27. Mitigation

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Key Messages

1. **Carbon dioxide is removed from the atmosphere by natural processes at a rate that is roughly half of the current rate of emissions from human activities. Therefore, mitigation efforts that only stabilize global emissions will not reduce atmospheric concentrations of carbon dioxide, but will only limit their rate of increase. The same is true for other long-lived greenhouse gases.**

2. **To meet the lower emissions scenario (B1) used in this assessment, global mitigation actions would need to limit global carbon dioxide emissions to a peak of around 44 billion tons per year within the next 25 years and decline thereafter. In 2011, global emissions were around 34 billion tons, and have been rising by about 0.9 billion tons per year for the past decade. The world is therefore on track to exceed this level within a decade.**

3. **Over recent decades, the U.S. economy has emitted a declining amount of carbon dioxide per dollar of gross domestic product for many reasons, but to date U.S. population and economic growth have outweighed these trends. In the absence of additional public policies, greenhouse gas emissions are expected to remain roughly constant.**

4. **Carbon storage in land ecosystems, especially forests, has offset around 17% of annual U.S. fossil fuel emissions of greenhouse gases over the past several decades, but this carbon “sink” may not be sustainable.**

5. **Both voluntary activities and a variety of policies and measures that lower emissions are currently in place at federal, state, and local levels, even though there is no comprehensive national greenhouse gas policy. While these efforts represent**

significant steps towards reducing greenhouse gases, and often result in additional co-benefits, they are not close to sufficient to reduce total U.S. emissions to a level consistent with the lower scenario (B1) analyzed in this assessment.

Mitigation refers to actions that reduce the human contribution to the planetary greenhouse effect. Mitigation actions include lowering emissions of greenhouse gases like carbon dioxide and methane, and particles like black carbon (soot) that have a warming effect. Increasing the net uptake of carbon dioxide by land-use change and forestry can make a contribution as well. As a whole, human activities result in higher global concentrations of greenhouse gases and to a warming of the planet – and the effect is increased by various self-reinforcing cycles in the Earth system (such as the way melting sea ice results in more dark ocean water, which absorbs more heat, and leads to more sea ice loss). Also, the absorption of increased carbon dioxide by the oceans is leading to increased ocean acidity with adverse effects on marine ecosystems. Engineering a reduction of incoming solar energy could limit the effect of increased greenhouse gas concentrations on temperature but would not help alleviate the ocean acidification problem.

Four mitigation-related topics are assessed in this chapter. First, it presents an overview of greenhouse gas emissions and their climate influence, to provide a context for discussion of mitigation efforts. Second, the chapter provides a survey of activities contributing to U.S. emissions of carbon dioxide and other greenhouse gases. Third, it provides a summary of current government and voluntary efforts to manage these emissions. Finally, there is an assessment of the adequacy of these efforts relative to the magnitude of the climate change threat and a discussion of preparation for potential future action. While the chapter presents a brief overview of mitigation issues, it does not provide a comprehensive discussion of policy options, nor does it attempt to review or analyze the range of technologies available to reduce emissions.

These topics have also been the subject of other assessments, including those by the National Academy of Sciences[1] and the U.S. Department of Energy.[2] Mitigation topics are addressed throughout this report (See Ch. 4: Energy, Key Message 5; Ch. 5: Transportation, Key Message 4; Ch. 7: Forests, Key Message 4; Ch. 9: Human Health, Key Message 5; Ch. 10: Energy, Water, and Land, Key Messages 1, 2, 3; Ch. 13: Land Use and Land Cover Change, Key Messages 2, 4; Ch. 15: Biogeochemical Cycles, Key Message 3; Ch. 26: Decision Support, Key Messages 1, 2, 3; Appendix 3: Climate Science, Supplementary Message 5; Appendix 4: FAQs N, S, X, Y, Z;).

Emissions, Concentrations, and Climate Forcing

Setting mitigation objectives requires knowledge of the Earth system processes that determine the relationship among emissions, atmospheric concentrations and, ultimately, climate. Human-caused climate change results mainly from the increasing atmospheric concentrations of greenhouse gases.[3] These gases cause radiative "forcing" – an imbalance of heat trapped by the atmosphere compared to an equilibrium state. Atmospheric concentrations of greenhouse gases are the result of the history of emissions and of processes that remove them from the atmosphere; for example, by "sinks" like growing forests.[4] The fraction of emissions that remains in the atmosphere, which is different for each greenhouse gas, also varies over time as a result of Earth system processes.

The impact of greenhouse gases depends partly on how long each one persists in the atmosphere.[5] Reactive gases like methane and nitrous oxide are destroyed chemically in the atmosphere, so the relationships between emissions and atmospheric concentrations are determined by the rate of those reactions. The term "lifetime" is often used to describe the speed with which a given gas is removed from the atmosphere. Methane has a relatively short lifetime (largely removed within a decade or so, depending on conditions), so reductions in emissions can lead to a fairly rapid decrease in concentrations as the gas is oxidized in the atmosphere.[6] Nitrous oxide has a much longer lifetime, taking more than 100 years to be substantially removed.[7] Other gases in this category include industrial gases, like those used as solvents and in air conditioning, some of which persist in the atmosphere for hundreds or thousands of years.

Carbon dioxide (CO_2) does not react chemically with other gases in the atmosphere, so it does not, strictly speaking, have a "lifetime."[8] Instead, the relationship between emissions and concentrations from year to year is determined by patterns of release (for example, through burning of fossil fuels) and uptake (for example, by vegetation and by the ocean).[9] Once CO_2 is emitted from any source, a portion of it is removed from the atmosphere over time by plant growth and absorption by the oceans, after which it continues to circulate in the land-atmosphere-ocean system until it is finally converted into stable forms in soils, deep ocean sediments, or other geological repositories (Figure 27.1).

