Emissions Inventory Considerations for Supporting the Development of State & Local Climate Change Mitigation Plans

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ABSTRACT

This paper presents a discussion of greenhouse gas (GHG) emissions inventory issues that have arisen during the development of state and local climate change mitigation plans (CCMPs). Recommendations for addressing these issues are provided. The authors will present inventory issues and recommendations based on CCMP work performed in several U.S. states including – Arizona (AZ); New Mexico (NM); and North Carolina (NC). A team of consultants, lead by the Center for Climate Strategies (CCS), is acting as a facilitator and technical analyst for the development of CCMPs in each of these states (with work in additional states underway). Members of this group have been involved in the development of CCMPs in other states and regions in the past.

For the purposes of these CCMP processes, the GHG sources have been aggregated into four sectors: Energy Supply (ES); Transportation & Land Use (TLU); Residential/Commercial/Industrial (RCI); and Agriculture & Forestry (AF). Waste Management issues have either been included in the RCI or AF sectors. The inventories have covered all six gases typically included: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. In addition, for the AZ CCMP process, a black carbon emissions inventory covering all sectors was also developed.

These inventories are important elements of CCMP processes, as they are essential in identifying where emissions are headed and where opportunities lie for reducing emissions. In tandem with inventories, we prepare emissions projections out to 2020 (or beyond). Then, as a next key step in the development of the CCMPs, dozens of emissions-reducing policy options are considered by stakeholders in each state. As of the writing of this paper, AZ and NM stakeholders are finalizing consideration of about 50 policy options for potential approval. NC stakeholders are just beginning the review of policy options and CCMP planning processes are under development through CCS in Montana and Vermont. In addition, the Western Regional Air Partnership (WRAP) has requested assistance from CCS in developing current and comprehensive GHG emissions inventories and forecasts for member states that do not have such assessments in place (11 states). The state of South Carolina also has requested assistance by CCS in the development of inventory and forecast assessments.

Inventory tools such as EPA's State GHG Inventory Tool (SGIT) or STAPPA/ ALAPCO's Clean Air and Climate Protection software (CACP) are often used as a starting point for CCMP inventory development. Often, during the development of policy options, data gaps in the base year inventory or forecasts are identified which require further analysis. This paper will explore many of the inventory issues that have arisen during CCMP development processes and methods/data sources that have been used to resolve these issues. The lessons learned from these projects should help other developers of CCMPs during the development of their emission inventories and forecasts.

INTRODUCTION

This paper provides recommendations on methods and data sources for greenhouse gas (GHG) emissions inventory and forecast assessments to support the development of state and local climate change mitigation plans (CCMPs). The Center for Climate Strategies (CCS) is assisting several States in the development of CCMPs, which will serve as a report to the Governor and environment Department in each State. States currently receiving assistance from CCS toward the current or future development of CCMPs include AZ, NM, NC, MT, and VT. Each of these State processes is a stepwise, fact-based, stakeholder-driven process based on a model of facilitated self-determination. An advisory group of stakeholders, usually referred to as the Climate Change Advisory Group or CCAG, is assembled. These advisory groups consist of members of government, industry, non-government organizations, and the public. The advisory groups have the responsibility of making final recommendations to the governor on actions that should be taken to mitigate climate change.

In support of each advisory group, technical work groups (TWGs) consisting of advisory group members and additional stakeholders work with technical facilitators from CCS to develop policy options for consideration by the overall advisory group. The entire CCMP development process can be summarized by the following 10 steps:

1. Develop initial GHG inventories and forecasts;
2. Identify conceivable GHG mitigation options;
3. Identify initial priorities for evaluation;
4. Evaluate supply potential, cost effectiveness; ancillary and feasibility issues as needed;
5. Identify barriers, alternative policy design needs;
6. Modify, add or subtract options as needed;
7. Evaluate cumulative results of options;
8. Iterate to consensus, with votes as needed;
9. Aggregate options into implementation scenarios; and
10. Finalize recommendations and report language.

The CCS staff assist each of the advisory groups by developing the initial GHG inventory and forecast, preparing a list of conceivable mitigation options, facilitating the TWGs to identify policy priorities for evaluation, assisting TWG members in quantifying the costs and benefits of each policy option, evaluating the cumulative results of all options toward each State's goals, and assisting in the production of the final report to the governor.

The focus of this paper is on methods and data sources for developing GHG inventories and forecasts to support state and local planning of GHG mitigation programs and policies.

Standard GHG EI and Forecast Methods

The primary purpose of State GHG inventory and reference case projections[a] is to provide the State and stakeholders with an initial comprehensive understanding of current and possible future GHG emissions and variables that significantly affect emissions change over time, thereby informing analysis and design of GHG mitigation strategies. The analyses provide key information on:

- Current levels of GHG emissions and contribution of different activities (typically as close to present as possible, but often indexed to year 2000);
- How the emissions are estimated to change in the future (typically through 2020), in total and by activity; and
- How emissions have changed in the past (typically from 1990 to present).

This information helps provide focus on particular activities for the mitigation strategies and provides some information on the impacts of past policies and programs on GHG emissions. As mitigation strategies are developed and implemented, the inventory and projections are used to estimate the impacts of these strategies. This information also assists states in the development of ongoing statewide inventory and reporting systems to measure progress against state goals and programs. It also provides a macroeconomic framework to support development of micro scale inventory, reporting and registry systems.

Since the state GHG inventories and projections are voluntary and have no current[b] regulatory implication at the federal level, each state can define their own scope and approach. CCS seeks to maintain the following principles in developing our inventories and projections:

1. **Transparency:** We report data sources, methods, and key assumptions to provide open review and opportunities for additional revisions later based on stakeholder input.
2. **Consistency:** To the extent possible, the inventory and projections are designed to be externally consistent with current or likely future systems for state and national GHG emissions reporting. As a signatory to the United Nations Framework Convention on Climate Change, the U.S. is required to produce a national GHG inventory, and many states have completed their own GHG inventories. Seeing the value in having harmonized approaches to these inventories, the U.S. EPA developed a set of guidelines for states developing GHG inventories, as part of the Emission Inventory Improvement Program (EIIP). The EIIP guidelines[1] have been adapted from Volumes 1-3 of the *Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories*[2] and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*.[3] EPA is currently in the process of updating the EIIP guidelines. EPA's state-level GHG inventory tool based on these EIIP methods is called the State GHG Inventory Tool or SGIT.

