Executive Summary

Greenhouse gases other than carbon dioxide (CO_2) play an important role in the effort to understand and address global climate change. Non-carbon dioxide (non-CO_2) greenhouse gases include methane (CH_4), nitrous oxide (N_2O), and a number of high global warming potential or fluorinated gases. The non-CO_2 greenhouse gases are more potent than CO_2 (per unit weight) at trapping heat within the atmosphere and, once emitted, can remain in the atmosphere for either shorter or longer periods of time than CO_2. Approximately 30% of the anthropogenic greenhouse effect since preindustrial times can be attributed to these non-CO_2 greenhouse gases (Intergovernmental Panel for Climate Change [IPCC], 2001b); approximately 25% of GWP-weighted greenhouse gas emissions in the year 2005 comprise the non-CO_2 greenhouse gases (U.S. Environmental Protection Agency [USEPA], 2012).

Greenhouse gases are the primary driver of climate change, which can lead to hotter, longer heat waves that threaten the health of the sick, poor, or elderly; increases in ground-level ozone pollution linked to asthma and other respiratory illnesses; and other threats to human health and welfare. In some cases, reducing non-CO_2 emissions can have a more rapid effect on the climate and be more cost-effective than reducing CO_2 emissions. Given the important role that mitigation of non-CO_2 greenhouse gases can play in climate strategies, there is a clear need for an improved understanding of the mitigation potential for non-CO_2 sources, as well as for the incorporation of non-CO_2 greenhouse gas mitigation in climate economic analyses. This report is a follow-on to the 2006 EPA report *Global Mitigation of Non-CO_2 Greenhouse* Gases and illustrates the abatement potential of non-CO_2 greenhouse gases through a comprehensive global analysis and resulting data set of marginal abatement cost (MAC) curves.

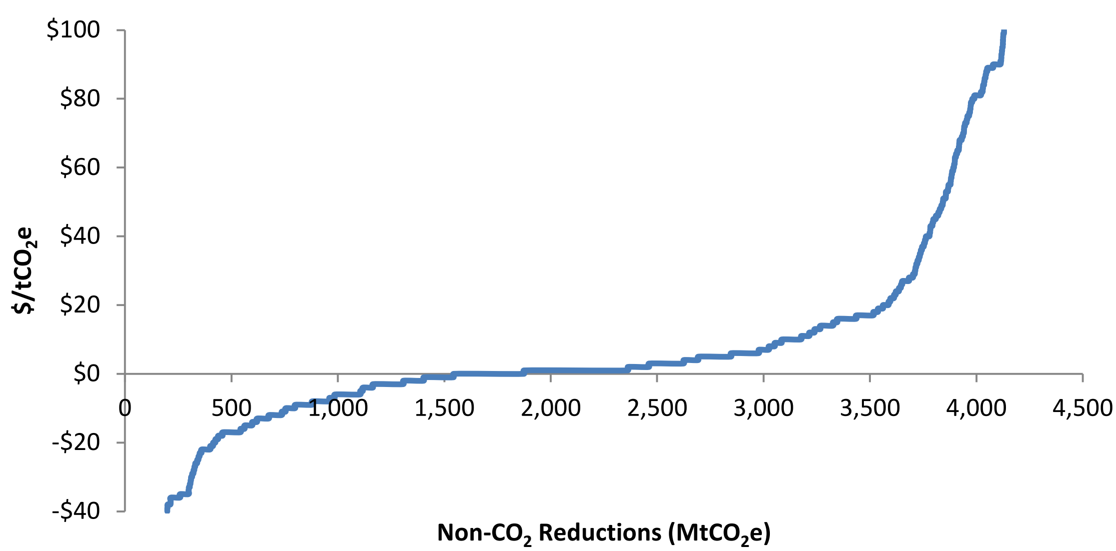
The report provides a comprehensive global analysis and resulting data set of MACs that illustrate the abatement potential of non-CO_2 greenhouse gases by sector and by region. This analysis incorporates updated mitigation technologies, costs, and emissions baselines with an updated modeling approach. The results of the analysis are MAC curves that reflect aggregated break-even prices for implementing mitigation options in a given sector and region with more detail than available in the previous report. This assessment of mitigation potential is unique because it is comprehensive across all non-CO_2 greenhouse gases, across all emitting sectors of the economy, and across all regions of the world. The MAC curves allow for improved understanding of the mitigation potential for non-CO_2 sources, as well as inclusion of non-CO_2 greenhouse gas mitigation in economic modeling of multigas mitigation strategies.

The basic methodology—a bottom-up, engineering cost approach—is the same as the methodology followed in the 2006 report. Building on the baseline non-CO_2 emissions projections from the USEPA's *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990–2030* (2012), this analysis applies mitigation options to the emissions baseline in each sector. The technical abatement potential and cost are calculated for each mitigation option across all the emitting greenhouse gas sectors. The average break-even price is calculated for the estimated abatement potential for each mitigation option. The options are then ordered in ascending order of break-even price (cost) and plotted against abatement potential. The resulting MAC is a stepwise function; each point on the curve represents the break-even price point for a discrete mitigation option (or defined bundle of mitigation strategies) and the associated abatement potential. This report makes no explicit assumption about policies that would be required to facilitate and generate adoption of mitigation options. Therefore, this report provides estimates of technical mitigation potential.

The results of this analysis are MAC curves that reflect the prices for implementing mitigation options in a given sector and region. This report provides improved data to better understand the mitigation potential for non-CO_2 sources and allows for inclusion of non-CO_2 greenhouse gas mitigation approaches in economic modeling of multigas mitigation strategies. The MAC data sets can be downloaded in spreadsheet format from the USEPA Web site at http://www.epa.gov/climatechange/EPAactivities/economics/nonco2mitigation.html.

Mitigation of Non-CO_2 Gases Can Play an Important Role in Climate Strategies. Worldwide, the potential for cost-effective non-CO_2 greenhouse gas abatement is significant. Figure ES-1 shows the global total aggregate MAC for the year 2030. Without a price signal (i.e., at \$0/tCO_2e), the global mitigation potential is greater than 1,800 million metric tons of CO_2 equivalent ($MtCO_2e$), or 12% of the baseline emissions (refer to Section I.3.3 of this report for a more detailed explanation of unrealized mitigation potential in the MACs). As the break-even price rises, the mitigation potential grows. Significant mitigation opportunities could be realized in the lower range of break-even prices. The global mitigation potential at a price of \$10/tCO_2e is greater than 3,000 $MtCO_2e$, or 20% of the baseline emissions, and greater than 2,400 $MtCO_2e$ or 24% of the baseline emissions at \$20/tCO_2e. In the higher range of break-even prices, the MAC becomes steeper, and less mitigation potential exists for each additional increase in price.

Figure ES-1: Global Total Aggregate MAC for Non-CO_2 Greenhouse Gases in 2030



Globally, the Sectors with the Greatest Potential for Mitigation of Non-CO_2 Greenhouse Gases are the Energy and Agriculture Sectors. Figure ES-2 shows the global MACs by economic sector in 2030. At a break-even price of \$5/tCO_2e, the potential to reduce of non-CO_2 greenhouse gases is greater than 1,190 $MtCO_2e$ in the energy sector and approximately 1,080 $MtCO_2e$ in the industrial process sector. At a break-even price of \$30/tCO_2e, the potential increases to approximately 1,475 $MtCO_2e$ in the industrial sector, nearly 1,400 $MtCO_2e$ in the energy sector, and 500 and 332 $MtCO_2e$ in the agriculture and waste sectors, respectively.

Methane Mitigation has the Largest Potential across All the Non-CO_2 Greenhouse Gases. Figure ES-3 shows the global MACs by greenhouse gas type for 2030. At or below \$0/tCO_2e, the potential for CH_4 mitigation is greater than 1,000 MtCO_2e. The potential for reducing CH_4 emissions grows to over 2,000 MtCO_2e as the break-even price rises from \$0 to \$30/tCO_2e, while less than that of CH_4, N_2O, and F-gases exhibit significant mitigation potential at or below \$0/tCO_2e.

