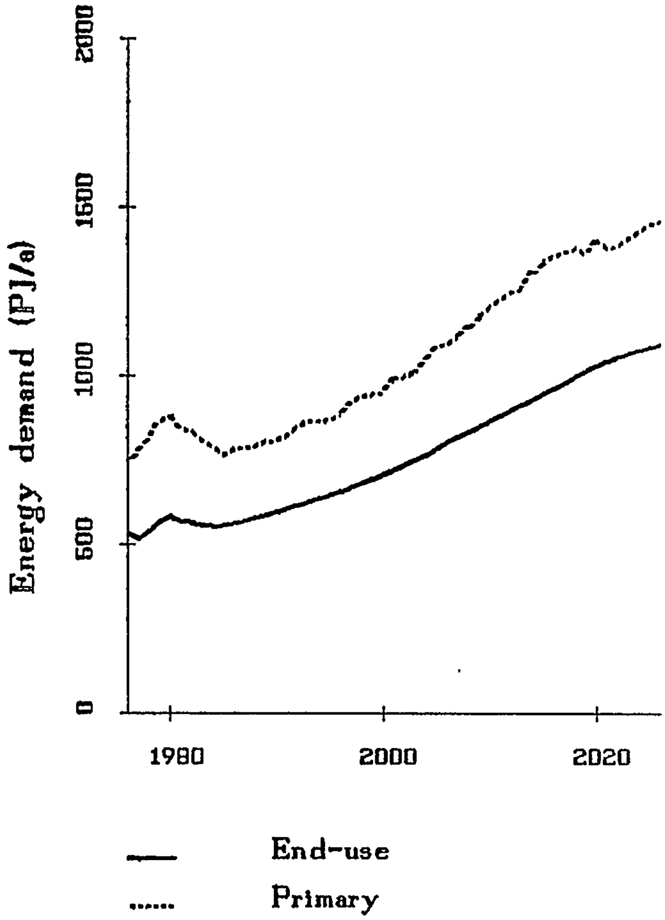

Figure 5-16. Energy demand in the "economic efficiency" scenario

heat, and 2.78 $/GJ for low temperature heat). Since these costs are used directly as energy prices, there is potential for reducing demand to a level which will eliminate the need for capitals and still allow a modest increase in population.

This scenario suggests that an economically efficient society would make decisions leading to a society based almost completely on income energy sources.

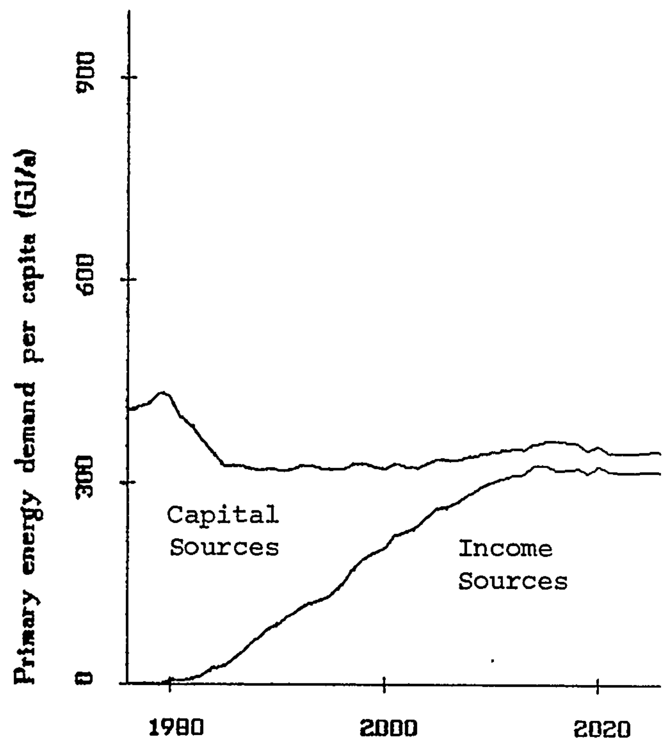

Figure 5-17. Primary energy demand per capita in the "economic efficiency" scenario

5.3 Gradual Transition Scenario

The "gradual transition" scenario has energy prices gradually rising with a steady slope from 1976 to 2026. Government subsidies of capital energy sources are gradually removed over the 50 year period. This scenario simulates an orderly transition from a relatively inefficient energy system based on capital energy to a more efficient one based almost entirely on income sources of energy.

5.3.1 Energy demand

5.3.1.1 Domestic energy demand

As presented in Figure 5-18, domestic energy demand rises until 1979 because of the lag time of responses to rising prices.

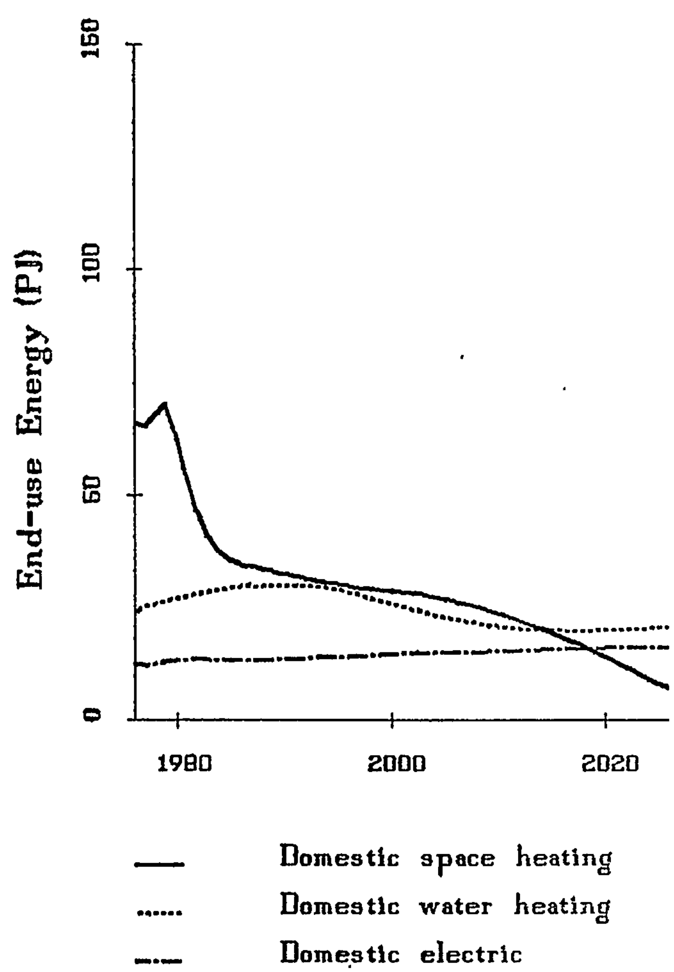

Figure 5-18. Domestic end-use energy demand from the "gradual transition" scenario

Beginning in 1979, domestic space heating needs start falling off dramatically as new houses and apartments are built with the features of the Saskatchewan Conservation House and old dwellings are retrofit. The energy required for water heating within each unit falls gradually until about 2008. However, until 1992, this falling is not great enough to compensate for the increase in the number of units and total energy use for heating water rises until that time. After 2008, the increased saturations of dishwashers and clotheswashers results in a very slight increase in energy use for water heating. Residential electric use drops to 57 per cent of its original level of 13.8 GJ/unit/a. This is in spite of significant increases in the saturation and number of appliances.

5.3.1.2 Commercial energy demand

Within commercial buildings, the higher prices also result in a dramatic decrease in specific energy need from its historically high value of 85 W/m^2 to 52.4 W/m^2 for pre-1976 buildings and to 9.0 W/m^2 for post-1976 buildings. This level of energy use is attained in 2026. As discussed in Section 3.2, buildings with lower specific energy needs have higher fractions of that need contributed by electricity and this is reflected in the rising electricity demand as presented in Figure 5-19. The drop in space conditioning needs in buildings is so dramatic that in spite of a doubling of commercial floor area per capita and a 130 per cent increase in population, total space conditioning energy demand drops 42 per cent between 1976 and 2026.

5.3.1.3 Transportation energy demand

Hazel Henderson has suggested that transportation demand is a measure of disfunction of societal organisation since higher transportation demands indicate that people are farther from where they want to be

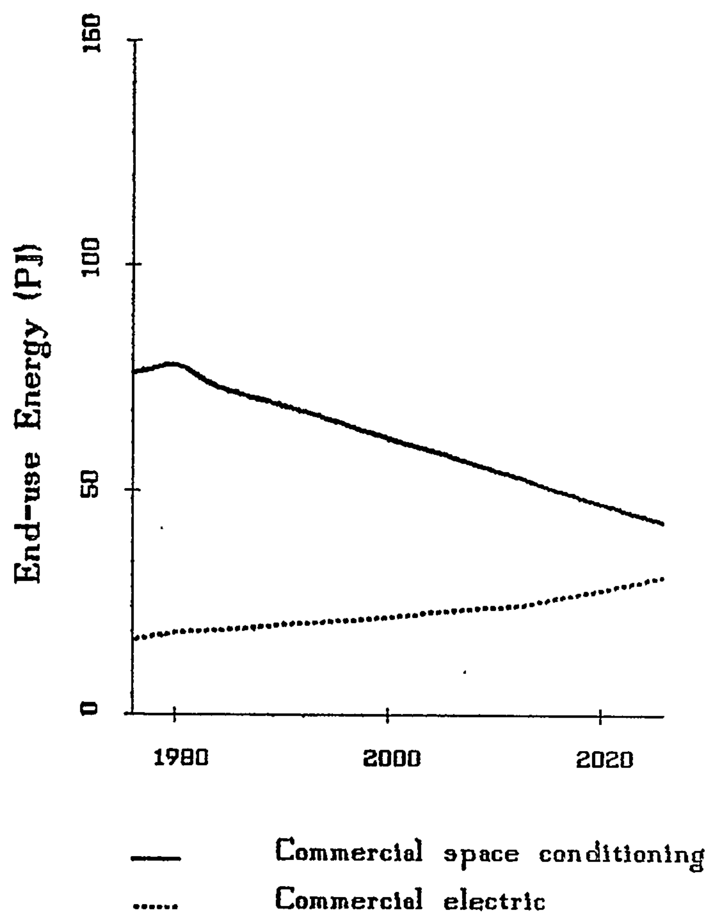

Figure 5-19. End-use energy demand in the commercial sector from the "gradual transition" scenario

(Hayes 1977). Within the "gradual transition" scenario, urban transportation demand decreases from 4200 km/capita/a in 1976 to 3800 km/capita/a in 2026. Automobile use drops off at an even greater rate since buses can serve transportation needs more efficiently than today due to the higher density of urban areas. Automobile energy use still shows a slow but steady increase, however, because population growth outstrips automobile efficiency improvements and reduced per capita travel.

Inter-city transportation demand shows a significant increase, although not as large as in the other two scenarios. Transportation by all modes increases until 2006, especially inter-city bus and rail transportation. After 2006, inter-city auto travel drops off slightly but all other modes continue to increase.

Freight transportation, measured in t-km/capita/a is 40 per cent greater in 2026 than in 1976. However, the mass of goods delivered is considerably larger since higher transportation costs have resulted in a shift to more localised production of goods. This decentralisation of manufacturing leads to a drop in inter-city truck transport demand after 1991 and a drop in rail freight transport after 2002. Urban truck transport increases five fold in the 50 years from 1976 to 2026, in spite of efficiency improvements in the vehicles.

Transportation energy use is illustrated in Figure 5-20.

5.3.1.4 Industrial energy demand

Within the industrial sector, rising energy prices result in an increasing efficiency of energy use. Energy use for industry in 2026 from the "gradual transition" scenario is only 90 per cent of the use from the "economic efficiency" scenario and 82 per cent of the energy use from the "business as usual" scenario. The dynamics of industrial energy use are presented in Figure 5-21.

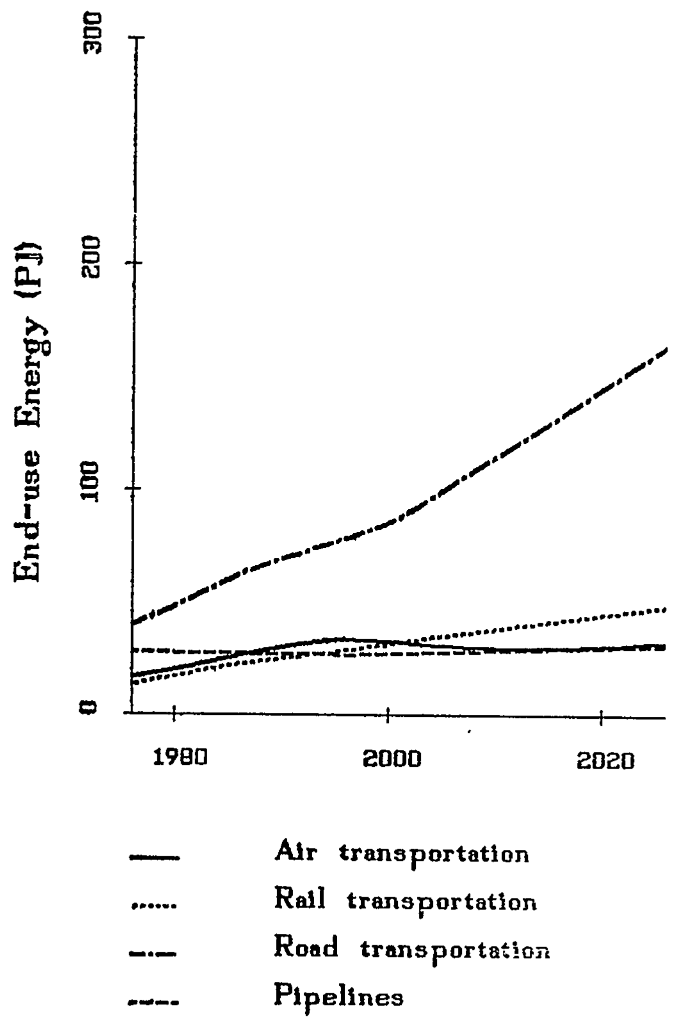

Figure 5-20. End-use energy demand in the transportation sector from the "gradual transition" scenario

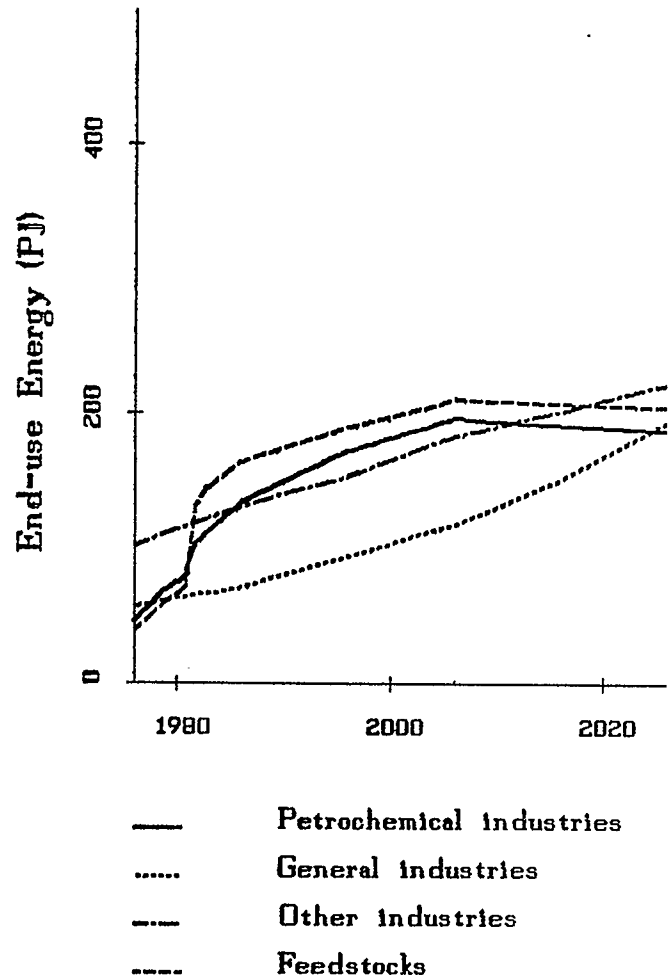

Figure 5-21. End-use energy demand by the industrial sector from the "gradual transition" scenario

5.3.2 Energy supply

5.3.2.1 Portable fuels supply

Total demand for portable fuels falls until 1983 and then rises until 2026. It is about 1983 that methanol from biomass becomes competitive with oil, both costing about 2.50 \$/GJ. After 1983, the falling price of biomass and the rising price of oil results in a rapid shift to biomass as the source of portable fuels. This is illustrated in Figure 5-22.