   The CCS state inventories use the EIIP guidelines and software tools but have been supplemented with local or more up-to-date data where available and with slight variations in the approach when deemed preferable to capture local conditions. For example, the software tools were released in August 2004, while the inventories discussed in this paper were developed in 2005. CCS modified the EPA software tool to include more recent and updated data on energy consumption, animal stock, and agriculture. For some smaller emission categories, such as industrial processes, the EPA tool also provided rough estimates of state emissions using the state's share of population or industrial production to estimate the state's share of national emissions. By contacting industrial experts in each state (such as semi-conductor producers), CCS was able to

[a] For the purpose of this discussion, the GHG inventory refers to actual emissions that have occurred while reference case projections are estimates of future emissions.

[b] Should GHGs become covered under the Clean Air Act in the future and subject to State Implementation Plans, GHG inventories and forecasts would be required in support of the mitigation policy planning process.

improve the emission estimates with direct data. We also make all efforts to check and correct for internal consistency among the variety of data sources.

Reference case projections are estimates of future emissions based on actions that are currently in place or reasonably expected over the time period of analysis and growth in source activity. Few states have developed reference case projections, and the EPA does not prepare GHG emission projections or provide guidelines for state projections. Our approach relied on compiling various existing, documented sources for projections of electricity generation, fuel use, and other GHG emitting activities, along with a set of simple, transparent assumptions often based on population or economic growth forecasts.

3. **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** The inventories and projections make every effort to comprehensively cover GHG emissions associated with activities in the state.
   a. All sectors. Emissions are generally reported under the following sector categories to support policy analysis and formulation:

      Energy Use
         Electricity supply
         Residential, commercial and industrial fuel use
         Transportation fuel use
      Non-Energy Use
         Industrial processes
         Agriculture
         Solid waste and wastewater
      Forestry and Land Use

      Functionally this information is provided to TWGs that typically are organized as follows:

      - Energy Supply
      - Residential, Commercial and Industrial
      - Transportation and Land Use
      - Agriculture, Forestry and Waste Management
      - Cross Cutting Issues (inventories, reporting, registries and education)

      These categories and sub-categories may differ between states to reflect different relative importance of activities. For example, the fossil fuel production industry is a large source of emissions in New Mexico and is reported under a separate category. In Arizona, this industry is relatively small and the emissions are reported as part of the industrial sector and non-energy sectors.
   b. All six greenhouse gases covered by U.S. and other national inventories. Carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). We aggregate six gas results into CO2 equivalence (CO2e) using IPCC 100-year global warming potentials, consistent with EPA methods. In Arizona, we have also constructed an inventory of black carbon (BC) emissions (described further below).
   c. Emissions from 1990 onward. We start the inventory with 1990, and include available subsequent years up to the most recently available data (2002, 2003 or 2004), with projections to 2010 and 2020.
   d. Emissions at the statewide level, with local detail as needed and practical. In general, we report emissions at the state-level at a minimum. Reporting of emissions from individual entities is limited to publicly-available data – in general only for historical emissions from large emitters.
   e. Report both total gross emissions and total net emissions. *Gross* emissions estimates do not include the effects of carbon sinks, i.e., the net carbon sequestered in, or

released from, soils and vegetation. Our estimates of emissions from carbon sinks are based on U.S. Forest Service estimates that have been collected between 1982 and 2002. Refined estimates of forest carbon stock change may result in significant changes to current estimates and should, in some cases, be the focus of further analysis. We report *net* GHG emissions – which include the above net forest carbon stock change estimates – separately from the *gross* GHG emissions.

4. **Use of Consumption-Based Emissions Estimates:** A key question when developing GHG inventory and projections is should states focus on: a) all emissions produced within the State (*production-based emissions*), or b) the emissions associated with the production of electricity, natural gas, and/or other energy-intensive products consumed through activities within the State (*consumption-based emissions*). This issue is described in further detail in the next section.
5. **Priority of Significant Emissions Sources:** Activities with very small emissions levels are not reported in the same level of detail as other activities, if it is too costly or cumbersome to do so.
6. **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources may conflict, we place highest priority on using local and state data and analyses, followed by regional sources with national data used as defaults where necessary.
7. **Presentation of Additional Metrics and Units for Better Understanding:** SGIT provides emission estimates (tons of CO2e emissions), but not the underlying activity data (energy use, land use, cement production estimates, etc.). For additional analysis, as well as for stakeholder understanding, we provide the activity data in energy units (BTU, GWh, etc.), land use (acres), agricultural units (e.g., head of livestock), and other relevant units that are the basis for emission estimates. This information is often important to policy development.

As mentioned above, a key question when developing GHG inventory and projections is whether states focus on: a) all emissions produced within the State (*production-based emissions*), or b) the emissions associated with production of electricity, natural gas, and/or other energy-intensive products consumed within the State (*consumption-based emissions*). It is possible also to create hybrid systems to address intermediate energy processing issues such as embedded energy in energy and product exports/imports.

Reporting production-based emissions has the advantages of simplicity and consistency with typical inventory methods (this approach is used in the EIIP Guidelines). Production-based reporting accounts for increases in emissions resulting from new in-state power plants or gas production facilities, even if such facilities are built largely to serve out-of-state consumption. Conversely, future declines in natural gas production, due for example to the depletion of gas reserves, could lead to significant reductions in reported state emissions related to gas production activities. Such changes in the state's reported emissions could be very significant, and but may also be rather difficult to predict or manage. Furthermore, one could argue that these changes do not reflect "real" emissions changes, if electricity or gas consumers would otherwise source their electricity or gas from similar sources in other states or countries.

In contrast, reporting consumption-based GHG emissions can be more complex from an accounting perspective. However, the consumption-based approach may also better reflect the emissions (and emissions reductions) associated with consuming activities occurring within the State, particularly with respect to electricity use (and efficiency improvements), and may be useful in a policy context. Under this approach, emissions associated with electricity exported to other states would need to be covered in those states' accounts in order to avoid double counting or exclusions. The same principle holds for petroleum imports; states account for the consumption of fuel imported from other states and nations and do not exclude it from statewide inventories. It also holds for a variety of imports and exports of raw materials, products and waste. The consumption-based approach leads to projections that are likely to be less volatile (subject to major changes), and future GHG emissions are more directly influenced by state-based policy strategies such as energy efficiency on overall emissions. However, developing a robust tracking system for a consumption-based approach could be more challenging than a production based approach in some cases.