Figure ES-2: Global 2030 MACs for Non-CO_2 Greenhouse Gases by Major Sector

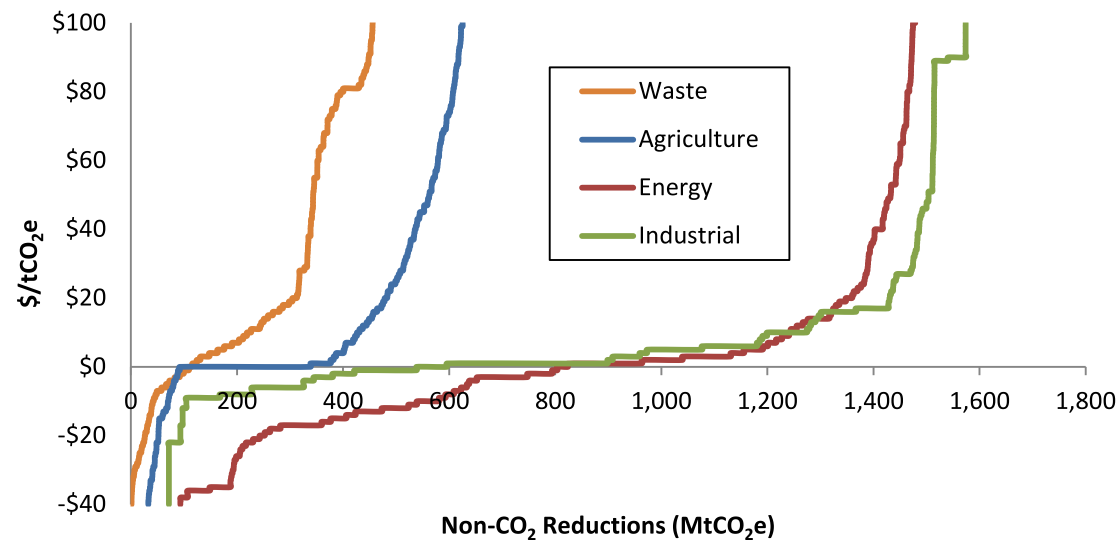
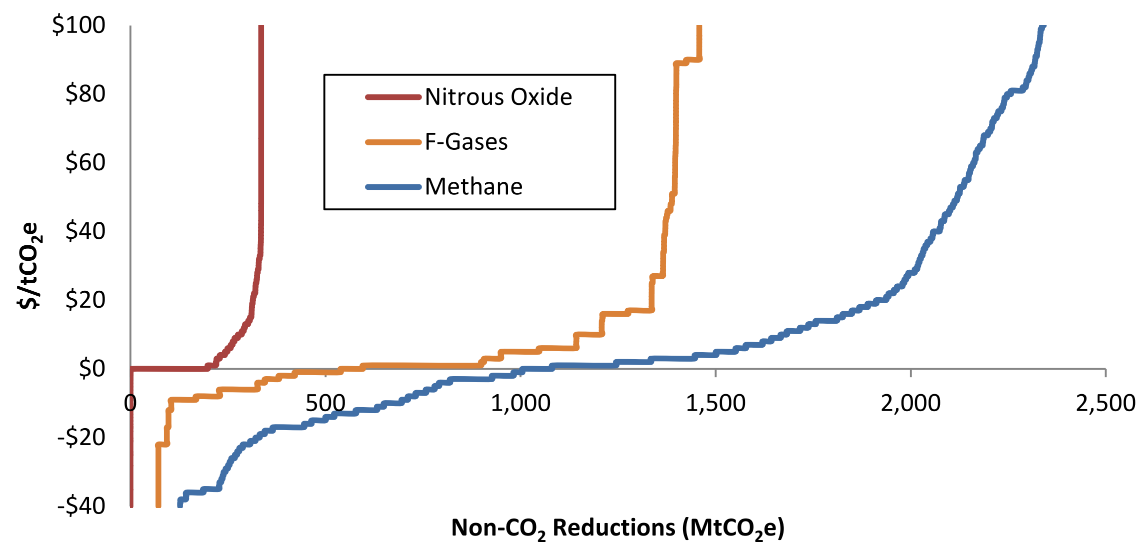
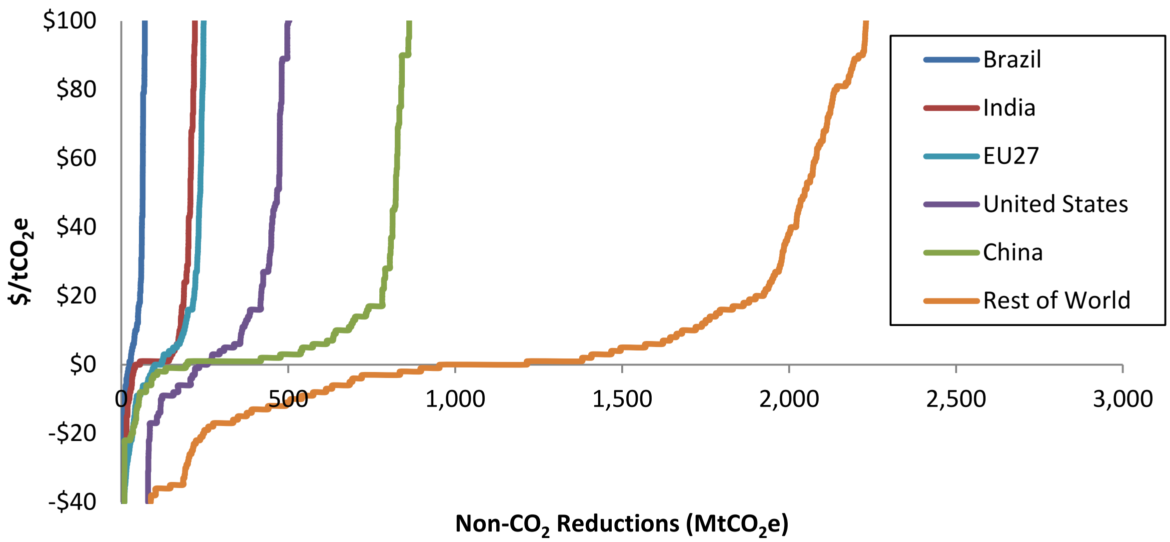


Figure ES-3: Global 2030 MACs by Non-CO_2 Greenhouse Gas Type



Major Emitting Regions of the World Offer Large Potential Mitigation Opportunities. Figure ES-4 shows the global MACs by region for 2030. The United States and China are the top two contributors to global mitigation potential with cost-effective mitigation of 260 and 200 $MtCO_2e$, respectively. The largest sources of mitigation potential in these regions are oil/gas, refrigeration/ac, livestock, and coal. The EU, India, and Brazil represent significant mitigation potential as well. At a break-even price of $30/$tCO_2e$ the five largest emitting countries represent 46% of the global abatement potential.

Figure ES-4: Global 2030 MACs for Non-CO_2 Greenhouse Gases by Major Emitting Regions



The aggregate MACs by economic sector, greenhouse gas type, and region highlight the importance of including non-CO_2 greenhouse gases in the analysis of multigas climate strategies. The MACs illustrate that a significant portion of this emissions reduction potential can be realized at zero or low carbon prices. The mitigation potential in each economic sector is examined in greater detail in this report.

References

Intergovernmental Panel on Climate Change (IPCC). 2001b. *Technical Summary: A Report Accepted by Working Group I of the IPCC but not approved in detail*. A product resulting from The Third Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change, January 2001. Available at: www.ipcc.ch.

U.S. Environmental Protection Agency (USEPA). (2012a). *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2030*. EPA 430-R-12-006. Washington, DC: USEPA. Available at: http://www.epa.gov/climatechange/economics/international.html.

I. Technical Summary

I.1 Overview

The objective of this peer reviewed technical report is to provide a comprehensive and consistent data set on global mitigation of noncarbon dioxide (non-CO_2) greenhouse gases by sector and by region. Mitigating emissions of non-CO_2 greenhouse gases can be relatively inexpensive compared with mitigating CO_2 emissions. Thus, attention continues to focus on incorporating international non-CO_2 greenhouse gas mitigation options into climate economic analyses. This requires a large data collection effort and expert analysis of available technologies and opportunities for greenhouse gas reductions across diverse regions and sectors.

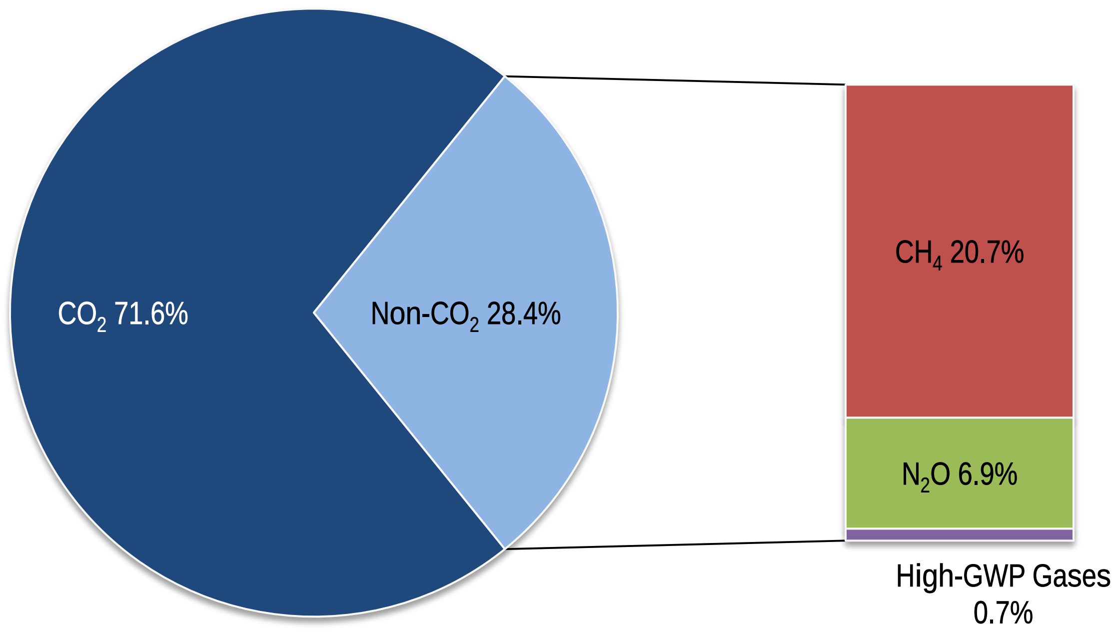
This report is an update to the 2006 EPA report, *Global Mitigation of Non-CO_2 Greenhouse Gases*, and incorporates an updated modeling approach and new data on mitigation technologies, costs, and emissions baselines. The basic methodology—a bottom-up, engineering cost approach—is the same as was followed in the 2006 report, with some enhancements (as described in Section I.3.4 of this report). The results of this analysis are marginal abatement cost (MAC) curves. The end result of this report is a set of marginal abatement curves (MACs) that allow for improved understanding of the mitigation potential for non-CO_2 sources, as well as inclusion of non-CO_2 greenhouse gas mitigation in economic modeling. The MAC data sets can be downloaded in spreadsheet format from the USEPA's Web site at http://www.epa.gov/climatechange/EPAactivities/economics/nonco2mitigation.html.

I.2 Non-CO_2 Greenhouse Gases

Greenhouse gases other than CO_2 play an important role in the effort to understand and address global climate change. The non-CO_2 gases include methane (CH_4), nitrous oxide (N_2O), and a number of high global warming potential or fluorinated gases. The non-CO_2 greenhouse gases are more potent than CO_2 (per unit weight) at trapping heat within the atmosphere and, once emitted, can remain in the atmosphere for either shorter or longer periods of time than CO_2. Figure I-1 shows that these non-CO_2 greenhouse gases are responsible for approximately 30 percent of the enhanced, anthropogenic greenhouse effect since preindustrial times.

Table I-1 shows the global total greenhouse gas emissions for the year 2010, broken down by sector and by greenhouse gas type. The non-CO_2 gases constitute 28 percent of the global total greenhouse gas emissions.