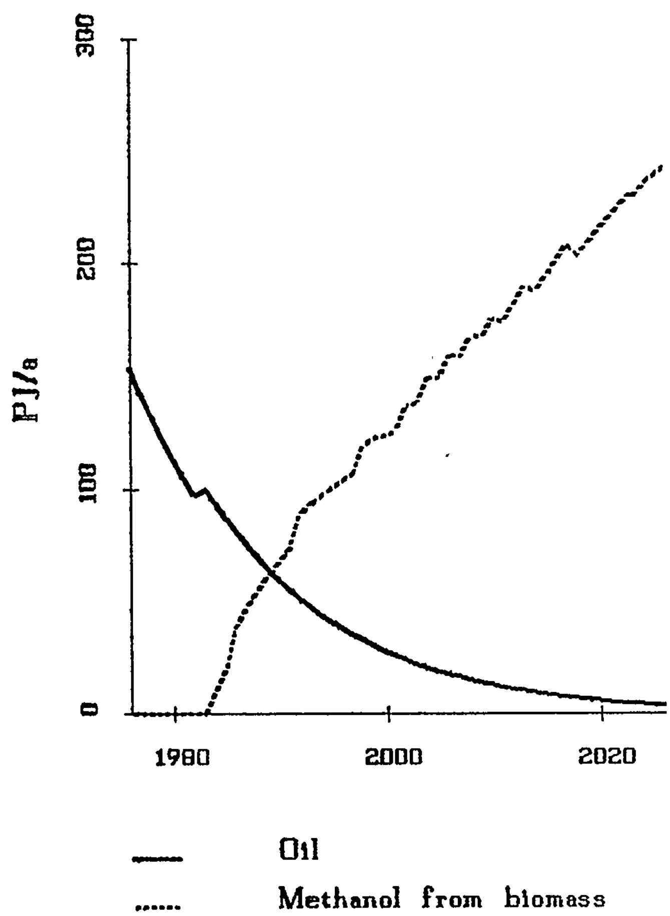

Figure 5-22. Production of portable fuels from the "gradual transition" scenario

5.3.2.2 Electricity supply

As presented in Table 5-3, income sources of energy also play an increasing role in the electric supply sector under the "gradual transition" scenario. Wind and hydroelectric energy are both developed to their maximum potential whereas coal plays an ever decreasing role.

Table 5-3. Installed process heat capacity from the gradual transition scenario (PJ/a)

Time	Solar	Biomass	Gas	Oil Sands	Byproduct Heat
1981.	0.0	0.0	118.0	16.5	21.0
1976.	0.0	0.0	89.8	26.1	10.0
1986.	0.0	0.0	171.2	10.4	34.0
1991.	0.0	0.0	201.4	6.6	35.0
1996.	0.0	20.0	209.8	4.1	30.0
2001.	0.0	116.3	143.0	2.6	28.0
2006.	0.0	181.9	97.4	1.6	29.0
2011.	0.0	216.6	66.4	1.0	31.0
2016.	0.0	240.2	45.2	0.7	38.0
2021.	0.0	264.9	30.8	0.4	45.0
2026.	65.7	197.4	21.0	0.3	61.0

Natural gas from electricity rises to 38.2 PJ/a in 1979 and then it falls off too.

5.3.2.3 High temperature heat supply

After an initial rise in the use of natural gas, reaching a maximum production of 225 PJ/a in 1995, income energies begin to dominate the high temperature heat sector. Most of the high temperature heat comes from biomass until 2022 when the maximum capacity of biomass is reached. At that time, solar concentrators are used to make up the deficit. Oil sands are uneconomic throughout the entire period and the only production is from plants which existed in 1976. The transition from capital to income energies is demonstrated by the graph in Figure 5-23.

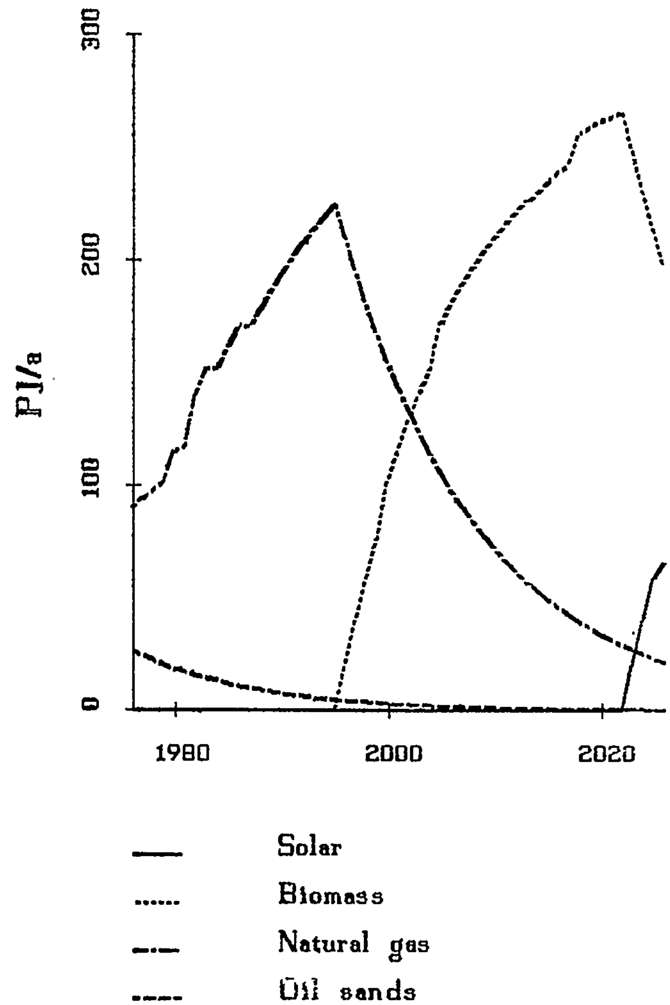

Figure 5-23. Production of high temperature heat by source from the "gradual transition" scenario

5.3.2.4 Low temperature heat

The Alberta soft energy model, when run with the "gradual transition" scenario, indicates that low temperature heat needs could be met largely by income energy sources if these are allowed to compete freely in the marketplace. Cheap natural gas is practically the only source of low temperature heat used until its price rises above 2.16 $/GJ in 1987. At that time, neighbourhood solar systems and industrial low temperature heat solar systems become competitive and these are rapidly developed. In 1999, these systems reach their maximum contribution of 110 PJ/a and fluctuate as they die off to 100 PJ/a or less. Since the minimum unit of increase in installed capacity is 10 PJ/a, solar systems cannot be replaced until installed capacity is at least 10 PJ/a less than the maximum. Filling the deficit left after the use of these solar systems and by-product heat is central biomass facilities and individual solar systems. The dynamics of the shift from natural gas to solar energy sources in the low temperature heat sector is presented in Figure 5-24.

5.3.2.5 Supply summary

Although total primary energy demand shows an overall increase (as shown in Figure 5-25), within the "gradual transition" scenario, in spite of a rapidly rising standard of living, primary energy demand per capita drops by 27 per cent. More than 96 per cent of the total primary energy demand is met by income energy sources. The form of the transition is presented in Figure 5-26.

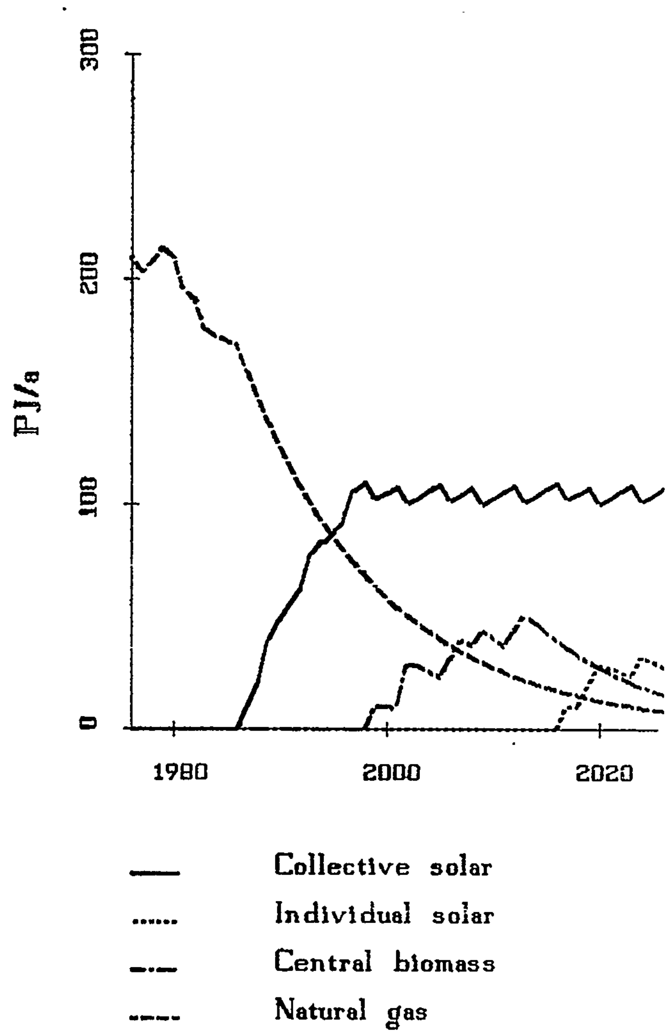

Figure 5-24. Low temperature heat production from the "gradual transition" scenario

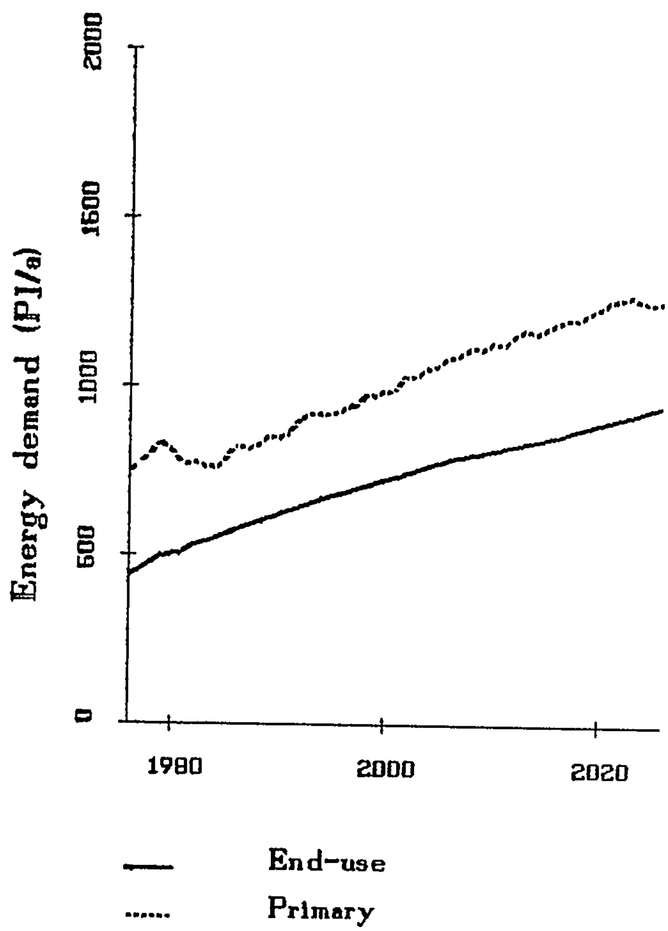

Figure 5-25. Energy demand from the "gradual transition" scenario

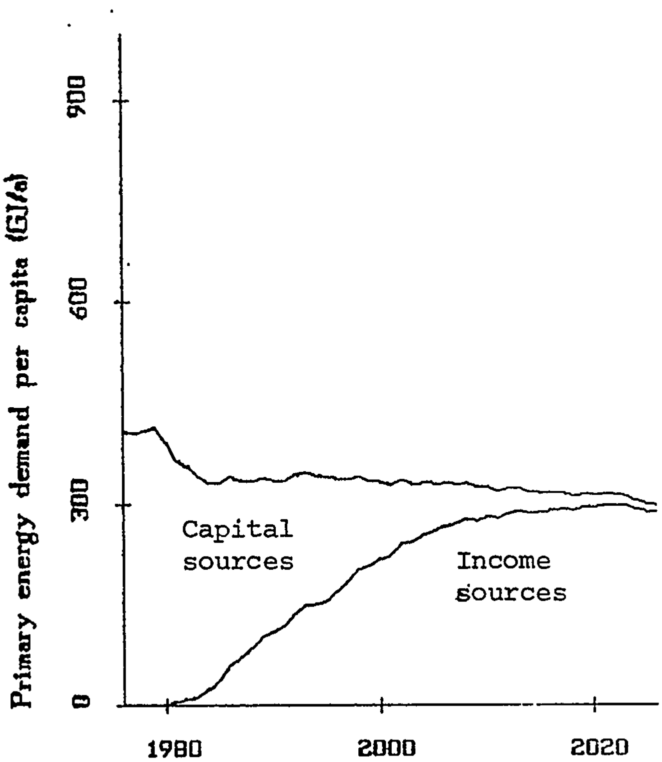

Figure 5-26. Primary energy demand per capita from the "gradual transition" scenario

5.3.3 Scenario summary

The "gradual transition" scenario demonstrates that with gradual increases in the price of energy, a transition to an income energy economy can be made in 50 years. This can be done at energy prices two to four times current levels and is accomplished concurrently with a rising standard of living and a rapidly growing population.

5.4 Summary of Scenarios

Three scenarios have been simulated on the soft energy model. The first is in many ways similar to conventional energy forecasts. In the other two scenarios, Alberta undergoes a transition from its present dependence on capital sources of energy to one based on income sources. This is accomplished at costs which are lower than those in the "business as usual" scenario.

