GREENHOUSE GAS EMISSIONS IN CHIHUAHUA AND REFERENCE CASE PROJECTIONS 1990-2025

Prepared by:

Stephen M. Roe, Juan A. Maldonado, Holly Lindquist, Brad Strode, Rachel Anderson, Cristina Quiroz, and Jackson Schreiber

The Center for Climate Strategies
1899 L Street, Suite 900
Washington, DC 20036

For:

Secretaría de Desarrollo Urbano y Ecología

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Acronyms and Key Terms

bbls – Barrels

BOD – Biochemical Oxygen Demand

Btu – British Thermal Unit

C – Carbon

$CaCO_3$ – Calcium Carbonate

CCS – Center for Climate Strategies

CCT – Carbon Calculation Tool

CFCs – Chlorofluorocarbons

CH_4 – Methane

CHP – Combined Heat and Power

CO_2 – Carbon Dioxide

CO_2e – Carbon Dioxide equivalent

CONAFOR – Comisión Nacional Forestal

EAF – Electric Arc Furnace

EIIP – Emission Inventory Improvement Program

Gg – Gigagram

GHG – Greenhouse Gas

GWh – Gigawatt-hour

GWP – Global Warming Potential

H_2CO_3 – Carbonic Acid

HCFCs – Hydrochlorofluorocarbons

HFCs – Hydrofluorocarbons

HNO_3 – Nitric Acid

HWP – Harvested Wood Products

INEGI – Instituto Nacional de Estadísticas, Geografía, e Informática

IPCC – Intergovernmental Panel on Climate Change

kg – Kilogram

kWh – Kilowatt-hour

lb – Pound

LF – Landfill

LFGTE – Landfill Gas Collection System and Landfill-Gas-to-Energy

LPG – Liquefied Petroleum Gas

Mg – Megagrams

MMBtu – Million British thermal units

MMt – Million Metric tons

$MMtCO_2e$ – Million Metric tons Carbon Dioxide equivalent

MSW – Municipal Solid Waste

N_2O – Nitrous Oxide

NEMS – National Energy Modeling System

NH_3 – Ammonia

ODS – Ozone-Depleting Substance

OEIDRUS - Oficina Estatal de Información para el Desarrollo Rural Sustentable

PFCs – Perfluorocarbons

ppb – Parts per billion

ppm – Parts per million

ppmv – Parts per million by volume

ppt – Parts per trillion

RCI – Residential, Commercial, and Industrial

SEMARNAT – Secretaría de Medio Ambiente y Recursos Naturales

SENER – Secretaría de Energía

SF_6 – Sulfur Hexafluoride

SIACON -- Sistema de Información Agropecuaria de Consulta

SIT – State Greenhouse Gas Inventory Tool

T&D – Transmission and Distribution

t – Metric ton (equivalent to 1.102 short tons)

US – United States

US EPA – United States Environmental Protection Agency

WW – Wastewater

yr – Year

Executive Summary

The Center for Climate Strategies (CCS) prepared with the Secretaría de Desarrollo Urbano y Ecología (SDUE) a preliminary assessment of the State's greenhouse gas (GHG) emissions from 1990 to 2005 and a forecast of emissions through 2025. SDUE provided leadership, coordination and technical input to the development of this report. The inventory and forecast estimates serve as a starting point to assist the State with an initial comprehensive understanding of Chihuahua's current and possible future GHG emissions.

Chihuahua's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2025. Historical GHG emission estimates (1990 through 2005)[1] were developed using a set of generally accepted principles and guidelines for State GHG emission inventories, relying to the extent possible on Chihuahua-specific data and inputs. The initial reference case projections (2006-2025) are based on a compilation of projections of electricity generation, fuel use, and other GHG-emitting activities for Chihuahua, which are based on official government projections and alternatively on an extrapolation of historical trends. The data sources, methods, and detailed sector-level results are provided in the appendices of this report.

The inventory and projections cover the six types of gases included in Mexico's national GHG emissions inventory[2] and commonly reported in international reporting under the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalents (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential- (GWP-) weighted basis.[3]

As shown in Table ES-1, activities in Chihuahua accounted for approximately 20.0 million metric tons (MMt) of *gross production-based*[4] CO_2e emissions in 2005, an amount equal to about 3.0% of Mexico's gross GHG emissions in 2005 excluding carbon sinks, such as accumulation of carbon stocks in forested land. Chihuahua's gross production-based GHG emissions increased by 27% from 1990 to 2005, while national emissions rose by 31% from 1990 to 2005. [5] The increase in emissions from 1990 to 2005 is primarily associated with increased electricity consumption and increased transportation activity.

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[1] The last year of available historical data varies by sector; ranging from 2000 to 2005.
[2] Inventario Nacional de Emisiones de Gases de Efecto Invernadero (INEGEI)
[3] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 1996). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm. Estimates of CO_2e emissions are based on the GWP values listed in the IPCC Second Assessment Report (SAR).
[4] "Gross" emissions exclude GHG emissions removed (sequestered) due to forestry and other land uses and "consumption-based" emissions exclude GHG emissions associated with exported electricity.
[5] Comparison with national results were drawn from *Mexico Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*. Mexico: INE-SEMARNAT, 2006. Available at www.ine.gob.mx. Available annual emissions values were on the order of 498,748 and 618,072 gigagrams in 1990 and 2002 respectively. 2005 emissions were derived from these values at 655,477 gigagrams.

Initial estimates of carbon sinks within Chihuahua's forests and landfill carbon storage have also been included in this report. However additional work is needed to gain an understanding of CO_2 emissions/sinks for urban forests, land use change, and cultivation practices leading to changes in agricultural soils. In addition, there is considerable need for additional work for the initial forestry sink estimates provided in this report (e.g. to account for losses/gains in forested area; see Appendix H). Additional work to improve the forest and agricultural carbon sink estimates could lead to substantial changes in the initial estimates provided in this report. The current estimates indicate that about 7.8 $MMtCO_2e$ were sequestered in Chihuahua forest biomass and landfills in 2005; however, this excludes any losses associated with forest land conversion due to a lack of data. Inclusion of emission sinks leads to *net* emissions of 12.1 $MMtCO_2e$ in Chihuahua for 2005.

Figure ES-1 compares the State's and Mexico's gross production-based emissions per capita and per unit of economic output.[6] On a per capita basis, Chihuahua emitted about 5.9 metric tons (t) of gross CO_2e in 1995, 2% greater than the 1995 national average of 6.0 tCO_2e. Chihuahua's per capita emissions slightly increased to 6.1 tCO_2e in 2005, while national per capita emissions for Mexico grew to 6.4 tCO_2e in 2005. Chihuahua's economic growth exceeded emissions growth for the 1995-2000 period leading to declining estimates of GHG emissions per unit of state product.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projection, Chihuahua's gross production-based GHG emissions increased from 1990 to 1995. Between 1995 and 2000 emissions in the electricity supply and agricultural sectors decreased. After 2000, historic emissions had a positive growth and are projected to reach 27.9 $MMtCO_2e$ by 2025. This would be an increase of 81% over 1990 levels. As shown in Figure ES-3, the transportation sector is projected to be the largest contributor to future emissions growth in Chihuahua, followed by emissions in the electricity sector.

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks in resolving the data gaps include review and revision of key emissions drivers that will be major determinants of Chihuahua's future GHG emissions (such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, industrial processes, and RCI fuel use). Appendices A through H provide detailed methods, data sources, and assumptions made for each GHG sector. Also included are descriptions of significant uncertainties in emission estimates and/or methods and suggested next steps for refinement of the inventory and reference case projection.

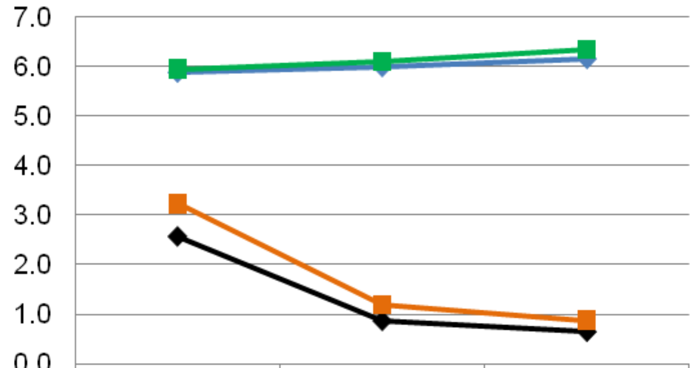
[6] Historic population available from Instituto Nacional de Estadísticas Geografía e Informática (INEGI). Population projection were available from Comisión Nacional de Población (CONAPO).

Table ES-1. Chihuahua Historical and Reference Case GHG Emissions by Sector

(Million Metric Tons CO2e)	1990	1995	2000	2005	2010	2015	2020	2025
Energy Consumption Based	**9.9**	**12.2**	**13.2**	**14.0**	**16.7**	**18.1**	**20.7**	**24.1**
Electricity Consumption Based	**4.02**	**5.34**	**5.83**	**5.91**	**6.86**	**6.98**	**8.52**	**10.79**
Electricity Production Based	4.31	4.04	5.96	6.20	5.55	8.22	7.19	7.55
Gas/Diesel Oil	0.23	0.25	0.20	0.02	0.00	0.00	0.00	0.00
Natural Gas	0.79	0.94	2.83	3.67	3.98	7.42	7.19	7.55
Residual Fuel Oil	3.29	2.85	2.93	2.51	1.57	0.81	0.00	0.00
Net Imported Electricity	-0.30	1.29	-0.13	-0.29	1.31	-1.24	1.33	3.24
Res/Comm/Ind (RCI)	**2.52**	**2.53**	**2.86**	**2.37**	**2.58**	**2.76**	**2.96**	**3.25**
Gas/Diesel Oil	0.08	0.19	0.22	0.08	0.07	0.07	0.07	0.06
Gasoline: Motor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liquefied Petroleum Gases	1.40	1.37	1.09	0.94	0.84	0.78	0.74	0.71
Natural Gas	1.01	0.93	1.39	1.18	1.46	1.68	1.90	2.20
Residual Fuel Oil	0.00	0.00	0.12	0.14	0.17	0.19	0.21	0.23
Solid Biofuels: Wood	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05
Transportation	**3.37**	**4.36**	**4.49**	**5.60**	**7.02**	**8.12**	**8.98**	**9.85**
Road Transport - Gasoline	1.95	2.88	3.05	3.84	4.57	5.26	5.77	6.29
Road Transport - Diesel	0.96	1.13	0.97	1.37	2.10	2.49	2.81	3.14
Road Transport - LPG	0.02	0.05	0.21	0.20	0.08	0.07	0.07	0.07
Road Transport - Nat. Gas	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03
Aviation	0.22	0.11	0.07	0.00	0.00	0.00	0.00	0.00
Rail	0.22	0.19	0.19	0.20	0.26	0.29	0.31	0.33
Fossil Fuel Industry	**0.00**	**0.00**	**0.05**	**0.11**	**0.20**	**0.21**	**0.21**	**0.22**
Natural Gas Transmission	0	0	0.01	0.01	0.01	0.01	0.01	0.01
Natural Gas Distribution	0	0	0.04	0.11	0.19	0.20	0.20	0.21
Industrial Processes	**0.98**	**1.17**	**1.59**	**2.10**	**2.25**	**2.64**	**3.04**	**3.44**
Cement Manufacture	0.18	0.24	0.30	0.42	0.62	0.78	0.93	1.09
Iron and Steel Production	0.38	0.38	0.38	0.65	0.61	0.72	0.83	0.94
Limestone / Dolomite Use	0.32	0.45	0.77	0.87	0.81	0.91	1.01	1.12
ODS Substitutes	0.09	0.11	0.13	0.17	0.20	0.24	0.27	0.30
Waste Management (Gross)	**0.73**	**0.82**	**0.91**	**1.02**	**0.89**	**0.88**	**0.93**	**1.03**
Domestic Wastewater	0.29	0.34	0.37	0.39	0.40	0.42	0.43	0.45
Industrial Wastewater	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solid Waste Disposal Sites	0.33	0.37	0.41	0.46	0.33	0.30	0.34	0.42
Open Burning	0.10	0.12	0.13	0.16	0.16	0.16	0.15	0.15
Landfill Carbon Storage	-0.08	-0.08	-0.10	-0.09	-0.10	-0.11	-0.12	0.00
Agriculture	**3.64**	**3.46**	**2.38**	**2.55**	**2.76**	**3.00**	**3.27**	**3.54**
Enteric Fermentation	2.23	2.19	1.39	1.54	1.70	1.88	2.08	2.26
Manure Management	0.05	0.06	0.04	0.04	0.05	0.05	0.06	0.07
Managed Soils	1.35	1.21	0.96	0.97	1.02	1.07	1.13	1.21
Forestry and Land Use	**-7.09**	**-7.65**	**-6.52**	**-7.85**	**-8.36**	**-8.36**	**-8.36**	**-8.36**
Forest (carbon flux)	-7.24	-7.69	-6.57	-7.75	-8.31	-8.31	-8.31	-8.31
Forest Fires (non-CO_2)	0.15	0.06	0.06	0.01	0.02	0.02	0.02	0.02
Woody Crops	0.01	-0.02	-0.01	-0.10	-0.06	-0.06	-0.06	-0.06
Gross Emissions Consumption Based	**15.40**	**17.74**	**18.18**	**19.67**	**22.57**	**24.60**	**27.94**	**32.13**
increase relative to 1990	*0%*	*15%*	*18%*	*28%*	*47%*	*60%*	*81%*	*109%*
Emission Sinks	**-7.32**	**-7.78**	**-6.67**	**-7.85**	**-8.41**	**-8.42**	**-8.43**	**-8.31**
Net Emissions (incl. forestry*)	**8.09**	**9.96**	**11.51**	**11.83**	**14.16**	**16.18**	**19.50**	**23.82**
increase relative to 1990	*0%*	*23%*	*42%*	*46%*	*75%*	*100%*	*141%*	*195%*
Gross Emissions Production Based	**15.70**	**16.45**	**18.31**	**19.97**	**21.26**	**25.85**	**26.61**	**28.89**
increase relative to 1990	*0%*	*5%*	*17%*	*27%*	*35%*	*65%*	*69%*	*84%*
Net Emissions (incl. forestry*)	**8.38**	**8.67**	**11.64**	**12.12**	**12.85**	**17.42**	**18.18**	**20.58**
increase relative to 1990	*0%*	*3%*	*39%*	*45%*	*53%*	*108%*	*117%*	*145%*

Note: Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

Figure ES-1. Historical Chihuahua and National Gross Production-Based GHG Emissions per Capita and per Unit of Economic Output[7]



	1995	2000	2005
Chihuahua GHG/Capita (tCO2e/capita)	5.89	6.00	6.16
MX GHG/Capita (tCO2e/capita)	5.96	6.10	6.35
Chihuahua GHG/$ (kgCO2e/$)	2.57	0.87	0.65
MX GHG/$ (kgCO2e/$)	3.24	1.19	0.88

[7] Economic activity expressed in 2006 values. Information retrieved from INEGI, Banco de Información Económica.

Figure ES-2. Chihuahua Gross Consumption-Based GHG Emissions by Sector, 1990-2025

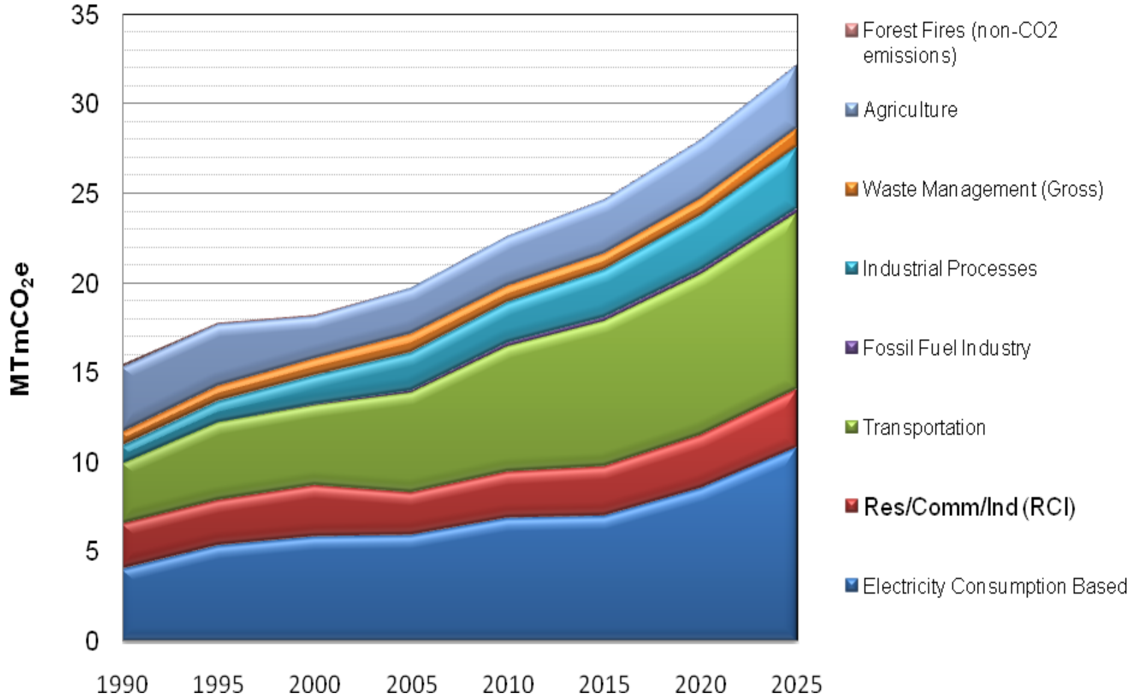
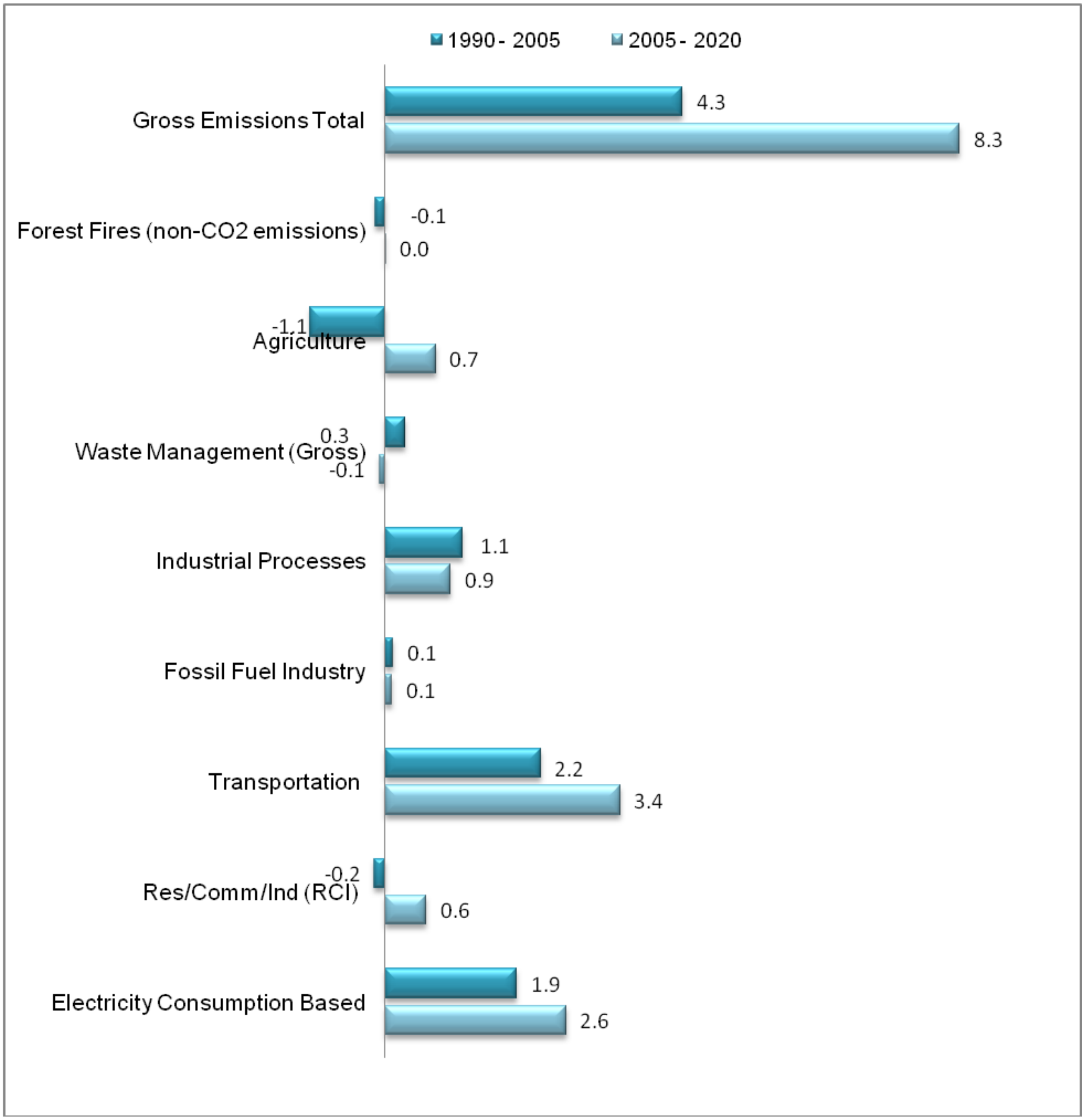


Figure ES-3. Sector Contributions to Gross Emissions Growth in Chihuahua, 1990-2020: Reference Case Projections (MMtCO$_2$e Basis)



Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph. Data for US states indicates a high expected growth in emissions for ODS substitutes. Forest-fires – emissions include methane and nitrous oxide emissions only. Waste management – emissions exclude landfill carbon storage.

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Summary of Preliminary Findings

Introduction

The Center for Climate Strategies (CCS) prepared prepared this report with the Secretaría de Desarrollo Urbano y Ecología del Estado de Chihuahua (SDUE). This report presents a preliminary assessment of the State's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2025. The inventory and forecast estimates serve as a starting point to assist the State with an initial comprehensive understanding of Chihuahua's current and possible future GHG emissions, and thereby can serve to inform the future identification and analysis of policy options for mitigating GHG emissions. In this report, the terms "forecast" and "reference case projection" are used interchangeably.

Historical GHG emission estimates (1990 through 2005) were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below. These estimates rely to the extent possible on Chihuahua-specific data and inputs. The initial reference case projections (2006-2025) are based on a compilation of projections of electricity generation, fuel use, and other GHG-emitting activities for Chihuahua, along with a set of simple, transparent assumptions described in the appendices of this report. While 2005 is commonly the year for the most recent historical data, there are some sources for which a different year applies. Still, the historical inventory will commonly be referred to here as the 1990 to 2005 time-frame. The sector-level appendices provide the details on data sources and applicable years of availability.

This report covers the six gases included in Mexico's national GHG emissions inventory and international GHG reporting under the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential- (GWP-) weighted basis.[8]

It is important to note that the preliminary emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Chihuahua's demands*, corresponding to a consumption-based approach to emissions accounting (see "Approach" section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* This report covers both methods of accounting for emissions, but for consistency and clarity, all total results shown in summary tables and graphs are reported as *consumption-based.*

[8] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 1996). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm. The CO_2e estimates presented in this report are based on the GWP values provided in the IPCC's Second Assessment Report (SAR).

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Chihuahua Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Chihuahua by sector for the years 1990, 2000, 2005, 2010, 2020, and 2025. Table 1 presents results according to four types of GHG accounting: 1) consumption based emissions; 2) production based emissions; 3) nete emissions; 4) gross emissions. The specific type of accounting is specified in each of the figures and tables of the report. Moreover, it is important to note that comparisons with the Inventario Nacional de Emisiones de Gases de Efecto Invernadero (INEGEI) were made on the basis of *gross, production-base emissions* in order to be consistent with the type of GHG accounting employed by the authors of the INEGEI.

Details on the methods and data sources used to construct the emission estimates are provided in the appendices to this report**.** In the sections below, a brief discussion is provided on the GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends and uncertainties clearly for each. A net emission estimate includes both sources and sinks of GHGs.

This next section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the reference-case projection emissions (2006 through 2025) and key uncertainties. An overview of the general methodology, principles, and guidelines followed for preparing the inventories is then provided. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector.

Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in Chihuahua accounted for approximately 20.0 million metric tons (MMt) of CO_2e emissions, an amount equal to about 3.0% of Mexico GHG emissions (based on 2005 national emissions).[9] Chihuahua's gross GHG emissions are rising at a lower rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Chihuahua's gross GHG emissions increased 27% from 1990 to 2005, while national emissions rose by 31% from 1990 to 2005.

Figure 1 compares the State's and Mexico's emissions per capita and per unit of economic output.[10] On a per capita basis, Chihuahua emitted about 5.9 metric tons (t) of gross CO_2e in 1995, 2% less than the 1995 national average of 6.0 tCO_2e. Chihuahua's per capita emissions decreased to 6.2 tCO_2e in 2005, while national per capita emissions for Mexico grew to only 6.2 tCO_2e in 2005. Chihuahua's economic growth exceeded emissions growth for the 1995-2000 period leading to declining estimates of GHG emissions per unit of state product.

[9] Comparison with national results were drawn from: *Mexico Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*. Mexico: INE-SEMARNAT, 2006. Available at www.ine.gob.mx. Available annual emission values were on the order of 498,748 and 618,072 gigagrams in 1990 and 2002 respectivively. 2005 emissions were derived from these values at 655,477 gigagrams.
[10] Historic population available from Instituto Nacional de Estadísticas Geografía e Informática (INEGI). Population projection were available from Comisión Nacional de Población (CONAPO).

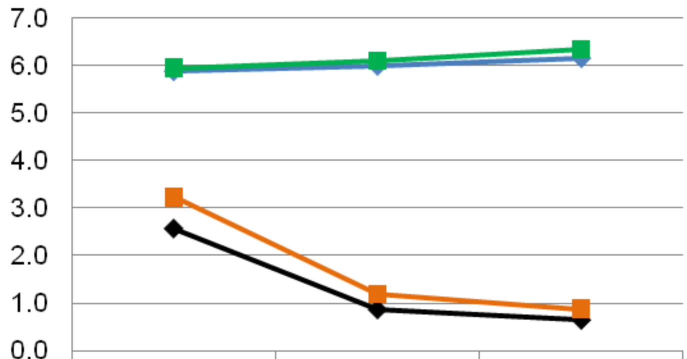
Figure 2 compares gross GHG emissions for Chihuahua to gross production based emissions for Mexico in 2005 according to GHG sectors used by Instituto Nacional de Ecología (INE). The principal source of Chihuahua's GHG emissions is energy use. Energy use includes activities such as power generation, transportation, fossil fuel production and exploration as well as residential, commercial, and industrial consumption of primary fuels (e.g. gasoline, diesel, coal, natural gas, liquefied petroleum gas). In 2005, the energy sector accounted for 72% of total GHG emissions in the state of Chihuahua. At the national level, the energy sector accounted for 63% of gross GHG emissions in 2005.

Table 1. Chihuahua Historical and Reference Case GHG Emissions by Sector

(Million Metric Tons CO2e)	1990	1995	2000	2005	2010	2015	2020	2025
Energy Consumption Based	**9.9**	**12.2**	**13.2**	**14.0**	**16.7**	**18.1**	**20.7**	**24.1**
Electricity Consumption Based	**4.02**	**5.34**	**5.83**	**5.91**	**6.86**	**6.98**	**8.52**	**10.79**
Electricity Production Based	4.31	4.04	5.96	6.20	5.55	8.22	7.19	7.55
Gas/Diesel Oil	0.23	0.25	0.20	0.02	0.00	0.00	0.00	0.00
Natural Gas	0.79	0.94	2.83	3.67	3.98	7.42	7.19	7.55
Residual Fuel Oil	3.29	2.85	2.93	2.51	1.57	0.81	0.00	0.00
Net Imported Electricity	-0.30	1.29	-0.13	-0.29	1.31	-1.24	1.33	3.24
Res/Comm/Ind (RCI)	**2.52**	**2.53**	**2.86**	**2.37**	**2.58**	**2.76**	**2.96**	**3.25**
Gas/Diesel Oil	0.08	0.19	0.22	0.08	0.07	0.07	0.07	0.06
Gasoline: Motor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liquefied Petroleum Gases	1.40	1.37	1.09	0.94	0.84	0.78	0.74	0.71
Natural Gas	1.01	0.93	1.39	1.18	1.46	1.68	1.90	2.20
Residual Fuel Oil	0.00	0.00	0.12	0.14	0.17	0.19	0.21	0.23
Solid Biofuels: Wood	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05
Transportation	**3.37**	**4.36**	**4.49**	**5.60**	**7.02**	**8.12**	**8.98**	**9.85**
Road Transport - Gasoline	1.95	2.88	3.05	3.84	4.57	5.26	5.77	6.29
Road Transport - Diesel	0.96	1.13	0.97	1.37	2.10	2.49	2.81	3.14
Road Transport - LPG	0.02	0.05	0.21	0.20	0.08	0.07	0.07	0.07
Road Transport - Nat. Gas	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03
Aviation	0.22	0.11	0.07	0.00	0.00	0.00	0.00	0.00
Rail	0.22	0.19	0.19	0.20	0.26	0.29	0.31	0.33
Fossil Fuel Industry	**0.00**	**0.00**	**0.05**	**0.11**	**0.20**	**0.21**	**0.21**	**0.22**
Natural Gas Transmission	0	0	0.01	0.01	0.01	0.01	0.01	0.01
Natural Gas Distribution	0	0	0.04	0.11	0.19	0.20	0.20	0.21
Industrial Processes	**0.98**	**1.17**	**1.59**	**2.10**	**2.25**	**2.64**	**3.04**	**3.44**
Cement Manufacture	0.18	0.24	0.30	0.42	0.62	0.78	0.93	1.09
Iron and Steel Production	0.38	0.38	0.38	0.65	0.61	0.72	0.83	0.94
Limestone / Dolomite Use	0.32	0.45	0.77	0.87	0.81	0.91	1.01	1.12
ODS Substitutes	0.09	0.11	0.13	0.17	0.20	0.24	0.27	0.30
Waste Management (Gross)	**0.73**	**0.82**	**0.91**	**1.02**	**0.89**	**0.88**	**0.93**	**1.03**
Domestic Wastewater	0.29	0.34	0.37	0.39	0.40	0.42	0.43	0.45
Industrial Wastewater	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solid Waste Disposal Sites	0.33	0.37	0.41	0.46	0.33	0.30	0.34	0.42
Open Burning	0.10	0.12	0.13	0.16	0.16	0.16	0.15	0.15
Landfill Carbon Storage	-0.08	-0.08	-0.10	-0.09	-0.10	-0.11	-0.12	0.00
Agriculture	**3.64**	**3.46**	**2.38**	**2.55**	**2.76**	**3.00**	**3.27**	**3.54**
Enteric Fermentation	2.23	2.19	1.39	1.54	1.70	1.88	2.08	2.26
Manure Management	0.05	0.06	0.04	0.04	0.05	0.05	0.06	0.07
Managed Soils	1.35	1.21	0.96	0.97	1.02	1.07	1.13	1.21
Forestry and Land Use	**-7.09**	**-7.65**	**-6.52**	**-7.85**	**-8.36**	**-8.36**	**-8.36**	**-8.36**
Forest (carbon flux)	-7.24	-7.69	-6.57	-7.75	-8.31	-8.31	-8.31	-8.31
Forest Fires (non-CO_2)	0.15	0.06	0.06	0.01	0.02	0.02	0.02	0.02
Woody Crops	0.01	-0.02	-0.01	-0.10	-0.06	-0.06	-0.06	-0.06
Gross Emissions Consumption Based	**15.40**	**17.74**	**18.18**	**19.67**	**22.57**	**24.60**	**27.94**	**32.13**
increase relative to 1990	*0%*	*15%*	*18%*	*28%*	*47%*	*60%*	*81%*	*109%*
Emission Sinks	**-7.32**	**-7.78**	**-6.67**	**-7.85**	**-8.41**	**-8.42**	**-8.43**	**-8.31**
Net Emissions (incl. forestry*)	**8.09**	**9.96**	**11.51**	**11.83**	**14.16**	**16.18**	**19.50**	**23.82**
increase relative to 1990	*0%*	*23%*	*42%*	*46%*	*75%*	*100%*	*141%*	*195%*
Gross Emissions Production Based	**15.70**	**16.45**	**18.31**	**19.97**	**21.26**	**25.85**	**26.61**	**28.89**
increase relative to 1990	*0%*	*5%*	*17%*	*27%*	*35%*	*65%*	*69%*	*84%*
Net Emissions (incl. forestry*)	**8.38**	**8.67**	**11.64**	**12.12**	**12.85**	**17.42**	**18.18**	**20.58**
increase relative to 1990	*0%*	*3%*	*39%*	*45%*	*53%*	*108%*	*117%*	*145%*

Note: Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

Figure 1. Historical Chihuahua and Mexico Gross Production-Based GHG Emissions per Capita and per Unit Gross Product in Dollars[11]

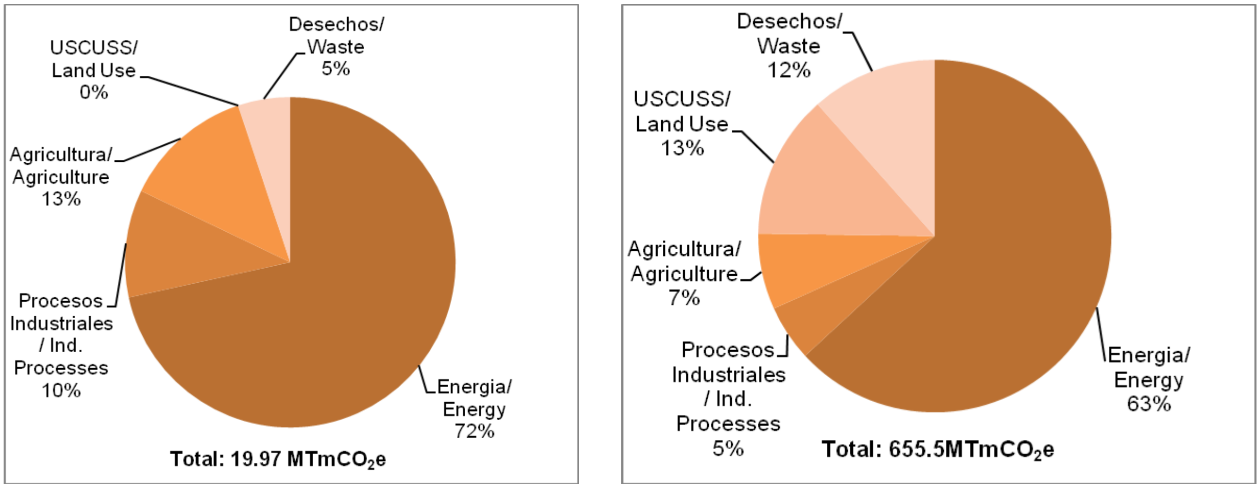


	1995	2000	2005
Chihuahua GHG/Capita (tCO2e/capita)	5.89	6.00	6.16
MX GHG/Capita (tCO2e/capita)	5.96	6.10	6.35
Chihuahua GHG/$ (kgCO2e/$)	2.57	0.87	0.65
MX GHG/$ (kgCO2e/$)	3.24	1.19	0.88

[11] Economic activity expressed in 2006 values. Information retrieved from INEGI, Banco de Información Económica.

