OECD Economics Department Working Papers No. 807

# Implementing Cost-Effective Policies in the United States to Mitigate Climate Change

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https://dx.doi.org/10.1787/5km5zrs4kc6l-en

OECD

**Unclassified** **ECO/WKP(2010)63**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **22-Oct-2010**

**English - Or. English**

**ECONOMICS DEPARTMENT**

**ECO/WKP(2010)63**
**Unclassified**

**IMPLEMENTING COST-EFFECTIVE POLICIES IN THE UNITED STATES TO MITIGATE CLIMATE CHANGE**

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*The consensus view of scientists is that the build-up of greenhouse gases (GHG) in the atmosphere is causing global warming. To reduce the probability of severe climate change impacts and costs occurring, global GHG emissions need to be reduced substantially over coming decades. The United States agreed to a global political agreement to reduce GHG emissions that was acknowledged at Copenhagen (COP15) in December 2009 and negotiations are continuing to work towards binding emissions-reduction commitments by all countries. In view of the scale of emission reductions called for, it is vital that the United States adopt a cost effective and comprehensive climate change policy. The current Administration is endeavouring to put such a policy package in place. Its core elements are comprehensive pricing of GHG emissions and increased support for the development and deployment of GHG-emissions-reducing technologies. The alternative regulatory approach would be more costly and unlikely to deliver the required scale of reductions in emissions.*



**JT03290933**

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**English - Or. English**

## ABSTRACT/ RÉSUMÉ


**Implementing cost-effective policies in the United States to mitigate climate change**

The consensus view of scientists is that the build-up of greenhouse gases (GHG) in the atmosphere is causing global warming. To reduce the probability of severe climate-change impacts and costs occurring, global GHG emissions need to be reduced substantially over coming decades. The United States agreed to a global political agreement to reduce GHG emissions that was acknowledged at Copenhagen (COP15) in December 2009 and negotiations are continuing to work towards binding emissions-reduction commitments by all countries. In view of the scale of emission reductions called for, it is vital that the United States adopt a cost-effective and comprehensive climate change policy. The current Administration is endeavouring to put such a policy package in place. Its core elements are comprehensive pricing of GHG emissions and increased support for the development and deployment of GHG-emissions-reducing technologies. The alternative regulatory approach would be more costly and unlikely to deliver the required scale of reductions in emissions.

This Working Paper related to the 2010 OECD Economic Survey of the United States. (www.oecd.org/eco/surveys/United States)



*JEL Codes:* Q01; Q28; Q48; Q54; Q55; Q58
*Keywords:* United States 2010; climate change; GHG emissions; cap-and-trade; carbon tax; bio-fuels.


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**Mettre en œuvre des politiques efficaces par rapport à leur coût aux États-Unis pour atténuer le changement climatique**

Les scientifiques s'accordent globalement à considérer que l'accumulation de gaz à effet de serre (GES) dans l'atmosphère est à l'origine d'un réchauffement de la planète. Pour réduire le risque que le changement climatique ait des répercussions graves et des coûts élevés, il faudra diminuer sensiblement les émissions mondiales de GES dans les décennies à venir. Les États-Unis ont souscrit à l'économie d'un accord politique mondial axé sur cette diminution, dont il a été pris acte à Copenhague en décembre 2009 (CdP15). Les négociations se poursuivent en vue d'obtenir de tous les pays des engagements contraignants de réduction de leurs émissions. Compte tenu de l'ampleur des réductions nécessaires, il est vital que les États-Unis adoptent une politique globale de lutte contre le changement climatique qui soit efficace par rapport à son coût. Le gouvernement en place s'efforce d'agencer ce dispositif, dont les principaux éléments sont la tarification générale des émissions de GES et le renforcement du soutien apporté au développement et au déploiement des technologies qui font diminuer ces dernières. L'approche alternative par la voie réglementaire serait plus coûteuse et peu susceptible de fournir à l'échelle requise des réductions des émissions.

Ce document de travail se rapporte à l'Étude économique de l'OCDE des États-Unis 2010 (www.oecd.org/eco/etudes/Etats-Unis)



*Codes JEL :* Q01; Q28; Q48; Q54 ; Q55 ; Q58.
*Mots-clés :* États-Unis 2010 *;* changement climatique *;* émissions de gaz à effet de serre ; système de plafonnement et d'échange ; taxe carbone ; biocarburants.

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# IMPLEMENTING COST-EFFECTIVE POLICIES IN THE UNITED STATES TO MITIGATE CLIMATE CHANGE

**By David Carey**[1]

1. There is now much scientific evidence that the build-up of greenhouse gases (GHG) in the atmosphere is causing global warming. Climate modelling suggests that the costs of global warming are likely to be significant, but are subject to great uncertainty. The probability of severe climate-change impacts and costs being incurred can be lowered by substantially reducing GHG emissions. To be effective, mitigation action must include the United States and other major GHG-emitting countries. The United States agreed to a global political agreement to reduce GHG emissions that was acknowledged in Copenhagen (COP15) in December 2009, and negotiations are continuing to work towards binding commitments from all countries. Given the scale of mitigation envisaged by the Copenhagen Accord, it is vital that the United States uses cost-effective policy instruments. After reviewing the climate-change problem and the need for the United States to participate in a global agreement, this paper assesses US climate-change policy in terms of its cost effectiveness. The main conclusions are that legislation needs to be passed to price GHG emissions comprehensively and that support for the development and deployment of GHG emissions reducing technologies should be stepped up further.

