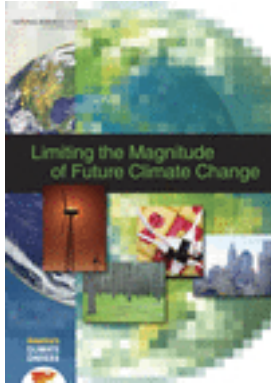


## Free Summary

### Limiting the Magnitude of Climate Change



America's Climate Choices: Panel on Limiting the Magnitude of Future Climate Change

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## Summary

In the legislation calling for an assessment of America's Climate Choices, Congress directed the National Research Council to "investigate and study the serious and sweeping issues relating to global climate change and make recommendations regarding the steps that must be taken and what strategies must be adopted in response to global climate change." As part of the response to this request, the ACC Panel on Limiting the Magnitude of Future Climate Change was charged to "describe, analyze, and assess strategies for reducing the net future human influence on climate, including both technology and policy options, focusing on actions to reduce domestic greenhouse gas (GHG) emissions and other human drivers of climate change, but also considering the international dimensions of climate stabilization." (see Appendix A for full Statement of Task).

Our Panel responded to this charge by evaluating the choices available for the United States to contribute to the global effort of limiting future climate change. More specifically, the panel focused on strategies to reduce concentrations of greenhouse gases (GHGs) in the atmosphere, including strategies that are technically and economically feasible in the near-term, as well as strategies that could potentially play an important role in the longer-term.

Because climate change limiting policy is highly complex and involves a wide array of political and ethical considerations, scientific analysis does not always point to unequivocal answers. We offer specific recommendations in cases where research clearly shows that certain strategies and policy options are particularly effective; but in other cases, we simply discuss the range of possible choices available to decision makers. On the broadest level, we conclude that the United States needs the following:

- *Prompt and sustained strategies to reduce GHG emissions.* There is a need for policy responses to promote the technological and behavioral changes necessary for making substantial near-term GHG emission reductions. There is also a need to aggressively promote research, development, and deployment of new technologies, both to enhance our chances of making the needed emissions reductions, and to reduce the costs of doing so.
- *An inclusive national framework for instituting response strategies and policies.* National policies for limiting climate change are implemented through the actions of private industry, governments at all levels, and millions of households and individuals. The essential role of the federal government is to put in place an overarching, national policy framework designed to ensure that all of these actors are furthering the shared national goal of emissions reductions. In addition, a national policy framework that both generates and is underpinned by international cooperation is crucial if the risks of global climate change are to be substantially curtailed.
- *Adaptable means for managing policy responses.* It is inevitable that policies put in place now will need to be modified in the future as new scientific information emerges, providing new insights and understanding of the climate problem. Even well-conceived policies may experience unanticipated difficulties, while others may yield unexpectedly high levels of success. Moreover, the degree, rate, and direction of technological innovation will alter the array of response options available and the costs of emissions abatement. Quickly and

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nimbly responding to new scientific information, the state of technology, and evidence of policy effectiveness will be essential to successfully managing climate risks over the course of decades.

While recognizing that there is ongoing debate about the goals for international efforts to limit climate change, for this analysis we have focused on a range of global atmospheric GHG concentrations between 450 and 550 ppm CO<sub>2</sub>-equivalent (eq), a range which has been extensively analyzed by the scientific and economic communities and is a focus of international climate policy discussions. In evaluating U.S. climate policy choices, it useful to set goals that are consistent with those in widespread international use, both for policy development and for making quantitative assessments of alternative strategies.

Global temperature and GHG concentration targets are needed to help guide long-term global action. Domestic policy, however, requires goals that are more directly linked to outcomes that can be measured and affected by domestic action. The Panel thus recommends that the U.S. policy goal be stated as a quantitative limit on domestic GHG emissions over a specified time period – in other words, a GHG emissions budget.

The Panel does not attempt to recommend a specific budget number, since there are many political and ethical judgments involved in determining an “appropriate” U.S. share of global emissions. As a basis for developing and assessing domestic strategies, however, the Panel used recent integrated assessment modeling studies<sup>2</sup> to suggest that a reasonable “representative” range for a domestic emissions budget would be 170 to 200 gigatons (Gt) of CO<sub>2</sub>-eq for the period 2012 through 2050. This corresponds roughly to a reduction of emissions from 1990 levels by 80 to 50 percent, respectively. We note that this budget range is based on “global least cost” economic efficiency criteria for allocating global emissions among countries. Using other criteria, different budget numbers could be suggested (for instance, some argue that based on global “fairness” concerns, a more aggressive U.S. emission reduction effort is warranted).

