Projection of Carbon Dioxide Emissions from Natural Gas Combustion and Steam-Reforming of Methane in Alberta

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Anthropogenic emissions of carbon dioxide into the atmosphere come primarily from the combustion of fossil fuels and deforestation. Concentrations of carbon dioxide, along with other greenhouse gases, are expected to exacerbate the climate warming trend and lead to a number of changes in the terrestrial biosphere. The purpose of this paper is to identify and project the sources of carbon dioxide emissions from combustion and conversion of natural gas in Alberta.

Les émissions anthropiques de dioxyde de carbone dans l'atmosphère proviennent principalement de la combustion des combustibles fossiles et du déboisement. On prévoit généralement que l'augmentation de la concentration de dioxyde de carbone, et aussi d'autres gaz à effet de serre, accélérera le réchauffement du climat et provoquera de nombreux changements dans la biosphère. L'auteur cherche à déterminer les sources d'émission de dioxyde de carbone par combustion et conversion du gaz naturel en Alberta et à effectuer des projections s'y rapportant.

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1. Introduction

Atmospheric concentrations of carbon dioxide (CO_2), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), tropospheric ozone (O_3), and methane (CH_4), generally known as greenhouse gases, have increased significantly. Because these gases behave as an insulating blanket, trapping heat within the lower atmosphere, they are generally known as greenhouse gases. All of them contribute to global warming, but with different percentage contributions and residence times. Carbon dioxide currently accounts for approximately 50% of the projected increase in global warming due to rising concentrations of greenhouse gases (Table 1). A decrease in CO_2 emissions is therefore the key to reducing global warming, even though emissions of CO_2 do not remain in the atmosphere as long as other gases. Approximately 80 to 90% of the concentration of CO_2 results from the extraction and use of fossil fuels and the remainder is mostly accounted for by biotic destruction, particularly tropical forest burning.

In 1988, more than 300 experts in science, law, energy, the environment, and economics gathered at a conference in Toronto to consider "The Changing Atmosphere: Implications for Global Security." The conference set a target for reduc-

Table 1: Manmade Contributions to the Greenhouse Effect and Atmospheric Life

	Contributions (%)	Atmospheric Life(Years)
Carbon Dioxide	50	2
Nitrous Oxide	6	120
Chlorofluorocarbons	14	65-110
Methane	18	5-10
Others*	12	-

* Including carbon monoxide, ozone, nitrogen oxides and water vapour.

Source: Rind (1989).

ing CO_2 emissions by 20% from 1988 levels by the year 2005 as an initial step for reducing global warming. Although no country has denied the importance of reducing CO_2, none has yet committed to the 20% CO_2 abatement, mainly because of the costs involved. For instance, Manne and Richels (1990) recently estimated that reduction of CO_2 emissions to the 1990 level by the year 2005 could cost the US $3.6 trillion in present value terms. Canada is currently the world's ninth largest contributor of CO_2 emissions with a share of 2%.

This paper examines the difficulties faced by the Province of Alberta, a fossil fuel exporter, in achieving targeted reductions in carbon dioxide emissions. We will show that Alberta has limited opportunities for reducing CO_2 emissions for two reasons: first, the production of natural gas represents the major source of Alberta's CO_2 emissions; and second, a high proportion of Alberta's energy consumption already comes from natural gas, which emits less CO_2 compared to other fossil fuels. The analysis is based on an integrated system of computer models developed by the Alberta Energy Resources Conservation Board.[1]

2. CO_2 Emissions in Alberta

The Toronto Conference projected that half of the targeted reduction in world CO_2 emissions could be achieved through improved energy efficiency, and the remainder through changes in fuel mix, i.e. substitutions in favour of energy sources that emit less CO_2. In many cases, the preferred fuel for substitution is natural gas. The extraction of each terajoule from the combustion of natural gas results in the emission of 49.41 tonnes of CO_2, an amount which is approximately 50% of the energy equivalent emissions from coal and 65% of those from oil.