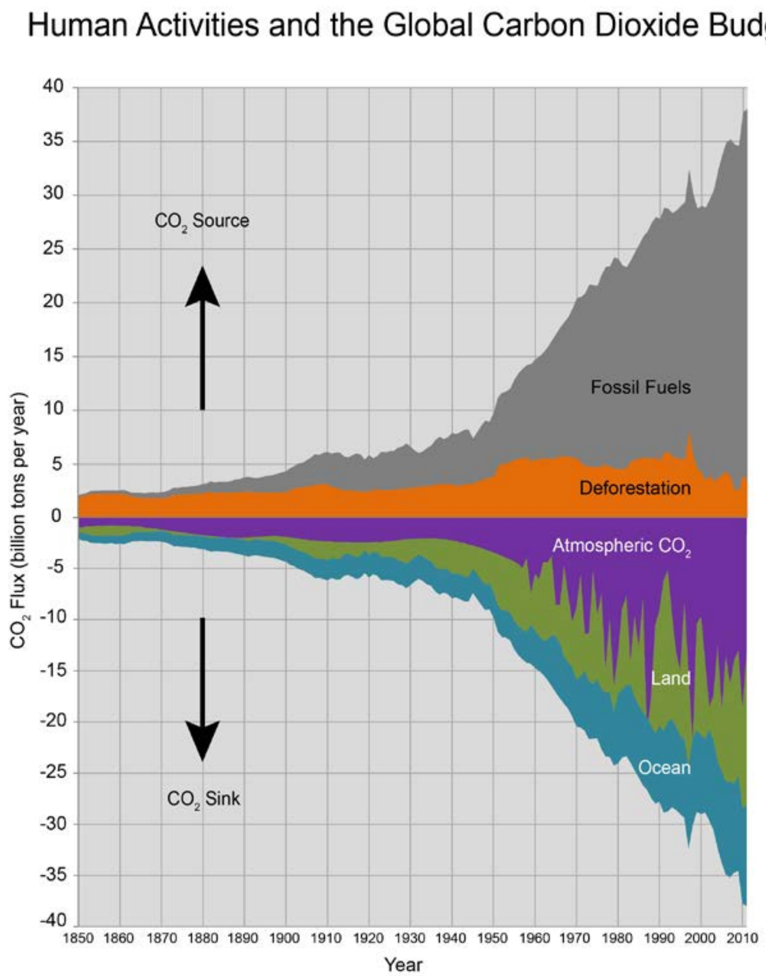

Figure 27.1: Human Activities and the Global Carbon Dioxide Budget

Caption: Figure shows human-induced changes in the global carbon dioxide budget roughly since the beginning of the Industrial Revolution. Emissions from fossil fuel burning are the dominant cause of the steep rise shown here from 1850 to 2012. (Global Carbon Project 2010, 2012).[10]

Of the carbon dioxide emitted from human activities in a year, about half is removed from the atmosphere by natural processes within a century, but around 20% continues to circulate and to affect atmospheric concentrations for thousands of years.[11] Stabilizing or reducing atmospheric carbon dioxide concentrations, therefore, requires very deep reductions in future emissions to compensate for past emissions that are still circulating in the Earth system. Avoiding future emissions, or capturing and storing them in stable geological storage, would prevent carbon dioxide from entering the atmosphere, and would have very long-lasting effects on atmospheric concentrations.

In addition to greenhouse gases, there can be climate effects from fine particles in the atmosphere. An example is black carbon (soot), which is released from coal burning, diesel engines, cooking fires, wood stoves, wildfires, and other combustion sources. These particles have a warming influence, especially when they absorb solar energy low in the atmosphere.[12] Other particles, such as those formed from sulfur dioxide released during coal burning, have a cooling effect by reflecting some of the sun's energy back to space, or by increasing the brightness of clouds (See: Ch. 2: Our Changing Climate, Appendix 3: Climate Science, and Appendix 4: FAQs).

The effect of each gas is related to both how long it lasts in the atmosphere (the longer it lasts, the greater its influence) and its potency in trapping heat. The warming influence of different gases can be compared using "global warming potentials" (GWP), which combine these two effects, usually added up over a 100-year time period. Global warming potentials are referenced to carbon dioxide – which is defined as having a GWP of 1.0 – and the combined effect of multiple gases is denoted in carbon dioxide equivalents, or CO_2-e.

The relationship between emissions and concentrations can be modeled using Earth System Models.[4] Such models apply our understanding of biogeochemical processes that remove greenhouse gas from the atmosphere to predict their future concentrations. These models show that stabilizing CO_2 *emissions* would not stabilize its atmospheric concentrations but instead result in a concentration that would increase at a relatively steady rate. Stabilizing atmospheric *concentrations* of CO_2 would require reducing emissions far below present-day levels. Concentration and emissions scenarios, such as the recently developed Representative Concentration Pathways (RCPs) and scenarios developed earlier by the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Emissions Scenarios (SRES), are used in Earth System Models to study potential future climates. The RCPs span a range of atmospheric targets for use by climate modelers,[13,14] as have the SRES cases. These global analyses form a framework within which the climate contribution of U.S. mitigation efforts can be assessed. In this report, special attention is given to the SRES A2 scenario (similar to RCP 8.5), which assumes continued increases in emissions, and the SRES B1 scenario (close to RCP 4.5), which assumes a substantial reduction of emissions (Ch. 2: Our Changing Climate, Appendix 5: Scenarios and Models).

Box: Geoengineering

Geoengineering has been proposed as a third option for addressing climate change in addition to, or alongside, mitigation and adaptation. Geoengineering refers to intentional modifications of the Earth system as a means to address climate change. Three types of activities have been proposed: 1) carbon dioxide removal (CDR), which boosts CO_2 removal from the atmosphere by various means, such as fertilizing ocean processes and promoting land use practices that help take up carbon, 2) solar radiation management (SRM), which reflects a small percentage of sunlight back into space to offset warming from greenhouse gases,[15] and 3) direct capture and storage of CO_2 from the atmosphere.[16]

Current research suggests that SRM or CDR could diminish the impacts of climate change. However, once undertaken, sudden cessation of SRM would exacerbate the climate effects on human populations and ecosystems, and some CDR might interfere with oceanic and terrestrial ecosystem processes.[17] SRM undertaken by itself would not slow increases in atmospheric CO_2 concentrations, and would therefore also fail to address ocean acidification. Furthermore, existing international institutions are not adequate to manage such global interventions. The risks associated with such purposeful perturbations to the Earth system are thus poorly understood, suggesting the need for caution and comprehensive research, including consideration of the implicit moral hazards.[18]

