Preparation of Virginia Greenhouse Gas Reference Case Inventory and Forecast

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Virginia Environmental Endowment (VEE). The report presents a preliminary assessment of the Virginia's greenhouse gas (GHG) emissions from 1990 to 2020. The inventory and forecast estimates serve as a starting point to assist the VEE and the State with an initial comprehensive understanding of Virginia's current and possible future GHG emissions, and thereby inform any processes that might be undertaken in the state to identify and analyze policy options for mitigating GHG emissions.

Virginia's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2020. Historical GHG emission estimates (1990 through 2005)[1] were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below, relying to the extent possible on Virginia-specific data and inputs. The initial reference case projections (2006-2020) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions.

This report covers the six gases included in the US Greenhouse Gas Inventory: 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 to global average radiative forcing on a Global Warming Potential- (GWP) weighted basis.

It is important to note that the preliminary emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Virginia'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, all total results are reported as *consumption-based.*

[1] The last year of available historical data varies by sector; ranging from 2000 to 2005.

Virginia Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Virginia by sector for the years 1990, 2000, 2005, 2010, and 2020. In the sections below, we discuss GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends, projections, and uncertainties clearly for each.

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-year emissions (2006 through 2020) and key uncertainties. We also provide an overview of the general methodology, principles, and guidelines followed for preparing the inventories.

Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in Virginia accounted for approximately 176 million metric tons (MMt) of gross CO_2e emissions (consumption basis), an amount equal to about 2.4% of total US gross GHG emissions (based on 2005 US data).[2] Virginia's gross GHG emissions are rising at a faster rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Virginia's gross GHG emissions increased by about 22% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005. The growth in Virginia's emissions from 1990 to 2005 is primarily associated with the electricity consumption and transportation sectors.

Figure 1 illustrates the State's emissions per capita and per unit of economic output. On a per capita basis, Virginia residents emitted about 23.2 metric tons (Mt) of gross CO_2e in 1990, which is slightly lower than the national average of 25.0 MtCO_2e in 1990. Per capita emissions in Virginia remained relatively constant from 1990 to 2005, with 2005 per capita emissions of 23.2 MtCO_2e/yr by 2005, while the per capita emissions for the US decreased slightly to 24.5 MtCO_2e/yr by 2005. As with the nation as a whole, economic growth exceeded emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). From 1990 to 2005, gross GHG emissions per unit of gross product dropped by 27% nationally, and by 26% in Virginia.[3]

[2] United States emissions estimates are drawn from US EPA 2007, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990 to 2005*; (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).
[3] Based on real gross domestic product (millions of chained 2000 dollars) that excludes the effects of inflation, available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). The national emissions used for these comparisons are based on 2005 emissions. (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

Table 1. Virginia Historical and Reference Case GHG Emissions, by Sector[a]