Although the "economic efficiency" and "gradual transition" scenarios provide energy at lower cost, on a sustainable basis, and with less environmental offence, the scenarios cannot be considered as predictions of what will happen. The barriers to both energy demand reduction and income energy are very high and will only be overcome with great effort. Unfortunately, the Alberta government does not seem to be prepared to undertake this effort. In fact, some of its policies (such as subsidised natural gas prices) seem to heighten the barriers.

CONCLUSIONS AND RECOMMENDATIONS

This study has been concerned with the potential for the Province of Alberta to pursue an energy path which relies on income energy sources, which, to the greatest extent possible, are diverse, flexible, matched in scale and in geographical distribution to end-use needs and whose energy quality is matched with its end use. This has been done through the development of a computerised model of energy supply and demand in Alberta.

The model was developed from three main areas of investigation, by considering human needs, societal goals and energy goals, by exploring the relationship between energy planning and models, and by evaluating a sample of existing energy models.

Energy goals are set up to help meet societal goals which in turn are specified in order to help individuals satisfy their human needs. Energy goals include sufficiency, equity, environmental harmony, sustainability and adaptability, a lack of coercion, safety, coordination, manageability and minimum resource useage. The present system for supplying energy does not meet these goals satisfactorily. Consequently, there is a need for energy planning to bridge the gap between the present state and the idealised state in which all these goals are met. However, conventional energy planning does not occur by this process but rather is based on deterministic forecasts. The soft energy approach does not use deterministic forecasts, but rather uses a normative planning approach.

In order to develop plans for a system, it is necessary to understand how that system works and humans do this by building models of the system. These models can be of various types including mental models and mathematical models. Mental models have limited capacity and ability, tend to be ill-defined, hard to communicate and manipulate, and they cannot easily be rewritten to include new information.

Mathematical models can be built which are more complex than mental models, can be worked through logically and coherently, and can help uncover counter-intuitive results and promote deeper understanding. However, these models still have severe limitations and cannot be used to make precise predictions.

Although energy models are now in common useage, few consider the potential for energy demand reduction and income energies. This was, however, one of the primary goals of the Alberta soft energy model. The model was developed from a consideration of service levels demanded and the potential energy intensities of these services in four demand sectors: a domestic sector, a commercial sector, a transportation sector, and an industrial sector. It was found that there is significant potential for reducing energy demand in all four sectors. Once service levels are determined along with their energy intensities, a profile of end-use energy demand can be developed and used as an input into the four supply sectors, each of which determines the "best" mix of energy sources to meet the demand. Four types of energy quality were considered in four supply sectors: portable fuels, electricity, high and medium temperature process heat, and low temperature heat. This study indicates that there is significant potential for the use of income sources of energy in each of the four sectors. Exactly which mix of sources is used and what the demand levels are is dependent on which assumptions are fed into the model. A set of assumptions which are used as an input to the model is a scenario and three scenarios were considered within the study.

The first scenario was a continuation of present trends. Both end-use and primary energy demand were large and grew rapidly. For the services provided, the scenario suggested that maintaining present energy efficiencies will result in a 3.4 fold increase in primary energy demand between 1976 and 2026. Coal, biomass and natural gas were the sources used to meet this demand.

The second scenario considered the consequences of using engineering costs as the basis for energy prices and gradually removing the effect of subsidies on capital energy sources. In this scenario, total primary energy almost doubled from 750 PJ/a to 1460 PJ/a, but primary energy demand per capita stayed quite constant from the middle 1980's. In 2026, incomes met 91 per cent of primary energy demand. However by 2015, the potential contribution of many income energy sources had reached its peak and capital energy use began to increase slightly. The scenario suggested that an economically efficient society would make decisions leading to a society based almost completely on income energy sources.

The third scenario simulated an orderly transition from a relatively inefficient energy system based on capital energy sources to a relatively efficient one based on income sources of energy. This transition was brought about with gradual energy price increases and the removal of subsidies to capital sources of energy.

Although the last two scenarios provide energy at lower cost, on a sustainable basis, and with less environmental offence, they cannot be considered as better predictions of what will happen than the first. Several barriers exist to prevent the "economically efficient" from being carried out. One of these barriers is the inertia of sytems: it takes time to replace capital equipment, to adapt institutions and to retrain individuals. Another barrier is institutional obstacles which distort the market resulting from local-focus-hocus-pocus: the ignoring of long term, broad consequences of actions because of either ignorance or conflicts of interest. The barriers to both energy conservation and income energy are very high and will only be overcome with great effort. Unfortunately, the present Alberta government does not seem to be prepared to undertake this effort. In fact, some of its policies (such as subsidised natural gas prices) seem to heighten the barriers.

It must be stated that the results given by the model would differ if the model was run with a different set of assumptions. This flexibility is one of the advantages of the model because it means that the model can be used to test the consequences of different sets of assumptions and can be modified as new or better data become available. That is, although the output of the model is only as good as the input data and assumptions, the model itself is a useful tool for both conceptualising the energy system and simulating the consequences of the set of data and assumptions which are used as an input.

Based on the study, several recommendations can be made in four areas: research recommendations, recommendations for energy planning, recommended government policies, and recommendations for further developing and improving the Alberta soft energy model.

Research recommendations

There is need for research to be undertaken in several areas. These areas include: inventorying income energy sources within the province; assessing the potential reductions in energy demand more thoroughly in the Alberta context, especially within the industrial sector; determining the social and environmental costs associated with energy sources including pollution, employment, and land, water, materials and other resource use; and testing income energy sources under Alberta conditions. The estimates of these given in the study can only be considered as first-cut evaluations and more research is needed to provide a good information base on which sound decisions can be made.

Recommendations for energy planning

The results of this soft energy model differ considerably from other assessments of Alberta demand and supply futures such as those by the Alberta Energy Resources Conservation Board (1978) and Ross (1980). Together, these studies can provide a broader base for planning than can any one alone. The different perspectives taken by these studies provide more insight into energy issues within the province. The development of various energy plans based on different techniques, assumptions and values will lead to more creative energy planning and a closer step towards achieving energy goals; they should therefore be encouraged. Energy decisions should be based on normative plans, not deterministic forecasts.

Recommended government policies

Energy use is presently subsidised by the government. Subsidised energy prices lead to energy efficiencies which are less than optimal and make it harder for new sources of energy to compete in the marketplace. If energy subsidies continue, demand will be inflated and use of income sources of energy will be suppressed, at the expense of society's energy goals. Thus old subsidies should be gradually phased out while trying to reduce the pain to innocent individuals. At the same time, energy conserving technologies and income energy equipment should be subsidised rather quickly so that they can get a foothold.

Energy prices are not, however, the only variables holding back conservation and income energy. The government should try to remove other barriers by implementing standards and other policies to discourage energy waste.

Finally, the government should be prepared to finance the research needed to get the information necessary for making rational energy decisions and to finance public interest groups to develop "alternative" energy plans.

Recommendations for the Alberta soft energy model

The soft energy model developed for this study is only a first order model. If Alberta is to pursue a soft energy path or even to assess such a path, several refinements should be made in the model to be used. The industry sector, in particular the general industry sector, needs to be further disaggregated and the optimal energy use level determined for each type of industry. Capital, employment, pollution, net energy and sectors which evaluate other impacts should be developed in order that the implications of any given scenario on other sectors of the economy can be determined.

Related to incorporating these other sectors into the model would be making the model more dynamic. At present, many variables, such as population and industrial product demands are specified exogenously. However, in the real world, these are affected by activities in the energy industry. If Alberta and other areas pursue a soft energy path, migration to Alberta is likely to be less than if they do not. Similarly, the demand for petrochemical products is price elastic. In addition, or perhaps alternatively, demands for goods and services should be developed based on human needs.

The present model ignores the effect of imports of energy contained in goods and the export of energy resources. These would be included in the ideal model.

Finally, the ideal model would be better able to simulate government policies and their effectiveness at overcoming institutional barriers.

Alberta has been blessed with abundant energy resources: both income and capital. Capital energy sources have allowed Alberta's economy to grow rapidly in recent years. However, if the economy is not to stagnate and slump, it must shift its focus away from these depleting reserves. Income energy technologies can play an important role in both diversifying and stabilising the economy. By beginning to make the shift towards a renewable society now, Alberta could continue to play a major role in energy, avoid a painful forced transition later and come closer to achieving its energy and societal goals.

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APPENDICES

Appendix A. Model listing

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c                        THE ALBERTA SOFT ENERGY MODEL

c             Implemented for Unix PDP 11/40 Version 6
c                  Faculty of Environmental Design
c                       University of Calgary
c                         Calgary, Alberta
c                          Canada, T2N 1N4
c
c                             June 1980




c
c
c     time  -- the present year
c     dt    -- years per iteration

      integer ans.demind

      common /pltinc/ tfirst,tlast,dptme,idummy
      common /warning/ nowarn
      common /when/ time,dt
      common /zdemand/ dempf.demel,demph,dembh,demfe,demand
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztrans/ tsel,tspf,tsgf

      dt=1.
      tfirst=1976.
      tlast=2026.
      tbltme=1000.
      dptme=1.
      tblinc=5.
      time=tfirst

c           **************************************************

c           iterate from tfirst to tlast in dt year increments

1     continue
c           listings of these subroutines are below
      call extern
      call domest
      call comm
      call indust
      call tranp
      call tranf
```

```
      call demsum

c          supply sector
      call portbl(dempf)
      call elec(demel)
      call process(demph)
      call lotemp(dembh)
      call supsum

      if (tbltme.ge.tblinc) tbltme=0.
      tbltme=tbltme+dt
      time=time+dt
      if (time.le.tlast) goto 1

c          **************************************************

      stop
      end
```

subroutine extern

```
c          This routine does the stuff outside the energy system

c          declare tables
      real popt(7)
      real costpht(6),costelt(6),costpft(6),costbht(6)
      real taxpft(6),taxelt(6),taxpht(6),taxbht(6),gpnont(6),gprt(6)
      integer demind,ans,nowarn
      real pfti,pftl,pfdt,phti,phtl,phdt


      common /pltinc/ tfirst,tlast,dptme,idummy
      common /warning/ nowarn
      common /when/ time,dt
      common /zdemand/ dempf,demel,demph,dembh,demfe,demand
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztax/ pftax,eltax,phtax,bhtax,gpnonr,gpr,rate

if (time.gt.tfirst) goto 13

c          which table is to be printed?
      read(5,1) ans
      write(19) ans
1     format(1i2)

c          scenario info is in extern.dat
      call setfil(1,"extern.dat ")

c          suppress warning messages? (nowarn>0)
      read(1,1) nowarn
```

```
c          when is the government conservation policy to be instituted?
      read(1,2) gpcons
2     format(g12.5)

c          are prices set exogenously?
      read(1,1) demind
      if (demind.le.0) goto 4
           read(1,3) pftci,pftcl,pfcdt, (costpft(l),l=1,6)
           read(1,3) eltci,eltcl,elcdt, (costelt(l),l=1,6)
           read(1,3) phtci,phtcl,phcdt, (costpht(l),l=1,6)
           read(1,3) bhtci,bhtcl,bhcdt, (costbht(l),l=1,6)
3          format(9g12.5)
4     continue
           read(1,3) pfti,pftl,pfdt, (taxpft(l),l=1,6)
           read(1,3) elti,eltl,eldt, (taxelt(l),l=1,6)
           read(1,3) phti,phtl,phdt, (taxpht(l),l=1,6)
           read(1,3) bhti,bhtl,bhdt, (taxbht(l),l=1,6)
           read(1,3) gprti,gprtl,gprdt, (gprt(l),l=1,6)
           read(1,3) gpnonti,gpnontl,gpnondt, (gpnont(l),l=1,6)
           read(1,2) rate
           costpf=0.
           costel=0.
           costph=0.
           costbh=0.
13    continue

      pop=table(popt,time,1976.,2026.,10.)
      data popt(1)/1.838e6/,popt(2)/2.410e6/,popt(3)/2.764e6/
      data popt(4)/3.295e6/,popt(5)/3.758e6/,popt(6)/4.231e6/

c          exogenous energy costs?

      if (demind.le.0) goto 17
           costpf=table(costpft,time,pftci,pftcl,pfcdt)
           costel=table(costelt,time,eltci,eltcl,elcdt)
           costph=table(costpht,time,phtci,phtcl,phcdt)
           costbh=table(costbht,time,bhtci,bhtcl,bhcdt)
                if ((ans.eq.1).and.(time.le.tfirst)) write(6,100)
100             format("Time",7x,"pop",2x,"costpf",x,"costel",x
&               ,"costph",x,"costbh",/)
                if ((ans.eq.1).and.(tbltme.ge.tblinc))
&                 write(6,200) time,pop,costpf,costel,costph,costbh
200             format(f5.0,f10.0,6f7.2,4x,f7.2)
17    continue

           pftax=table(taxpft,time,pfti,pftl,pfdt)
           eltax=table(taxelt,time,elti,eltl,eldt)
           phtax=table(taxpht,time,phti,phtl,phdt)
           bhtax=table(taxbht,time,bhti,bhtl,bhdt)
           gpnonr=table(gpnont,time,gpnonti,gpnontl,gpnondt)
           gpr=table(gprt,time,gprti,gprtl,gprdt)
           if ((ans.eq.1).and.(time.le.tfirst)) write (6,300)
300        format("Time",8x,"taxpf",6x,"taxel",6x,"taxph",
```

```
&             6x,"taxbh",6x,"gpr",7x,"gpnonr",/)
          if ((ans.eq.1).and.(tbltme.ge.tblinc))
&             write(6,400) time,taxpf,taxel,taxph,taxbh,gpr,gpnonr
400       format(f5.0,6f12.3)

      return
      end
```

subroutine domest

```
c         answer declarations
      integer ans
c         table and delay array declarations
      real rbdust(6),rbfwht(3),rsheit(6),rsaeit(6),rsheid(6),rsaeid(6)
      real rehnt(6),rehrpt(5),rwsdwt(3),rwscwt(3),rweft(4)
      real reheid(6),rwefd(6),rbdrat(10),rwrd(6)

c         common declarations
      common /when/ time,dt
      common /zdomtr/ rbfhd,rbaus
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zhomes/ re,rh
      common /zmisc/ ans,tbltme,tblinc,gpcons


c         Background stuff (rb)
      rbno=rbh+rba
      rbfhd=rba/rbno
      data rbh/448000./,rba/139700./
      rbdus=tabhl(rbdust,time,1976.,2001.,5.)
      data rbdust(1)/3.13/,rbdust(2)/2.98/,rbdust(3)/2.89/
      data rbdust(4)/2.84/,rbdust(5)/2.79/,rbdust(6)/2.75/
      rbfwh=table(rbfwht,rbdus,2.75,3.13,.38)
      data rbfwht(1)/.54/,rbfwht(2)/.71/
      rbaus=pop/rbno
      rbadus=rbaus/rbdus
      rbbr=amax1(0.,(rbh*(rbhbrn+rbadus-1.)+rba*(rbabrn+rbadus-1.)))
      rbhbr=rbbr*rbfwh
      rbabr=rbbr*(1.-rbfwh)
      data rbhbrn/.05/,rbhdrn/.05/,rbabrn/.05/,rbadrn/.05/
      rbdra=table(rbdrat,costbh,0.1,4.6,0.9)
      data rbdrat(1)/1.0/,rbdrat(2)/1.0/,rbdrat(3)/1.0/
      data rbdrat(4)/1.05/,rbdrat(5)/1.1/,rbdrat(6)/1.2/
      rbadr=amax1(0..(rba*rbadrn*rbdra))
      rbhdr=amax1(0.,(rbh*rbhdrn*rbdra))

c         Electric Needs (re)
      reheid(1)=clip(10.,7.,gpcons,time)
      rehei=delay3(rehein,reheid)*3.6e-3
      data rehein/6373./
      rehn=table(rehnt,time,1976.,2026.,10.)
```