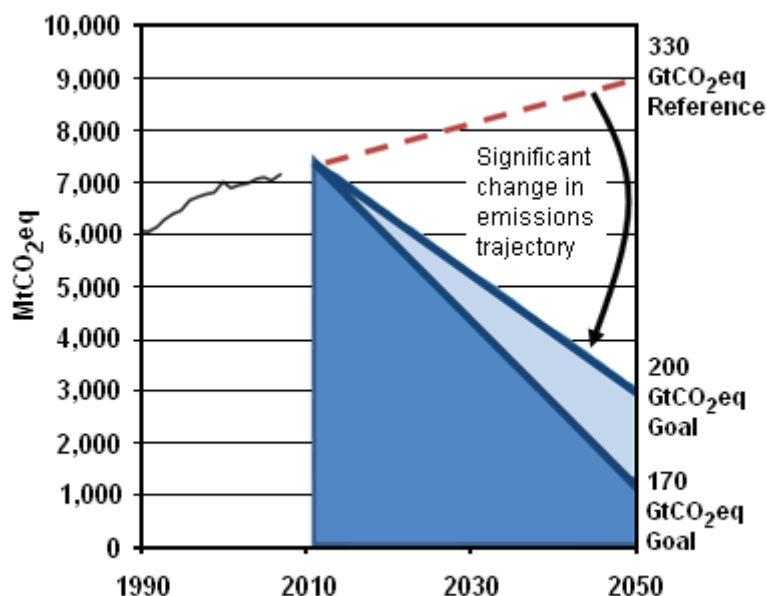
As illustrated in Figure 1, meeting an emissions budget in the range suggested above, especially the more stringent budget of 170 GtCO<sub>2</sub>-eq, will require a major departure from business-as-usual emission trends (in which U.S. emissions have been rising at a rate of ~one percent per year for the past three decades). The main drivers of GHG emissions are population growth and economic activity, coupled with energy use per capita and per unit of economic output (“energy intensity”). Although the energy intensity of the U.S. economy has been improving for the past two decades, total emissions will continue to rise without a significant change from business as usual. Our analyses thus indicate that without prompt action, the current rate of GHG emissions from the energy sector would consume the domestic emissions budget well before 2050<sup>3</sup>.

More than 80% percent of U.S. GHG emissions are in the form of CO<sub>2</sub> from combustion of fossil fuels. As illustrated in Figure 2, there are a range of different opportunities to reduce emissions from the energy system, including: reducing demand for goods and services requiring energy; improving the efficiency with which the energy is used to provide these goods and services; reducing the carbon intensity of this energy supply (e.g., replacing fossil fuels with renewables or nuclear power, or employing carbon capture and storage).

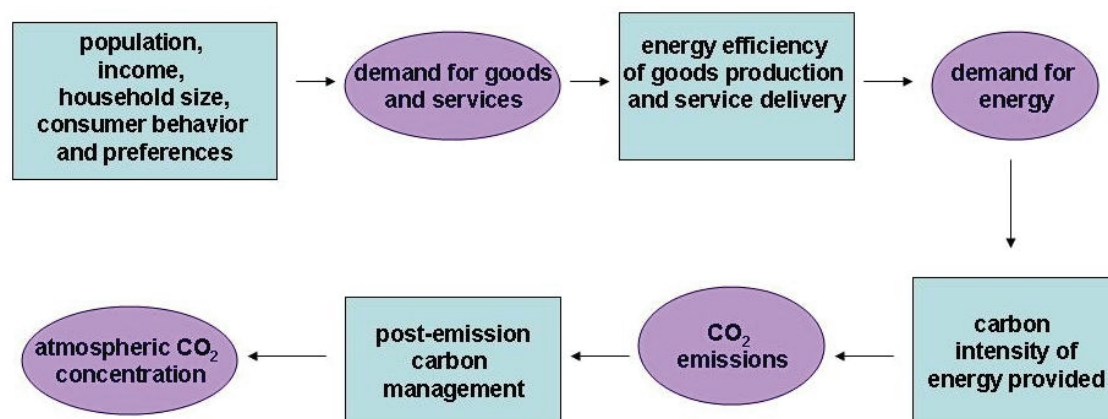
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<sup>2</sup> Specifically, we drew upon the Energy Modeling Forum 22 studies (<http://emf.stanford.edu/research/emf22/>). See Box 2.2 for details about this study and the reasons it was deemed particularly useful for our purposes.

<sup>3</sup> For reference, U.S. GHG emissions for 2008 (latest year available) were approximately 7 Gt CO<sub>2</sub>-eq.



**Figure 1.** Illustration of the representative U.S. cumulative GHG emissions budget targets --170 and 200 Gt CO<sub>2</sub>-eq (for Kyoto gases). (Gt = gigatons, or billion tons; Mt = megatons, or million tons). The exact value of the reference budget is uncertain, but regardless, illustrates a clear need for a major departure from business-as-usual.



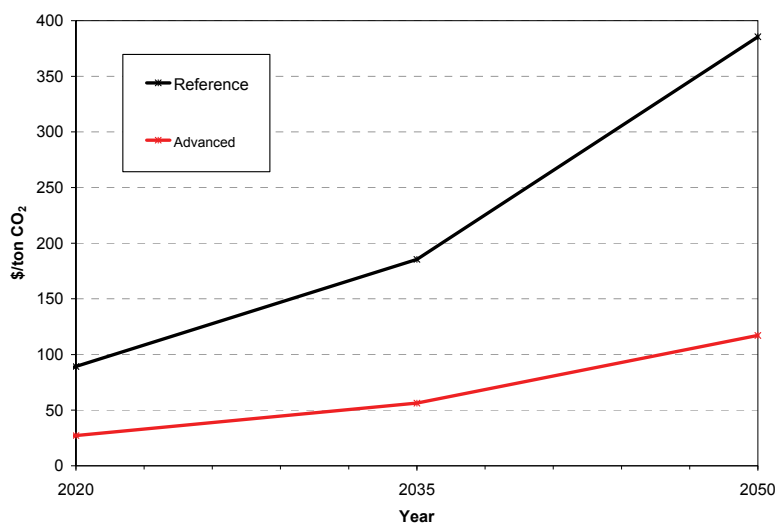
**Figure 2.** The chain of factors that determine how much CO<sub>2</sub> accumulates in the atmosphere. The blue boxes represent factors that can potentially be influenced to affect the outcomes in the purple circles.