$MMtCO_2e$	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	**131.4**	**146.5**	**161.2**	**167.1**	**183.3**	
Electricity Use (Consumption)	**37.1**	**57.3**	**63.9**	**63.6**	**67.1**	
Electricity Production (in-state)	20.2	35.1	37.4	38.5	41.6	
Coal	*18.2*	*30.1*	*29.7*	*31.4*	*34.0*	
Natural Gas	*0.36*	*1.83*	*2.38*	*2.73*	*2.97*	
Oil	*0.92*	*1.99*	*3.79*	*2.72*	*2.80*	
Wood (CH_4 and N_2O)	*0.002*	*0.001*	*0.005*	*0.06*	*0.05*	
MSW/LFG	*0.08*	*0.13*	*0.27*	*0.33*	*0.37*	
Pumped storage	*0.65*	*1.03*	*1.20*	*1.28*	*1.47*	
Imported Electricity	16.9	22.2	26.6	25.1	25.5	
Res/Comm/Ind (RCI)	**33.5**	**34.4**	**35.8**	**37.4**	**39.9**	
Coal	11.7	8.81	8.53	9.48	9.67	Based on USDOE regional projections normalized by VA population (residential) or VA employment (industrial and commercial) projections.
Natural Gas	9.20	12.2	12.2	13.3	15.4	
Petroleum	12.5	13.1	14.9	14.5	14.7	
Wood	0.20	0.24	0.20	0.21	0.23	
Transportation	**41.3**	**48.3**	**56.3**	**61.0**	**71.3**	
Gasoline	26.7	32.2	35.2	37.6	43.5	Based on USDOE regional projections
Diesel	6.31	9.91	12.6	15.2	19.3	Based on USDOE regional projections
Marine Vessels	1.29	1.79	1.45	1.41	1.47	
Rail, Natural Gas, and LPG	0.62	0.31	0.29	0.30	0.31	Based on USDOE regional projections
Jet Fuel and Aviation Gasoline	6.40	4.07	6.77	6.50	6.64	Based on USDOE regional projections
Fossil Fuel Industry	**19.42**	**6.63**	**5.19**	**5.03**	**4.97**	
Natural Gas Industry	0.67	0.59	0.63	0.68	0.78	
Coal Mining (CH_4)	18.7	6.0	4.6	4.4	4.2	Assumes constant coal mining emissions after 2005
Industrial Processes	**1.17**	**3.19**	**4.19**	**5.44**	**8.15**	
Cement Manufacture (CO_2)	0.37	0.51	0.39	0.39	0.40	Based on State's industrial employment projections (2000-2010)
Limestone and Dolomite Use (CO_2)	0.000	0.14	0.16	0.16	0.17	Based on State's industrial employment projections (2000-2010)
Soda Ash (CO_2)	0.07	0.07	0.07	0.07	0.07	Based on 2004 and 2009 projections for U.S. production
ODS Substitutes (HFC, PFC, and SF_6)	0.008	2.04	3.15	4.52	7.34	EPA 2004 ODS cost study report
Electric Power T & D (SF_6)	0.73	0.43	0.42	0.29	0.18	Based on national projections (USEPA)
Agriculture	**5.16**	**4.87**	**4.77**	**4.42**	**4.07**	
Enteric Fermentation	2.03	1.86	1.90	1.81	1.76	Based on historical livestock population
Manure Management	0.60	0.66	0.66	0.65	0.65	Based on historical livestock population
Agricultural Soils	2.52	2.35	2.21	1.96	1.65	Historical trend
Agricultural Burning	0.006	0.007	0.006	0.006	0.006	Historical trend
Waste Management	**5.82**	**5.24**	**5.39**	**5.05**	**4.57**	
Landfills	4.70	3.81	3.38	2.96	2.31	Based on default 1995-2005 data
Waste Combustion	0.35	0.52	1.04	1.04	1.04	Based on default 1995-2005 data
Wastewater Management	0.77	0.91	0.97	1.04	1.21	Based on default 1990-2005 data
Gross Emissions (Consumption Basis, Excludes Forest Sink)	**143.5**	**159.8**	**175.6**	**182.0**	**200.1**	
increase relative to 1990		*11%*	*22%*	*27%*	*39%*	
Forestry and Land Use	**-7.77**	**-17.8**	**-18.0**	**-18.3**	**-18.9**	

Forested Landscape	-0.55	-14.7	-14.7	-14.7	-14.7
Urban Forestry and Land Use	-7.22	-3.03	-3.28	-3.60	-4.12
Net Emissions (Consumption Basis, Includes Forest Sink)	**135.8**	**142.0**	**157.6**	**163.6**	**181.3**
increase relative to 1990		*16%*	*31%*	*36%*	*51%*

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding. NA = not available.