Figure I-1: Contribution of Anthropogenic Emissions of Greenhouse Gases to the Enhanced Greenhouse Effect from Preindustrial to Present (measured in watts/meter²)



Source: Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Table I-1: Global Non-CO_2 Greenhouse Gas (GHG) Emissions for 2010 ($MtCO_2e$) by Source and Gas Type

Sectors	CH_4	N_2O	F-Gases	Global Total Non-CO_2 Emissions	Percentage of Global Total Non-CO_2 GHGs
Agriculture	3,102	2,897	—	5,999	53%
Energy	2,991	54	—	3,044	27%
Industry	83	118	672	873	8%
Waste	1,374	97	—	1,471	13%
Global Total	7,549	3,166	672	11,387	
Percentage of Global Total Non-CO_2 GHGs	66%	28%	6%		

Source: USEPA. 2012. *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990 -2030.* EPA 430-S-12-006. USEPA: Washington D.C. Available at: http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html

I.2.1 Methane (CH_4)

CH_4 is about 21 times more powerful at warming the atmosphere than CO_2 over a 100-year period (IPCC, 1996). In addition, CH_4's chemical lifetime in the atmosphere is approximately 12 years, compared with approximately 100 years for CO_2. These two factors make CH_4 a candidate for mitigating global warming in the near term (i.e., within the next 25 years or so) or in the time frame during which atmospheric concentrations of CH_4 could respond to mitigation actions.

CH_4 is emitted from a variety of manmade sources, including landfills, oil and natural gas systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial processes. CH_4 is also a primary constituent of natural gas and an important energy source. As a result, efforts to prevent or capture and use CH_4 emissions can provide significant energy, economic, and environmental benefits.

I.2.2 Nitrous Oxide (N_2O)

N_2O is a clear, colorless gas with a slightly sweet odor. Because of its long atmospheric lifetime (approximately 120 years) and heat-trapping effects—about 310 times more powerful than CO_2 on a per-molecule basis—N_2O is an important greenhouse gas.

N_2O has both natural and manmade sources and is removed from the atmosphere mainly by photolysis (i.e., breakdown by sunlight) in the stratosphere. In the United States, the main manmade sources of N_2O are agricultural soil management, livestock waste management, mobile and stationary fossil fuel combustion, adipic acid production, and nitric acid production. N_2O is also produced naturally from a variety of biological sources in soil and water.

I.2.3 F-Gases Gases

There are three major groups or types of F-Gases gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). These compounds are the most potent greenhouse gases because of their large heat-trapping capacity and, in the cases of SF_6 and the PFCs, their extremely long atmospheric lifetimes. Because some of these gases, once emitted, can remain in the atmosphere for centuries, their accumulation is essentially irreversible. F-Gases gases are emitted from a broad range of industrial sources; most of these gases have few (if any) natural sources.

HFCs

HFCs are manmade chemicals, many of which have been developed as alternatives to ozone-depleting substances (ODSs) for industrial, commercial, and consumer products. The GWPs of HFCs range from 140 (HFC-152a) to 11,700 (HFC-23). The atmospheric lifetime for HFCs varies from just over a year (HFC-152a) to 260 years (HFC-23). Most of the commercially used HFCs have atmospheric lifetimes of less than 15 years (for example, HFC-134a, which is used in automobile air-conditioning and refrigeration, has an atmospheric lifetime of 14 years).

PFCs

Primary aluminum production, semiconductor manufacturing and flat panel display manufacturing are the largest known manmade sources of tetrafluoromethane (CF_4), and hexafluoroethane (C_2F_6). PFCs are also relatively minor substitutes for ODSs. Over a 100-year period, CF_4 and C_2F_6 are, respectively, 6,500 and 9,200 times more effective than CO_2 at trapping heat in the atmosphere.

Sulfur Hexaflouride (SF_6)

The GWP of SF_6 is 23,900, making it the most potent greenhouse gas evaluated by IPCC. SF_6 is a colorless, odorless, nontoxic, nonflammable gas with excellent dielectric properties. It is used (1) for insulation and current interruption in electric power transmission and distribution equipment; (2) to protect molten magnesium from oxidation and potentially violent burning in the magnesium industry; (3) to create circuitry patterns and to clean vapor deposition chambers during manufacture of semiconductors and flat panel displays; and (4) for a variety of smaller uses, including uses as a tracer gas and as a filler for sound-insulated windows.

Like the PFCs, SF_6 is very long lived, so all manmade sources contribute directly to its accumulation in the atmosphere. Measurements of SF_6 show that its global average concentration increased by about 7 percent per year during the 1980s and 1990s, from less than 1 ppt in 1980 to almost 4 ppt in the late 1990s (IPCC, 2001a).

I.2.4 Use of GWPs in this Report

The GWP compares the relative ability of each greenhouse gas to trap heat in the atmosphere during a certain time frame. Per IPCC (1996) guidelines, CO_2 is the reference gas and thus has a GWP of 1. Based on a time frame of 100 years, the GWP of CH_4 is 21 and the GWP of N_2O is 310. Table I-2 lists all GWPs used in this report to convert the non-CO_2 emissions into CO_2-equivalent units. This report uses GWPs from the 1996 IPCC Second Assessment Report (rather than the 2001 Third Assessment Report) because these are the values specified by greenhouse gas reporting guidelines under the United Nations Framework Convention on Climate Change.

Table I-2: Global Warming Potentials

Gas	GWP[a]
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_2O)	310
HFC-23	11,700
HFC-32	650
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Source: IPCC, 1996.
[a]100 year time horizon.

I.3 Methodology

This section describes the basic methodology used in this report to analyze potential emissions and abatement of non-CO_2 greenhouse gases. The analysis builds on the approach presented in the 2006 Global Mitigation of Non-CO_2 Greenhouse Gases report (USEPA, 2006a). For the current analysis several enhancements were made for the MAC analysis and these will be highlighted in the discussion that follows. Primary enhancements include:

- Updating baseline emissions projections
- Disaggregating mitigation potential and costs to the country level for 195 countries
- Updating reduction efficiencies for individual measures by country
- Updating capital and operation and maintenance (O&M) costs for individual measures
- Segmenting O&M costs into labor, materials and energy components
- Developing international adjustments factors used to construct country specific abatement costs and benefits
- Updating crop process model simulations of changes in crop yields and emissions associated with rice cultivation and cropland soil management

MAC curves are constructed for each region and sector by estimating the carbon price at which the present value benefits and costs for each mitigation option equilibrates. The methodology produces a stepwise curve, where each point reflects the average price and reduction potential if a mitigation technology were applied across the sector within a given region. In conjunction with appropriate baseline and projected emissions for a given sector the results are expressed in terms of absolute reductions of carbon dioxide equivalents ($MtCO_2e$).This section describes the components of our methodology.

First, we establish the baseline emissions for each sector as described in Section I.3.1. Section I.3.2 presents the methodology used to evaluate mitigation options, which involves calculating the abatement potential and the breakeven price for each option. Lastly, we describe the construction of the MACs in Section I.3.3. Some sectors deviate from this methodology depending on specific circumstances, which are briefly mentioned here and described in more detail in the sector-specific chapters.

The results of the analysis are presented as MACs by region and by sector and generally focus on the 2010 to 2030 time frame. Emissions abatement in the MACs is shown as both absolute emissions reductions and as percentage reductions from the baseline. Non-CO_2 emissions sources analyzed in this report are

- coal mining;
- oil and natural gas systems;
- solid waste management;
- wastewater;
- specialized industrial processes; and
- agriculture.

I.3.1 Baseline Emissions for Non-CO_2 Greenhouse Gases

For consistency across regions and sectors the MAC Report analysis primarily uses the EPA report, *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2030* for baseline emissions and projections. The Global Emissions Report (GER) was published in December of 2012, and uses a combination of country-prepared, publicly-available reports (UNFCCC National Communications) and IPCC Tier 1 methodologies to fill in missing or unavailable data. The basis for the U.S. historical emissions in the GER is the U.S. Inventory of Greenhouse Gases and Sinks published in April of 2011. The methods used to estimate and project non-CO_2 emissions in USEPA (2012) are briefly summarized here. In some cases, particularly for agricultural emissions, it was necessary to develop separate baselines from which to assess the mitigation analyses. For the agricultural sector, the baseline emissions used in this report were based on crop process model simulations and livestock population data combined with projected crop areas and livestock populations, respectively, from the International Food Policy Research Institute

International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model. These deviations are also explained in more detail in this report.

The preferred approach for estimating historical and projected emissions is to use country-prepared, publicly-available reports. EPA applied an overarching methodology to estimate emissions across all sectors, and deviations to this methodology are discussed in each of the source-specific methodology sections of USEPA (2012). The following summary of the general methodology used to estimate global non-CO_2 emissions is replicated from the USEPA (2012) report.

Historical Emissions

For Annex I Countries (A1), the UNFCCC flexible query system (UNFCCC, 2012) provides emission estimates for A1 countries from Common Reporting Format (CRF) files, submitted with annual national inventories. The full or partial time series of source disaggregated data is available for A1 countries from 1990 through 2007. The time series is complete for the majority of sources; however there are gaps in the time series for some countries and categories and data for missing years were supplemented. The methodology used by each source to interpolate, backcast, or forecast depends on the availability of CRF data and the distribution of that data over time. In general, the following methodology was applied to interpolate, backcast, or forecast data:

- When two years are reported such that a year requiring an estimate (e.g., 1995) occurred between the reported years (e.g., 1993 and 1997), EPA interpolates the missing estimate (1995) using reported estimates.
- EPA backcasted or forecasted emission estimates to complete the historical series for 1990, 1995, 2000, and 2005 on a source by source basis. For each source, EPA used growth rates for available activity data believed to best correlate with emissions (e.g., production, consumption). If either 1) more than one type of activity data should be used, 2) the emission factor will vary over time, or 3) the relationship between the activity data and emissions is not linear (i.e., exponential), then EPA used Tier 1 growth rates. This involves estimating emissions for 1990, 1995, 2000, and 2005 using a Tier 1 approach, then using the rate of growth of this emission estimate to backcast and forecast the country-reported emissions.
- If a country-reported an estimate for an individual source for one year, but reported aggregate estimates for other years, EPA disaggregated the estimates using the percent contribution of the individual source in the latest reported year.