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U.S. Emissions and Land-Use Change

Industrial, Commercial, and Household Emissions

U.S. greenhouse gas emissions, not accounting for uptake by land use and agriculture (see Figure 27.3), rose to as high as 7,260 million tons CO_2-e in 2007, and then fell by about 8% by 2011. Several factors contributed to the decline, but most significant were the reduction in energy use in response to the 2008-2010 recession and the displacement of coal in electric generation by lower priced natural gas.[19]

Carbon dioxide made up 84% of U.S. greenhouse gas emissions in 2011. Forty-one percent of these emissions were attributable to liquid fuels (petroleum), followed closely by solid fuels (principally coal in electric generation), and to a lesser extent by natural gas.[19] The two dominant production sectors responsible for these emissions are electric power generation (coal and gas) and transportation (petroleum). Flaring and cement manufacture together account for less than 1% of the total. If emissions from electric generation are allocated to their various end-uses, transportation is the largest CO_2 source, contributing a bit over one-third of the total, followed by industry at slightly over a quarter, and residential use and the commercial sector at around one-fifth each.

A useful picture of historical patterns of carbon dioxide emissions can be constructed by decomposing the cumulative change in emissions from a base year into the contributions of five driving forces: 1) decline in the CO_2 content of energy use, as with a shift from coal to natural gas in electric generation, 2) reduction in energy intensity (the energy needed to produce each unit of GDP) which results from substitution responses to energy prices, changes in the composition of the capital stock, and both autonomous and price-induced technological change, 3) changes in the structure of the economy, such as a decline in energy intensive industries and an increase in services that use less energy, 4) growth in per capita gross domestic product (GDP), and 5) rising population.

Over the period 1963-2008, annual U.S. carbon dioxide emissions slightly more than doubled, because growth in emissions potential attributable to increases in population and GDP per person outweighed reductions contributed by lowered energy and carbon intensity and changes in economic structure (Figure 27.2). Each series in the figure illustrates the quantity of cumulative emissions since 1963 that would have been generated by the effect of the associated driver. By 2008, fossil fuel burning had increased CO_2 emissions by 2.7 billion tons over 1963 levels. However, by itself the observed decline in energy would have reduced emissions by 1.8 billion tons, while the observed increase in per capita GDP would have increased emissions by more than 5 billion tons.

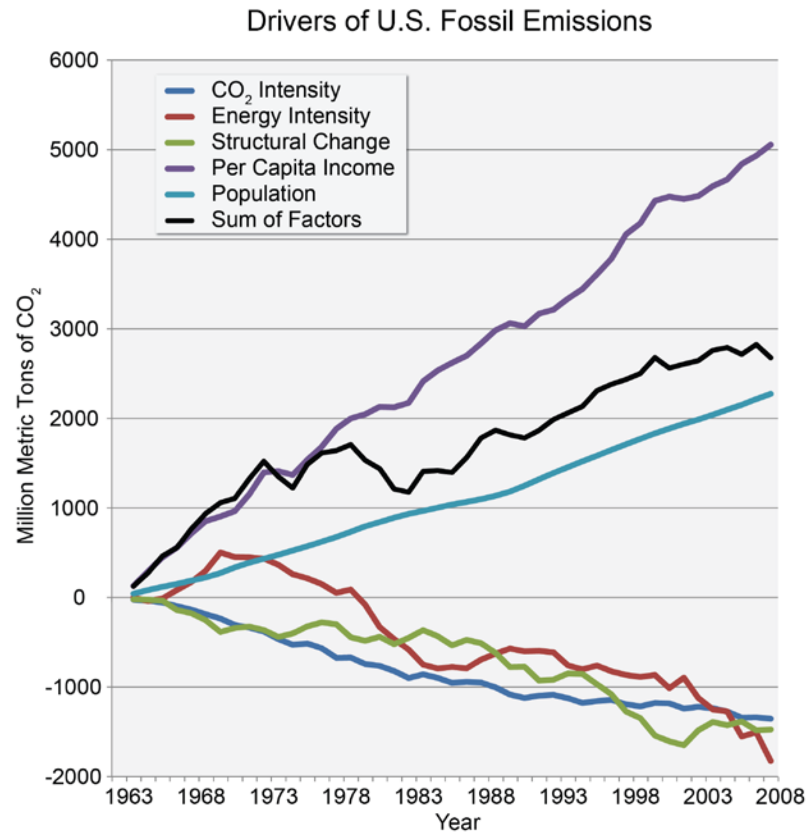

Figure 27.2. Drivers of U.S. Fossil Emissions

Caption: This graph depicts the changes in carbon dioxide (CO_2) emissions over time as a function of five driving forces: 1) the amount of CO_2 produced per unit of energy (CO_2 intensity); 2) the amount of energy used per unit of gross domestic product (energy intensity); 3) structural changes in the economy; 4) per capita income; and 5) population. Although CO_2 intensity, and especially energy intensity, have decreased significantly and the structure of the U.S. economy has changed, total CO_2 emissions have continued to rise as a result of the growth in both population and per capita income. (Baldwin and Sue Wing, 2013).[20]

These trends in driving forces are expected to continue in the future, though their relative contributions are subject to significant uncertainty. For example, a projection by the U.S. Energy Information Administration (EIA) shows their net effect being a slower rate of CO_2 emissions growth than in the past, and perhaps even a gradual decline, with total CO_2 emissions from energy use (97% of the total) remaining roughly constant to 2040.[21]

The primary non-CO_2 gas emissions in 2011 were methane (9% of total CO_2-e emissions), nitrous oxide (5%), and a set of industrial gases (2%). U.S. emissions of each of these gases have been roughly constant over the past half-dozen years.[21] Emissions of methane and nitrous oxide have been roughly constant over the past couple of decades, but there has been an increase in the industrial gases as some are substituted for ozone-destroying substances controlled by the Montreal Protocol.[22]