Figure 1. Historical Virginia and US Gross GHG Emissions, Per Capita and Per Unit Gross Product

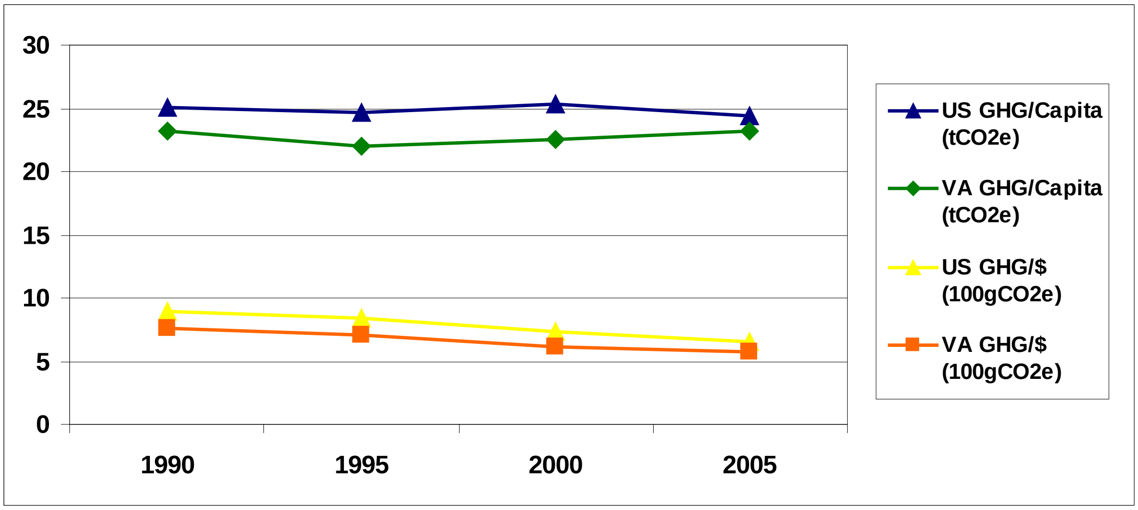


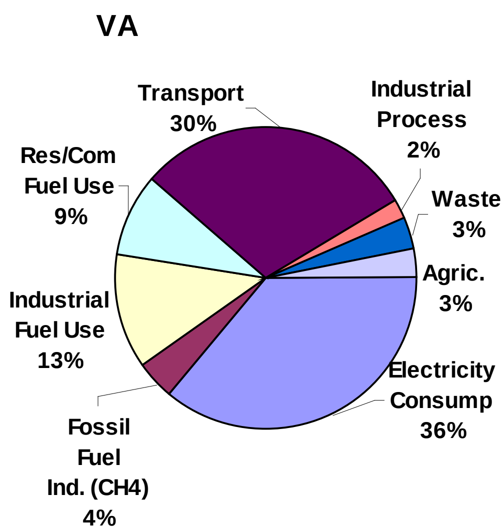
Figure 2 compares gross GHG emissions estimated for Virginia to emissions for the US for year 2000. Principal sources of Virginia's GHG emissions are the electricity consumption and transportation sectors, accounting for 36% and 30% of Virginia's gross GHG emissions in 2000, respectively. The next largest contributor is residential, commercial, and industrial fuel use (RCI), accounting for 22% of gross GHG emissions in 2000. The fossil fuel industries sector accounts for 4% of the 2000 gross GHG emissions, with a majority of these emissions coming from CH_4 released during coal mining. The waste management and agriculture sectors each contribute 3% of the state's total of gross GHG emissions in 2000.

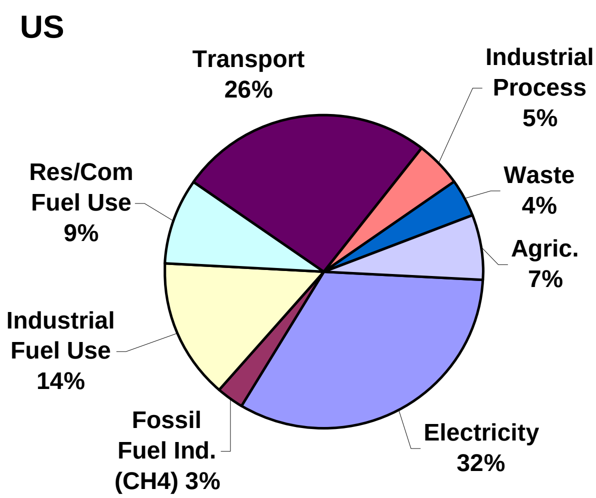
Industrial process emissions comprised 2% of State GHG emissions in 2000. Although industrial process emissions are rising rapidly due to the increasing use of HFC as substitutes for ozone-depleting chlorofluorocarbons (CFCs), their overall contribution is estimated to be only slightly more than 4% of Virginia's gross GHG emissions in 2020 due to significant growth in other sectors.[4] Other industrial process emissions result from the use of ODS substitutes; CO_2 released during cement manufacture as well as from soda ash and limestone and dolomite use; and releases of SF_6 from transformers used in the transmission and distribution of electricity and laboratory uses. Methane emissions associated with natural gas transmission and distribution (T&D) (included under the fossil fuel industry category) accounted for 0.5% of the State's gross GHG emissions in 2000.