## It would be prudent to reduce Greenhouse Gas (GHG) emissions to limit climate change

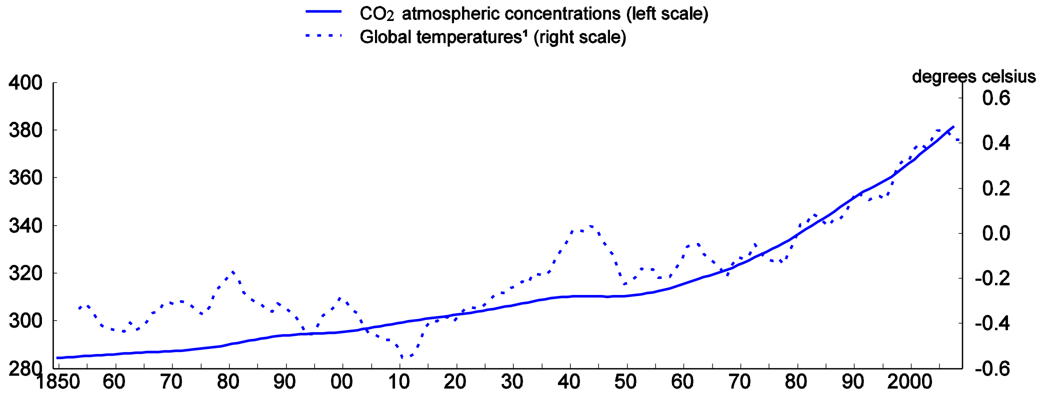
### *Anthropogenic GHG emissions are likely to be causing climate change*

2. The consensus view of scientists is that anthropogenic (*i.e.*, from human activities) GHG emissions are causing global warming; they have this effect independently of their geographical origin. There have been very large increases in atmospheric concentrations of important, long-lived GHG since the beginning of the industrial era (around 1750). Atmospheric concentrations of $CO_2$, which is the most important of the GHG emitted by human activities, have increased markedly in recent decades, reaching around 380 ppm in recent years compared with about 280 ppm in the pre-industrial era (Figure 1); while the atmospheric concentration of other GHG has also increased, their warming effect has been almost neutralised on balance by the net cooling effect of aerosols that have been added to the atmosphere by humans. Global mean temperatures are estimated to have increased by around 0.7 °C since the pre-industrial era, with much of that increase having occurred since 1980. The pattern of climate change - warming in the lower atmosphere and cooling in the stratosphere - is consistent with greenhouse gases being the main cause.

1 This paper was originally produced for the 2010 OECD Economic Survey of the United States and published in September 2010 under the authority of the Economic and Development Review Committee (EDRC) of the OECD. I would like to thank Christa Clapp, Helen Mountford, Andrew Dean, Robert Ford and members of the EDRC for valuable comments and discussions. I am also grateful to Jérôme Brézillon for technical assistance and to Heloise Wickramanayake for secretarial assistance.

**Figure 1. $CO_2$ atmospheric concentrations and global temperatures are rising**

Five year average




1. Deviation from average 1961-90.

*Source*: World Meteorological Organisation.

### *Large increases in GHG emissions are in prospect*

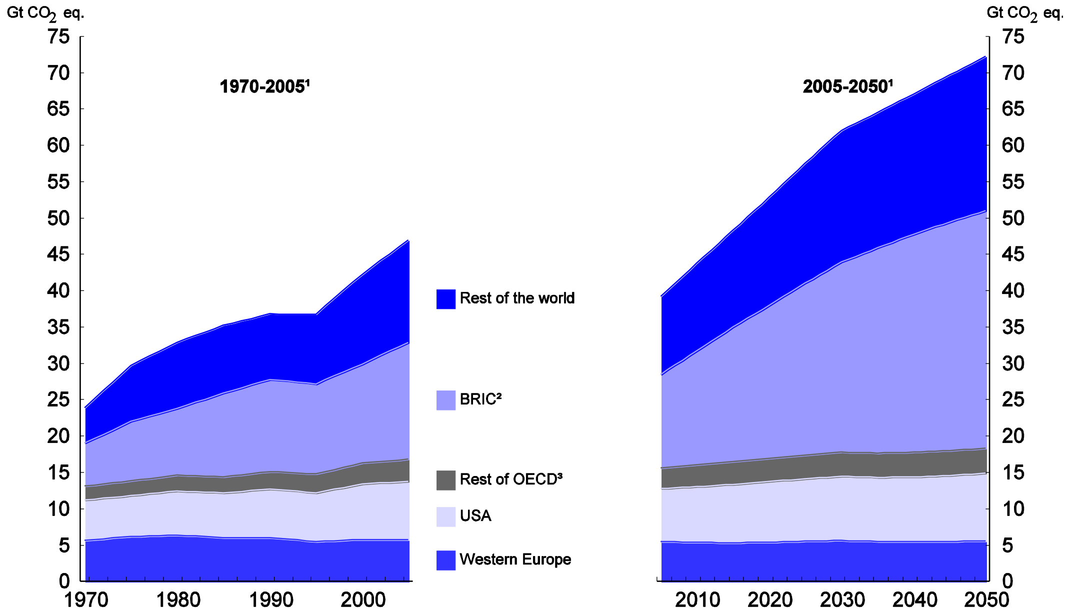
3. Growth in global GHG emissions has accelerated markedly in recent years, from an annual average rate of 1.7% over 1970-95 to 2.5% between 1995 and 2005 (IEA, 2009a) (Figure 2). This acceleration mainly reflects economic development in emerging countries, notably China. Despite this growth, GHG emissions per capita in China remain much lower than in developed countries, currently standing at only 20% of the US level. This suggests that emissions are likely to continue rising rapidly in emerging economies as they catch up economically with developed countries. Indeed, OECD (2009) projects that global-GHG emissions will increase from the 2005 level by 35% by 2020 and 84% by 2050 in a Business-As-Usual (BAU) scenario.

### *It would be prudent to reduce GHG emissions to limit climate change*

4. There is much uncertainty about the effect of rising GHG concentrations. Studies suggest that the costs of inaction are likely to be significant, but could be lower if climate sensitivity is very low. Based on the standard Intergovernmental Panel on Climate Change (IPCC, 2007) climate-sensitivity-parameter estimate, which suggests that the mean global temperature would rise by 3 °C if the atmospheric concentration of GHG were to double, OECD (2009) projects an increase in the global mean temperature of about 4 °C by 2100 on a BAU basis, but with a one-in-six chance of the increase being more than 5.8 °C and a one-in-six chance of it being less than 2.2 °C. Climate modelling suggests that damages rise much more than in proportion to the rise in global mean temperatures for increases beyond 2.0–2.5 °C (Nordhaus, 2007). Damage estimates associated with a given increase in global temperatures are also uncertain and have a probability distribution skewed towards high damages. In view of this uncertainty, mitigation action should be seen as reducing the probability of severe climate-change costs occurring rather than setting up a strict cost-benefit comparison using the expected values of benefits.

**Figure 2. Substantial growth in global GHG emissions is in prospect in a BAU scenario**

Gt $CO_2$ eq




1. Including emissions from Land Use, Land-Use Change and Forestry before 2005 and excluding after 2005.
2. For 1970-2005: Brazil, India and China.
3. Rest of OECD does not include Korea, Mexico and Turkey, which are aggregated in Rest of the World.