For Non-Annex I countries historical emissions data were available in the UNFCCC flexible query system as well, but generally these reported data do not constitute a full time series. The methodology for interpolating or backcasting missing historical data used by each source will follow the same general guidelines outlined in the earlier in this section. Because the data for non-A1 countries from the UNFCCC flexible query system do not generally have a complete time series, it is likely that non-A1 sources will rely more heavily on Tier 1 calculated growth rates or activity data growth rates for backcasting and forecasting emissions between 1990 and 2005.

Projected Emissions

Emission projections by source and country were obtained from National Communications (NCs) reports. For A1 countries, this refers to the Fifth NCs currently being released. For non-A1 countries, EPA reviewed the most recent NCs submitted to the UNFCCC.

If an NC had projections for a sector but not a source, EPA used the relative proportion of emissions for the latest year of historical emissions to disaggregate projected emissions for a source. For example, if France projected CH_4 emissions from agriculture to 2030 but does specify what portion is from manure management, EPA took the proportion of emissions that manure contributes to agriculture CH_4 emissions in France's 2007 GHG Inventory, assume this proportion remains constant for 2030, and apply this to the 2030 agriculture estimate.

If projections for a sector are not available from a NC, EPA used activity data drivers or Tier 1 growth rates, specific to each source. The specific methodology followed by each source category is outlined in each sector's methodology description.

For most countries, emissions and projections are not available for the sources of F-GHGs. Therefore, EPA estimates F-GHG emissions and projections using detailed source methodologies described in USEPA (2012).

Baseline Emissions for Agriculture

Although USEPA (2012) contains estimates of baseline emissions for agricultural sources, alternative baselines were developed for the purposes of the mitigation report. The primary rationale was to ensure consistency in the area, number of livestock head, production, and price projections used across the entire agricultural sector. Projections provided by IFPRI from their IMPACT model of global agricultural markets were used to adjust values for agricultural activities and associated emissions over time. In addition, detailed process-based models—Daily Century (DAYCENT) for croplands and DeNitrification–DeComposition (DNDC) for rice cultivation—were used for both the baseline emissions estimates and the greenhouse gas implications of mitigation options, thus allowing for a clear identification of baseline management conditions and consistent estimates of changes to those conditions through mitigation activities. Emissions obtained using these detailed simulation models differ from those obtained in USEPA (2012), which relied upon IPCC default emissions factors. For emissions associated with livestock, the mitigation analysis in this report relies on projections similar to those used in USEPA (2012), but with some differences due to the adjustments made for consistency with IFPRI IMPACT projections across all agricultural sectors. The baseline emissions were also disaggregated by livestock production system and intensity using data provided by the United Nations Food and Agriculture Organization (FAO). Further details about the emissions baselines estimated by the DAYCENT and DNDC models, and their relationship to USEPA (2012) estimates, are provided in Section V Agriculture of this report.

I.3.2 Mitigation Option Analysis Methodology

Mitigation options represented in the MACs of this report are applied to the baselines described in Section IV.1.3.1. The mitigation option analysis throughout this report was conducted using a common methodology and framework. This section outlines the basic methodology. The sector-specific chapters describe the mitigation estimation methods in greater detail, including any necessary deviations from the basic methodology.

The abatement analysis for all non-CO_2 gases for agriculture, coal mines, natural gas systems, oil systems, landfills, wastewater treatment, and nitric and adipic acid production are based on USEPA , 2006 and improve upon DeAngelo et al. (2006), Beach et al. (2008), Delhotal et al. (2006), and Ottinger et al. (2006). These studies provided estimates of potential CH_4 and N_2O emissions reductions from major emitting sectors and quantified costs and benefits of these reductions.

Given the detailed data available for U.S. sectors, the USEPA's U.S. analysis uses representative facility estimates but then applies the estimates to a highly disaggregated and detailed set of emissions sources for all the major sectors and subsectors. For example, the USEPA analysis of the natural gas sector is based on more than 100 emissions sources in that industry, including gas well equipment, pipeline compressors and equipment, and system upsets. Thus, the USEPA analysis provides significant detail at the sector and subsector levels.

The analysis generally begins with developing sector level model facilities or units to which mitigation options are applied. In many cases the model facilities, abatement costs and mitigation potential are based on detailed US and EU inventory estimates, and then extrapolate to "model" facilities for other countries. For some sectors, such as wastewater, landfills, and selected industrial sectors, additional detail on international abatement options and costs are available and are incorporated into the model.

A scaling factor is used to reconcile inventory data with the GER baseline emissions data. For the F-Gases abatement analysis, natural gas and oil, and landfills sectors it is assumed that some mitigation technologies are adopted to meet future regulations or voluntary industry reduction targets. Therefore, some mitigation options are accounted for in the baseline emissions. If an option is assumed to be adopted in the baseline, it is not included when generating the MAC. In addition, expert judgment determines market shares for mitigation technologies competing for the same set of emissions (when multiple options are available that are substitutes for each other).

The agricultural sector's emissions abatement analysis improves upon previous studies supported by the USEPA (USEPA, 2006; DeAngelo et al., 2006; Beach et al., 2008) that generated MACs by major world region for cropland N_2O, livestock enteric CH4, manure management CH4, and rice cultivation CH4. The most significant change in this report is the use of updated versions of the biophysical, process-based models used in previous studies (i.e., DAYCENT and DNDC) applied at a more disaggregated spatial scale to better capture the net greenhouse gas and yield effects and to capture the spatial and temporal variability of those effects for the cropland and rice emissions baseline and mitigation scenarios. Use of these process-based models is intended to show broad spatial and temporal baseline trends and broad changes when mitigation scenarios are introduced, rather than to show definitive absolute emissions numbers for specific locations. In addition, baseline emissions estimates have been updated and a larger number of mitigation options are now assessed, particularly for rice cultivation (e.g., increased emphasis on options that reduce N_2O as well as CH_4). Considerably greater disaggregation of the baseline by production system has been incorporated to improve our ability to characterize technical applicability for different types of livestock and cropping systems. More detailed results are provided for rice cultivation under deepwater, upland, rainfed, and irrigated conditions, with separate calculations for alternative irrigated water management strategies and for livestock management based on livestock production system and management intensity.

Technical Characteristics of Abatement Options

The non-CO_2 abatement options evaluated in this report are compiled from the studies mentioned above, as well as from the literature relevant for each sector. For each region, either the entire set of sector-specific options or the subset of options determined to be applicable is applied. Options are omitted from individual regions on a case-by-case basis, using either expert knowledge of the region or technical and physical factors (e.g., appropriate climate conditions). In addition, the share or extent of applicability of an option within different regions may vary based on these conditions.

The selective omission of options represents a static view of the region's socioeconomic conditions. In some instances the reduction efficiency of an option improves over time reflecting anticipated technology advances. However, the applicability of options is held constant over time. Ideally, more detailed information on country-specific conditions, technologies, and experiences will be available in the future, which will enable more rigorous analyses of abatement option availability over time in each region. In addition, the average technical lifetime of an option (in years), determined using expert knowledge of the technology or recent literature, is held constant over time and across regions.

Table I-3 summarizes how the potential emission reduction is calculated for each of the available abatement options. First the technical effectiveness of each option is calculated by multiplying the options technical applicability by its market share by its reduction efficiency. This yields the percentage of baseline emissions that can be reduced at the national or regional level by a given option. This is then applied to the Emissions stream ($MtCO_2e$) to which the option is applied to yield the emissions reductions for the mitigation option.

Table I-3: Calculation of Potential Emission Reduction for an Abatement Option

Technical Applicability (%)	X	Market Share[a] (%)	X	Reduction Efficiency (%)	=	Technical Effectiveness (%)				
						Technical Effectiveness (%)	X	Baseline Unit Emissions ($MtCO_2e$)	=	Unit Emission Reduction ($MtCO_2e$)
Percentage of total baseline emissions from a particular emissions source to which a given option can be potentially applied.		Percentage of technically applicable baseline emissions to which a given option is applied; avoids double counting among competing options		Percentage of technically achievable emissions abatement for an option after it is applied to a given emissions stream		Percentage of baseline emissions that can be reduced at the national or regional level by a given option.		Emissions stream to which the option is applied		Unit emission reductions

[a] Implied market share non competing options (i.e., only one options is applicable for an emissions streams) is assumed to add to 100 percent

Technical applicability accounts for the portion of emissions from a facility or region that a mitigation option could feasibly reduce based on its application. For example, if an option applies only to the underground portion of emissions from coal mining, then the technical applicability for the option would be the percentage of emissions from underground mining relative to total emissions from coal mining.

The implied market share of an option is a mathematical adjustment for other qualitative factors that may influence the effectiveness or adoption of a mitigation option. For certain energy, waste, and agriculture sectors, it was outside the scope of this analysis to account for adoption feasibility, such as social acceptance and alternative permutations in the sequencing of adoption. For example, if n competing (overlapping) mitigation options are available for a single emissions stream, the implied market share of each of the n overlapping options is equal to $1/n$. This avoids cumulative reductions of greater than 100 percent across options. Given the lack of region-specific data for determining the relative level of diffusion among options that could compete for the same emissions stream, we applied this conservative adjustment. An example of overlapping options is the sequencing of cropland mitigation options, where the adoption of one option (e.g., conversion to no tillage) affects the effectiveness of subsequent options (e.g., reduced fertilizer applications). While this describes the basic application of the implied adoption rate in the energy, waste, and agriculture sectors, this factor is informed by expert insight into the potential market penetration over time in the industrial processes sector. For sectors such as landfills, where market share assumptions are available, customized shares that sum to one are used instead of $1/n$.

When nonoverlapping options are applied, they affect 100 percent of baseline emissions from the relevant source. Examples of two nonoverlapping options in the natural gas system are inspection and maintenance of compressors and replacement of distribution pipes. These options are applied independently to different parts of the sector and do not compete for the same emissions stream.

The reduction efficiency of a mitigation option is the percentage reduction achieved with adoption. The reduction efficiency is applied to the relevant baseline emissions as defined by technical applicability and adoption effectiveness. Most abatement options, when adopted, reduce an emissions stream less than 100 percent. If multiple options are available for the same component, the total reduction for that component is less than 100 percent.