Yet another warming influence on the climate system is black carbon (soot), which consists of fine particles that result mainly from incomplete combustion of fossil fuels and biomass. Long a public health concern, black carbon particles absorb solar radiation during their short life in the atmosphere (days to weeks). When deposited on snow and ice, these particles darken the surface and reduce the reflection of incoming solar radiation back to space. These particles also influence cloud formation in ways yet poorly quantified.[23]

Land Use, Forestry, and Agriculture

The main stocks of carbon in its various biological forms (plants and trees, dead wood, litter, soil, and harvested products) are estimated periodically and their rate of change, or flux, calculated as the average annual difference between two time periods. Estimates of carbon stocks and fluxes for U.S. lands are based on land inventories augmented with data from ecosystem studies and production reports.[24,25]

U.S. lands were estimated to be a net sink of between approximately 640 and 1,074 million tons CO_2-e in the late 2000s.[25,26] Estimates vary depending on choice of datasets, models, and methodologies (See Ch. 15: Biogeochemical Cycles, Carbon Sink box, for more discussion). This net land sink effect is the result of sources (from crop production, livestock production, and grasslands) and sinks (in forests, urban trees, and wetlands). Sources of carbon have been relatively stable over the last two decades, but sinks have been more variable. Long-term trends suggest significant emissions from forest clearing in the early 1900s followed by a sustained period of net uptake from forest regrowth over the last 70 years.[27] The amount of carbon taken up by U.S. land sinks is dominated by forests, which have annually absorbed 7% to 24% (with a best estimate of about 16%) of fossil fuel CO_2 emissions in the U.S. over the past two decades.[19]

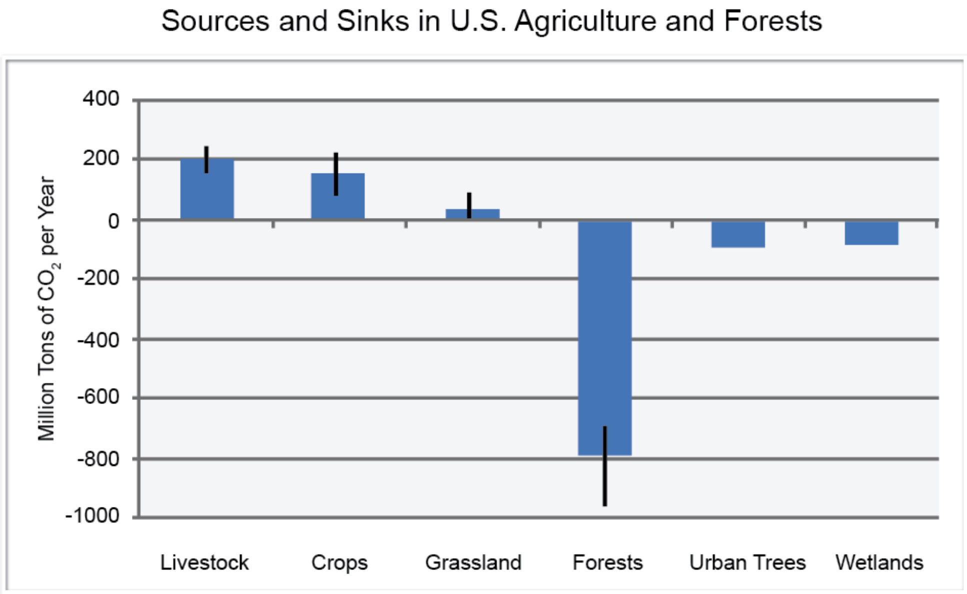

Figure 27.3: Sources and Sinks in U.S. Agriculture and Forests

Caption: Chart shows annual average greenhouse gas emissions from land use including livestock and crop production, but does not include fossil fuels used in agricultural production. Forests are a significant "sink" that absorbs carbon dioxide from the atmosphere. All values shown are for 2008, except wetlands, which are shown for 2003. (Pacala et al. 2007; USDA 2011).[25,26]

The persistence of the land sink depends on the relative effects of several interacting factors: recovery from historical land-use change, atmospheric CO_2 and nitrogen deposition, natural disturbances, and the effects of climate variability and change – particularly drought, wildfires, and changes in the length of the growing season. Deforestation continues to cause an annual loss of 877,000 acres (137,000 square miles) of forested land, offset by a larger area gain of new forest of about 1.71 million acres (268,000 square miles) annually.[28] Since most of the new forest is on relatively low productivity lands of the Intermountain West, and much of the deforestation occurs on high productivity lands in the East, recent land-use changes have decreased the potential for future carbon storage.[29] The positive effects of increasing carbon dioxide concentration and nitrogen deposition on carbon storage are not likely to be as large as the negative effects of land use change and disturbances.[30] In some regions, longer growing seasons associated with climate change may increase annual productivity.[31] Droughts and other disturbances, such as fire and insect infestations, have already turned some U.S. land regions from carbon sinks into carbon sources (see Ch. 13: Land Use and Land Cover Change and Ch. 15: Biogeochemical Cycles).[30] The land sink may not be sustainable for more than a few more decades,[32] though there is a lack of consistency in published results about the relative effects of disturbance and other factors on net land use emissions.[30,33]

Activities Affecting Emissions

Early and large reductions in global emissions would be necessary to achieve the lower emissions scenarios (such as the B1 scenario; see Ch. 2: Our Changing Climate) analyzed in this assessment. The principal types of national actions that could effect such changes include putting a price on emissions, setting regulations and standards for activities that cause emissions, changing subsidy programs, and direct federal expenditures. Market based approaches include cap-and-trade programs that establish markets for trading emissions permits, analogous to the Clean Air Act provisions for sulfur dioxide reductions. None of these price-based measures has been implemented at the national level in the U.S., though cap-and-trade systems are in place in California and in the Northeast's Regional Greenhouse Gas Initiative. Moreover, a wide range of governmental actions are underway at federal, state, regional, and city levels using other measures, and voluntary efforts, that have the effect of reducing the U.S. contribution to total global emissions. Many, if not most of these programs are motivated by other policy issues – energy, transportation, and air pollution – but some are directed specifically at greenhouse gas emissions, including:

- Reduction in CO_2 emissions from energy end-use and infrastructure through the adoption of energy-efficient components and systems – including buildings, vehicles, manufacturing processes, and electric grid systems;
- Reduction of CO_2 emissions from energy supply through the promotion of renewables (such as wind, solar, and bioenergy), nuclear energy, and coal and natural gas electric generation with carbon capture and storage; and
- Reduction of emissions of non-CO_2 greenhouse gases and black carbon; for example, by lowering methane emissions from energy and waste, transitioning to climate-friendly alternatives to HFCs, cutting methane and nitrous oxide emissions from agriculture, and improving combustion efficiency and means of particulate capture.