For the initial inventory and projections, we prepared simplified consumption-based estimates for electricity and fossil fuel production activities, as well as biomass. For energy sources, we estimated the ratio of in-State consumption to total production, and applied this ratio to the total GHG emissions from that sector. While this method may not precisely reflect the sources of electricity or fuels used to meet in-state demands, it does provide a rough guide. Production-based emissions are included in the full reports for each state, to provide additional information for the stakeholder process.

Results for Arizona

As shown in Table 1, our preliminary analysis suggests that in 2000, Arizona accounted for approximately 80 million metric tons (MMt) of *net* CO2e emissions, an amount equal to 1.2% of total U.S. GHG emissions.[4] Arizona GHG emissions are rising rapidly compared with the nation as a whole, driven by the rapid pace of Arizona's population and economic growth. Arizona GHG emissions were up 51% from 1990 to 2000, while national emissions rose by 23% during this period. During the 1990s, population grew by 39% in Arizona compared with 13% nationally. Furthermore, Arizona's economy grew faster on a per capita basis (up 63% vs. 52% nationally). The reference case projections indicate that net Arizona GHG emissions would climb to 154 $MMtCO_2e$ by 2020, 87% above 2000 levels and 159% above 1990 levels.

Table 1. Arizona GHG emissions, reference case – consumption based.

(Million Metric Tons CO2e)	1990	2000	2010	2020
Energy Use (CO2, CH4, N2O)	**57.9**	**78.8**	**103.6**	**144.6**
Electricity Use	***24.9***	***34.5***	***46.6***	***73.2***
Electricity Production (in-state)	32.3	44.5	58.4	76.9
Net Electricity Exports	-7.4	-10.0	-11.8	-3.7
Residential/Commercial/Industrial	***7.7***	***9.3***	***11.6***	***13.8***
Transportation	***25.3***	***35.0***	***45.4***	***58.6***
Non-Energy Use (CO2, CH4, N2O, SF6, HFC, PFC)	**8.1**	**10.2**	**12.9**	**15.7**
Industrial Processes	***1.9***	***4.1***	***6.3***	***9.1***
Agriculture	***4.1***	***4.2***	***4.6***	***4.7***
Waste Management	***2.1***	***1.9***	***2.0***	***1.9***
Total Emissions - Consumption-Based				
Gross (excluding sinks)	**66.0**	**89.0**	**116.6**	**161.3**
Increase relative to 1990		*35%*	*77%*	*144%*
Increase relative to 2000			*31%*	*81%*
Forestry and Land Use	**-6.7**	**-6.7**	**-6.7**	**-6.7**
Net (including sinks)	**59.3**	**82.3**	**109.9**	**154.6**
Increase relative to 1990		*39%*	*85%*	*161%*
Increase relative to 2000			*34%*	*88%*

Overall, the projected rate of emissions growth is 3.0% per year from the year 2000 onward, well below anticipated levels of economic growth (4.9% per year), but nonetheless significant. Emissions track population growth fairly closely until the latter half of this decade, after which they begin to rise more rapidly. The increase in per capita emissions after 2010 appears largely as the result of four factors: 1) electricity growth at a rate faster than population growth; 2) increasing reliance on coal-based generation; 3) freight traffic growing faster than population; and 4) increasing hydrofluorocarbon emissions in refrigeration, air conditioning, and other applications. For nearly all other sources, with the exception of natural gas use in residential, commercial, and industrial sectors, emissions are projected to grow at a pace slower than State population.

Examples of Inventory and Forecast Enhancements to Support CCMP Development

Energy Supply Sector

Electricity. See discussion provided above regarding production and consumption based estimates for GHG emissions. Standard CCS practice has been to present both sets of numbers to inform policy analysts. Note that the production/consumption issues also extend to other energy sources, such as oil, coal, and natural gas production.

Fossil Fuel Production. In New Mexico, fossil fuel industry emissions grew rapidly in the 1990s with total natural gas production rising from 1,015 billion cubic feet in 1990 to 1,802 billion cubic feet in 2000. Natural gas production has dropped slightly since 2000. The future of New Mexico natural gas and oil production is highly uncertain, dependent on global price trends, discovery of new reserves, and other factors. For projection purposes, we assumed that new reserves would be found and exploited such that recent production levels of oil and gas will be maintained.[c]

The sheer number and wide diversity of oil, gas, and coal production and processing activities in NM presents a major challenge for greenhouse gas assessment. Emissions of carbon dioxide and methane occur at many stages of the production process (mining, drilling, production, and processing/refining), and can be highly dependent upon local resource characteristics (pressure, depth, water content, etc.), technologies applied, and practices employed (such as well venting to unload liquids which may result in the release of billions of cubic feet of methane annually). For example in New Mexico, with over 40,000 oil and gas wells, three oil refineries, several gas processing plants, and tens of thousands of miles of gas pipelines in the State – and no regulatory requirements to track CO_2 or CH_4 emissions – there are significant uncertainties with respect to the State's GHG emissions from this sector.

At the same time, considerable research – sponsored by the American Petroleum Institute, the Gas Research Institute, U.S. EPA, and others – has been directed towards developing relatively robust GHG emissions estimates at the national level. For the national GHG inventory, US EPA uses a combination of top-down and detailed bottom-up techniques to estimate national emissions of methane from the oil and gas industry.[5] As noted earlier, U.S. EPA has also developed a tool (SGIT) that enables the development of state-level GHG estimates, whereby emissions-related activity levels (numbers of wells, and amount of oil and gas produced) can be multiplied by aggregate emission factors to yield rough estimates of total CH4 emissions. Furthermore, EIA provides estimates of fuel used in New Mexico for natural gas production, processing, and distribution, which enables the estimation of CO2 emissions.