In 1988 Alberta produced around 121 Mt of CO_2 emissions. The largest sources were natural gas (60 Mt), coal (33 Mt), refined petroleum products (18 Mt), coke (4 Mt), process gas (4 Mt), and propane (2 Mt). An examination of different economic sectors in Alberta illustrates the difficulty in achieving reduced CO_2 emissions through efficiency and substitutions given an expanding economic base.

2.1 Residential Sector

CO_2 emissions in the residential sector are related to the amount of natural gas used for space and water heating, as well as the operation of those appliances requiring natural gas. In Alberta, the type of energy used for space and water heating and their average penetration rates are: natural gas (95.5%); propane (1.7%); oil (1.4%); electricity (1.2%); and wood (0.2%). In this sector, CO_2 production is directly tied to growth in the number of households, housing stock by type and vintage, and gas requirement per household.

Table 2 shows average CO_2 emissions by dwelling types. Dwellings are categorized into single, double, row, apartment, and mobile

1/ The Integrated Model of Alberta (IMA) was used for the projection of economic activity and energy requirements in Alberta, and for greenhouse gas emissions resulting from the combustion and conversion of fossil fuels. The structure of the IMA is very briefly described in Appendix 2. Assumptions about conservation, new industrial projects, alternative fuel substitution, etc, were adopted from the "High Case" of "Energy Requirements in Alberta", ERCB Report 89-A. In this report the "High Case" represents the most likely case.

Table 2: Average Carbon Dioxide Emissions from Combustion of Natural Gas Per Occupied Housing Unit (tonnes/year)

Single-Detached	
Pre-1981	11.0
Pre-1981 retrofitted	9.0
Post-1980 retrofitted*	6.5
Post-1980 with higher furnace and better wall and basement insulation	3.4
Semi-detached	
Pre-1981	7.5
Pre-1981 retrofitted	6.0
Post-1980 retrofitted*	5.0
Row Housing	
Pre-1981	6.5
Pre-1981 retrofitted	5.4
Post-1980 retrofitted*	4.4
Apartments	
Pre-1981	4.1
Post-1980	2.9
Mobile Homes	
Pre-1981	8.8
Pre-1981 retrofitted	7.1
Post-1980 retrofitted*	5.0

* It is assumed that all houses after 1980 are retrofitted.

homes. Projected gas conservation assumptions distinguish between housing stocks of post-1980 and pre-1981 vintages, the base year that the Alberta government changed the home insulation code. Table 3 forecasts probable CO_2 emission levels for every three years from 1988 to 2003. CO_2 emissions from natural gas used as fuel are expected to increase from 7.11 Mt in 1988 to 8.49 Mt in 2003, representing an average annual growth rate of 1.2%. This modest increase assumes that more mid and high-efficiency furnaces will be used, some existing houses will be retrofitted, and new houses will be better insulated.

Further reduction of residential CO_2 emissions is still practical through improved heating systems and the thermal insulation of buildings. This is evident from the CO_2 emission rates by dwelling type shown in Table 2. As this table displays, a post-1980 single detached house with a higher-efficiency furnace and better wall and

Table 3: CO_2 Production From Natural Gas Combustion and Steam-Reforming of Methane in Alberta 1988-2003 (Megatonnes)

	1988	1991	1994	1997	2000	2003
Residential	7.11	7.37	7.72	8.05	8.32	8.49
Commercial	4.58	4.95	5.31	5.66	5.89	6.11
Industrial*	45.41	50.57	58.25	63.35	69.25	67.97
Transportation	1.51	1.66	1.92	2.01	2.05	2.04
Electricity Generation	2.31	2.53	2.76	3.03	3.46	3.44
Total	60.92	67.08	75.96	82.10	88.97	88.05

* CO_2 Production from process gas is included in the industrial sector.

basement insulation produces only 30% of the CO_2 emitted by a pre-1981 non-retrofitted house. Among dwelling types, apartments produce the least CO_2, 2.9 tonnes per unit per year.

2.2 Commercial Sector

The CO_2 emissions in the commercial sector depend on the amount of natural gas used for space and water heating, as well as the operation of commercial appliances. In this sector, CO_2 production is directly tied to the growth of new floor space and the gas requirement per square metre by building type. The major commercial buildings are divided into schools, hospitals, commercial buildings and others. Table 4 shows CO_2 emitted to the atmosphere per square metre of floor space for three different commercial building types.