Federal Actions

The Federal Government has implemented a number of measures that promote energy efficiency, clean technologies, and alternative fuels.[34] Sample federal mitigation measures are provided in Table 27.1. These actions fall into two general categories: 1) research and development, to accelerate the development of innovative equipment and systems; and 2) commercialization and deployment, including information dissemination, voluntary standards-setting, tax and other financial incentives, and rules and regulations.

At the national level, the Environmental Protection Agency has authority to regulate greenhouse gas emissions under the Clean Air Act. The Act has been in effect for 40 years, and it has resulted in reductions in the concentration and deposition of criteria pollutants. It provides a framework for several of the actions identified in the current Administration's Climate Action Plan.[35] The Department of Energy provides most of the funding for energy research, development, and demonstration activities and has the authority to regulate the efficiency of appliances and building codes for manufactured housing. In addition, most of the other federal agencies – including the Departments of Defense, Housing and Urban Development, Transportation, and Agriculture – have programs related to greenhouse gas mitigation.

City, State, and Regional Actions

Jurisdiction for greenhouse gases and energy policies is shared between the federal government and the states.[1] For example, states regulate the distribution of electricity and natural gas to consumers, while the Federal Energy Regulatory Commission regulates wholesale sales and transportation of natural gas and electricity. In addition, many states have adopted climate initiatives as well as energy policies that reduce greenhouse gas emissions. For a survey of many of these state activities, see Table 27.2. Many cities are taking similar actions.

The most ambitious state activity is California's Global Warming Solutions Act (AB 32), which sets a state goal to reduce its greenhouse gas emissions to 1990 levels by 2020. The state program will cap emissions and use a market-based system of trading in emissions credits (cap-and-trade), as well as a number of regulatory actions. The most well-known, multi-state effort has been the Regional Greenhouse Gas Initiative (RGGI), formed by ten northeastern and Mid-Atlantic states (though New Jersey exited in 2011). RGGI is a cap-and-trade system applied to the power sector with revenue from allowance auctions directed to investments in efficiency and renewable energy.

Voluntary Actions

Corporations, individuals, and non-profit organizations have initiated a host of voluntary actions. The following examples give the flavor of the range of efforts:

- The Carbon Disclosure Project has the largest global collection of self-reported climate change and water-use information. The system enables companies to measure, disclose, manage, and share climate change and water-use information. Some 650 U.S. signatories include banks, pension funds, asset managers, insurance companies, and foundations.
- Many local governments are undertaking initiatives to reduce greenhouse gas emissions within and outside of their organizational boundaries.[36] For example, over 1,055 municipalities from all 50 states have signed the U.S. Mayors Climate Protection Agreement,[37] and many of these communities are actively implementing strategies to reduce their greenhouse gas footprint.
- Under the American College and University Presidents' Climate Commitment (ACUPCC), 677 institutions have pledged to develop plans to achieve net-neutral climate emissions through a combination of on-campus changes and purchases of emissions reductions elsewhere.
- Voluntary compliance with efficiency standards developed by industry and professional associations, such as the building codes of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), is widespread.
- Federal voluntary programs include Energy STAR, a labeling program that identifies energy efficient products for use in residential homes and commercial buildings and plants, and programs and partnerships devoted to reducing methane emissions from fossil fuel production and landfill sources and high GWP emissions from industrial activities and agricultural conservation programs.

The national cost of achieving U.S. emissions reductions over time depends on the level of reduction sought and the particular measures employed. Studies of price-based policies, such as a cap-and-trade system, indicate that a 50% reduction in emissions by 2050 could be achieved at a cost of a year or two of projected growth in gross domestic product over the period (for example,[38]). However, because of differences in analysis method, and in assumptions about economic growth and technology change, cost projections vary considerably even for a policy applying price penalties.[39] Comparisons of emissions reduction by prices versus regulations show that a regulatory approach can cost substantially more than a price-based policy.[40]

Box: Co-Benefits for Air Pollution and Human Health

Actions to reduce greenhouse gas emissions can yield co-benefits for objectives apart from climate change, such as energy security, health, ecosystem services, and biodiversity.[41,42] The co-benefits for reductions in air pollution have received particular attention. Because air pollutants and greenhouse gases share common sources, particularly from fossil fuel combustion, actions to reduce greenhouse gas emissions also reduce air pollutants. While some greenhouse gas reduction measures might increase other emissions, broad programs to reduce greenhouse gases across an economy or a sector can reduce air pollutants markedly.[14,43] (Unfortunately for climate mitigation, cutting sulfur dioxide pollution from coal burning also reduces the cooling influence of reflective particles formed from these emissions in the atmosphere.[44])

There is significant interest in quantifying the air pollution and human health co-benefits of greenhouse gas mitigation, particularly from the public health community,[42,45] as the human health benefits can be immediate and local, in contrast to the long-term and widespread effects of climate change.[46] Many studies have found that monetized health and pollution control benefits can be of similar magnitude to abatement costs (for example,[46,47]). Methane reductions have also been shown to generate health benefits from reduced ozone.[48] Similarly, in developing nations, reducing black carbon from household cook stoves substantially reduces air pollution-related illness and death.[49] Ancillary health benefits in developing countries typically exceed those in developed countries for a variety of reasons.[46] But only in very few cases are these ancillary benefits considered in analyses of climate mitigation policies.