```
      data rehnt(1)/1.00/,rehnt(2)/1.18/,rehnt(3)/1.31/
      data rehnt(4)/1.42/,rehnt(5)/1.45/,rehnt(6)/1.45/
      rehrp=table(rehrpt,costel,0.,22.4,5.6)
      data rehrpt(1)/1.0/,rehrpt(2)/0.76/,rehrpt(3)/0.47/
      data rehrpt(4)/0.36/,rehrpt(5)/0.36/
      rehein=rehrp*rehn*reheii
      data reheii/6373./
      reaei=rehei*refha
      data refha/0.6/
      reh=rehei*rbh
      rea=reaei*rba
      re=(reh+rea)*1.0e-6

c           Water Heating Needs (rw)
      rwbei=rwpcei*rbaus
      data rwpcei/3.8/
      rwsdw=table(rwsdwt,time,1976.,2026.,25.)
      data rwsdwt(1)/.37/,rwsdwt(2)/.82/,rwsdwt(3)/.88/
      data rwdwei/2.5/
      rwscw=table(rwscwt,time,1976.,2026.,25.)
      data rwscwt(1)/.73/,rwscwt(2)/.91/,rwscwt(3)/.93/
      data rwcwei/3.76/
      rwei=rwbei*rbaus+rwscw*rwcwei+rwsdw*rwdwei
      rwefn=table(rweft,costbh,1.,4.,1.)
      data rweft(1)/1.0/,rweft(2)/0.8/,rweft(3)/0.77/,rweft(4)/0.75/
      rwefd(1)=clip(12.,8.,gpcons,time)
      rwef=delay3(rwefn,rwefd)
      gpwc=gpcons+10.
      rwrp=clip(1.0,0.5,gpwc,time)
      data gpwc/2100./
      rwr=delay3(rwrp,rwrd)
      data rwrd(1)/15.0/
      rw=rwei*rwef*rbno*rwr/1.0e6

c           Residential Space Heating (rs)
      rshei=delay3(rshein,rsheid)
      data rshein/152./
      rshein=table(rsheit,costbh,0.1,4.6,0.9)
      data rsheit(1)/160./,rsheit(2)/80./,rsheit(3)/60./
      data rsheit(4)/40./,rsheit(5)/20./,rsheit(6)/20./
      rsh=rshei*rbh*1.e9
      data rsheid(1)/5./
      rsaei=delay3(rsaein,rsaeid)
      data rsaein/80./
      rsaein=table(rsaeit,costbh,0.1,4.6,0.9)
      data rsaeit(1)/85./,rsaeit(2)/30./,rsaeit(3)/20./
      data rsaeit(4)/13./,rsaeit(5)/5./,rsaeit(6)/5./
      rsa=rsaei*rba*1.e9
      data rsaeid(1)/5./
      rs=amax1(0.,((rsa+rsh)/1.0e15-(rswrf*rw+rserf*re)))
      data rswrf/0.25/,rserf/0.60/

c           Summary of Residential Sector
```

```
      rh=rs+rw
      r=re+rh

c           Integration of dwelling unit numbers
      rbh=rbh+dt*(rbhbr-rbhdr)
if (ans.eq.2) write (19) rs,rw,re
      rba=rba+dt*(rbabr-rbadr)

c           Print out table of the variables at tblinc year intervals
c           initial condition only
      if ((ans.eq.2).and.(tbltme.ge.100.)) write (6,100) ans
100   format("Table ",i2,". Domestic sector",/,"Time",6x,
&     "houses",8x,"apts",7x,"s heat",6x,"w heat",8x,"elec",8x,"r(PJ)",/)
      if ((ans.eq.2).and.(tbltme.ge.tblinc))
&        write(6,200) time,rbh,rba,rs,rw,re,r
200   format(f5.0,2f12.0,4f12.1)
      if ((ans.eq.3).and.(tbltme.ge.100.)) write (6,300) ans
300   format("Table ",i2,". Domestic sector energy intensities (GJ/a)",/,
&     "Time",7x,"w heat",7x,"rshei",7x,"rsaei",7x,"rehei",7x,"reaei",/)
      if ((ans.eq.3).and.(tbltme.ge.tblinc))
&        write (6,400) time,rwei,rshei,rsaei,rehei,reaei
400   format(f5.0,5f12.1)

      return
      end
```

<u>subroutine comm</u>

```
c           common declarations
      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /zcomm/ ce,cs

c           declare delay and table arrays
      real cfoeit(5),cefet(13),cfneit(5),cfod(6),cfoeid(6)
      real cfneid(6),cfgrt(6)
      integer ans

c           initialise table arrays
      data cfoeit(1)/85./,cfoeit(2)/72./,cfoeit(3)/61./
      data cfoeit(4)/55./,cfoeit(5)/52./
      data cfneit(1)/85./,cfneit(2)/12./,cfneit(3)/11.5/
      data cfneit(4)/10./,cfneit(5)/9./

      cfnorm=cfnorm+dt*cfgr
      data cfgr/0./
      cfgrn=table(cfgrt,time,1976.,2026.,10.)
      cfgr=cfnorm*cfgrn
      data cfgrt(1)/.04/,cfgrt(2)/0.02/,cfgrt(3)/0.01/
```

```
      data cfgrt(4)/0.008/,cfgrt(5)/0.0075/.cfgrt(6)/0.0075/
      data cfnorm/20.0/,cfalf/1.0/
      cf=cfnorm*pop

      cfo=delay3(cfor,cfod)
      cfor=cforf
      data cfor/36.8e6/,cforf/36.8e5/
      data cfod(1)/50./
      cfn=amax1(0.,(cf-cfo))
      cfoeid(1)=clip(10.,5.,gpcons,time)
      cfoeia=delay3(cfoei,cfoeid)
      data cfoei/80./
      cfofe=tabhl(cefet,cfoeia,5.,60.,5.)
      data cefet(1)/1.0/,cefet(2)/0.5/,cefet(3)/0.40/,cefet(4)/0.35/
      data cefet(5)/0.32/,cefet(6)/0.29/,cefet(7)/0.22/,cefet(8)/0.20/
      data cefet(9)/.19/,cefet(10)/0.18/,cefet(11)/0.18/,cefet(12)/0.18/
      cfoei=table(cfoeit,costbh,0.,4.,1.)
      cfoe=cfo*cfoeia*cfofe*31.56e-9
      cfos=cfo*cfoeia*(1.-cfofe)*31.56e-9

      cfnei=table(cfneit,costbh,0.,4.,1.)
      cfneid(1)=clip(6.,3.,gpcons,time)
      cfneia=delay3(cfnei,cfneid)
      cfnfe=table(cefet,cfneia,5.,60.,5.)
      cfne=cfn*cfneia*cfnfe*31.56e-9
      cfns=cfn*cfneia*(1.-cfnfe)*31.56e-9

      ce=cfoe+cfne
      cs=cfos+cfns
      c=ce+cs

      if (ans.eq.4) write(19) cs,ce
c           initial condition only
      if ((ans.eq.4).and.(tbltme.ge.100)) write(6,100)
100   format("Time",9x,"cfos",8x,"cfoe",8x,"cfns",8x,"cfne",8x,"c",/)
      if ((ans.eq.4).and.(tbltme.ge.tblinc))
&        write(6,101) time,cfos,cfoe,cfns,cfne,c
101   format(f5.0,5f12.1)
c           initial condition only
      if ((ans.eq.5).and.(tbltme.ge.100)) write(6,102)
102   format("Time",9x,"cfnorm",7x,"cfo",8x,"cfoei",7x,"cfn",9x,"cfnei")
      if ((ans.eq.5).and.(tbltme.ge.tblinc))
&        write(6,104) time,cfnorm,cfo,cfoei,cfn,cfnei
104   format(f5.0,f12.1,2(f12.0,f12.1))

      return
      end
```

subroutine tranp

```
c         declare tab:e and delay arrays
      real tupdt(5),tupmtt(5),tipcrt(5),tipdgrt(6)
      real taplft(4),tapomt(4),tcufet(7),tculft(3),tcifet(7)
      real tcilft(3),tblft(4),tbomt(4),tbidft(4),trpdft(4),tapdft(4)
      real trplft(4),trpomt(4),tcidft(4),tipdit(4)
      real taplfd(6),tapomd(6),tblfd(6),tbomd(6),trffed(6),trfefd(6)
      real trflfd(6),trplfd(6),trpomd(6),ttefd(6),tapfcd(6),tcufed(6)
      real tcifed(6),taffcd(6)
      integer ans


      common /when/ time,dt
      common /zdomtr/ rbfhd,rbaus
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztptf/ trffe,trflf,tapom,trpe,trfe,tep,tc
&        ,tb,tt,tap,taf,trpl,trfl,trp
      common /ztrans/ tsel,tspf,tsng

c         TRANSPORT DEMAND

c         urban passenger (tup)
      tupd=table(tupdt,rbfhd,0.,1.0,0.25)*tupdi
      data tupdt(1)/1.2/,tupdt(2)/1./,tupdt(3)/0.88/
      data tupdt(4)/0.6/,tupdt(5)/0.28/
      data tupdi/4170./
      tupmt=table(tupmtt,rbfhd,0.,1.2,0.3)
      data tupmtt(1)/0.04/,tupmtt(2)/.04/,tupmtt(3)/.2/
      data tupmtt(4)/.35/,tupmtt(5)/.5/
      tcud=tupd*(1.-tupmt)
      tbud=tupd*tupmt

c         interurban passenger

      tipdi=table(tipdit,costpf,2.,8.,2.)
      data tipdit(1)/1./,tipdit(2)/.70/,tipdit(3)/0.65/,tipdit(4)/0.6/
      tipdn=tipdn+dt*tipdngr
      tipd=tipdn*tipdi
      data tipdngr/0./
      tipdngr=tipdn*table(tipdgrt,time,1976.,2026.,10.)
      data tipdgrt(1)/0.03/,tipdgrt(2)/0.03/,tipdgrt(3)/0.02/
      data tipdgrt(4)/0.02/,tipdgrt(5)/0.015/,tipdgrt(6)/0.015/
      data tipdn/10775./
      tcidf=table(tcidft,costpf,0.,6.,2.)
      data tcidft(1)/.73/,tcidft(2)/.73/,tcidft(3)/.40/,tcidft(4)/.15/
      tcid=tipd*tcidf
      tbidf=table(tbidft,costpf,0.,6.,2.)
      data tbidft(1)/.02/,tbidft(2)/0.02/,tbidft(3)/.2/,tbidft(4)/.27/
      tbid=tipd*tbidf
      trpdf=table(trpdft,costpf,0.,6.,2.)
      data trpdft(1)/.01/,trpdft(2)/.01/,trpdft(3)/.18/,trpdft(4)/.38/
```

```
      trpd=tipd*trpdf
      tapdf=table(tapdft,costpf,0.,6.,2.)
      data tapdft(1)/.24/,tapdft(2)/.24/,tapdft(3)/.22/,tapdft(4)/.2/
      tapd=tipd*tapdf

c           passenger air travel (tap)

      taplfn=table(taplft,costpf,0.,6.,2.)
      data taplft(1)/.55/,taplft(2)/.7/,taplft(3)/.72/,taplft(4)/.75/
      taplfd(1)=clip(2.,1.,gpcons,time)
      taplf=smooth(taplfn,taplfd)
      tapgp=clip(0.,0.5,gpcons,time)
      taplf=amax1(tapgp,taplf)
      tapvcn=clip(2.2,1.1,1990.,time)
      tapfc=delay3(tapvcn,tapfcd)
      data tapfcd(1)/15.0/
      tapomn=table(tapomt,costpf,1.,7.,2.)
      data tapomt(1)/1.0/,tapomt(2)/0.95/,tapomt(3)/0.9/,tapomt(4)/0.8/
      tapomd(1)=clip(2.,1.,gpcons,time)
      tapom=smooth(tapomn,tapomd)
      tapei=tapfc*tapom
      tap=pop*tapd/taplf*tapei/1.0e9

c           automobile (tc)

      tcufec=table(tcufet,costpf,0.,6.,1.)
      data tcufet(1)/23.5/,tcufet(2)/16.3/,tcufet(3)/6.6/,tcufet(4)/6.0/
      data tcufet(5)/5.4/,tcufet(6)/4.8/,tcufet(7)/4.1/
      tcufeg=clip(200.,13.5,1980.,time)
      tcufeg=clip(tcufeg,10.0,1985.,time)
      tcufen=amin1(tcufec,tcufeg)
      tcufe=delay3(tcufen,tcufed)
      data tcufed(1)/7./
      tcuei=tcufe*348.0e3
      tculf=table(tculft,rbaus,2.75,3.51,0.38)
      data tculft(1)/2.4/,tculft(2)/2.2/,tculft(3)/2.2/
      tcu=pop*tcud*tcuei/tculf/1.0e15


      tcifec=table(tcifet,costpf,0.,6.,1.)
      data tcifet(1)/13.5/,tcifet(2)/11.4/,tcifet(3)/4.7/
      data tcifet(4)/4.3/,tcifet(5)/3.9/,tcifet(6)/3.4/,tcifet(7)/2.9/
      tcifeg=clip(200.,9.9,1980.,time)
      tcifeg=clip(tcifeg,6.9,1985.,time)
      tcifen=amin1(tcifec,tcifeg)
      tcife=delay3(tcifen,tcifed)
      data tcifed(1)/7./
      tciei=tcife*348.0e3
      tcilf=table(tcilft,rbaus,2.75,3.51,0.38)
      data tcilft(1)/1.2/,tcilft(2)/1.5/,tcilft(3)/1.5/
      tci=pop*tcid*tciei/tcilf/1.0e15
      tc=tci+tcu
```