Once the technical effectiveness of an option is calculated as described above, this percentages multiplied by the baseline emissions for each sector and region to calculate the absolute amount of emissions reduced by employing the option. The absolute amount of baseline emissions reduced by an option in a given year is expressed in million metric tons of CO_2 equivalent ($MtCO_2eq$).[1]

If the options are assumed to be technically feasible in a given region, the options are assumed to be implemented immediately, Furthermore, once options are adopted, they are assumed to remain in place for the duration of the analysis, and an option's parameters are not changed over its lifetime.

Economic Characteristics of Abatement Options

Each abatement option is characterized in terms of its costs and benefits per an abated unit of gas (tCO_2eq or tons of emitted gas [e.g., tCH_4]). The benefits include a carbon value/price expressed as $\$/\text{tCO-}_2\text{e}$. The carbon price at which an option's benefits equal the costs is referred to as the option's breakeven price.

For each mitigation option, the carbon price (*P*) at which that option becomes economically viable is calculated using the equation below (i.e., where the present value of the benefits of the option equals the present value of the costs of implementing the option). A present value analysis of each option is used to determine breakeven abatement costs in a given region. Breakeven calculations are independent of the year the mitigation option is implemented but are contingent on the life expectancy of the option. The net present value calculation solves for breakeven price *P*, by equating the present value of the benefits with the present value of the costs of the mitigation option. More specifically,

$$\underbrace{\sum_{t=1}^{T}\left[\frac{(1-TR)(P\cdot ER+R)+TB}{(1+DR)^t}\right]}_{\textit{Net Present Value Benefits}} = \underbrace{CC+\sum_{t=1}^{T}\left[\frac{(1-TR)RC}{(1+DR)^t}\right]}_{\textit{Net Present Value Costs}}$$

where

P = the breakeven price of the option ($\$/tCO_2e$);
ER = the emissions reduction achieved by the technology ($MtCO_2e$);
R = the revenue generated from energy production (scaled based on regional energy prices) or sales of by-products of abatement (e.g., compost) or change in agricultural commodity prices ($);
T = the option lifetime (years);
DR = the selected discount rate (%);

[1] One $MtCO_2eq$ equals 1 teragram of CO_2 equivalent ($TgCO_2eq$); 1 metric ton = 1,000 kg = 1.102 short tons = 2,205 lbs.

CC = the one-time capital cost of the option ($);
RC = the recurring (O&M) cost of the option (portions of which may be scaled based on regional labor and materials costs) ($/year);
TR = the tax rate (%); and
TB = annual tax benefit of depreciation = $\left(\frac{CC}{T}\right) \cdot TR$.

Assuming that the emissions reduction ER, the recurring costs RC, and the revenue generated R do not change on an annual basis, then we can rearrange this equation to solve for the breakeven price P of the option for a given year:

$$P = \frac{CC}{(1-TR) \cdot ER \cdot \sum_{t=1}^{T} \frac{1}{(1+DR)^t}} + \frac{RC}{ER} - \frac{R}{ER} - \frac{CC}{ER \cdot T} \cdot \frac{TR}{(1-TR)}$$

Costs include capital or one-time costs and operation and maintenance (O&M) or recurring costs. Most of the agricultural sector options, such as changes in management practices, do not have applicable capital costs, with the exception of anaerobic digesters for manure management.

Benefits or revenues from employing an abatement option can include (1) the intrinsic value of the recovered gas (e.g., the value of CH_4 either as natural gas or as electricity/heat, the value of HFC-134a as a refrigerant), (2) nongreenhouse gas benefits of abatement options (e.g., compost or digestate for waste diversion options, increases in crop yields), and (3) the value of abating the gas given a greenhouse gas price in terms of dollars per tCO_2 eq ($/$tCO_2eq$) or dollars per metric ton of gas (e.g., $/$tCH_4$, $/tHFC-134a). In most cases, there are two price signals for the abatement of CH_4: one price based on CH_4's value as energy (because natural gas is 95 percent CH_4) and one price based on CH4's value as a greenhouse gas. All cost and benefit values are expressed in constant year 2010 U.S. dollars. This analysis is conducted using a 10 percent discount rate and a 40 percent tax rate. For quick reference, Table I-4 lists the basic financial assumptions used throughout this report.

Table I-4: Financial Assumptions in Breakeven Price Calculations for Abatement Options

Economic Parameter	Assumption
Discount Rate	10%
Tax Rate	40%
Constant Year Dollars	2010$

International Adjustment Factors

Costs and benefits of abatement options are adjusted to reflect regional prices. Wages and prices will vary by country. Hence recurring O&M costs are segmented into labor, energy and materials costs. Material costs components range from materials and supplies in the in the industrial and energy sectors, to fertilizer costs in the agricultural sectors – all of which are likely to vary by region. One-time capital costs are assumed to relatively stable across regions and not adjusted from country to country.

For some options data were available on the relative cost shares between labor, energy and materials. For instance, in coal mining, different technologies have different cost shares which were developed based on expert judgment. For options without detailed cost breakouts, the shares are generally assigned evenly as 33% each to labor, energy, and materials. For the agricultural sector, labor, energy, water and other input costs are calculated from their shares of agricultural production costs based on social accounting matrix (SAM) data from the Global Trade Analysis Project (GTAP) v8 database and agricultural wage data from the International Food Policy Research Institute (IFPRI).

In regions where there is a lack of detailed revenue (benefits) data, revenues are scaled based on the ratio between average prices of natural gas (when CH_4 is abated and sold as natural gas) or of electricity (when CH_4 is used to generate electricity or heat) in a given region and in the United States. Similarly, revenues from non-CH_4 benefits of abatement options are scaled based on the ratio between the GDPs per capita in a given region and in the United States. In the agricultural sector, changes in revenue occur as a change in either crop yield or livestock productivity. Data on changes in crop yield or livestock productivity are combined with data on regional producer prices for the relevant agricultural commodity to calculate revenue changes.

Table I-5 lists the international economic adjustment factors for selected countries. Using publically available data on country-specific wage rates and energy prices, along with input from previous MAC analysis, indices reflecting each country's wage rates and prices relative to the United States were created. Adjustment Factors were created for labor, natural gas, electricity, coal and material costs. When data was not available for a country, the country was either mapped to a similar country (with data) or previously developed EMF factors were used.

Table I-5: International Economic Adjustment Factors for Selected Countries

Country	Labor[a]	Natural Gas[b]	Electricity[b]	Coal[b]	Materials[c]
Afghanistan	0.02	0.75	1.30	0.89	0.01
Brazil	0.24	1.30	1.60	0.76	0.13
Congo	0.19	1.06	0.34	0.37	0.05
China	0.04	0.62	0.63	0.68	0.07
India	0.03	0.67	1.69	0.69	0.02
Madagascar	0.19	1.06	0.34	0.37	0.01
Mexico	0.12	1.04	1.42	0.94	0.20
Norway	1.80	1.62	0.77	2.57	1.61
Poland	0.26	0.98	1.19	1.25	0.24
Russian Federation	0.12	0.19	0.56	0.67	0.15
Switzerland	1.35	1.62	1.41	2.04	1.30
United States	1.00	1.00	1.00	1.00	1.00
Uzbekistan	0.12	0.19	0.38	0.19	0.02

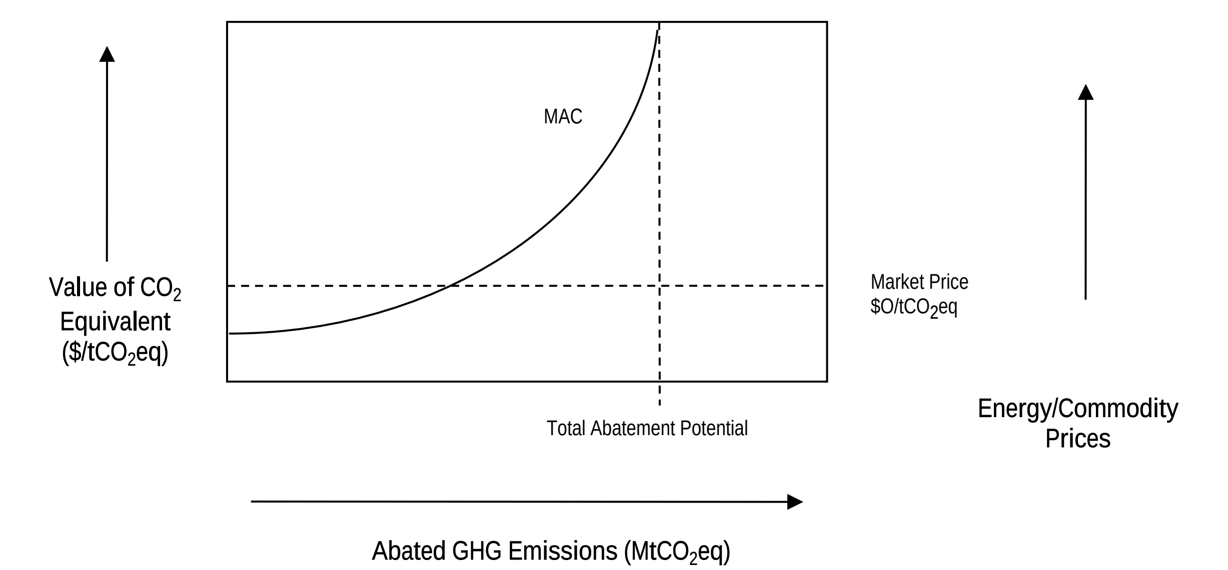
[a]Wage data was obtained primarily from U.S Bureau of Labor Statistics's International Labor Comparisons (BLS, 2010) and augmented with (BLS, 2010b), (BLS, 2010c) and (FSSS,2010).
[b]Energy Prices were obtained from EIA's *International Energy Statistics* (EIA, 2010b).
[c]Material factors were based on GDP/Capita statistics obtained from UNCTAD Statistical Database (UNCTAD, 2012).

Note that breakeven price calculations for this analysis do not include transaction or monitoring and reporting costs, because there are no explicit assumptions in this report about policies that would encourage and facilitate adoption of the mitigation options. Refer to Section I.5 for a more complete discussion of the limitations of this analysis.