These sources provide a starting point for analysis of oil and gas industry emissions. However, to develop state-specific estimates, additional data and insights are often essential. In NM, we solicited input from industry sources, such as the New Mexico Oil and Gas Association (NMOGA) and individual facility managers, U.S. EPA staff, and State agency experts. These sources provided "ground truthing" on several aspects related to State emissions.

An interesting example is that of entrained CO2 emissions. Raw gas that emerges from gas and oil wells often contains "entrained" CO_2 in excess of pipeline specifications. This CO_2 is typically separated at gas processing plants and vented to the atmosphere (except in some other states, such as Wyoming and Texas, where it is compressed and transported for enhanced oil

[c] This Energy Supply Technical Working Group reviewed and affirmed this assumption for projection purposes.

recovery).[d] In the case of New Mexico, the CO_2 concentrations in natural gas from the state's primary source, Fruitland coal bed methane, are known to be quite significant (currently around 18%), and these concentrations have been rising over time. Data provided by the Oil Conservation Division of EMNRD and NMOGA enable estimates of entrained CO_2 emissions. The resulting estimate shows that entrained CO2 from oil and gas production may account for 5 MMtCO2e or over 5% of the state's GHG emissions.

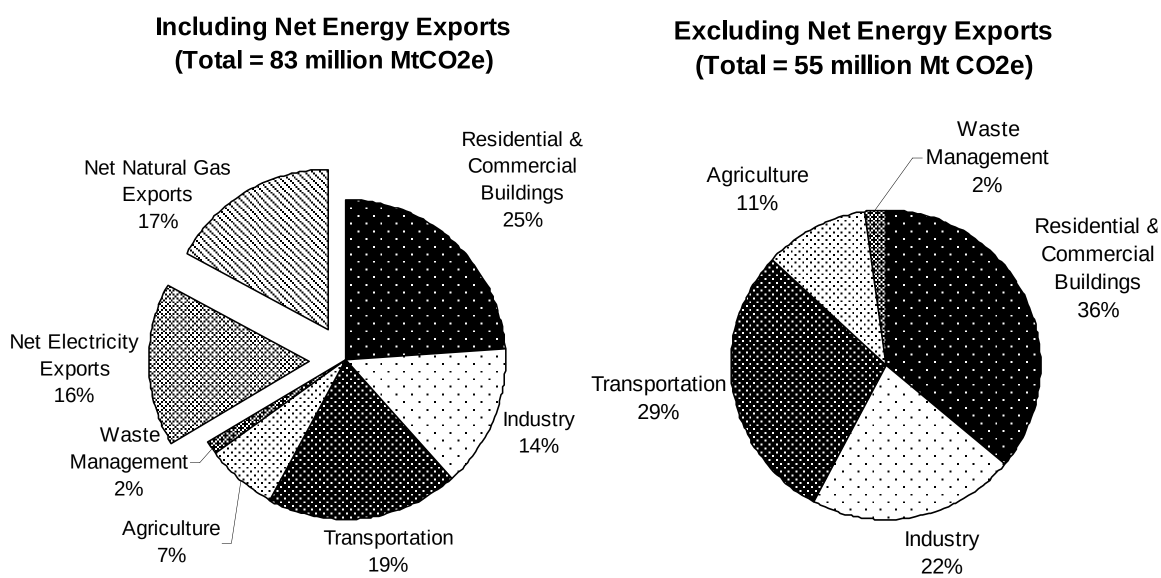
Residential/Commercial/Industrial Sector

The estimation of GHG emissions from Residential, Commercial, and Industrial sectors is relatively straightforward. Fuel use is typically the predominant source of emissions and is well documented. A major uncertainty relates to trace gas emissions, particularly of HFCs leaking from refrigeration applications.

However, reporting on the RCI emissions related to direct fuel combustion emissions can provide a misleading picture of the importance of RCI activities. Building and industrial activities are indeed the "driver" of many emissions occurring in other sectors; demands for electricity, fossil fuels, building materials, and other supplies are the motor driving emissions in these other sectors.

During the review of the draft inventory, members of New Mexico's Residential, Commercial, and Industrial Technical Working Group suggested another, useful representation of the state's GHG emissions. Figure 1 illustrates the state's emissions by economic sector, incorporating the emissions associated with delivering electricity and fossil fuels used by these sectors. This gives a sense of the contributions of activity in each sector to overall emissions, as well as the level of effort that might be needed to achieve overall emissions reductions in line with state goals.

Figure 1. Representation of NM GHG emissions by consuming sector.



[d] On a national level, the USEPA GHG inventory suggests that these entrained CO_2 emissions are quite significant (about 25 MMtCO2in 2002). However, U.S. EPA is still working to systematically incorporate this emissions source into the national inventory, given concerns about double counting emissions in locations (outside New Mexico) where this CO_2 may be used for enhanced oil recovery.

The left hand pie chart shows that, of the state's estimated 83 million MtCO2e of GHG emissions in 2000, about one-third was associated with electricity and natural production in excess of state consumption levels ("net exports"). Excluding these slices, and looking only at the in-state consumption, the right hand pie chart shows that, of the remaining 55 million MtCO2e in GHG emissions, about 36% are associated with residential and commercial building energy consumption, 22% with industrial energy consumption and process GHG emissions, 29% with transportation fuel use, 11% with agricultural activities, and 2% with waste management emissions.

Transportation & Land Use Sector

Transportation. Use of the EPA SGIT tool is relatively straightforward for the transportation sector. CO2 emissions are calculated separately from CH4 and N2O emissions. The CH4 and N2O onroad emission calculations are based on vehicle miles traveled (VMT) activity data by vehicle type and model year group while onroad CO2 emissions are based on fuel consumption. Emissions from nonroad engines are all based on fuel consumption. Due to the difference in basis for the onroad sector, it is important to be sure that the fuel consumption and VMT data are consistent. In preparing the onroad inventory forecasts, analysts should consider whether any changes are expected in the projection years from the base year in the rate of fuel consumption per VMT. It should be noted that the use of the EPA tool does not allow the calculation or tracking of onroad CO2 emissions by vehicle type—only fuel type. In evaluating GHG control measures that apply to a specific vehicle type, crude methods can to be applied to estimate the portion of emissions contributed by specific vehicle types.