The forestry sector is a net sink of GHG emissions in Virginia in 2000, sequestering 17.8 $MMtCO_2e$ in 2000. Overall, activities associated with forestry and land use changes in Virginia are estimated to be net sinks of GHG emissions throughout the period from 1990 through 2020. Through sequestration, forested lands in Virginia are expected to store 7.8 $MMtCO_2e$ in 1990, increasing to 18.0 $MMtCO_2e$ in 2005, and increasing to 18.9 $MMtCO_2e$ by 2020.

[4] CFCs are also potent GHGs; they are not, however, included in GHG estimates because of concerns related to implementation of the Montreal Protocol. HFCs are used as refrigerants in the RCI and transport sectors as well as in the industrial sector; they are included here, however, within the industrial processes emissions.

Figure 2. Gross GHG Emissions by Sector, 2000, Virginia and US





NOTE: at a national level, forests act as a net sink of CO_2; therefore, they do not show up in the above graph of gross U.S. emissions sources.

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

Electricity Supply Sector

Virginia is a net importer of electricity, meaning that the State consumes more electricity than is produced in the State. For this analysis, it was assumed that all power generated in Virginia was consumed in Virginia, and that remaining electricity demand was met by imported power. Imported power accounted for 36% of the electricity consumed in Virginia in 2003.[5] Emissions from the power produced in-state are dominated by coal use. As shown in Figure 2, electricity consumption accounted for about 36% of Virginia's gross GHG emissions in 2000 (about 57.3 $MMtCO_2e$), which was higher than the national average share of emissions from electricity consumption (32%).[6] The GHG emissions associated with Virginia's electricity sector increased by about 26.8 $MMtCO_2e$ between 1990 and 2005, accounting for nearly 84% of the state's net growth in gross GHG emissions in this time period.

In 2005, emissions associated with Virginia's electricity consumption (63.9 $MMtCO_2e$) were about 26.6 $MMtCO_2e$ higher than those associated with electricity production (37.4 $MMtCO_2e$). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity to meet Virginia's electricity demand.[7] Projections of electricity sales for 2005 through 2020 indicate that Virginia will remain a net importer of electricity. For the period covering 2005 through 2020, the reference case projection assumes that production-based emissions (associated with electricity generated in-state) will increase by about 4.2 $MMtCO_2e$, and consumption-based emissions (associated with electricity consumed in-state) will increase by about 3.8 $MMtCO_2e$.

The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in Virginia, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making.

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 30% of Virginia's gross GHG emissions in 2000 (about 48.3 $MMtCO_2e$), which was higher than the national average share of emissions from transportation fuel consumption (26%). The GHG emissions associated with Virginia's transportation sector increased by 15.0 $MMtCO_2e$ between 1990 and 2005, accounting for about 34% of the State's net growth in gross GHG emissions in this time period.