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Preparation for Potential Future Mitigation Action

Current voluntary and governmental efforts have lowered U.S. greenhouse gas emissions, but are not close to sufficient to yield a U.S contribution to the reductions needed to meet the lower emissions scenario (B1) used in this assessment (Ch. 2: Our Changing Climate). The Annual Energy Outlook prepared by the Department of Energy's Energy Information Administration attempts to take account of these activities, yet it projects continued growth in energy-related CO_2 emissions in the U.S. through 2035.[50] To meet the emissions reduction in the (B1) scenario under reasonable assumptions about managing costs, annual global CO_2 emissions would need to peak at around 44 billion tons within the next 25 years or so and decline steadily for the rest of the century. The U.S. share of global CO_2 emissions in recent years has been about 16%. At the current rate of emissions growth, the world is on a track to exceed the 44 billion ton level within a decade (see Emissions Scenarios and RCPs box). More aggressive greenhouse concentration targets, such as those associated with a frequently-discussed limit of a 3.6ºF (2ºC) temperature increase above pre-industrial levels[51] would require an even more dramatic reduction in global emissions.[52]

Box: Emissions Scenarios and RCPs

The Representative Concentration Pathways (RCPs) specify alternative limits to human influence on the Earth's energy balance, stated in watts per square meter (W/m^2) of the Earth's surface.[13,53] The A2 emissions scenario implies atmospheric concentrations with radiative forcing slightly lower than the highest RCP, which is 8.5 W/m^2. The lower limits, at 6.0, 4.5 and 2.6 W/m^2, imply ever-greater mitigation efforts. The B1 scenario (rapid emissions reduction) is close to the 4.5 W/m^2 RCP[54] and to a similar case (Level 2) analyzed in a previous federal study.[55] Those assessments find that, to limit the economic costs, annual global CO_2 emissions from fossil fuels and industrial sources like cement manufacture, need to peak by 2035 to 2040 at around 44 billion tons of CO_2, and decline thereafter. The scale of the task can be seen in the fact that these global emissions were already at 34 billion tons CO_2 in 2011, and over the previous decade they rose at around 0.92 billion tons of CO_2 per year (Global Carbon Project 2010, 2012). The lowest RCP would require an even more rapid turnaround and negative net emissions – that is, removing more CO_2 from the air than is emitted globally – in this century.[53]

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Achieving the B1 emissions path would require substantial decarbonization of the global economy by the end of this century, implying a fundamental transformation of the global energy system. Details of the energy mix along the way differ among analyses, but the implied involvement by the U.S. can be seen in studies carried out under the U.S. Climate Change Science Program[55] and the Energy Modeling Forum.[56,57] In these studies, direct burning of coal without carbon capture is essentially excluded from the power system, and the same holds for natural gas toward the end of the century – to be replaced by some combination of coal or gas with carbon capture and storage, nuclear generation, and renewables. Biofuels and electricity are projected to substitute for oil in the transport sector. A substantial component of the task is accomplished with demand reduction, through efficiency improvement, conservation, and shifting to an economy less dependent on energy services.

The challenge is great enough even starting today, but delay by any of the major emitters makes meeting any such target even more difficult and may rule out some of the more ambitious goals.[55,56] A study of the climate change threat and potential responses by the U.S. National Academies therefore concludes that there is "an urgent need for U.S. action to reduce greenhouse emissions."[58] The National Research Council (NRC) goes on to suggest alternative national-level strategies that might be followed, including an economy-wide system of prices on greenhouse gas emissions and a portfolio of possible regulatory measures and subsidies. Deciding these matters will be a continuing task, and U.S. Administrations and Congress face a long series of choices about whether to take additional mitigation actions, and how best to do it. Two supporting activities will help guide this process: opening future technological options and development of ever-more-useful assessments of the cost effectiveness and benefits of policy choices.

Many technologies are potentially available to accomplish emissions reduction. They include ways to increase the efficiency of fossil energy use and facilitate a shift to low-carbon energy sources; sources of improvement in the cost and performance of renewables (for example, wind, solar, and bioenergy) and nuclear energy; ways to reduce the cost of carbon capture and storage; means to expand terrestrial sinks through management of forests and soils and increased agricultural productivity;[2] and phasing down HFCs. In addition to the research and development carried out by private sector firms with their own funds, the federal government traditionally supports major programs to advance these technologies. This support is accomplished in part by credits and deductions in the tax code, and in part by federal expenditure. For example, the 2012 federal budget devoted approximately $6 billion to clean energy technologies.[59] Success in these ventures, lowering the cost of greenhouse gas reduction, can make a crucial contribution to future policy choices.[1]

Because they are in various stages of market maturity, the costs and effectiveness of many of these technologies remain uncertain: continuing study of their performance is important to understanding their role in future mitigation decisions.[60] In addition, evaluation of broad policies and particular mitigation measures requires frameworks that combine information from a range of disciplines. Study of mitigation in the near future can be done with energy-economic models that do not assume large changes in the mix of technologies or changes in the structure of the economy. Analysis over the time spans relevant to stabilization of greenhouse gas concentrations, however, requires Integrated Assessment Models, which consider all emissions drivers and policy measures that affect them, and that take account of how they are related to the larger economy and features of the climate system.[55,56,61] This type of analysis is also useful for exploring the relations between mitigation and measures to adapt to a changing climate.

Box: Interactions Between Adaptation and Mitigation

There are various ways in which mitigation efforts and adaptation measures are interdependent (See Ch. 28: Adaptation). For example, the use of plant material as a substitute for petroleum-based transportation fuels or directly as a substitute for burning coal or gas for electricity generation has received substantial attention.[50] But land used for mitigation purposes is potentially not available for food production, even as the global demand for agricultural products continues to rise.[62] Conversely, land required for adaptation strategies, like setting aside wildlife corridors or expanding the extent of conservation areas, is potentially not available for mitigation involving the use of plant material, or active management practices to enhance carbon storage in vegetation or soils. These possible interactions are poorly understood but potentially important, especially as climate change itself affects vegetation and ecosystem productivity and carbon storage. Increasing agricultural productivity to adapt to climate change can also serve to mitigate climate change.