Figure 2. Gross GHG Emissions by Sector, 2005, Chihuahua and Mexico

Chihuahua[12] Mexico



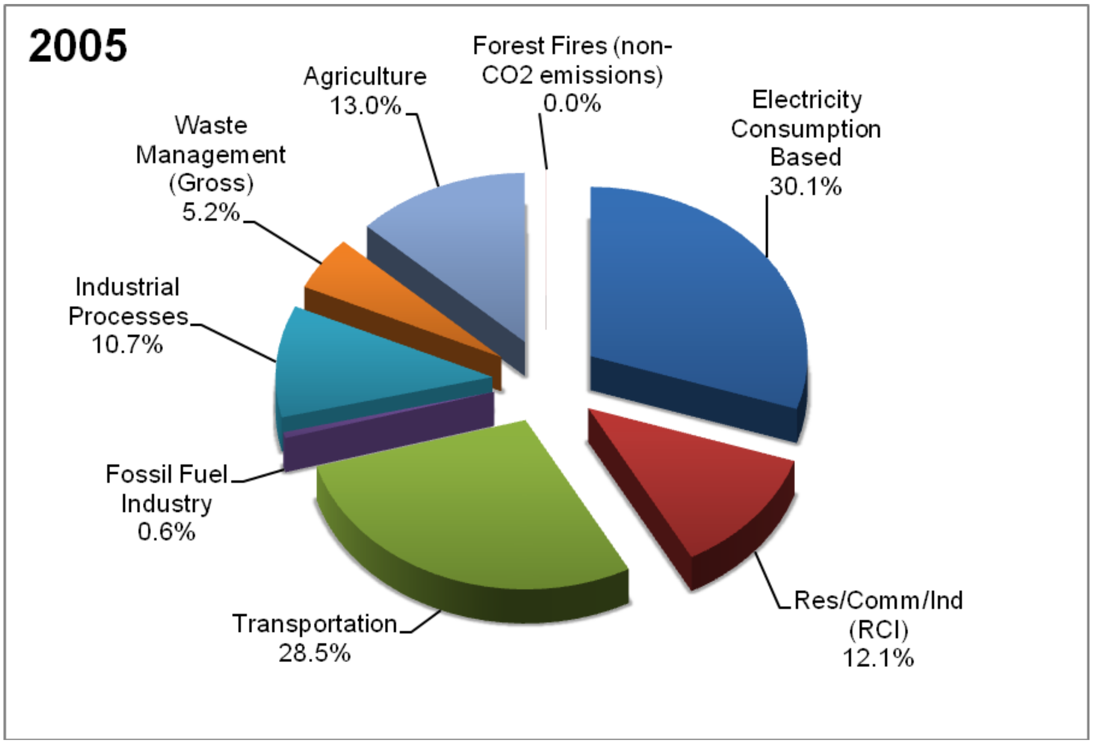
Summary results in this inventory and forecast for Chihuahua are presented with additional disaggregation of emission sources in comparison with the summary results of the *Inventario Nacional de Emisiones de Gases de Efecto Invernadero* prepared by INE. Table 2 provides correspondence between the Chihuahua and INE GHG sectors and Figure 3 shows the distribution of emissions according to Chihuahua GHG activity sectors for the year 2005.

Table 2. Correspondence between INE and Chihuahua GHG Sectors

INE	Chihuahua
Energia / Energy	Electricity (Consumption Based)
Energia / Energy	Fossil Fuel Industry
Energia / Energy	RCI Fuel Use
Energia / Energy	Transportation Road/Gasoline
Energia / Energy	Transportation Road/Diesel
Energia / Energy	Aviation
Agricultura / Agriculture	Agriculture
Procesos Industriales / Ind. Processes	ODS Substitutes
Procesos Industriales / Ind. Processes	Other Ind. Process
Desechos / Waste	Waste Management
USCUSS / Land Use	Forestry and Land Use (net emissions)

[12] Additional work to improve carbon flux due to land use and changes to land use (USCUSS) could lead to substantial differences in the initial estimates provided in this report. Due to limited information, the current estimates focus on carbon flux within selected land uses, excluding carbon losses due to deforestation (e.g when forest land is converted cropland).

Figure 3. Chihuahua Gross GHG Emissions by Sector, 2005



A Closer Look at the Two Major Sectors: Electricity Supply and Transportation

Electricity Supply Sector

Emission associated with the electric sector accounted for 30% of Chihuahua's gross GHG emissions in 2005. Consumption of electricity in Chihuahua in 2005 resulted in 5.9 MMtCO_2e of GHG emissions, 6.2 MMtCO_2e from in-state production and -0.3 MMtCO_2e from exported electricity. In 2007, 3 combined cycle plants (Samalyuca II, Chihuahua, and Chihuahua II) generated 79% of the state's electricity using natural gas; 16% of the state's electricity was generated at conventional thermal facilities from a mixture of residual fuel oil, diesel fuel oil, and natural gas; and just under 4% of electricity was imported from other Mexican states, as well as the U.S. from Rio Grande Cooperative and American Electric Power.

Consumption-based electricity sector emissions are estimated to increase to 10.8 MM tCO_2e in 2025, a 83% increase over 2005 emissions. Natural gas is expected to remain the dominate source of fuel for the electricity sector in Chihuahua, accounting for 100% of in-state electricity production in 2025.

Transportation Sector

The transportation sector in Chihuahua includes road transportation, marine vessels, rail engines, and aviation. During inventory years (1990 through 2005), total transportation emissions increased by 67% reaching 5.6 $MMtCO_2e$ in 2005. The largest transportation sources of GHG emissions were activities related to onroad gasoline and onroad diesel combustion, accounting for 93% of total transportation GHG emissions in 2005.

In 2025, total transportation emissions are expected to be on the order of 9.9 $MMtCO_2e$ representing a 194% increase from 1990. Road transportation emissions are expected to account for 97% of total transportation emissions in 2025. Aviation emissions decreased to zero in 2002 and are estimated to account for 0% in 2025, down from 6% in 1990. Rail emissions are expected to account for 3% of total transportation emissions in 2025, down from 7% in 1990.

Reference Case Projections

Relying on a variety of sources for projections, as noted below and in the appendices, CCS developed a simple reference case projection of GHG emissions through 2025. As illustrated in Figure 4 below and shown numerically in Table 1 above, under the reference case projections, Chihuahua gross GHG emissions continue to grow steadily, climbing to about 32.1 $MMtCO_2e$ by 2025, 109% above 1990 levels. This equates to an annual rate of growth of 2.1% per year for the period starting 1990 through 2025.

Inventory estimates and reference case projections are shown in Figure 4 for all sectors. Sector contributions to growth in gross GHG emissions are shown in Figure 5. Figure 5 provides estimates of contribution to growth in gross GHG emissions between inventory (1990-2005) and reference case projection (2005-2020) estimates. The largest increases in emissions from both 1990-2005 and 2005-2020 are seen in the transportation sector, and in the electricity supply sector. Table 3 summarizes the growth rates that drive the growth in the Chihuahua reference case projections, as well as the sources of these data.

Figure 4. Chihuahua Gross GHG Emissions by Sector, 1990-2025

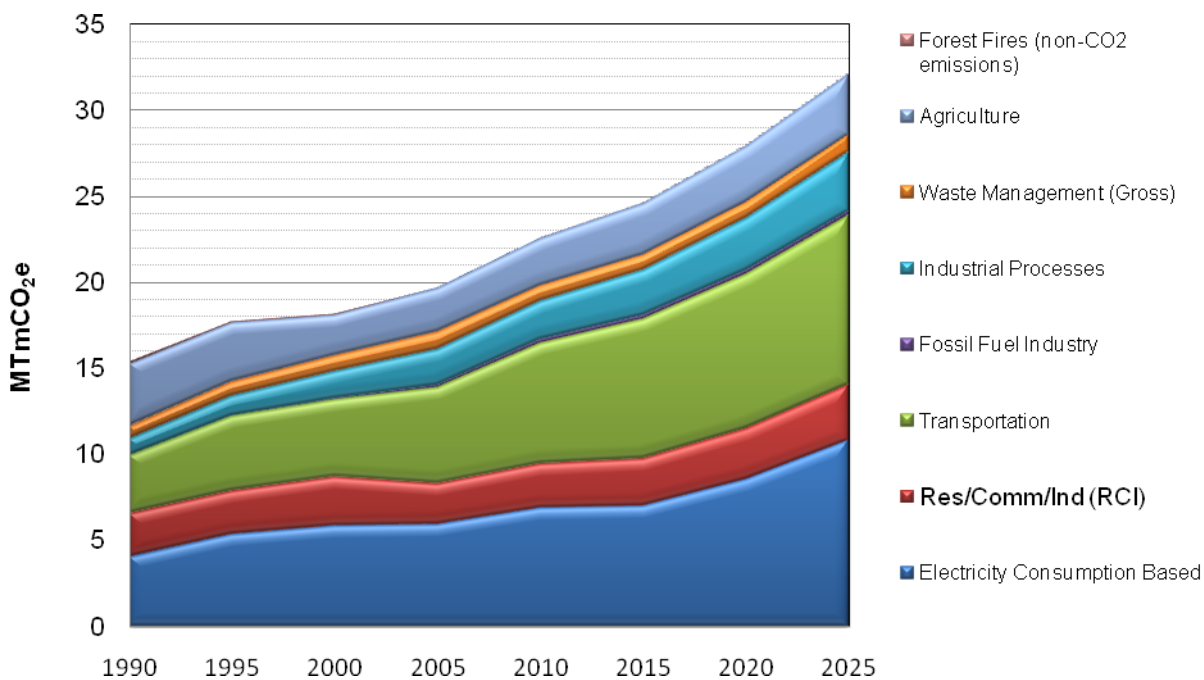
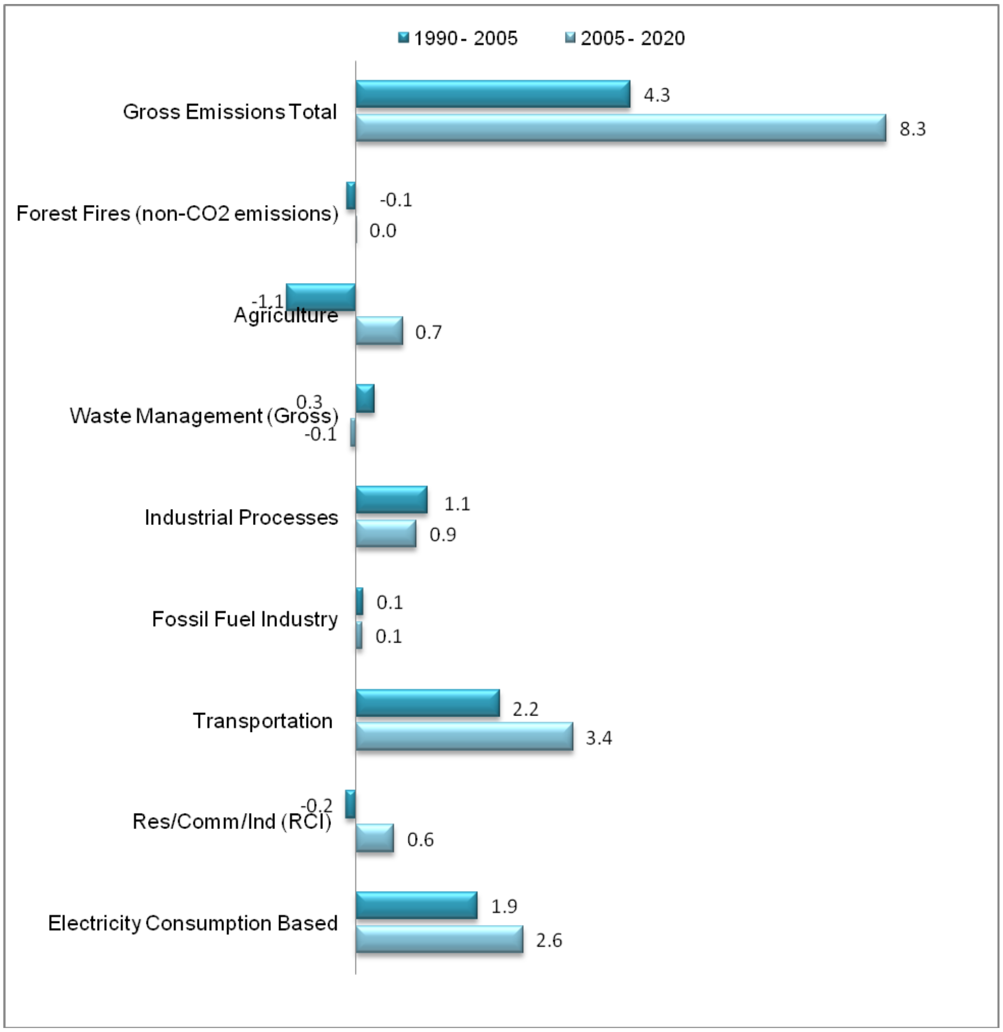


Figure 5. Sector Contributions to Gross Emissions Growth in Chihuahua, 1990-2020



Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph. Data for US states indicates a high expected growth in emissions for ODS substitutes. Forest-fires – emissions include methane and nitrous oxide emissions only. Waste management – emissions exclude landfill carbon storage.

Table 3. Key Annual Growth Rates for Chihuahua, Historical and Projected

Activity Data	Rate Period	Mean Annual Rate (%)	Sources
Population	1990 - 2005 2005 - 2025	1.91 0.76	Historical population, INEGI Projected population, CONAPO
Electricity Demand	1990 - 2007 2008 - 2017	2.76 1.83	SENER: *Prospectiva del Sector Eléctrico 2008-2017*
Diesel	1990 - 2007	3.86	Sistema de Información Energética, PEMEX
Gasoline	1990 - 2007	4.61	Sistema de Información Energética, PEMEX
Jet Kerosene	1990 - 2002	-1.86	Sistema de Información Energética, PEMEX
Vehicle Registration	1990 - 2007	4.10	INEGI. Estadísticas de vehículos de motor registrados en circulación
Livestock Population	1990 - 2005	-1.00	SIACON
Crop Production	1990 - 2005	4.52	SIACON

Key Uncertainties and Next Steps

Some data gaps exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as demand for electricity from fuel oil, imported electricity, and electricity from hydroelectric plants. Additional information relating to the segregation of in-state diesel consumption by mode of transportation (marine vessel, railway, onroad) for inventory years can help reduce uncertainty in projected emissions. Historical activity data relating to cement production, lime production, and limestone use can also reduce uncertainty associated with forecast estimates.

Additional work is needed to: further refine the carbon sequestration estimates for the forested landscape; add sequestration estimates for urban forests; add soil carbon flux in cropland; and add net carbon flux associated with land use change (e.g. losses/gains in forest acreage). As described in Appendix H, the lack of data to adequately capture net carbon flux due to land use change is a key area for future work. The current estimates of a net carbon sink in the forestry sector could change dramatically once the land use change emissions are quantified due to historic and potential future losses of forest area.

Applied growth rates are driven by uncertain economic, demographic and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion. These are listed in Table 3. More details on key uncertainties and suggested next steps for the refinement of the estimates presented in this report are provided in each of the sector appendices.

Approach

The principal goal of compiling the inventory and reference case projection presented in this document is to provide the State of Chihuahua with a general understanding of Chihuahua's historical, current, and projected (expected) GHG emissions. The following sections explain the general methodology and the general principles and guidelines followed during development of these GHG estimates for Chihuahua.

General Methodology

The overall goal of this effort was to provide simple and straightforward estimates with an emphasis on robustness, consistency, and transparency. As a result, CCS relied on reference forecasts from best available State and regional sources where possible. In general state-level forecast data for Chihuahua were lacking. Therefore, CCS used straight-forward spreadsheet analysis and constant growth-rate extrapolations of historical trends rather than complex modeling to estimate future year emissions.

CCS followed similar approaches to emissions accounting for historical inventories as recommended by INE in its national GHG emissions inventory[13] and its guidelines for States.[14] These inventory guidelines were developed based on the guidelines from the Intergovernmental Panel on Climate Change (IPCC), the international organization responsible for developing coordinated methods for national GHG inventories.[15]Any exception to this approach is identified in the applicable sector appendix with a rationale provided for the selection of alternative methods or data sources. The inventory methods provide flexibility to account for local conditions. A summary of the key sources of inventory data and overall methods used are shown in Table 4 along with a comparison to methods used to construct Mexico's national inventory (INEGEI). The reader should consult the associated sector appendix for a detailed discussion of methods and data sources used to construct the inventory and forecast for that sector.

[13] INE. *Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*.,2006 http://www.ine.gob.mx/cpcc-lineas/637-cpcc-comnal-3. http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[14] PNUD, FMAM, INE. Manejo del Proceso de Elaboración del Inventario Nacional de Gases de Efecto Invernadero. http://www.ine.gob.mx/cpcc-estudios-cclimatico.

[15] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Table 4. Key Data Sources and Methods and Comparison to National Inventory Methods

Sector	Key Data Sources	Method	Comparison with INEGEI
Electricity Consumption and Supply	SENER and CFE: state-level sector-based electricity consumption data; INEGI: state-level electricity generation data	2006 IPCC, Tier 1 method, where fuel consumption is multiplied by default emission factors.	1996 IPCC, Tier 1 method; national electricity production data from SENER.
Residential, Commercial, and Industrial (RCI) Fuel Combustion	SENER: state-level fuel consumption for RCI sectors	2006 IPCC, Tier 1 method, where fuel consumption is multiplied by default emission factors	1996 IPCC, Tier 1 method; national-level fuel consumption from SENER.
Transportation Energy Use	SENER: State-level fuel consumption by fuel type SCT: State-level statistics used to allocate fuel sales to end use (e.g. rail infrastructure, national cargo movement by water)	2006 IPCC, Tier 1 method, where fuel consumption is multiplied by default emission factors.	1996 IPCC, Tier 1 method; SENER provided fuel consumption data for all sources except aircraft. 1996 IPCC, Tier 2 method for aviation based on landing & takeoff statistics.
Industrial Processes and Product Use	CANACEM : national cement production allocated to state-level as a function of population	2006 IPCC, Tier 1 method, where clinker production is multiplied by a default emission factor.	1996 IPCC, Tier 1 method; national cement production data from CANACEM.
	Servicio Geológico Mexicano: mineral production by state	2006 IPCC, Tier 1 consumption is multiplied by a default emission factor. Consumption is obtained through mass balance using state production.	1996 IPCC, Tier 1 method, where mineral production from Servicio Geológico Mexicano production is multiplied by a default emission factor. Consumption is obtained through mass balance using national production, and import/export data.
	INEGI: state-level vehicle registration data and IPCC emission factors for HFC emissions as originally developed by Centro Mario Molina, Inventario Estatal de Emisiones de GEI del Estado de Chihuahua, 2005	IPCC: HFC emissions - the number mobile air conditioning (AC) units are multiplied by an IPCC default emission factor.	1996 IPCC, Tier 1 method, where fugitive HCF are calculated through mass balance using national production, import and export data.

Sector	Key Data Sources	Method	Comparison with INEGEI
Fossil Fuel Industry	SENER, PEMEX, CRE: data on production, transmission and distribution infrastructure (e.g. state-level transmission & distribution pipelines, gas compressors, storage facilities)	EPA, SIT method, where fossil fuel industry infrastructure is multiplied by US industry average emission factors.	1996 IPCC, Tier 1 method, where national production data from PEMEX is multiplied by default emission factors.
Agriculture	SAGARPA - SIACON: crop and livestock production data at the state-level, International Fertilizer Industry Association: fertilizer application data	2006 IPCC, Tier 1 method and emission factors.	1996 and 2003 IPCC guidelines and SAGARPA-SIACON national data. A number of emission factors were the updated based on field studies conducted in Mexico.
Waste Management	SEDESOL: state-level solid waste generation data CONAGUA: domestic wastewater treatment data at the state-level	2006 IPCC, Tier 1 method and emission factors.	1996 IPCC, Tier 1 method with SEDESOL national data for solid waste generation.
Forestry and Land Use	United Nations Food and Agriculture Organization (FAO): total forested area by state SEMARNAT- CONAFOR: state-level wood harvest, forest fire, and diseased acres SIACON: Acreage on woody perennial crops	2006 IPCC, Tier 1 method. CCS relied on forest coverage statistics from FAO and woody crop coverage from SIACON. CCS' assessment covers carbon flux in selected land use categories due to land use practices.	2003 IPCC methods. INE assessed carbon flux based on national digital maps (mapas de vegetación del INEGI, 1993, 2003). INE's assessment covers carbon flux in selected land use categories due to land use practices, and changes in land use.

General Principles and Guidelines

A key part of this effort involves the establishment and use of a set of generally accepted accounting principles for evaluation of historical and projected GHG emissions, as follows:

- **Transparency:** CCS reported data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from subsequent reviewers. In addition, key uncertainties are reported, where they exist.
- **Consistency:** To the extent possible, the inventory and projection were designed to be externally consistent with current or likely future systems for State and national GHG emissions reporting. In nearly all sectors, CCS used IPCC methodologies and gave special attention to the way these were adapted in Mexico to fit national needs. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and reference-case projection needs (i.e. needs of GHG mitigation planning analyses). For consistency in making reference case projections, CCS defined reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis*.
- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, CCS placed highest priority on local and State data and analyses, followed by regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.
- **Priority of Significant Emissions Sources:** In general, sources with relatively small emissions levels received less attention than those with larger GHG contributions.
- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** This analysis aimed to comprehensively cover GHG emissions/sinks associated with activities in Chihuahua. It covers all six GHGs covered by IPCC guidelines and reported in national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2005 to 2007). The projection for each source begins in the year following the most recent inventory year and extends for each year out to 2025.
- **Use of Consumption-Based Emission Estimates:** For the electricity supply sector, CCS estimated emissions that are driven by electricity consumption in Chihuahua. The rationale for this common method of reporting is that it more accurately reflects the impact of State-based policy strategies aimed at energy efficiency on overall GHG emissions. Although this is a common approach for state and local GHG inventory development, it can differ from how some inventories are compiled, if they are based on an in-state electricity production basis.

As mentioned above, CCS estimated the emissions related to electricity *consumed* in Chihuahua. This entails accounting for the electricity sources used by Chihuahua utilities to meet consumer demands. As this analysis is refined and potentially expanded in the future, one could also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for emissions from transportation fuel used in Chihuahua, but also accounting for extraction, refining, and distribution emissions (some of these occurring out of state). As in this example, this can require venturing into the relatively complex terrain of life-cycle analysis. In general, CCS recommends considering a consumption-based approach, where it will significantly improve the estimation of the emissions impact of potential mitigation strategies. For example, in the solid waste management sector, re-use, recycling, and source reduction can lead to emission reductions resulting from lower energy requirements for material production (such as paper, cardboard, and aluminum), even though production of those materials, and emissions associated with materials production, may not occur within the state.

While the primary data and methods for most sectors are consistent with the national inventory, for some sectors, state-level or region-level data were used. Table 4 summarizes these key data sources and methods. However, the reader should consult the applicable appendix listed below for details on the methods and data sources used to construct the inventories and forecasts for each source sector:

- Appendix A. Electricity Use and Supply
- Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Appendix C. Transportation Energy Use
- Appendix D. Industrial Processes
- Appendix E. Fossil Fuel Industry
- Appendix F. Agriculture
- Appendix G. Waste Management
- Appendix H. Forestry and Land Use

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Appendix A. Electricity Supply and Use

Overview

This Appendix describes the data sources, key assumptions, and the methodology used to develop an inventory and forecast of greenhouse gas (GHG) emissions over the 1990-2025 period associated with the generation of electricity supplied by Chihuahua's electric utility and distribution company: the Comisión Federal de Electricidad (CFE). The historic inventory and reference case projections of GHG emissions emitted by the electricity supply sector in Chihuahua rely heavily on historical and projected electricity generation and fuel use provided by the Secretaría de Energía (SENER).

From analytical, and ultimately a policy perspective, it is important to distinguish between GHG emissions that are associated with electricity produced within the state (some of which may be consumed outside the state) as compared with the GHG emissions associated with electricity consumed within the state (some of which may produced outside the state). Such a distinction requires an accounting for electricity imports and exports, and their associated emissions. Consequently, emissions information is provided in this appendix for both a production-based as well as a consumption-based approach. For the purposes of reviewing total state emissions summaries for all sectors in this report, consumption-based emission estimates are used.

The following topics are covered in this Appendix:

- *Scope of greenhouse gas inventory and reference case forecast:* this section provides a summary of GHGs included in the inventory, the level (upstream or downstream) at which these emissions are estimated, and a discussion of the production-based and consumption-based inventory and forecast assumptions.
- *Data sources:* this section provides an overview of the data sources that were used to develop the inventory and forecast.
- *Production-based greenhouse gas inventory and reference case forecast methodology:* this section provides an overview of the methodological approach used to develop the production-based GHG inventory and forecast.
- *Consumption-based greenhouse gas inventory and reference case forecast methodology:* this section provides an overview of the methodological approach used to develop the consumption-based GHG reference case projections (forecast).
- *Greenhouse gas inventory and reference case forecast results:* for both the production-based and consumption-based methods, these sections provide an overview of key results of the GHG inventory and forecast for the electric power sector.
- *Key uncertainties and future research needs:* this section reviews the key uncertainties in this analysis related available data, emission factors, and other parameters and assumptions utilized to create this inventory and forecast.

Scope of Electricity Supply Inventory and Forecast

The GHGs included in this inventory and forecast of emissions from the electricity supply sector include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Emissions for this sector are estimated at the source of combustion – the electric power supply facility (i.e. downstream emissions). Emissions from the exploration, extraction, refinement, and transportation of fossil fuels (i.e. upstream emissions) are not included in this appendix. Upstream emissions from the electricity supply sector that occur within the borders of Chihuahua are addressed in the Fossil Fuel Industry sector. Also, emissions of high global warming gases like sulfur hexafluoride and hydrofluorocarbons emitted by electricity generators are captured within the Industrial Processes sector.

Within the electricity supply sector, GHG emissions can be quantified on the basis of fuels combusted in the state during electricity generation (i.e. production-based estimate). Electricity supply sector emissions can also be characterized on the basis of electricity consumed within the state, which captures in-state generation, as well as electricity imports and exports (i.e. consumption-based estimate). Both types of estimates are useful. Consumption-based estimates are particularly useful for GHG mitigation analysis when considering the implications of policies and actions that could impact electricity demand from power plants both within and outside a state or region, such as energy efficiency measures. For the purposes of presenting total state emissions summaries across all sectors in this report, consumption-based emission estimates are used.

The production-based inventory and forecast includes emissions resulting from electricity exported by Chihuahua power producers, while the consumption-based inventory includes emissions from imported electricity and excludes emissions from exported electricity. As Chihuahua is a net importer of electricity in most years, the production-based inventory estimates are lower than the estimates for the consumption-based inventory. The consumption-based inventory and forecast assume some loss through transmission & distribution (T&D) and theft. Emissions due to T&D loss and theft are inherently captured within the production-based estimates.

Data Sources

CCS considered several sources of information in the development of the inventory and forecast for GHG emissions from the electricity supply sector in Chihuahua. These are briefly summarized below:

- *Historic fossil fuel consumption*: an Excel workbook containing fuel consumption for residual fuel oil and diesel oil at electricity supply facilities in Chihuahua and other Mexican border states was provided by SENER;[1]
- *Historic and projected demand of natural gas in the electricity supply sector:* this information was obtained from SENER publication *Natural Gas Market Outlook 2008-*

[1] Historical fossil fuel consumption at power generation plants was obtained directly from Secretaría de Energía (SENER) in response to Nuevo Leon's Agencia de Protección al Medio Ambiente y Recursos Naturales (APMARN) letter of inquiry. March 2007.

2017.[2] This report provides historical data dating back to 1996, as well as projected natural gas consumption in the electricity supply sector through 2017;

- *Planned electric capacity additions:* this information was obtained from a SENER publication titled *Electricity Sector Outlook 2008-2017*. This source provided information on electricity generation units that are scheduled to open before 2017, including the rated capacity, technology, and fuel used to generate electricity. Projects in the developmental phase for which site and feasibility studies have not been completed are not considered in the forecast. The SENER report also provides technology specifications for the typical project, including capacity factor, efficiency, and own-use factor;
- *State electricity generation data:* this information was obtained from a SENER publication titled *Electricity Sector Outlook 2008-2017*. This source provides historical data and projections for state electricity consumption, renewable and nonrenewable power plants installed capacity and average annual generation, and the electric power domestic and foreign trade needed to meet the increasing demand estimated for 2008-2017;[3] While this source provided records for historic electricity imports and exports with the U.S., there were no sources available that provided information on the quantity of electricity traded between Mexican states;
- *Electricity loss:* information on electricity lost through transmission, distribution, electricity generator internal use, and theft was provided by CFE. Loss data for CFE is available for the years 2000-2009.
- *Energy content of petroleum products:* this information was obtained from México Federal Government, Ministry of Energy -- Secretaría de Energía (SENER) -- publications titled *Balance Nacional de Energía 2007* and previous editions;[4]
- *Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emission factors:* for all fuels, these emission factors were based on default values listed on Tables 2.2, 2.3, 2.4, 2.5, Chapter 2, Volume 2, of the 2006 Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories*;[5]
- *Global warming potentials:* the global warming potentials for CH_4 and N_2O are based on values proposed by the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report.[6]

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[2] SENER. 2009. "Prospectiva del Mercadode Gas Natural 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466

[3] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466

[4] SENER. 2008. "Balance Nacional de Energía 2007." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=48#prop2008

[5] IPCC. 2006. "2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories." Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

[6] IPCC. 1995. "Intergovernmental Panel on Climate Change Second Assessment Report." Available at: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm#1

General Greenhouse Gas Inventory and Reference Case Forecast Methodology

The 2006 IPCC Guidelines provide methods for estimating GHG emissions in terms of the source and gases, offering three approaches for estimating emissions from fossil fuels for stationary combustion. A Tier I approach was used to estimate GHG emissions from the electricity supply sector. According to the 2006 IPCC guidelines, a Tier I method is best suited when country-specific, technology-specific, or facility-specific emission factors are not available. Tier II methods are used when fuel combustion data from national energy statistics and country-specific emission factors are available. Tier III methods are appropriate when fuel combustion data and technology-specific emission factors are available. Tier III methods include emission measurements at power generation plants or emissions modeling that matches state fuel statistics. While Tier II methods (and to a lesser extent Tier III methods) might be more accurate and appropriate for Chihuahua, available data and technology or facility-level emission factors are not sufficient to fully complete an inventory and forecast based on a Tier II or Tier III approach.

The IPCC Tier I method is fuel-based and emissions from all sources of combustion are estimated on the basis of the quantities of fuel combusted and fuel-specific emission factors. Tier I emission factors are available for each of the relevant greenhouse gases, and are presented in Table A-1. The quality of these emission factors differs between gases. For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ash, etc.) may vary by a small amount based on the age and condition of the combustion unit. However, given the lack of facility-specific emission factors, CO_2 emissions are estimated fairly accurately based on the total amount of fuels combusted and the average carbon content of the fuels.[7]

The SENER *Electricity Sector Outlook* reports indicate that Chihuahua imports electricity from the United States through an interconnection between El Paso, TX and Ciudad Juárez. The emissions from electricity that is imported from the U.S. are calculated using emission factors for the WECC Southwest eGRID sub-region, as documented in The Climate Registry's General Reporting Protocol.[8] The remainder of the electricity that is needed to bridge the gap between electricity production and demand is assumed to be transferred from neighboring Mexican states. Prior to 2007, SENER reports that the only interconnection between Chihuahua and another Mexican state is with the state of Durango. The SENER *Electricity Sector Outlook* reports also show that there is ample excess generation in Durango to provide Chihuahua with the extra electricity. After 2007, the SENER reports show an interconnection between Chihuahua and Coahuila, MX. Coahuila is also is expected to be an exporter of electricity, based on the Electricity Sector Inventory and Forecast developed for that state by CCS. The generation profiles in those states are used to develop the emission factors for imports.

[7] Emission factors for methane and nitrous oxide depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and within the same unit over time. Due to this variability, use of average fuel-specific emission factors for these gases introduces relatively large uncertainties. This paragraph is quoted from Chapter 1, Volume 2 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories, page 1.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
[8] The Climate Registry. 2008. "General Reporting Protocol v.1.1." Table 14.1. Available at http://www.theclimateregistry.org/downloads/GRP.pdf.

Table A-1. Emission Factors used for the Inventory and Forecast

Energy Source	EF CO_2	EF N_2O	EF CH_4
Natural Gas (kg/TJ)	56,100	0.1	1
Fuel oil (kg/TJ)	77,400	0.6	3
Diesel Oil (kg/TJ)	77,400	0.6	3
Imports from U.S. (kg/MWh)	1,254	0.018	0.015
Interstate Imports	Varies by Year		

The approach used for inventorying GHG emissions gives priority to available historic records, namely electricity sector and natural gas reports by SENER, which provide both historic data and projections through 2017. The first set of historic records pertained to the volume of natural gas in millions of cubic feet per day used by the electricity supply sector in the state of Chihuahua from 1996 to 2008.[9] The second set of historic records detailed diesel oil and residual fuel oil consumption within the electricity supply sector in Chihuahua, expressed in Terajoules (TJ) for the period 1996 through 2008.[10] Finally, the third set of historic records provides international electricity imports and exports for 1993 to 2007, reported in SENER's *Electricity Sector Outlook* reports.[11] Imported flows of electricity to Chihuahua are through existing interconnections between the U.S. and Mexico; these interconnections are managed by the Servicio Eléctrico Nacional (SEN), the Western Electricity Coordinating Council (WECC), and the Electric Reliability Council of Texas (ERCOT).

The forecasts of GHG emissions from the electricity supply sector are based on official forecast estimates of electricity sales, official forecast estimates of natural gas combustion within the electricity supply sector, and information on planned additional generation capacity in Chihuahua. Planned generation capacity addition and retirement of electricity generating units are considered in order to assure that the projected fuel combusted within the electricity supply sector does not exceed the amount of fuel that could be combusted at operational electricity generation facilities in each year. The following sections will show that there is insufficient capacity to maintain the 2008-2020 growth rate of natural gas consumption after 2020. Therefore, the amount electricity produced is assumed to flatten out after 2020. However, as Chihuahua is projected to be a net importer of electricity in these years, it is expected that electricity consumption will continue to grow after 2017, with the shortfall in production made up by electricity generated outside Chihuahua. As with the historical GHG inventory, GHG emissions are forecast for both the production-based and consumption-based scenarios.

[9] SENER. 2009. "Prospectiva del Mercadode Gas Natural 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466

[10] Historical fossil fuel consumption at power generation plants was obtained directly from Secretaría de Energía (SENER) in response to APMARN's letter of inquiry. March 2007.

[11] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466

Production-based Inventory Methodology

The production-based inventory utilized fuel consumption data, in addition to fuel-specific generation data at Chihuahua electricity generation facilities to estimate the total electricity generated within the borders of Chihuahua from 1990 to 2007. The following steps were taken to apply available data and assumptions based on those data to generate the historic production-based inventory of GHGs from the electricity supply sector in Chihuahua.

Electricity generation: the generation of electricity at Chihuahua electricity generation facilities is reported in SENER's *Electricity Sector Outlook 2008-2017* and previous editions.[12] From these reports, electricity generation, by fuel, can be determined for the years 2003 through 2007. Total electricity generation values dating back to 1990 were supplied by SENER. In 2007, 3 combined cycle plants (Samalyuca II, Chihuahua, and Chihuahua II) generated 79% of the state's electricity using natural gas; 16% of the state's electricity was generated at conventional thermal facilities from a mixture of residual fuel oil, diesel fuel oil, and natural gas; and just under 4% of electricity was imported from other Mexican states, as well as the U.S. from Rio Grande Cooperative and American Electric Power.[13] Summaries of the 2007 data are displayed in Table A-2 and Figure A-1. Figure A-2 is a representation of the generation at electricity generation facilities from 2003 to 2007.

Natural gas: data concerning the quantity of natural gas used in the electricity supply sector are provided by the *Natural Gas Market Outlook 2008-2017*, and previous editions of that report. The energy content of the natural gas consumed was found by multiplying the volume of natural gas combusted each year (as reported by the *Natural Gas Market Outlook* reports) by the energy content, using the net energy content values per year published by SENER in *Balance Nacional de Energía 2007*.[14] The fuel consumption values for natural gas were back-cast for the years 1990 to 1994 by assuming a constant share of total generation for each fossil fuel generation source. Electricity generation prior to 2003 was estimated by multiplying the energy content by the heat rate (TJ/GWh) for 2003, as calculated from the available fuel use and generation data.

Other fossil fuels: there is no known coal consumption by the electricity supply sector in Chihuahua. The consumption data for residual fuel oil and diesel oil for the years 1996 through 2008 were provided directly to CCS by SENER.[15] The energy content of these fuels was found by multiplying the volume of these fuels combusted each year by the energy content (in TJ per barrel), using the net energy content values per year published by SENER in *Balance Nacional de Energía 2007*.[16] The fuel consumption values for

[12] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466. Previous editions available at same site.
[13] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466
[14] SENER. 2008. "Balance Nacional de Energía 2007." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=48#prop2008
[15] Historical fossil fuel consumption at power generation plants was obtained directly from Secretaría de Energía (SENER) in response to APMARN's letter of inquiry. March 2007.
[16] SENER. 2008. "Balance Nacional de Energía 2007." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=48#prop2008

residual fuel oil and diesel fuel oil were back-cast for the years 1990 to 1995 by assuming a constant share of total generation for each fossil fuel generation source. Electricity generation prior to 2003 was estimated by multiplying the energy content by the heat value (TJ/GWh) for 2003.

Renewable energy*:* information provided to CCS by SENER indicated that there are two small hydroelectric facilities that accounted for 99 GWh of electricity generation in 2007. As SENER's *Electricity Sector Outlook 2008-2017* does not provide any information on these facilities, it was assumed that 99 GWh of electricity from hydro-power was generated in each year over the historic inventory.