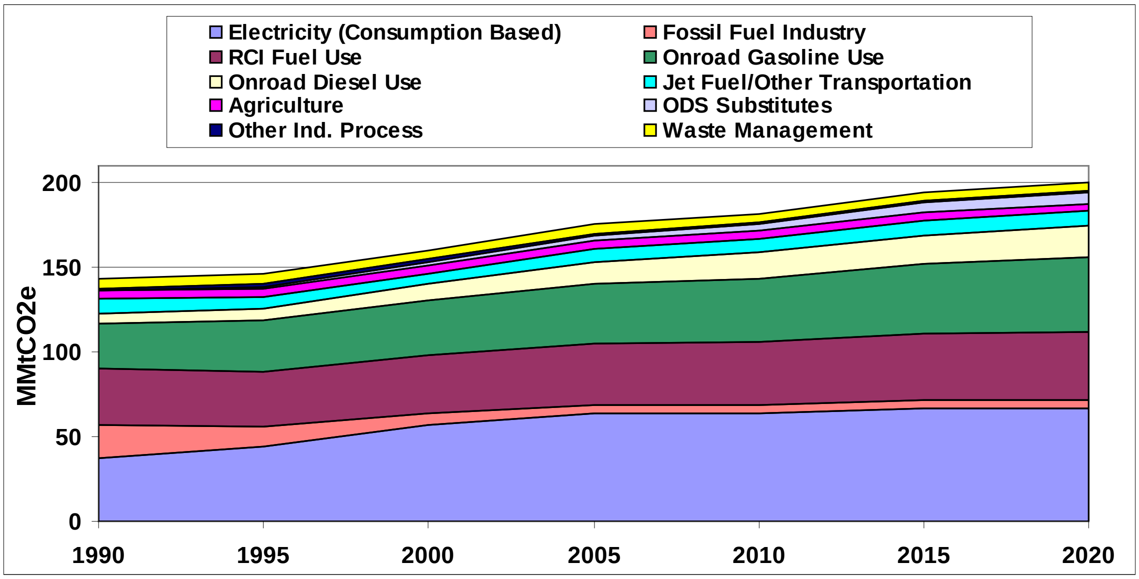
[5] Based on EIA 2004 State Electricity Profiles.
[6] For the US as a whole, there is relatively little difference between the emissions from electricity use and emissions from electricity production, as the US imports only about 1% of its electricity, and exports far less. Virginia's situation is different, since it is a net electricity importer.
[7] Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-state and out-of-state) used by utilities to meet consumer demand. The current estimate reflects some very simple assumptions.

From 1990 through 2005, Virginia's GHG emissions from transportation fuel use have risen steadily at an average rate of about 2.0% annually. In 2005, onroad gasoline vehicles accounted for about 63% of transportation GHG emissions. Onroad diesel vehicles accounted for another 22% of emissions, and air travel for roughly 12%. Marine vessels, rail, and other sources (natural gas- and liquified petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 3% of transportation emissions. As a result of Virginia's population and economic growth and an increase in total vehicle miles traveled (VMT) during the 1990s, onroad gasoline use grew about 35% between 1990 and 2005. Meanwhile, onroad diesel use doubled, rising by 100% during that period, suggesting an even more rapid growth in freight movement within or across the State. Marine residual fuel decreased by about 54%, while rail fuel use decreased about 85% from 1990 to 2005.

Reference Case Projections

Relying on a variety of sources for projections, as noted below, we developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Virginia's gross GHG emissions continue to grow steadily, climbing to about 200 $MMtCO_2e$ by 2020, 39% above 1990 levels. The transportation sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with ODS Substitutes (HFCs), RCI fuel use, and electricity consumption, as shown in Figure 4.