In Arizona, CCS found that the transportation sector was the largest contributor of CO2e associated with black carbon (BC) emissions. The dominant sources in this sector were onroad diesel vehicles. BC emissions are described in more detail below.

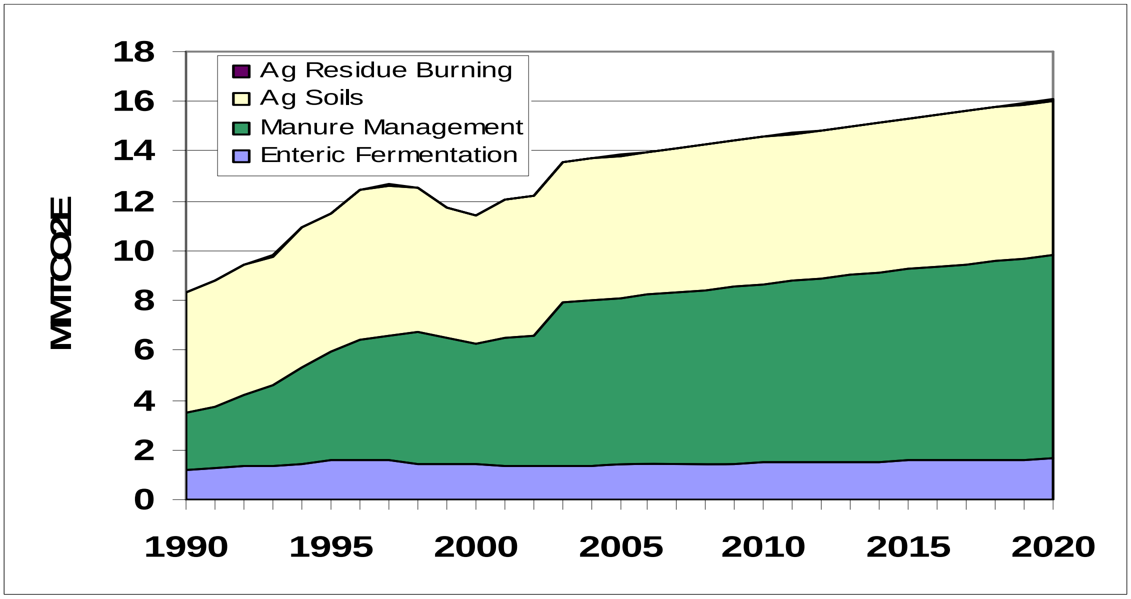
Agriculture, Forestry & Waste Sector

Agriculture. EPA's SGIT covers many of the most important agricultural sources of GHGs. These sources include methane emissions from both livestock operations and crop production. For livestock, important sources include methane from enteric fermentation (driven by cattle) and manure management (including application to crops). For crops, important sources include nitrous oxide emissions from organic and inorganic fertilizer application and nitrogen fixing crops, as well as methane and nitrous oxide emissions from agricultural burning. SGIT includes default activity data on historic livestock populations, manure management practices, crop acreages, and fertilizer application.

Arguably, the agricultural sector emission estimates carry the largest uncertainty. The science behind these estimates continues to evolve, and there will be a need to incorporate improved emission estimation methods developed as a result of ongoing work sponsored by EPA, the U.S. Department of Agriculture, and others. From a policy development perspective, we believe that the EIIP/SGIT methods allow for the identification of important contributors to state and local inventories, even though the emission estimates themselves are less precise than most of the other sectors (e.g. those for fuel combustion). It is important to get review of the SGIT default data (animal populations, manure management practices, etc.) from local agricultural experts, as these can have a large influence on emissions. An example of emission estimates for the agricultural sector produced using SGIT is shown in Figure 2.

Important considerations for inventory & forecast development include the need to incorporate available information on projected future populations of livestock and any anticipated changes to manure management practices. For example, NC has a large hog production industry, which contributes substantially to the agricultural sector emissions. However, the effects of a state moratorium on additional large (>250 head) hog farms in 2000 needed to be incorporated into the forecast. Failure to do so would have resulted in a significant emissions forecast for hog operations in 2010 and 2020. To the extent that energy recovery (e.g. from animal waste) is already being practiced, these activities should also be incorporated into the inventory and forecast.

Figure 2. GHG inventory & forecast for North Carolina agricultural sources using SGIT.



Emissions associated with energy consumption in the agricultural sector are embodied within the RCI energy consumption estimates. In our CCMP projects, agricultural policy options often have an energy component (e.g. production of electricity or liquid fuels from manure or crops; reduction through efficiency measures). Hence, when quantifying future GHG reductions from these options, there is a need to exchange the energy impacts data (energy supply potential) with the energy supply, RCI, and transportation sectors.

An important agricultural source of CO2 that is not covered by SGIT is the loss of soil carbon when agricultural land is converted to developed uses. Since the soil carbon content tends to be higher in cropland than for developed lands (e.g. suburban tracts), a net loss of carbon (as CO2) occurs as a result of this change. CCS is currently quantifying these losses as part of our stakeholder support projects. Sources of information include the Natural Resources Inventory (NRI) from the Natural Resources Conservation Service[6], the scientific literature, and local experts.

Forestry. To date, our CCMP inventories have relied on information from the U.S. Forest Service (USFS) on forest carbon pools based on the agency's FORCARB model. The FORCARB model in turn relies on forest inventory data from USFS' Forest Inventory & Analysis (FIA) database. For the CCMP inventories, we have assessed inter-annual changes for the following carbon pools to estimate flux: standing live trees; standing dead trees; down dead trees (coarse woody debris); understory; forest floor; and soil carbon. This includes the effects of land cover change or the change of forests to nonforest uses through FIA and NRI data. Past assessments have shown this to be the major source of change in carbon stocks over time. Through compilations of data covering the latest 10 – 15 years, annual changes in carbon stocks can be calculated for each pool and an overall estimate of flux (typically sequestration) is made. A final carbon pool incorporates carbon removed from the forests in the form of durable wood products or landfilled waste. Table 2 provides an example for North Carolina forests. In the year 2000, about 24 MMtCO2e were estimated to be sequestered annually.

Table 2. Estimates of carbon sequestration in NC forests.