*Source*: OECD (2009).

## The United States is a major emitter of GHG

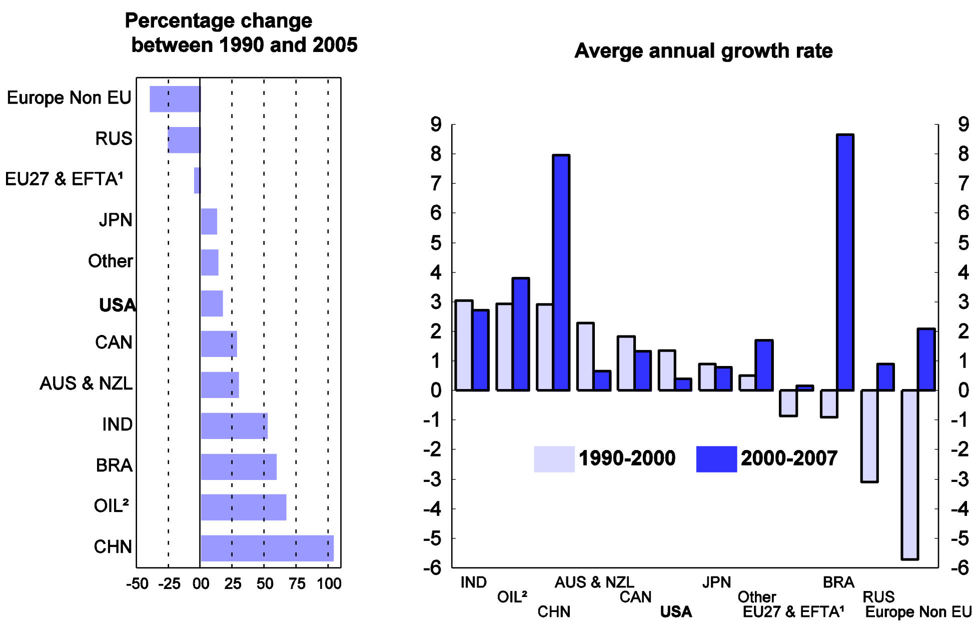
### *The United States remains a major GHG emitter, despite slowing emissions growth*

5. Growth in US GHG emissions has slowed substantially since 2000, from an average annual rate of 1.4% over 1990-2000 to 0.4% over 2000-07, but remains higher than in the EU27 + EFTA countries and much lower than in China (Figure 3). GHG emissions were 17% higher in the United States in 2007 than in 1990, whereas they were 7% lower on average in the EU27 + EFTA countries, partly reflecting the collapse of heavy industry in Eastern Europe during the 1990s. This factor clearly contributed to a large decline in emissions in Germany over this period. Emissions also fell steeply in the United Kingdom, due in part to declining coal consumption following the discovery of North Sea natural gas; emissions in other western European countries on average grew during this period at a somewhat slower pace than in the United States, partly reflecting lower economic and population growth. The US share of current global emissions has declined in recent years to 15% in 2005 as its emissions growth has slowed and emerging countries have developed (Figure 4). The US share is the second largest of any country or region after China's and is significantly larger than that for the EU27 + EFTA countries, even though they have a larger population and economy. The OECD (2009) projects that US GHG emissions will increase by 28% by 2050 on a BAU basis, which, together with rapid growth in developing countries' emissions, will result in the US share of global emissions falling to 13% by 2050.

6. Growth in GHG emissions has been slower than economic growth both in the United States and most other countries. The GHG emissions intensity of the US economy (GHG emissions per unit of GDP in 2005 prices) fell by one quarter between 1990 and 2005 (Figure 5). This reduction in GHG intensity was less than achieved in EU27 + EFTA countries on average, but more than in the remaining OECD countries (GDP is converted to USD at 2005 PPP exchange rates). The GHG emissions intensity of output is higher in the United States than in the EU27 + EFTA countries on average and Japan, but lower than in Canada, and the Australia and New Zealand region.

**Figure 3. Growth in US GHG emissions has slowed, but remains higher than in European countries**

$CO_2$ equivalent

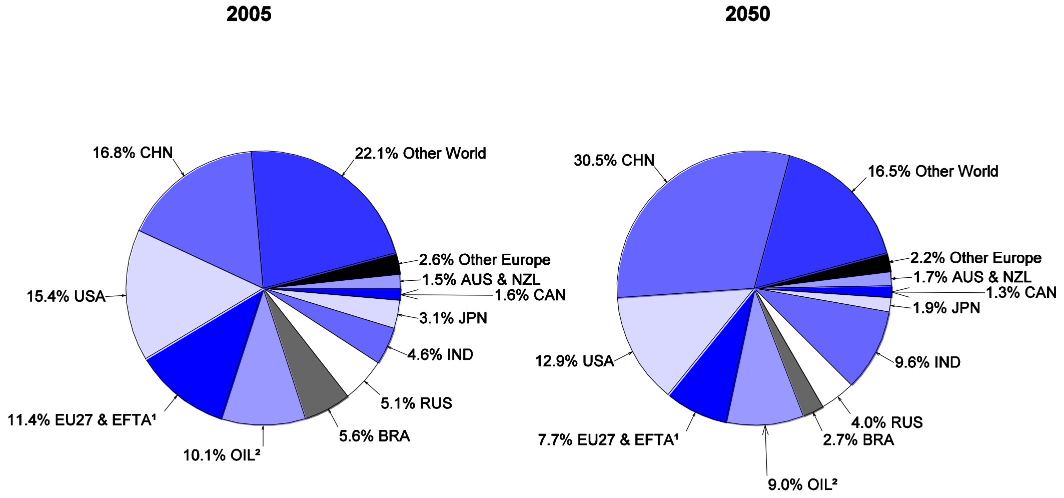



1. EU27, Iceland, Norway and Switzerland.

2. Indonesia, Venezuela, Middle East, North Africa and Nigeria.

*Source*: IEA (2009a); OECD, ENV-Linkages model.