To evaluate the magnitude and feasibility of needed changes in all of these areas, we examined the results of a recent NRC study *America's Energy Future*, which estimated the technical potential for aggressive near-term (i.e., for 2020 and 2035) deployment of key technologies for energy efficiency and low-carbon energy production. We compared this to estimates of the technology deployment levels that might be needed to meet the representative emissions budget. This analysis suggests that limiting domestic GHG emissions to 170 GtCO<sub>2</sub>-eq

by 2050 by relying only on these near-term opportunities may be technically possible, but will be very difficult. Meeting the 200 GtCO<sub>2</sub>-eq goal will be somewhat less difficult, but also very demanding. In either case however, falling short of the full technical potential for technology deployment is likely, as it would require overcoming many existing barriers (e.g., social resistance, institutional and regulatory concerns).

Some important opportunities exist to control non-CO<sub>2</sub> GHGs (such as methane, nitrous oxide, and the long-lived fluorinated gases) and to enhance biological uptake of CO<sub>2</sub> through afforestation and tillage change on suitable lands. These opportunities are worth pursuing, especially as a near-term strategy, but they are not large enough to make up the needed emissions reductions if the United States falls short in reducing CO<sub>2</sub> emissions from energy sources.

Acting to reduce GHG emissions in any of these areas will entail costs as well as benefits, but it is difficult to estimate overall economic impacts over timeframes spanning decades. While different model projections suggest a range of possible impacts, all recent studies indicate that GDP continues to increase substantially over time. Studies also clearly indicate that the ultimate cost of GHG emission reduction efforts depends upon successful technology innovation (**Figure 3**).



**Figure 3.** A model projection of the future price of CO<sub>2</sub> emissions under two scenarios - a “reference” case that assumes continuation of historical rates of technological improvements, and an “advanced” case with more rapid technological change. The absolute costs are highly uncertain, but studies clearly indicate that costs are reduced dramatically when advanced technologies are available. Source: Adapted from Kyle et al., 2009

We thus conclude that there is an urgent need for U.S. action to reduce GHG emissions. In response to this need for action, we recommend the following core strategies to U.S. policy makers:

- Adopt a mechanism for setting an economy-wide carbon pricing system.
- Complement the carbon price with a portfolio of policies to:
  - realize the practical potential for near-term emissions reductions through energy efficiency and low-emission energy sources in the electric and transportation sectors;
  - establish the technical and economic feasibility of carbon capture and storage and new-generation nuclear technologies;

- accelerate the retirement, retrofitting or replacement of GHG emission-intensive infrastructure.
- Create new technology choices by investing heavily in research and crafting policies to stimulate innovation.
- Consider potential equity implications when designing and implementing climate change limiting policies, with special attention to disadvantaged populations.
- Establish the United States as a leader to stimulate other countries to adopt GHG reduction targets.
- Enable flexibility and experimentation with policies to reduce GHG emissions at regional, state, and local levels.
- Design policies that balance durability and consistency with flexibility and capacity for modification as we learn from experience.

These recommendations are each discussed in greater detail below.

### **Adopt a mechanism for setting an economy-wide carbon pricing system<sup>4</sup> (see Chapter 4).**

A carbon pricing strategy is a critical foundation of the policy portfolio for limiting future climate change. It creates incentives for cost-effective reduction of GHGs and provides the basis for innovation and a sustainable market for renewable resources. An economy-wide carbon pricing policy would provide the most cost-effective reduction opportunities, would lower the likelihood of significant emissions leakage<sup>5</sup>, and could be designed with a capacity to adapt in response to new knowledge.

Incentives for emissions reduction can be generated either by a taxation system or a cap-and-trade system. Taxation sets prices on emissions and lets quantities of emissions vary; cap-and-trade sets quantity limits on emissions and lets prices vary. There are also options for hybrid approaches that integrate elements of both taxation and cap-and-trade.

Any such systems face common design challenges. On the question of how to allocate the financial burden, research strongly suggests that economic efficiency is best served by avoiding free allowances (in cap-and-trade) or tax exemptions. On the question of how to use the revenues created by tax receipts or allowance sales, revenue recycling could play a number of important roles -- for instance, by supporting complementary efforts such as R&D and energy efficiency programs, by funding domestic or international climate change adaptation efforts, or by reducing the financial burden of a carbon pricing system on low-income groups.

In concept, both tax and cap-and-trade mechanism offer unique advantages and could provide effective incentives for emission reductions. In the United States and other countries however, cap-and-trade has received the greatest attention, and we see no strong reason to argue that this approach should be abandoned in favor of a taxation system. In addition, the cap-and-trade system has features that are particularly compatible with other of our recommendations. For instance, it is easily compatible with the concept of an emissions budget and more transparent with

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<sup>4</sup> We use the terms 'carbon price' and 'carbon tax' (denominated as \$/tCO<sub>2</sub>-eq) because they are already widely-recognized terms, but note that the terms are intended to encompass other GHGs.

<sup>5</sup> Emissions leakage refers to the phenomenon where controlling emissions within one region or sector causes activity and resulting emissions to shift to another, uncontrolled region or sector.

regards to monitoring progress towards budget goals. It is also likely to be more durable over time, since those receiving emissions allowances have a valued asset that they will likely seek to retain.