Carbon Pool	2000 CO2e (MMt)
Live and dead standing trees, Understory	-6.9
Forest floor and coarse woody debris	-0.8
Soils	-3.1
Wood products and landfills	-13.0
Total	**-23.7**

Current FORCARB estimates may not fully account for mortality associated with forest health issues and has been supplemented by the U.S. Forest Service through the Forest Health Management Assessment database. Land use change data requires adjustments to account for forested carbon retained on lands that move from forest to nonforest uses in the FIA system, particularly suburban lands. CCS has developed specific protocols for retained carbon in the land conversion process. Wood products and landfill carbon storage and emissions are provided by the HARVCARB and WOODCARB models used by the U.S. Forest Service in formulating FORCARB estimates. These models estimate post harvest biomass carbon storage and emissions for a 100-year period. Adjustments for biomass imports and exports may be needed using state-level wood processor reports. Recently, the USFS has updated the FORCARB system to address these state-level inventory issues through its new Carbon Online Evaluation (COLE) system. It may not, however, fully address forecasting issues and the condition of future forests. Typically, expert work groups are content to assume that forest conditions through 2020 are likely to mirror trends in place from 1990 to present. They are not comfortable with constant extrapolation of trends to longer time periods, such as 2050.

Waste Management. This sector incorporates emissions (primarily methane) from both municipal solid waste landfills and wastewater treatment (both industrial and residential). Of these sources, methane emissions from landfills tend to be the most important from both a CO2e perspective, as well as an energy capture opportunity. SGIT treats all three sources. For landfills, SGIT offers a simple method for estimating emissions; however depending on the importance of this source as a CO2e contributor or as a potential source of renewable energy, a more rigorous approach might be warranted. SGIT estimates emissions at the state-level using information on total waste in place at either large (>1.1 million tons in place) or small landfills, average rainfall, and the amount of methane recovered for flaring or energy recovery.

For large or small landfills, SGIT uses the waste in place and a regression equation to estimate the total amount of methane generated. The regression equations were developed from actual landfill gas recovery projects. A problem with applying these equations to all landfills in the state is that the age of the waste is not taken into account. In a typical landfill, waste put in place during year one will often generate methane for up to 30 years or more. However, the generation tends to ramp up quickly following emplacement and tail off after 10 to 15 years. Hence, in situations where a significant amount of waste in place is fairly old (> 15 years), the regression equations will overestimate methane emissions. Because the data underlying the regression equations came from active recovery systems, the associated waste was most likely placed into the landfills in relatively recent times.

The EIIP/SGIT also recognize that emissions need to be adjusted for methane recovery and control/utilization. Users should be aware that even the best recovery systems on dual-lined landfills with impermeable caps will still not recover 100% of the methane generated. EPA's AP-42 default recovery efficiency is 75% and allows for 90% recovery efficiency when active recovery systems have been installed at dual-lined sites with impermeable caps. We recommend state-level surveys to identify sites where the methane is either flared or utilized (as well as how the methane is utilized – electricity generation, space heat). Not only is this information important in estimating emissions and developing forecasts, it is also needed to identify whether any additional policy development is needed during CCMP development.

Upcoming GHG Emissions Inventory Issues

New emissions inventory guidance from the Intergovernmental Panel on Climate Change (IPCC) is expected later this year. This new guidance could expand the range of climate change pollutants that should be covered in GHG inventories. There are also other air pollutants in addition to the standard six IPCC gases that affect the earth's radiative balance. These include aerosols, volatile organic compounds, and ozone. We have not seen any evidence that the IPCC will recommend the quantification of any aerosol species as part of GHG inventories; however, quantification of the CO2e associated with VOC emissions might be recommended. A discussion of both aerosols and VOC follows.

Aerosols

Aerosols are small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. They affect radiative forcing in both direct and indirect ways: directly by scattering and absorbing solar and thermal infrared radiation; and indirectly by increasing droplet counts that modify the formation, precipitation efficiency, and radiative properties of clouds. Aerosols are removed from the atmosphere relatively rapidly by precipitation. Because aerosols generally have short atmospheric lifetimes, and have concentrations and compositions that vary regionally, spatially, and temporally, their contributions to radiative forcing are difficult to quantify.[7,8]

The indirect radiative forcing from aerosols are typically divided into two effects. The first effect involves decreased droplet size and increased droplet concentration resulting from an increase in airborne aerosols. The second effect involves an increase in the water content and lifetime of clouds due to the effect of reduced droplet size on precipitation efficiency.[8] Recent research has placed a greater focus on the second indirect radiative forcing effect of aerosols.

Various categories of aerosols exist, including naturally-produced aerosols such as soil dust, sea salt, biogenic aerosols, sulphates, and volcanic aerosols; and anthropogenically-produced aerosols such as industrial dust and carbonaceous aerosols (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning.[7]

The net effect of aerosols is believed to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions.[9] Current research suggests that another constituent of aerosols, elemental (black) carbon, has a positive radiative forcing.[10] The primary anthropogenic emission sources of elemental carbon include diesel exhaust, coal combustion, and biomass burning.

BC Inventory for Arizona. For the Arizona process, CCS was tasked with developing an inventory of black carbon (BC) emissions for the state. BC is recognized by the IPCC as having positive climate forcing potential. However, the IPCC does not currently have a global warming potential assigned to BC. The details of the BC inventory are presented in an appendix to the GHG inventory report.[4] Briefly, BC mass emissions were estimated through chemical speciation of particulate matter emissions for the state of Arizona. To present these mass emission estimates of BC as CO2e, we applied climate response factors based on recent global climate modeling.[10]

The results included a range (both low and high estimates) of CO2e associated with BC emissions. Organic material (OM), another component of particulate matter emissions, also needed to be factored in to the CO2e estimates. OM is generally recognized as having a negative climate forcing potential (net cooling effect). [OM represents organic carbon plus the associated hydrogen, oxygen, nitrogen, and other atoms]. Based on the modeling results mentioned above, we selected a cut-off ratio of 4:1 (OM:BC) to include in our CO2e estimates for BC. Above this ratio, it was assumed that the particulate matter emitted did not have a positive climate forcing potential. Results of the analysis are shown in Figure 3 and Table 3 below.[4]

For BC, the results for the high end of the range in CO2e are shown in Figure 3. Onroad diesel sources dominated the inventory. Other significant contributors included nonroad diesel engines (e.g. rail, construction, etc.). In total, the estimated BC emissions on a CO2e-basis contribute 3%-6% of the gross CO2e associated with the gaseous emissions (shown in Table 1).