**Figure 4. The United States is a major emitter of GHG**

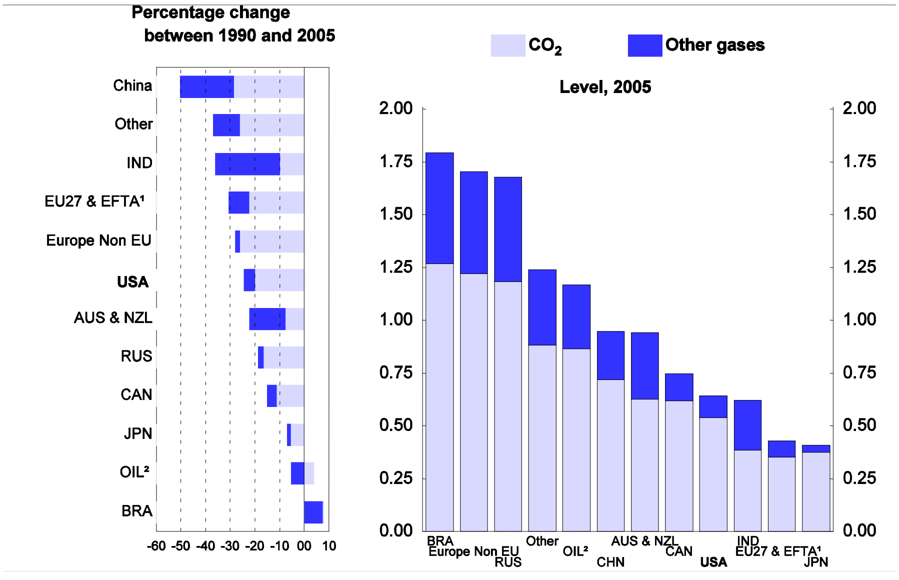



1. EU27, Iceland, Norway and Switzerland.
2. Indonesia, Venezuela, Middle East, North Africa and Nigeria.

*Source*: IEA (2009a); OECD, ENV-Linkages model.

**Figure 5. GHG emissions intensity of output is declining in the United States but is higher than in most OECD countries**

kg $CO_2$eq. per 2000 USD PPP




1. EU27, Iceland, Norway and Switzerland.
2. Indonesia, Venezuela, Middle East, North Africa and Nigeria.

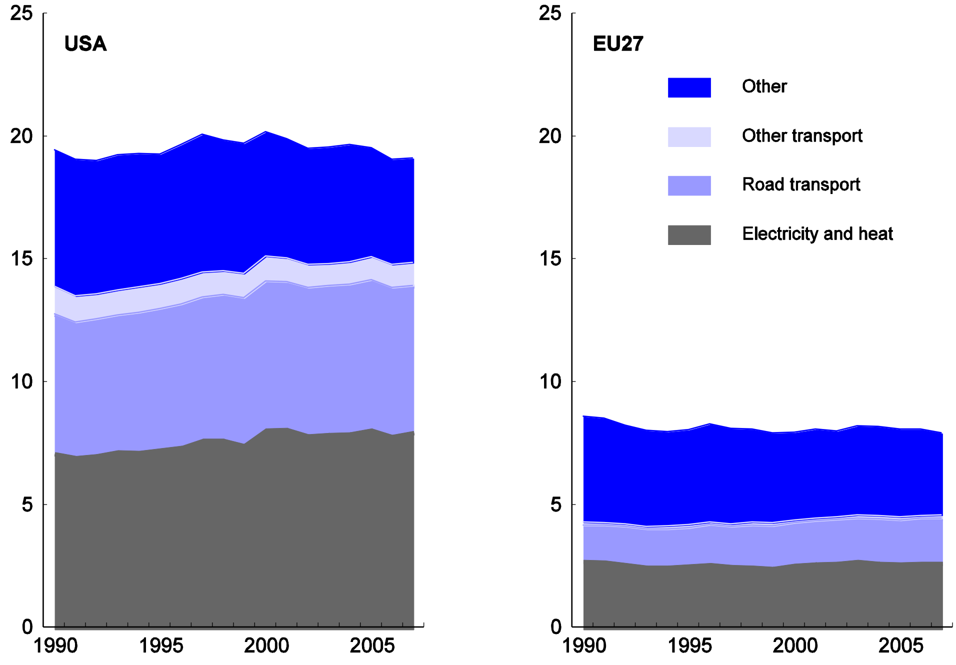
*Source*: IEA (2009a).

***GHG emissions are much higher in the United States than in European countries***

7. US GHG emissions per capita in 2005 were approximately double the EU27 + EFTA level, though they were lower than in the Australia and New Zealand region. The large difference between US- and EU27 + EFTA emissions is mainly attributable to much higher $CO_2$ emissions from electricity and heat production and from transportation (Figure 6). Emissions from electricity production in the United States are relatively high owing to heavy reliance on traditional coal-fired power stations (they supply almost one half of electricity). This technology choice reflects the low cost of coal relative to natural gas in parts of the country, fuel prices that are distorted by subsidies and the absence of strong financial incentives to encourage more efficient use of fossil plants or to use cleaner fuels for power generation (IEA, 2008). Even though public-mass-transit investment and usage have been increasing in the United States, its development is still limited compared to in European countries, contributing to transport emissions. Other factors that contribute to relatively high transport emissions are the low population density and consequent long distances travelled per capita and the low mileage performance of the vehicle fleet, although US-fuel-economy standards are being raised (see below). Low fuel taxes relative to EU27 + EFTA countries may contribute to these phenomena (Figure 7).

**Figure 6. $CO_2$ emissions per capita are much higher in the United States than in the EU27**

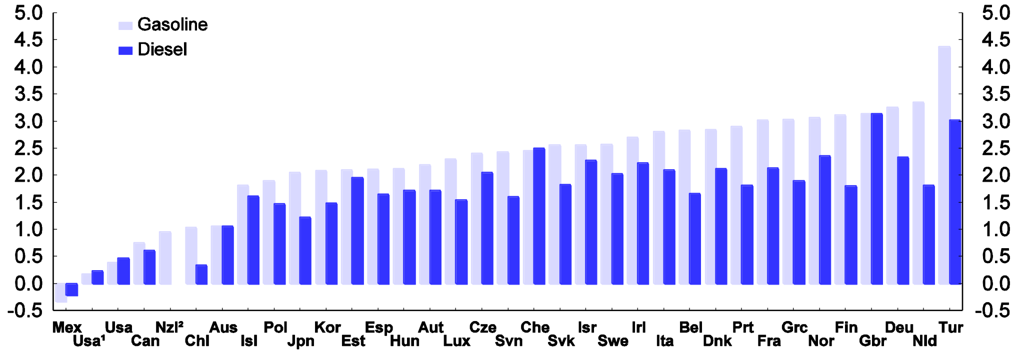
Tonnes




*Source*: IEA (2009a).