Table A-2. Electricity Generation Characteristics by Fossil Fuel Plant, 2007

Plant name	Generator type	Fuel type	Gross capacity (MW)	Gross generation (GWh)	Fuel consumption (TJ)
Francisco Villa	TC	Fuel oil/Diesel	300	1,026	10,907.48
Samalayuca	TC	Fuel oil/Natural gas	316	1,004	14,695.46
Samalayuca II	CC	Natural gas	522	3,982	32,638.60
Chihuahua II (El Encino)	CC	Natural gas	619	4,301	35,253.29
Chihuahua (PIE)	CC	Natural gas	259	1,428	11,704.65

CT: conventional thermoelectric, CC: combined cycle

Figure A-1. Share of Gross Electricity Generation by Energy Source, 2007

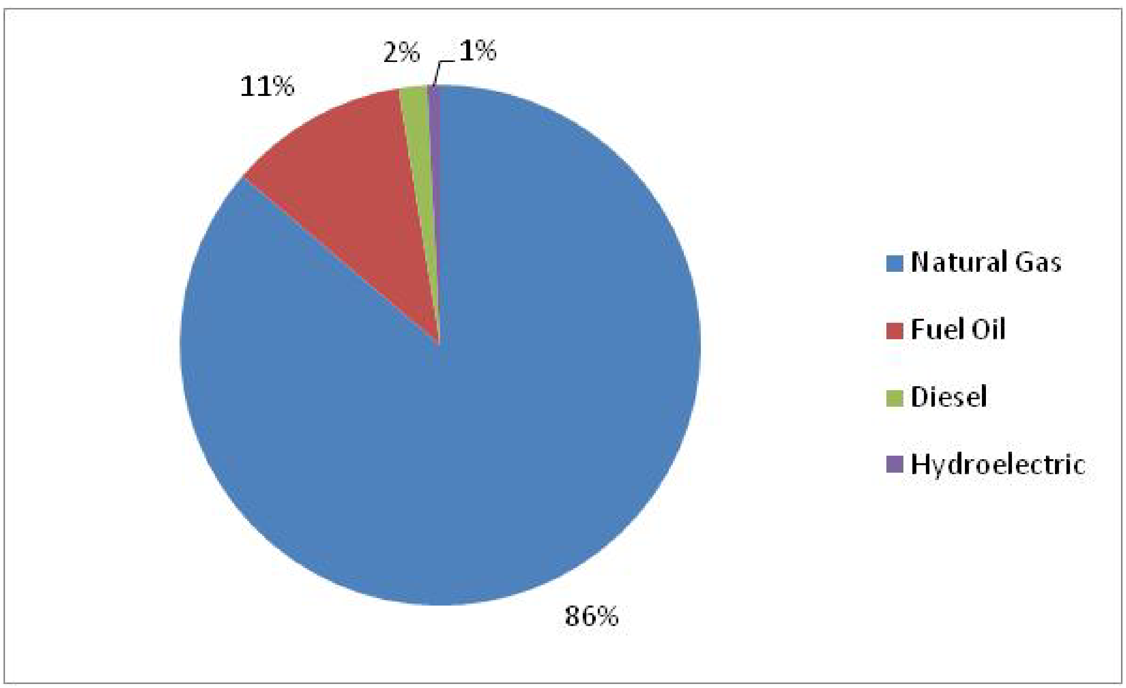
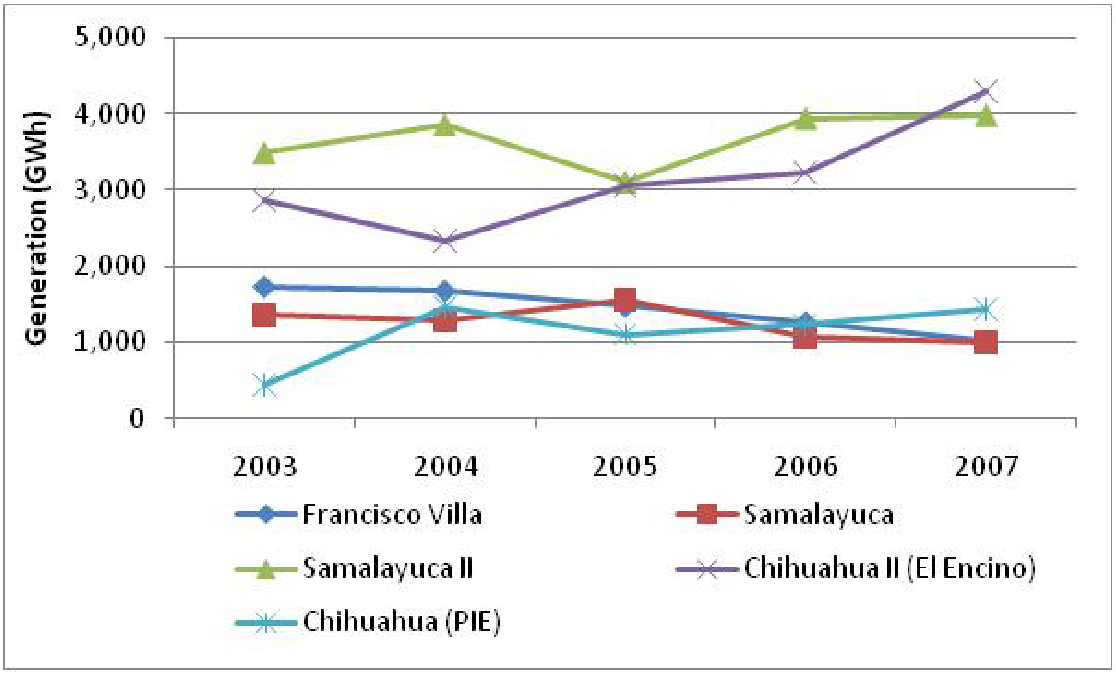


Figure A-2. Electricty Generation by Fossil Fuel Plant, 2003-2007



PIE: Productores Independientes de Energía (Independent Power Producers)

Production-based Reference Case Forecast Methodology

The production-based forecast utilized SENER projections on fuel use, electricity sales, and planned capacity to generate the production-based forecast. The specific forecast methodology for each fuel-type is described below:

Natural gas: the electricity supply sector natural gas consumption projection for the years 2008 through 2017 is provided in the *Natural Gas Market Outlook 2008-2017* report.[17] The 2008 through 2017 average annual increase of 3.5% was applied for each year after 2018. However, based on the available and planned capacity (shown in Table A-3),[18] it is evident that there will not be sufficient capacity to increase natural gas consumption after 2020. Therefore, natural gas consumption in the electricity supply sector for 2021 through 2025 is assumed equal the amount of natural gas needed to power the facilities at the assumed 80% capacity factor. The 2007 heat rate for the existing facilities, as calculated in the historic GHG inventory, is applied to fuel used at the existing facilities to estimate generation.

[17] SENER. 2009. "Prospectiva del Mercadode Gas Natural 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466

[18] Table displays planned added capacity, as well as assumed generation, based on typical power plant characteristics. Capacity data and characteristic assumptions taken from: SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466.

Table A-3. Planned Natural Gas Capacity Additions and Assumed Characteristics[19]

Plant Type	Year	Capacity	Gross Efficiency	Capacity Factor	Own-Use	Heat Rate (TJ/GWh)	Estimated Generation (GWh)
Combined Cycle	2012	459	51.4%	0.8	2.9%	7.21	3,123
Combined Cycle	2014	690	51.4%	0.8	2.9%	7.21	4,695

Other fossil fuels: the data provided by SENER on the consumption of residual fuel oil and diesel oil for 1996 through 2008 was the primary source from which the forecast assumptions on these fuels are based.[20] According to the *Electricity Sector Outlook*, the Francisco Villa facility (300 MW; residual fuel oil and diesel) will go off-line in 2014 and the Samalayuca I facility (316 MW; residual fuel oil and natural gas) will go off-line in 2017. Therefore, CCS assumed that in 2014, diesel fuel is no longer used in the electricity sector and the residual fuel oil use is reduced. In 2017, it is assumed that residual fuel is no longer used in the electricity sector. The heat rate for diesel fuel and residual fuel oil in 2007 from the historic GHG inventory is used to estimate generation for 2008 and beyond for the years where these fuels are being used.

Renewable energy: the hydroelectric generation in Chihuahua is not reported in SENER's *Electricity Sector Outlook 2008-2017*.[21] Therefore, it is assumed that the annual electricity generated at the hydroelectric facilities for 2008 through 2025 is equal to the generation total for the year 2007 (99 GWh).

Table A-4 and Figure A-3 display the fossil fuel consumption by fuel type over the historic inventory and reference case forecast periods (1990-2025). Hydro-derived electricity is not included in these visuals, as these are just the fossil-based energy sources used to generate electricity. Table A-5 and Figure A-4 display the electricity generation over this period for all energy sources. These visuals show that natural gas became the primary fossil fuel source for electricity generation in Chihuahua during the 2000 to 2005 period. The peak occurring in 2015 in Figures A-3 and A-4 is higher than the 2020-2025 level of fossil fuel consumption and electricity generation. The 2020-2025 values are lower than the peaks in previous years due to the reduction in generation capacity that occurs when the Francisco Villa and Samalayuca I facilities are retired in 2014 and 2017.

[19] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466.
[20] Historical fossil fuel consumption at power generation plants was obtained directly from Secretaría de Energía (SENER) in response to Nuevo Leon's letter of inquiry. March 2007.
[21] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466.

Table A-4. Production-based Inventory and Forecast – Fossil Fuel Consumption (TJ)

Year	Natural gas	Fuel oil	Diesel oil	Total Fuel Consumption
1990	14,105	42,413	3,085	59,603
1995	16,752	36,754	3,341	56,847
2000	50,471	37,705	2,660	90,836
2005	65,366	32,344	307	98,016
2010	70,804	20,279	50	91,134
2015	132,061	10,403	0	142,464
2020	128,007	0	0	128,007
2025	134,482	0	0	134,482

Figure A-3. Production-based Inventory and Forecast – Fossil Fuel Consumption

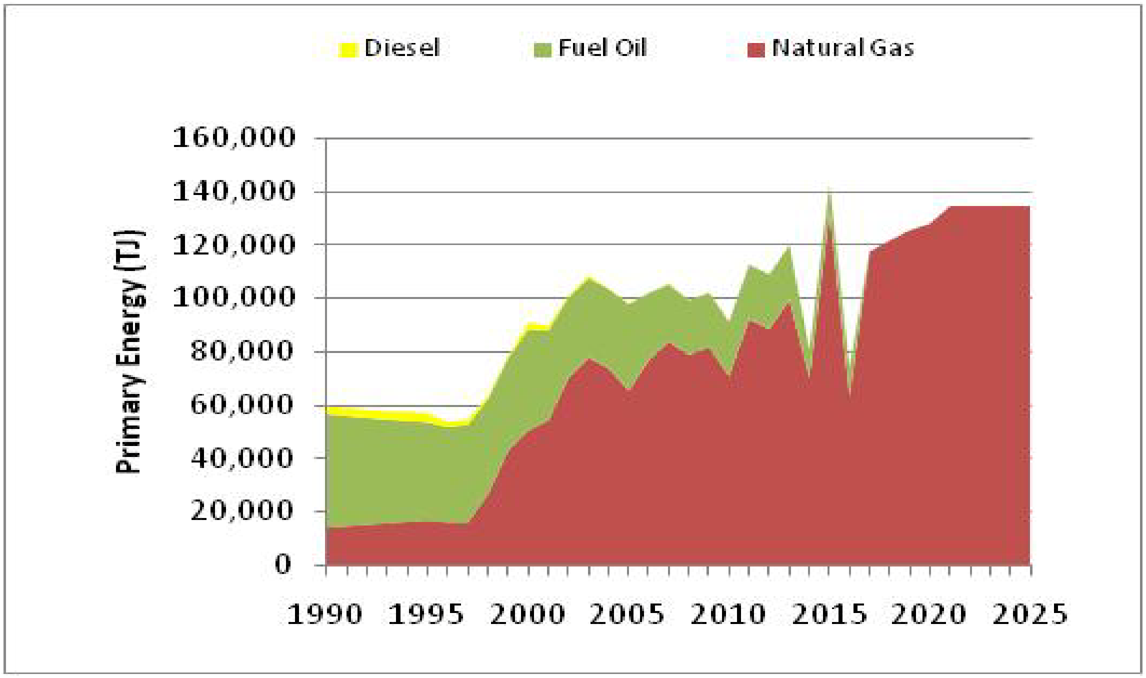
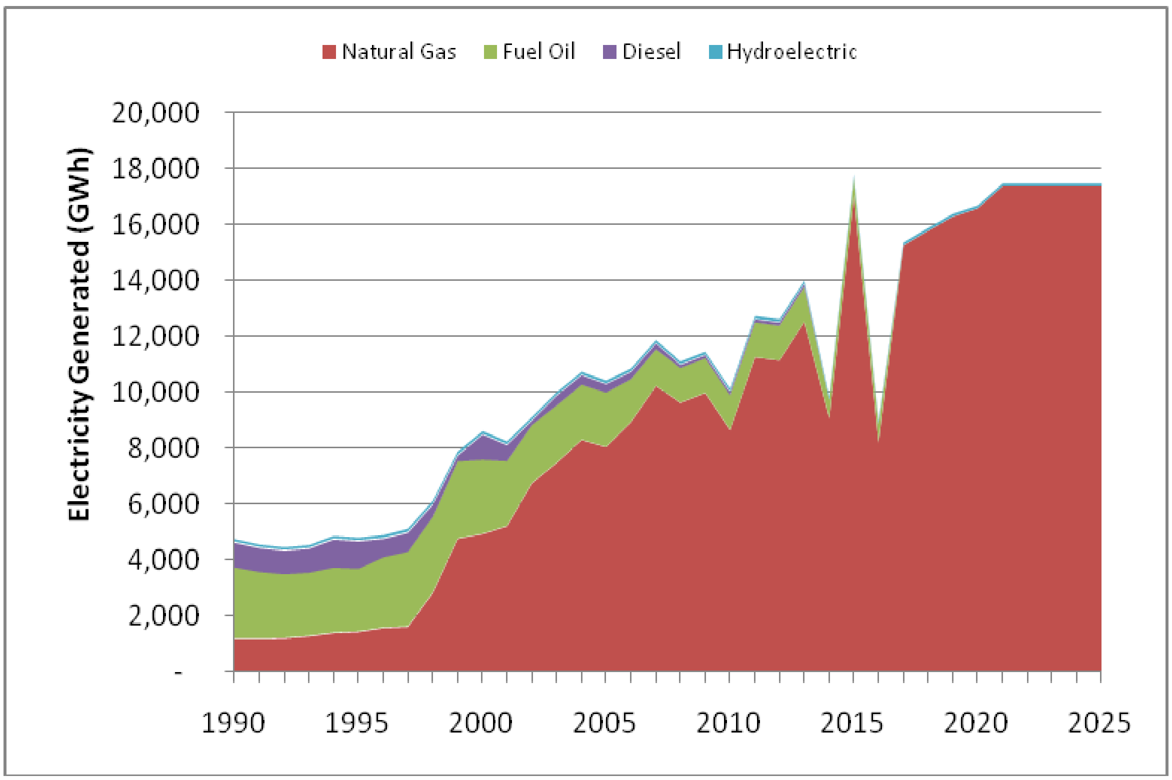


Table A-5. Production-based Inventory and Forecast – Electricity Generation (GWh)

Year	Natural gas	Fuel oil	Diesel oil	Hydroelectric	Total Production
1990	1,180	2,568	883	86	4,717
1995	1,430	2,271	976	88	4,764
2000	4,930	2,667	889	101	8,587
2005	8,030	1,963	296	99	10,388
2010	8,638	1,254	109	99	10,100
2015	17,044	643	0	99	17,787
2020	16,555	0	0	99	16,654
2025	17,345	0	0	99	17,444

Figure A-4. Total Electricity Generation – by Fuel Type: 1990-2025



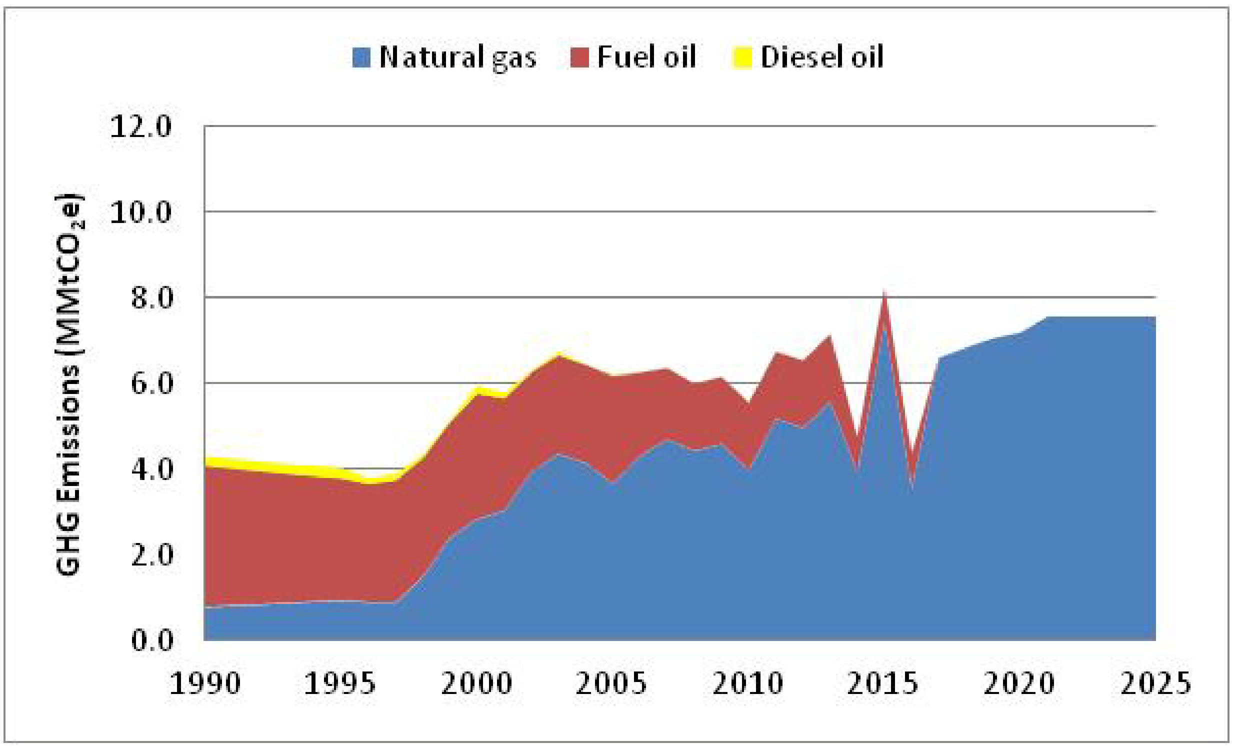
Production-based Inventory and Reference Case Forecast Results

The methods described in the previous two sections provide details on how CCS utilized existing data and official projections to estimate the energy content of fuels used for producing electricity from 1990 through 2025. The resulting production-based historic and projected GHG emissions are displayed in Table A-6 and Figure A-5. The contribution of each fuel type to the GHG emissions estimates are in line with the fossil energy consumption, in that GHG emissions from natural gas dominate the total production-based GHG emission estimates after the 2000 to 2005 time frame.

Table A-6. Production-based GHG Emissions from the Electricity Supply Sector ($MMtCO_2e$)

Year	Natural gas	Fuel oil	Diesel oil	Total Production-based Emissions
1990	0.79	3.29	0.23	4.31
1995	0.94	2.85	0.25	4.04
2000	2.83	2.93	0.20	5.96
2005	3.67	2.51	0.02	6.20
2010	3.98	1.57	0.004	5.55
2015	7.42	0.81	0.00	8.22
2020	7.19	0.00	0.00	7.19
2025	7.55	0.00	0.00	7.55

Figure A-5. Production-based GHG Emissions from the Electricity Supply Sector



Consumption-based Inventory Methodology

The consumption-based inventory accounts for emissions resulting from electricity consumed in Chihuahua, including emissions from imported electricity, but excluding emissions from electricity produced in, but exported from, the state.

Consumption-based Electricity (GWh) = In-State Sales + Losses

The consumption-based inventory is primarily based on electricity sales data reported in SENER's *Electricity Sector Outlook 2008-2017* and previous editions.[22] It is assumed that the same mix of generation sources applies to in-state sales (consumption) of electricity. These source-specific breakdowns of electricity consumption were multiplied by the heat rates (TJ/GWh) found in the production-based inventory to yield the energy content used in the emissions calculations.

The amount of electricity imported from the U.S. for the years 1993 through 2007 was reported by SENER's *Electricity Sector Outlook* reports. Information on imports from other states in Mexico was not available. It was noted in SENER's *Electricity Sector Outlook* reports that there is transmission capacity connecting the electricity grid in Chihuahua with other Mexican states. The amount of electricity imported was adjusted by taking the difference between the sum of electricity sold and electricity loss and gross electricity production. In the case that the value of this difference is negative for a given year, it is assumed that Chihuahua was a net exporter of electricity in that year.

Prior to 2007, the only known interconnection between Chihuahua and another Mexican state was with Durango. The emission factor for imports from Durango is based on the 2007 generation profile in Durango, which are about 76% natural gas and 26% residual fuel oil.

There are significant losses of electricity due to T&D loss and theft. While a small amount of loss from T&D is normal (e.g. 3% from the transmission network and 5% used at electricity generation facilities), a scholarly report from Rice University in Houston, TX claims that total loss for the national electricity system in Mexico may exceed 25%.[23] However, it was determined that the loss rate for CFE was a more realistic representation of electricity loss in Chihuahua. The CFE loss rate was applied to total generation in each year to estimate the amount of electricity lost. For years where there is no loss rate available (1990-1999), it is assumed that the loss rate was the average of the annual loss rate for 2000-2009 (10.7%). Interstate exports and imports were estimated by assuming that any excess electricity or deficiency in electricity would be explained by interstate exports or imports, respectively.

Considering that electricity T&D loss is inherent to the electricity supply system, it is necessary to account for total T&D losses in the consumption-based inventory. In the production-based

[22] SENER. 2009. "Prospectiva del Sector Eléctrico 2008-2017." Available at: http://www.sener.gob.mx/webSener/portal/index.jsp?id=466. Previous editions available at same site.
[23] Hartley, Peter and Eduardo Martinez-Chombo. 2002. "Electricity Demand and Supply in Mexico." Rice University, Houston, TX. Available at: http://www.rice.edu/energy/publications/docs/Hartley_ElectricityDemandSupplyMexico.pdf.

inventory, T&D loss and theft are captured within the estimates of total generation, so no separate accounting is necessary. Emissions due to exported electricity are not accounted for in the consumption-based inventory, but will be shown in this appendix as an adjunct result. Emissions from exports and loss are estimated by assuming the same ratio of fuel-specific consumption to total fuel consumption for each year as the production-based inventory.

Consumption-based Reference Case Forecast Methodology

The consumption-based forecast is driven by the expected growth in electricity consumption in Chihuahua. The electricity consumption for Mexico's Northeast region is projected by SENER's *Electricity Sector Outlook 2008-2017*. The electricity consumption for Chihuahua is indexed to the projection of the Northwest region for the years 2008 through 2017. The average annual increase of 4.6% was applied each year to estimate total consumption for 2018 through 2025. Then, the fuel-specific breakdowns were multiplied by the 2007 heat rates (TJ/GWh) calculated from the historic GHG production-based inventory to yield the energy content used in the emissions calculations.

Consistent with the historical GHG inventories, forecast electricity sales exceeds electricity production from 2008 through 2025, with the exception of 2015. Projections of electricity imported to Chihuahua from other Mexican states were not available. Therefore, it was necessary to make an assumption regarding total production levels or assuming electricity import and export demands in order to reconcile the production-based and consumption-based reference case forecasts.

It was assumed that the percentage of electricity lost would be equal to the 2000-2009 average annual loss rate (10.7%). This was chosen as conservatively low estimate of transmission and distribution loss that is consistent with the amount of electricity reported to be lost through the high voltage transmission network. The amount of electricity imported annually during the forecast period was calculated by subtracting electricity loss and consumption from production. If this difference is positive, then Chihuahua is projected to be a net exporter in that year. If this difference is negative, it is projected that Chihuahua is a net importer in that year. Emissions from loss and exports are calculated by multiplying the ratio of fuel-specific consumption to total fuel consumption for each year (i.e. natural gas TJ / Total TJ; as generated by the production-based forecast) by the total primary energy used to generate exported or lost electricity.

Emissions from imports during the forecast period are calculated based on the annual emission factors derived from the Coahuila inventory and forecast. Coahuila was chosen as the most likely state for imports since it is projected to have a large excess of production capacity and the transmission capacity between Chihuahua and Coahuila is larger than for Chihuahua and Durango. In the event that there is not enough electricity exported in Coahuila to meet the demand in Chihuahua, the excess demand is assumed to be made up by imports from Durango. The emission factor for imports from Durango is based on the 2007 generation profile in Durango, which is about 76% natural gas and 26% residual fuel oil.

Table A-7 and Figure A-6 display the disposition of electrical power in the State; including in-state consumption, imports, loss, and exports. Figure A-7 shows the primary energy consumption through the historic inventory and reference case forecast period that was used to calculate the GHG emissions estimates.

Table A-7. State-Wide Electrical Power Disposition (GWh)

	Consumption-based Inventory			
Year	Chihuahua Consumption	Import	Loss	Export
1990	4,112	857	503	958
1995	6,223	1,967	508	0
2000	7,493	129	910	312
2005	8,774	6	1,126	494
2010	10,455	1,432	1,077	0
2015	13,200	0	1,897	2,689
2020	16,489	1,611	1,777	0
2025	20,647	5,064	1,861	0

Figure A-6. State-Wide Electrical Power Disposition

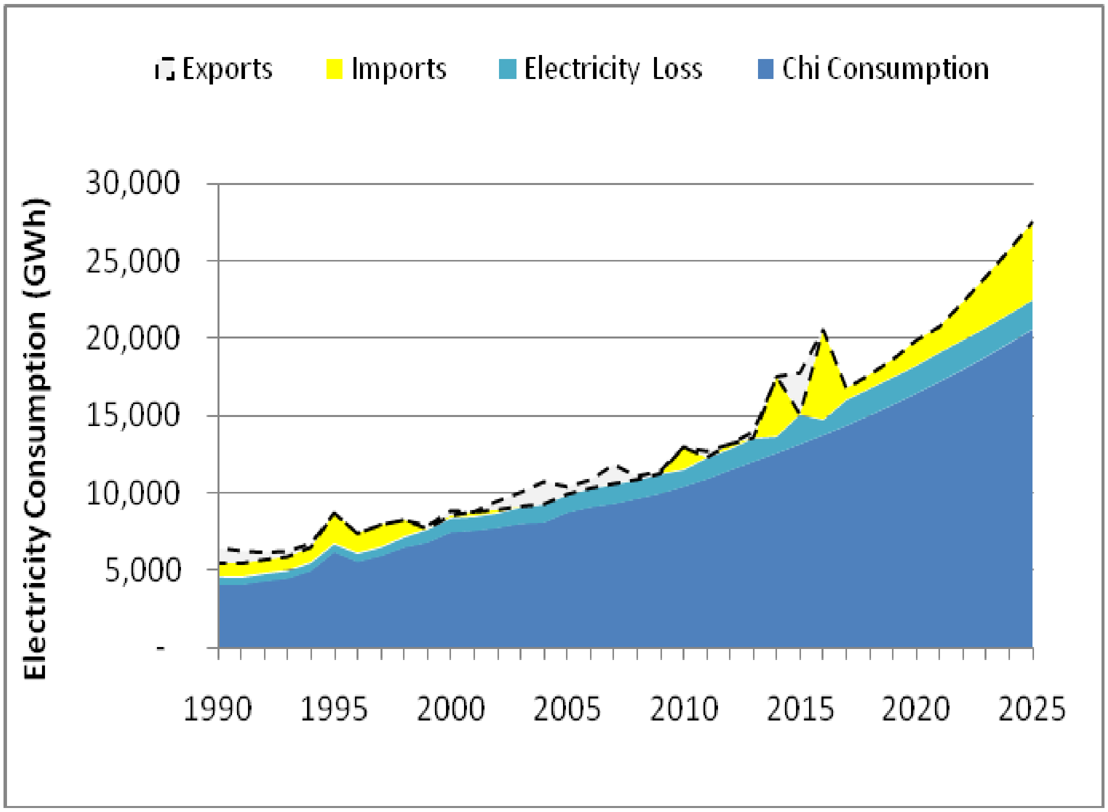
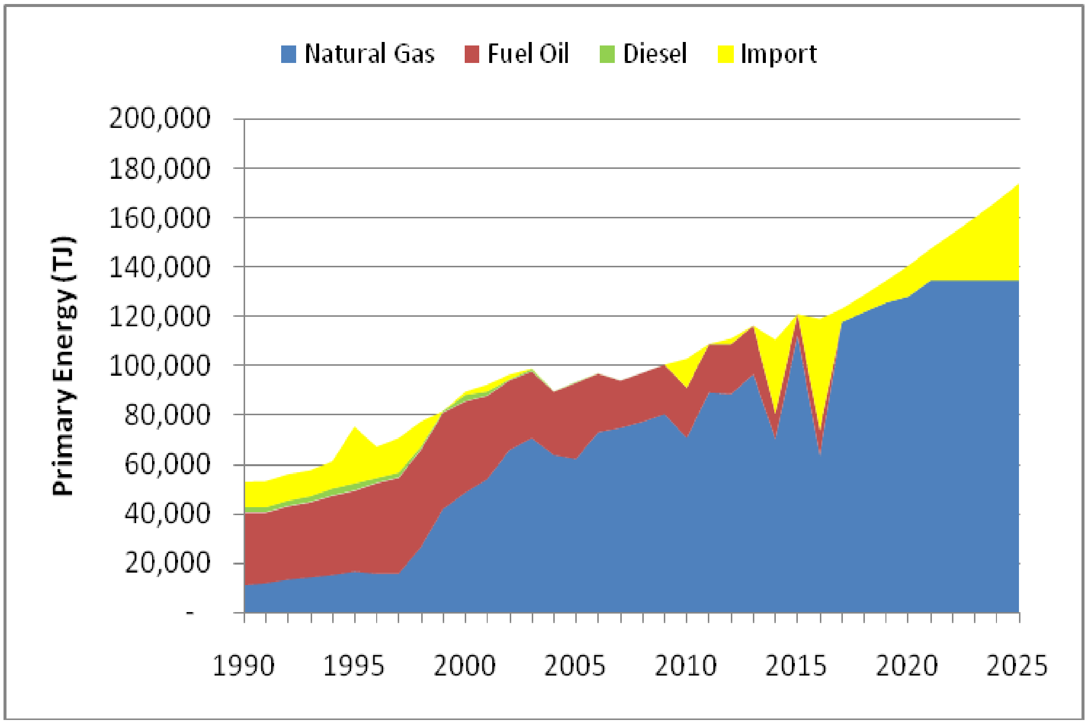


Figure A-7. Consumption-based Inventory and Forecast – Fossil Energy Use

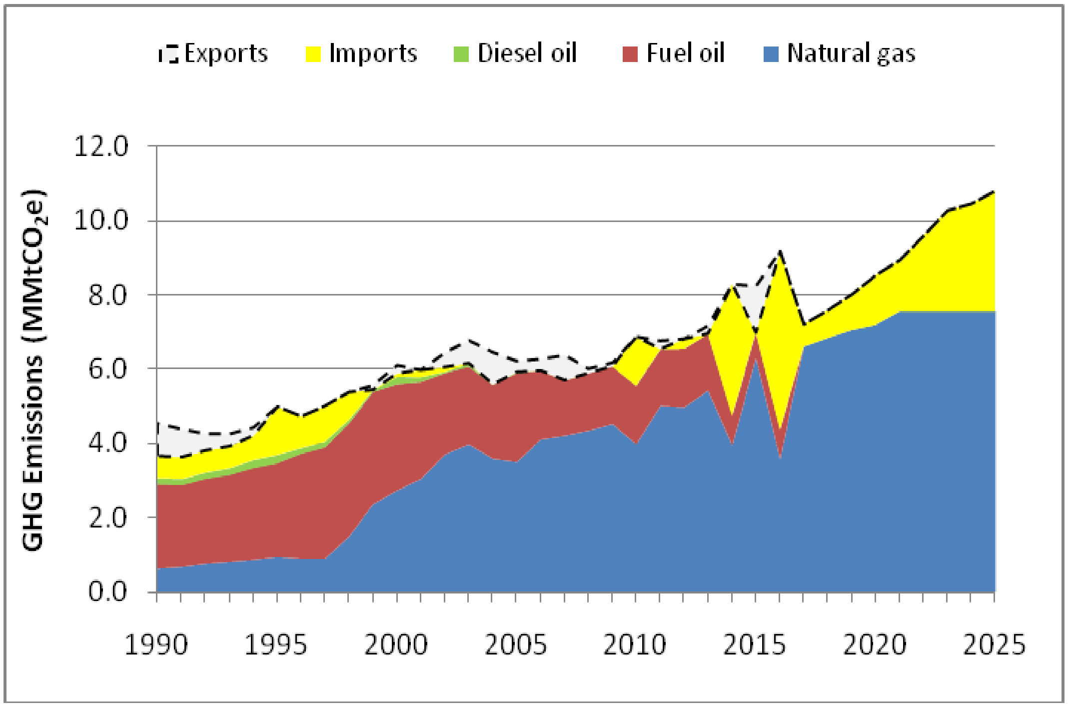


Consumption-based Inventory and Reference Case Forecast Results

The methods described in the previous two sections provide details on how CCS utilized existing data and official projections to estimate the energy content of fuels used for delivery of electricity in Chihuahua from 1990 through 2025. The consumption-based historic and projected GHG emissions are displayed in Figure A-8. This figure breaks down the contribution of each fuel type to the in-state consumption-based inventory and reference case forecast. It also includes a dashed line to show the impact of electricity exports on GHG emissions, although GHG emissions from electricity exports are not included in the consumption-based inventory and forecast. Emissions from electricity losses are embedded in the fuel source emissions in Figure A-8.

Table A-8 and Figure A-9 show the consumption-based GHG emissions by component. These estimates show the contribution to total consumption-based emissions from electricity exports, imports, and loss, relative to emissions directly resulting from consumption of electricity generated in Chihuahua.

Figure A-8. Total Consumption-Based Electricity Supply GHG Emissions



Key Uncertainties and Future Research Needs

Key sources of uncertainty underlying the estimates above and opportunities for future research are as follows:

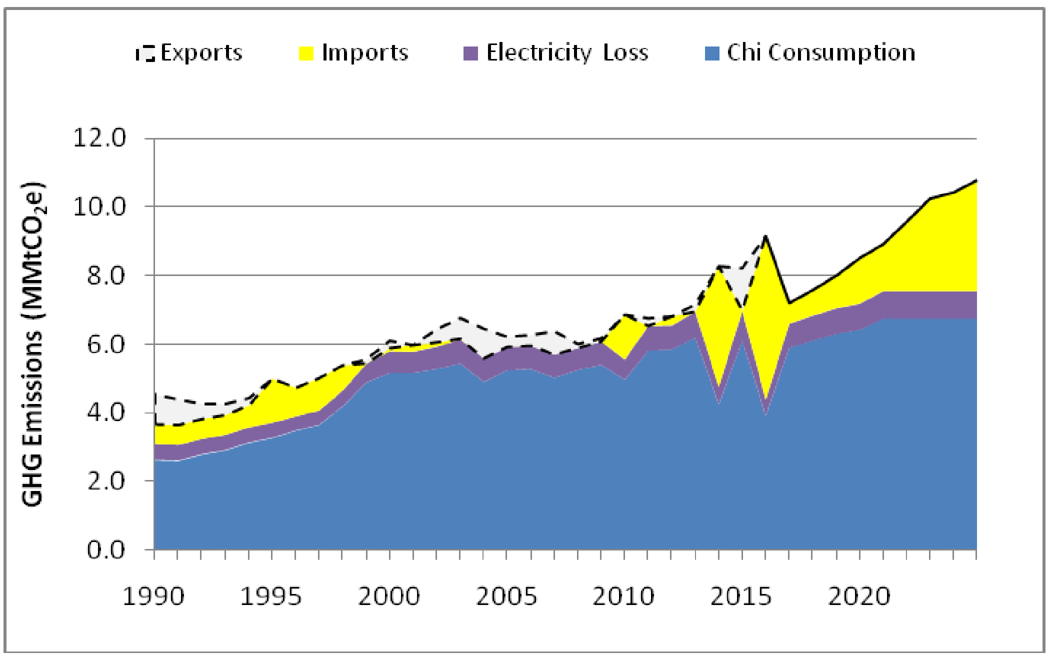
- The generation and consumption (sales) for Chihuahua, as portrayed in the historical data and projections provided by SENER, show that Chihuahua must import electricity in some years order to meet demand. In other years, Chihuahua has excess supply and is an exporter of electricity. However, there were no data sources available to CCS that identified the quantity and source of imported or the quantity and destination of exported electricity. The only information available regarding the trade of electricity between Mexican states is the transmission capacity (existing and future) between states. Therefore, the amount of imported (or exported) electricity had to be calculated. The quantity of imported (or exported) electricity is based on projected electricity consumption, production, and an assumed loss factor.
- Electricity sales are fluid by nature. Therefore, as there are no data available for interstate imports and exports of electricity, it was necessary to project imports and exports on a net basis. While Chihuahua is projected to be a net importer of electricity through the forecast period, it is possible that some portion of electricity production will be exported.
- Electricity on-site usage and transmission and distribution loss estimates were assumed during the historic inventory period, and are based on national loss rates estimated from

CFE. During the forecast period, the loss rate is assumed to be equal to the average annual loss rate from 2000-2009. Improvements to these estimates could help to improve the consumption-based estimates, including the need for imported electricity.