High-quality domestic and international GHG offsets can play a useful role in lowering the overall costs of achieving a specific emissions reduction, both by expanding the scope of a pricing program to include uncovered emission sources, and by offering a financing mechanism for emission reductions in developing countries (although only for cases where adequate certification, monitoring and verification are possible, including a demonstration that the reductions are real and additional). Note however, that using international offsets as a way to meet the domestic GHG emissions budget could ultimately create a more onerous emissions-reduction burden for the countries selling the offsets; and absent some form of compensation to ease this burden, seller countries may resist the use of offsets that are counted against their own emission budget.

**Complement the carbon pricing system with policies to help realize the practical potential of near-term technologies; to accelerate the retrofit, replacement or retirement of emission-intensive infrastructure; and to create new technology choices** (See Chapters 3, 4, 5).

Pricing GHGs is a crucial but not sufficient component of the effort to limit future climate change. Since many market barriers exist and a national carbon pricing system will take time to develop and mature, a strategic, cost-effective portfolio of complementary policies is necessary to encourage early actions that increase the likelihood of meeting the 2050 emissions budget. This policy portfolio should have three major objectives, listed below.

**(i) Realize the practical potential for near-term emission reductions.** End-use energy demand, and the technologies used for electricity generation and transportation, drive the majority of U.S. CO<sub>2</sub> emissions. Key near-term opportunities for emission reductions in these areas include:

- *Increase energy efficiency.* Enhancing efficiency in the production and use of electricity and fuels offers some of the largest near-term opportunities for GHG reductions. These opportunities can be realized at a relatively low marginal cost, thus leading to an overall lowering of the cost of meeting the 2050 emissions budget. Furthermore, achieving greater energy efficiency in the near term can help defer new power plant construction while low-GHG technologies are being developed.
- *Increase the use of low GHG-emitting electricity generation options, including:*
  - *Accelerate the use of renewable energy sources.* Renewable energy sources offer both near-term opportunities for GHG emission reductions and potential long-term opportunities to meet global energy demand. Some renewable technologies are at and others are approaching economic parity with conventional power sources (even without a carbon-pricing system in place); but continued policy impetus is needed to encourage their development and adoption. This includes, for instance, advancing the development of needed transmission infrastructure, offering long-term stability in financial incentives, and encouraging the mobilization of private capital support for research, development, and deployment (RD&D).
  - *Address and resolve key barriers to the full-scale testing and commercial-scale demonstration of new-generation nuclear power.* Improvements in nuclear technology are commercially available, but power plants using this technology have not yet been built in the United States. Although such plants have a large potential to reduce GHG

emissions, the risks of nuclear power such as waste disposal and security/proliferation issues remain as significant concerns and must be successfully resolved.

- *Develop and demonstrate power plants equipped with carbon capture and storage technology.* Carbon capture and storage<sup>6</sup> could be a critically important option for our future energy system. It needs to be commercially demonstrated in a variety of full-scale power plant applications, to better understand the costs involved and the technological, social, and regulatory barriers that may arise and require resolution.
- *Advance low GHG-emitting transportation options.* Near-term opportunities exist to reduce GHGs from the transportation sector through increasing vehicle efficiency, supporting shifts to energy efficient modes of passenger and freight transport, and advancing low-GHG fuels (such as cellulosic ethanol).

**(ii) Accelerate the retirement, retrofitting or replacement of emissions-intensive**

**infrastructure.** Transitioning to a low-carbon energy system requires clear and credible policies that enable not only the deployment of new technologies, but also the retrofitting, retiring or replacement of existing emissions-intensive infrastructure. However, the turnover of the existing capital stock of the energy system may be very slow. Without immediate action to encourage retirements, retrofitting, or replacement, the existing emissions-intensive capital stock will rapidly consume the U.S. emissions budget.

**(iii) Create new technology choices.** The United States currently has a wide range of policies available to facilitate technological innovation; but many of these policies need to be strengthened, and in some cases additional measures enacted, to accelerate the needed technology advances. The magnitude of U.S. government spending for (non-defense) energy-related R&D has declined substantially since its peak nearly three decades ago. The United States also lags behind many other leading industrialized countries in the rate of government spending for energy-related R&D as a share of national GDP. While recommendations for desired levels and priorities for federal energy R&D spending are outside the scope of this study, we do find that the level and stability of current spending does not appear to be consistent with the magnitude of R&D resources needed to address the challenges of limiting climate change. In the private sector as well, compared to other U.S. industries, the U.S. energy sector spends very little on R&D relative to income or sales profits.

Research is a necessary first step in developing many new technologies, but bringing innovations to market requires more than basic research. Policies are also needed to establish and expand markets for low-GHG technologies, to more rapidly bring new technologies to commercial scale (especially support for large-scale demonstrations), to foster workforce development and training, and more generally to improve our understanding of how social and behavioral dynamics interact with technology, and how technological changes interact with the broader societal goals of sustainable development.

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<sup>6</sup> CCS refers to the process of removing CO<sub>2</sub> from the exhaust gases of power plants or industrial plants and storing the CO<sub>2</sub> in some sort of underground geologic reservoir.



**Consider potential equity implications when designing and implementing climate change limiting policies, with special attention to disadvantaged populations** (See Chapter 6).