Over the forecast period, the CO_2 emissions from natural gas increased from 4.58 Mt to 6.11 Mt, yielding an average growth rate of 1.8% per year (see Table 3). A further reduction in CO_2 emissions in this sector is also practical through improved boiler efficiency, better insulation, and using heat pumps.

Table 4: Carbon Dioxide Emissions from Combustion of Natural Gas by Selected Commercial Building Types (kg/m^2)

Schools	55 - 62
Business/Commercial	58 - 72
General Hospitals	214 - 314

2.3 Industrial Sector

In the industrial sector, natural gas is used as fuel for process heat and the operation of machinery and equipment, and as a feedstock for synthesis gas production.

FUEL GAS

In 1988 the CO_2 emissions from natural gas combustion were 37.3 Mt. In this year, the distribution of CO_2 emissions among industrial fuel-burning groups were: oil refineries (3.3%); oil sands (8.9%); petrochemicals (10.8%); gas processing plants (65.3%); and all others (11.7%), including oil fields, coal mines, gas reprocessing plants, forest products, cement plants, etc. From the above groups, the largest CO_2 emitters are the gas processing plants which extract natural gas liquids, sulphur or other substances from raw gas.[2] It is estimated that every 1000 m^3 of raw gas entering gas processing plants emits 265 kilograms of CO_2 to the atmosphere, of which approximately 19.5% is related to gas flaring, 24.5% to tail gas burning and 56% to fuel gas burning.

In 1988 Alberta produced 85 billion m^3 of natural gas through 594 processing plants. Of this, 24 billion m^3 were used in Alberta, 27 billion m^3 were delivered to other provinces, and the remainder was exported to the US. The above data show that more than 70% of CO_2 emissions resulting from gas processing plants are related to markets outside of Alberta.

During the forecast period, natural gas production (based on 4.8 trillion m^3 or 170 trillion ft^3 of ultimate potential reserves) is projected to increase until 1999, followed by a decline over the next three years (Table 3). It should be mentioned that, unlike SO_2 and NO_x emissions, CO_2 emissions are unavoidable when natural gas is burned. CO_2 is not recoverable by pollution-control equipment in either gas processing plants or in other industrial fuel-burning groups. Table 5 shows the CO_2 emissions from fuel gas in selected industries.

FEEDSTOCK GAS

In petrochemical plants, natural gas is used as feedstock for synthesis gas production, where the hydrogen of synthesis gas (steam-reforming of methane) is used for production of methanol and ammonia.[3] Ammonia is also upgraded to urea when mixed with CO_2; therefore the proportion of CO_2 production which is used to produce urea should be excluded from CO_2 emissions. In Alberta, not all ammonia is upgraded to urea; some is marketed as ammonia and some is used for production of ammonium sulphate, nitrate, phosphate, etc, processes which do not use up CO_2. Similarly in oil sands operations, the hydrogen from steam-reforming of methane is used for increasing the hydrogen-to-carbon ratio of bitumen as part of the upgrading of bitumen to synthetic crude oil. In total, industrial CO_2 emissions from natural gas combustion and steam-reforming of methane, as well as process gas,[4] are projected to increase from 45 Mt in 1988 to 68 Mt in 2003, representing an annual growth rate of 2.7% (Table 3).

Table 5: Average Carbon Dioxide Emissions from Combustion of Natural Gas by Selected Industries

Gas Processing (kg/1000 m^3)	
Flared gas	52
Tail gas	65
Fuel gas	148
Oil Sands (kg/m^3)	
Syncrude (synthetic crude oil)	88
Suncor (synthetic crude oil)	75
Commercial and Experimental (non-upgraded bitumen)	408
Petrochemicals (kg/tonne)	
Ethylene	460
Methanol	254
Ammonia	368
Forest Products (kg/tonne)	
Kraft mill	98
TMP mill	41

2/ The processing of raw gas to yield marketable natural gas is described in Appendix 3.

3/ Methods for synthesis gas production and steam reforming of methane are described in Appendix 1.