Table A-8. Total GHG Emissions Associated with Electricity Consumption ($MMtCO_2e$)

Year	Chihuahua Consumption	Imports	Loss	Total Consumption-based Emissions	Exports
1990	2.61	0.58	0.46	3.65	0.88
1995	3.26	1.29	0.43	4.99	0.00
2000	5.16	0.09	0.63	5.88	0.22
2005	5.24	0.004	0.67	5.91	0.30
2010	4.96	1.31	0.59	6.86	0.00
2015	6.10	0.00	0.88	6.98	1.24
2020	6.42	1.33	0.77	8.52	0.00
2025	6.75	3.24	0.81	10.8	0.00

Figure A-9. Consumption-based Electricity Supply GHG Emissions – by Component



- The information in the SENER electricity and natural gas forecast reports did not provide sufficient information to discern the level of imports and exports in the future, especially from and to other states in Mexico. Projected updates to grid interconnections are reported in SENER's *Electricity Sector Outlook* reports. However, this information is only sufficient to prove or disprove whether there is sufficient grid capacity to transfer electricity between Chihuahua and the U.S. or another Mexican state. The actual quantities of exports and imports are based on calculations of future generation, sales, and assumed losses. More sophisticated market analysis may prove useful in assessing the future contribution of exports and imports to the GHG emissions contribution of the electricity supply sector in Chihuahua, including the correct import regions.

- The quantity of exported electricity is based on projected electricity consumption, production, and the aforementioned loss factor. Electricity sales are fluid, by nature. Therefore, as there is no data available for interstate imports and exports of electricity, it was necessary to project imports and exports on a net basis. While Chihuahua is projected to be a net importer of electricity in most years, it is possible that some electricity will be exported as well.
- The SENER reports that provided the electricity and natural gas data (historical and projected) display the gross generation at the largest power plants in Chihuahua. CCS was not able to identify gross generation and the type of fuel combusted at smaller, privately owned facilities in Chihuahua. Therefore, it is possible that CCS has underestimated the amount of electricity produced in Chihuahua. This underestimation would lead to an overestimation in the electricity imported, and the corresponding emissions from that electricity. Since the production-based inventory uses the primary energy from fuel supplied to the Electricity Supply sector, CCS believes that the emissions estimates from electricity produced in Chihuahua are accurate. Complete data providing total generation at all facilities in Chihuahua, the type of fuel combusted at each facility, and the net imports of electricity from other Mexican states would increase the precision of the consumption-based emissions estimate and the elements therein (specifically, emissions from imports and loss).
- There are uncertainties associated with the statewide fuel mix, emission factors, and conversion factors (to convert electricity from a heat input basis to electricity output) that should be reviewed and revised with data that is specific to Chihuahua power generators.
- For combined heat and power facilities that generate and sell electricity to the power grid, fuel use associated with these facilities is aggregated by fuel and sector. Therefore, fuel use cannot be broken out easily, so that it can be reported under the electricity supply and use sector, instead of the industrial fuel use sector. Future work could include an assessment to determine how best to isolate emissions associated with combined heat and power facilities.
- Fuel price changes influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, and thereby affect emissions estimates. Unanticipated events that affect fuel prices could affect the electricity forecast for Chihuahua.
- Population and economic growth are the principal drivers for fuel use. The reference case projections are based on the estimates of electric generation requirements as reported by SENER's *Electricity Sector Outlook* reports. Electricity demand forecasts by other sectors could help to refine the forecast for Chihuahua.

Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion

Overview

Activities in the RCI[1] subsectors produce CO_2, CH_4, and N_2O emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. This appendix covers fuel combustion only for these subsectors. In 2005, direct total GHG emissions from RCI fuel combustion of oil, natural gas, liquefied petroleum gas (LPG), coal, and wood were 2.4 $MMtCO_2e$ of which 57% was emitted by residential sources, 35% by industrial sources, and 8% by commercial sources. Non-combustion emissions relating to residential, commercial, and industrial activity may be found in the agriculture, waste, industrial processes, and forestry sector appendices.

Emissions and Reference Case Projections

The 2006 IPCC Guidelines offer three approaches for estimating emissions from fossil fuel combustion by stationary sources. Based on available information, a Tier 1 approach was selected. [2]

The 2006 IPCC Guidelines estimate carbon emissions in terms of the species which are emitted. During the combustion process, most carbon is immediately emitted as CO_2. However, some carbon is released as carbon monoxide (CO), CH_4 or non-methane volatile organic compounds (NMVOCs). Most of the carbon emitted as these non-CO_2 species eventually oxidizes to CO_2 in the atmosphere. In the case of fuel combustion, the emissions of these non-CO_2 gases contain very small amounts of carbon compared to the CO_2 estimate and, at Tier 1, it is more accurate to base the CO_2 estimate on the total carbon in the fuel. This is because the total carbon in the fuel depends on the fuel alone, while the emissions of the non-CO_2 gases depend on many factors such as technologies or maintenance, which, in general, are not well known.

The Tier 1 method is fuel-based, since emissions from all sources of combustion can be estimated on the basis of the quantities of fuel combusted and average emission factors. Tier 1 emission factors are available for CO_2, CH_4, and N_2O. The quality of these emission factors differs between gases. For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (including combustion efficiency and carbon retained in slag and ashes) are relatively unimportant.[3] Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of fuels combusted and the average carbon content of the fuels. Emission factors for CH_4 and N_2O, however, depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and over time. Due to this variability, the use of average emission factors for these gases will

[1] The industrial sector includes some emissions associated with agricultural energy use and natural gas consumed as lease and plant fuel. Emissions associated with pipeline fuel use are included in Appendix E.
[2] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 1, page 1.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
[3] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 1, page 1.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

introduce relatively large uncertainties.[4] Fortunately, CH_4 and N_2O contribute very little to the total CO_2e emissions from combustion processes. Emissions estimates from wood combustion include only N_2O and CH_4. CO_2 evolved from wood is considered a biogenic source and is not included in this inventory. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis. N_2O and CH_4 emissions in this inventory are reported in CO_2 equivalents (CO_2e).

In order to capture the difference in CH_4 and N_2O emissions, default emission factors in the 2006 IPCC Guidelines are listed in separate tables according to four subsectors: 1) energy industries, 2) manufacturing industries and construction, 3) commercial and institutional, and 4) residential and agriculture/forestry/fishing farms.[5] The emissions factors used for this inventory and forecast are summarized in Table B-1, followed by a brief description of the methods and activity data used to develop the inventory and reference case projections.

Table B-1. Emissions Factors for RCI Fuels (kg/TJ)

Source	Fuel Type	CO_2	N_2O	CH_4
Commercial	Liquefied Petroleum Gases	63,100	0.1	5
Industrial	Diesel Oil	74,100	0.6	3
	Liquefied Petroleum Gases	63,100	0.1	1
	Liquefied Petroleum Gases (Agriculture)	63,100	0.1	5
	Natural Gas	56,100	0.1	1
	Residual Fuel Oil	77,400	0.6	3
Residential	Liquefied Petroleum Gases	63,100	0.1	5
	Natural Gas	56,100	0.1	5
	Residual Fuel Oil	77,400	0.6	3
	Solid Biofuels: Wood	112,000	4	300

Diesel

Diesel consumption in the RCI sector for 1993-2007 as well as projected estimates for 2008-2009 was obtained directly from SENER.[6] SENER attributed all diesel consumption to the industrial subsector. Prior to 1993, consumption was extrapolated backwards linearly to 1990. Forecast values were derived by calculating the mean annual growth rate (-1.3%) from the 2005-

[4] This paragraph is quoted with minor editing from Chapter 1, Volume 2 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories, page 1.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

[5] Default emission factor tables are found in Chapter 2, Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[6] Diesel consumption information was prepared by SENER for the Agencia de Protección al Medio Ambiente y Recursos Naturales (APMARN) de Nuevo León.

2009 SENER dataset and applying that to the years 2010-2025. The growth rates applied for this fuel and all the other fuels in the sector are summarized in Table B-2.

Residual Fuel Oil
Residual fuel oil consumption was derived from state total fuel oil sales from 1990-2007.[7] Forecast values were derived by calculating the mean annual growth rate (2.2%) for 1998-2007 and applying that to the years 2008-2025.

Table B-2. Annual Growth Rates used in RCI Forecast

Source	Fuel Type	Annual Growth Rate
Commercial	Liquefied Petroleum Gases	-0.3%
Industrial	Diesel Oil	-1.3%
	Liquefied Petroleum Gases	1.7%
	Liquified Petroleum Gases (Agriculture)	0.9%
	Natural Gas	2.0%
	Residual Fuel Oil	0.0%
Residential	Liquefied Petroleum Gases	-2.6%
	Natural Gas	3.8%
	Residual Fuel Oil	2.2%
	Solid Biofuels: Wood	1.2%

Liquefied Petroleum Gas
State consumption of LPG and forecast consumption were obtained from SENER.[8] Fuel consumption information by state was published for 1996-2005. Consumption by subsector including residential, commercial, and industrial were published by region. The regional percentages were multiplied by the total state consumption for all three subsectors combined to estimate state subsector consumption. Consumption for prior years back to 1990 was estimated by back-casting from reported consumption. Official SENER LPG consumption projections were available for 2006-2016. For the remaining forecast years through 2025, LPG consumption in each subsector was assumed to grow at the same rate as SENER's projection (the 2009-2016 mean annual growth rate). For residential this is -2.6% per year; industrial, 1.7% per year; and commercial, -0.3% per year.

LPG consumption for industrial uses ancillary to agricultural production was also reported and is included here as part of the industrial subsector. Many activities in the agricultural sector require

[7] Sistema de Información Energética - productos petroliferos, accessed from http://sie.energia.gob.mx/sie/bdiController.
[8] SENER: *Prospectiva del Mercado de Gas LP 2006-2015*, *Prospectiva del Mercado de Gas LP 2007-2016*, and *Prospectiva del Mercado de Gas LP 2008-2017* Accessed from http://www.sener.gob.mx/webSener/index.jsp.

the use of fuel energy such as the operation of tractors and machinery. However, segregated information relating to the consumption of energy in the agricultural sector was only available for LPG. The latter is not representative of primary energy consumption in the agricultural sector as the predominant form of energy is diesel used in tractors and heavy machinery. Diesel fuel consumption by vehicles (e.g, tractors and trailers) is captured under Transportation: Road/Diesel (see Appendix C).

Natural Gas

State consumption of natural gas and forecast consumption data were obtained from SENER.[9] Fuel consumption segregated by subsector was available at the state level for industry for 1998-2007. Aggregate natural gas consumption for residential, commercial, and transportation was reported for the state for 2000-2007. National data from SENER indicate that the majority of this aggregate consumption is from residential use.[10] Hence, all of the consumption from this aggregate was assigned to the residential subsector. Consequently, the commercial sector has very little consumption assigned to it. Consumption values for prior years back to 1990 were estimated by back-casting the reported consumption. SENER's official natural gas consumption projections were available for 2009-2017. For remaining forecast years up to 2025, state total consumption was assumed to grow at the same rate as SENER's projection (the 2009-2017 mean annual growth rate). For the industrial subsector this is 2.0%. For residential, commercial, and transportation this is 3.8%.

Solid Biofuels: Wood

The use of wood fuel by the residential subsector was derived from two sources of information. The 2000 Censo de Población y Vivienda (Population and Housing Census) provided the breakdown of households according to the type of fuel consumed for cooking. This source was used to determine the fraction of homes with wood fuel stoves (8.7%) .and infer the share of the population that relies on wood fuel for cooking SENER provided the average annual wood fuel use for one person for 1996 and 2006 (in natural gas equivalents).[11] Wood fuel use was assumed to decrease linearly between 1996 and 2006. The years 1990-1995 were held constant at the 1996 level. Energy use from wood fuel was calculated by multiplying the percentage of residents who use wood fuel times the average annual wood fuel use per capita. Forecast values were derived by calculating the mean annual growth rate (1.2%) for 1990-2005 and applying that to the years 2006-2025. Only CH_4 and N_2O emissions associated with wood combustion are reported here as any CO_2 emitted would be considered biogenic.

Results

Energy use in the RCI sector totaled 38,396 terajoules (TJ) in 2005. Energy consumption values are shown in Table B-3.

[9] SENER: *Prospectiva del Mercado de Gas Natural 2007-2016* and *Prospectiva del Mercado de Gas LP 2008-2017*. Accessed from http://www.sener.gob.mx/webSener/index.jsp.
[10] SENER: *Prospectiva del Mercado de Gas Natural 2007-2016* and *Prospectiva del Mercado de Gas LP 2008-2017*. Accessed from http://www.sener.gob.mx/webSener/index.jsp.
[11] SENER: *Prospectiva del Mercado de Gas Natural 2007-2016, Cuadro 23.* Accessed from http://www.sener.gob.mx/webSener/index.jsp.

Table B-3. Historical Energy Used in RCI Sector, TJ

Source	Fuel Type	1990	1995	2000	2005
Commercial	Liquefied Petroleum Gases	2,938	2,641	3,145	2,777
Industrial	Diesel Oil	1,102	2,548	2,974	1,051
	Liquefied Petroleum Gases	2,220	1,809	2,257	1,740
	Liquefied Petroleum Gases (Agriculture)	956	977	592	444
	Natural Gas	12,594	11,647	16,504	11,053
	Residual Fuel Oil	0	0	0	0
Residential	Liquefied Petroleum Gases	15,631	15,829	10,877	9,591
	Natural Gas	5,133	4,667	7,903	9,628
	Residual Fuel Oil	0	0	1,495	1,696
	Solid Biofuels: Wood	347	397	439	415
Total		**40,921**	**40,514**	**46,185**	**38,396**

Figure B-1 and Tables B-4 and B-5 provide a summary profile of GHG emissions for the entire RCI sector. In 2005, total RCI GHG emissions were 2.4 million metric tons of carbon dioxide equivalent (MMtCO_2e), of which 57% is associated with fuel combustion in the residential subsector, 35% is from the industrial subsector, and 8% is from the commercial subsector. In 2005, industrial natural gas and residential LPG consumption each accounted for 26% of total RCI energy use, followed by residential natural gas (23%).

By 2025, total RCI GHG emissions are projected at 3.2 MMtCO_2e of which 56% are from residential fuel combustion, 39% from industrial fuel combustion, and 4% from commercial fuel combustion. Overall, RCI emissions are driven by the combustion of natural gas in the residential and industrial sectors. Natural gas consumption was reported as an aggregate total in the state for the residential and commercial subsectors and the transportation sector. In addition to the commercial natural gas consumption included in this aggregate, it is likely that some commercial consumption is included in the industrial subsector consumption. More detailed data from state agencies or fuel suppliers would be necessary to clarify this.

Figure B-1. GHG Emissions in RCI Sector

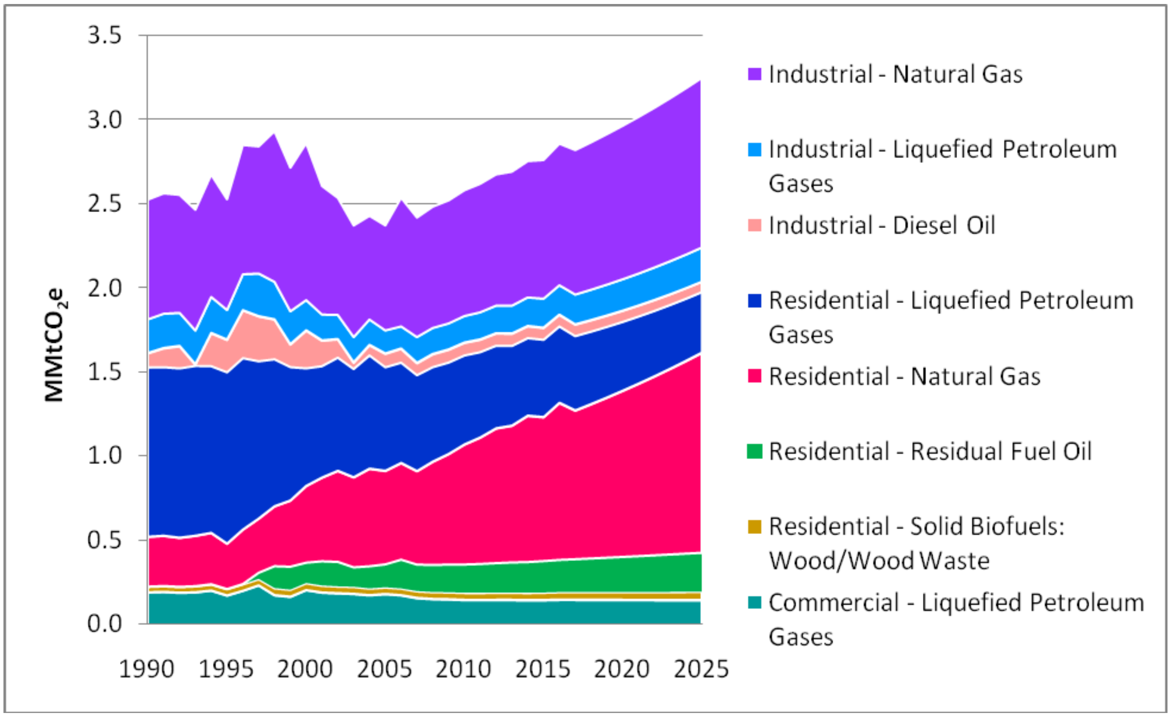


Table B-4. GHG Emissions RCI Sector ($MMtCO_2e$)

Source	Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Commercial	Liquefied Petroleum Gases	0.19	0.17	0.20	0.18	0.14	0.14	0.14	0.14
Industrial	Diesel Oil	0.08	0.19	0.22	0.08	0.07	0.07	0.07	0.06
	Liquefied Petroleum Gases	0.14	0.11	0.14	0.11	0.13	0.14	0.19	0.20
	Liquefied Petroleum Gases (Agriculture)	0.06	0.06	0.04	0.03	0.03	0.03	0.00	0.00
	Natural Gas	0.71	0.66	0.93	0.62	0.75	0.82	0.91	1.01
Residential	Liquefied Petroleum Gases	1.01	1.02	0.70	0.62	0.53	0.46	0.41	0.36
	Natural Gas	0.30	0.27	0.46	0.56	0.71	0.86	0.99	1.19
	Residual Fuel Oil	0.00	0.00	0.12	0.14	0.17	0.19	0.21	0.23
	Solid Biofuels: Wood	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05
Total		**2.5**	**2.5**	**2.9**	**2.4**	**2.6**	**2.8**	**3.0**	**3.2**

Table B-5. GHG Emissions Distribution in RCI Sector

Source	Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Commercial	Liquefied Petroleum Gases	8%	7%	7%	8%	6%	5%	5%	4%
Industrial	Diesel Oil	3%	8%	8%	3%	3%	3%	2%	2%
	Liquefied Petroleum Gases	6%	5%	5%	5%	5%	5%	6%	6%
	Agriculture - LPG	2%	3%	1%	1%	1%	1%	0%	0%
	Natural Gas	28%	26%	33%	26%	29%	30%	31%	31%
Residential	Liquefied Petroleum Gases	40%	41%	25%	26%	21%	17%	14%	11%
	Natural Gas	11.7%	11%	16%	23%	28%	31%	33%	37%
	Residual Fuel Oil	0.0%	0%	4%	6%	7%	7%	7%	7%
	Solid Biofuels: Wood	1.3%	1.5%	1.4%	1.6%	1.6%	1.6%	1.6%	1.5%

Although emissions associated with the generation of electricity that is consumed by the RCI subsectors are accounted for in the electricity generation sector (see Appendix A), it is useful to know the distribution of electricity use between the RCI subsectors to inform possible future approaches for mitigating energy use and thus GHG emissions. In 2005, the industrial sector accounted for the majority of electricity use (69%), followed by the residential (24%) and commercial subsectors (7%). Table B-6 shows historic growth rates for electricity sales by RCI subsector. The proportion of each RCI subsector's sales to total sales was used to allocate emissions associated with the electricity supply sector to each of the RCI subsectors. Figure B-2 illustrates the 2005 breakdown of electricity sales by RCI subsector.

Figure B-2. 2005 Electricity Sector Sales by Subsector

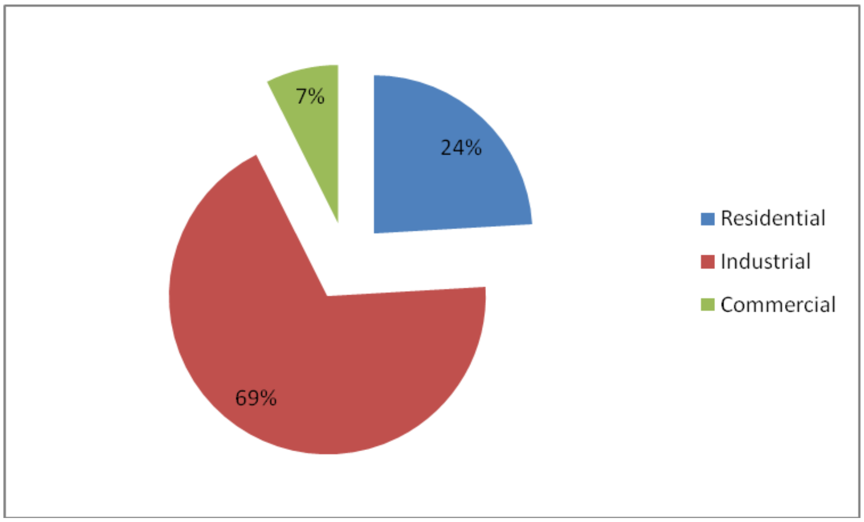


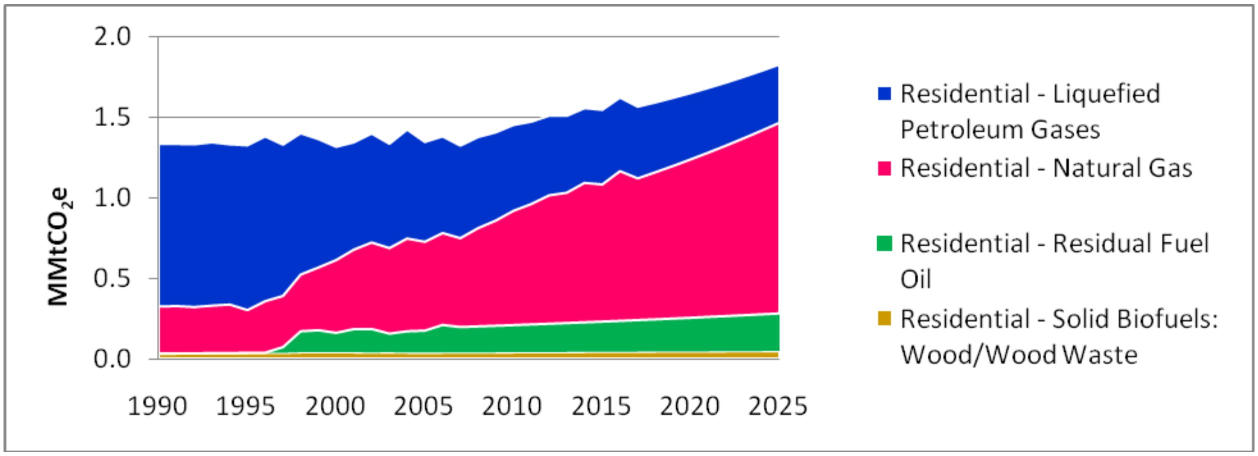
Table B-6. Historical Electricity Sales Annual Growth Rates

Sector	1990-2005*
Residential	5.3%
Commercial	2.7%
Industrial	5.5%
Total	**5.2%**

* 1990-2005 compound annual growth rates calculated from electricity sales by year from SENER.

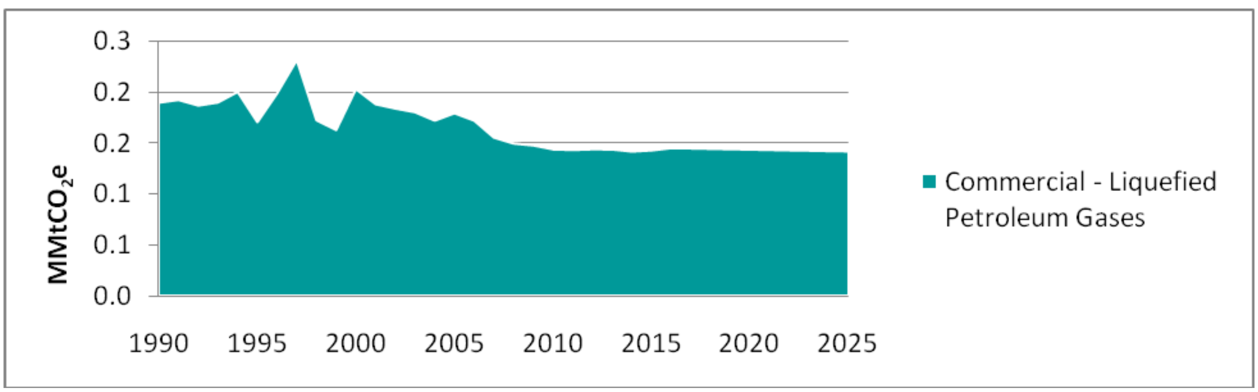
Emissions from residential sources were driven by the combustion of LPG and natural gas, which represented 46% and 41%, respectively of total residential emissions in 2005, followed by the combustion of residual fuel oil at 10%. Emissions relating to the combustion of wood fuels represented 3% of the total. Historical and projected residential GHG emission trends are shown in Figure B-3. Projected emissions growth is driven by residential combustion of natural gas while emissions associated with LPG are estimated to decrease. Emissions associated with wood combustion and residual fuel oil are estimated to grow only slightly above 2005 levels.

Figure B-3. GHG Emissions from Residential Sector Fuel Combustion



Emissions from commercial sources amounted to 0.2 $MMtCO_2e$ in 2005 and were driven by the combustion of LPG, which is associated with stoves. It seems plausible that the restaurant business utilizes LPG in significant quantities. If that is the case, then emissions values for the commercial sector are expected to be larger. Additional work is warranted to better profile this sector. Historical and projected commercial GHG emission trends are shown in Figure B-4. From 2005 through 2025, commercial emissions are estimated to decrease by 21%, or by about 1% per year.

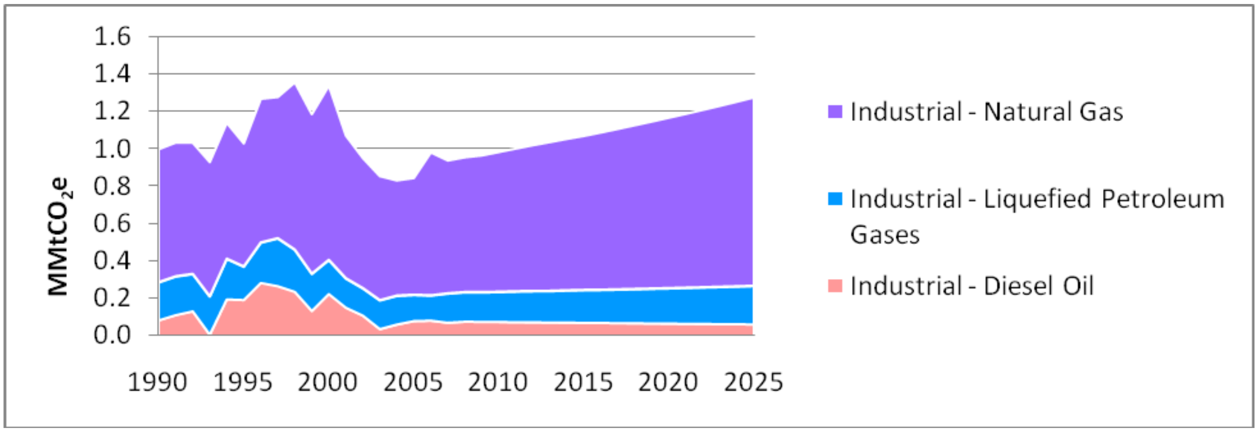
Figure B-4. GHG Emissions from Commercial Sector Fuel Combustion



In 2005, emissions from industrial sources were driven by the combustion of natural gas (74%) followed by LPG (13%) and diesel oil (10%). Historical and projected industrial GHG emission trends are shown in Figure B-5. The LPG consumption data included a breakout of combustion associated with agricultural industry. LPG was the only fuel for which data were available to extract agricultural consumption from the rest of industrial consumption.

From 2005 through 2025, industrial emissions are estimated to increase by 51%, or about 2.6% per year.

Figure B-5. GHG Emissions from Industrial Sector Fuel Combustion



Key Uncertainties and Next Steps

Segregated RCI activity data per state, per fuel, and per subsector were not always available. Several assumptions were made during the activity data segregation process in an attempt to assess RCI emissions. Reported diesel and residual fuel oil consumption was attributed to the industrial subsector. For diesel consumption in particular, some of this is likely to be consumed within the commercial sector.

Additionally, natural gas consumption information was combined into one value for the residential, commercial, and transportation subsectors. Nationally most natural gas consumption is in the residential sector, hence the aggregate values for natural gas consumption in Chihuahua were attributed to the residential subsector. In future work, better sector-level break-out might be possible with the use of bottom-up data from surveys of fuel suppliers.

LPG was the only fuel for which agricultural uses were delineated. However, other fuels are likely used in agricultural industries, particularly diesel, and these may be accounted for in other appendices. Future research may be needed to determine the quantity that is consumed by agriculture versus other industries.

Some fuel consumption was forecast, and in some cases back-cast, based on historical consumption. The use of economic indicators could improve consumption forecasts, rather than relying strictly on historical growth rates, and would allow the capture of economic cycles including recessions and growth bursts. Historical economic indicators back to 1990 would also prove helpful for back-casts and could capture fuel consumption expansion and contraction that accompanied periods of growth and recession. Currently, state-specific economic indicators are only available for the years 1993-2007, so are not able to inform the back-cast from 1990-1993 for diesel and residual fuel oil consumption. There was a recession in the early 1990's so diesel and residual fuel oil consumption may be lower than what is estimated. Additional state-specific economic indicators are needed to improve the back-cast as well as the forecast.

Appendix C. Transportation Energy Use

Overview

This appendix summarizes emissions from energy consumption associated with each of the following sources: road transportation, marine vessels, rail engines, and aviation. The fossil fuels combusted in these sources produce carbon dioxide (CO_2) in addition to small amounts of methane (CH_4) and nitrous oxide (N_2O). In 2007, CO_2 accounts for over 96% of greenhouse gas emissions followed by N_2O (3%) and CH_4 (0.5%) emissions on a carbon dioxide equivalent (CO_2e) basis.

Inventory and Reference Case Projections

Methodology

Based on the information available, emissions were estimated on a fuel consumption basis. According to the 2006 Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories*, emissions are expressed in terms of mass of greenhouse gas per unit of energy consumed. Because the method estimates emissions in terms of energy consumption (e.g. joules), fossil fuel sales data were converted from units of volume to units of energy according to the energy content of each fuel. Emissions were calculated as follows:

$$Emission = \Sigma\ [Fuel_a \times EF_a \times GWP]$$

Where:

Emission = greenhouse gas emissions by species in kilograms (kg) of carbon dioxide equivalent (CO_2e)

$Fuel_a$ = fuel sold in terajoules (TJ)

EF_a = emission factor (kg/TJ). This is equal to the carbon content of the fuel multiplied by the atomic weight ratio of carbon dioxide to carbon (44/12)[1]

a = type of fuel (e.g. petrol, diesel, natural gas, LPG etc)

GWP = global warming potential (from the IPCC Second Assessment Report or SAR)

Fuel consumption information was obtained from Petróleos Mexicanos (PEMEX) and Chihuahua's Secretaría de Energía (SENER) for each year.[2] Because of limited information on rail diesel consumption, national data were allocated to Chihuahua, based on the proportion of total national rail line length in Chihuahua. No marine diesel was allocated to Chihuahua because it is a landlocked state with no ports or major navigable waterways. Table C-1 lists all

[1] Emission factors for mobile combustion sources are listed in Chapter 3, Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

[2] Sistema de Información Energética, con información de Petróleos Mexicanos, http://sie.energia.gob.mx/sie/bdiController.

transportation sources and their corresponding activity data. Additional details of the emissions estimation methods are provided by sector below.

Table C-1. Activity Factors by Transportation Mode

GHG Source Sector	Activity Data	Data Source
Road Transportation - Gasoline	State of Chihuahua: fuel consumption, 1990-2007	Secretaría de Energía: Sistema de Información Energética, with information from Petróleos Mexicanos.
Road Transportation - Diesel	State of Chihuahua: fuel consumption, 1990-2007	Secretaría de Energía: Sistema de Información Energética, with information from Petróleos Mexicanos.
Road Transportation - LPG	State of Chihuahua: fuel consumption, 1996-2007	Secretaría de Energía: Prospectiva del mercado de gas LP 2007 - 2016
Road Transportation – Natural Gas	State of Chihuahua: fuel consumption, 1996-2007	Secretaría de Energía: Prospectiva del mercado de Gas Natural 2007 - 2016
Aviation	State of Chihuahua: fuel consumption, 1990-2007	Secretaría de Energía de Chihuahua: Sistema de Información Energética, con información de Petróleos Mexicanos.
Rail	National rail diesel consumption, 1990-2002	Instituto Nacional de Ecología: Inventario Nacional de Emisiones de Gases de Efecto Invernadero 1990-2002
	National rail diesel consumption, 2003-2007	Secretaría de Energía: Prospectiva de Petrolíferos 2008 – 2017
	Length of existing railways for Mexico and Chihuahua	Secretaría de Comunicaciones y Transportes: Longitud de Vías Férreas Existentes Por Entidad Federativa Según Tipo de Vía[3]

Greenhouse gas emission forecasts were estimated based on fuel consumption forecasts for 2001-2017 from SENER's *Prospectiva de Petrolíferos 2008-2017* and *Prospectiva del Mercado de Gas LP 2008–2017*. The growth trends for the latter part of the projection period (2011-2017) are assumed to continue through 2025. Forecasted annual growth rates are listed in Table C-2. Due to a lack of projection data specific to Chihuahua, national projections were used for gasoline and diesel. Projections for LPG and jet fuel are specific to the Northeastern Region of Mexico.

[3] Secretaría de Comunicaciones y Transportes: " Longitud De La Red Carretera Y Ferroviaria Por Mesoregión Y Entidad Federativa" Disponible en: http://Dgp.Sct.Gob.Mx/Fileadmin/User_Upload/Estadistica/Indicadores/Infra-Comytrans/Io5.Pdf
y "Distribución Porcentual De La Infraestructura De Transportes Y Comunicaciones Por Entidad Federativa Según Modo De Transporte Y Servicio De Comunicaciones". Disponible en: http://dgp.sct.gob.mx/fileadmin/user_upload/Estadistica/Indicadores/Infra-ComyTrans/IO4.pdf

Table C-2. Compounded Annual Growth Rates

Source	2007-2010	2010-2015	2015-2020	2020-2025
Road Transportation - Gasoline	2.6%	2.8%	1.9%	1.7%
Road Transportation - Diesel	1.8%	3.4%	2.5%	2.2%
Road Transportation - LPG	-25.5%	-1.4%	0.0%	0.0%
Road Transportation – Natural Gas	14.5%	14.9%	8.6%	6.2%
Aviation	-12.8%	3.0%	2.8%	2.5%
Rail	2.0%	2.3%	1.3%	1.4%

Road Transportation

Annual consumption of gasoline and diesel in Chihuahua for 1990-2007 was obtained from SENER. For diesel onroad transportation, estimates of marine and rail diesel (estimates discussed below) were subtracted from the total transportation diesel values for each year. Transportation LPG and natural gas consumption was not available for Chihuahua; therefore, consumption was estimated based on data in SENER's *Prospectiva del Mercado de Gas LP 2007–2016* and *Prospectiva del Mercado de Gas Natural 2007–2016* . For LPG, the proportion of transportation LPG to total LPG consumption for the northeastern region of Mexico was applied to total LPG consumption in Chihuahua. The same method was used to estimate transportation natural gas consumption in Chihuahua.