I.3.3 Marginal Abatement Cost Curves

MACs are used to show the amount of emissions reduction potential at varying carbon price levels. In theory, a MAC illustrates the cost of abating each additional ton of emissions. Figure I-2 shows an illustrative MAC. The x-axis shows the amount of emissions abatement in $MtCO_2eq$, and the y-axis shows the breakeven price in $\$/tCO_2eq$ required to achieve the level of abatement. Therefore, moving along the curve from left to right, the lowest cost abatement options are adopted first.

Figure I-2: Illustrative Non-CO_2 Marginal Abatement Curve



The curve becomes vertical at the point of maximum total abatement potential, which is the sum of all technically feasible abatement options in a sector or region. At this point no additional price signals from GHG credit markets could motivate emissions reductions; any additional emissions reductions (shifting the vertical axis to the right) are due to increased energy efficiencies, conservation of production materials, or both.

The points on the MAC that appear at or below the zero cost line ($\$0/tCO_2eq$) illustrate potentially profitable mitigation options. These "below-the-line" amounts represent mitigation options that are already cost-effective given the costs and benefits considered (and are sometimes referred to as "no-regret" options) yet have not been implemented. However, there may be nonmonetary barriers that are preventing their adoption.

The MACs in this report are constructed from bottom-up average breakeven price calculations. The average breakeven price is calculated for the estimated abatement potential for each mitigation option (see Section I.). The options are then ordered in ascending order of breakeven price (cost) and plotted against abatement potential. The resulting MAC is a stepwise function, rather than a smooth curve, as seen in the illustrative MAC (Figure I-2), because each point on the curve represents the breakeven price point for a discrete mitigation option (or defined bundle of mitigation strategies).

Conceptually, marginal costs are the incremental costs of an additional unit of abatement. However, the abatement cost curves developed here reflect the incremental costs of adopting the next cost-effective mitigation option. We estimated the costs and benefits associated with all or nothing adoption of each well-defined mitigation practice. We did not estimate the marginal costs of incremental changes within each practice (e.g., the net cost associated with an incremental change in paddy rice irrigation). Instead, the MACs developed in this report reflect the average net cost of each option for the achieved reduction – hence the noncontinuous, stepwise nature of the curve.

In the energy and waste sectors, representative facilities facing varied mitigation costs employ mitigation technologies based on the lowest average breakeven option price. In calculating the abatement potential, options are evaluated according to whether they are complements or substitutes. If a group of options are complements (or independent of one another), the implied market shares are all equal to one. If options are substitutes for each other, then market shares that sum to one are used to distribute adoption across the available options (see table I.3). In some instances, the lowest price option is selected for each representative facility. When limited information is available, the market share is evenly distributed (1/n) across all viable options. In this way, the implied adoption rate for each technology is estimated.

In the industrial processes sector, mitigation options are applied to representative facilities, in order of lowest average breakeven price to highest average breakeven price. Each option is applied to a portion of the baseline emissions based on the implied adoption rate (the market share factor, as described in Section I.3.2.2), which, in the industrial sector, is informed by expert insight into potential adoption rates of various mitigation technologies.

In the agriculture sector, mitigation options are applied to the portion of emissions where they are technically applicable (e.g., anaerobic digesters are assumed to be applicable only in intensively managed dairy and hog production systems). The implied market share for competing options is based purely on the number of available migration options (n) that are applicable to a given subset of emissions and that reduce emissions[2] (1/n), where each option is applied to an equal portion of the cropland base or livestock population and, thus regional baseline emissions, for each region over time. Given the existence of nonprice and implementation factors that influence market share and the lack of accurate and detailed information regarding these qualitative characteristics, we assume an even distribution of options across the relevant baseline for the agriculture sector. This approach allows options to share a portion of market penetration, regardless of their cost-effectiveness, rather than allowing only the least-cost option to completely dominate the market. Our methodology is more conservative than if we had assumed only price factors exist, thus allowing the least-cost option to penetrate the sector by 100 percent.

The MACs represent the average economic potential of mitigation technologies in that sector, because it is assumed that if a mitigation technology is technically feasible in a given region, then it is implemented according to the relevant economic conditions. Therefore, the MACs do not represent the market potential or the social acceptance of a technology. The models used in the analysis are static (i.e., they do not represent adoption of mitigation technologies over time). This analysis assumes partial equilibrium conditions that do not represent economic feedbacks from the input or output markets. This analysis makes no assumptions regarding a policy environment that might encourage the implementation of mitigation options. Additional discussion of some key limitations of the methodology is provided in Section I.5.

[2] Some agricultural mitigation options may increase emissions under certain conditions depending on baseline regional management and soil, climate, and other considerations. In addition, there are many mitigation options that increase emissions per head of livestock or per hectare of land, but reduce emissions intensity per unit of output. Thus, agricultural MACs are calculated both assuming constant production and constant area/head of livestock to present a range of potential mitigation. The options that provide net emissions reductions may differ between these alternative methods of MAC generation.

The end result of this analysis is a tabular data set for the MACs by sector, gas, and region, which are presented in Appendix A.[3] Sectoral MACs are aggregated by gas and by region to create global MACs, which are presented in Section I.4.2.

I.3.4 Methodological Enhancements from Analysis

This report builds on a study previously conducted by the USEPA for Stanford's EMF-21 and the USEPA (2006) report. The EMF-21 focused specifically on multigas strategies and the incorporation of non-CO_2 greenhouse gas data sets into economic models. Although this analysis is built largely on the previous USEPA analysis for the EMF-21, we have made several key enhancements.

New mitigation options have been added to the analysis for coal mining, agriculture, natural gas and oil systems sectors. This report also presents MAC curves for the domestic wastewater sector, flat panel display production, and photovoltaic cell production, which were not available in the previous report.

For industrial sources of fluorinated gases, the emissions baselines have been updated since the EMF-21 analysis. In addition, the MACs for aluminum manufacturing and electrical power systems have been enhanced with additional data.

The emissions baselines in the ODS substitute sector have also been enhanced. The EMF-21 ODS substitute baseline was an average between baselines derived by the USEPA and ECOFYS. For this report, the USEPA has generated an updated baseline. Assumptions in the ODS substitute sector, such as the market penetration potential of various mitigation options, have been updated from the EMF-21 analysis based on the input of industry experts.

In the agricultural sector, the previous methodology is improved on for this analysis by using updated versions of the biophysical, process-based models DAYCENT and DNDC that are utilized at a more spatially disaggregated level and with a more disaggregated set of baseline management types to which these options can be applied. These models capture the net greenhouse gas effects of the cropland and rice baseline emissions and mitigation options, and they reflect the heterogeneous emissions and yield effects of adopting mitigation practices. In addition, new agricultural mitigation options are now assessed, and more detailed results are provided for alternative baseline crop and livestock management practices.

I.4 Aggregate Results

Global total non-CO_2 greenhouse gas baseline emissions in 2010 are estimated at 11,389 $MtCO_2e$, and projected to increase 33% by 2030, totaling 15,157 $MtCO_2e$. Non-CO_2 anthropogenic emissions come from four major emitting sectors: the energy, waste management, industrial processes, and agricultural industries. China, United States, Russia, India and Brazil are the 5 largest country emitters and account for 40% of total emissions.

This section presents the projected baseline emissions for non-CO_2 anthropogenic greenhouse gases and provides a global overview of the MAC analysis results by sector and top emitting countries and regions from 2010-2030. The gases represented in the analysis are CH_4, N_20, and F-Gases[4], which are

[3] Tables are presented that provide the percentage abatement for a series of breakeven prices. The MAC data are presented as tables so that exact values can be determined for use in modeling activities.

[4] F-Gases include fluorinated gases used as substitutes for Ozone Depleting Substances (ODS) and High-GWP gases from industrial processes (PFC, HFC-23, SF_6).

emitted from four major sectors: the agricultural, energy, waste, and industrial processes industries. China, the United States, the European Union, Brazil, and Russia are the world's five largest emitting countries as of 2010, accounting for 46 percent of total non-CO_2 emissions.

The data are aggregated in this chapter and provide a summary of all emitting sources and non-CO_2 greenhouse gases. The individual chapters are organized by source and present the full details of these analyses. For a complete set of mitigation potential by sector, gas, and region, refer to Appendix A.

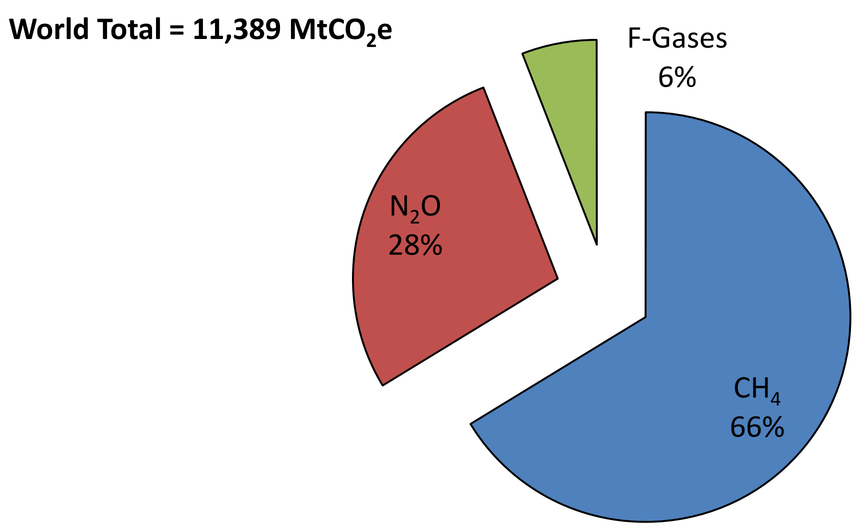
Baseline projections presented in this section come from the *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2030* (USEPA, 2012). Since its publication there have been some minor revisions to the baseline projections for the industrial processes photovoltaic (PV) and flat panel display (FPD) manufacturing. The totals presented in this report will differ slightly from the projections in the 2012 report.

I.4.1 Baselines

By Non-CO_2 Greenhouse Gas

Figure I-3 illustrates the relative share of each non-CO_2 greenhouse gas that comprises the global baseline emissions total. CH_4 represents the largest share of emissions worldwide, accounting for approximately 66% of the total non-CO_2 greenhouse gas emissions in 2010, while N_2O and F-Gases account for the 28 percent and 6 percent, respectively.