Low-income groups consume less energy per capita and therefore contribute less to energy-related GHG emissions. Yet, low-income and some disadvantaged minority groups are likely to suffer disproportionately from adverse impacts of climate change and may also be adversely affected by policies to limit climate change. For instance, energy-related goods make up a larger share of expenditures in poor households, so raising the price of energy for consumers may impose the greatest burden on these households. Likewise, limited discretionary income may preclude these households from participating in many energy efficiency incentives. Because these impacts are likely but not well-understood, it will be important to monitor the impacts of climate change limiting policies on poor/disadvantaged communities, and adapt policies in response to unforeseen adverse impacts. Some key strategies to consider include:

- structuring policies to offset adverse impacts to low-income and other disadvantaged households (for instance, structuring carbon pricing policies to provide relief from higher energy prices to low-income households);
- designing incentive-based climate change limiting policies to be accessible to poor households (such as graduated subsidies for home heating or insulation improvements);
- assuring that efforts to reduce energy consumption in the transport sector avoid disadvantaging those with already limited mobility;
- actively and consistently engaging representatives of poor and minority communities in policy planning efforts.

Major changes to our nation's energy system will inevitably result in shifting employment opportunities, with job gains in some sectors and regions, but losses in others (i.e. energy-intensive industries and regions most dependant on fossil fuel production). Policymakers could help smooth this transition for the populations that are most vulnerable to job losses, through additional, targeted support for educational, training, and retraining programs.

**Establish the United States as a leader to stimulate other countries to adopt GHG emissions reduction targets** (See Chapter 7).

Even substantial U.S. emissions reductions will not, by themselves, substantially alter the rate of climate change. Although the United States is responsible for the largest share of historic contributions to global GHG concentrations, all major emitters must ultimately reduce emissions substantially. However, the *indirect* effects of U.S. action or inaction are likely to be very large. That is, what this nation does about its own GHG emissions will have a major impact on how other countries respond to the climate change challenge; and without domestic climate change limiting policies that are credible to the rest of the world, no U.S. strategy to achieve global cooperation is likely to succeed. Continuing efforts to inform the U.S. public of the dangers of climate change and to devise cost-effective response options will therefore be essential for global cooperation, as well as for effective, sustained national action.

U.S. international climate change strategy will need to operate at multiple levels. Continuing attempts to negotiate a comprehensive climate agreement under the United Nations Climate Change Convention are essential to establish good faith and to maximize the legitimacy of policy. At the same time, intensive negotiations must continue with the European Union, Japan and other OECD (i.e. high income) countries, and with low- and middle-income countries that are major emitters of,

or sinks for GHGs (especially China, India, Brazil, and the former Soviet Union countries). These multiple tracks need to be pursued in ways that reinforce rather than undermine one another. It may be worthwhile to negotiate sectoral as well as country-wide agreements; and GHGs other than CO<sub>2</sub> should be subjects for international consideration. In such negotiations, the United States should press for institutional arrangements that provide credible assessment and verification of national policies around the world, and that help the low- and middle- income countries attain their broader goals of sustainable development.

Competition among countries to take the lead in advancing green technology will play an important role in stimulating emissions reduction efforts, but strong cooperative efforts will be needed as well. Sustaining large, direct governmental financial transfers to low-income countries may pose substantial challenges of political feasibility; however, large financial transfers via the private-sector could be facilitated via a carbon-pricing system that allows purchases of allowances or offsets. There is a clear need for support of innovative scientific and technical efforts to help low- and middle-income countries limit their emissions. To provide leadership in these efforts, the United States needs to develop and share technologies that not only reduce GHG emissions, but also help advance economic development and reduce local environmental stresses.

### **Enable flexibility and experimentation with emission reduction policies at regional, state, and local levels** (See Chapter 7).

State and local action on climate change has already been significant and wide-ranging. For instance, states are operating cap-and-trade programs, imposing performance standards on utilities and auto manufacturers, running renewable portfolio standard programs, and supporting and mandating energy efficiency. Cities across the United States are developing and implementing climate change action plans. Many federal climate change limiting policies will need ongoing cooperation of states and localities in order to be successfully implemented -- including for example energy efficiency programs, which are run by localities or state-level programs; and energy efficiency building standards, which are sometimes enacted statewide and implemented by local authorities. Moreover, states have regulatory capacity (for example, in regulating energy supply and implementing building standards) that may be needed for implementing new federal initiatives.

Subnational programs will thus need to continue playing a major role in meeting U.S. climate change goals. In addition, since climate change limiting policies will continue to evolve, policy experimentation at sub-national levels will provide useful experience for national policy makers to draw upon. On the other hand, sub-national regulation can pose costs, such as the fact that businesses operating in multiple jurisdictions may face multiple state regulatory programs and therefore increased compliance burdens. Overlap with state cap-and-trade programs can make a federal program less effective by limiting the freedom of the market to distribute reductions efficiently. These costs, however, may be worth the benefits gained from state and local regulatory innovation; and regardless, they illustrate the tradeoffs Congress will have to consider when deciding whether to preempt state action.

Thus a balance must be struck to preserve the strengths and dynamism of state and local actions, while also making tough choices about the extent to which national policies should prevail. In some instances, it may be appropriate to limit state and local authority, and instead mandate compliance with minimum national standards. But Congress could promote regulatory flexibility and innovation across jurisdictional boundaries when this is consistent with effective and efficient national policy. To this end, we suggest that Congress avoid punishing or disadvantaging states (or

entities within the states) that have taken early action to limit GHG emissions, avoid preempting state and local authority to regulate GHG emissions more stringently than federal law without a strong policy justification, and ensure that sub-national jurisdictions have sufficient resources to implement and enforce programs mandated by Congress.