Emissions due to gasoline combustion by onrad transportation were calculated using a combination of emissions factors. The default CO_2 emission factor from the 2006 IPCC guidelines was used in conjunction with CH_4 and N_2O emissions factors reported in the INEGEI base on the national vehicle age distribution. The latter emissions factors change overtime in function of vehicle age and control technology and were available for the period 1990-2002. For the period 2003-2025., it was assumed that the CH_4 and N_2O emissions factors were the same as for year 2002. It is important to highlight that the emission factor for CO_2 is not sensitive to the use of control technology (catalytic converter). Table C-3 shows the set of emission factors utilized in this report.

Table C-3. Factores de Emisión para el Consumo de Gasolina en Autotransporte

Factores de Emisión del INEGEI (CH_4, N_2O) y del IPCC 2006 (CO_2) (kg/TJ)			
Ano	CO_2	CH_4	N_2O
1990	69,300	46.8	1.5
1991	69,300	46.8	1.5
1992	69,300	46.8	1.5
1993	69,300	45.39	1.767
1994	69,300	43.895	2.05
1995	69,300	43.242	2.174
1996	69,300	42.205	2.371
1997	69,300	40.685	2.659
1998	69,300	38.681	3.039
1999	69,300	36.719	3.41
2000	69,300	34.215	3.885
2001	69,300	31.74	4.354
2002	69,300	29.686	4.743

Marine Vessels

Marine diesel consumption was assumed to be zero for Chihuahua, since the state is land-locked and has no marine ports.

Aviation

Jet fuel consumption in Chihuahua for 1990-2007 was obtained from SENER. Consumption of aviation gasoline in Chihuahua was not available. However, aviation gasoline only accounts for about 1% of total aviation fuel consumption in Mexico.[4] Therefore, emissions from this fuel were assumed to be negligible.

Railways

Rail diesel consumption was not available for Chihuahua. Therefore, consumption was estimated for this fuel by allocating national usage to the state level. National rail fuel consumption for 1990-2002 was taken from the national GHG inventory. Consumption values were grown from 2002 to 2007 using daily rail diesel consumption values from SENER's *Prospectiva de Petrolíferos 2008-2017*. National consumption was allocated to Chihuahua using the proportion of national rail lines in Chihuahua. Actual activity, such as ton-miles of rail freight would provide more accurate allocation; however, these data are not available.

[4] Instituto Nacional de Ecología: Inventario Nacional de Emisiones de Gases de Efecto Invernadero 1990-2002.

Results

During inventory years (1990 through 2005), total transportation emissions increased by 66% reaching 5.6 $MMtCO_2e$ in 2005. In 1990, the largest sources of greenhouse gas emissions were activities relating to onroad gasoline and onroad diesel combustion, accounting for 87% of total transportation GHG emissions in 1990. The fastest growing source through the time period was road transportation LPG, with an average annual growth rate of 18% from 1990 to 2005, followed by road transportation gasoline (5%).

In 2025, total transportation emissions are expected to be on the order of 9.9 $MMtCO_2e$ representing a 193% increase from 1990. Road transportation emissions are expected to account for 97% of total transportation emissions in 2025. Aviation emissions decreased to zero in 2002 and are estimated to account for 0% in 2025, down from 6% in 1990. Rail emissions are expected to account for 3% of total transportation emissions in 2025, down from 7% in 1990

Table C-4 and Figure C-1 summarize greenhouse gas emission estimates by source. The distribution of greenhouse gas emissions by source is presented in Table C-5. Finally, emissions growth rates for selected time intervals are listed in Table C-6.

Table C-4. GHG Emissions from Transportation ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Road Transportation - Gasoline	1.95	2.88	3.05	3.84	4.57	5.26	5.77	6.29
Road Transportation - Diesel	0.96	1.13	0.97	1.37	2.10	2.49	2.81	3.14
Road Transportation - LPG	0.02	0.05	0.21	0.20	0.08	0.07	0.07	0.07
Road Transportation – Natural Gas	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03
Aviation	0.22	0.11	0.07	0.00	0.00	0.00	0.00	0.00
Rail	0.22	0.19	0.19	0.20	0.26	0.29	0.31	0.33
Total	**3.37**	**4.36**	**4.49**	**5.60**	**7.02**	**8.12**	**8.98**	**9.85**

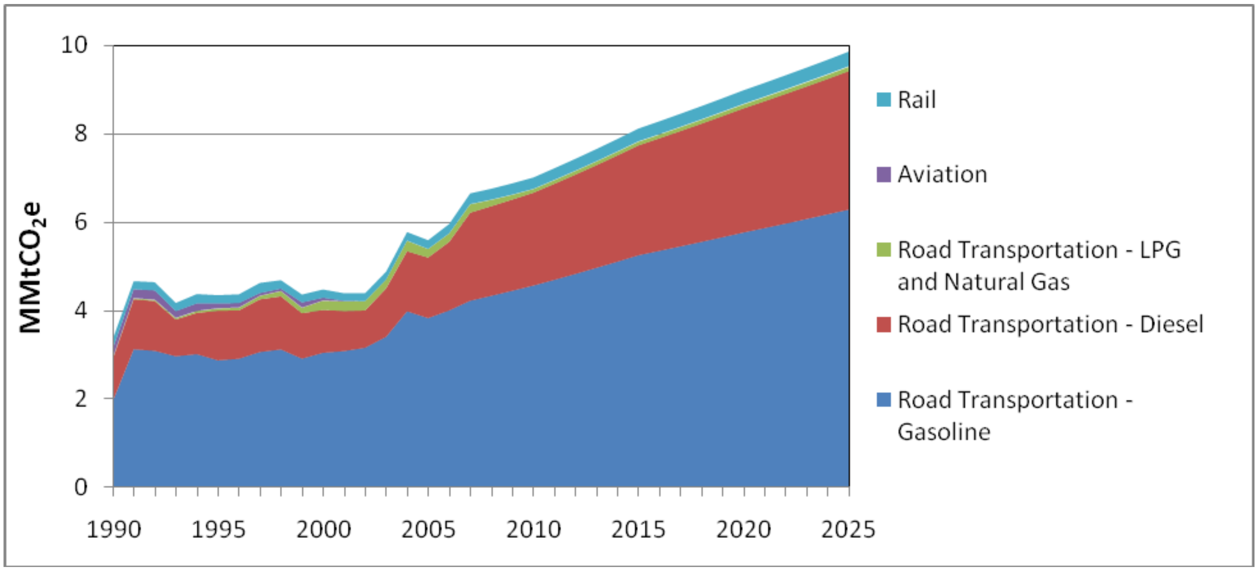
Table C-5. GHG Emissions Distribution in the Transportation Sector

Source	1990	1995	2000	2005	2010	2015	2020	2025
Road Transportation - Gasoline	57.9%	66.1%	68.0%	68.5%	65.2%	64.8%	64.2%	63.8%
Road Transportation - Diesel	28.6%	25.8%	21.7%	24.5%	30.0%	30.6%	31.3%	31.8%
Road Transportation - LPG	0.5%	1.2%	4.7%	3.5%	1.1%	0.9%	0.8%	0.7%
Road Transportation – Natural Gas	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.3%
Aviation	6.4%	2.6%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Rail	6.6%	4.3%	4.2%	3.5%	3.7%	3.5%	3.4%	3.3%

Table C-6. Percentage Change in GHG Emissions for Selected Time Intervals

Source	1990-2005	2005-2025	1990-2025
Road Transportation - Gasoline	97%	64%	223%
Road Transportation - Diesel	43%	128%	226%
Road Transportation - LPG	1027%	-63%	314%
Road Transportation – Natural Gas	NA	NA	NA
Aviation	-100%	NA	-100%
Rail	-11%	67%	48%

Figure C-1. Transportation Gross GHG Emissions by Fuel, 1990-2025



Key Uncertainties and Future Research Needs

Per the 2006 IPCC guidelines, fuel energy consumption is the preferred form of activity data.[5] State-level fuel consumption for rail diesel was not available and had to be estimated based on national consumption. National emissions were allocated to Chihuahua based on the proportion of it total rail line to the national total. More accurate estimates would be derived using estimates of actual rail activity (e.g. tonne-kilometers and/or passenger-kilometers). Based on current estimates, the contribution from the rail sector is very small.

Nitrous oxide and methane emission estimates are based on fuel consumption and on the type of control equipment installed in a vehicle. In order to capture the effect of control technology (e.g. oxidation catalyst) on greenhouse gas emissions, it is necessary to obtain a profile of Chihuahua's vehicle fleet indentifying the fraction of vehicles with control equipment.

As stated above, national projections were used for gasoline and diesel, and projections for the Northeastern Region of Mexico were used for LPG and jet fuel. Projections specific to Chihuahua would be preferred, since Chihuahua's fuel consumption may grow at a different rate than in the rest of Mexico. Significantly, the onroad fuel consumption projections do not factor in changes that are likely to occur in the future to improve the fuel economy of onroad vehicles. The U.S. Corporate Average Fuel Economy (CAFÉ) standards were revised through the Energy Independence and Security Act (EISA) of 2007 and further fuel economy improvements will be achieved in the U.S. through the national adoption of the California GHG vehicle emission standards through the 2016 model year. It is likely that many of the U.S. vehicles available for purchase in Mexico would be designed to meet these U.S. standards. Even with likely fuel economy improvements, the onroad vehicle sector is one where policies that could be enacted in Chihuahua or throughout Mexico in the future could result in significant reductions in GHG emissions.

[5] Section 3.2.1.3, Chapter 3, Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Appendix D. Industrial Processes and Product Use

Overview

Emissions in the industrial processes sector span a wide range of activities, and reflect non-combustion sources of GHG emissions. Combustion emissions for the industrial sector are covered in the Residential, Commercial, and Industrial Fuel Combustion sector. The industrial processes that exist in Chihuahua, and for which emissions are estimated in this inventory, include the following:

Carbon Dioxide Emissions:

- Non-combustion emissions from cement manufacturing *[IPCC category: Cement Production]* [1];
- Limestone and dolomite use*[IPCC category: Other Process Uses of Carbonates]*, which includes all uses that emit CO_2, except cement, lime, and glass manufacturing [2, 3]
- Non-combustion emissions from iron and steel production *[IPCC category: Iron and Steel Production]*[4]

Ozone depleting substance (ODS) substitutes:

- These are primarily HFCs used in refrigeration and air conditioning applications *[IPCC category: Refrigeration and Air Conditioning]* [5]

Other industrial processes that are sources of non-combustion GHG emissions but were not identified in Chihuahua include the following:

Carbon dioxide emissions from:

- Lime manufacture
- Soda ash manufacture and consumption
- Ammonia & urea production

Nitrous oxide emissions from

- Nitric acid production
- Adipic acid production[6]

HFC, PFC, and SF_6 emissions from:

- Semiconductor manufacturing
- Magnesium production
- Electric power transmission and distribution systems
- Hydrochlorofluorocarbon-22 (HCFC-22) production

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[1] 2006 IPCC, Volume 3, Chapter 2, Section 2.2.
[2] A primary use of limestone and dolomite includes agricultural soil amendment (to neutralize acidic soils). The agriculture appendix currently does not capture limestone and dolomite consumption; however, if consumption can be determined in future work, then analysis should be performed to reduce the potential for double-counting.
[3] 2006 IPCC, Volume 3, Chapter 2, Section 2.5.
[4] 2006 IPCC, Volume 3, Chapter 4, Section 4.2.
[5] 2006 IPCC, Volume 3, Chapter 7, Section 7.5.
[6] There is no adipic acid production in Mexico according to INE. *Informes del Inventario Nacional de Emisiones de Gases de Efecto Invernadero 1990 – 2002*. 2008.

- Aluminum production[7]

Evaluation of Registro de Emisiones y Transferencias de Contaminantes (RETC)

RETC stands for the Registry of Emissions and Pollutant Releases. The registry collects information on pollutant transfers to various media (air, water, or soil) during production processes of industrial establishments or activities performed by service establishments (e.g. dry cleaners, baths, hotels, etc.). RETC stores information starting with year 2004, covering 104 federally regulated substances including three GHGs: CO_2, N_2O, and CH_4.[8] Emissions data reported to the RETC were not used directly in this inventory. Rather, the RETC was used to identify industrial sources of GHG within the state.

The use of RETC in this inventory was limited due to a number of reasons. First, RETC provides outputs that combine energy and non-energy emission sources. The focus of the Industrial Processes sector is non-energy emission sources. The IPCC defines energy emissions as those resulting from the intentional oxidation of materials within an apparatus that is designed to provide heat or for use away from the apparatus.[9] Energy emissions are associated with the combustion of fossil fuels in ovens, boilers, furnaces, and engines; energy use emissions are reported as part of Electricity Supply, Transportation, Fossil Fuel Industries, and Residential, Commercial, Industrial Fuel Use. The distinction between energy and non-energy emission sources is significant and is best exemplified in the case of cement plants where non-energy emissions (CO_2) result from the calcination of raw minerals to produce clinker, whereas energy emissions relate to fossil fuel combustion in cement ovens. Second, RETC provides data for only 2004 and 2005. A two-year time series is not sufficient to identify emissions trends from historic activity data. Finally, RETC is a young program that is experiencing tremendous growth. In 2004, the number of participants nationwide totaled 1,715 and increased to 2,452 in 2005. The large difference in program participation suggests that the 2004 data set is incomplete in comparison with 2005.

In spite of these limitations, RETC was a valuable tool for identifying industrial sources of GHG emissions. Moreover, RETC has the potential to generate reports for energy and non-energy emissions since the registry operates with information from state and federal Cédulas de Operación Anual (environmental permits) detailing the quantity and nature of emission sources. Table D-1 lists businesses that reported GHG emissions to RETC. As mentioned above, values reflect both energy and non-energy related emissions.

[7] Idem. Aluminum is only produced in the state of Veracruz.
[8] This evaluation of RETC is based on data retrieved prior to June 1, 2009 from http://app1.semarnat.gob.mx/retc/tema/faq.html
[9] 2006 IPCC, Volume 3, Chapter 1, p.1.8

Table D-1. GHG Emissions Results from RETC (Metric Tons of CO_2e)

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
FOOD INDUSTRY				
BIMBO S.A. DE C.V.			2,449	
CONFECCIONES DE JUAREZ S.A. DE C.V.	2,076		5,924	
DULCES BLUEBERRY S.A. DE C.V	9,666			258
EMPACADORA Y FRIGORIFICO RODEO S.A.DE C.V.	153			
SIGMA ALIMENTOS NORESTE S.A. DE C.V. PLANTA CHIHUAHUA	2,571			
UNION DE GANADEROS LECHEROS DE JUAREZ S.A DE C.V			0	
ALCOHOL AND TOBACCO				
EMBOTELLADORA DE LA FRONTERA S.A DE C.V.			0	
NOVAMEX MEXICO S.A. DE C.V.	3,632		2,709	
METAL PRODUCTS MANUFACTURING				
APLICADORES MEXICANOS S.A. DE C.V.			0.03	
COLUMBUS INDUSTRIES MÉXICO S. DE R. L. DE C.V.	1,199		3	
GRUPO AMERICAN INDUSTRIES, S.A. DE C.V. PROYECTO WERNER 1			3,076	
INTERNATIONAL MANUFACTURING SOLUTIONS OPERACIONES S DE R L DE C V PLANTA 9			0.1	
MAQUILADOS TECNICOS S.A. DE C..V.	1,242			
POTTER & BRUMFIELD DE MÉXICO S.A DE C.V.			3	
PRODUCTOS DE AGUA S. DE R.L. DE C.V.	1,526		2,227	
PRODUCTOS DE CONSUMO ELECTRONICO PHILIPS S.A. DE C.V. PLANTA 10	220			
PULIDOS DE JUAREZ SA DE CV			0.0001	
SABRE MANUFACTURING S. DE R.L. DE C.V. PLANTA I			1	
SABRE MANUFACTURING S. DE R.L. DE C.V. PLANTA II			1	
SENSUS METERING SYSTEMS DE MEXICO, S. DE R.L. DE C.V.			55	
SYSTEM SENSOR DE MEXICO S. DE R.L. DE C.V.	136		7	
THOMSON TELEVISIONES DE MEXICO S.A. DE C.V.	1,546		227	
TORO COMPANY DE MEXICO S. DE R.L. DE C.V.			0.004	
TORO COMPANY DE MÉXICO S. DE R.L. DE C.V. PLANTA II			941	
VIENTEK MEXICO S. DE R.L DE C.V..			0.01	
PLASTIC PRODUCTS MANUFACTURING				
ARBOLES NAVIDEÑOS DE JUARÉZ S.A. DE C.V.	436		458	
GRUPO AMERICAN INDUSTRIES S.A. DE C.V. PROYECTO FLEXFAB	51,000		1,649	
GRUPO AMERICAN INDUSTRIES S.A. DE C.V. PROYECTO WERNER 2			144	
INDUSTRIAL INTERNATIONAL SERVICES S.A DE C.V.			0.0000	
INDUSTRIAS BM DE MEXICO S.A. DE C.V.	2,093		1,836	
INTERNATIONAL MANUFACTURING SOLUTIONS OPERACIONES S. DE R. L. DE C. V. PLANTA 16			41	
THERMOTECH S.A. DE C.V.			5	
PRODUCTS COMPOSED OF DIFFERENT MATERIALS				
ANSELL PERRY DE MEXICO S.A DE C.V PLANTA SALVARCAR			0.2	

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
CORDIS DE MEXICO S.A. DE C.V.	1,209		3,311	
CRITIKON DE MÉXICO S. DE R.L. DE C.V.	363		376	
DAVOL SURGICAL INNOVATIONS S.A. DE C.V.	313		313	
DYNAMIC PLASTICS MEXICANA S.A DE C.V				4
EATON MOLDED PRODUCTS S. DE R.L. DE C.V.			205	
EES S.A. DE C.V.	700		700	
EES S.A. DE C.V. PLANTA 2			55	
GRUPO AMERICAN INDUSTRIES S.A. DE C.V. PLANTA 1	92,972		56	
GRUPO AMERICAN INDUSTRIES S.A. DE C.V. PLANTA 2	91,503		329	
GUADALUPE GUTIERREZ GARCIA			8	
INTERMEX MANUFACTURA S.A. DE C.V. PLANTA 8 TOMOEGAWA			0.02	
MMJ S.A. DE C.V. PLANTA 2			600	
MMJ S.A. DE C.V. PLANTA BERMÚDEZ			3	
PHTP AUTOMOTIVE MEXICOS.A DE C..			0.03	
PRODUCTION SHARING DE MEXICO S.A. DE C.V. PLANTA II			916	
SIPPICAN DE MEXICO S DE R.L. DE C.V.			0.0000	
SPECIALTY PACKAGING PRODUCTS DE MEXICO S.A. DE C.V.			9	
SUBENSAMBLES INTERNACIONALES S.A. DE C.V.			1,899	
TOSHIBA ELECTROMEX S.A DE C.V.				87
VENUSA DE MÉXICO SA DE CV PLANTA 1	111		0.4	
VENUSA DE MEXICO SA DE CV PLANTA 2			1	
AUTOMOTIVE				
AUTOVIDRIO S.A. DE C.V.	841			
CABLE BERGEN DE MEXICOS.S.A DE C.V.			7	
CADIMEX S.A. DE C.V.	103			
CAPSONIC S.A. DE C.V.			206	
COCLISA S.A DE C.V. PLANTA SAN LORENZO	1,183		1,371	
COCLISA S.A. DE C.V. COMPLEJO OMEGA	6,922		9,960	
DELMEX DE JUAREZ S. DE R.L. DE C.V.			2,181	
DELMEX DE JUAREZ S. DE R.L. DE C.V. PLANTA II	5,717		5,619	
DELPHI AUTOMOTIVE SYSTEMS, S.A. DE C.V.			190	
EAGLE OTTAWA S.A. DE C.V. PLANTA BERMÚDEZ	340		340	
EAGLE OTTAWA S.A. DE C.V. PLANTA JARUDO			431	
ENSAMBLE DE INTERIORES AUTOMOTRICES S. DE R.L. DE C.V.	321		669	
ENSAMBLE DE INTERIORES AUTOMOTRICES S. DE R.L. DE C.V. PLANTA II	370		370	
ENSAMBLE DE INTERIORES AUTOMOTRICES, S. DE R.L. DE C.V	150			
EXPORTACIONES DIAZ S.A. PLANTA II			0.5	
GRUPO AMERICAN INDUSTRIES S.A. DE C.V. PROYECTO CAMOPLAST	7,608			
GRUPO AMERICAN INDUSTRIES S.A. DE C.V. PROYECTO INTERDYNAMICS			583	
HOWE DE MEXICO S.A. DE C.V.			0.01	
INDUSTRIAL DE MOLDEO DE MÉXICO S. DE R. L. DE C.V.			0.1	
JEMCO DE MEXICO S.A. DE C. V. PLANTA GUADALUPE			0.03	

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
JEMCO DE MEXICO S.A. DE.C. V. PLANTA JUAREZ			0.03	
KEY SAFETY SYSTEMS DE MEXICO S. DE R.L. DE C.V.	226			
LABINAL DE CHIHUAHUA S.A. DE C.V. PLANTA I			3	
LABINAL DE CHIHUAHUA S.A. DE C.V. PLANTA II			38,105	
LEAR MEXICAM TRIM OPERATIONS S.DE R.L DE C.V. PLANTA JUAREZ.	459		459	
LEAR MEXICAN TRIM OPERATION S. DE R.L DE C.V.			194	
LEAR MEXICAN TRIM OPERATIONS PLANTA VICTORIA			0.001	
LEAR MEXICAN TRIM OPERATIONS S. DE R.L. DE C.V.	528		1,056	
LEAR MEXICAN TRIM OPERATIONS S. DE R.L. DE C.V. PLANTA RÍO BRAVO			283	
LEAR MEXICAN TRIM OPERATIONS S.R. DE C.V. PLANTA SAN LORENZO	194			
MANUFACTURERA EL JARUDO S. DE R.L. DE C.V.	1,621			
MORSE AUTOMOTIVE CORPORATION MÉXICO S DE R. L DE C.V.	2,413		2,378	
NORTH AMERICAN PRODUCTION SHARING DE MEXICO S.A. DE C.V.			3	
PRODUCTOS POWERS DE MEXICO S.A. DE C.V.			30	
RIO BRAVO ELECTRICOS, S.A. DE C.V. PLANTA XX			16,747	
ROBERT BOSCH SISTEMAS AUTOMOTRICES S.A. DE C.V.	201		126	
SIEMENS VDO S.A DE C.V			4	
SMALL PARTS DE MEXICO S. DE R.L DE C.V.	143		94	
STRATTEC COMPONENTES AUTOMOTRICES S.A. DE C.V.	331		257	
STRATTEC DE MÉXICO S.A. DE C.V.	970		1,009	
VIDRIOCAR S. DE R.L. DE C.V.			833	
PULP AND PAPER				
AVERY DE MEXICO S.A. DE C.V.			544	
CORRMEX CIUDAD JUAREZ C.A DE C.V			0.0001	
EXPORTACIONES DIAZ S.A. PLANTA I			2,520	
PACTIV MEXICO S. DE R.L. DE C.V.	10,655			
SMURFIT CARTON Y PAPEL DE MEXICO S.A. DE C.V.			3,900	
CEMENT AND LIME				
GCC CEMENTO S. A. DE C. V. PLANTA SAMALAYUCA			645,975	
GCC CEMENTO S.A. DE C.V.	20,516			
GCC CONCRETO S.A. DE C.V. PLANTA BLOQUERA III			708	
GCC CONCRETO S.A. DE C.V. PLANTA PORVENIR			4	
PRODUCTOS DE BARRO INDUSTRIALIZADO S. A.	1,910		2,423	
ELECTRONICS				
ADEMCO DE JUAREZ S.A. DE C.V.			1,471	
ADVANCE TRANSFORMER CO. S. A. DE C. V. DIVISIÓN CAPACITORES			13	
ADVANCE TRANSFORMER CO. S.A. DE C.V. DIVISION FESA			4,577	
ALAMBRADOS Y CIRCUITOS ELÉCTRICOS, S.A. DE C.V. PLANTA IV	157			
ALAMBRADOS Y CIRCUITOS ELÉCTRICOS, S.A. DE C.V. PLANTA VI	173			
ARK LES COMPONENTS S.A DE C.V.			30	
AUTOELECTRONICA DE JUAREZ S.A DE C.V. PLANTA I			0.1	

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
AUTOELECTRONICA DE JUÁREZ S.A DE C.V.PLANTA II	15,753		15,753	
AUTOPARTES Y ARNESES DE MEXICO S.A. DE C.V.			0.04	
AUTOPARTES Y ARNESES DE MEXICO S.A. DE C.V. PLANTA 2			350	
AUTOPARTES Y ARNESES DE MEXICO S.A. DE C.V. PLANTA 7			228	
AUTOPARTES Y ARNESES DE MEXICO S.A. DE.C.V.PLANTA 1			227	
BARLOMEX S.A. DE C.V.			0.01	
BEL MANUFACTURERA S.A. DE C.V. PLANTA 4	2,968		2,728	
BOBINAS DE CALIDAD S. DE R.L. DE C.V.			17	
BOBINAS DEL SUR S.A. DE C.V.			31	
BURNER SYSTEMS INTERNATIONAL DE JUAREZ S.A. DE C.V.			215	
BUSSMANN S. DE R.L. DE C.V.			65	
CADIMEX S.A. DE C.V.			14	
CHERRY DE MEXICO S.A. DE C.V			0.04	
COMPONENTES DE ILUMINACION S.DE R.L. DE C.V.			1,174	
COMPONENTES ELECTRICOS DE LAMPARAS S.A DE C.V			234	
CONDUCTORES TECNOLIGICOS DE JUAREZ SA DE CV PLANTA 6A			7	
CONDUCTORES TECNOLOGICOS DE JUAREZ SA DE CV PLANTA 1			17	
CONDUCTORES TECNOLOGICOS DE JUAREZ SA DE CV PLANTA 2			11	
CONDUCTORES TECNOLOGICOS DE JUAREZ SA DE CV PLANTA 3			4	
CONDUCTORES TECNOLOGICOS DE JUAREZ SA DE CV PLANTA 4			8	
CONDUCTORES TECNOLOGICOS DE JUAREZ SA DE CV PLANTA 5			20	
CONDUCTORES TECNOLOGICOS DE JUAREZ SA DE CV PLANTA 6B			7	
DIGITAL CONCEPTS DE MEXICO S.A DE C.V.	318			
ELCOTEC JUAREZ, S.A. DE C.V.	502			
ELECTRO COMPONENTES DE MÉXICO S.A. DE C.V. PLANTA 1	107		107	
ELECTRO COMPONENTES DE MEXICO S.A. DE C.V. PLANTA 2			66	
ELECTRO COMPONENTES DE MEXICO S.A. DE C.V. PLANTA 3			3	
ENLIGHT MEXICO S.A DE C.V			0.0000	
FCI ELECTRONICS MEXICO S. DE R.L DE C.V.			0.06	
FOSTER ELECTRIC MEXICO S.A. DE C.V.	198		12	
FOXCONN MEXICO PRECISION INDUSTRY CO. S.A. DE C.V.	125		206	
GENASCO S. A. DE C. V.			133	
HARMAN BECKER AUTOMOTIVE SYSTEMS SA DE CV			84	
HARPER MEX S.A. DE C.V.	108			
HOPKINS MANUFACTURING DE MEXICO S. DE R.L. DE C.V.			149	
I.G. MEX. S. DE R.L. DE C.V. PLANTA 3			31	
IG MEX S DE R.L. DE C.V. PLANTA 2	767		980	
IG MEX S DE R.L. DE C.V. PLANTA 6			277	

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
IG MEX S. DE R.L. DE C.V. PLANTA 4	7,660			
IK PRECISION DE MEXICO SA DE CV IKPMI			4	
IK PRECISION DE MEXICO SA DE CV PLANTA IKPME			7	
INDUSTRIA DE TRABAJOS ELECTRICOS S.A. DE C.V.			72	
INTERNATIONAL MANUFACTURINFG SOLUTIONS OPERACIONES S DE R L DE C V PLANTA 15			0.03	
INTERNATIONAL MANUFACTURING SOLUTIONS OPERACIONES S DE R L DE C V PLANTA 11			8	
INTERNATIONAL MANUFACTURING SOLUTIONS OPERACIONES S DE R L DE C V PLANTA 13			35	
JUVER INDUSTRIAL S.A. DE C.V.	244		236	
KENSA DE MEXICO S. DE R.L. DE C.V.			0.0000	
KLINGLER INTERNATIONAL TECHNOLOGIES DE MEXICO S. A. DE C.V			2	
LEAR ELECTRICAL SYSTEMS DE MEXICO S. DE R.L DE C.V. PLANTA FUENTES			36	
LEAR ELECTRICAL SYSTEMS DE MEXICO S. DE R.L DE C.V. PLANTA SENECU			36	
LEAR ELECTRICAL SYSTEMS DE MÉXICO S. DE R.L. DE C.V. PLANTA MONARCA			89	
LEAR ELECTRICAL SYSTEMS DE MÉXICO S. DE R.L. DE C.V. PLANTA REFORMA	832,769		14	
LEVITON DE MEXICO S. DE R.L. DE C.V.			11	
LEXMARK INTERNACIONAL S.A DE C.V BA1			45	
LITE ON MEXICO S DE RL DE CV			19,322	
MANUFACTURAS AVANZADAS S.A. DE C.V.	222			
MOTORES ELECTRICOS DE JUAREZ S. DE R.L. DE C.V. PLANTA FCDM	4,615		1,000	
MOTORES ELECTRICOS DE JUAREZ S. DE R.L. DE C.V. PLANTA FCM	149		0.1	
MOTORES ELECTRICOS DE JUAREZ S. DE R.L. DE C.V. PLANTA FME	229		986	
MOTORES ELECTRICOS DE JUAREZ S. DE R.L. DE C.V. PLANTA IGMEX PLANTA 4			4,864	
MOTORES ELECTRICOS DE JUAREZ S. DE R.L. DE C.V. PLANTA MEJ 1			22	
MOTORES ELECTRICOS DE JUAREZ S. DE R.L. DE C.V. PLANTA MEJ 2	248		298	
OPERACIONES DE MAQUILA DE JUAREZ S. DE R.L. DE C.V.	3,807			
OPTRON DE MEXICO S A DE C V			41	
OUTOKUMPU HEATCRAFT DE MEXICO S. DE R. L. DE C. V.				0.1
PEIKER ACUSTIC DE MEXICO S A DE C V			26	
PLATI MEXICO S.A. DE C.V.			5	
PLEXUS ELECTRÓNICA S. DE R. L DE C. V.	238			
PRODUCTOS DE CONSUMO ELECTRONICO PHILIPS S. A. DE C. V.			135	
RAPID INDUSTRIES DE MEXICO S.A DE C. V.			0.02	
RAYCHEM JUÁREZ S.A DE C.V	344			
RIO BRAVO ELÉCTRICOS, S.A. DE C.V. PLANTA IV	211		314	
RIO BRAVO ELÉCTRICOS, S.A. DE C.V. PLANTA VII	177			
SGI DE MEXICO S.A DE C.V.	2,000		1,998	
SHURE ELECTRONICA S.A DE C.V.			2	

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
SISTEMAS ELÉCTRICOS Y CONMUTADORES, S.A. DE C.V.	289		213	
SISTEMAS Y CONEXIONES INTEGRADAS S.A. DE C.V.			466	
SOLECTRON GLOBAL SERVICES MEXICO S.A. DE C.V.			1,075	
SPECTRUM CONTROL DE MEXICO S.A. DE C.V.			2	
SYLVANIA COMPONENTES ELECTRONICOS S.A.			6	
TATUNG MEXICO SA DE CV			4	
TECNOLOGIA DE ILUMINACIÓN AUTOMOTRIZ S A DE C V			1	
TOTOKU ELECTRONICA MEXICANA S.A. DE C.V.			10	
WISTRON MEXICO S.A. DE C.V.	775		389	
WOODHEAD DE MEXICO S.A. DE C.V. PLANTA 1			0.02	
WOODHEAD DE MEXICO S.A. DE C.V. PLANTA 2			0.001	
ELECTRIC GENERATION				
COMISION FEDERAL DE ELECTRICIDAD C.CICLO COMBINADO SAMALAYUCA II	739,792		595,218	
COMISION FEDERAL DE ELECTRICIDAD C.T. GRAL.FRANCISCO VILLA			1,626	
COMISION FEDERAL DE ELECTRICIDAD C.T. SAMALAYUCA I			1,072	
COMISION FEDERAL DE ELECTRICIDAD C.TG. JUAREZ INDUSTRIAL			0.003	
COMISION FEDERAL DE ELECTRICIDAD C.TG. JUAREZ PARQUE			0.01	
FLEXCEL JUAREZ S.A. DE C.V.			0.2	
MCS DE MEXICO S.A. DE C.V.			0.0001	
METALLURGICAL (INCLUDING STEEL)				
ADVANCE TRANSFORMER CO. S.A DE C.V.			1	
BRP MEXICO S.A. DE C.V.			0.5	
CMC COMMERCIAL METALS DE MEXICO S. DE R.L. DE C.V.	3,199			
CONTROLES DE TEMPERATURA S.A. DE C.V.			0.002	
ELECTROLUX HOME PRODUCTS DE MEXICO S.A. DE C.V.			1,889	
FALCON DE JUAREZ S.A. DE C.V.			158	
FUNDIDORA DE LA FRONTERA S.A DE C. V.			0.02	
FUNDIDORA URECA S. A. DE C. V.	829		842	
I G MEX S DE R.L. DE C.V. PLANTA 5			21	
INDUSTRIAL DIGITAL JUAREZ S.A. DE C.V.			0.0000	
INDUSTRIAS SELKIRK DE MEXICO S. DE R.L. DE C.V.			1	
MICROCAST TECHNOLOGIES MEXICANA S. DE R.L. DE C.V.	17,323		20,568	
MINAS DE LA ALTA PIMERIA S.A. DE C.V.			324,215	
PETROLEUM AND PETROCHEMICAL INDUSTRY				
GASODUCTOS DE CHIHUAHUA S. DE R.L. DE C.V.		7,707		
PEMEX GAS Y PETROQUIMICA BASICA SUBDIRECCION DE DUCTOS SECTOR		3,920		
TERMINAL DE DISTRIBUCIÓN DE GAS LICUADO CIUDAD JUÁREZ CHIHUAHUA			0.3	
PAINTS AND INKS				
EPSON DE JUAREZ S.A. DE C.V. PLANTA 1	250		189	
EPSON DE JUAREZ S.A. DE C.V. PLANTA 2			75	
CHEMICAL MANUFACTURING				
AGRIESTRELLA S. DE R.L. DE C.V.	3,687			

SECTOR/COMPANY	2004		2005	
	CO_2	CH_4	CO_2	CH_4
ANSELL EDMONT INDUSTRIAL INC. DE MEXICO S.A. DE C.V.			0.3	
CREATEC DE MEXICO S DE R L DE C V	10,674		5,110	
CRONI S.A DE C.V.	2,566		1,055	
FANOSA S.A. DE C.V.			1,619	
FOAMEX DE JUAREZ S.A. DE C.V.			27	
GUAJADO INDUSTRIAL S.A. DE C.V.			1,805	
PETRO PAC DE CHIHUAHUA S.A. DE C.V.	4,014		4,014	
PLASTICO GIGANTE DE MEXICO S.A. DE C.V.			5	
PRINCE MANUFACTURING DE MEXICO S. DE R.L. DE C.V.			2,575	
PRODUCTOS QUÍMICOS DE CHIHUAHUA S.A. DE C.V.			338	
SCA NORTH AMERICAN PACKAGING DE DIVISION S.A. DE C.V.			0.03	
SOLVAY FLUOR MEXICO S.A. DE C.V.	5,464			
SPECIALTY MINERALS S.A. DE C.V.			0.3	
TEXTILES				
AMEX MEXICANA S.A DE C.V.			1	
BOMAR DE MEXICO S.A DE C.V			11	
CONVERTORS DE MEXICO S.A DE C.V			86	
INTERNATIONAL MANUFACTURING SOLUTIONS OPERACIONES S DE R L DE C V PLANTA 5			0.02	
MANUFACTURAS DIVRSIFICADAS S.A. DE C.V.	490		490	
MANUFACTURAS Y SERVICIOS INTERNACIONALES S. DE R.L. DE C.V.			29	
MOLNLYCKE HEALTH CARE S.A. DE C.V. PLANTA 1	313		313	
MOLNLYCKE HEALTH CARE S.A. DE C.V. PLANTA 2			46	
VAL MEX SA DE CV			36	
OTHER				
ARCHWAY MARKETING SERVICES DE MEXICO S.A. DE C.V.			77	
ARROW GAMES DE MEXICO S.A. DE C.V.			0.001	
DATAMARK DE MEXICO S.A. DE C.V.			81	
EDM S. DE R.L. DE C.V. PLANTA CENTRO			0.003	
EDM S. DE R.L. DE C.V. PLANTA SALVARCAR			0.03	
INGENIERIA EN MANUFACTURAS Y SERVICIOS S.A. DE C.V.			431	
MONARCH LITHO DE MEXICO S.A. DE C.V.			44	
PROMOTORA COMERCIAL DE LAS ARTES GRAFICAS S.A DE C.V.			1	
TOTAL	1,992,142	11,626	1,795,211	349

Historical Emissions and Reference Case Projections

Greenhouse gas emissions were estimated using the 2006 IPCC Guidelines.[10] Table D-2 identifies for each emissions source category the information needed for input to calculate emissions, the data sources used for the analyses described here, and the historical years for which emissions were calculated based on the availability of data.