4/ Process gas, or off gas, is the amount of gas produced during oil refining and bitumen upgrading to synthetic crude oil. The CO_2 emissions from process gas are included in the industrial sector.

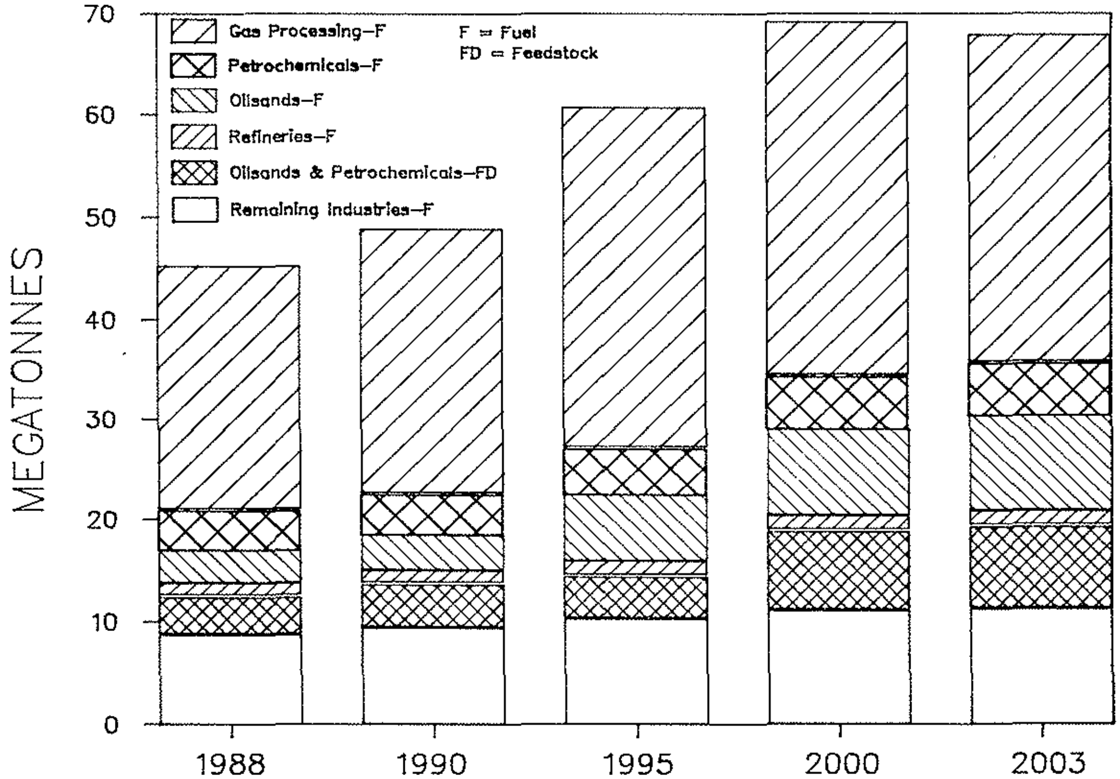

Figure 1: CO_2 Production from Natural Gas used as Fuel and Feedstock in the Industrial Sector

Figure 1 shows that CO_2 emissions from the use of natural gas as fuel and feedstock grow rapidly between 1988 and 2003 due to the rising production of natural gas and expansion of certain industrial groups, particularly petrochemicals and oil sands operations.

Although the use of natural gas in lieu of other fossil fuels provides a net benefit in terms of reduced CO_2 emissions, the release of methane resulting from natural gas production and distribution reduces this advantage. While the sources of methane emissions and their contribution to the greenhouse effect are the subject of considerable uncertainty, many analysts consider a molecule of methane to be 20 to 30 times more effective as a greenhouse gas than a molecule of CO_2. Despite all of the uncertainties, there is no doubt that producing and using natural gas reduces methane emissions from coal seams and seepage from natural gas reservoirs to some extent. In general, since methane emissions are not yet well quantified, it is not clear whether natural gas production and distribution actually reduce or increase net methane emissions.[5]

2.4 Transportation Sector

Natural gas in the transportation sector is used as an alternative fuel for private, commercial, and farm vehicles, as well as a compressor fuel in pipelines. The CO_2 production from natural gas vehicles (NGV) is projected from the penetration rate of NGV in road transportation energy (motive fuels) requirements.