**Design policies that balance durability and consistency with flexibility and capacity for modification as we learn from experience** (See Chapter 8).

The strategies and policies outlined above are complex efforts with extensive implications for other domestic issues and for international relations. It is therefore crucial that policies are properly implemented and enforced, and are designed in ways that are durable and resistant to distortion or undercutting by subsequent pressures. At the same time, policies must be sufficiently flexible to allow for modification as we gain experience and understanding (as discussed earlier in the summary). Transparent, predictable mechanisms for policy evolution will be needed.

There are inherent tensions between these goals of durability and adaptability, and it will be an ongoing challenge to find a balance between them. Informing such efforts requires processes for assuring that policymakers regularly receive timely information about scientific, economic, technological, and other relevant developments. One possible mechanism for this process is a periodic (e.g., biennial) collection and analysis of key information related to our nation's climate change response efforts. This effort could take the form of a "*Climate Report of the President*" that would provide a focal point for analysis, discussion, and public attention, and ideally, would include requirements for responsible implementing agencies to act upon pertinent new information gained through this reporting mechanism.

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# Limiting the Magnitude of Future Climate Change

America's Climate Choices: Panel on Limiting the Magnitude of Climate  
Change

Board on Atmospheric Sciences and Climate

Division on Earth and Life Studies

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**AMERICA'S CLIMATE CHOICES:  
PANEL ON LIMITING THE MAGNITUDE OF FUTURE CLIMATE CHANGE**

**ROBERT W. FRI** (Chair), Resource for the Future, Washington D.C.  
**MARILYN A. BROWN** (Vice-Chair), Georgia Institute of Technology, Atlanta  
**DOUG ARENT**, National Renewable Energy Laboratory, Golden, Colorado  
**ANN CARLSON**, University of California, Los Angeles  
**MAJORA CARTER**, Majora Carter Group, LLC, Bronx, New York  
**LEON CLARKE**, Pacific Northwest National Laboratory, College Park, Maryland  
**FRANCISCO DE LA CHESNAYE**, Electric Power Research Institute, Washington, D.C.  
**GEORGE C. EADS**, CRA Charles River Associates, Washington, D.C.  
**GENEVIEVE GIULIANO**, University of Southern California, Los Angeles  
**ANDREW HOFFMAN**, University of Michigan, Ann Arbor  
**ROBERT O. KEOHANE**, Princeton University, New Jersey  
**LOREN LUTZENHISER**, Portland State University, Oregon  
**BRUCE MCCARL**, Texas A&M University, College Station  
**MACK MCFARLAND**, DuPont, Wilmington, Delaware  
**MARY D. NICHOLS**, California Air Resources Board, Sacramento  
**EDWARD S. RUBIN**, Carnegie Mellon University, Pittsburgh, Pennsylvania  
**THOMAS H. TIETENBERG**, Colby College (retired), Waterville, Maine  
**JAMES A. TRAINHAM**, RTI International, Research Triangle Park, North Carolina

**NRC Staff:**

**LAURIE GELLER**, Study Director  
**ALAN CRANE**, Senior Program Officer  
**TOM MENZIES**, Senior Program Officer  
**KATIE WELLER**, Research Associate  
**SHELLY FREELAND**, Senior Program Assistant

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v



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## Foreword

# America's Climate Choices

Convened by the National Research Council in response to a request from Congress (Public Law 110-161), *America's Climate Choices* is a suite of five coordinated activities designed to study the serious and sweeping issues associated with global climate change, including the science and technology challenges involved, and provide advice on the most effective steps and most promising strategies that can be taken to respond.

The *Committee on America's Climate Choices* is responsible for providing overall direction, coordination, and integration of the America's Climate Choices suite of activities and ensuring that these activities provide well-supported, action-oriented, and useful advice to the nation. The Committee convened a *Summit on America's Climate Choices* on March 30-31, 2009 to help frame the study, provide an opportunity for high-level participation and input on key issues, and hear about relevant work carried out by others. The Committee is also charged with writing a final report that builds on four panel reports and other sources to answer the following four overarching questions:

- What short-term actions can be taken to respond effectively to climate change?
- What promising long-term strategies, investments, and opportunities could be pursued to respond to climate change?
- What are the major scientific and technological advances needed to better understand and respond to climate change?
- What are the major impediments (e.g., practical, institutional, economic, ethical, intergenerational, etc.) to responding effectively to climate change, and what can be done to overcome these impediments?

The *Panel on Limiting the Magnitude of Future Climate Change* was charged to describe, analyze, and assess strategies for reducing the net future human influence on climate, including both technology and policy options. The panel's report focuses on actions to reduce domestic greenhouse gas emissions and other human drivers of climate change, such as changes in land use, but also considers the international dimensions of climate stabilization.

The *Panel on Adapting to the Impacts of Climate Change* was charged to describe, analyze, and assess actions and strategies to reduce vulnerability, increase adaptive capacity, improve resiliency, and promote successful adaptation to climate change in different regions, sectors, systems, and populations. The panel's report draws on a wide range of sources and case studies to identify lessons learned from past experiences, promising current approaches, and potential new directions.