[10] 2006 IPCC Guidelines, Volume 3.

Table D-2. Approach to Estimating Inventory Emissions

Source Category	Time Period for which Data Available	Required Data	Data Source
Cement Manufacture	2000-2008	Metric tons (Mt) of clinker produced	National cement production and the inventory of manufacturing plants by state retrieved from Camara Nacional de Cemento statistics. http://www.canacem.org.mx/la_industria_del_cemento.htm 2004-2008 data replaced with production data from Grupo Cementeros de Chihuahua. Clinker content developed by CCS from INEGI national cement statistic data and IPCC characterization of cement blends.
Limestone and Dolomite Consumption	2003-2007	Mt of limestone and dolomite consumed	Consumption was assumed to be equal to limestone production less the amount of limestone in cement. Source: Servicio Geológico Mexicano. 2008. *Anuario Estadístico de la Minería Mexicana Ampliada, 2007*. Estadísticas por Producto para Minerales Metálicos y no Metálicos, Capítulo IV.
Iron and Steel Production	2003-2007	Mt of crude steel produced by production method	Servicio Geológico Mexicano. 2008. *Anuario Estadístico de la Minería Mexicana Ampliada, 2007*. Estadísticas por Producto para Minerales Metálicos y no Metálicos, Capítulo IV.
ODS Substitutes	1980-2007	Number of operating vehicles	Instituto Nacional de Estadísticas, Geografía, e Informática. Estadísticas de vehículos de motor registrados en circulación. http://www.inegi.org.mx/inegi/default.aspx

Cement production for 2004-2008 was provided by Grupo Cementeros de Chihuahua.[11] Cement production for 2000-2004 was estimated based on national production and the number of cement manufacturing plants in the state. National production data were not available for 1990-1999. For these years, production was estimated based on the state population and the estimate of national per capita cement consumption for 2000 from Camara Nacional de Cemento. 2006 IPCC methodologies require the identification of the clinker concentration in a given cement blend. Based on national cement statistics covering the period 1994-2008, the weighted average concentrations of clinker per cement blend was determined. Prior to 1994, the average concentration of clinker was applied. Table D-7 summarizes the analysis of clinker content by cement blend. Finally, the amount of clinker produced is multiplied by the default 2006 IPCC emission factor (0.52 metric tons CO_2 per metric ton of clinker) to calculate emissions.

Limestone and dolomite consumption includes all uses except cement manufacturing. Strictly following the IPCC methodology, limestone and dolomite used in lime manufacturing and glass manufacturing would also be subtracted and reported separately. However, due to a lack of state-level data for lime and glass manufacturing, consumption in these processes is included in the limestone and dolomite consumption category. Limestone and dolomite consumption data were unavailable; therefore, consumption was assumed to equal in-state production of these minerals

[11] Email correspondence between Ing. Bertha Terán of Secretaría de Desarrollo Urbano y Ecología and Ing. Raúl A. Ambriz of Grupo Cementeros de Chihuahua, 5/13/09.

minus limestone used for cement manufacturing (to avoid double-counting).[12] Limestone production data were only available for 2003-2007. Limestone production for 2002 was assumed to be the same as 2003, and 1990-2002 values were estimated by assuming the same trend as found in the national limestone production values from the INEGEI. The default emission factor was 0.44 tons of CO_2 per ton of mineral consumed. .

Iron production data are available and the RETC confirms that there are several facilities involved in iron smelting within the state. However, state-level steel production data from CANACERO does not list Chihuahua.[13] Therefore, the IPCC emission factor for pig iron not processed into steel[14] was used to estimate emissions from iron processing. Production data for iron was only available for 2003-2007. Production values for 1990-2002 were assumed to be equal to the smallest production value during the 2003-2007 period.

IPCC methods were not used to estimate HFC's from mobile air-conditioning systems. These were calculated using an approach developed for the State of Baja California's 2005 GHG inventory.[15] This approach consists of basing emissions on the number of vehicles operated during each year in the state[16] and the assumption that all vehicles are equipped with air conditioning units. This approach deviates from the methodology outlined in Section 7.5.2, Chapter 7, Volume 3 of the 2006 IPCC Guidelines;[17] however, it was adopted in the absence of better activity data (e.g. HFCs sales information for the IPCC methodology). The number of mobile air conditioning units was converted to emissions using an emission factor published by IPCC in a special technical report.[18] Emissions from stationary refrigeration units were not included in this inventory.[19]

Similarly, ODS substitute emissions from refrigeration and stationary air conditioning were calculated using the approach adopted in Baja California's GHG inventory. This approach consists of basing emissions on the number and size of homes connected to the electricity grid. It is assumed that all homes with electricity have one refrigerator and one stationary air conditioning unit. Homes with two or more rooms were assumed to own two air conditioning units. This approach deviates from methodology outlined in Section 7.5.2, Chapter 7, Volume 3 of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National

[12] IPCC default values were used to estimate limestone consumption in cement manufacturing. Cement is assumed to contain 75% clinker, clinker is assumed to be 65% lime, and 100% of the lime is assumed to come from limestone.
[13] Camara Nacional de la Industria del Hierro y del Acero (CANACERO). Subgerencia de Análisis Estadístico e Información . 2009.
[14] 1.35 mt of CO2/mt of pig iron, Volume 3 of the 2006 IPCC Guidelines
[15] *Inventario de Emisiones de Gases de Efecto Invernadero del Estado de Baja California 2005: Versión Final Secretaría de Protección al Ambiente del gobierno del estado Baja California,* Centro Mario Molina, Diciembre, 2007, pp. 26-27.
[16] Instituto Nacional de Estadística Y Geografía (INEGI). Motor Vehicle Active Registration Statistics.
[17] Retrieved May, 2008 from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.
[18] IPCC/TEAP, Bert Metz, Lambert Kuijpers, Susan Solomon, Stephen O. Andersen, Ogunlade Davidson, José Pons, David de Jager, Tahl Kestin, Martin Manning, and Leo Meyer (Eds). *Safeguarding the Ozone Layer and the Global Climate System: Issues related to hydrofluorocarbons and perfluorocarbons*. Cambridge University Press: Cambridge, England. 2005 (p. 306) http://www.ipcc.ch/pdf/special-reports/sroc/sroc_full.pdf.
[19] Emissions from stationary refrigeration is assumed to be HCFC-22, a hydrochlorofluorocarbon subject to the stipulation of the Montreal Protocol and exempt from GHG inventory considerations.

Greenhouse Gas Inventories[20]; however, it was adopted in the absence of better activity data (e.g. HCFCs sales information). Moreover, this approach assumes that 10% of all units have leaks and 15% of the refrigerant released is composed of HCFC-22. The latter is a hydrochlorofluorocarbon subject to the stipulation of the Montreal Protocol and exempt from GHG inventory considerations. Emissions associated with HCFC-22 were included in this appendix for the purposes of comparison. Nonetheless, HCFC-22 emissions will not be incorporated in the state summary of GHG emissions.

Table D-3 lists the data and methods that were used to estimate future activity levels related to industrial process emissions and the annual compound growth rates computed from the data/methods for the reference case projections. Sources of economic forecast data were not identified; therefore, forecasts were based on historical data. Historical data for iron production (tons), mineral products production (man hours), and total manufacturing volume were obtained from Sistema Nacional de Información Estadística y Geográfica (SNIEG).[21]

Table D-3. Approach to Estimating Projections for 2005 through 2025

Source Category	Projection Assumptions	Average Annual Growth Rates (%)			
		2005 - 2010	2010 - 2015	2015 - 2020	2020 - 2025
Cement Manufacture	Based on 2003-2007 mineral products manufacturing man hours from SNIEG	8.2	4.5	3.7	3.1
Limestone and Dolomite Consumption	Based on 2003-2007 manufacturing physical volume from SNIEG	-1.5	2.4	2.1	1.9
Iron and Steel Production	Based on 2003-2008 iron production (tons) from SNIEG	-1.1	3.3	2.8	2.5
ODS Substitutes	Based on 2003-2007 vehicle registration data from INEGI	4.1	3.1	2.7	2.3

Results

GHG emissions have been summarized in Figure D-1 and Table D-4. The distribution of emissions in the industrial processes sector is shown for selected years in Table D-5. In 2005, GHG emissions from non-combustion industrial processes were estimated to be about 2.2 $MMtCO_2e$. The largest source of emissions is limestone and dolomite use, followed by iron and steel production. Forecast industrial process and product use emissions are projected to reach about 3.6 $MMtCO_2e$ by 2025, of which 33% is expected be associated with limestone and dolomite use, 32% associated with cement manufacture, and 26% associated with iron and steel production. Emissions associated with the release of ODS substitutes are projected to increase by

[20] Retrieved May, 2008 from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
[21] Sistema Nacional de Información Estadística y Geográfica (SNIEG), http://www.inegi.org.mx/inegi/default.aspx?s=est&c=125&e=08.

about 1.4 $MMtCO_2e$ from 2005 through 2025; however, their relative contribution to total industrial process and product use emissions is expected to remain constant at about 8%.

Figure D-1. GHG Emissions from Industrial Processes 1990-2025

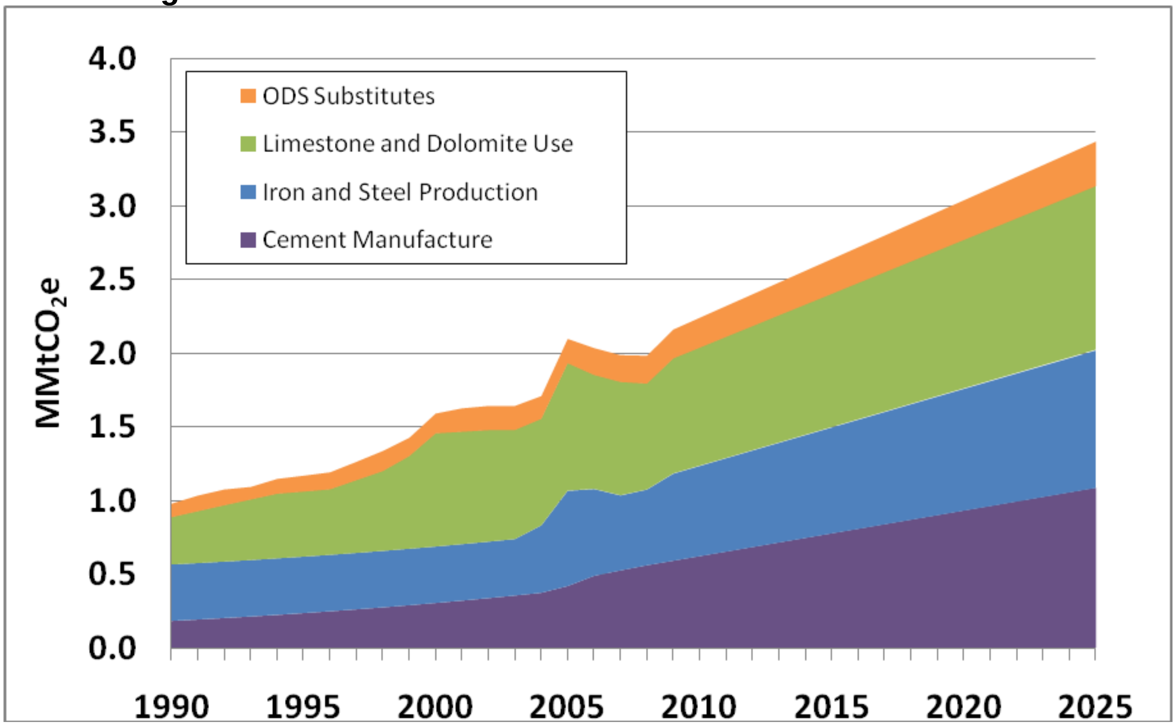


Table D-4. Historic and Projected GHG Emissions for Industrial Processes ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Cement Manufacture	0.18	0.24	0.30	0.42	0.62	0.78	0.93	1.09
Limestone and Dolomite Use	0.32	0.45	0.77	0.87	0.81	0.91	1.01	1.12
Iron and Steel Production	0.38	0.38	0.38	0.65	0.61	0.72	0.83	0.94
ODS Substitutes	0.09	0.11	0.13	0.17	0.20	0.24	0.27	0.30
Grand Total	**0.98**	**1.17**	**1.59**	**2.10**	**2.25**	**2.64**	**3.04**	**3.44**

Table D-5. GHG Emission Distribution for Industrial Processes (Percent)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Cement Manufacture	19%	20%	19%	20%	28%	29%	31%	32%
Limestone and Dolomite Use	33%	38%	48%	41%	36%	34%	33%	32%
Iron and Steel Production	39%	33%	24%	31%	27%	27%	27%	27%
ODS Substitutes	9.4%	9.2%	8.5%	7.9%	9.1%	8.9%	8.9%	8.8%

Table D-6. HCFC Emissions from Refrigeration and Air Conditioning

Year	1990	1995	2000	2005	2010	2015	2020
Refrigeration (kg HCFC-22)	1,052	1,203	1,315	1,396	1,467	1,533	1,601
Air Conditioning (kg HCFC-22)	25,625	29,315	32,037	34,015	35,750	37,351	39,024
Total (MMtCO2e)	0.045	0.052	0.057	0.060	0.063	0.066	0.069

Table D-7. Clinker Content in National Production of Cement

Año	National production by cement blend in metric tons					Clinker content (weighted average)
	Portland Gris (96% clinker)	Blanco (28.8% clinker)	Mortero (64% clinker)	Other (64.4% clinker)	Clinker (100% clinker)	
1994	30,243,326	516,684	720,232	113,625	220,619	94.1%
1995	24,033,981	441,975	645,663	173,169	793,455	94.0%
1996	26,440,746	466,440	1,140,024	127,125	1,447,276	93.8%
1997	27,679,233	530,803	1,316,355	158,327	1,073,967	93.4%
1998	28,608,786	568,795	1,549,994	187,670	592,846	93.1%
1999	29,738,734	642,632	1,420,243	156,321		93.1%
2000	31,518,759	613,075	1,096,005	201,128		93.5%
2001	30,177,359	636,394	1,319,868			93.3%
2002	30,897,412	623,680	1,850,420			93.0%
2003	31,143,454	632,386	1,817,561			93.0%
2004	32,374,824	680,380	1,937,238			92.9%
2005	34,571,534	773,499	2,106,583			92.8%
2006	37,180,967	843,869	2,337,166			92.7%
2007	37,757,921	864,999	2,590,337			92.6%
2008	36,608,126	823,449	2,679,457			92.5%
Elaborated by CCS from typical clinker composition (2006 IPCC) and industry production data (INEGI, Encuesta Industrial Mensual (EIM)).						

Key Uncertainties and Research Needs

Key sources of uncertainty and associated research needs underlying the estimates above are as follows:

- Limestone and dolomite consumption for chemical applications that result in CO_2 release are associated with various segments of industry including agriculture, chemical manufacturing, glass manufacturing, environmental pollution control, and the metallurgical industry. For instance, limestone and dolomite are used to adjust pH in agricultural soils or can be used as flux stones or purifiers in refining metals such as iron. A crude estimate of emissions was prepared based on production of these minerals. This method does not account for crushed limestone consumed for road construction or other uses that do not result in CO_2 emissions. This approach is provisory while more accurate methods are developed or new activity data are collected from economic statistics and/or industry surveys.

- Since emissions from industrial processes are determined by the level of production and the production processes of a few key industries there is relatively high uncertainty regarding future emissions from the industrial processes category as a whole. Future emissions depend on the competitiveness of Chihuahua manufacturers in these industries, and the specific nature of the production processes used in Chihuahua. Forecast emissions based on economic data or industry performance data are usually more reliable that those based on historic trends. The use of relevant economic data in this analysis will likely paint a better picture of forecast emissions.

- Significant uncertainty stems from the method adopted to estimate GHG emissions from mobile air-conditioning systems. These were calculated for Chihuahua according to the approach described in Baja California's 2005 GHG inventory.[22] Although this approach deviates from the methodology outlined in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, it allowed the quantification of ODS substitute emissions. According to the 2006 IPCC guidelines, more accurate estimates can be obtained by collecting information from equipment manufacturers/importers on the total charge of ODS substitutes in the equipment they manufacture or import. Alternatively, sales information can be used to trace sources of emissions more precisely.

- Due to the lack of reasonably specific projection surrogates, historical trend data were used to project emission activity level changes for multiple industrial processes. There is significant uncertainty associated with any projection, including a projection that assumes that past historical trends will continue in future periods. All assumptions on growth should be reviewed by industry experts and revised to reflect their expertise on future trends especially for the cement manufacturing industry, and for limestone and dolomite consumption and ODS substitutes.

- For the electric power transmission and distribution systems and semiconductor industries, future efforts should include a survey of companies within these industries to determine the extent to which they are experiencing SF_6 losses.

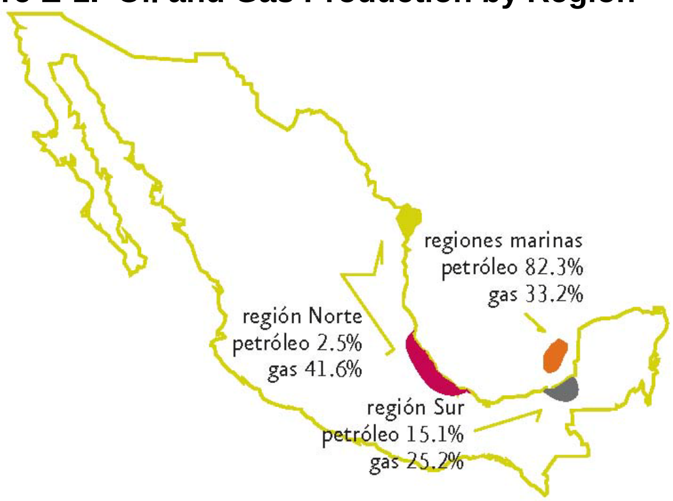
[22] *Inventario de Emisiones de Gases de Efecto Invernadero del Estado de Baja California 2005: Versión Final Secretaría de Protección al Ambiente del gobierno del estado Baja California.* Centro Mario Molina. Diciembre, 2007 (26-27)

Appendix E. Fossil Fuel Industries

Overview

The GHG emissions associated with the fossil fuel industries sector include fugitive emissions associated with the production, processing, transmission, and distribution of oil and gas as well as fugitive emissions from coal mining.[1] In Chihuahua, GHG emissions are limited to the transmission and distribution of natural gas. It is unlikely that other sources of emissions would occur because Chihuahua does not have coal deposits, or oil and natural gas reserves[2] . Mexico's petroleum rich areas are located around the Gulf of Mexico as illustrated in Figure E-1 below.

Figure E-1. Oil and Gas Production by Region[3]



Fuente: Sistema de Información Energética, Sener.
La suma de los parciales puede no coincidir con los totales, debido al redondeo de las cifras.

Emissions and Reference Case Projections

Methodology

For the development of natural gas emissions estimates, CCS considered several possible methods that could be applied based on the nature and availability of activity data. A Tier 1 method from the *2006 IPCC Guidelines* was considered (Method A). This approach estimates emissions as function of the volume of natural gas marketed in the system and emission factors recommended for developing countries that are based on regions outside the Americas with a large uncertainty range (-40 to 250%).[4] This approach was utilized by the authors of the *Inventario Nacional de Emisiones de Gases de Efecto Invernadero* (INEGEI).

[1] Note that emissions from natural gas consumed as lease fuel (used in well, field, and lease operations) and plant fuel (used in natural gas processing plants) are included in Appendix B in the industrial fuel combustion category.
[2] Information on oil and gas reserves were obtained from PEMEX. *Reservas de Hidrocarburos al 1 de Enero de 2009*. Marzo, 2009. http://www.ri.pemex.com/index.cfm?action=content&sectionID=134&catID=12201
[3] Secretaría de Energía. *Balance Nacional de Energía 2006*. (p.37)
[4] Default IPCC values are based on unpublished studies in China, Romania, and Uzbekistan. See 2006 IPCC Guidelines, Volume 2, Chapter 4, Table 4.2.5.

Alternatively, the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*[5] offers an approach for North America that improves correlation between activity data and emissions (Method B). Improved correlation is achieved through increased disaggregation of the industry and in many cases by switching to a different parameter of activity data like units of natural gas processing units and length of transmission pipeline. Method B represents a simplified version of the quantification methods developed by GRI study for the US EPA[6]. The full study identified approximately 100 components of natural gas systems that are methane-emission sources. For each component, the study developed an emission factor. To estimate emissions, the emission factors were multiplied by the activity level for each component (e.g., amount of gas produced, numbers of wells, miles of pipe of a given type and operating regime, or hours of operation of a given type of compressor).

The GRI study also served as the basis for the State Greenhouse Gas Inventory Tool (SIT), a tool commissioned by the US EPA to facilitate the development of state-level GHG emissions inventories (Method C).[7] Similar to Method B, the SIT streamlines the bottom- up approach of the GRI study by grouping industry segments together and correlating emissions to various parameters besides natural gas throughput.

IPCC *Good Practice Guidance* recommends the approach inherent in methods B and C, namely, the correlation of segments of the fossil fuel industry to a diversity of activity data parameters. For the purposes of this inventory, CCS selected Method C because it offers an estimate of emissions based on a wider number of parameters and also provides a consistent basis of comparison with state –level GHG inventories in the US.

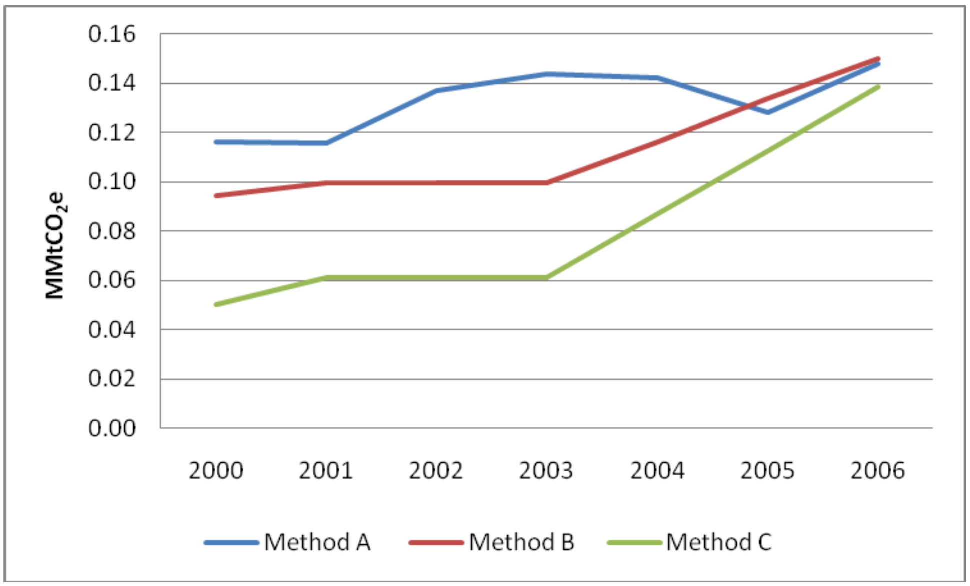
CCS conducted a comparison of emissions estimated by these various methods (see Figure E-2). The values using Method A represent higher emissions where regulatory and operational controls are few to none. The values derived from methods B and C reflect lower emissions where the natural gas system is well maintained and highly reliable. Table E-1 list Method C emission factors by occurring activity in Chihuahua.

[5] See Chapter 2, Section 2.7.1.2. The document is available from www.ipcc-nggip.iges.or.jp/public/gp/english/
[6] GRI/US EPA (1996). *Methane Emissions from the Natural Gas Industry*. Report No. EPA-600/R-96-080, GRI / United States Environmental Protection Agency.
[7] Additional information about the EPA SIT is found at www.epa.gov/climatechange/emissions/state_guidance.html

Table E-1. Fossil Fuel Industry Emission Factors by Occurring Activity in Chihuahua

Activity	Emission factors	
Natural gas transmission		
Miles of transmission pipeline	0.6	tonnes CH4 per year per activity unit
Number of gas storage compressor	964.1	tonnes CH4 per year per activity unit
Natural gas distribution		
Total miles of distribution pipeline	0.541	tonnes CH4 per year per activity unit
Total number of services	0.015	tonnes CH4 per year per activity unit

Figure E-2. Comparison of Natural Gas System Emissions by Competing Method



Natural Gas Industry Emissions

Key information sources for the activity data were the Secretaria de Energía (SENER), and the Comisión Reguladora de Energía (CRE). SENER provided information about natural gas transmission and distribution infrastructure (including pipeline lengths, and the number of planned and operating storage units).[8] It also provided data on the number of users serviced by this infrastructure (indicating the number of meters). The CRE offered information about companies licensed to build and operate natural gas lines and the date of these concessions.[9]

[8] Secretaría de Energía. *Prospectiva del Mercado de Gas Natural*. México: SENER. Information taken from publications dated 2003 to 2007. http://www.sener.gob.mx/webSener/portal/index.jsp?id=48#prop2008
[9] A list of permits for natural gas transmission and distribution is available at http://www.cre.gob.mx/articulo.aspx?id=169

Information obtained by means of these data sources was sparse and largely derived from permit descriptions where projected information was listed (e.g., number of services at the end of the 5-year concession); it is possible therefore that emission are slightly over-estimated. Table E-2 summarizes activity data used in estimating natural gas industry emissions. Please note that some information on the table was not provided on an annual basis but in periods of five years. A linear interpolation was applied to obtain annual values.

Oil Industry Emissions

As described above, there is no oil production or refinement in Chihuahua.

Coal Industry Emissions

There is no coal production or processing in Chihuahua.

Table E-2. Approach to Estimating Historical/Projected Emissions from Fossil Fuel Systems

Activity	Approach to Historical Emissions		
	Required Data	**Data Source**	**Available Data**
Natural gas production	Number of wells	Not present in Chihuahua	
Natural gas processing, venting and flaring	Volume of natural gas processed	Not present in Chihuahua	
Natural gas transmission	Miles of transmission pipeline	PEMEX/ CRE/SENER	Permit dated 4/7/97 = 38 km Permit dated 2/6/99 = 805 km Permit dated 2005-06 = 14.9 km
	Number of gas transmission compressor stations	Not present in Chihuahua	
	Number of storage stations	Not present in Chihuahua	
Natural gas distribution	Miles of distribution pipeline	CRE SENER	Permit dated 2/12/97 = 1828 km 2004-2009 = 5478 km
	Number of services	SENER	Permit dated 2/12/97 = 1828 km 2004-2009 = 5478 km
Oil systems	Volume of petroleum processed	Not present in Chihuahua	
Coal mining	Tons of production	Not present in Chihuahua	

Emission Forecast

Several assumptions were made in the preparation of the forecast. Due to the large investment involved in building natural gas transmission infrastructure, the forecast assumed no transmission pipeline or storage stations additions to what existed in 2006. On the other hand, the distribution network and the number of users were assumed to grow annually at 4.0% until

2010, at the same rate as the growth in the number of homes equipped with gas stoves from 1990 to 2000.[10] This vigorous growth accounts for rapid development of the natural gas sector in Mexico and in Chihuahua in particular. However, starting in 2011, growth is assumed to slow down to the state population growth rate of 0.63% for the period 2011-2025.[11]

In short, the forecast is driven by strong growth in emissions from the natural gas distribution system without any assumed growth in corresponding transmission system.

Results

Table E-3 displays the estimated emissions from the fossil fuel industry in Chihuahua over the period 1990 to 2025. Natural gas transmission is the major contributor to both historic emissions and emissions growth. The relative contributions to sector total emissions are shown in Table E-4. Figure E-3 displays process-level emission trends from the fossil fuel industry, on a million-metric-tons-of-carbon-dioxide-equivalent ($MMtCO_2e$) basis.

Table E-3. Historical and Projected Emissions for the Fossil Fuel Industry in $MMtCO_2e$

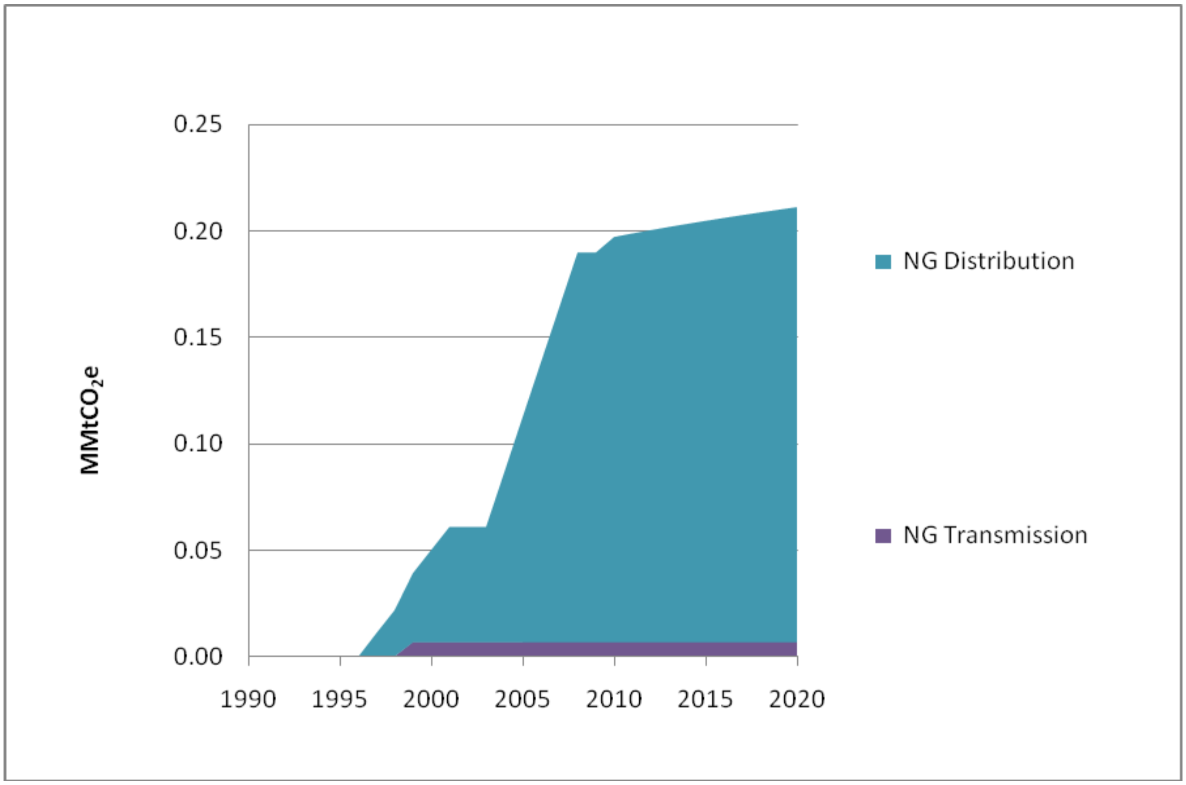
Source	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
NG Transmission	0.000	0.000	0.007	0.007	0.007	0.007	0.007	0.007
NG Distribution	0.000	0.000	0.043	0.106	0.191	0.198	0.205	0.210
Total	**0.000**	**0.000**	**0.050**	**0.113**	**0.197**	**0.205**	**0.211**	**0.217**

Table E-4. Historical and Projected Distribution of Emissions by Source

Source	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
NG Transmission	0%	0%	14%	6%	4%	3%	3%	3%
NG Distribution	0%	0%	86%	94%	96%	97%	97%	97%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

[10] Instituto Nacional de Estadísticas, Geografía e Informática. 1990. *Censos Generales de Población y Vivienda*. Instituto Nacional de Estadísticas, Geografía e Informática. 2000. *Censos Generales de Población y Vivienda*.
[11] Consejo Nacional de la Población. http://www.conapo.gob.mx/

Figure E-3. Fossil Fuel Industry Emission Trends ($MMtCO_2e$)



Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- The earliest reference to fossil fuel industry infrastructure dates back to 1997 from CRE's list of active natural gas distributors[12]. Due to limited amount of historical records, there is much uncertainty around emissions estimates for the period 1990 to 1997.
- Emission factors were based on U.S industry-wide averages. Until fugitive emissions are disclosed based on plant specific operation and maintenance records and local studies (at least specific to Mexican states), significant uncertainties remain around both the natural gas transmission and distribution emission estimates.
- The assumptions used for the projections do not reflect all potential future changes that could affect GHG emissions, including future capital expenditures, potential changes in regulations and emissions-reducing improvements in oil and gas production, processing, and pipeline technologies.

[12] See footnote 6.

Appendix F. Agriculture

Overview

The emissions covered in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from livestock and crop production. Emissions and sinks of carbon in agricultural soils due to changes in cultivation practices are also covered. CO_2 emissions can also occur as a result of urea, lime and dolomite application. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates (see Appendix B). Other CO_2 emissions or sequestration as a result of livestock and crop production are considered to be biogenic, and therefore per IPCC guidelines, are not included in GHG emission estimates.

The primary GHG sources and sinks - livestock production, agricultural soils, and crop residue burning are further subdivided as follows:

- *Enteric fermentation:* CH_4 emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach.
- *Manure management:* CH_4 and N_2O emissions from the storage and treatment of livestock manure (e.g., in storage piles, compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited conditions. In contrast, N_2O emissions are increased under aerobic conditions. The 2006 IPCC guidelines segregate this source sector as follows:
  - CH_4 emissions due to manure management;
  - Direct N_2O emissions due to manure management;
  - Indirect N_2O emissions due to leaching of nitrogen following manure application;
  - Indirect N_2O emissions due to volatilization of nitrogen (e.g. as ammonia) following manure application with subsequent nitrogen deposition, denitrification, and N_2O emissions.
- *Agricultural soils:* The management of agricultural soils can result in N_2O emissions and net fluxes of carbon dioxide (CO_2) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive underlying soil nitrification and denitrification cycles, which produce N_2O as a by-product. The 2006 IPCC guidelines segregate this source sector as follows:
  - Direct N_2O emissions due to managed soils;
  - Indirect N_2O emissions due to nitrogen volatilization and subsequent atmospheric deposition;
  - Indirect N_2O emissions due to leaching & runoff.

Note: Agricultural soils can store or release soil carbon, if these soil carbon pools are disturbed and oxidized; when oxidized, the soil carbon is released as CO_2. Agricultural soil carbon flux is considered part of the land use category, and therefore is discussed in the land use and forestry appendix.

- *Aggregate sources and non-CO_2 emissions sources on land:* These include all agricultural sources which result in CH_4 and N_2O emissions that do not fall into the above categories. The 2006 IPCC guidelines segregate this source sector as follows:
  - Urea application(which is also addressed under agricultural soils above as a nitrogen fertilizer): CO_2 is emitted during urea decomposition in soils;
  - Liming: CO_2 is emitted as a result of pH adjustment in acidic soils;
  - Residue burning: CH_4 and N_2O emissions are produced when crop residues are burned (CO_2 that is emitted is considered biogenic and not reported).

Emissions and Reference Case Projections

Inventory Data

Enteric fermentation. Methane emissions for 1990 through 2005 were estimated using a Tier 1 method described in the 2006 Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories* (2006 IPCC).[1] This method multiplies annual methane emission factors specific to each type of ruminant animal to activity data (livestock population by animal type). The activity data were provided by SIACON[2] and are summarized in Table F-1. This methodology, as well as the others described below, is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[3]

[1] GHG emissions were calculated using a Tier 1 method described in Volume 4, Chapter 10 of the 2006 Intergovernmental Panel on Climate Change *Guidelines for National Greenhouse Gas Inventories,* published by the National Greenhouse Gas Inventory Program of the IPCC, available at (http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[2] Sistema de Información Agropecuaria de Consulta (SIACON), a national database that stores agriculture and animal farming statistics. Document in Spanish. *Sistema de Información Agroalimentaria y de Consulta 1980-2006*. 2007. http://www.oeidrus-tamaulipas.gob.mx/cd_anuario_06/SIACON_2007.html

[3] Revised 2006 IPCC *Guidelines for National Greenhouse Gas Inventories* and *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (http://www.ipcc-nggip.iges.or.jp/public/gp/english/).