Oil and gas pipelines require two main types of energy: natural gas and electricity. The key determinant of CO_2 production in pipeline distribution systems is the amount of natural gas

5/ Other sources of methane emissions are: biomass combustion, rice fields, ruminant animals (cud chewers), biogenic sources and coal extraction and use.

that is used as compressor fuel for delivering gas to inside and outside of the province (throughput volume). Over the forecast period, CO_2 emitted from this sector increases from 1.51 Mt in 1988 to 2.04 Mt in 2003 (Table 3). This sector has the least emissions.

2.5 Electricity Generation

In Alberta, there are several different types of electricity generating units, each designed for a particular type of service corresponding to the amount of time the unit may be required to operate. Furthermore, the majority of plants and loads in the provincial system are interconnected, although a few relatively small, isolated plants are not. Alberta's mix of primary energy for the utility generation of electricity in 1988 was 89.7% coal, 6.4% gas, 3.8% hydroelectric, and 0.03% oil. The projection of natural gas-related CO_2 emissions depends on the amount of electricity generation associated with gas-fired units and the plant thermal efficiency. The Optimal Generation Planning Model was used to determine the appropriate mix of primary energy in the forecast period. Over that period, CO_2 emitted from natural gas use for electricity generation increases from 2.3 Mt in 1988 to 3.4 Mt in 2003 (Table 3).

3. Conclusions

In Alberta emissions of CO_2 from natural gas combustion and steam reforming of methane are projected to increase from 60.9 Mt in 1988 to 88.1 Mt in 2003 (Table 3). This represents growth of 45%, which is a substantial divergence from the goal of a 20% reduction in emissions by 2005 established at the Toronto Conference.

The major producers of CO_2 are gas processing plants. In 1988, approximately 24.4 Mt (40%) of CO_2 emissions from natural gas occurred at gas processing plants which ultimately exported more than 70% of their product. To further illustrate the relative significance of gas production versus gas consumption for Alberta's emissions of CO_2, it is useful to note that, over the forecast period, CO_2 emissions from gas flaring (4.77-6.3Mt) are approximately equal to the CO_2 emissions from natural gas combustion in the commercial sector (4.58 - 6.11 Mt). CO_2 emissions from natural gas combustion in the residential, commercial, transportation and electrical generation sectors amounted in total to only 62% of CO_2 emissions from gas processing plants. Consequently, as other jurisdictions replace more damaging fossil fuels with natural gas, Alberta's emissions of CO_2 unavoidably rise.

At present, natural gas accounts for 48% of the fuel consumed (on an energy equivalent basis) in Alberta, a percentage which is much higher than that for other provinces: Quebec 21%; Ontario 30%; Manitoba 27%; Saskatchewan 37%; British Columbia 39%; and Yukon and Northwest Territories 20%. Thus, Alberta also has limited opportunity for the substitution of natural gas for other fuels in its domestic usage.

Since natural gas processing and usage is the major source of CO_2 emissions in Alberta, fuel substitution in Alberta is not a solution, and fuel substitution outside of the province increases Alberta's CO_2 emissions. Improved fuel efficiency, particularly for gas processing plants, is the key factor in reducing CO_2 emissions in Alberta.

References

Aitken, W.R.O. (1988) 'Conserving the Environment; Sustaining Economic Growth,' *Canadian Business Review* 16:2.

Burn, I (1989) *Energy-Related Carbon Dioxide Emissions in Alberta 1988-2002*, (Department of Energy, Alberta).

Davison, A. (1989) *Fossil Fuel Consumption and the Environment* (Oxford: Oxford Institute for Energy Studies).

Energy Resources Conservation Board (1989) *Energy Requirements in Alberta 1989-2003*, (Alberta: ERCB), Report 89-A.

Energy Resources Conservation Board (1988) *Alberta Energy Industry Annual Statistics*, (Alberta: ERCB) ST 89-28.

Environmental Protection Series (1990) *National Inventory of Sources and Emissions of Carbon Dioxide*, (Canada: Environment Canada) Reports EPS 5/AP/2.