The *Panel on Advancing the Science of Climate Change* was charged to provide a concise overview of past, present, and future climate change, including its causes and its impacts, then recommend steps to advance our current understanding, including new observations, research programs, next-generation models, and the physical and human assets needed to support these and

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vii

other activities. The panel's report focuses on the scientific advances needed both to improve our understanding of the integrated human-climate system and to devise more effective responses to climate change.

The *Panel on Informing Effective Decisions and Actions Related to Climate Change* was charged to describe and assess different activities, products, strategies, and tools for informing decision makers about climate change and helping them plan and execute effective, integrated responses. The panel's report describes the different types of climate change-related decisions and actions being taken at various levels and in different sectors and regions; and it develops a framework, tools, and practical advice for ensuring that the best available technical knowledge about climate change is used to inform these decisions and actions.

*America's Climate Choices* builds on an extensive foundation of previous and ongoing work, including current and past National Research Council reports, assessments from other national and international organizations, the current scientific literature, climate action plans by various entities, and other sources. More than a dozen boards and standing committees of the National Research Council were involved in developing and organizing the study, and many additional groups and individuals provided additional input during the study process. Outside viewpoints and perspectives were also obtained via public events and workshops (including the *Summit*), invited presentations at committee and panel meetings, and comments and questions received through the study website <http://americasclimatechoices.org>.

Collectively, the *America's Climate Choices* suite of activities involve more than 90 volunteers from a range of communities including academia, various levels of government, business and industry, other nongovernmental organizations, and the international community. Study participants were charged to write consensus reports that provide broad, action-oriented, and authoritative analyses to inform and guide responses to climate change across the nation. Responsibility for the final content of each report rests solely with the authoring panel and the National Research Council. However, the development of each report included input from and interactions with members of all five study groups; the membership of each group is listed in Appendix A.

## Preface

Tackling climate change promises to be one of the most significant social and technological challenges of the 21st century. Since the industrial revolution, the atmosphere has been one of the world's principal waste repositories because it has offered an easy and inexpensive means of managing unwanted byproducts. It is currently absorbing a net gain of two parts per million of CO<sub>2</sub> per year as the result of global emissions, and the world's leading scientists believe that this change in atmospheric composition is changing the global climate.

This report focuses on actions available to the United States to reduce greenhouse gas (GHG) emissions. The goal of actually limiting<sup>1</sup> global climate change requires international cooperation, since most of this century's emissions will come from developing countries, with U.S. emissions representing a shrinking portion of the total. Thus our national strategy must promote domestic actions while at the same time influencing the rest of the world to control their emissions.

The United States has successfully reduced emissions of several key atmospheric pollutants – including SO<sub>2</sub>, NO<sub>x</sub>, and particulates – through the Clean Air Act. The creation of a market for SO<sub>2</sub> allowances, in conjunction with performance standards and a cap on emissions, provided strong incentives for entrepreneurs to develop lower-cost SO<sub>2</sub> abatement technologies and approaches, and is one of the past century's greatest environmental policy successes. Emissions of most GHGs, however, remain largely unregulated and continue to be discharged without penalty, through smokestacks, tailpipes, and chimneys, and by the destruction of forests. With no price on carbon, or regulatory pressure, there exist few incentives to mitigate emissions. Thus we continue to “lock in” incumbent technologies and systems that are typically carbon-intensive. Changing these practices will require scientific and engineering genius to create new energy systems that avoid emitting all but a small fraction of today's GHGs while simultaneously powering global economic growth. Success will also necessitate institutional, economic, social, and policy innovations to foster the widespread and rapid deployment of transformational technologies.

In this study, the Panel was charged with describing, analyzing, and assessing strategies for reducing the future human influence on climate (see full Statement of Task in Appendix A). We considered both existing and emerging technologies, as well as existing and innovative new policies. Technologies and policies were assessed according to their scale of impact, cost, feasibility, and other critical factors, with the assistance of a set of guiding principles. Based on these factors and principles, the Panel was able to recommend a short list of options that appear to be most important for significantly reducing GHG emissions.

There are numerous important issues closely related to the topic of limiting climate change that are not addressed here. This report does not, for instance:

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<sup>1</sup> The term “limiting” climate change rather than “mitigation” of climate change was deliberately chosen, because in some circles, mitigation often refers to mitigating the impacts of climate change, that is – adaptation (the focus of another America's Climate Choices panel report). Our focus is on limiting the main drivers of climate change (i.e., greenhouse gas emissions), with the expectation that this will contribute to limiting climate change itself.

- describe the scientific evidence for why climate change is real and being driven largely by human influences and why this poses a serious threat to humans and ecosystems;
- identify the impacts that may result from not taking sufficient action to limit climate change and the vulnerability of different populations and regions to those impacts;
- analyze the economic impacts of acting versus not acting to limit climate change (i.e. cost/benefit analyses);
- discuss 'solar radiation management' geoengineering strategies;
- explore (in any considerable depth) the scientific research needed for improving our understanding of climate change and the specific types of technological research and development needed for reducing emissions;
- examine strategies for improving education and communication about climate change with the general public and the media.

Many of these issues are addressed in the other America's Climate Choices panel reports (*Advancing the Science of Climate Change*, *Adapting to the Impacts of Climate Change*, *Informing Effective Decisions about Climate Change*), and/or will be addressed in the final report of the ACC main committee.