```
c         bus transportation (tb)
      tblfn=table(tblft,costpf,0.,6.,2.)
      data tblft(1)/0.6/,tblft(2)/0.64/,tblft(3)/0.68/,tblft(4)/0.7/
      tblfd(1)=clip(2.,1.,gpcons,time)
      tblf=smooth(tblfn,tblfd)
      data tbifc/0.5/,tbufc/1.1/
      tbomn=table(tbomt,costpf,0.,6.,2.)
      data tbomt(1)/1.0/,tbomt(2)/0.8/,tbomt(3)/0.77/,tbomt(4)/0.7/
      tbomd(1)=clip(2.,1.,gpcons,time)
      tbom=smooth(tbomn,tbomd)
      tbiei=tbifc*tbom
      tbuei=tbufc*tbom
      tbi=pop*tbid*tbiei/tblf/1.0e9
      tbu=pop*tbud*tbuei/tblf/1.0e9
      tb=tbi+tbu

c         rail passenger (trp)
      trplfn=table(trplft,costpf,0.,6.,2.)
      data trplft(1)/0.4/,trplft(2)/0.6/,trplft(3)/0.7/,trplft(4)/0.8/
      trplfd(1)=clip(2.,1.,gpcons,time)
      trplf=smooth(trplfn,trplfd)
      trpomn=table(trpomt,costpf,1.,7.,2.)
      data trpomt(1)/1.0/,trpomt(2)/0.8/,trpomt(3)/0.77/,trpomt(4)/0.7/
      trpomd(1)=clip(2.,1.,gpcons,time)
      trpom=smooth(trpomn,trpomd)
      trpeei=trpefc*trpom
      trplei=trplfc*trpom
      data trpefc/0.35/,trplfc/0.7/
      trpe=pop*trpd*trffe/trplf*trpeei/1.e9
      trpl=pop*trpd*(1.-trffe)/trplf*trplei/1.e9
      trp=trpe+trpl

c         Print the table of variables at tblinc year intervals
c         initial condition only
      if ((ans.eq.7).and.(tbltme.ge.100.)) write (6,100)
100   format("Time",8x,"tipd",8x,"tcid",8x,"tapd",8x,"trpd",8x,"tbid",/)
      if ((ans.eq.7).and.(tbltme.ge.tblinc))
&        write(6,200) time,tipd,tcid,tapd,trpd,tbid
200   format(f5.0,2f12.0,4f12.0)
c         initial condition only
      if ((ans.eq.6).and.(tbltme.ge.100.)) write (6,300)
300   format("Time",8x,"tupd",8x,"tcud",8x,"tbud",8x,"tcu ",8x,"tbu ",/)
      if ((ans.eq.6).and.(tbltme.ge.tblinc))
&        write(6,400) time,tupd,tcud,tbud,tcu,tbu
400   format(f5.0,3f12.0,2f12.1)

      return
      end
```

subroutine tranf

```
c         declare table and delay arrays
      real  tufft(3),ttift(2),trffet(4),trfeft(4),tfmdgrt(6)
      real trflft(4),tteft(4),tpet(4),tpgt(4),tfddt(6)
      real taplfd(6),tapomd(6),tblfd(6),tbomd(6),trffed(6),trfefd(6)
      real trflfd(6),trplfd(6),trpomd(6),ttefd(6),tapfcd(6),tcufed(6)
      real tcifed(6),taffcd(6),tafdgrt(6)
      integer ans


      common /when/ time,dt
      common /zdomtr/ rbfhd,rbaus
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztptf/ trffe,trflf,tapom,trpe,trfe,tep,tc
&        ,tb,tt,tap,taf,trpl,trfl,trp
      common /ztrans/ tsel,tspf,tsgf

c         TRANSPORT DEMAND

      tfmd=tfmd+dt*tfmdgr
      data tfmdgr/0./
      tfmdgrn=table(tfmdgrt,time,1976.,2026.,10.)
      tfmdgr=tfmd*tfmdgrn
      data tfmdgrt(1)/0.03/,tfmdgrt(2)/0.015/,tfmdgrt(3)/0.0075/
      data tfmdgrt(4)/0.0069/,tfmdgrt(5)/0.0064/,tfmdgrt(6)/0.006/
      tfdd=table(tfddt,costpf,0.,10.,2.)
      data tfddt(1)/1.0/,tfddt(2)/0.8/,tfddt(3)/0.7/
      data tfddt(4)/0.65/,tfddt(5)/0.62/,tfddt(6)/0.6/
      tfd=tfdd*tfmd
      data tfmd/39940./
      tuff=table(tufft,costpf,2.,4.,1.)
      data tufft(1)/0.045/,tufft(2)/0.06/,tufft(3)/0.15/
      ttud=tuff*tfd
      tifd=tfd*(1.-tuff)*tfdd
      ttif=table(ttift,costpf,2.,4.,2.)
      data ttift(1)/0.137/,ttift(2)/0.10/
      ttid=ttif*tifd
      tafd=(tafd+dt*tafdgr)
      data tafd/40./,tafalf/0.6/
      tafdgrn=table(tafdgrt,time,1976.,2026.,10.)
      tafdgr=tafd*tafdgrn
      data tafdgrt(1)/.02/,tafdgrt(2)/.015/,tafdgrt(3)/.01/
      data tafdgrt(4)/.005/,tafdgrt(5)/0./,tafdgrt(6)/-.01/
      trfd=tifd-(tafd+ttid)


c         rail freight (trf)
      trffen=table(trffet,costpf,0.,6.,2.)
      data trffet(1)/0./,trffet(2)/.12/,trffet(3)/.13/,trffet(4)/.14/
      trffed(1)=clip(10.,5.,gpcons,time)
      trffe=smooth(trffen,trffed)
```

```
      trfefn=table(trfeft,costel,0.,18.,6.)
      data trfeft(1)/1.0/,trfeft(2)/.95/,trfeft(3)/.90/,trfeft(4)/0..85/
      trfefd(1)=clip(2.,1.,gpcons,time)
      trfef=smooth(trfefn,trfefd)
      trfe=trfd*pop*trffe*trfef*trfeei/1.0e9
      data trfeei/.2/
      trflfn=table(trflft,costpf,0.,6.,2.)
      data trflft(1)/1.0/,trflft(2)/.95/,trflft(3)/.90/,trflft(4)/.9/
      trflfd(1)=clip(2.,1.,gpcons,time)
      trflef=smooth(trflfn,trflfd)
      trfl=trfd*(1.-trffe)*trflef*pop*trflei/1.0e9
      data trflei/0.4/
      trf=trfl+trfe

c           air freight (taf)

      tafom=tapom
      tafvcn=clip(29.8,14.9,1990.,time)
      taffc=delay3(tafvcn,taffcd)
      data taffcd(1)/10.0/
      tafei=taffc*tafom
      taf=pop*tafd*tafei/1.0e9

c           road commercial (tt)
      ttefn=table(tteft,costpf,0.,6.,2.)
      data tteft(1)/1.0/,tteft(2)/0.65/,tteft(3)/0.55/,tteft(4)/0.5/
      ttefd(1)=clip(2.,1.,gpcons,time)
      ttef=smooth(ttefn,ttefd)
      ttuei=ttufc*ttef
      ttiei=ttifc*ttef
      data ttufc/5.1/,ttifc/1.8/
      ttu=pop*ttud*ttuei*1.0e-9
      tti=pop*ttid*ttiei*1.0e-9
      tt=tti+ttu

c           pipeline (tp)
      tpe=table(tpet,time,1976.,2036.,20.)
      data tpet(1)/1.7/,tpet(2)/6.8/,tpet(3)/9.7/,tpet(4)/12.6/
      tpg=table(tpgt,time,1976.,2036.,20.)
      data tpgt(1)/26.3/,tpgt(2)/20.0/,tpgt(3)/20.0/,tpgt(4)/20.0/
      tp=(tpg+tpe)

c           summary of transportation sector (ts)
      tsel=trpe+trfe+tpe
      tspf=tc+tb+tt+tap+taf+trpl+trfl
      tsgf=tpg
      t=tsel+tspf+tsgf

c           print out a table of the variables at tblinc year intervals
c           initial condition only
      if ((ans.eq.9).and.(tbltme.ge.100.)) write(6,100)
100   format("Time",7x,"taf ",8x,"trf ",8x,"tti ",8x,"ttu ",8x,"tp",/)
      if ((ans.eq.9).and.(tbltme.ge.tblinc))
```

```
&        write(6,200) time,taf,trf,tti,ttu,tp
200   format(f5.0,8f8.1)
c           initial condition only
      if ((ans.eq.8).and.(tbltme.ge.100.)) write(6,300)
300   format("Time",7x,"tafd",08x,"trfd",08x,"ttid",08x,"ttud",/)
      if ((ans.eq.8).and.(tbltme.ge.tblinc))
&        write(6,400) time,tafd,trfd,ttid,ttud
400   format(f5.0,4f12.0)
            dummy1=tap+taf
            dummy2=trpe+trpl+trf
            dummy3=tc+tt+tb
            dummy4=tp
 if (ans.eq.7) write(19) dummy1,dummy2,dummy3,dummy4
      return
      end
```

subroutine indust

```
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zind/ dsfeed,dsel,dshi,dsme,dslo
      common /zmisc/ ans,tbltme,tblinc,gpcons

c           declaration of table and delay arrays
      real dceict(5),dpxeft(8),dpxelt(6),dpbdt(5),dpadt(6),dot(6)
      real dpedt(6),dpmdt(6),dpodt(4),dppeft(8),dppedt(6),dpphdt(6)
      real dfeft(7).dfdt(6),dneft(4),dnit(6),dgeft(8),dgit(6),doeft(4)
      real dpsaft(6)
      real dceid(6),dpxefd(6),dppefd(6),dfefd(6),dgefd(6),dnefd(6)
      integer ans

c           CEMENT (dc)

      dcd=dcd+dt*dcdgr
      data dcd/1.3e6/,dcdgr/91.e3/
      dceic=table(dceict,costph,0.,4.,1.)
      data dceict(1)/5.5/,dceict(2)/4.7/,dceict(3)/3.8/
      data dceict(4)/3.8/,dceict(5)/3.8/
      dceid(1)=clip(6.,4.,gpcons,time)
      dcei=delay3(dceic,dceid)
      dce=dcd*dcfe*dcei*1.0e-6
      data dcfe/0.28/
      dch=dcd*dcei*(1-dcfe)*1.0e-6
      dc=dce+dch

c           PETROCHEMICALS (dp)

      dpxefn=table(dpxeft,costph,1.,13.,2.)
      data dpxeft(1)/1.00/,dpxeft(2)/0.84/,dpxeft(3)/0.81/
      data dpxeft(4)/0.78/ dpxeft(5)/0.77/,dpxeft(6)/0.75/
```

```
      data dpxeft(7)/0.74/,dpxeft(8)/0.74/
      dpxefd(1)=clip(6.,3.,gpcons,time)
      dpxef=smooth(dpxefn,dpxefd)
c           electrical energy demand
      dpxeld=table(dpxelt,time,1976.,2026.,10.)
      data dpxelt(1)/860./,dpxelt(2)/3260./,dpxelt(3)/3980./
      data dpxelt(4)/4500./,dpxelt(5)/4600./,dpxelt(6)/4700./
      dpxel=dpxeld*dpxef*.0036

c           ammonia (dpa)
      dpsaf=table(dpsaft,costph,1.,6.,1.)
      data dpsaft(1)/1.0/,dpsaft(2)/0.9/,dpsaft(3)/0.80/
      data dpsaft(4)/0.7/,dpsaft(5)/0.65/,dpsaft(6)/0.6/
      if (time.lt.gpcons) dpsaf=1.
      dpad=table(dpadt,time,1976.,2026.,10.)
      data dpadt(1)/980.e3/,dpadt(2)/2.1e6/,dpadt(3)/2.1e6/
      data dpadt(4)/2.3e6/,dpadt(5)/2.3e6/,dpadt(6)/2.3e6/
      dpa=dpad*dpsaf*(dpafr+dpape*dpxef)/1.e6
      data dpafr/21.9/,dpape/22.1/

c           benzene (dpb)   oil initially
      dpbd=tabhl(dpbdt,time,1973.,2013.,10.)
      data dpbdt(1)/-3.2/,dpbdt(2)/58.8/,dpbdt(3)/56.3/
      data dpbdt(4)/53.2/,dpbdt(5)/52.6/
      dpbd=clip(0.,dpbd,1982.,time)
c           above sets dpbd to zero before 1982
      dpb=dpbd*(dpbfr+dpbpe*dpxef)
c           dbbfr and dpbpe are relative, not absolute
      data dpbfr/1.0/,dpbpe/0.28/

c           ethylene (dpe) initially oil,methane or propane
      dped=table(dpedt,time,1976.,2026.,10.)
      data dpedt(1)/82000./,dpedt(2)/1.04e6/,dpedt(3)/2.09e6/
      data dpedt(4)/2.83e6/,dpedt(5)/2.83e6/,dpedt(6)/2.83e6/
      dpe=dped*(dpefr+dpepe*dpxef)/1.e6
      data dpefr/31.2/,dpepe/49.6/

c           methanol (dpm)
      dpmd=tabhl(dpmdt,time,1976.,2006.,10.)
      data dpmdt(1)/0.37e6/,dpmdt(2)/0.84e6/,dpmdt(3)/0.79e6/
      data dpmdt(4)/0.75e6/,dpmdt(5)/0.75e6/,dpmdt(6)/0.75e6/
      dpm=dpmd*(dpmfr+dpmpe*dpxef)/1.e6
      data dpmfr/35.7/,dpmpe/10.2/

c           other petrochemicals (dpo) methane and butane
      dpod=tabhl(dpodt,time,1976.,2006.,10.)
      data dpodt(1)/2.9e15/,dpodt(2)/2.9e15/
      data dpodt(3)/2.6e15/,dpodt(4)/2.5e15/
      dpo=dpod*(dpofr+dpope*dpxef)/1.e15
      data dpofr/1.0/,dpope/5.1/

c           petrochemical summary
      dp=dpa+dpb+dpe+dpm+dpo+dpxel
```

```
c          PULP AND PAPER (dpp)

      dppefn=table(dppeft,costph,1.,13.,2.)
      data dppeft(1)/1.0/,dppeft(2)/.76/,dppeft(3)/.73/,dppeft(4)/.71/
      data dppeft(5)/.69/,dppeft(6)/.67/,dppeft(7)/.65/,dppeft(8)/.57/
      dppefd(1)=clip(6.,3.,gpcons,time)
      dppef=delay3(dppefn,dppefd)
c          electric
      dpped=table(dppedt,time,1976.,2026.,10.)
      data dppedt(1)/1.26/,dppedt(2)/2.02/,dppedt(3)/2.48/
      data dppedt(4)/3.6/,dppedt(5)/4.0/,dppedt(6)/4.7/
      dppe=dpped*dppef
c          non-electric
      dpphd=table(dpphdt,time,1976.,2026.,10.)
      data dpphdt(1)/4.85/,dpphdt(2)/3.32/,dpphdt(3)/3.94/
      data dpphdt(4)/4.85/,dpphdt(5)/5.70/,dpphdt(6)/6.63/
      dpph=dpphd*dppef
      dpp=dpph+dppe

c          FARMS (df) oil

      dfefn=table(dfeft,costpf,2.,8.,1.)
      data dfeft(1)/1.00/,dfeft(2)/0.94/,dfeft(3)/0.91/,dfeft(4)/0.89/
      data dfeft(5)/0.86/,dfeft(6)/0.85/,dfeft(7)/0.85/
      dfefd(1)=clip(6.,3.,gpcons,time)
      dfef=delay3(dfefn,dfefd)
      dfd=tabhl(dfdt,time,1976.,2006.,10.)
      data dfdt(1)/53.24/,dfdt(2)/61.2/,dfdt(3)/55.7/,dfdt(4)/50.8/
      df=dfef*dfd

c          NON-ENERGY (dn) oil

      dnefn=table(dneft,costph,2.,8.,2.)
      data dneft(1)/1.00/,dneft(2)/0.67/,dneft(3)/0.65/,dneft(4)/0.63/
      dnefd(1)=clip(6.,3.,gpcons,time)
      dnef=delay3(dnefn,dnefd)
      dni=table(dnit,time,1976.,2026.,10.)
      data dnit(1)/30.7/,dnit(2)/41.1/,dnit(3)/54.1/
      data dnit(4)/67.7/,dnit(5)/81.3/,dnit(6)/94.9/
      dn=dni*dnef

c          GENERAL INDUSTRY (dg) methane,propane,butane,oil

      dgefn=table(dgeft,costph,1.,13.,2.)
      data dgeft(1)/1.00/,dgeft(2)/0.84/,dgeft(3)/0.79/,dgeft(4)/0.74/
      data dgeft(5)/0.69/,dgeft(6)/0.64/,dgeft(7)/0.57/,dgeft(8)/0.57/
      dgefd(1)=clip(6.,3.,gpcons,time)
      dgef=delay3(dgefn,dgefd)
      dgi=table(dgit,time,1976.,2026.,10.)
      data dgit(1)/59.9/,dgit(2)/76.9/,dgit(3)/106.1/,dgit(4)/139.2/
      data dgit(5)/182.8/,dgit(6)/237.5/
      dg=dgi*dgef
```