Keepin, B. and G. Kats (1988) *Greenhouse Warming: Comparative Analysis of Two Abatement Strategies*, (Snowmass, Colorado: Rocky Mountain Institute).
Manne, A.S. and R.G. Richels (1990) 'CO_2 Emission Limits: An Economic Cost Analysis for the USA,' *The Energy Journal* 11:2.
Rind, D. (1989) 'A Character Sketch of Greenhouse,' *EPA Journal* 15:1.
Schneider, S.H. (1989) *Global Warming: Are We Entering the Greenhouse Century?* (San Francisco: Sierra Club Books).
Toronto Conference Statement (1988) 'The Changing Atmosphere: Implications for Global Security'.
Wiggins, E. and W. Yurko (1989) 'The Greenhouse Effect and The Alberta Fossil Fuels Industry,' A Discussion Paper (Alberta: Oil Sands Technology and Research Authority).

Appendix 1: Steam - Reforming of Methane

The two predominant methods for synthesis gas (various mixtures of carbon monoxide (CO) and hydrogen (H_2)) production are steam-reforming and partial oxidation of methane. Steam-reforming involves methane and steam, while partial oxidation occurs at high temperatures and pressures. The conversion process is as follows:

$CH_4 + H_2O \rightarrow CO + 3H_2$
synthesis gas - steam-reforming

$CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2$
synthesis gas - partial oxidation.

Methanol is produced from mixtures of the hydrogen of synthesis gas with either carbon monoxide or carbon dioxide. In the latter process, since some hydrogen ends up as water, the reaction is considered less efficient. Therefore, direct hydrogenation of carbon monoxide is the preferred route:

$CO + H_2O \rightarrow CO_2 + H_2$
carbon dioxide

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$
methanol (not preferred route)

$CO + 2H_2 \rightarrow CH_3OH$
methanol (preferred route).

The basic route for ammonia production is a reaction between gaseous nitrogen and hydrogen, the latter obtained by steam-reforming of methane unless hydrogen is available from an adjacent facility. Every molecule of methane consumed in steam-reforming results in one molecule of CO_2 emitted to the atmosphere. However, subsequent upgrading of ammonia to urea combines ammonia and CO_2, so that not all of the CO_2 from steam-reforming is emitted to the atmosphere:

$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$
synthesis gas - steam reforming

$N_2 + 3H_2 \rightarrow 2NH_3$
ammonia

$4N_2 + 3CH_4 + 6H_2O \rightarrow 3CO_2 + 8NH_3$
ammonia - net reaction from the above two equations

$2NH_3 + CO_2 \rightarrow NH_2CONH_2 + H_2O$
urea

Appendix 2: The Integrated Model of Alberta

The Integrated Model of Alberta (IMA) has been developed by the author and his colleagues in the Economics Department of the Alberta Energy Resources Conservation Board. IMA consists of four major models: the Macro-Economic Model of Alberta (MEMA), the Energy Price Forecast Model (ENEPRICE), the Energy Requirements Model of Alberta (ERMA), and the Greenhouse Gases Model (GREEN) (see Figure 2).

IMA is a long-term forecasting model, which consists of over 1,800 endogenous equations and identities and uses a variety of estimation techniques, including econometrics, engineering, accounting and market information. The major exogenous inputs to IMA comprise a set of national economic variables, such as unemployment, inflation and interest rates, as well as a set of 'forecast assumptions,' which include a major industrial profile, fuel efficiency and conservation.

ENEPRICE projects the prices of Alberta's energy resources, which are then used as inputs to MEMA and ERMA. ENEPRICE is based on an accounting type framework, which attempts to reflect both domestic and international energy policies, using the West Texas Intermediate (WTI) crude oil price at Chicago as the primary exogenous input.

The potential impact of oil price changes on Alberta's performance is measured by MEMA, a provincial econometric model designed to provide key economic and demographic inputs to ERMA, which in turn impacts on Alberta's economic activity. MEMA consists of approximately 400 equations and is divided into eight interdependent sectors: demographic, labour force, prices and wages, housing, energy industry, other industries, input-output and final demand.