This study began at a time when the United States and countries around the world were actively debating options for addressing global climate change. It is particularly timely, therefore, that the NRC has taken on this task; and in doing so, we were fortunate to engage a Panel of experts with a diversity of backgrounds – including for instance, physical scientists, social scientists, economists, engineers, community organizers, lawyers, and executives of nongovernmental organizations. This broad-based group of experts proved capable of resolving many opposing viewpoints that at first blush might have seemed irreconcilable. Their active involvement and commitment to producing a useful report is greatly appreciated.

The Panel approached its task by conducting its own review of the literature and by supplementing the Panel members' expertise with informational briefings on key topics from outside authorities. In particular, we wish to thank: Jonathan Black, Senate Energy and Natural Resources Committee; Rachel Cleetus and Steve Clemmer, Union of Concerned Scientists; Ana Unruh Cohen, House Select Committee on Energy Independence and Global Warming; Robert Marlay, Climate Change Technology Program, U.S. Department of Energy; W. David Montgomery, CRA International; Bill Parton, Colorado State University; Robert Pollin, University of Massachusetts Amherst; and Michael Ryan, USDA Forest Service.

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Bob Fri (Chair) and Marilyn Brown (Vice-Chair)  
America's Climate Choices:  
Panel on Limiting the Magnitude of Future Climate Change

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by **Robert Frosch** (Harvard University) and **Tom Graedel** (Yale University). Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring panel and the institution.

Institutional oversight for this project was provided by:

**BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE**

**ANTONIO J. BUSALACCHI, JR.** (*Chair*), University of Maryland, College Park  
**ROSINA M. BIERBAUM**, University of Michigan, Ann Arbor  
**RICHARD CARBONE**, National Center for Atmospheric Research, Boulder, Colorado  
**WALTER F. DABBERDT**, Vaisala, Inc., Boulder, Colorado  
**KIRSTIN DOW**, University of South Carolina, Columbia  
**GREG S. FORBES**, The Weather Channel, Inc., Atlanta, Georgia  
**ISAAC HELD**, National Oceanic and Atmospheric Administration, Princeton, New Jersey  
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**JOHN T. SNOW**, University of Oklahoma, Norman  
**THOMAS H. VONDER HAAR**, Colorado State University/CIRA, Fort Collins  
**XUBIN ZENG**, University of Arizona, Tucson

*Ex Officio Members*

**GERALD A. MEEHL**, National Center for Atmospheric Research, Boulder, Colorado

*NRC Staff*

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**MAGGIE WALSER**, Associate Program Officer  
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**JOSEPH CASOLA**, Postdoctoral Fellow  
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**LAUREN M. BROWN**, Research Assistant  
**ROB GREENWAY**, Program Associate  
**SHELLY FREELAND**, Senior Program Assistant  
**AMANDA PURCELL**, Senior Program Assistant  
**JANEISE STURDIVANT**, Program Assistant  
**RICARDO PAYNE**, Program Assistant  
**SHUBHA BANSKOTA**, Financial Associate

# Table of Contents

SUMMARY	1
1 INTRODUCTION	11
Context and Purpose of this Report, 11	
Principles to Guide Climate Change Limiting Policy and Strategy, 13	
Organization of the Report, 14	
2 GOALS FOR LIMITING FUTURE CLIMATE CHANGE	15
Reference U.S. and Global Emissions, 15	
Setting Climate Change Limiting Goals, 22	
Global Emission Targets, 26	
U.S. Emission Targets, 28	
Implications of U.S. Emission Goals, 31	
Key Conclusions and Recommendations, 37	
3 OPPORTUNITIES FOR LIMITING FUTURE CLIMATE CHANGE	38
Opportunities for Limiting GHG Emissions, 38	
The Case for Urgency, 61	
The Larger Context for Technology, 66	
Key Conclusions and Recommendations, 66	
4 CRAFTING A PORTFOLIO OF CLIMATE CHANGE LIMITING POLICIES	68
Pricing Strategy Design Features, 68	
Comparing Taxes with Cap-and-Trade, 75	
Complementary Options for the Policy Portfolio, 81	
Integrating the Policy Options, 94	
Key Conclusions and Recommendations, 99	
5 FOSTERING TECHNOLOGICAL INNOVATIONS	101
The Role of Technological Innovation, 101	
The Process of Technological Change, 102	
Resources Currently Available for Technology Innovation, 105	
Assessment of Current U.S. Innovation Policies, 116	
Key Conclusions and Recommendations, 120	
6 INTERACTION WITH OTHER MAJOR POLICY CONCERNS	121
Linkages with Energy and Environmental Policy Issues, 121	
Key Conclusions and Recommendations, 126	
Equity and Employment Impacts, 127	
Key Conclusions and Recommendations, 139	
7 MULTI-LEVEL RESPONSE STRATEGIES	140

*PREPUBLICATION COPY*

*xiii*



International Strategies, 140	
Key Conclusions and Recommendations, 149	
Balancing Federal with State and Local Action, 149	
Key Conclusions and Recommendations, 155	
8 POLICY DURABILITY AND ADAPTABILITY	156
Policy Stability, Durability, and Enforcement, 156	
Generating Timely Information for Adaptive Management, 159	
Key Conclusions and Recommendations, 161	
REFERENCES	163
APPENDIXES	
A America's Climate Choices: Membership Lists	177
B Panel on Limiting the Magnitude of Future Climate Change: Statement of Task	180
C Panel on Limiting the Magnitude of Future Climate Change: Biographical Sketches	181
D Acronyms, Energy Units, Chemical Formulas	187