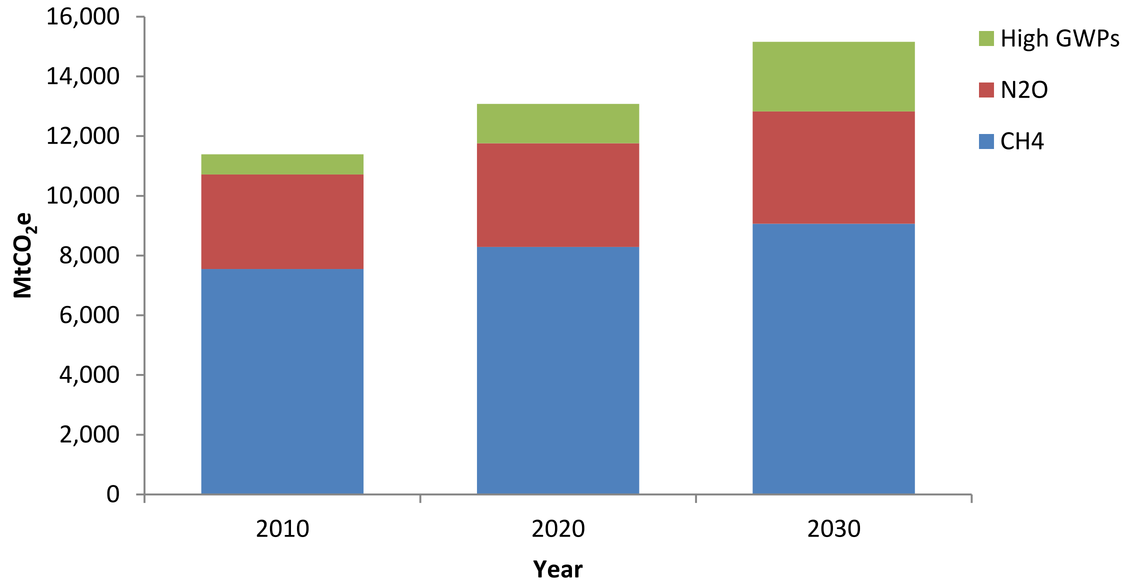
Figure I-3: Percentage Share of Global Non-CO_2 Emissions[a] by Type of Gas in 2010



Source: USEPA, 2012.
[a] CO_2 equivalency based on 100-year GWP.

Figure I-4 presents the projected baseline emissions by greenhouse gas for 2010, 2020, and 2030. F-Gases represent the most significant change in baseline emissions. Accordingly to Figure I-4, high GWPs are to increase nearly 300 percent between 2010 and 2030. CH_4 and N_2O observe a more modest increase at an average decadal rate of roughly 10 percent. As a result, F-Gases are projected to gain 15 percent of the total share of non-CO_2 greenhouse gas emission by 2030, up from 4 percent in 2010

Figure I-4: Non-CO_2 Global Emissions Forecast to 2030 by Greenhouse Gas



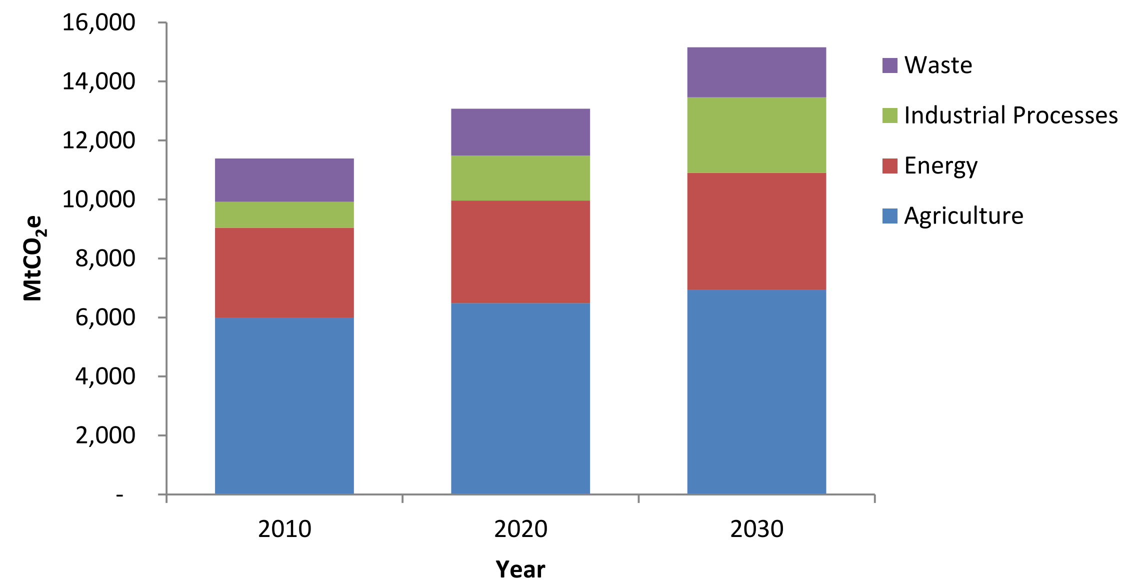
Source: USEPA, 2012.

By Major Emitting Sectors and Countries

The sources of non-CO_2 emissions are categorized into four major emissions sectors: energy, waste, industrial processes, and agriculture. Figures I-5 and I-6 provide the projected global baseline emission for 2010, 2020, 2030, by major emissions sector and by major emitting region, respectively. The agriculture sector includes soil and manure management, rice cultivation, enteric fermentation, and other nonindustrial sources such as biomass burning. Emissions sources categorized in the energy sector include coal mining activities, natural gas transmission and distribution, and gas and oil production. The waste sector includes municipal solid waste management, as well as human sewage and other types of wastewater treatment. The industrial processes sector includes a wide range of activities, such as semiconductor manufacturing, primary aluminum production, and electricity transmission and distribution.

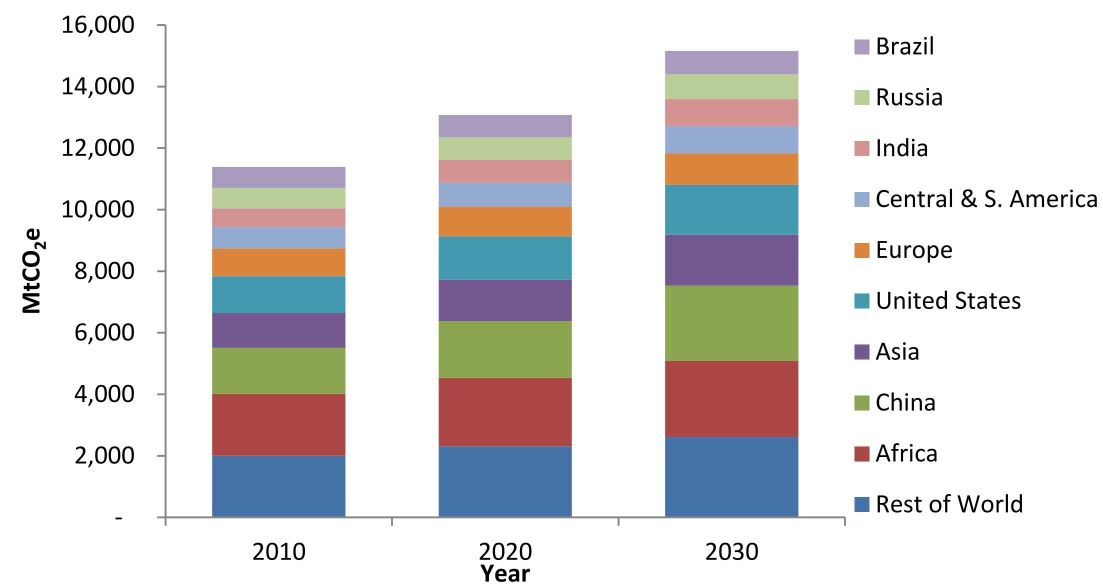
Agriculture is the primary source of non-CO_2 greenhouse gas emissions, accounting for 45 percent of the total 2010 baseline. Energy holds the second largest share of non-CO_2 emissions, representing 23 percent of the baseline. The waste and industrial processes sectors represent 11 and 7 percent, respectively. This trend will change through 2030, however, as emissions from the industrial processes sector is projected to increase by more than double, and will therefore produce more non-CO_2 emissions that waste by 2030.

Figure I-5: Global Emissions by Major Sector for all Non-CO_2 Greenhouse Gases



Source: USEPA, 2012.

Figure I-6: Projected World Emissions Baseline for Non-CO_2 Greenhouse Gases, Including Top Emitting Regions



Source: USEPA, 2012.

Figure I-6 shows the projected emissions baselines for the world, as well as the largest emitting countries. The largest non-CO_2 emitting countries are typically characterized as mature, highly industrialized countries or countries with significant agricultural industries. In 2010, the top five emitting countries – China, the United States, EU-15, Brazil, and Russia – account for 44% of the world's total non-

CO_2 emissions. Although 2010's top five emitting countries is projected to change during the next 20 years, their relative contribution to the world baseline will likely remain constant through 2030.

I.4.2 Global MACs

The MAC analysis methodology described in Section I.3 of this report develop bottom-up projections of potential reduction in non-CO_2 emissions in terms of the break-even price ($/t$CO_2$e). The emission reduction potential is constrained by the limitations of the technologies considered in the analysis, as well as regional and geographical applicability. In this report, MACs are developed for each major source by sector and country. The resulting series of MACs are aggregated up across sectors, gases and regions. The MACs indicate the potential reduction in non-CO_2 gas emissions for a given breakeven price. Figure I-7 presented the results from the MAC analysis for 2030 by major economic sector. Figure I-8 presents aggregate MACs by greenhouse gas type for 2030. Figure I-9 presents the 2030 MACs for the world's largest non-CO_2 greenhouse gas emitting regions.