```
c          OTHER ELECTRIC (do)

      dob=table(dot,time,1976.,2026.,10.)
      doef=table(doeft,costel,3.,21.,6.)
      data doeft(1)/1.0/,doeft(2)/0.9/,doeft(3)/0.8/,doeft(4)/0.75/
      doe=dob*doef
      data dot(1)/7.2/,dot(2)/17.5/,dot(3)/36.1/
      data dot(4)/66.2/,dot(5)/81.9/,dot(6)/102.1/

c          industry summary

      dsfeed=(dpad*dpafr+dped*dpefr+dpmd*dpmfr+
&     dpod/1.e9*dpofr)/1.0e6+dpbd*dpbfr
      dshi=dpxef*((dpad*dpape+dped*dpepe+dpm*dpmpe)/1.e6+
&     (dpod*dpope)/1.e15)+dc+dpbd*dpbpe
      dsme=(dn+dg+dpph)*dsmef
      dslo=(dn+dg+dpph)*(1.-dsmef)
      data dsmef/0.5/
      dsport=df
      dsel=dpxel+dppe+doe
      dsgf=dsfeed+dshi+dc
      dslf=df+dn+dg
      d=dsel+dsgf+dslf


      dummy6=dp-dsfeed
      dummy7=dg
      dummy8=df+dpp+dn+dc+doe
      dummy9=dsfeed
if (ans.eq.11) write(19) dummy6,dummy7,dummy8,dummy9

c          print out the table at tblinc year intervals
c          initial condition only
      if ((ans.eq.10).and.(tbltme.ge.100.)) write (6,100)
100   format(12x,"dpa",9x,"dpb",9x,"dpe",9x,"dpm",9x,"dpo",9x,"dpxel")
      if ((ans.eq.10).and.(tbltme.ge.tblinc))
&        write(6,200) time,dpa,dpb,dpe,dpm,dpo,dpxel
200   format(f5.0,6f12.1)
c          initial condition only
      if ((ans.eq.11).and.(tbltme.ge.100.)) write (6,300)
300   format(12x,"dp ",9x,"dpp",9x,"dc ",9x,"df ",9x,"dn ",9x,"dg ")
      if ((ans.eq.11).and.(tbltme.ge.tblinc))
&        write(6,400) time,dp,dpp,dc,df,dn,dg
400   format(f5.0,6f12.1)

      return
      end
```

subroutine demsum

```
c         demand summary
c
c         declare arrays
      integer ans
      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /zhomes/ re,rh
      common /zcomm/ ce,ch
      common /ztrans/ te,tpf,tgf
      common /zind/ dfeed,de,dhitmp,dmetmp,dlotmp
      common /zdemand/ dempf,demel,demph,dembh,demfe,demtot

      demel=re+ce+te+de
            hitemp=dhitmp
            metemp=dmetmp+tgf
      demph=metemp+hitemp
      dembh=dlotmp+rh+ch
      dempf=tpf
      demfe=dfeed
      demtot=demel+demph+dembh+dempf

c                 dummy's to do cumulative plots
            dummy1=dembh+demph
            dummy2=dummy1+demel
            dummy3=dummy2+dempf

      transp=te+tpf+tgf
      domes=rh+re
      comms=ce+ch
      dustry=dfeed+de+dhitmp+dmetmp+dlotmp

c                 dummy's to do cumulative plots
            dummy4=domes+comms
            dummy5=dummy4+transp
            dummy6=dummy5+dustry

c                 dummy's for per capita plots

            dummy7=dembh*1.e6/pop
            dummy8=dummy7+demph*1.e6/pop
            dummy9=dummy8+demel*1.e6/pop
            dummy10=dummy9+dempf*1.e6/pop


c         print out the table at tblinc year intervals
c         initial condition only
      if ((ans.eq.15).and.(tbltme.ge.100.)) write (6,100)
100   format("Time",8x,"elec",6x,"hitemp",7x,"metemp",6x,"lotemp",3x,
```

```
&      "portables",7x,"feeds ",2x,"Total demand",/)
       if ((ans.eq.15).and.(tbltme.ge.tblinc)) write(6,200) time,demel
&           ,hitemp,metemp,dembh,dempf,demfe,demtot
200    format(f5.0,7f12.1)
       if (ans.eq.15) write(19) dembh,dummy1,dummy2,dummy3

       if ((ans.eq.14).and.(tbltme.ge.100.)) write (6,300)
300    format("Time",8x,"domest",6x,"commer",6x,"trans",7x,"indust",/)
       if ((ans.eq.14).and.(tbltme.ge.tblinc))
&         write(6,400) time,domes,comms,transp,dustry
400    format(f5.0,7f12.1)
       if (ans.eq.14) write(19) domes,dummy4,dummy5,dummy6

       if (ans.eq.13) write(19) dummy7,dummy8,dummy9,dummy10

       return
       end
```

<u>subroutine portbl(demand)</u>

```
c            i=1 -- biomass
c            i=2 -- conventional oil
c            i=3 -- oil sands
c            i=4 -- coal
c            i=5 -- natural gas

       integer ans
c            common blocks
       common /pltinc/ tfirst,tlast,dptme,idummy
       common /when/ time,dt
       common /zext/ pop,costpf,costel,costph,costbh,demind
       common /zmisc/ ans,tbltme,tblinc,gpcons
       common /ztax/ pftax,eltax,phtax,bhtax,gpnonr,gpr,rate
       common /zsupply/ waste
       common /zport/ pdp,pic,pict
       common /zmax/ biomax

       real costpfd(6),biomaxt(3)
       real pac(5),pc(5),pcap(5),pce(5),pcgr(5),pcgrct(5),pcgrf(5)
       real pcgrl(5),pdp(5),peff(5),pic(5),picdn(5),picdr(5)
       real plife(5),popc(5),pwh(5),pwhrf(5),pmax(5),pmax2t(6)

       if (time.gt.tfirst) goto 1
            pic(1)=0.
            pic(2)=154.
            pic(3)=0.
            pic(4)=0.
            pic(5)=0.
       do 1 i=1,5

           picdn(i)=1.-exp(alog(0.1)/plife(i))
```

```
c           picdn -- normal portable installed capacity destruction rate
c           plife -- life of the technology (years)

          data plife(1)/30./,plife(2)/30./,plife(3)/25./
          data plife(4)/30./,plife(5)/30./

          data popc(1)/1.99/,popc(2)/2.63/,popc(3)/3.50/
          data popc(4)/3.50/,popc(5)/2.69/
          data pcap(1)/8.94/,pcap(2)/1.34/,pcap(3)/14.38/
          data pcap(4)/5.8/,pcap(5)/0.89/

          rate1=1.+rate
          pc(i)=pcap(i)/rate1/(1.-rate1**(-plife(i)))*rate+popc(i)
c           pc -- cost of portable fuels ($/GJ)
c           pcap -- capital cost ($/GJ/a)
c           rate -- interest rate (fraction/a)
c           popc -- operating costs ($/GJ)

1     continue

c           installed capacity expiry
      do 2 i=1,5

c           pic can't be less than zero
          pic(i)=amax1(0.,(pic(i)-dt*picdr(i)))

          picdr(i)=pic(i)*picdn(i)

c           what are the costs of the various sources?

          pc(i)=pc(i)+dt*pcgr(i)
          pce(i)=pc(i)*gpnonr+pftax
          if (i.eq.1) pce(1)=pc(1)*gpr+pftax

c           what is the incremental cost for this period?
          pcgr(i)=pc(i)*clip(pcgrf(i),pcgrl(i),pcgrct(i),time)
c           pcgr -- cost growth rate ($/GJ)
c           pcgrf -- first growth rate (fraction/a)
c           pcgrl -- last growth rate (fraction/a)
c           pcgrct -- time at which pcgrl replaces pcgrf
          data pcgrf(1)/-.02/,pcgrf(2)/.061/,pcgrf(3)/.033/
          data pcgrf(4)/.064/,pcgrf(5)/.066/
          data pcgrl(1)/.005/,pcgrl(2)/.02/,pcgrl(3)/.033/
          data pcgrl(4)/.015/,pcgrl(5)/.02/
          data pcgrct(1)/2000./,pcgrct(2)/1985./,pcgrct(3)/1985./
          data pcgrct(4)/1985./,pcgrct(5)/1985./
2     continue

      pict=pic(1)+pic(2)+pic(3)+pic(4)+pic(5)
c           pict -- total installed capacity for portable fuels

c           is capacity sufficient?
```

```
      if (pict.ge.demand) pec=pict-demand
      if (pict.ge.demand) goto 4

      iter=int((demand-pict)/10.)+1

      do 4 j=1,iter

           pce(1)=clip((pc(1)*gpr+pftax),1000.,pmax(1),(pic(1)+10.))
           data pmax(3)/1000./,pmax(4)/1000./,pmax(5)/1000./
c           biomass is available in limited quantities
      biomax=tabhl(biomaxt,time,1976.,1996.,10.)
      data biomaxt(1)/100./,biomaxt(2)/400./,biomaxt(3)/800./
      pmax(1)=biomax/peff(1)
           pmax(2)=table(pmax2t,time,1976.,2026.,10.)
           data pmax2t(1)/200./,pmax2t(2)/250./,pmax2t(3)/200./
           data pmax2t(4)/150./,pmax2t(5)/125./,pmax2t(6)/100./
           min=1
           do 3 i=2,5
             pce(i)=clip((pc(i)*gpnonr+pftax),1.e3,pmax(i),(pic(i)+10.))
             if (pce(i).lt.pce(min)) min=i
3          continue

           pic(min)=pic(min)+10.
           pac(min)=((pic(min)-10.)*pac(min)+new*pc(min))/pic(min)

4     continue

      pict=pic(1)+pic(2)+pic(3)+pic(4)+pic(5)
      pec=pict-demand
      costpfn=(pic(1)*pc(1)+pic(2)*pc(2)+pic(3)*pc(3)
&           +pic(4)*pc(4)+pic(5)*pc(5))/pict+pftax
      costpf=delay3(costpfn,costpfd)
      data costpfd(1)/5./

c           energy supply sector demands

c           convert end-use to primary
      do 6 i=1,5
         pdp(i)=pic(i)/peff(i)
c           peff is the set of efficiencies
         data peff(1)/0.4/,peff(2)/0.9/,peff(3)/0.6/
         data peff(4)/0.7/,peff(5)/0.6/

c           waste heat recovery?

         pwh(i)=pic(i)*pwhrf(i)
         data pwhrf(1)/0.75/,pwhrf(3)/0.2/,pwhrf(4)/0.2/
         data pwhrf(5)/0.35/

6     continue

c           any biomass left over for other sectors?
      biomax=amax1(0.,(biomax-pic(1)/peff(1)))
```

```
      pdpt=pdp(1)+pdp(2)+pdp(3)+pdp(4)+pdp(5)
      waste=pwh(1)+pwh(2)+pwh(3)+pwh(4)+pwh(5)

c           print out the variables at tblinc year intervals
c           initial condition only
      if ((ans.eq.16).and.(tbltme.ge.100.)) write(6,100) ans
100   format("Table ",i2,". Portable fuel supply sector summary",/,
&           "time",3x,"demand",2x,"pict",2x,"costpf",4x
&           ,"pec",5x,"pdpt",5x,"by-heat",/)
      if ((ans.eq.16).and.(tbltme.ge.tblinc)) write(6,200)time
&           ,demand,pict,costpf,pec,pdpt,waste
200   format(f5.0,6f8.2)
if (ans.eq.16) write(19) demand,pict
      if ((ans.eq.17).and.(tbltme.ge.100.)) write(6,300) ans
300   format("Table ",i2,". Portable fuels installed capacity",/,
&           "time",4x,"biomass",5x," oil",3x,"o sand",5x
&           ,"coal",4x,"n gas",3x,"total",/)
      if ((ans.eq.17).and.(tbltme.ge.tblinc)) write(6,400) time
&           ,(pic(l),l=1,5),pict
400   format(f5.0,6f9.1)
if (ans.eq.17) write(19) pic(2),pic(1)
      if ((ans.eq.18).and.(tbltme.ge.100.)) write(6,500) ans
500   format("Table ",i2,". Portable fuels energy costs ($/GJ)",/,
&     "time",3x,"biomass",5x," oil",3x,"o sand",4x,"n gas",5x,"coal",/)
      if ((ans.eq.18).and.(tbltme.ge.tblinc)) write(6,600) time
&           ,(pce(l),l=1,5)
600   format(f5.0,5f9.2)

      return
      end


subroutine elec(demand)

c           i=1 — falling water
c           i=2 — wind
c           i=3 — biomass
c           i=4 — conventional oil
c           i=5 — natural gas
c           i=6 — coal
c           i=7 — pumped storage

      integer ans
c           common blocks
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztax/ pftax,eltax,phtax,bhtax,gpnonr,gpr,rate
      common /zsupply/ waste
      common /zelec/ edp,eic,eict
```

```
      common /zmax/ biomax

      real costeld(6)
      real eac(7),ec(7),ecap(7),ece(7),ecgr(7),ecgrct(7),ecgrf(7)
      real ecgrl(7),edp(7),eeff(7),eic(7),eicdn(7),eicdr(7)
      real elife(7),eopc(7),ewh(7),ewhrf(7),emax(3)

c           account for transmission losses
      demand=demand*(1.+eloss)
      data eloss/0.1/

      if (time.gt.tfirst) goto 1
         eic(1)=1.6
         eic(2)=0.
         eic(3)=0.
         eic(4)=.5
         eic(5)=11.2
         eic(6)=35.0
         eic(7)=0.
      do 1 i=1,7

         eicdn(i)=1.-exp(alog(0.1)/elife(i))
         data elife(1)/60./,elife(2)/30./,elife(3)/30./,elife(4)/30./
         data elife(5)/30./,elife(6)/20./,elife(7)/60./

         data eopc(1)/0.21/,eopc(2)/2.51/,eopc(3)/8.14/,eopc(4)/3.00/
         data eopc(5)/3.00/,eopc(6)/3.28/,eopc(7)/0.35/
         data ecap(1)/30.24/,ecap(2)/58.07/,ecap(3)/36./,ecap(4)/15./
         data ecap(5)/15.00/,ecap(6)/17.35/,ecap(7)/72.24/

         rate1=1.+rate
         ec(i)=ecap(i)/rate1/(1.-rate1**(-elife(i)))*rate+eopc(i)