Figure 3. Virginia Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



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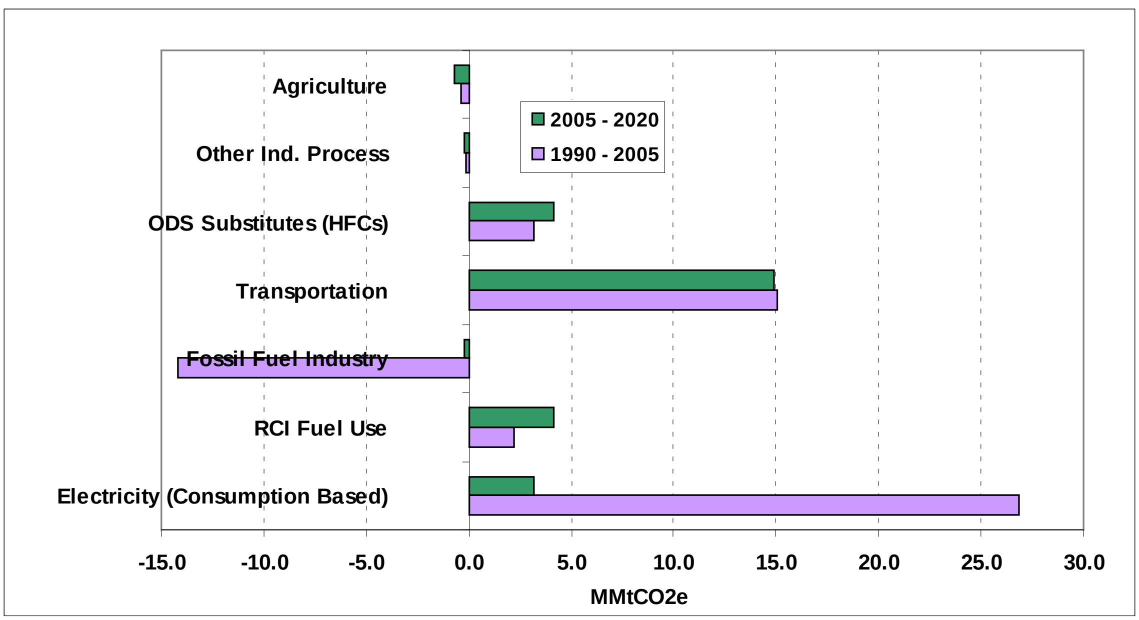
CI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance.

Figure 4. Sector Contributions to Gross GHG Emissions Growth in Virginia, 1990-2020: Reference Case Projections ($MMtCO_2e$ Basis)



RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons.

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 the transportation, electricity demand, and RCI fuel use growth rates that will be major determinants of Virginia's future GHG emissions (See Table 2 and Figure 4). These 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.

Table 2. Key Annual Growth Rates for Virginia, Historical and Projected

	1990-2005	2005-2020	Sources
Population[a]	1.35%	1.10%	Historical population data from US Census for Virginia for 1990 and 2000. 2005 population estimate from Weldon Cooper Center for Public Service, Demographics & Workforce Section[8]. Projections from Virginia Employment Commission[9]
Employment[a]			
Goods	-0.6%	2.0%	Annual growth rates for 2005-2020 based on Virginia Employment Commission projections from 2004 to 2014.[10]
Services	0.6%	0.2%	
Electricity Sales			Historical annual growth rates calculated using data for 1990 and 2005 from EIA's State Electricity Profiles for each year. For the period 2004 through 2020, assume the growth rate for in-state electricity sales is consistent with growth in the Mid-Atlantic Area Council (MAAC) region, and apply this growth rate to the 2003 retail sale level to forecast annual sales.
VA Sales[b]	2.4%	1.3%	
Imported Sales[c]	2.4%	0.2%	
Vehicle Miles Traveled	1.9%	1.7%	Forecasted based on regression of historical VMT.

[a] For the RCI fuel consumption sectors, population and employment projections for Virginia were used together with US DOE EIA's Annual Energy Outlook 2006 (AEO2006) projections of changes in fuel use for the EIA's South Atlantic region on a per capita basis for the residential sector, and on a per employee basis for the commercial and industrial sectors. For instance, growth in Virginia's residential natural gas use is calculated as the Virginia population growth times the change in per capita natural gas use for the South Atlantic region.
[b] Represents annual growth in total sales of electricity by generators in Virginia to RCI sectors located within Virginia (production basis). Annual growth rate calculated using data for 1990 and 2004.
[c] Represents annual growth rate in sales of electricity imported into Virginia.

[8] Available at http://www.coopercenter.org/demographics/POPULATION%20ESTIMATES/Previous%20Estimates.php.
[9] Available at http://velma.virtuallmi.com/analyzer/.
[10] Virginia Employment Commission data available at https://www.vawc.virginia.gov/.

Approach

The principal goal of compiling the inventories and reference case projections presented in this document is to provide a general understanding of Virginia'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 inventories for Virginia.