**Figure 7. Gasoline and diesel tax rates are relatively low in the United States**

USD per gallon, 2010




1. Federal.

2. New Zealand levies road-user charges on diesel vehicles.

*Source*: OECD, EEA database.

## Participation of the United States and other large emitters is pivotal to reaching an international agreement to reduce GHG emissions

### *Major GHG emitting countries must participate in global abatement efforts if they are to combat climate change effectively*

8. Stabilising the $CO_2$–equivalent concentration of long-lived GHG in the atmosphere at around 550 ppm (which corresponds to a $CO_2$ concentration of about 450 ppm) would offer about a 50% chance of limiting the long-term increase in global mean temperature above pre-industrial levels to about 3 °C (IPCC, 2007). However, it would be difficult for a global coalition of countries and/or regions to achieve this goal by 2050 without the participation of the United States and any other large emitter as this would entail very high global mitigation costs for participants and would be impossible if neither the United States nor China participated. To achieve the 550 ppm-GHG-concentration goal by 2100, economically feasible coalitions would need to include all major emitting regions except Africa. OECD (2009) analysis using the World Induced Technological Change Hybrid (WITCH) model (Bosetti *et al*., 2009a; and Bosetti, Massetti and Tavoni, 2007) provides theoretical support for these conclusions (Box 1). In the absence of a single carbon price across the coalition of emissions-abating countries and/or regions, which is probably more realistic, it would be even more difficult to achieve the target by 2050 without US participation as mitigation costs would be higher than otherwise, no longer being minimised across coalition countries, and would remain impossible by 2100. Moreover, it would be difficult to assemble a coalition of countries to take action that did not include the United States as other countries, especially developing countries, are unlikely to consider it equitable that they bear abatement burdens while the United States, which is one of the richest countries and largest emitters in the world, does not. This makes US leadership vital. Indeed, some countries have made the adoption of mitigation policies dependent on US action, with this link being explicit in the case of Canada. The current Administration has clearly signalled its desire for the United States to assume its leadership responsibilities by adopting a comprehensive package of policies to substantially reduce GHG emissions, subject to Congress passing the associated legislation (see below).

**Box 1. Strategic considerations for forming a global coalition to combat climate change**

OECD (2009) analysis using the World Induced Technical Change Hybrid (WITCH) model suggests that, in the absence of participation by the United States and any other large emitter, it would be difficult to form a coalition of countries and regions capable of achieving the long-lived-GHG-550 ppm-base target by 2050 through a single (coalition-wide) feasible carbon price without mitigation costs becoming very high and would be physically impossible if neither the United States nor China participated (other countries would have to have negative emissions). Even though mitigation costs are typically low in this version of the model owing to the assumption that new technologies will emerge gradually over the coming decades (Box 5.1, OECD, 2009, and Bosetti *et al* 2009b), economically feasible coalitions (*i.e.,* not having excessively high mitigation costs) would need to include all major emitting regions, including at least China or India to achieve the target by 2050, and all regions except Africa to achieve it by 2100 (OECD, 2009, Table 6.2).

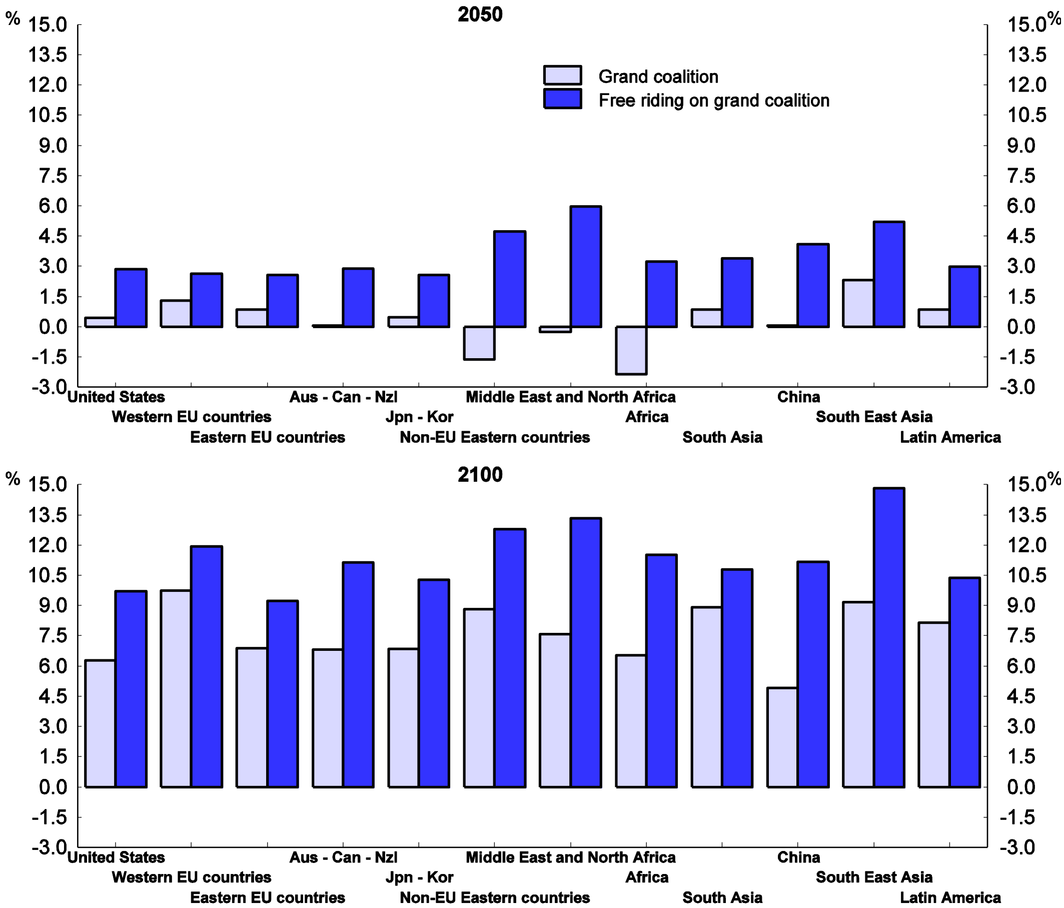
While US participation would facilitate the formation of an economically efficient coalition of countries and regions to combat climate change, countries and regions would need to consider that it is in their interests to join. This assessment of national interest depends on three main factors:

- *The expected impacts of climate change.* Developing countries are expected to be more adversely affected by climate change.
- *The influence of future impacts on current policy decisions*. How governments value these impacts has a large effect on incentives to take action. For example, the lower (higher) the discount rate used, the higher (lower) the value placed on the welfare of future generations.
- *The costs of mitigation policies*. In general, the higher the carbon intensity of a country's output, the larger will be its abatement costs under a global carbon tax (or a world emissions trading scheme (ETS) with full permit auctioning), and the smaller will be its incentive to participate in a climate coalition.