Figure I-7: Global 2030 MACs by Non-CO_2 Greenhouse Gas

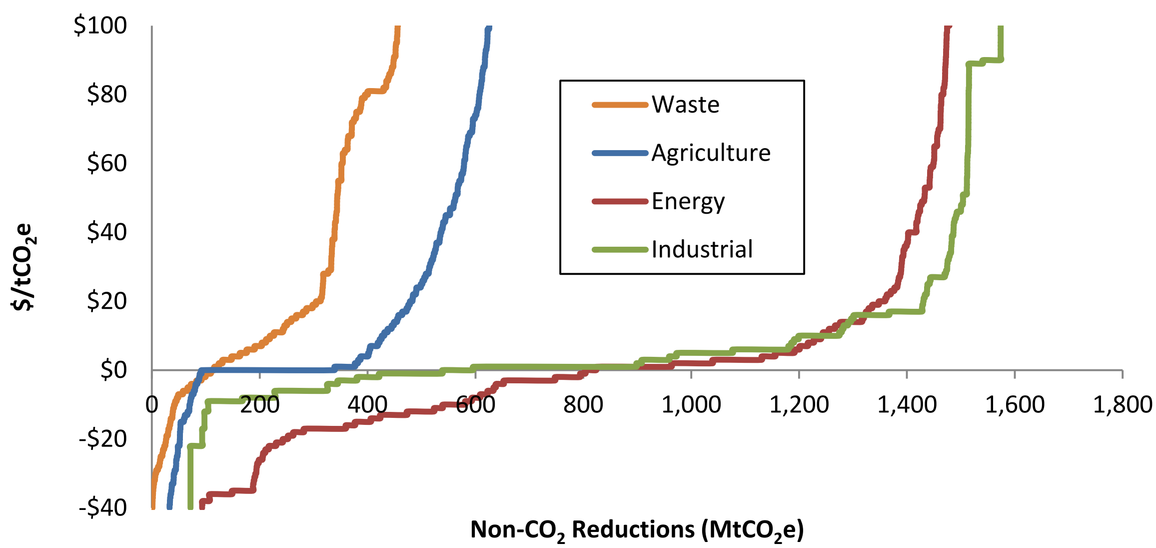


Figure I-8: Global 2030 MACs for Non-CO_2 Greenhouse Gases by Major Emitting Regions

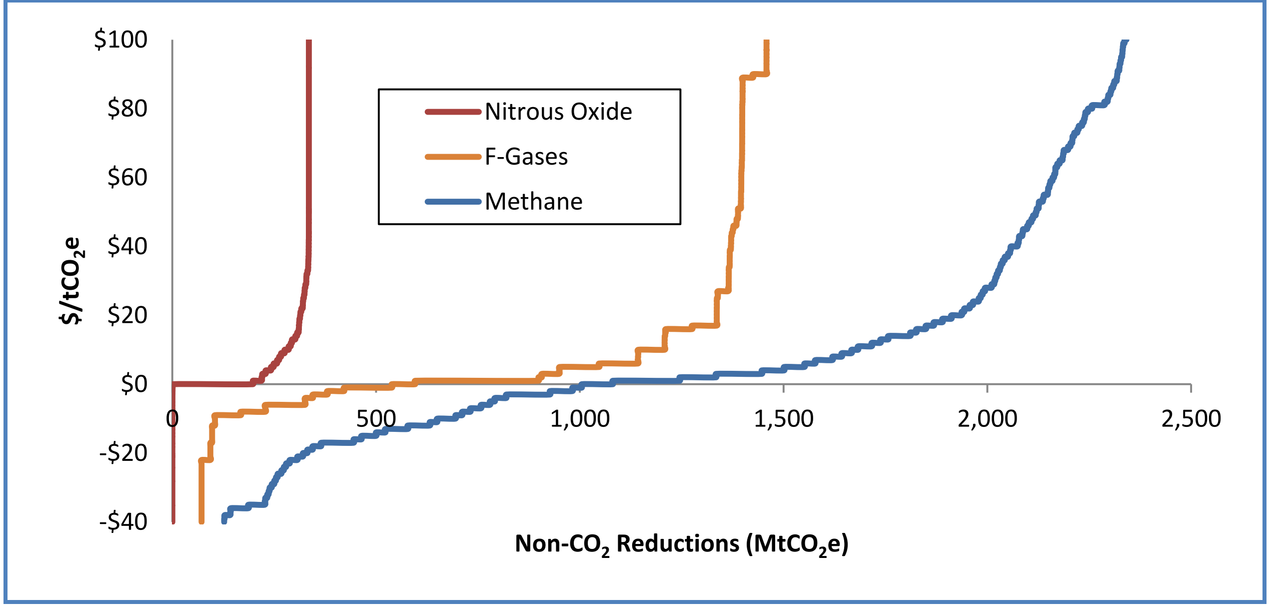
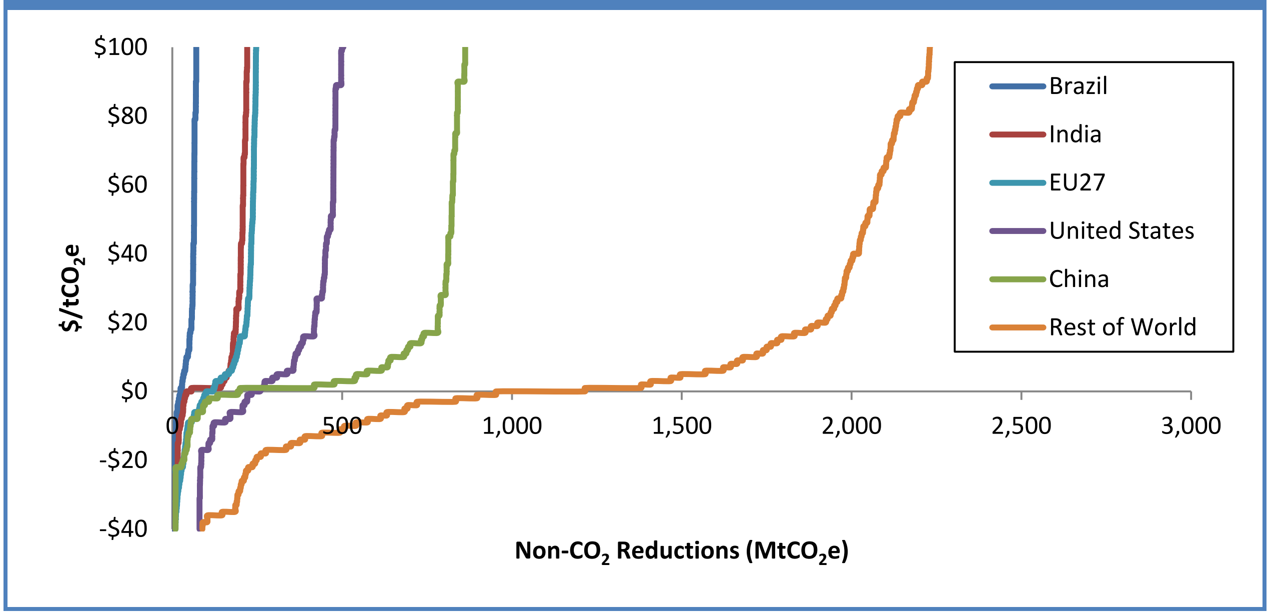


Figure I-9: Global 2030 MACs for Non-CO_2 Greenhouse Gases by Major Emitting Regions



I.5 Limitations and Uncertainties

The results of this analysis cover the major emitting regions, emissions sources, and abatement options; we discuss a few limitations of this analysis briefly below.

I.5.1 Exclusion of Transaction Costs

Ongoing work in the area of mitigation costs continues focus on including transactions costs. As discussed in the 2006 version of this report, Lawrence Berkeley National Laboratory (LBNL), *Assessing Transaction Costs of Project-based Greenhouse Gas Emissions Trading* (Antinori and Sathaye 2007), which reported that transactions costs range between $0.03 per metric ton of carbon dioxide for large projects to $4.05 per ton of carbon dioxide for smaller projects, with a weighted average of $0.36 per tonne of carbon dioxide for a suite of projects considered. More recent MAC work by others (Rose, et al. 2013) estimated the unit cost of an abatement project increases by an average of 15% when transaction costs are included. Transaction costs vary significantly, contingent on the size of the project, the applicable mitigation technology, and other factors. Given the lack of comprehensive data, this analysis continues to exclude transaction costs from the analysis.

I.5.2 Static Approach to Abatement Assessment

This analysis does not account for the technological change in such option characteristics as availability, reduction efficiency, applicability, and costs. For example, the same sets of options are applied in 2010 and 2030 and an option's parameters are not changed over its lifetime. This current limitation likely underestimates abatement potential because technologies generally improve over time and costs fall. The introduction of a dynamic approach to assessing regional abatement potentials requires additional assumptions about rates of technological progress and better baseline projections, that, once incorporated into this analysis, will yield a better representation of how MACs change over space and time. Developing more dynamic MACs to capture the impacts of technological change should be included in any future MAC development.

I.5.3 Limited Use of Regional Data

The analytic framework used in this study is flexible enough to incorporate regional differences in all the characteristics of abatement options. However, a lack of country-specific data led to a reliance on expert judgment, as noted in the sector-specific chapters. This expert judgment was obtained from source-level technical experts in government and industry with knowledge of project-level technologies, costs, and specific regional conditions. Applicability of abatement options, for example, is reliant on expert judgment, because the makeup of the current infrastructure in a given country in a given sector is uncertain. A much greater use of data originating from local experts and organizations is recommended for the follow-up research of CH_4 abatement in countries outside the United States and EU. Incorporating more regional data could also enhance the range of emissions sources and mitigation options addressed in this analysis.

I.5.4 Exclusion of Indirect Emissions Reductions

This analysis does not account for indirect emissions reductions, which can result from either the substitution of electricity from the grid, with electricity produced on-site from recovered CH_4, or from the substitution of natural gas in pipelines with recovered CH_4. Calculation of such indirect reductions requires additional assumptions about the carbon intensity of electricity in different regions. In the U.S. landfill sector, indirect reductions generally augment emissions reductions by about 15 percent. In the agricultural sector, although some mitigation options primarily target a single gas, implementation of the mitigation options will have multiple greenhouse gas effects, most of which are reflected in the agricultural results.

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