Table F-1. Livestock Populations

Livestock Type		1990	1995	2000	2005
Dairy Cows	Vacuno lechero	0	118743	205317	216892
Other Cattle	Otros vacunos	1,849,579	1,683,114	920,989	1,027,771
Buffalo	Búfalo				
Sheep	Ovinos	80,010	69,656	65,085	120,588
Goats	Caprinos	408,402	345,839	202,953	236,480
Camels	Camelidos				
Horses	Equinos				
Mule/Asses	Mulas y asnos				
Deer	Ciervos				
Alpacas	Alpacas				
Swine	Porcinos	327,737	377,797	163,982	215,873
Poultry	Aves de corral	1,753,407	1,577,301	2,647,093	1,984,398
Rabbits	Conejo				

Manure management. 2006 IPCC guidelines were used to estimate methane and nitrous oxide emissions using activity data on Chihuahua livestock populations from 1990 to 2005. The activity data were retrieved from Sistema de Información Agropecuaria de Consulta (SIACON; see Table F-1).

To calculate CH_4 emissions due to manure management, population values are multiplied by an estimate for typical animal mass and a volatile solids (VS) production rate to estimate the total VS produced. The VS estimate for each animal type is then multiplied by a maximum potential CH_4 emissions factor and a weighted methane conversion factor (MCF) to derive total CH_4 emissions. The MCF adjusts the maximum potential methane emissions based on the types of manure management systems employed in Chihuahua.

The emission factors were derived from a combination of regional expert studies[4] and state practices in manure management. Default IPCC emission and conversion factors were used for all emission sources in this sector with input information relating to livestock population by type, geographic area, and climate region. The geographic area category selected for Chihuahua was Latin America and climate region categories selected were warm (>26 degrees C) and temperate (15-25 degrees C) assigned to 76% and 24% of livestock population by type according to the terrain covered by each climate zone (see Figure F-1). The assumptions of livestock manure managed by system type and the associated methane conversion factors are shown in Tables F-2 and F-3 below. Manure management system distribution and methane conversion factors were assumed to remain constant through the inventory and forecast years.

Direct N_2O emissions due to manure management are derived by using the same animal population values above multiplied by the typical animal mass and a total Kjeldahl nitrogen (K-nitrogen) production factor. The total K-nitrogen is multiplied by a non-volatilization factor to

[4] Study results are summarized in Table 10-A-4 in Volume 4, Chapter 10, of the 2006 IPCC *Guidelines for National Greenhouse Gas Inventories.*

determine the fraction that is managed in manure management systems. The unvolatilized portion is then divided into fractions that get processed in either liquid (e.g. lagoons) or solid waste management systems (e.g. storage piles, daily spread, dry lot). Table F-4 shows the N_2O emission factor per manure management system.

Indirect N_2O emissions due to leaching are derived by taking the mass of nitrogen excreted per animal per manure management system multiplied by the fraction of nitrogen released through leaching and runoff. The product is then multiplied by a N_2O emission factor. Indirect N_2O emissions due to volatilization are derived by taking the mass of nitrogen excreted per animal per manure management system multiplied by the fraction of nitrogen released through volatilization. The product is then multiplied by a N_2O emission factor. The volatilization N_2O emissions factor is 0.01 kg N_2O-N/kg N, while the emission factor for leaching is 0.0075 kg N_2O-N/kg N.

Figure F-1. Climate Zone Distribution in Chihuahua

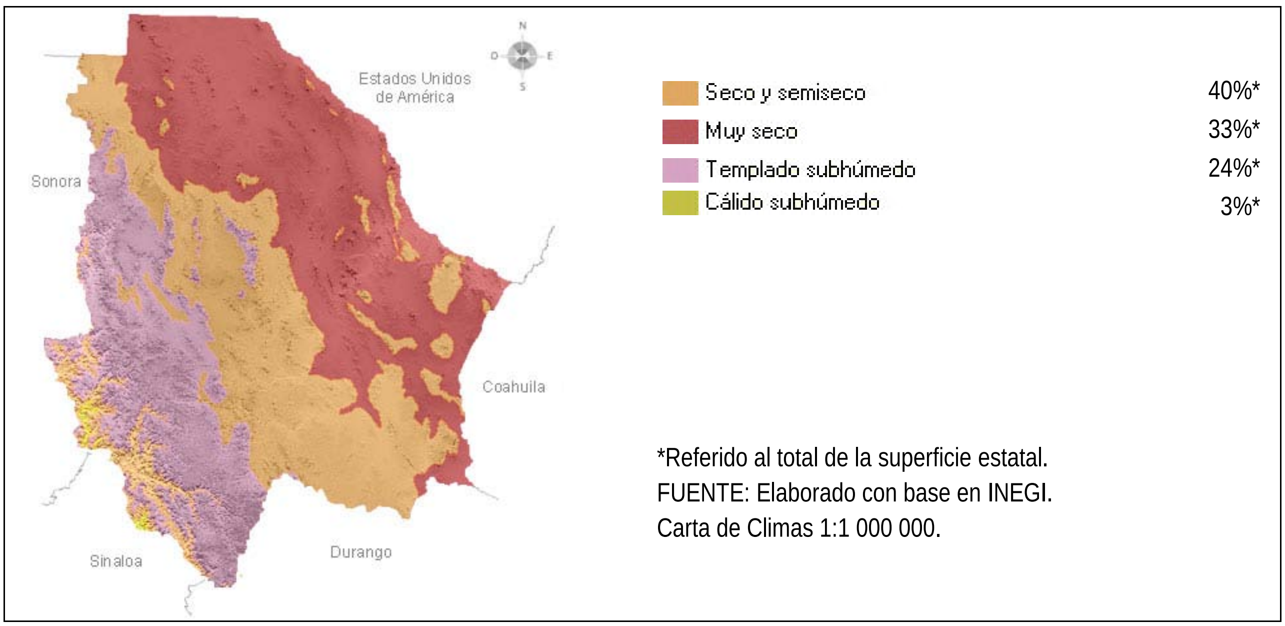


Table F-2. Default Manure Management Systems Distribution for Latin America

Livestock	Burned for fuel	Daily Spread	Digester	Dry Lot	Liquid Slurry	Other	Pasture, Range, Paddock	Solid Storage
Breeding Swine		2.0%	0.0%	20.5%	4.0%	44.5%		25.0%
Broilers						100.0%		
Dairy Cows	0.0%	62.0%	0.0%	0.0%	1.0%	0.0%	36.0%	1.0%
Goats						100.0%		
Horses						100.0%		
Layers (dry)						100.0%		
Layers (wet)						100.0%		
Market Swine		2.0%	0.0%	41.0%	8.0%	39.0%		10.0%
Mule/Asses						100.0%		
Other Cattle	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	99.0%	0.0%
Sheep						100.0%		
Turkeys						100.0%		

Table F-3. MCF for Manure Management Systems by Climate Zone

Livestock	Climate	Burned for fuel	Daily Spread	Digest-er	Dry Lot	Liquid Slurry	Other	Pasture, Range, Paddock	Solid Storage
Breeding Swine	Temperate		0.5%	10.0%	1.5%	42.0%	1.0%		4.0%
	Warm		1.0%	10.0%	2.0%	78.0%	1.0%		5.0%
Broilers	Temperate						1.5%		
	Warm						1.5%		
Dairy Cows	Temperate	10.0%	0.5%	10.0%	1.5%	42.0%	10.0%	1.5%	4.0%
	Warm	10.0%	1.0%	10.0%	2.0%	78.0%	1.0%	2.0%	5.0%
Goats	Temperate						1.5%		
	Warm						2.0%		
Horses	Temperate						1.5%		
	Warm						2.0%		
Layers (dry)	Temperate						1.5%		
	Warm						1.5%		
Layers (wet)	Temperate						78.0%		
	Warm						80.0%		
Market Swine	Temperate		0.5%		1.5%	42.0%	1.0%		4.0%
	Warm		1.0%		2.0%	78.0%	1.0%		5.0%
Mule/ Asses	Temperate						1.5%		
	Warm						2.0%		
Other Cattle	Temperate	10.0%	0.5%	10.0%	1.5%	42.0%	1.0%	1.5%	4.0%
	Warm	10.0%	1.0%	10.0%	2.0%	78.0%	1.0%	2.0%	5.0%
Sheep	Temperate						1.5%		
	Warm						2.0%		
Turkeys	Temperate						1.5%		
	Warm						1.5%		

Table F-4. Nitrous Oxide Emission Factors Applied to Manure Management Systems

Management System	Emission Factor (kg N_2O-N/kg N excreted)
Daily Spread	0
Digester	0
Dry Lot	0.02
Lagoon	0
Liquid Slurry	0.005
Other	0.001
Pit	0.002
Pit >1 month	0.002
Solid Storage	0.005

Agricultural soils. The decomposition of crop residues and nitrogen fixing crops add nitrogen to the nitrification and de-nitrification cycle in the soil, which produces N_2O as a by-product. The amount of nitrogen in crop soils was calculated as the product of crop dry matter harvested annually, the ratio of plant dry matter to crop dry matter, the nitrogen fraction of the plant dry matter, and the default nitrogen emission factor. In Table F-5, nitrogen fixing crops are beans and pulses.

Table F-5. Inventory Crop Production in Metric Tons[5]

Crop Type		1990	1995	2000	2005
N-fixing forages	Forrajes fijadores de N	0	0	0	0
Non-N-fixing forages	Forrajes no fijadores de N	1,041,342	828,318	1,215,262	4,025,327
Beans & pulses	Frijoles y legumbres	89,049	70,197	28,360	47,364
Grains	Granos	0	0	0	0
Perennial grasses	Hierbas perennes	415,908	407,744	309,350	262,637
Grass-clover mixtures	Mezcla de hierba y trébol	0	0	0	0
Root crops, other	Raíces, otros	0	0	8,069	5,730
Tubers	Tubérculos	0	0	0	0
Alfalfa	Alfalfa	2,604,005	2,083,880	3,919,540	4,490,734
Rice	Arroz	0	0	0	0
Oats	Avena	96,786	25,315	18,730	84,630
Peanut (w/pod)	Cacahuetes (c/ vaina)	10,982	5,103	29,071	17,663
Barley	Cebada	21,214	16,136	10,573	202
Rye	Centeno	0	0	0	0
Dry bean	Frijoles	0	0	0	0
Non-legume hay	Heno no leguminoso	0	0	0	0
Maize	Maíz	435,729	303,627	454,061	672,454
Millet	Mijo	0	0	0	0
Potato	Patatas	42,574	81,404	165,771	151,839
Soyabean	Soja	21,309	1,154	684	573
Sorghum	Sorgo	126,144	59,835	76,593	45,231
Wheat	Trigo	180,324	71,023	52,585	58,755

Application of synthetic fertilizer also adds nitrogen to the nitrification and de-nitrification cycle in the soil and contributes the release of N_2O to the atmosphere. Emissions from the application of fertilizer to agricultural lands were based on data from the International Fertilizer Industry Association.[6] Table F-6 shows the estimate of N applied for each year.

[5] Sistema de Información Agropecuaria de Consulta (SIACON), a national database that stores agriculture and animal farming statistics. Document in Spanish. *Sistema de Información Agroalimentaria y de Consulta 1980-2006*. 2007. http://www.oeidrus-tamaulipas.gob.mx/cd_anuario_06/SIACON_2007.html

[6] International Fertilizer Industry Association (http://www.fertilizer.org/ifa/ifadata/search). Data on N applied by state for 1990-2005.

Table F-6. Fertilizer Application Data

Concept	1990	1995	2000	2005
Quantity (kg N)	65,601,649	47,410,491	59,662,872	51,526,147

Additions of nitrogen to the soil from organic fertilizers was calculated as the amount of total nitrogen available from reclaimed manure less the amount of this nitrogen dedicated for the purposes of feed, fuel or construction. In the case of Chihuahua, it was assumed no manure went to feed, fuel, or construction.

Nitrogen input to soils from the deposition of urine and dung by grazing animals on pasture, range and paddock was calculated as the fraction of nitrogen in manure that is left unmanaged on fields as a result of grazing. Table F-3 identifies the default fraction of manure left unmanaged.

In regard to cultivation of histosols which can also result in N_2O emissions, it was determined that the cultivation of these highly organic soils did not apply to Chihuahua, because histosols only exist in boreal regions. Similarly, no consideration was given to flooding and draining of organic soils because such practice does not occur in the state.

Aggregate sources and non-CO_2 emissions sources on land. These include urea (applied as a source of N) and lime and dolomite which are used to neutralize acidic soils. All three amendments emit CO_2, which results from the breakdown of each compound. No data have been identified for Chihuahua to estimate emissions from these additional amendments. Urea could be one of the commercial fertilizers captured within the total N represented in Table F-6 above; however, detailed information on the types of fertilizers applied was not available.

Residue burning. Agricultural burning can result in emissions of both N_2O and CH_4. Data on acres burned in Chihuahua could not be found, and therefore emissions from residue burning are bit estimated as recommended by IPCC guidelines. When estimates of the tons or acres of Chihuahua crops burned are found, these emissions will be included in the analysis.

Forecast Data

Forecast estimates were based on livestock population and crop production trends from 1990-2005. The resulting growth rates used to estimate 2005 through 2025 emissions are listed in Tables F-7 and F-8. Note that a negative growth indicates a decrease in livestock population or crop production. Based on these growth rates, forecast livestock and crop production activity were estimated through the year 2025. Forecast livestock population and crop production values are shown in Tables F-9 and F-10.

Livestock population figures are used to estimate emissions from manure management, and enteric fermentation. Population figures are also used to estimate organic additions and animal waste deposits on the land, which are used in the calculations of N_2O emissions from agricultural soils. The crop production figures are used to estimate the crop residues left on the soil, which also gets factored into the ag soils N_2O emissions calculation. N fertilizer applications also contribute to the calculation of N_2O emissions from ag soils. The fertilizer estimate (-1.5%

annual growth) is forecast based on the change in N fertilizer application between 1990 and 2005.

Table F-7. Annual Growth Rates Applied to Livestock Population

Livestock Type		Rate (%)	Period of Measurement
Dairy Cows	Vacuno lechero	1.1%	2000-2005
Other Cattle	Otros vacunos	2.2%	2000-2005
Buffalo	Búfalo		
Sheep	Ovinos	0.0%	N/A*
Goats	Caprinos	3.1%	2000-2005
Camels	Camelidos		
Horses	Equinos		
Mule/Asses	Mulas y asnos		
Deer	Ciervos		
Alpacas	Alpacas		
Swine	Porcinos	5.7%	2000-2005
Poultry	Aves de corral	-5.6%	2000-2005
Rabbits	Conejo		

* In some cases, data from year to year fluctuated dramatically, and no distinct growth trend could be seen. In these cases, no growth was assumed.

Table F-8. Growth Rates Applied to Crop Production

Crop Type		Mean Annual Growth	
English	Spanish	Rate (%)	Period of Measurement
N-fixing forages	Forrajes fijadores de N		N/A
Non-N-fixing forages	Forrajes no fijadores de N	0.0%	2000-2005
Beans & pulses	Frijoles y legumbres	0.0%	2000-2005
Grains	Granos		
Perennial grasses	Hierbas perennes	-3.2%	2000-2005
Grass-clover mixtures	Mezcla de hierba y trébol		
Root crops, other	Raíces, otros	-6.6%	2000-2005
Tubers	Tubérculos		
Alfalfa	Alfalfa	2.8%	2000-2005
Rice	Arroz		
Oats	Avena	0.0%	2000-2005
Peanut (w/pod)	Cacahuetes (c/ vaina)	-9.5%	2000-2005
Barley	Cebada	0.0%	2000-2005
Rye	Centeno		
Dry bean	Frijoles		
Non-legume hay	Heno no leguminoso		
Maize	Maíz	0.0%	2000-2005
Millet	Mijo		
Potato	Patatas	-1.7%	2000-2005
Soyabean	Soja	-3.5%	2000-2005
Sorghum	Sorgo	-10.0%	2000-2005
Wheat	Trigo	2.2%	2000-2005

* In some cases, data from year to year fluctuated dramatically, and no distinct growth trend could be seen. In these cases, no growth was assumed

Table F-9. Forecast Livestock Populations 2005-2025

Livestock Type		2005	2010	2015	2020	2025
Dairy Cows	Vacuno lechero	216,892	229,120	242,036	255,682	270,096
Other Cattle	Otros vacunos	1,027,771	1,146,934	1,279,912	1,428,309	1,593,911
Buffalo	Búfalo	0	0	0	0	0
Sheep	Ovinos	120,588	120,588	120,588	120,588	120,588
Goats	Caprinos	236,480	275,546	321,065	374,103	435,903
Camels	Camelidos	0	0	0	0	0
Horses	Equinos	0	0	0	0	0
Mule/Asses	Mulas y asnos	0	0	0	0	0
Deer	Ciervos	0	0	0	0	0
Alpacas	Alpacas	0	0	0	0	0
Swine	Porcinos	215,873	284,185	374,113	492,498	648,346
Poultry	Aves de corral	1,984,398	1,487,608	1,115,188	836,002	626,711
Rabbits	Conejo	0	0	0	0	0

Table F-10. Forecast Crop Production 2005-2025

Crop Type		2005	2010	2015	2020	2025
N-fixing forages	Forrajes fijadores de N	0	0	0	0	0
Non-N-fixing forages	Forrajes no fijadores de N	4,025,327	4,025,327	4,025,327	4,025,327	4,025,327
Beans & pulses	Frijoles y legumbres	47,364	47,364	47,364	47,364	47,364
Grains	Granos	0	0	0	0	0
Perennial grasses	Hierbas perennes	262,637	222,978	189,307	160,721	136,451
Grass-clover mixtures	Mezcla de hierba y trébol	0	0	0	0	0
Root crops, other	Raíces, otros	5,730	4,069	2,890	2,052	1,457
Tubers	Tubérculos	0	0	0	0	0
Alfalfa	Alfalfa	4,490,734	5,145,167	5,894,970	6,754,042	7,738,306
Rice	Arroz	0	0	0	0	0
Oats	Avena	84,630	84,630	84,630	84,630	84,630
Peanut (w/pod)	Cacahuetes (c/ vaina)	17,663	10,731	6,520	3,961	2,407
Barley	Cebada	202	202	202	202	202
Rye	Centeno	0	0	0	0	0
Dry bean	Frijoles	0	0	0	0	0
Non-legume hay	Heno no leguminoso	0	0	0	0	0
Maize	Maíz	672,454	672,454	672,454	672,454	672,454
Millet	Mijo	0	0	0	0	0
Potato	Patatas	151,839	139,077	127,388	116,681	106,874
Soyabean	Soja	573	480	402	336	282
Sorghum	Sorgo	45,231	26,711	15,774	9,315	5,501
Wheat	Trigo	58,755	65,649	73,352	81,958	91,575

Results

During inventory years (1990 through 2005), total agricultural emissions decreased by 30% reaching levels on the order of 2.55 million metric tons of carbon dioxide equivalents (MMtCO_2e). In 1990, the top two emitting sources were enteric fermentation, and agricultural soils. Enteric fermentation alone accounted for 61% of total greenhouse gas emissions in 1990. The all emissions categories declined between 1990 and 2005.

During forecast years (2005 through 2025), total agriculture emissions are projected to increase by 39% attaining levels around 3.54 million metric tons of carbon dioxide equivalents. In 2025, the top two emitting source sectors are expected to be enteric fermentation and agricultural soils. Enteric fermentation accounts for 64% of total greenhouse gas emissions in 2025. Enteric fermentation also showed the most growth between 2005 and 2025.

Figure F-2 and Table F-12 summarize greenhouse gas emission estimates by source sector. The distribution of greenhouse gas emissions by source is presented in Table F-13. Finally, mean annual growth rates for selected time intervals are listed in Table F-14.

Figure F-2. GHG Emissions from Agriculture 1990-2025

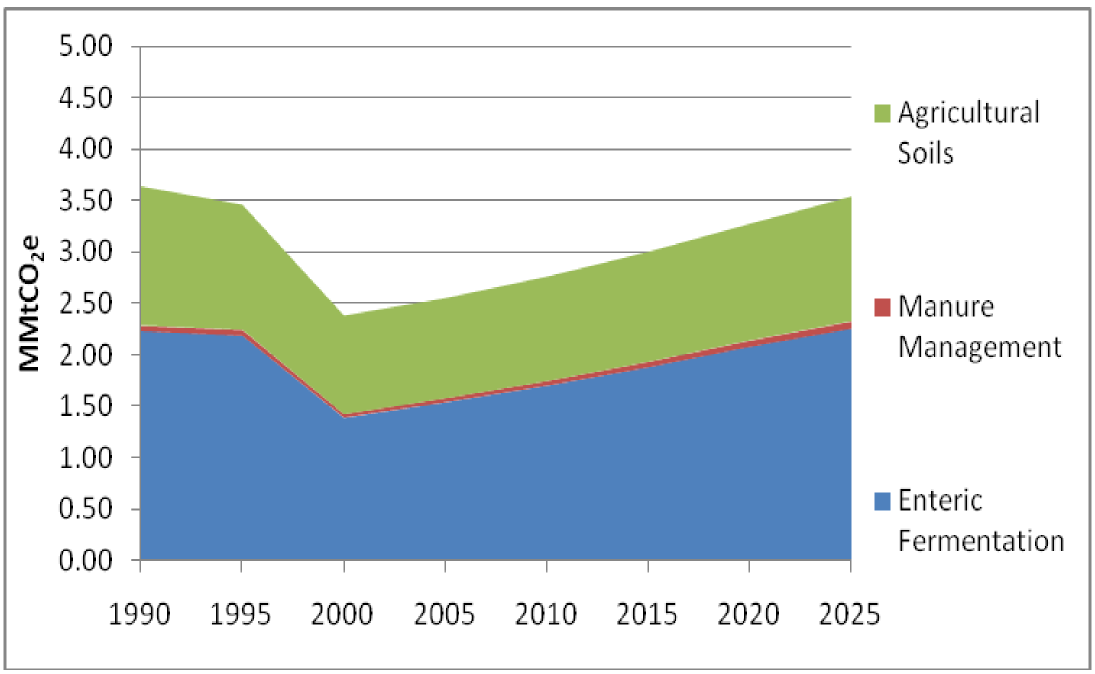


Table F-12. GHG Emissions from Agriculture ($MMtCO_2e$)

Source Sector	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	2.23	2.19	1.39	1.54	1.70	1.88	2.08	2.26
Manure Management	0.05	0.06	0.04	0.04	0.05	0.05	0.06	0.07
Agricultural Soils	1.35	1.21	0.96	0.97	1.02	1.07	1.13	1.21
Residue Burning	Not Estimated							
Total	**3.64**	**3.46**	**2.38**	**2.55**	**2.76**	**3.00**	**3.27**	**3.54**

Table F-13. GHG Emission Distribution in the Agriculture Sector

Source Sector	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	61.4%	63.3%	58.2%	60.3%	61.5%	62.6%	63.5%	63.8%
Manure Management	1.5%	1.6%	1.5%	1.6%	1.7%	1.7%	1.8%	2.0%
Agricultural Soils	37.1%	35.1%	40.3%	38.2%	36.8%	35.6%	34.6%	34.2%

Table F-14. GHG Mean Annual Growth Rate for Selected Time Intervals

Agriculture	1990-2005	2005-2025	1990-2025
Enteric Fermentation	-2.5%	1.9%	0.0%
Manure Management	-1.9%	2.8%	0.8%
Agricultural Soils	-2.2%	1.1%	-0.3%

Key Uncertainties

In order to reduce uncertainty associated with greenhouse gas emissions from enteric fermentation processes, it is recommended that an enhanced characterization of the livestock population be developed. In the case of Chihuahua, “other cattle” (non-dairy cows) accounts for 83% of the ruminant population. This broad category could be broken down into subcategories (e.g. calves, bulls, etc) and by the number of cattle in pasture versus on feedlots. Then emission factors specific to each of the subcategories could be applied. At a minimum, the following information is required to develop livestock subcategory specific emission factors: 1) feed intake estimate, 2) average animal weight, 3) animal activity index, 4) feeding conditions, and 5) mean winter conditions. Additional effort put into this source category will significantly impact a large share of total enteric fermentation emissions.

For manure management, no information was identified to indicate that any of the State’s confined animal operations was employing controls to reduce methane emissions, such as anaerobic digesters. The forecast also assumes that none of these projects will be implemented prior to 2025. To the extent that this assumption is incorrect, future methane emissions from manure management are over-estimated.

Emissions from the application of fertilizer to agricultural lands were calculated from estimates of fertilizer application from the International Fertilizer Industry Association. Since the application of fertilizers varies significantly from crop to crop, it is recommended that nitrogen additions be segregated by crop and by fertilizer type, if possible (including different commercial fertilizers and organic fertilizers, like manure). This information combined with fertilized area by crop will result in decreased uncertainty.

In accordance with IPCC best practices, agricultural residue burning is not considered in this analysis because of a lack of data. Emissions factors do exist for the GHG emissions of burning various crop residues; however data on the acreage of crop residue burning in Chihuahua does not exist. If that information could be found it would improve the analysis. Prescribed burning is not typically a significant source (less than 1% of total ag emissions in most US states), but, nonetheless, it does contribute to overall GHG emissions.

A final contributor to the uncertainty in the emission estimates is the forecast assumptions. Mean annual growth rates were derived from historical trends during the period 2000 through 2005; however, historical data were inconsistent. The early nineties experienced very high livestock population and crop production values which declined sharply by 2000. Even during high yield years, values oscillated sharply from one year to the next. The fluctuation of values may indicate poor quality data. In cases where data from year to year fluctuated dramatically, and no distinct growth trend could be seen, no growth was assumed. Input from in-state agricultural experts could improve the forecast estimates.

Appendix G. Waste Management

Overview

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste disposal – methane (CH_4) emissions from solid waste disposal sites (SWDS), accounting for potential CH_4 that is flared or captured for energy production (this includes both open and closed landfills):[1]
- Incineration and open burning of waste – CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions from the combustion of solid waste (e.g. residential open burning); and
- Wastewater (WW) treatment and discharge – CH_4 and N_2O from domestic wastewater and CH_4 from industrial wastewater treatment facilities.

Inventory and Reference Case Projections

Solid Waste Disposal

For solid waste management, solid waste disposal site (SWDS) emplacement data were obtained from studies conducted by the Secretaría de Desarrollo Social (SEDESOL) compiled and available through the Sistema Nacional de Información Ambiental y Recursos Naturales (SNIARN).[2] This database provided the annual mass of municipal solid waste (residuos sólidos urbanos) by state for the period 1998-2006. Historic population values were used to model emplacement starting in 1960; similarly, population projections were used to determine future municipal waste generation rates. Population projections through 2025 were obtained from the Comisión Nacional de la Población (CONAPO). Emissions were modeled using the first order decay (FOD) model from the 2006 IPCC guidelines.[3]

The term "generation" typically refers to all waste entering the waste stream, which would include waste incineration, landfilling, recycling, and composting. However, as Chihuahua does not track solid waste managed via incineration, recycling, composting, or other methods, it is assumed that all waste generated (entering the waste stream) decomposes at SWDS according to the FOD model, whether the waste is disposed of in a regulated or non-regulated SWDS. Waste treated through open burning is assumed to not enter the waste stream and is therefore not subtracted from the total waste generation (i.e. solid waste managed via open burning is not captured within the SNIARN solid waste generation estimates).

[1] CCS acknowledges that N_2O and CH_4 emissions are also produced from the combustion of landfill gas; however, these emissions tend to be negligible for the purposes of developing a state-level inventory for policy analysis. Note also that the CO_2 emitted from landfills is considered to be of biogenic origin (e.g. forest products waste, food waste, yard waste); hence, these emissions are excluded from the estimates of CO_2e from waste generation.
[2] Secretaría de Medio Ambiente y Recursos Naturales. *Sistema Nacional de Información Ambiental y Recursos Naturales*. Dimensión Ambiental, Residuos. Based on municipal studies conducted by (SEDESOL. Online at: http://www.semarnat.gob.mx/informacionambiental/Pages/index-sniarn.aspx
[3] IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5: Waste*. Online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

The classification of industrial waste (desechos de manejo especial) exists in the Mexican legislation;[4] however, in practice, municipal solid waste (desechos sólidos urbanos) and industrial waste (desechos de manejo especial) are consolidated at disposal sites. Consequently, no additional/separate emissions were estimated for industrial waste, since these emissions are already counted as part of emissions from municipal solid waste sites.

The classification of landfills for Chihuahua as of 2006 was 39% managed, 25% semi-managed "Controlled sites," and 36% unmanaged open-air dumps, according to the state municipal solid waste study referenced above.[5] It was assumed that in 1950 the fraction of landfills was 50% semi-managed, 50% unmanaged, and 0% managed, and that these fractions changed linearly until reaching the 2006 fractions above. For future years it was assumed that the fraction of landfill management types remained the same as 2006.

The methane correction factor (MCF) accounts for the fact that waste at unmanaged sites tends to decompose in an aerobic environment, producing less methane per unit of waste than waste at managed sites, where waste decomposes in an anaerobic manner. The MCF for unmanaged is 0.4, for semi-managed is 0.5, and for managed is 1.0. The MCF for each year was determined by multiplying the fraction of landfills in each management category by the MCF for that category.

The oxidation factor takes into account the amount of methane that is oxidized (converted from methane to CO_2 before it enters the atmosphere). The oxidation factor is low for open landfills or dumps where methane does not pass through layers of soil containing oxidizing bacteria. The oxidation factor is higher for managed landfills that are covered and depends upon the type of soil covering the landfill (22% for clay soils and 55% for sandy soils, with a mean of 36% for all soils).[6] Since historical landfill management is unknown, the oxidation factor was assumed to be low (5%) for all years in the inventory and forecast. It is important to note here that the CO_2 emitted from SWDS is considered to be of biogenic origin (e.g. forest products waste, food waste, yard waste); hence, these emissions are excluded from the estimates of CO_2e from SWDS.

According to the United Nations Framework for Climate Change Convention (UNFCCC),[7] there is one landfill site in Chihuahua – the Ciudad Juarez landfill – that is a participant in the Clean Development Mechanism (CDM) program, accepting credit for emission reductions for the years 2007 through 2014.[8] CCS accounted for the GHG reductions from methane destruction; however, any offset fossil fuel combustion to generate electricity is not reflected in this chapter, but would be accounted for under the Residential, Commercial and Industrial Fuel Combustion Appendix. The CDM report does not provide information on annual estimated methane destruction prior to 2007 and after 2014. However, the report does provide the total CO_2e abated for the first 7 years (2007-2013), the first 14 years (2007-2020), and the first 21 years (2007-

[4] Ley General par la Prevención y gestión Integral de los Residuos, Articulo 5.
[5] DiagChih_Cap05_CondTecyOp_vf.pdf, page 5-29.
[6] Jeffrey P. Chanton, David K. Powelson, and Roger B. Green , "Methane Oxidation in Landfill Cover Soils, is a 10% Default Value Reasonable?", *J Environ Qual*, 2009, 38: 654-663.
[7] UNFCCC, 2009. CDM Project Search. http://cdm.unfccc.int/Projects/projsearch.html. Reference retrieved from Climate Action Reserve. *Protocolo de Reporte de Proyectos en Rellenos Sanitarios en México Recolección y Destrucción del Metano de los Rellenos Sanitarios; Versión 1.0*. March 2009
[8] UNFCCC, 2006. Clean Development Mechanism Project Design Document Form – Ciudad Juarez Landfill Gas to Energy Project. Version 03.1.

2027). CCS used the detailed annual reductions information from the first crediting period, as well as the total abatement for each crediting period, to generate annual methane destruction estimates for 2015 through 2025.[9] Table G-1 displays the methane destruction values for the Ciudad Juarez landfill provided by the CDM report, as well as the methane destruction extrapolated by CCS. The GHG reductions through methane destroyed are subtracted from the methane generation forecast made by the FOD equation in the IPCC waste model.

Table G-1. Destruction of Methane at Ciudad Juarez Landfill, 2007-2025

Year	Methane Destruction – CDM Report (tCO_2e/year)	Methane Destruction – CCS Model Inputs (tCO_2e/year)
2007	55,642[a]	55,642
2008	105,857	105,857
2009	100,694	100,694
2010	95,783	95,783
2011	164,602	164,602
2012	156,574	156,574
2013	148,938	148,938
2014	70,837[a]	141,674
2015	0	127,913
2016	0	127,913
2017	0	127,913
2018	0	127,913
2019	0	127,913
2020	0	127,913
2021	0	107,557
2022	0	107,557
2023	0	107,557
2024	0	107,557
2025	0	107,557

a) Represents half of calendar year

Another factor used by the IPCC Waste Model to compute methane emissions at SWDS is the composition of waste at the SWDS. IPCC provides default waste composition for North America. Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) also provided national-level waste composition data for Mexico. However, the UNFCCC report on the Ciudad Juarez Landfill Gas CDM project provides SWDS-specific waste composition data based on a survey of waste going into the SWDS. It is assumed that these data are more representative of the waste composition in Chihuahua and are used as the waste composition inputs for the IPCC model. Table G-2 displays the waste composition input options, including the Ciudad Juarez Landfill, which was used for this inventory and forecast project. This table shows that the waste composition at the Ciudad Juarez landfill is reasonably similar to the IPCC default and Mexico national data.

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[9] It is assumed that the methane destruction reported for 2007 is the actual value for methane destruction in that year. The methane destruction value reported for 2014 only included half of that year. Therefore, the methane destruction value for 2014 was doubled.

Table G-2. Waste Composition Inputs (% of Waste Landfilled)

Waste Type	MX National	IPCC Default	Ciudad Juarez Landfill
Food	51.7%	33.9%	43.5%
Garden	0.0%	0.0%	3.6%
Paper	14.4%	23.2%	15.2%
Wood	0.0%	6.2%	1.4%
Textile	1.5%	3.9%	0.0%
Nappies	0.0%	0.0%	0.0%
Plastics, other inert	32.4%	32.8%	36.3%
Total	**100.0%**	**100.0%**	**100.0%**

As organic wastes are deposited in landfills, some of the carbon in those wastes is not released as landfill gas, and therefore is sequestered long-term in the SWDS. Such sequestration from food and garden wastes is considered in this inventory and forecast. Sequestration of carbon in paper and wood products is considered as long-term sequestration attributed to the forestry sector. As described in the Forestry & Land Use Appendix; this I&F currently does not have information on in-state wood products manufacturing and modeled end use (e.g. paper, lumber, energy, waste). As described in the Forestry & Land Use Appendix, it is likely that much of the forest products waste that is disposed at SWDS in Chihuahua comes from out of state sources; hence, sequestration in SWDS for these wastes is not counted in this I&F. However, the quantity of carbon sequestered in landfills from food and garden waste is quantified using the aforementioned waste composition inputs for Chihuahua SWDS and the IPCC Waste Model and represented in the results shown below.

Incineration and Open Burning of Waste

There are two types of solid waste combustion: 1) by incineration, and 2) open burning. The incineration of solid waste is not regulated by the state and no data were identified to estimate the amount of waste incinerated and the associated GHG emissions. Also, open burning is common but not recorded. Open burning of solid waste is assumed to be most common in rural areas, where residents do not have access to solid waste management services. Waste generation and disposal data specific to rural and urban areas are not available, leading CCS to make assumptions necessary to complete the estimation of emissions from this source.

CONAPO produced a projection of population for each state in Mexico, including detail on population in areas considered rural (less than 2,500 people in a population center). The CONAPO data provided projections of rural population for the years 2005 through 2025.[10] Rural population for 1990 through 2004 was calculated by multiplying the ratio of rural:total population by the total population for each year reported by Instituto Nacional de Estadística,

[10] State population projections were obtained from CONAPO for 2006 to 2025. Source: http://www.conapo.gob.mx/00cifras/5.htm.

Geografía, e Informática (INEGI).[11] The per-capita MSW generation estimates from the solid waste disposal sector were multiplied by the rural population to produce an estimate of waste generated and assumed to be combusted through open burning in each year. Emissions from open burning were calculated using the Chihuahua waste generation estimates and IPCC emission factors.[12]

Wastewater Treatment and Discharge

GHG emissions from domestic and industrial wastewater treatment were also estimated. Data for estimating industrial wastewater treatment emissions were limited and these are described further below.

Domestic Wastewater Treatment. For domestic (municipal) wastewater treatment, emissions are calculated using 2006 IPCC guidelines and are based on state population, fraction of each treatment and discharge type (e.g. aerobic treatment plant, anaerobic lagoon, septic system, or latrine treatment), and emission factors for N_2O and CH_4.[13] The IPCC emission factors are shown in Table G-3.