OECD (2009) analysis using the WITCH model finds that in the high damage/low-discounting case, which defines an upper bound for emission reductions, a fully co-operative welfare-maximising "grand coalition" involving all regions would cut emissions by 15% by 2050 relative to 2005 levels, and keep overall GHG atmospheric concentrations below 550 ppm $CO_2$-equivalent by the end of the century. All countries and regions except non-EU Eastern Europe, the Middle East and North Africa, and Africa would be better off in 2050 participating in the grand coalition than remaining in the non-cooperative BAU scenario, and all countries and regions would benefit by 2100 (Figure 8); in the low damage/high discounting case, which defines a lower bound for emission reductions, the grand coalition would allow emissions to rise by 75% by 2050 relative to 2005 levels (representing a cut of only 13% compared with BAU) and would not stabilise GHG concentrations. The problem is that all countries and regions would be still better off by free riding on the grand coalition, assuming that the rest of the coalition went forward with action without them. Given the assumed coalition-wide carbon tax, which equalises marginal abatement costs across countries and therefore precludes trade in emissions between coalition members, incentives to free ride are most acute for countries with flatter abatement cost curves and/or flatter marginal damage curves, because they would contribute more to the coalition's abatement effort and/or would benefit less. China, in particular, has stronger incentives than the United States, to free ride on a grand coalition.

**Figure 8. Most regions gain more from free riding than from participating in a world coalition**[1]

Percentage deviation of GDP from BAU Scenario - no international transfers, high-damage/low-discounting case




1. WITCH being an integrated assessment model, the damages from climate change explicitly affect GDP and consumption. Furthermore, not only the market, but also the non-market impacts of climate change are taken into account in the high-damage case featured here. This explains why all countries are found to gain from a grand coalition against climate change by 2100, compared with a BAU scenario.

*Source*: OECD (2009).

Financial incentives for developing countries with weak incentives to participate in global mitigation efforts might therefore be required for them to join a global coalition, with the incentives needing to be higher in the high damage/low discounting case than in the low damage/high discounting case. Such incentives could be provided through the way in which emission reduction commitments are negotiated across countries in a framework where all countries adopt national emission caps. Relatively generous caps in relation to global mitigation objectives would increase incentives for these countries to participate in global mitigation actions. This would separate the issue of who takes action – ensuring that mitigation action takes place wherever it is cheapest – from who pays for that action.

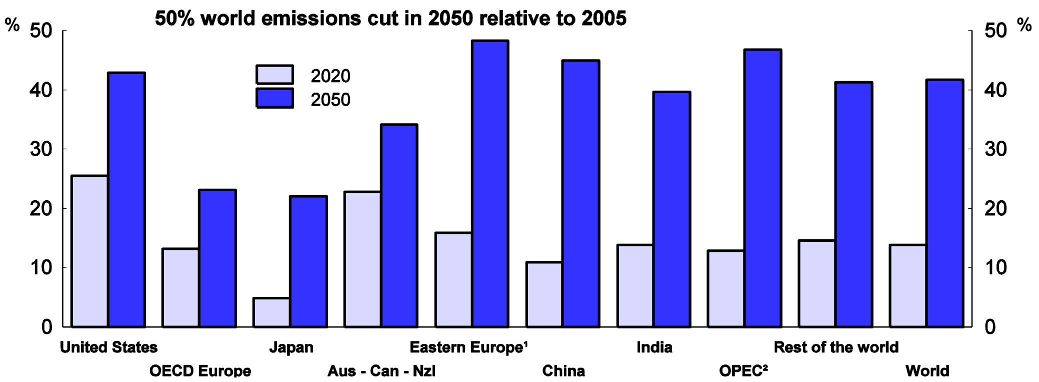
***Health and energy security co-benefits would reduce the net cost of US abatement measures***

9. In addition to reducing the exposure of Americans to the risk of high-cost climate-change events, US participation in global mitigation efforts would generate health co-benefits from reduced local air pollution (LAP) and energy-security co-benefits as dependence on oil from politically unstable regions would be reduced. There are other co-benefits of GHG mitigation policy, such as for ecosystems and biodiversity, but they are not examined here.

10. Bollen *et al*. (2008 and 2009) estimate that if a global carbon tax were implemented to reduce world emissions by 50% by 2050, premature deaths caused by LAP in the United States could be more than 40% lower than in a BAU scenario, which assumes that existing regulations (in 2008) to control LAP will be maintained and will become stricter over time as real incomes rise (Figure 9).[1] These benefits, which are higher than in most other OECD countries, are estimated to drop off sharply as the global emission reduction increases – most of the benefits are obtained from the first 25% reduction in emissions relative to BAU. Bollen *et al.*, (2008 and 2009) estimate that these health co-benefits could reduce the annual net cost of mitigation in the United States by two thirds by 2050 in this scenario, although they would remain modest as a share of GDP (about ½ per cent) (Figure 10). Health co-benefits in developing countries would have a smaller proportionate impact on the net cost of mitigation but would represent a significantly larger share of GDP (e.g., over 3% of GDP in China). The relatively large health co-benefits as a share of GDP in developing countries reflects the facts that LAP is worse than in developed countries and that developing countries would make proportionately greater reductions in their GHG emissions (especially from burning coal) than developed countries given the assumption underlying this analysis of a uniform global carbon price.