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Continued development of these analytical capabilities can help support decisions about national mitigation and the U.S. position in international negotiations. In addition, as shown above, mitigation is being undertaken by individuals and firms as well as by city, state, and regional governments. The capacity for mitigation from individual and household behavioral changes, such as increasing energy end-use efficiency with available technology, is known to be large.[63] Although there is capacity, there is not always broad acceptance of those behavioral changes, nor is there sufficient understanding of how to design programs to encourage such changes.[64] Behavioral and institutional research on how such choices are made and the results evaluated, would be extremely beneficial. For many of these efforts, understanding of cost and effectiveness is limited, as is understanding of aspects of public support and institutional performance; so additional support for studies of these activities is needed to ensure that resources are efficiently employed.

Research Needs

- Engineering and scientific research is needed on the development of cost-effective energy use technologies (devices, systems, and control strategies) and energy supply technologies that produce little or no CO_2 or other greenhouse gases.
- Better understanding of the relationship between emissions and atmospheric greenhouse gas concentrations is needed to more accurately predict how the atmosphere and climate system will respond to mitigation measures.
- The processes controlling the land sink of carbon in the U.S. require additional research, including better monitoring and analysis of economic decision-making about the fate of land and how it is managed, as well as the inherent ecological processes and how they respond to the climate system.
- Uncertainties in model-based projections of greenhouse gas emissions and of the effectiveness and costs of policy measures need to be better quantified. Exploration is needed of the effects of different model structures, assumptions about model parameter values, and uncertainties in input data.
- Social and behavioral science research is needed to inform the design of mitigation measures for maximum participation and to prepare a consistent framework for assessing cost effectiveness and benefits of both voluntary mitigation efforts and regulatory and subsidy programs.

Table 27.1. Sample Federal Mitigation Measures

Caption: A number of existing federal laws and regulations target ways to reduce future climate change by decreasing greenhouse gas emissions emitted by human activities.

Greenhouse Gas Regulations
Emissions Standards for Vehicles and Engines -- For light-duty vehicles, rules establishing standards for 2012-2016 model years and 2017-2025 model years. -- For heavy- and medium-duty trucks, a rule establishing standards for 2014-2018 model years.
Carbon Pollution Standard for New Power Plants -- A proposed rule setting limits on CO_2 emissions from future power plants.
Stationary Source Permitting -- A rule setting greenhouse gas emissions thresholds to define when permits under the New Source Review Prevention of Significant Deterioration and Title V Operating Permit programs are required for new and modified industrial facilities.
Greenhouse Gas Reporting Program -- A program requiring annual reporting of greenhouse gas data from large emission sources and suppliers of products that emit greenhouse gases when released or combusted.
Other Rules and Regulations with Climate Co-benefits
Oil and Natural Gas Air Pollution Standards -- A rule revising New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants for certain components of the oil and natural gas industry.
Mobile Source Control Programs -- Particle control regulations affecting mobile sources (especially diesel engines) that reduce black carbon by controlling direct particle emissions. -- The requirement to blend increasing volumes of renewable fuels.
National Forest Planning -- Identification and evaluation of information relevant to a baseline assessment of carbon stocks. -- Reporting of net carbon stock changes on forestland.

Standards and Subsidies
Appliance and Building Efficiency Standards -- Energy efficiency standards and test procedures for residential, commercial, industrial, lighting, and plumbing products. -- Model residential and commercial building energy codes, and technical assistance to state and local governments, and non-governmental organizations.
Financial Incentives for Efficiency and Alternative Fuels and Technology -- Weatherization assistance for low-income households, tax incentives for commercial and residential buildings and efficiency appliances, and support for state and local efficiency programs. -- Tax credits for biodiesel and advanced biofuel production, alternative fuel infrastructure, and purchase of electric vehicles -- Loan guarantees for innovative energy or advanced technology vehicle production and manufacturing; investment and production tax credits for renewable energy.
Funding of Research, Development, Demonstration, and Deployment
-- Programs on clean fuels, energy end-use and infrastructure, CO_2 capture and storage, and agricultural practices.
Federal Agency Practices and Procurement
-- Executive orders and federal statutes requiring federal agencies to reduce building energy and resource consumption intensity and to procure alternative fuel vehicles. -- Agency-initiated programs in most departments oriented to lowering energy use and greenhouse gas emissions.

Table 27.2. State Climate and Energy Initiatives

STATE CLIMATE AND ENERGY INITIATIVES

Most states and native communities have implemented programs to reduce greenhouse gases or adopt increased energy efficiency goals. Examples of greenhouse gas policies include:

◙ Greenhouse Gas Reporting and Registries
  http://www.c2es.org/us-states-regions/policy-maps/ghg-reporting[65]

◙ Greenhouse Gas Emissions Targets
  http://www.c2es.org/us-states-regions/policy-maps/emissions-targets[66]

◙ CO_2 Controls on Electric Powerplants
  http://www.edf.org/sites/default/files/state-ghg-standards-03132012.pdf[67]

◙ Low-Carbon Fuel Standards
  http://www.c2es.org/us-states-regions/policy-maps/low-carbon-fuel-standard[68]

◙ Climate Action Plans
  http://www.c2es.org/us-states-regions/policy-maps/action-plan[69]

◙ Cap-and-Trade Programs
  http://arb.ca.gov/cc/capandtrade/capandtrade.htm[70]

◙ Regional Agreements
  http://www.c2es.org/us-states-regions/regional-climate-initiatives#WCI[71]

◙ Tribal Communities
  http://www.epa.gov/statelocalclimate/tribal[72]

Also, states have taken a number of energy measures, motivated in part by greenhouse gas concerns. For example:

◙ Renewable Portfolio Standards
  http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf[73]

◙ Energy Efficiency Resource Standards
  http://www.dsireusa.org/documents/summarymaps/EERS_map.pdf[74]

◙ Property Tax Incentives for Renewables
  http://www.dsireusa.org/documents/summarymaps/[75]