1     continue

c           installed capacity expiry
      do 2 i=1,6

         eic(i)=amax1(0.,(eic(i)-dt*eicdr(i)))

         eicdr(i)=eic(i)*eicdn(i)

c           what are the costs of the various sources?

         ec(i)=ec(i)+dt*ecgr(i)
         ece(i)=ec(i)*gpnonr+eltax
c           if wind use exceeds capacity in Southern AB then costs rise
c           due to lower wind speeds
         ece(2)=clip(ec(i),(ec(i)*1.5),90.,(eic(i)+10.))*gpr+eltax
c           if wind use exceeds 15% of demand, then need pumped storage
         if ((eic(2)+10.).gt.(.15*demand)) ece(2)=ece(2)+ec(7)
         if (i.eq.1) ece(1)=ec(1)*gpr+eltax
```

```
c           what is the incremental cost for this period?
           ecgr(i)=ec(i)*clip(ecgrf(i),ecgrl(i),ecgrct(i),time)
           data ecgrf(1)/.01/,ecgrf(2)/-.02/,ecgrf(3)/-.02/
           data ecgrf(4)/.18/,ecgrf(5)/.1/,ecgrf(6)/.064/,ecgrf(7)/.029/
           data ecgrl(1)/.01/,ecgrl(2)/.01/,ecgrl(3)/.005/,ecgrl(4)/.02/
           data ecgrl(5)/.02/,ecgrl(6)/.015/,ecgrl(7)/.025/
           data ecgrct(1)/1985./,ecgrct(2)/2000./,ecgrct(3)/2000./
           data ecgrct(4)/1985./,ecgrct(5)/1985./,ecgrct(6)/1985./
           data ecgrct(7)/1985./
2     continue

      eict=eic(1)+eic(2)+eic(3)+eic(4)+eic(5)+eic(6)+eic(7)

c           is capacity sufficient?

      if (eict.ge.demand) eec=eict-demand
      if (eict.ge.demand) goto 4

      iter=int((demand-eict)/10.)+1

      do 4 j=1,iter

           min=1
           do 17 i=1,3
           data emax(1)/65./,emax(2)/110./
      emax(3)=biomax/eeff(3)
           ece(i)=clip((ec(i)*gpr+eltax),1000.,emax(i),(eic(i)+10.))
           if (ece(i).lt.ece(min)) min=i
17         continue
           do 3 i=4,6
             ece(i)=ec(i)*gpnonr+eltax
             if (ece(i).lt.ece(min)) min=i
3          continue

           eic(min)=eic(min)+10.
           eac(min)=((eic(min)-10.)*eac(min)+new*ec(min))/eic(min)

4     continue

      eict=eic(1)+eic(2)+eic(3)+eic(4)+eic(5)+eic(6)
      eec=eict-demand
      costeln=(eic(1)*ec(1)+eic(2)*ec(2)+eic(3)*ec(3)+eic(4)*ec(4)
&        +eic(5)*ec(5)+eic(6)*ec(6)+eic(7)*ec(7))/eict+eltax
      costel=delay3(costeln,costeld)
      data costeld(1)/5./

c           energy supply sector demands

c           convert end-use to primary
      do 6 i=1,6
        edp(i)=eic(i)/eeff(i)
        data eeff(1)/1.0/,eeff(2)/1.0/,eeff(3)/0.315/,eeff(4)/0.2/
        data eeff(5)/0.2/,eeff(6)/0.342/,eeff(7)/0.01/
```

```
c          waste heat recovery?

         ewh(i)=eic(i)*ewhrf(i)
         data ewhrf(1)/0./,ewhrf(2)/0./,ewhrf(3)/1.0/,ewhrf(4)/3.0/
         data ewhrf(5)/3.0/,ewhrf(6)/1.0/,ewhrf(7)/0./

6      continue

c          any biomass left over?
       biomax=amax1(0.,(biomax-eic(3)/eeff(3)))

       edpt=edp(1)+edp(2)+edp(3)+edp(4)+edp(5)+edp(6)+edp(7)+eloss*demand
       ewaste=ewh(1)+ewh(2)+ewh(3)+ewh(4)+ewh(5)+ewh(6)+ewh(7)
       waste=waste+ewaste


c          print out a table of the variables at tblinc year intervals
c          initial condition only
       if ((ans.eq.19).and.(tbltme.ge.100.)) write(6,100) ans
100    format("Table ",i2,".  Electric supply summary",/,"Time",3x,
&      "demand",3x,"eict",2x,"costel",4x,"eec",5x,"edpt",5x,"by-heat",/)
       if ((ans.eq.19).and.(tbltme.ge.tblinc)) write(6,200)time
&          ,demand,eict,costel,eec,edpt,ewaste
200    format(f5.0,6f8.2)
if (ans.eq.19) write(19) demand,eict
       if ((ans.eq.20).and.(tbltme.ge.100.)) write(6,300) ans
300    format("Table ",i2,".  Installed electric capacity (PJ/a)",/,
&      "time",6x,"hydro",4x,"wind",2x,"biomass",6x,
&      "oil",4x,"n gas",5x,"coal",6x,"eic",/)
       if ((ans.eq.20).and.(tbltme.ge.tblinc))
&         write(6,400) time,(eic(l),l=1,6),eict
400    format(f5.0,8f9.1)
if (ans.eq.20) write(19) eic(1),eic(4),eic(5),eic(6)
       if ((ans.eq.21).and.(tbltme.ge.100.)) write(6,500) ans
500    format("Table ",i2,".  Costs of generating electricity ($/GJ)",/,
&      "time",5x,"hydro",5x,"wind",2x,"biomass",5x," oil",
&      4x,"n gas",5x,"coal",/)
       if ((ans.eq.21).and.(tbltme.ge.tblinc))
&         write(6,600) time,(ece(l),l=1,6)
600    format(f5.0,6f9.2)

       return
       end
```

<u>subroutine process(demand)</u>

```
c          i=1 — solar concentrator
c          i=2 — biomass
c          i=3 — coal
c          i=4 — natural gas
c          i=5 — oil sands
```

```
      integer ans
c           common blocks
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztax/ pftax,eltax,phtax,bhtax,gpnonr,gpr,rate
      common /zsupply/ waste
      common /zproc/ hdp,hic,hict
      common /zmax/ biomax

      real costphd(6)
      real hac(5),hc(5),hcap(5),hce(5),hcgr(5),hcgrct(5),hcgrf(5)
      real hcgrl(5),hdp(5),heff(5),hic(5),hicdn(5),hicdr(5)
      real hlife(5),hopc(5),hwh(5),hwhrf(5),hmax(3),hcogent(6)

      if (time.gt.tfirst) goto 1
           hic(1)=0.
           hic(2)=0.
           hic(3)=0.
           hic(4)=69.8
           hic(5)=26.1
      do 1 i=1,5

           hicdn(i)=1.-exp(alog(0.1)/hlife(i))
           data hlife(1)/30./,hlife(2)/30./,hlife(3)/20./,hlife(4)/30./
           data hlife(5)/25./

           data hopc(1)/1.35/,hopc(2)/1.99/,hopc(3)/3.50/,hopc(4)/0.89/
           data hopc(5)/2.60/
           data hcap(1)/23.90/,hcap(2)/4.34/,hcap(3)/4.34/,hcap(4)/1.16/
           data hcap(5)/3.59/

           rate1=1.+rate
           hc(i)=hcap(i)/rate1/(1.-rate1**(-hlife(i)))*rate+hopc(i)

1     continue

      hcogenp=table(hcogent,costel,0.,22.4,5.6)
      data hcogent(1)/0./,hcogent(2)/.1/,hcogent(3)/.7/,hcogent(4)/.8/
      data hcogent(5)/1./
      hcogen=amin0((hcogenp*waste),(demand*0.5))
      demand=demand-hcogen
      waste=waste-hcogen

c           installed capacity expiry
      do 2 i=1,5

           hic(i)=amax1(0.,(hic(i)-dt*hicdr(i)))

           hicdr(i)=hic(i)*hicdn(i)

c           what are the costs of the various sources?
```

```
          hc(i)=hc(i)+dt*hcgr(i)
          hce(i)=hc(i)*gpnonr+phtax
          if (i.eq.1) hce(1)=hc(1)*gpr+phtax

c          what is the incremental cost for this period?
          hcgr(i)=hc(i)*clip(hcgrf(i),hcgrl(i),hcgrct(i),time)
          data hcgrf(1)/0.0/,hcgrf(2)/-0.02/,hcgrf(3)/0.033/
          data hcgrf(4)/0.066/,hcgrf(5)/.18/
          data hcgrl(1)/0.0/,hcgrl(2)/.005/,hcgrl(3)/.0075/
          data hcgrl(4)/.03/,hcgrl(5)/.01/
          data hcgrct(1)/1983./,hcgrct(2)/2000./,hcgrct(3)/1983./
          data hcgrct(4)/1983./,hcgrct(5)/1978./
2     continue

      hict=hic(1)+hic(2)+hic(3)+hic(4)+hic(5)

c          is capacity sufficient?

      if (hict.ge.demand) hec=hict-demand
      if (hict.ge.demand) goto 4

      iter=int((demand-hict)/10.)+1

      do 4 j=1,iter

          min=1
          do 17 i=1,2
      hmax(2)=biomax/heff(2)
          hce(i)=clip((hc(i)*gpr+phtax),1000.,hmax(i),(hic(i)+10.))
          data hmax(1)/100./
          if (hce(i).lt.hce(min)) min=i
17        continue
          do 3 i=3,5
            hce(i)=hc(i)*gpnonr+phtax
            if (hce(i).lt.hce(min)) min=i
3         continue

          hic(min)=hic(min)+10.
          hac(min)=((hic(min)-10.)*hac(min)+new*hc(min))/hic(min)

4     continue

      hict=hic(1)+hic(2)+hic(3)+hic(4)+hic(5)
      hec=hict-demand
      costphn=(hic(1)*hc(1)+hic(2)*hc(2)+hic(3)*hc(3)+hic(4)*hc(4)
&        +hic(5)*hc(5))/hict+phtax
      costph=delay3(costphn,costphd)
      data costphd(1)/5./

c          energy supply sector demands

c          convert end-use to primary
      do 6 i=1,5
```

```
         hdp(i)=hic(i)/heff(i)
         data heff(1)/0.85/,heff(2)/0.85/,heff(3)/0.87/,heff(4)/0.85/
         data heff(5)/0.80/

c           waste heat recovery?

         hwh(i)=hic(i)*hwhrf(i)
         data hwhrf(1)/.09/,hwhrf(2)/.09/,hwhrf(3)/.09/,hwhrf(4)/.09/
         data hwhrf(5)/.09/

6       continue

c           any biomass left over?
        biomax=amaxl(0.,(biomax-hic(2)/heff(2)))

        hdpt=hdp(1)+hdp(2)+hdp(3)+hdp(4)+hdp(5)
        hwaste=hwh(1)+hwh(2)+hwh(3)+hwh(4)+hwh(5)
        waste=waste+hwaste


c           print out the variables at tblinc year intervals
c           initial condition only
        if ((ans.eq.22).and.(tbltme.ge.100.)) write(6,100) ans
100     format("Table ",i2,".  Process heat supply summary",/,"Time",3x,
&         "demand",4x,"hic",2x,"costph",4x,"hec",5x,"hdpt",5x,"hwaste",/)
        if ((ans.eq.22).and.(tbltme.ge.tblinc))
&          write(6,200)time,demand,hict,costph,hec,hdpt,hwaste
200     format(f5.0,6f8.2)
        if (ans.eq.22) write(19) demand,hict
        if ((ans.eq.23).and.(tbltme.ge.100.)) write(6,300) ans
300     format("Table ",i2,".  Installed process heat capacity",/,
&       "time",6x,"solar",4x,"biomass",2x,"coal",6x,
&       "gas",4x,"o sands",5x,"by-heat",/)
        if ((ans.eq.23).and.(tbltme.ge.tblinc))
&          write(6,400) time,(hic(l),l=1,5),hcogen
400     format(f5.0,8f9.1)
        if (ans.eq.23) write(19) hic(1),hic(2),hic(4),hic(5)
        if ((ans.eq.24).and.(tbltme.ge.100.)) write(6,500) ans
500     format("Table",i3,".  Costs of process heat",/,
&       "time",6x,"solar",4x,"biomass",2x,"coal",6x,
&       "gas",4x,"o sands",5x," ",/)
        if ((ans.eq.24).and.(tbltme.ge.tblinc))
&          write(6,600) time,(hce(l),l=1,5)
600     format(f5.0,7f9.2)

        return
        end
```

```
subroutine lotemp(demand)

c          i=1 solar homes
c          i=2 — collective solar
c          i=3 — collective biomass
c          i=4 — individual biomass (wood stoves and furnaces)
c          i=5 — coal
c          i=6 — natural gas

      integer ans
c           common blocks
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /ztax/ pftax,eltax,phtax,bhtax,gpnonr,gpr,rate
      common /zsupply/ waste
      common /zlo/   bdp,bic,bict
      common /zmax/ biomax

      real costbhd(6)
      real bac(7),bc(7),bcap(7),bce(7),bcgr(7),bcgrct(7),bcgrf(7)
      real bcgrl(7),bdp(7),beff(7),bic(7),bicdn(7),bicdr(7)
      real blife(7),bopc*7),bwh(7),bwhrf(7),bmax(4),bcogent(6)

      if (time.gt.tfirst) goto 1
           bic(1)=0.
           bic(2)=0.
           bic(3)=0.
           bic(4)=0.
           bic(5)=0.
           bic(6)=90.
      do 1 i=1,6

           bicdn(i)=1.-exp(alog(0.1)/blife(i))
           data blife(1)/30./,blife(2)/30./,blife(3)/25./,blife(4)/30./
           data blife(5)/25./,blife(6)/30./

           data bopc(1)/0.1/,bopc(2)/.1/,bopc(3)/2.35/,bopc(4)/4.00/
           data bopc(5)/2.41/,bopc(6)/1.35/
           data bcap(1)/32.46/,bcap(2)/18.55/,bcap(3)/13.91/
           data bcap(4)/24.34/, bcap(5)/13.91/,bcap(6)/4.64/

           ratel=1.+rate
           bc(i)=bcap(i)/ratel/(1.-ratel**(-blife(i)))*rate+bopc(i)

1     continue

      bcogenp=table(bcogent,costel,0.,22.4,5.6)
      data bcogent(1)/0./,bcogent(2)/.1/,bcogent(3)/.7/,bcogent(4)/.8/
      data bcogent(5)/1.0/
      bcogen=amin0((bcogenp*waste),(demand*0.5))
      demand=demand-bcogen
```