**Figure 9. The impact of reduced local air pollution through GHG mitigation policies on the percentage of premature deaths avoided**

Differences from the baseline in %




1. Including Russia.

2. Including Mexico.

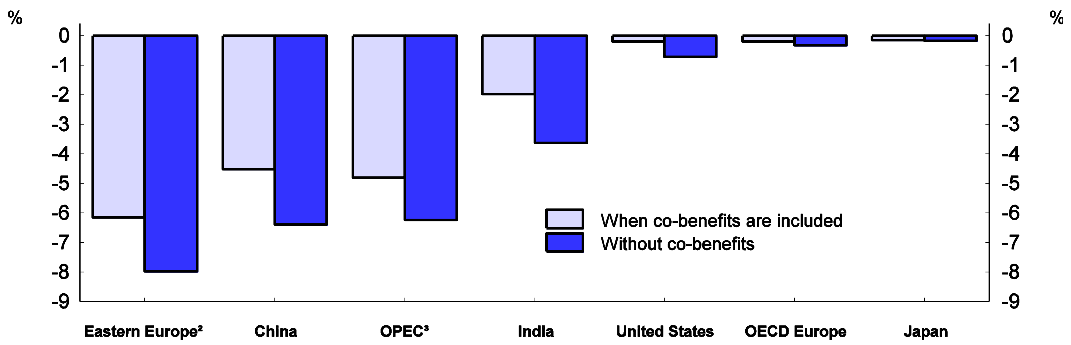
*Source*: Bollen *et al*., (2008).

11. Mitigation action could also improve energy security, which can be broadly defined as a low risk of disruption to energy supply, both in terms of physical availability and price stability (Bohi and Toman, 1996). Climate change mitigation could be expected to improve long-term energy security by reducing exposure to large unforeseen oil price shocks from OPEC countries, reducing economies' energy and fossil fuel dependence and hence the macroeconomic impact of any future price shocks, and by fostering energy risk diversification. As the most significant source of energy insecurity over coming decades is the risk of oil price shocks, the major source of enhanced energy security comes from reduced

oil intensity of GDP. The OECD (2009) estimates that the United States could halve its oil intensity of GDP by 2050 under various abatement scenarios (Figure 11). This reduction in oil intensity is similar to those in other OECD economies with relatively high GHG-emissions intensities of output (Canada, and the Australia and New Zealand region) and more than in European countries or Japan.

**Figure 10. Co-benefits only partially improve incentives for participation in a global climate-change agreement to reduce emissions by 50% by 2050[1]**

In per cent of GDP

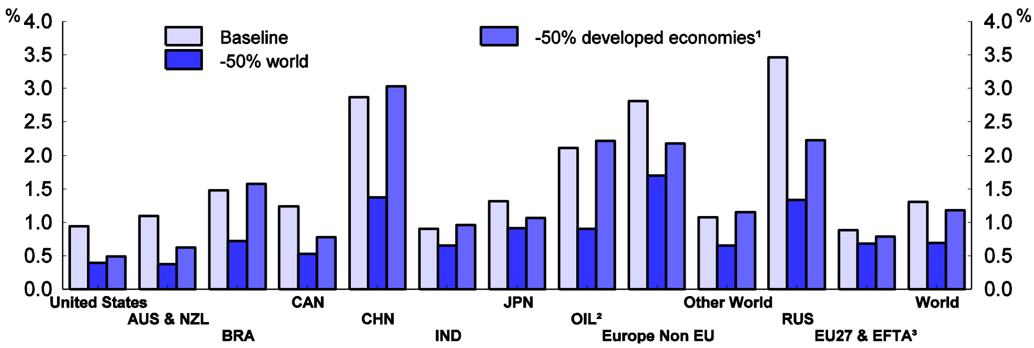



1. "Without co-benefits" is the return from GHG mitigation policy when co-benefits are not included, or the difference between the benefits in terms of avoided global climate change and the cost of mitigation policy. "When co-benefits are included" is the return from GHG mitigation policy when co-benefits are included, *i.e* the difference between the benefit in terms of both avoided global climate change and local air pollution and the cost of mitigation policy to which the opportunity gain of not having to achieve the same level of Local air pollution (LAP) reduction through direct policies is then added.
2. Including Russia.
3. Including Mexico.

*Source*: Bollen *et al*., (2008).

**Figure 11. The United States could reduce its oil intensity by more than most other OECD countries under different mitigation policies**

Domestic demand for refined oil as a % of GDP in 2050




1. United States, China, Australia, New Zealand, Canada, Japan, India, Russia, Brazil, EU27, Iceland, Norway and Switzerland.
2. Indonesia, Venezuela, Rest of Middle East, Islamic Republic of Iran, Rest of North Africa and Nigeria.
3. EU27, Iceland, Norway and Switzerland.

*Source*: OECD (2009).

***The United States agreed to the Copenhagen Accord and made conditional emission reduction commitments***

12. The United States agreed to the Copenhagen Accord (noted by the United Nations Framework Convention on Climate Change, Conference of the Parties 15th session (COP15)) in December 2009. It commits signatories to cooperate to achieve the peaking of global and national emissions as soon as possible, recognising that the timing for peaking will be longer in developing countries than in developed countries. Developed countries commit to economy-wide emission targets for 2020 while developing countries commit to mitigation actions. In the context of meaningful mitigation actions and transparency on implementation, developed countries also commit to provide funding for developing countries to help with mitigation and adaptation. As the Accord was "noted" rather than agreed to, there are no binding commitments. Nevertheless, the Accord makes clear the broad lines of a future agreement. Developed countries will commit to emission reduction targets, and developing countries, especially the larger more advanced ones, must take ambitious mitigation actions commensurate with their capability. As noted above, all major emitters, including notably China, must participate in abatement efforts for global-climate-change goals to be in reach.