The percentage of Chihuahua residents on city sewer is 90%, according to 2005 housing statistics published by INEGI[14], and it is presumed that 10% of domestic wastewater generation is uncollected.[15] Comisión Nacional del Agua (CONAGUA) provided in-state wastewater treatment capacity by treatment system. This information was used to break down the population, whose wastewater is collected by city sewers, by each type of treatment system.[16] Three assumptions were made in the process of allocating wastewater flow to each discharge pathway; 1) all wastewater collected by a sewer system is treated by a wastewater treatment facility, 2) uncollected wastewater is treated in latrines, and 3) direct nitrous oxide emission occur in centralized aerobic treatment plants, and indirect nitrous oxide emissions occur from the discharge of wastewater effluent from anaerobic treatment systems to aquatic environments. Figure G-1 shows the overall wastewater treatment system and discharge pathways for Chihuahua with the fraction of effluent associated by each system. Domestic wastewater emissions were projected based on the projected population growth rate for 2005-2025 for a growth rate of 0.073% per year.[17]

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[11] INEGI. Historic state population for years 1990, 1995, 2000, 2005. Source: http://www.inegi.org.mx/inegi/default.aspx.

[12] IPCC, 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 5: Waste." Chapter 5: Incineration and Open Burning of Waste. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_5_Ch5_IOB.pdf.

[13] IPCC, 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 5: Waste." Chapter 6: Wastewater Treatment and Discharge. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[14] INEGI. *Censos Generales de Población y Vivienda*: http://www.inegi.org.mx/inegi/default.aspx

[15] Retrieved May, 2008 from: http://www.inegi.gob.mx/est/contenidos/espanol/sistemas/conteo2005/iter2005/selentcampo.aspx

[16] Consejo Nacional del Agua, 2007. *Inventario Nacional de Plantas Municipales de Potabilización y de Tratamiento de Aguas Residuales en Operación*. México: CONAGUA.

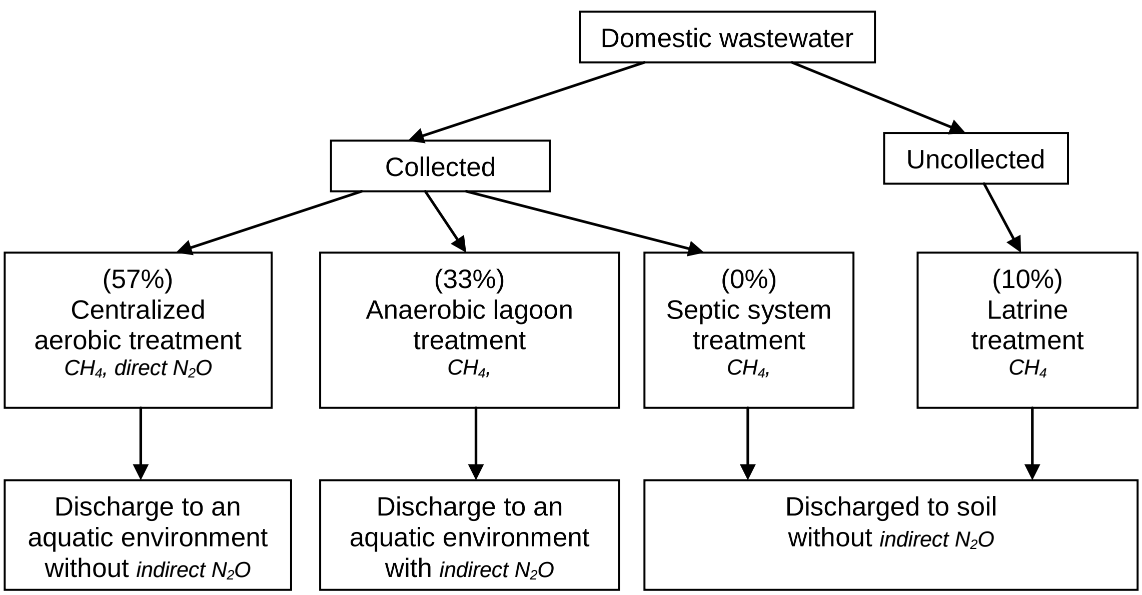
[17] INEGI. Historic state population for years 1990, 1995, 2000, 2005. Source: http://www.inegi.org.mx/inegi/default.aspx. Population projections were obtained from CONAPO for 2006 to 2025. Source: http://www.conapo.gob.mx/00cifras/5.htm.

Table G-3. IPCC Emission Factors for Domestic Wastewater Treatment

Treatment System	N_2O Emission Factor	CH_4 Emission Factors		
		MCF	B_o (kg CH_4/kg BOD)	BOD (g/person/day)
Latrine	n/a	0.5	0.6	40
Anaerobic Lagoon	n/a	0.8	0.6	40
Septic system	n/a	0.5	0.6	40
Centralized, aerobic treatment plant	3.2 g N_2O/person/year[a]	0.3	0.6	40
Effluent discharge to aquatic environment	0.005 kg N_2O-N/kg N[b]	n/a	n/a	n/a

[a] Emission factor for direct nitrous oxide emissions
[b] Emission factor for indirect nitrous oxide emissions

Figure G-1. Wastewater Treatment Systems and Discharge Pathways



Methods for estimating methane and nitrous oxide emissions from domestic wastewater (WW) treatment are detailed separately below:

a. Domestic WW – methane: for each treatment option, methane is calculated as the fraction of the population utilizing the treatment system, the capacity of the system to generate methane based on BOD, population and BOD generation rate per capita. This is described by the formula:

$$Emisiones_{CH4} = \sum_j [U_j \times B_o \times MCF_j] \times P \times BOD \times 325.25$$

Where:
U_j = population fraction connected to treatment system j
Bo= maximum methane generation capacity
MCF_j =methane correction factor
j = treatment system/option
P = population
BOD = BOD per capita per day
325.25 = days in a year

b. Domestic WW – nitrous oxide: emissions occur in aerobic treatment plants and during the discharge of effluent to aquatic environments. Emissions from aerobic treatment plants is calculated as the fraction of the population serviced by the plant times a default plant emission factor (see 2006 IPCC, Volume 5, Equation 6.9). CCS correlated the treatment categories in operation in the state from CONAGUA publications with the treatment categories described in the IPCC guidance. As part of this exercise, all aerobic treatments systems were correlated under one single IPCC category encompassing all aerobic systems, namely, centralized aerobic plants. For aerobic treatment processes, the equation for estimating N_2O emissions is as follows:

$$N_2O_{PLANT} = P \; x \; T_{PLANT} \; x \; P_{IND\text{-}COM} \; x \; EF_{PLANT}$$

Where:
N_2O_{PLANTS} = total N_2O emissions from plants in inventory year, kg N_2O/yr
P = human population
T_{PLANT} = degree of utilization of aerobic modern, centralized WWT plants, %. This fraction was determined as the ratio of state-wide nitrification/denitrification treatment capacity to total treatment capacity multiplied by the fraction of the population that is connected to the sewer.
$F_{IND\text{-}COMM}$ = factor to allow for co-discharge of industrial nitrogen into sewer; default value 1.25.
EF_{PLANT} = emission factor, 3.2 g N_2O/person/year.

Most nitrous oxide emissions occur by the discharge of wastewater effluent that is ultimately released to aquatic environments. The effluent contains residual levels of nitrogen rich substances that eventually decompose and release nitrous oxide emissions. This estimate is driven by population and the amount of protein consumption per capita:

$$Emissions_{N2O} = P \; x \; Protein \; x \; F_{NPR} \; x \; F_{IND\text{-}COM} \; x \; EF \; x \; (44/28)$$

Where:
P = population
Protein = annual protein consumption rate per capita. Per the Food and Agriculture Organization (FAO), the average rate from 1990 to 2003 for México is 31 kg/person/year.
F_{NPR} = fraction of nitrogen in protein.
$F_{IND\text{-}COM}$ = factor to allow for co-discharge of industrial nitrogen into sewer; default value 1.25
EF = emission factor, the product of B_o and MCF factors
(44/28) = N to N_2O conversion factor.

Industrial Wastewater Treatment. For industrial wastewater emissions, the IPCC provides default assumptions and emission factors for four industrial sectors: Malt and Beer, Red Meat & Poultry, Pulp & Paper, and Fruits & Vegetables. INEGI provided data on red meat processing.[18] No data were available for malt and beer, pulp and paper, fruit and vegetable and poultry processing. Current industrial production data for red meat were used to estimate emissions for all historic years from 2002-2007, along with the IPCC emission factors for red meat production. Emissions were back-cast to 1990, assuming that activity in each year (1990 through 2001) was equal to the 2002 activity, where no industrial wastewater was processed. Emissions were forecast, assuming that emissions in each year were equal to the 2007 emission estimate.

Results

Figure G-2 and Table G-4 show the emission estimates for the waste management sector. Overall, Figure G-2 shows that the sector accounts for 1.02 $MMtCO_2e$ in gross emissions in 2005, and gross emissions are estimated to be 1.03 $MMtCO_2e$/yr in 2025. As shown in Table G-4, accounting for SWDS carbon storage yields the net emission estimates of 0.91 $MMtCO_2e$ and 0.91 $MMtCO_2e$ for 2005 and 2025, respectively. The large dip in landfill emissions after 2009 is due to the reduction of methane emissions from the aforementioned Ciudad Juarez CDM landfill gas project.

As shown in Table G-5, in 2005, the largest sources in the waste management sector were emissions from SWDS and emissions from domestic wastewater, accounting for 45% and 40% of total sector emissions. By 2025, the contribution of emissions from SWDS (41%) and domestic wastewater emissions (44%) will change slightly from 2005. Emissions from open burning account for 16% and 14% of the total sector emissions in 2005 and 2025, respectively. Emissions from industrial wastewater contributed minimally towards the waste sector emissions; however, data for only red meat production were available. The relative contribution from SWDS decreases at the point where the methane destruction values relative to emissions are highest (2010, 2015).

Key Uncertainties and Future Research Needs

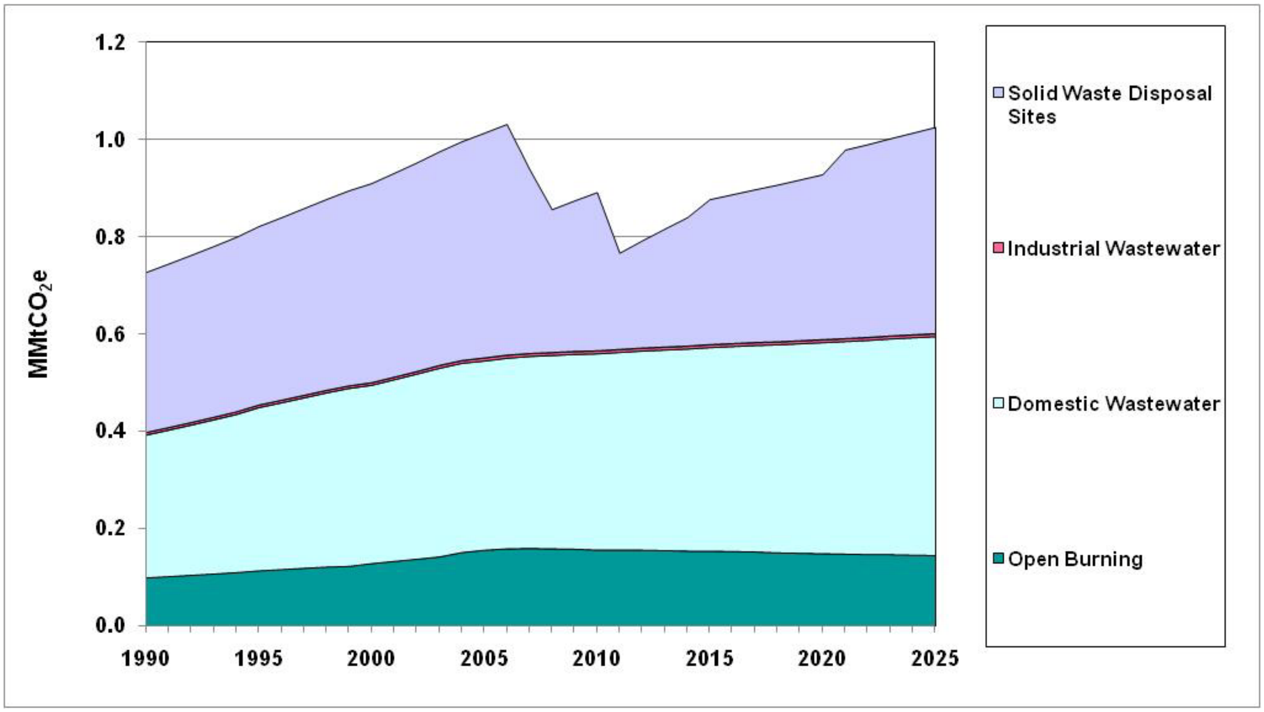
According to the Guidelines of the IPCC, a first order decay model to estimate emission from solid waste disposal sites contains inherent uncertainties, which are described below:

- Decay of carbon compounds to methane involves a series of complex chemical reactions and may not always follow a first-order decay reaction. Higher order reactions may be involved, and reaction rates will vary with conditions at the specific solid waste disposal site (SWDS). Reactions may be limited by restricted access to water and local variations in populations of bacteria;
- SWDS are heterogeneous. Conditions such as temperature, moisture, waste composition and compaction vary considerably even within a single site, and even more between

[18] Instituto Nacional de Estadísticas, Geografía e Informática. *Estadísticas de Ganado en Rastros Municipales por Entidad Federativa 2002-2007*. Online at: http://www.inegi.org.mx/est/contenidos/espanol/proyectos/coesme/programas/programa2.asp?clave=063&c=10984.

different sites in a country. Selection of 'average' parameter values typical for a whole country is difficult; and
- Use of the FOD method introduces additional uncertainty associated with decay rates (half-lives) and historical waste disposal amounts. Neither of these are well understood or thoroughly researched.

Figure G-2. Chihuahua Gross GHG Emissions from Waste Management



Source: Based on approach described in text.

Table G-4. Chihuahua GHG Emissions from Waste Management ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Solid Waste Disposal Sites	0.33	0.37	0.41	0.46	0.33	0.30	0.34	0.42
Open Burning	0.10	0.12	0.13	0.16	0.16	0.16	0.15	0.15
Domestic Wastewater	0.29	0.34	0.37	0.39	0.40	0.42	0.43	0.45
Industrial Wastewater	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Gross Emissions	**0.73**	**0.82**	**0.91**	**1.02**	**0.89**	**0.88**	**0.93**	**1.03**
Carbon Stored at SWDS	0.07	0.08	0.09	0.11	0.09	0.10	0.11	0.12
Total Net Emissions	**0.66**	**0.74**	**0.82**	**0.91**	**0.80**	**0.78**	**0.82**	**0.91**

Table G-5. Gross GHG Emission Distribution in the Waste Management Sector

Source	1990	1995	2000	2005	2010	2015	2020	2025
Solid Waste Disposal Sites	45%	45%	45%	46%	36%	34%	37%	41%
Open Burning	14%	14%	14%	16%	18%	18%	16%	14%
Domestic Wastewater	40%	41%	40%	38%	45%	48%	47%	44%
Industrial Wastewater	1%	1%	1%	1%	1%	1%	1%	1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Another source of uncertainty is the quality of the activity data. Waste accumulation values that are available from SEMARNAT are based on population and waste generation rates per capita. Actual records of waste accumulation per site were not available for all waste disposal facilities. A comprehensive set of accumulation records would reduce some of the uncertainty associated with SWDS methane emissions. CCS used total state population to model waste generation for waste that is assumed to be landfilled; however, as noted under the discussion for open burning, at least some of the waste generated in rural areas is not landfilled. Surveys of solid waste managers in the state could improve upon these initial assumptions of urban versus rural waste management.

Also, the waste composition data used for Chihuahua is representative of a single landfill, but may not be representative of the state as a whole, although this is the assumption made in this analysis. Additionally, the only methane recovery project included was the Ciudad Juarez Landfill Gas project recognized by the UNFCCC CDM program. It is possible in the future that landfill gas at other managed landfills will be captured and destroyed during the forecast period (e.g. due to increasingly popular carbon offset programs).

Open burning quantities of waste at residential sites were estimated by assuming that the rural portion of the Chihuahua population conducts open burning. As some of this waste may be deposited at an SWDS or managed in some other way, this assumption is likely to lead to an overestimate. However, this overestimate could help correct for the assumption that no open burning (or incineration) takes place in urban areas, which is probably not the case. Emissions from open burning of MSW include biogenic CO_2, which is released from the combustion of paper, wood, food and garden waste, and any other biogenic waste material. However, CH_4 and N_2O emissions due to the combustion of these materials may be significant and are included in the inventory as an anthropogenic GHG source. CO_2, CH_4, and N_2O from fossil-based carbon in sources, such as plastic and tires, are also included. Clearly, this initial estimate of residential open burning emissions can be greatly improved through surveys of solid waste experts in Chihuahua.

For the domestic wastewater sector, the key uncertainties are associated with the application of IPCC default values for the parameters listed in Table G-3 above. To the extent that additional methane is being generated outside of the anaerobic treatment process, these emissions will be underestimated. Also, if any methane is being collected and combusted (e.g. flared) in domestic WW treatment processes, it is not captured in this I&F due to a lack of data (e.g. methane formed in a biosolids digester). Potential emissions (primarily N_2O) from treatment plant sludge that is applied to the surface of landfills or otherwise land-applied were not quantified in this inventory.

For industrial wastewater, emissions were only estimated for the red meat industry using state data. There are no data for malt and beer, fruit and vegetable processing, or poultry processing facilities. To the extent that these industries are present in Chihuahua, the emissions from industrial wastewater will be underestimated.

Appendix H. Forestry and Land Use

Overview

Forestry and land use emissions refer mainly to the net carbon dioxide (CO_2) flux[1] from forests and perennial woody crops in Chihuahua, which account for about 30% of the state's land area.[2] Currently, there are approximately 7.6 million hectares of forests and 73,000 hectares of perennial woody crops in Chihuahua. In addition to forest CO_2 flux, additional CO_2 is either emitted or sequestered within urban forests. Additional GHG emissions can occur from other land use practices, including non-farm fertilizer application.

Through photosynthesis, carbon dioxide is taken up by trees and plants and converted to carbon in forest biomass. Carbon dioxide removals and emissions occur during respiration in live trees, decay of dead biomass, and combustion (both forest fires and biomass removed from forests for energy use). In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. Carbon dioxide flux is the net balance of carbon dioxide removals from and emissions to the atmosphere from the processes described above.

According to the 2006 IPCC guidelines, the Forestry and Land Use Sector includes six land use categories: 1) forest land, 2) cropland, 3) grassland, 4) wetlands, 5) settlements, and 6) other land.[3] Wetlands do not represent a key land use in Chihuahua. Losses of terrestrial carbon can also occur during conversion of grasslands to agricultural or developed use (i.e. land use change); however, no data were identified to quantify this potential source in Chihuahua. In this inventory, the forestry and land use sector CO_2 flux is categorized into two primary subsectors:

- *Forest Land Use [IPCC Categories: Forestland Remaining Forestland and Land Converted to Forestland]:* this consists of carbon flux occurring on lands that are not part of the urban landscape. Fluxes covered include net carbon sequestration, carbon stored in harvested wood products (HWP), and emissions from forest fires and prescribed burning.
- *Other Land Use:* these include Perennial Woody Crops [IPCC Category: Cropland Remaining Cropland] which cover carbon flux occurring on croplands that contain perennial woody vegetation, such as oil palm and fruit and nut orchards. Fluxes include biomass accumulation and tree removal.

  Other sources that could be included here if data were available include settlements (including urban forest carbon flux). Net carbon fluxes for grassland and other land are not considered to be significant and data to quantify these are unavailable. Also not included due to a lack of data are carbon fluxes associated with land management changes in crop cultivation, including losses/gains in soil carbon. Finally, as mentioned above, wetlands are not a significant land use in Chihuahua.

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[1] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[2] Sistema Nacional de Información Estadística y Geográfica (SNIEG), http://mapserver.inegi.gob.mx/geografia/espanol/estados/chih/agr_veget.cfm?c=1215&e=08&CFID=1762489&CFTOKEN=31412962
[3] IPCC defines other land as bare soil, rock, ice, and any other land not included in one of the other five land use categories.

Inventory and Reference Case Projections

Forested Landscape

2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC) offers two methods for estimating carbon flux. Based on the information available for Chihuahua, the "gain-loss" method was adopted which expresses the annual change in carbon stocks in biomass in forested land as the annual increase in carbon stocks due to biomass growth minus the annual decrease of carbon stock due to biomass loss:

$$\Delta C_B = \Delta C_G - \Delta C_L$$

where:

ΔC_B = annual change in carbon stocks in biomass considering the total area, metric tons (t) of carbon (C) per year (yr), tC/yr;

ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tC/yr;

ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tC/yr.

The annual increase in carbon stocks due to biomass growth (ΔC_G) is calculated for each vegetation type as follows:

$$\Delta C_G = \Sigma A_i \bullet G_{wi} \bullet (1+\mathrm{R}) \bullet CF_i$$

where:

A = land area, ha;

G_w = Above-ground biomass growth, t dry mass (d.m.) ha^{-1} yr^{-1};

R = Ratio of below-ground biomass to above-ground biomass, t d.m. below-ground biomass per t d.m. above-ground biomass; and

CF = carbon fraction of dry matter, tC/t d.m.

Estimates for the dead wood and litter carbon pools were not included in these estimates. The default assumption is that the stocks for these pools are not changing over time, if the land remains within the same land-use category.

Forest information was obtained from land surveys conducted in 1990 and 1995 by the United Nations Food and Agriculture Organization (FAO) Global Forest Resources Assessment (FRA).[4] In order to supplement missing historical data, land area values for 1991-1994 were interpolated

[4] *FRA 2000 Bibliografía Comentada Cambios en la Cobertura Forestal: México*, Departamento de Montes, Organización de las Naciones Unidas para la Agricultura y la Alimentación, August, 2000.

from the 1990 and 1995 data, and it was assumed that mean annual area for the time period 1996-2025 would remain constant from 1995. The FAO data only provides the total forest area. Forest area was allocated to climate zone and forest types using a 2002 survey from the Secretaría de Medio Ambiente Y Recursos Naturales (SEMARNAT).[5] This survey divides forest land area into bosques and selvas. Bosques were assigned to temperate mountain systems and selvas were assigned to sub-tropical mountain systems based on IPCC criteria.[6]

More recent and more detailed forest land data are available from INEGI.[7] However, the data, available as digital maps, required processing that was beyond the resources of this preliminary I&F project. Due to the relatively small contribution of the forest sector for Chihuahua, the less precise and less resource intensive set of forest data were chosen for this inventory. The FAO survey data in Table H-1 show a slight decline (<0.5%) in the forested area of Chihuahua from 1990 to 1995.

Table H-1. Forest Land Description and Coverage

Climate domain (i)	Ecological zone (j)	1990 (ha)	1995 (ha)
Sub-Tropical	Mountain Systems	518,405	516,421
Temperate	Mountain Systems	7,083,095	7,055,979
	Totals	**7,601,500**	**7,572,400**

Table H-2 lists the values used for carbon conversion factors, G_w, *R* and *CF* taken from the 2006 IPCC guidelines.[8]

Table H-2. Factors Used to Estimate Carbon Gain in Chihuahua Forest

Factor		Sub-Tropical Value	Temperate Value	Units
Above-ground biomass growth	G_w	0.5	0.9	t d.m. ha^{-1} yr^{-1}
Ratio of below-ground biomass to above-ground biomass	*R*	0.53	0.28	t d.m. below-ground biomass per t d.m. above-ground biomass
Carbon fraction of dry matter	*CF*	0.47	0.47	t C/t d.m.

[5] SEMARNAT. Compendio de Estadísticas Ambientales, 2002. México, D.F., 2003.
[6] Table 4.5, Chapter 4, Volume 4 of the IPCC guidelines.
[7] Land use and vegetation maps are referenced as: conjunto uso del suelo y vegetación escala 1:250 000, datum ITRF 92, formato SHP, seris I, II y III, clave D1502.
[8] Table 4.9, Chapter 4, Volume 4 of the 2006 IPCC guidelines lists values of above-ground net biomass growth in natural forests expressed as a range of plausible values. For the purposes of a conservative estimate of carbon sinks, lower end values were selected.

Several factors should be considered when estimating the annual decrease of carbon stocks due to biomass loss (ΔC_L), including harvesting wood products, fuel wood removals from forests, and carbon stock losses due to disturbances such as fires or insect infestations. Carbon stock decreases due to disturbances and wood products harvesting were calculated; however, information relating to fuel wood removals was not available. Consequently, the annual decrease of carbon stocks was calculated as the sum of carbon losses due to disturbances ($L_{disturbance}$) and carbon losses due to wood removals ($L_{removals}$) according to the following equation.

$$\Delta C_L = L_{removals} + L_{disturbance}$$

Data on forest surface area disturbed by fire and disease was obtained from Secretaría de Medio Ambiente y Recursos Naturales, Comisión Nacional Forestal (SEMARNAT).[9] Data on forest diseases were obtained for 1990-2008. Area disturbed by fires for 2009-2025 was estimated as the average of 2004-2008 values. For forest fires, data were obtained for the years 1995 through 2006; values for 1990-1995 were estimated by taking the average of the values for 1995-2005; and values for 2007-2025 were estimated as the average of 2002-2006 values. Carbon stocks losses due to disturbances were calculated using default conversion numbers listed in Table H-3 and calculated as follows:

$$L_{disturbance} = \{A_{disturbance} \bullet B_W \bullet (1+ R) \bullet CF \bullet fd\}$$

where:

$L_{disturbances}$ = annual other losses of carbon, t C/yr;

$A_{disturbance}$ = area affected by disturbances, ha/yr;

B_W = average above-ground biomass of land areas affected by disturbances, t d.m./ha;

R = ratio of below-ground biomass to above-ground biomass, in t d.m. below-ground biomass per t d.m. above-ground biomass;

CF = carbon fraction of dry matter, t C per t d.m.; and

fd = fraction of biomass lost in disturbance.

[9] SEMARNAT, Anuario Estadistico de la Producción Forestal, http://www.semarnat.gob.mx/gestionambiental/forestalysuelos/Pages/anuariosforestales.aspx.

Table H-3. Forest Area to Carbon Content Conversion Factors

Factor		Sub-Tropical Value	Temperate Value	Units
Above-ground biomass	B_w	60	50	t d.m./ ha
Ratio of below-ground biomass to above-ground biomass	*R*	0.28	0.53	t d.m. below-ground biomass per t d.m. above-ground biomass
Carbon fraction of dry matter	*CF*	0.47	0.47	t C/t d.m.
Fraction of biomass lost in fire	*fd*	0.90	0.90	NA
Fraction of biomass lost to disease or infestation	*fd*	0.10	0.10	NA

Non-CO_2 emissions from forest fires were also estimated. Methane (CH_4) and nitrous oxide (N_2O) emission factors from the 2006 IPCC Guidelines[10] were applied to the tonnes of biomass burned, as estimated using the factors in Table H-3 above.

Finally, wood harvest volume by type of wood was obtained from the *Anuario Estadistico de la Producción Forestal* from SEMARNAT for the years 1990 through 2005. Carbon loss due to wood harvest was calculated as:

$$L_{removals} = BCEF_{\mathrm{R}} \bullet (1 + R) \bullet CF$$

where: $BCEF_R$ is the biomass conversion and expansion factor, or the mass of above-ground biomass per volume of harvested wood [t biomass per cubic meter (m^3) of wood volume].

The values for $BCEF_R$ are shown in Table H-4 below. Due to lack of data, long-term storage in the resulting durable wood products (i.e., furniture, lumber), was not considered in this inventory.

Table H-4. Biomass Conversion and Expansion Factors

Climate Zone	Forest Type	$BCEF_R$ (t biomass/m^3 wood)
Dry Tropical	Hardwoods	0.89
Dry Tropical	Conifers	0.67
Temperate	Hardwoods	1.55
Temperate	Pines	0.83

Other Land Use

Other than perennial woody crops, data were not identified to estimate GHG emissions from other land uses in Chihuahua. These other sources/sinks include urban forest carbon flux, use of fertilizers on settlement soils, carbon flux on grasslands and other lands.

[10] Emission factors for non-tropical forests from Table 2.5 of Volume 4 (4.7 g CH_4 /kg of biomass and 0.26 g N_2O/kg biomass).

Perennial Woody Crops. The only data available for woody perennial crops were total area and harvested area for 1989 to 2006 from Sistema de Informacion Agroalimentaria de Consulta (SIACON). Crop areas for 2007-2025 were held constant at the average of 2002-2006 values. A list of woody crops identified from the SIACON and sample data for the 1990 and 2006 are shown in Table H-5.

Harvested area was assumed to be the surface area of mature trees, while the difference between total area and harvested area was assumed to be the surface area of immature trees. The change in carbon for mature trees ($\Delta C_{B,M}$) was estimated by taking the difference between total biomass for a given year (n) and the total biomass for the previous year (n-1):

$$\Delta C_{B,M} = B_{w,n} \bullet \mathrm{A}_{\mathrm{n}} - B_{w,n-1} \bullet \mathrm{A}_{\mathrm{n-1}}$$

where:

A = land area, ha;

B_w = average above-ground biomass, t d.m./ha.

Immature trees were assumed to gain carbon each year, estimated as:

$$\Delta C_{B,I} = G_{w,n} \bullet \mathrm{A}$$

where: G_w = above-ground biomass growth, tonnes d.m. ha^{-1} yr^{-1}.

The total change in carbon for woody crops was then estimated as the sum of the carbon flux for mature trees and immature trees:

$$\Delta C_{B,} = \Delta C_{B,M} + \Delta C_{B,I}$$

Default values for below-ground biomass for agricultural systems are not available. According to IPCC guidelines, the default assumption is that there is no change in below-ground biomass of perennial trees in agricultural systems.[11] Estimates for the dead wood and litter carbon pools were also not included in these estimates. The default assumption is that the stocks for these pools are not changing over time if the land remains within the same land-use category.

[11] While the removal of mature trees probably results in the loss of below-ground biomass, the 2006 IPCC guidelines establish that, for Tier 1 estimates, no change is assumed for below-ground biomass, Section 5.2.1.2 of Volume 4.

Table H-6. Surface Area of Woody Perennial Crops in Chihuahua in 1990 and 2006

Crop Name		1990 Total Area (ha)	1990 Harvested Area (ha)	2006 Total Area (ha)	2006 Harvested Area (ha)
Aceituna	olive	-	-	-	-
Aguacate	avocado	-	-	-	-
Algarrobo	carob tree	-	-	-	-
Almendra	almond	-	-	-	-
Chabacano	apricot	-	-	-	-
Ciruela	prunes	-	-	10	10
Citricos	citric tree	-	-	-	-
Datil	dates	-	-	-	-
Durazno	peaches	1,820	1,386	2,375	1,781
Eucalipto	eucalyptus	-	-	-	-
Frutales Varios	various fruits	997	815	-	-
Granada	pomegranate	-	-	-	-
Guayaba	guayaba	-	-	-	-
Higo	fig	-	-	-	-
Limon	lime	-	-	-	-
Macadamia	macadamia	-	-	-	-
Mandarina	tangerine	-	-	-	-
Manzana	apple	21,488	21,488	25,708	25,708
Membrillo	quince	-	-	128	128
Mostaza	mustard	-	-	-	-
Naranja	orange	-	-	-	-
Nectarina	nectarine	-	-	-	-
Nuez	walnut	17,428	17,267	44,656	30,920
Palma De Ornato	palm	-	-	-	-
Palma De Ornato (planta)	palm	-	-	-	-
Pera	pear	-	-	68	16
Pistache	pistache	-	-	249	25
Uva	grapevine	340	303	287	287
Toronja (pomelo)	grapefruit (pomelo)	-	-	-	-
	Total	**42.073**	**41,259**	**73,481**	**58,874**

Table H-7. Woody Crop Area to Carbon Content Conversion Factors

Factor		**Value**	**Units**
Above-ground biomass	B_w	63	t d.m. ha^{-1}
Above-ground biomass growth	G_w	2.1	t d.m. ha^{-1} yr^{-1}

Results

Carbon flux associated with forestry and other land uses are summarized in Table H-8. In 2005, the carbon flux for forested lands and perennial tree agricultural systems was estimated to be a net sequestration of 7.8 $MMtCO_2e$. The analysis of historical records indicates that: 1) biomass growth in Chihuahua's forested landscape exceeds the carbon decrease due to disturbances (forest fires) and the harvest of wood products combined, and 2) biomass loss is largely attributed to forest fires. A notable and potentially significant data gap is the amount of wood harvested for use as a fuel. Finally, the data in Table H-2 indicate a slight loss of forested area during 1990 and 1995. The potential loss of the associated carbon stocks on those lands has not been factored into the results below (e.g. permanent loss due to clearing and conversion to other land use).

Table H-8. Forestry and Land Use Flux and Reference Case Projections ($MMtCO_2e$)

Subsector	1990	1995	2000	2005	2010	2015	2020	2025
Forest Land Use	-7.1	-7.6	-6.5	-7.7	-8.3	-8.3	-8.3	-8.3
Growth	*-10.4*	*-10.3*	*-10.3*	*-10.3*	*-10.3*	*-10.3*	*-10.3*	*-10.3*
Fires (carbon loss)	*0.38*	*0.16*	*0.16*	*0.02*	*0.04*	*0.04*	*0.04*	*0.04*
Fires (CH_4 and N_2O)	*0.15*	*0.06*	*0.06*	*0.06*	*0.02*	*0.02*	*0.02*	*0.02*
Disease	*0.003*	*0.000*	*0.000*	*0.12*	*0.03*	*0.03*	*0.03*	*0.03*
Harvested Wood	*2.7*	*2.5*	*3.6*	*2.4*	*1.9*	*1.9*	*1.9*	*1.9*
Other Land Use	0.01	-0.02	-0.01	-0.10	-0.06	-0.06	-0.06	-0.06
Perennial Woody Crops	*0.01*	*-0.02*	*-0.01*	*-0.10*	*-0.06*	*-0.06*	*-0.06*	*-0.06*
Total Carbon Flux	**-7.2**	**-7.7**	**-6.6**	**-7.9**	**-8.4**	**-8.4**	**-8.4**	**-8.4**
Total (including CH_4 and N_2O)	**-7.1**	**-7.6**	**-6.5**	**-7.8**	**-8.4**	**-8.4**	**-8.4**	**-8.4**

NOTE: totals may not add exactly due to independent rounding.

Key Uncertainties and Future Research Needs

As stated above, not all IPCC land use categories relevant to Chihuahua were covered in this inventory due to a lack of data for some categories. For example, losses of terrestrial carbon can also occur during conversion of grasslands to agricultural or developed use; however, no data were identified to quantify this potential source in Chihuahua. For settlements, future research should include efforts to quantify urban forest terrestrial carbon storage (e.g. using estimates of tree canopy cover as an important input). Information on the use of commercial fertilizers in non-farm applications would allow for estimates to be made of N_2O emissions from settlement soils.

For the forested landscape, detailed data on forest types could not be utilized due to insufficient resources. Based on available data, such as satellite imagery, it may be possible to expand the detail of the inventory for forest lands as well as include the additional land use categories (including urban land area). However, additional resources will be needed to process digital imagery files available from INEGI.[12] There is also a need to review additional land cover data in the post-1995 period in order to evaluate whether the forest base is continuing to decline or if

[12] Land use and vegetation maps are referenced as: conjunto uso del suelo y vegetación escala 1:250 000, datum ITRF 92, formato SHP, seris I, II y III, clave D1502

gains have been made (and could continue). Changes in overall forest area after 1995 have not been captured in these initial estimates, nor have any associated losses of carbon stocks (if indeed there have been losses in forest area).

There is much uncertainty associated with the selection of above-ground net biomass growth values. Tables 4.8 and Table 4.9, Chapter 4, Volume 4 of 2006 IPCC guidelines lists values of above-ground net biomass and above-ground net biomass growth in natural forests expressed as a range of plausible values. For the purposes of a conservative estimate of carbon sinks, lower end values were selected. However, this was an assumption that needs verification. The selection of median values results in the carbon sequestration estimates listed in Table H-9. The results show differences of almost an order of magnitude. Clearly, data from in-state forest biomass surveys could greatly reduce the uncertainty associated with the use of the IPCC defaults.

Table H-9. Alternative Forested Landscape Flux (MMtCO_2e)

Subsector	1990	1995	2000	2005
Forest Land – Lower End Factors	-7.2	-7.7	-6.6	-7.9
Forest Land – Median Value Factors	-55	-56	-55	-57

Several processes contributing to the annual decrease of carbon stocks due to biomass loss should be considered, including harvesting of wood products, fuel wood removals from forests, and carbon stock losses due to disturbances such as fires or insect infestations. For Chihuahua, information regarding the annual decrease of carbon stocks due to fuel wood removals was not available and could have a substantial impact on the estimated carbon flux. Additionally, carbon loss by insect infestation was not considered in these estimates. Finally, carbon storage can occur from harvested wood products, when the harvested biomass is converted to durable wood products, such as lumber or furniture. Storage of forest carbon can also occur in landfills, when forest products are disposed. Research is needed on the end uses of wood harvested in Chihuahua in order to adequately characterize the full net flux of forest carbon.