ERMA, composed of 1,200 equations, is a hybrid model which primarily uses econometric and engineering techniques. ERMA forecasts long-run secondary (end-use) and primary energy demand for different types of fossil fuels, as well as electricity. The end-use demand is projected using a bottom-up approach based on the residential, commercial, industrial and transportation sectors. Energy exports from ERMA are used as inputs to MEMA. Hence, the convergence of variables between MEMA and ERMA must be obtained through several iterations during the simulation process.

GREEN forecasts Alberta's carbon dioxide and nitrous oxide emissions resulting from secondary energy requirements for each of the main end use sectors, as well as for energy producing industries. GREEN, composed of 200 equations, is based on emission factors. Alberta's energy requirements and production from ERMA are used as inputs to GREEN.

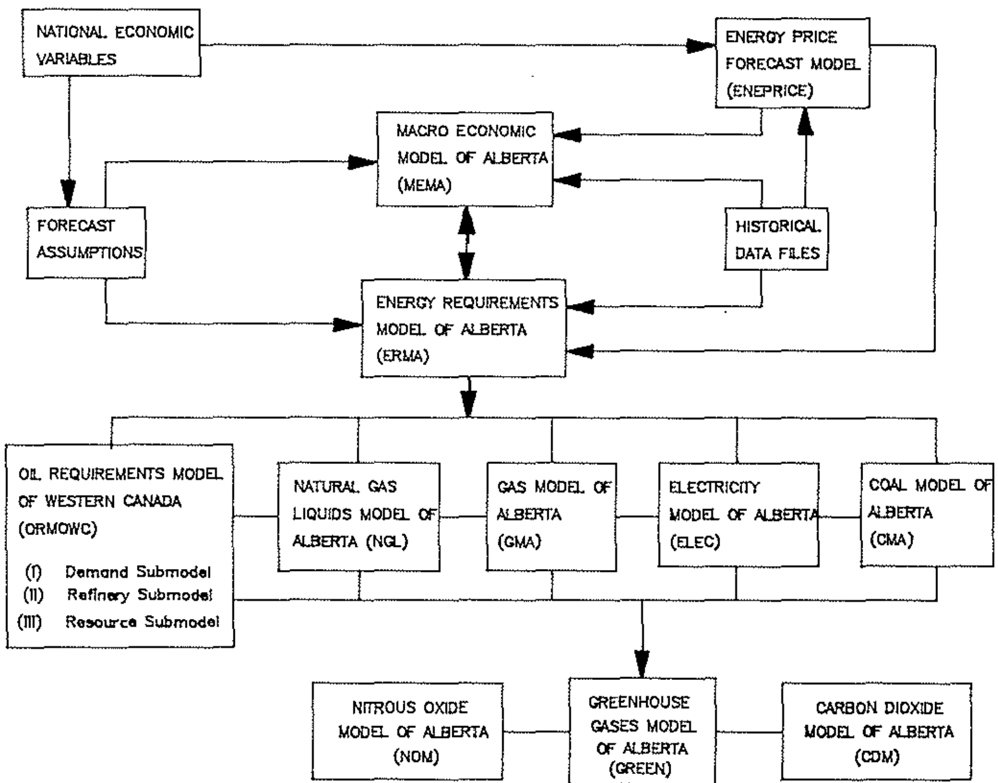

Figure 2: Integrated Model of Alberta

Appendix 3: Natural Gas Production and CO_2 Emissions

Marketable natural gas is a mixture of methane and other light hydrocarbons derived from raw gas through processing to remove some constituents, and which meets specifications for pipeline transportation and for use as a fuel and feedstock. The CO_2 emitted during production activity is divided into gas flaring, tail gas burning and gas used as fuel in gas processing plants.

Gas Flaring

The volume of raw gas which is burned in the field and in the associated gathering system is recorded as "flared". In general, flaring occurs due to either emergency and operational problems or the production of solution gas that is not within economic reach of an existing pipeline. Historical data show that CO_2 emissions of flared gas are approximately 2.8% of the CO_2 obtainable by burning marketable natural gas production.