Figure 3. CO2e emissions estimated for black carbon in Arizona.

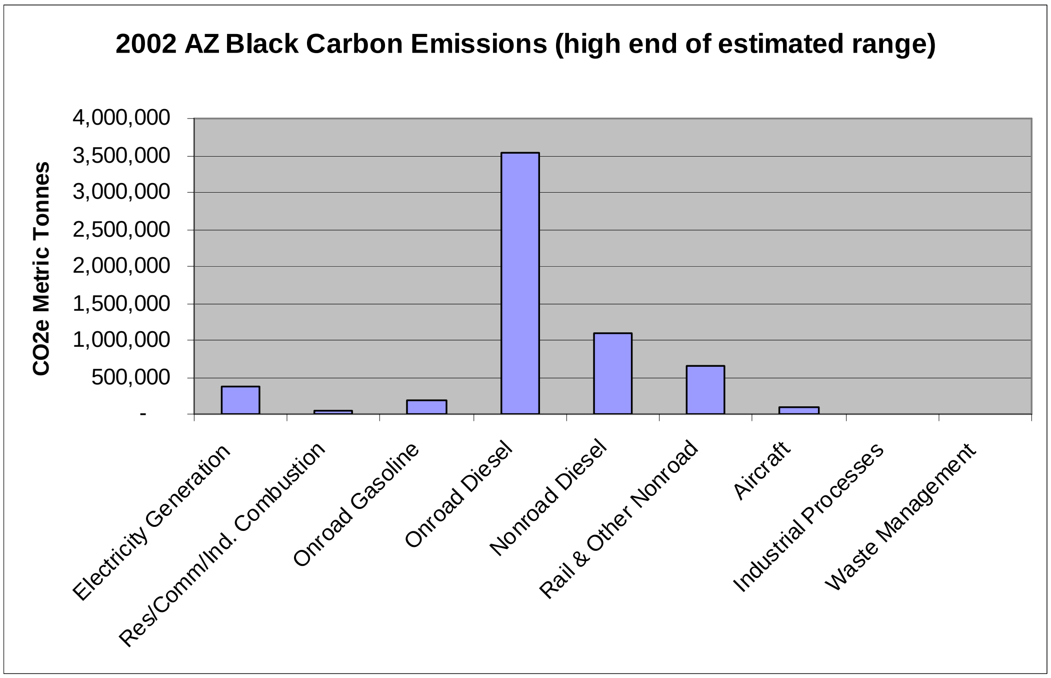


Table 3. 2002 AZ BC+OM emissions summary.

Sector	Subsector	Mass Emissions					CO_{2e}	
		BC	POA	BC	POA	BC + OM	Low	High
		Short Tons		Metric Tons			Metric Tons	
Electric Generating Units (EGUs)	Coal	193	275	175	250	425	173,028	365,456
	Oil	1.1	0.4	1.0	0.33	1.3	994	2,100
	Gas[a]	0	94	0	86	86	0	0
Non-EGU Fuel Combustion	Coal	5.7	8.2	5.2	7.5	13	5,161	10,900
(Residential,Commercial, and Industrial)	Oil	22	11	20	9.5	29	19,691	41,589
	Gas	0.03	241	0.03	218	218	0	0
	Other[b]	237	1,161	215	1,054	1,269	1,985	4,193
Onroad Gasoline (Exhaust, Brake Wear, & Tire Wear)		192	737	174	669	843	82,966[c]	175,235[c]
Onroad Diesel (Exhaust, Brake Wear, & Tire Wear)		1,864	728	1,692	661	2,353	1,671,922	3,531,302
Aircraft[d]		50	28	45	25	70	44,589	94,177
Other Energy Use	Nonroad Gasoline	52	560	47	508	555	0	0
	Nonroad Diesel	579	193	526	175	701	520,169	1,098,660
	Nonroad Other[e]	338	106	307	96	403	303,511	641,160
	Other Combustion[f]	8.7	72	7.9	65	73	237	500
Industrial Processes[g]		42	606	38	550	588	326	690
Agriculture[h]		27	1,362	25	1,236	1,261	0	0
Waste Management	Landfills	0.12	7.3	0.11	6.6	7	0	0
	Incineration[i]	5.3	9.8	4.8	8.9	14	4,741	10,015
	Open Burning[j]	260	3,039	236.28	2,758.88	2,995	0	0
Wildfires/Prescribed Burns[k]		8,400	71,501	7,626	64,909	72,534	0	0
Miscellaneous[l]		94	1,446	85	1,312	1,398	86	182
	Totals	**12,370**	**82,183**	**11,230**	**74,606**	**85,835**	**2,829,406**	**5,976,157**

NOTE: CO_2e is zeroed out for sources with OM:BC ratio >4.0 (see text).
[a] The SPECIATE3.2 PM profile showed zero for PEC (BC). A review of other in-house data showed that BC is present in PM emissions from natural gas combustion at a OM:BC ratio of around 1:1. This ratio was used to calculate BC+OM and the associated CO_{2e} emissions.
[b] Most of these emissions are from residential wood combustion.
[c] The CO_2e estimates are associated with tire wear only, since the exhaust and brake wear components have OM:BC ratios >4:1.
[d] Note for aircraft, criteria pollutant emissions are only estimated for the boundary (mixing) layer (i.e., mainly landing and take-off cycle emissions). Therefore, these estimates do not include emissions occurring above the mixing layer but within AZ airspace.
[e] Nearly all emissions are from the railroad source categories.
[f] About 60% of emissions are from vehicle fires. Other contributors include structure fires and aircraft/rocket engine firing and testing.
[g] In this summary, construction is included in the Industrial Processes sector. Construction source categories (industrial/commercial/institutional, residential, road, and other) are the major contributors (96%) of the Industrial Processes emissions.
[h] The Agriculture sector includes food industries. 80% of the BC emissions come from agricultural tilling. Agricultural tilling and commercial cooking each contribute about 43% of the POA emissions.
[i] About 97% of BC and POA emissions come from commercial/institutional incineration.
[j] Open burning of land clearing debris contributes about 68% of BC/POA emissions. Other contributors include open burning of yard waste and household waste.
[k] Wildfire/Prescribed burn emissions were excluded from the CO_2e estimates due to the much higher OM to BC ratio (about 7:1).
[l] Paved and unpaved road dust are significant contributors to the EC and OC emissions.