1 # Traceable Accounts

2 ## Chapter 27: Mitigation

3 **Key Message Process:** Evaluation of literature by Coordinating Lead Authors

Key message #1/5	**Carbon dioxide is removed from the atmosphere by natural processes at a rate that is roughly half of the current rate of emissions from human activities. Therefore, mitigation efforts that only stabilize global emissions will not reduce atmospheric concentrations of carbon dioxide, but will only limit their rate of increase. The same is true for other long-lived greenhouse gases.**
Description of evidence base	The message is a restatement of conclusions derived from the peer-reviewed literature over nearly the past 20 years (see Section I of chapter). Publications have documented the long lifetime of CO_2 in the atmosphere, resulting in long time lags between action and reduction,[9,11,76] and Earth System Models have shown that stabilizing emissions won't immediately stabilize atmospheric concentrations, which will continue to increase.[4]
New information and remaining uncertainties	There are several important uncertainties in the current carbon cycle, especially the overall size, location, and dynamics of the land-use sink[9,11] and technological development and performance. Simulating future atmospheric concentrations of greenhouse gases requires both assumptions about economic activity, stringency of any greenhouse gas emissions control, and availability of technologies, as well as a number of assumptions about how the changing climate system affects both natural and anthropogenic sources.
Assessment of confidence based on evidence	**Very High**. Observations of changes in the concentrations of greenhouse gases are consistent with our understanding of the broad relationships between emissions and concentrations.

4

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

5

Chapter 27: Mitigation

Key Message Process: Please see KM #1 for description of process.

Key message #2/5	**To meet the lower emissions scenario (B1) used in this assessment, global mitigation actions would need to limit global carbon dioxide emissions to a peak of around 44 billion tons per year within the next 25 years and decline thereafter. In 2011, global emissions were around 34 billion tons, and have been rising by about 0.9 billion tons per year for the past decade. The world is therefore on track to exceed this level within a decade..**
Description of evidence base	A large number of emissions scenarios have been modeled, with a number of publications showing what would be required to limit CO_2[13,54,55,77] to any predetermined limit. At current concentrations and rate of rise, the emissions of CO_2 would need to peak around 44 billion tons within the next 25 years in order to stabilize concentrations as in the B1 scenario. Given the rate of increase in recent years,[10] this limit is expected to be surpassed.[78]
New information and remaining uncertainties	Uncertainties about the carbon cycle could affect these calculations, but the largest uncertainties are the assumptions made about the strength and cost of greenhouse gas emissions policies.
Assessment of confidence based on evidence	The confidence in the conclusion is **high**. This is a contingent conclusion, though – we do not have high confidence that the current emission rate will be sustained. However, we do have high confidence that if we do choose to limit concentrations as in the B1 scenario, emissions will need to peak soon and then decline.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: Please see KM #1 for description of process.

Key message #3/5	**Over recent decades, the U.S. economy has emitted a declining amount of carbon dioxide per dollar of gross domestic product for many reasons, but to date U.S. population and economic growth have outweighed these trends. In the absence of additional public policies, greenhouse gas emissions are expected to remain roughly constant.**
Description of evidence base	Trends in greenhouse gas emissions intensity are analyzed and published by governmental reporting agencies.[19,22,25] Published, peer-reviewed literature cited in Section II of the Mitigation Chapter supports the conclusions about why these trends have occurred,[79] and government agency calculations support the statement about how population and economic growth are expected to counterbalance these trends.[50]
New information and remaining uncertainties	Economic and technological forecasts are highly uncertain.
Assessment of confidence based on evidence	**High**. The statement is a summary restatement of published analyses by government agencies and interpretation from the reviewed literature.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: Please see KM #1 for description of process.

Key message #4/5	**Carbon storage in land ecosystems, especially forests, has offset around 17% of U.S. fossil fuel emissions of greenhouse gases over the past several decades, but this carbon "sink" may not be sustainable.**
Description of evidence base	Underlying data come primarily from U.S. Forest Service Forest Inventory and Analysis plots, supplemented by additional ecological data collection efforts. Modeling conclusions come from peer review literature. All references are in Section II of the Mitigation Chapter. Studies have shown that there is a large land-use carbon sink in the United States.[25,26,27] Many publications attribute this sink to forest re-growth, and the sink is projected to decline as a result of forest aging[29,30,32] and factors like drought, fire, and insect infestations[30] reducing the carbon sink of these regions.
New information and remaining uncertainties	FIA plots are measured extremely carefully over long time periods, but do not cover all U.S. forested land. Other U.S. land types must have carbon content estimated from other sources. Modeling relationships between growth and carbon content, and taking CO_2 and climate change into account have large scientific uncertainties associated with them.
Assessment of confidence based on evidence	**High**. Evidence of past trends is based primarily on government data sources, but these also have to be augmented by other data and models in order to incorporate additional land-use types. Projecting future carbon content is consistent with published models, but these have intrinsic uncertainties associated with them.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: Please see KM #1 for description of process.

Key message #5/5	**Both voluntary activities and a variety of policies and measures that lower emissions are currently in place at federal, state, and local levels, even though there is no comprehensive national greenhouse gas policy. While these efforts represent significant steps towards reducing greenhouse gases, and often result in additional co-benefits, they are not close to sufficient to reduce total U.S. emissions to a level consistent with the lower scenario (B1) analyzed in this assessment.**
Description of evidence base	The identification of state, local, regional, federal, and voluntary programs that will have an effect of reducing greenhouse gas emissions is a straightforward accounting of both legislative action and announcements of the implementation of such programs. Some of the programs include the Carbon Disclosure Project (CDP), the American College and University Presidents' Climate Commitment (ACUPCC), U.S. Mayors Climate Protection Agreement,[37] and many other local government initiatives.[36] Several states have also adapted climate policies including California's Global Warming Solutions Act (AB 32) and the Regional Greenhouse Gas Initiative (RGGI). The assertion that they will not lead to a reduction of US CO_2 emissions is supported by calculations from the US Energy Information Administration.
New information and remaining uncertainties	The major uncertainty in the calculation about future emissions levels is whether a comprehensive national policy will be implemented.
Assessment of confidence based on evidence	**Very High**. There is recognition that the implementation of voluntary programs may differ from how they are originally planned, and that institutions can always choose to leave voluntary programs (as is happening with RGGI, noted in the chapter). The statement about the future of U.S. CO_2 emissions cannot be taken as a prediction of what will happen – it is a conditional statement based on an assumption of no comprehensive national legislation or regulation.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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