Tail Gas Burning

As Figure 3 shows, the first gas processing operation occurs at the inlet separator of the gas plant, where the raw gas (1) is separated into sour gas (2), sour condensate (3), and water. Sour gas, which contains significant quantities of hydrogen sulphide (H_2S) and CO_2, is sent on for further treatment such as sweetening, dehydration, and removal of natural gas liquids. Sour condensate flows to the stabilization facilities for removal of remaining gases and pentanes plus (10). In the sweetening section of processing plants, sour gas is processed to become sweet wet gas and acid gas. The sweet wet gas is dehydrated to reduce the water content of the gas and to eliminate the potential of hydrate formation. After this process, the dry gas can be used onsite as fuel, or sold in the market as marketable gas (4), or sent to the fractionation unit. A fractionation unit is used to separate a gaseous mixture of hydrocarbons into individual products such as propane (5), butanes (6), and pentanes plus (10).

In the next process H_2S, CO_2, and any small quantities of carbonyl sulphide, carbon disulphide, and mercaptans in the acid gas (7), are removed and directed to sulphur recovery. After recovery of sulphur, the tail gas (8) is discharged to the atmosphere through stack plants for burning (9). The CO_2 emitted during the burning of tail gas is equivalent to 3.5% of the CO_2 obtainable by burning marketable gas production.

Fuel Gas

In the gas processing plants, after the aforementioned process, the dry gas can be used on site as fuel, or sold as marketable gas. There are 594 processing plants in Alberta; thus the on site gas used as fuel contributes a substantial amount of CO_2 emissions to the atmosphere. In Alberta, the CO_2 content of fuel gas burned for process heat at field, gathering and gas processing plants amounts to 8% of the CO_2 content of marketable gas production.

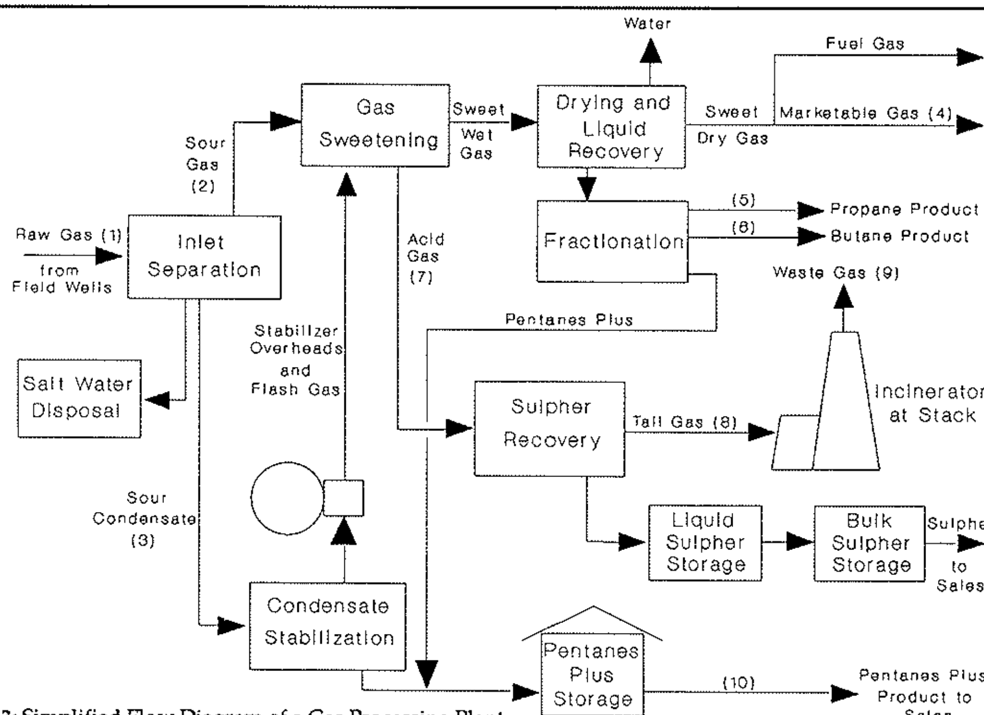

Figure 3: Simplified Flow Diagram of a Gas Processing Plant