Volatile Organic Compounds

VOC emissions play a role in climate change as a result of their eventual photochemical degradation to CO2. Quantifying the CO2e associated with VOC emissions requires knowledge of the carbon content of the emissions in addition to the mass emission rate. Determining the carbon content of the VOC emissions from a source requires an understanding of the chemical speciation of the various organic compounds emitted. EPA has recently sponsored a great deal of work to update the SPECIATE system. Recent work products and project information can be found at the following website: http://projects.pechan.com/speciate.

An example calculation of CO2e from VOC mass emissions is shown in Table 4. This estimate was made for 2002 VOC emissions from the gasoline marketing sector in AZ (e.g. stage I and stage II gasoline marketing). For each organic species in the speciation profile, the weight fraction is multiplied by the total VOC emissions (10,980 tons/yr) to derive the species mass emissions. This value is then converted to carbon mass by multiplying by the number of carbon atoms in the species and 12 (the molecular weight of carbon), and then divided by the molecular weight of the species. The carbon mass for each organic species is then multiplied by the ratio of 44/12 to convert to CO2e. The CO2e for each species is then totaled to derive the annual estimate of 29,251 tons/year (26,536 Mt). This value is equivalent to about 0.03% of the total year 2000 CO2e estimated for AZ (89 MMtCO2e gross emissions, as shown in Table 1). Overall, 2002 VOC emissions in AZ are over 2.9 million tons. This suggests that VOC emissions could contribute another 1-3% on a CO2e basis to GHG emissions in AZ (it is important to note that the gasoline marketing VOC example shown here has a high carbon content relative to other VOC sources).

Table 4. Example calculation of CO2e from gasoline marketing VOC emissions.

Weight %	CAS#	Species	MW	Structure	Speciated Emissions (tons/year)	CO2e (tons/year)
25.95	78-78-4	Isopentane	72.15	C5H12	2,849	8,688
14.20	1634-04-4	Methyl t-butyl ether	88.15	C5H12O	1,559	3,891
6.60	106-97-8	N-butane	58.12	C4H10	724	2,193
3.88	109-66-0	N-pentane	72.15	C5H12	426	1,300
3.60	107-83-5	2-methylpentane	86.17	C6H14	395	1,211
3.17	108-88-3	Toluene	92.13	C7H8	348	1,163
3.16	540-84-1	2,2,4-trimethylpentane	114.22	C8H18	347	1,069
3.04	79-29-8	2,3-dimethylbutane	86.17	C6H14	334	1,023
2.88	513-35-9	2-methyl-2-butene	70.13	C5H10	316	992
2.45	646-04-8	Trans-2-pentene	70.13	C5H10	269	845
2.35	75-28-5	Isobutane	58.12	C4H10	258	782
1.98	96-14-0	3-methylpentane	86.17	C6H14	217	666
1.93	563-46-2	2-methyl-1-butene	70.13	C5H10	212	664
1.74	107-01-7	2-Butene	56.11	C4H8	191	598
1.62	590-18-1	Cis-2-butene	56.11	C4H8	178	558
1.30	627-20-3	Cis-2-pentene	70.13	C5H10	143	449
1.24	109-67-1	1-pentene	70.13	C5H10	136	427
1.17	110-54-3	N-hexane	86.18	C6H14	129	394
0.96	565-75-3	2,3,4-trimethylpentane	114.22	C8H18	105	324
0.93	115-11-7	Isobutylene	56.1	C4H8	102	320
0.90	96-37-7	Methylcyclopentane	84.16	C6H12	99	312
					remaining species	1,383
					Total CO2e	**29,251**

RECOMMENDATIONS

States that have conducted inventories that are not at the same level of detail, comprehensiveness, and consistency of those by CCS should consider updates to ensure accurate and policy relevant information. As well, they should develop GHG emissions forecasts to support measurement and policy development systems. While consistency of data sources, methods and assumptions is important across state assessments, it remains critical for states to look at all potential emissions sources and sinks in the event that they may not be adequately covered by the SGIT tool or previous assessments. CCS has found substantial omissions in past data, and significant need for updates and upgrades in assessment approaches to support program and policy use by states. As a result of these CCS-facilitated CCMP development projects, states are gaining an understanding of the breadth of policy development required to meet their reduction goals.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of each State's environmental agency: Arizona Department of Environmental Quality, New Mexico Environment Department, the North Carolina Department of Environment and Natural Resources, the Montana Department of Environmental Quality, the Vermont Department of Environmental Conservation; and the Western Regional Air Partnership.

REFERENCES

1. *Volume VIII: Estimating Greenhouse Gas Emissions* of the Emission Inventory Improvement Program (EIIP) Document Series; ICF Consulting: Washington, DC, 2003.

2. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories;* IPCC, 1997. http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm,

3. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003;* U.S. Environmental Protection Agency, Washington, DC, 2005. http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

4. *Arizona Greenhouse Gas Inventory and Reference Case Projections 1990-2020;* The Center for Climate Strategies, Harrisburg, PA, February 2006. http://www.azclimatechange.us/template.cfm?FrontID=4670.

5. *2005 Inventory of Greenhouse Gases Emissions and Sinks,* U.S. EPA, 2005, www.epa.gov/globalwarming/publications/emissions.

6. Natural Resources Inventory Website, Natural Resources Conservation Service, U.S. Department of Agriculture, http://www.nrcs.usda.gov/technical/NRI/, accessed March 2006.

7. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2000*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002. www.epa.gov/globalwarming/publications/emissions

8. *Climate Change 2001: A Scientific Basis*, Intergovernmental Panel on Climate Change; J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, C.A. Johnson, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

9. *Climate Change 1995: The Science of Climate Change*, Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

10. Jacobson, M.Z., *Journal of Geophysical Physical Research*, **2002**, *107*, 4410, 2002.

KEY WORDS
Climate Change
Greenhouse Gases
Aerosols
State Action
Carbon Dioxide
Emissions Inventory