General Methodology

The overall goal of this effort is to provide simple and straightforward estimates, with an emphasis on robustness, consistency, and transparency. As a result, we rely on reference forecasts from best available State and regional sources where possible. Where reliable existing forecasts are lacking, we use straightforward spreadsheet analysis and constant growth-rate extrapolations of historical trends rather than complex modeling.

In most cases, we follow the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[11] and its guidelines for States.[12] 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.[13] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 3. Table 3 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

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:** We report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, we will report key uncertainties where they exist.
- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. We have used the EPA tools for State inventories and projections as a starting point. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and base-case projection needs. For consistency in making reference case projections, we define reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis*.

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[11] US EPA 2007, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990 to 2005*; (http://www.epa.gov/climatechange/emissions/usinventoryreport.html)..
[12] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[13] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Table 3. Key Sources for Virginia Data, Inventory Methods, and Growth Rates

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SIT)	US EPA SIT is a collection of linked spreadsheets designed to help users develop State GHG inventories for 1990-2005. US EPA SIT contains default data for each State for most of the information required for an inventory. The SIT methods are based on the methods provided in the Volume VIII document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html).	Where not indicated otherwise, SIT is used to calculate emissions for 1990-2005 from RCI fuel combustion, transportation, industrial processes, agriculture and forestry, and waste. We use SIT emission factors (CO_2, CH_4, and N_2O per BTU consumed) to calculate energy use emissions.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2004 for all fuels, and to 2005 for natural gas and wood.	EIA SED is the source for most energy use data. Emission factors from US EPA SIT are used to calculate energy-related emissions.
EIA *Annual Energy Outlook 2006* (AEO2006)	EIA AEO2006 projects energy supply and demand for the US from 2003 to 2030. Energy consumption is estimated on a regional basis. Virginia is included in the South Atlantic region (SC, DE, MD, DC, WV, VA, NC, GA, FL).	EIA AEO2006 is used to project changes in per capita (residential), per employee (commercial/industrial).
EIA State Electricity Profiles	EIA provides information on the electric power industry generation by primary energy source for 1990 – 2005.	EIA State Electricity Profiles were used to determine the mix of in-state electricity generation by fuel .
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas transmission pipeline mileage, and distribution pipeline mileage and number of services for 1990 – 2005.	Emissions projected to increase at an average annual rate of 0.38% from 2005-2010; 0.45% from 2010-2015; and 0.35% from 2015-2020; based on AEO2006 regional forecast in natural gas consumption for South Atlantic region.
US Forest Service	Data on forest carbon stocks and land use cover for multiple years.	Data are used to calculate CO_2 flux over time (terrestrial CO_2 sequestration in forested areas).
USDS National Agricultural Statistics Service (NASS)	USDA NASS provides data on crops and livestock.	Crop production data used to estimate agricultural residue and agricultural soils emissions; livestock population data used to estimate manure and enteric fermentation emissions.

- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, we 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, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.
- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods.** This analysis aims to comprehensively cover GHG emissions associated with activities in Virginia. It covers all six GHGs covered by US and other 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 2002 to 2005), with projections to 2010 and 2020.
- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in Virginia. For example, we reported emissions associated with the electricity consumed in Virginia. The rationale for this method of reporting is that it can more accurately reflect the impact of State-based policy strategies such as energy efficiency on overall GHG emissions, and it resolves double-counting and exclusion problems with multi-emissions issues. This approach can differ from how inventories are compiled, for example, on an in-state production basis, in particular for electricity.

For electricity, we estimate, in addition to the emissions due to fuels combusted at electricity plants in the State, the emissions related to electricity *consumed* in Virginia. This entails accounting for the electricity sources used by Virginia utilities to meet consumer demands. As this analysis is refined 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 Virginia, but purchased out-of-state. In some cases, this can require venturing into the relatively complex terrain of life-cycle analysis. In general, we recommend considering a consumption-based approach where it will significantly improve the estimation of the emissions impact of potential mitigation strategies. For example 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.