```
      waste=waste-bcogen

c          installed capacity expiry
      do 2 i=1,6

           bic(i)=amax1(0.,(bic(i)-dt*bicdr(i)))

           bicdr(i)=bic(i)*bicdn(i)

c          what are the costs of the various sources?

           bc(i)=bc(i)+dt*bcgr(i)
           bce(i)=bc(i)*gpnonr+bhtax
           if (i.lt.5) bce(i)=bc(i)*gpr+bhtax

c          what is the incremental cost for this period?
           bcgr(i)=bc(i)*clip(bcgrf(i),bcgrl(i),bcgrct(i),time)
           data bcgrf(1)/0.0/,bcgrf(2)/0.0/,bcgrf(3)/-0.02/
           data bcgrf(4)/-0.02/,bcgrf(5)/.064/,bcgrf(6)/.066/
           data bcgrl(1)/.0/,bcgrl(2)/.0/,bcgrl(3)/.005/
           data bcgrl(4)/.005/,bcgrl(5)/.015/,bcgrl(6)/.02/
           data bcgrct(1)/1985./,bcgrct(2)/2000./,bcgrct(3)/2000./
           data bcgrct(4)/2000./,bcgrct(5)/1985./,bcgrct(6)/1985./
2     continue

      bict=bic(1)+bic(2)+bic(3)+bic(4)+bic(5)+bic(6)

c          is capacity sufficient?

      if (bict.ge.demand) bec=bict-demand
      if (bict.ge.demand) goto 4

      iter=int((demand-bict)/10.)+1

      do 4 j=1,iter

           bmax(3)=biomax/beff(3)
           bmax(4)=biomax/beff(4)
           min=1
           do 17 i=1,4
           bce(i)=clip((bc(i)*gpr+bhtax),1.e3,bmax(i),(bic(i)+10.))
           data bmax(1)/100./,bmax(2)/110./
           if (bce(i).lt.bce(min)) min=i
17         continue
           do 3 i=5,6
             bce(i)=bc(i)*gpnonr+bhtax
             if (bce(i).lt.bce(min)) min=i
3          continue

           bic(min)=bic(min)+10.
           bac(min)=((bic(min)-10.)*bac(min)+new*bc(min))/bic(min)
           if ((min.eq.3).or.(min.eq.4)) biomax=biomax-10./beff(min)
```

```
4     continue

      bict=bic(1)+bic(2)+bic(3)+bic(4)+bic(5)+bic(6)
      bec=bict-demand
      costbhn=(bic(1)*bc(1)+bic(2)*bc(2)+bic(3)*bc(3)+bic(4)*bc(4)
&        +bic(5)*bc(5)+bic(6)*bc(6))/bict+bhtax
      costbh=delay3(costbhn,costbhd)
      data costbhd(1)/5./

c           energy supply sector demands

c           convert end-use to primary
      do 6 i=1,6
         bdp(i)=bic(i)/beff(i)
         data beff(1)/1.0/,beff(2)/1.0/,beff(3)/0.85/,beff(4)/0.5/
         data beff(5)/0.87/,beff(6)/0.75/

6     continue

      bdpt=bdp(1)+bdp(2)+bdp(3)+bdp(4)+bdp(5)+bdp(6)
      bwht=bwh(1)+bwh(2)+bwh(3)+bwh(4)+bwh(5)+bwh(6)


c           print out the variables at tblinc year intervals
c           initial condition only
      if ((ans.eq.25).and.(tbltme.ge.100.)) write(6,100) ans
100   format("Table ",i2,".  Building heat supply summary",/,
&     "time",3x,"demand",2x,"costbh",4x,"bec",5x,"bdpt",5x,"bwht",/)
      if ((ans.eq.25).and.(tbltme.ge.tblinc)) write(6,200)time
&           ,demand,bict,costbh,bec,bdpt,bwht
200   format(f5.0,6f8.2)
      if (ans.eq.25) write(19) demand,bict
      if ((ans.eq.26).and.(tbltme.ge.100.)) write(6,300) ans
300   format("Table ",i2,".  Installed building heat capacity",/,
&     "time",4x,"i solar",1x,"n solar",1x,"c biomass",1x,
&     "i biomass",4x,"coal",5x,"n gas",6x,"bict",/)
      if ((ans.eq.26).and.(tbltme.ge.tblinc))
&        write(6,400) time,(bic(l),l=1,6),bict
400   format(f5.0,8f9.1)
      if (ans.eq.26) write(19) bic(2),bic(1),bic(3),bic(6)
      if ((ans.eq.27).and.(tbltme.ge.100.)) write(6,500) ans
500   format("Table ",i2,".  Costs of low temperature heat.",/,
&     "time",5x,"i solar",5x,"n solar",2x,"n biomass",5x," i biomass",
&     4x,"coal",5x,"n gas",/)
      if ((ans.eq.27).and.(tbltme.ge.tblinc))
&        write(6,600) time,(bce(l),l=1,6)
600   format(f5.0,7f9.2)

      return
      end
```

subroutine supsum

```
c          supply sector summary

      integer ans
      real nonren,nonrenp,nonrcap
      real eic(7),edp(7),pdp(5),pic(5),hic(5),hdp(5)
      real bdp(7),bic(7)

      common /when/ time,dt
      common /zext/ pop,costpf,costel,costph,costbh,demind
      common /pltinc/ tfirst,tlast,dptme,idummy
      common /zport/ pdp,pic,pict
      common /zelec/ edp,eic,eict
      common /zproc/ hdp,hic,hict
      common /zlo/   bdp,bic,bict
      common /zmisc/ ans,tbltme,tblinc,gpcons
      common /zdemand/ dempf,demel,demph,dembh,demfe,demtot

c          installed capacity
      biomass=pic(1)+eic(3)+hic(2)+bic(3)+bic(4)
      solar=bic(1)+bic(2)
      wind=eic(2)
      hydro=eic(1)
      oil=pic(2)+eic(4)
      gas=pic(5)+eic(5)+hic(4)+bic(5)
      sands=pic(3)+hic(5)
      coal=pic(4)+eic(6)+hic(3)+bic(6)

      renew=biomass+solar+wind+hydro
      nonren=oil+gas+sands+coal

c          primary energy demand
      biomasp=pdp(1)+edp(3)+hdp(2)+bdp(3)+bdp(4)
      solarp=bdp(1)+bdp(2)
      windp=edp(2)
      hydrop=edp(1)
      oilp=pdp(2)+edp(4)
      gasp=pdp(5)+edp(5)+hdp(4)+bdp(5)
      sandsp=pdp(3)+hdp(5)
      coalp=pdp(4)+edp(6)+hdp(3)+bdp(6)

      renewp=biomasp+solarp+windp+hydrop
      nonrenp=oilp+gasp+sandsp+coalp

      primary=renewp+nonrenp

      recap=renewp*1.e6/pop
      nonrcap=nonrenp*1.e6/pop
      pricap=primary*1.e6/pop

           if ((ans.eq.28).and.(time.le.tfirst)) write(6,100) ans
100   format("Table ",i2,". Primary energy demand",/,
```

```
&     "Time",5x,"Income",4x,"Capital",//)
      if ((ans.eq.28).and.(tbltme.ge.tblinc))
&        write(6,200) time,renewp,nonrenp,primary
200   format(f5.0,3f12.1)
      if (ans.eq.28) write(19) nonrenp,primary

      if ((ans.eq.29).and.(time.le.tfirst)) write (6,300) ans
300   format("Table ",i2,". Energy demand",/,
&     "Time",5x,"End-use",x,"Primary",//)
      if ((ans.eq.29).and.(tbltme.ge.tblinc))
&        write (6,200) time,demtot,primary
      if (ans.eq.29) write(19) demtot,primary

      if ((ans.eq.30).and.(time.le.tfirst)) write(6,500) ans
500   format("Table",i3,". Primary energy demand per capita (GJ/a)",/
&     "Time",5x,"Income",3x,"Capital",/)
      if ((ans.eq.30).and.(tbltme.ge.tblinc))
&        write(6,200) time,recap,nonrcap,pricap
      if (ans.eq.30) write(19) recap,pricap

      if ((ans.eq.31).and.(time.le.tfirst)) write(6,700) ans
700   format("Table",i3,". Primary energy demand from income sources"
&     ,/,"Time",5x,"Biomass",2x,"Solar",2x,"Wind",2x,"Hydro",/)
      if ((ans.eq.31).and.(tbltme.ge.tblinc))
&        write(6,800) time,biomasp,solarp,windp,hydrop
800   format(f5.0,4f12.1)
      if (ans.eq.31) write(19) biomasp,solarp,windp,hydrop

      if ((ans.eq.32).and.(time.le.tfirst)) write(6,900) ans
900   format("Table",i3,". Primary energy demand from capital sources",/,
&     "Time",5x,"Oil",5x,"Gas",2x,"Oil sands",2x,"Coal",/)
      if ((ans.eq.32).and.(tbltme.ge.tblinc))
&        write(6,800) time,oilp,gasp,sandsp,coalp
      if (ans.eq.32) write(19) oilp,gasp,sandsp,coalp

      if ((ans.eq.33).and.(time.le.tfirst)) write(6,1100) ans
1100  format("Table ",i2,". Energy costs",/,"Time",5x,
&     "Portable",x,"Electricity",x,"High temp heat",x,"Low temp",/)
      if ((ans.eq.33).and.(tbltme.ge.tblinc))
&        write(6,1200) time,costpf,costel,costph,costbh
1200  format(f5.0,4f12.2)
      if (ans.eq.33) write(19) costpf,costel,costph,costbh

      if ((ans.eq.34).and.(time.le.tfirst)) write(6,1300) ans
1300  format("Table ",i2,". Primary energy demand by sector (PJ/a)",/,
&     "Time",5x,"Portable",6x,"Electric",5x,"High temp",5x,"Low temp",/)
      if ((ans.eq.34).and.(tbltme.ge.tblinc))
&        write(6,1400) time,pict,eict,hict,bict
1400  format(f5.0,4f12.1)
      if (ans.eq.34) write(19) pict,eict,hict,bict

      return
      end
```

Appendix B. Dynamo functions

function clip(xl,x2,cl,c2)

```
c     clip uses xl if present date is less than cl
c     clip uses x2 if present date is greater than cl

      if (c2.ge.cl) goto 2
      clip=xl
      return
2     continue
      clip=x2
      return
      end
```

function delay3(x,trx)

```
c     third-order exponential material delay

      dimension trx(6)
c     trx(3-5) — internal delay variables
c     trx(1) - - time to recognise x in time units
c     trx(2) — dummy for initialisation
c     trx(6) — previous delay3
      common /when/ time,dt
c           check for values that won't work
      if(trx(1).ge.(dt*3.)) goto 2
          write(7,100)
100         format(" Error - Delay time is too short, delay ignored")
            trx(2)=0.
            delay3=x
            return
2     continue
      trx5=trx(1)/3.
c     initialise
      if(trx(2).ge.5.) goto 4
      trx(2)=10.
      do 3 i=3,6
      trx(i)=x
3     continue
4     continue
      trx(5)=trx(5)+dt*(trx(4)-trx(5))/trx5
      trx(4)=trx(4)+dt*(trx(3)-trx(4))/trx5
      trx(3)=trx(3)+dt*(trx(6)-trx(3))/trx5
      trx(6)=x
      delay3=trx(5)
      return
      end
```

function smooth(x,smtm)

```
c     first order exponential average of a physical rate of flow
c     smtm(1) — delay time
c     smtm(2) — flag for first time through
c     smtm(3) — last smooth value
c     x       — variable delayed
c
c     aiopc=smooth(iopc,ieat)
      dimension smtm(3)
      common /when/ time,dt
c     initialising
      if(smtm(2).ge.5.) goto2
      smtm(2)=10.
      smtm(3)=x
2     continue
      smtm(3)=smtm(3)+(dt*(x-smtm(3)))/smtm(1)
      smooth=smtm(3)
      return
      end
```

function tabhl(tabv,x,xf,xl,xi)

```
c           table lookup and linear interpolation
c           for equally spaced abcissa values

89    dimension tabv(20)
c           check for out of range abcissa values
      if (x.le.xf) go to 10
      if (x.ge.xl) go to 20
c           value within table range
      k=int((x-xf)/xi+1.)
      tabhl=tabv(k)+(tabv(k+1)-tabv(k))*(x-(k-1)*xi-xf)/xi
      return
c           abcissa below lowest tabulated
10    continue
      tabhl=tabv(1)
      return
c           abcissa above highest value tabulated
20    continue
      k=int((xl-xf)/xi+1.+1.e-10)
      tabhl=tabv(k)
      return
      end
```

function table(tabv,x,xf,xl,xi)

```
c          table lookup and linear interpolation
c          error message printed if value is out of table range
c          for equally spaced abcissa values

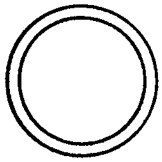
      common /when/ time,dt
      common /warning/ nowarn

      dimension tabv(20)
c          check for out of range abcissa values
      if (x.le.xf) go to 10
      if (x.ge.xl) go to 20
c          value within table range
      k=int((x-xf)/xi+l.)
      table=tabv(k)+(tabv(k+l)-tabv(k))*(x-(k-l)*xi-xf)/xi
      return
c          abcissa below lowest tabulated
10    continue
      if ((x.lt.xf).and.(nowarn.eq.0)) write(7,99) x,xf,xl,time
99    format(" Warning -- value of ",f8.3," not within range of ",f8.3,
&     " and ",f8.3," in ",f5.0)
      table=tabv(l)
      return
c          abcissa above highest value tabulated
20    continue
      k=int((xl-xf)/xi+l.+l.e-10)
      if ((x.gt.xl).and.(nowarn.eq.0)) write(7,99) x,xf,xl,time
      table=tabv(k)
      return
      end
```

Appendix C. Abbreviations

a	- year
AENR	- Alberta Energy and Natural Resources
AERCB	- Alberta Energy Resources Conservation Board
CONAES	- Demand and Conservation Panel of the Committee on Nuclear and Alternative Energy Systems
EMR	- Energy Mines and Resources Canada
G	- giga (10**9)
GDP	- Gross Domestic Product
J	- joule (1/1055 Btu)
k	- kilo (10**3)
L	- litre
M	- mega (10**6)
NEB	- National Energy Board
ODt	- oven dried tonne
OEC	- Office of Energy Conservation, Energy Mines and Resources Canada
P	- peta (10**15)
sqm	- square meter(s)
t	- tonne (.907 short tons)
W	- watt

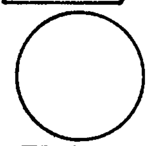
Appendix D. Meaning of flow chart symbols



— Concentric circles are used to represent an exogenous variable. That is, they are used to represent a variable which is specified directly as a function of time.

— A rectangle is used to represent a level variable.

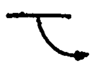
— A valve is used to represent a rate variable.



— A circle is used to represent an auxiliary variable.

— A rectangle containing four rectangles is used to represent a delayed variable.

— A variable that is underlined and overlined is determined by using a look-up table.



— An arrow is used to indicate a constant parameter which is input directly.

Further description on the various types of variables can be found in Meadows (1974) and Forrester (1968).