13. As part of the Copenhagen Accord, the US government also committed to a national target for reducing GHG emissions in the range of 17% by 2020 from the 2005 level (equivalent to a reduction of about 3% from the 1990 level), in conformity with anticipated US energy and climate legislation, recognizing that the final target will be reported to the Secretariat in light of enacted legislation.[2] The EU27 + EFTA group of countries committed to a 30% reduction from the 1990 level (equivalent to a reduction of about 25% from the 2005 level) provided that other industrialised countries make comparable commitments and that developing countries make adequate commitments, falling to a 20% reduction otherwise. OECD (2010a) estimates that the EU27 + EFTA maximum commitment and the US commitment entail comparable efforts in terms of loss of real income (around 0.7% of BAU income by 2020 below). Based on the maximum commitments made by other OECD countries, OECD (2010a) estimates that the countries with high emissions intensity (Canada, Australia and New Zealand) would incur somewhat larger income losses while Japan would incur a smaller income loss. According to OECD (2010a), the US target, taken together with the declared targets of other industrialised countries, would lead to a 12-18% reduction in GHG emissions in 2020 compared with 1990 levels. While this is significant, further reductions from industrialised countries and the more advanced developing countries would be required to achieve the reductions judged by the IPCC to be necessary by 2050 to have a 50% probability of limiting warming to 2°C (this scenario entails stabilising the atmospheric concentration of long-lived GHG at 450 ppm $CO_2$-equivalent). To reach a final agreement, it will be necessary to agree a fair distribution of abatement burdens.

14. In the context of the above noted commitment of developed countries to provide financial assistance to developing countries to help them with abatement and adaptation measures, the US government announced that it would contribute its share to developed country financing of almost USD 30 billion over 2010-12 (US Department of State, 2010 for this sentence and the rest of the paragraph), which would entail a substantial increase in US climate assistance. In keeping with this commitment, the FY 2010 budget provides for more than a three-fold increase in bilateral and multilateral funding for climate-related activities from the enacted funding in the previous year. Funding for US Agency for International Development (USAID) climate programmes increases by 70%, with significant new investments in mitigation and adaptation strategies that will build on USAID experience in this area. Developed countries also committed to a goal of mobilising USD 100 billion globally from public- and private-sector sources by 2020 for climate assistance, subject to meaningful mitigation actions and transparency on implementation in recipient (developing) countries.

**The most cost-effective way to reduce GHG emissions is to price them and to support the development and diffusion of emission-reducing technologies**

*Pricing GHG emissions*

15. Private production and consumption decisions are made without taking into account the full costs of GHG emissions. Consequently, the level of GHG-intensive production and consumption activity is higher than is socially optimal. The most cost-effective means of ensuring that these external costs are internalised is to price emissions, either through an emission tax or a cap-and-trade scheme (which sets a cap on emissions and allows trade in emission permits). This will encourage producers and consumers to exploit abatement opportunities to the extent that their marginal abatement costs are less than the price of emitting GHGs. Because the cheapest opportunities are likely to be exploited first (absent other barriers), abatement costs are minimised by the pricing of emissions. This is all the more important at the international level, where there are large differences in marginal abatement costs across countries. The power of pricing to minimise abatement costs has been amply demonstrated in the United States through experience with the cap-and-trade scheme to reduce sulphur dioxide ($SO_2$) emissions in the electric-power sector (and hence acid rain) introduced in 1995. It has resulted in almost a halving of these emissions and compliance costs are estimated to have been 30-40% lower than would have been incurred had the command and control regulatory approaches considered by Congress instead been adopted (Stavins, 2005 and 1998; Carlson *et al*., 2000). Railroad deregulation increased cost savings from the cap-and-trade scheme by enabling Mid-Western electric utilities to reduce their $SO_2$ emissions by increasing their use of low-sulphur coal from Wyoming.

16. Most legislative proposals to price GHG emissions, both in the United States and in other countries, have opted for cap-and-trade schemes over a tax. A major reason for this preference is that cap-and-trade facilitates building political support through grandfathering (*i.e.,* giving permits to exiting emitters for free), which may be less transparent than recycling the revenues from a tax and more politically sustainable (subsidies have to be renewed regularly). Another reason is that cap-and-trade gives greater certainty about the amount of abatement to be achieved than does a tax, which generates strong political support from environmentalists. However, there is more uncertainty about marginal costs than with a tax, which sets such costs directly. This is potentially an important disadvantage for cap-and-trade because the increased certainty over short-term abatement costs with a tax is likely to be more valuable than the loss of certainty about short-term abatement because the slope of the marginal environmental damage curve is flatter than that of the marginal cost curve (OECD, 2009; Hoel and Karp, 2001; Newell and Pizer, 2003; Pizer, 2002). It is possible, however, largely to eliminate this disadvantage by including in a cap-and-trade scheme features such as price floors and ceilings and banking provisions that contribute to limiting short-term price volatility (Duval, 2008), as was done in the American Clean Energy and Security Act of 2009 (ACES) passed by the US House of Representatives and the American Power Act (sponsored by Senators Kerry-Lieberman) recently submitted to the Senate (see below). In any case, as experience is gained with either taxes or cap-and-trade, it is likely that adjustments will have to be made in, respectively, tax rates (to ensure that abatement is on track to meet emission reduction targets) or the caps (to ensure that the cost of permits remains in line with the marginal social costs of emissions). Further, if free allocations are conditioned on any behaviour by recipients (e.g., conditioned on facilities remaining open), attention should be paid to limiting the extent to which this may distort industry dynamics (*i.e.,* entry and exit incentives).

*Supporting the move to low-GHG-emission technologies*

17. Pricing GHG emissions would also increase incentives to invest in energy R&D to develop low-emission technologies and to deploy them. Such Induced Technological Change (ITC) would ultimately reduce emission abatement costs. OECD (2009) finds that pricing carbon to achieve stabilisation of the

overall GHG concentration at 550 ppm $CO_2$-equivalent in 2050 would quadruple both energy R&D expenditures and investments in installing renewable power generation, although this estimate would be lower if political uncertainty about the future path of carbon prices (current governments cannot commit future governments to a climate-change policy, while future governments have incentives to ease policy once irreversible investments in R&D and new equipment have been made) were taken into account. This analysis also suggests, however, that ITC alone may only have modest effects on mitigation costs. This is because low-carbon options (nuclear and carbon capture and storage, CCS) already exist in the electricity sector, marginal impacts of R&D on energy efficiency are decreasing, and learning effects in renewable energies fade.

18. Even with pricing of GHG emissions and without political uncertainty about the future path of carbon prices, the development and diffusion of low-emission technologies would still be less than is socially optimal. An important reason for this conclusion is that firms investing in R&D are typically unable to appropriate all or most of the social returns they generate owing to the public-good nature of knowledge. Much of the social return on R&D investments will accrue as spillovers to competing firms, downstream firms that purchase the innovating firm's products, or to consumers (Griliches, 1992). Empirical evidence suggests that social rates of return to R&D are substantially higher than private rates of return (Griliches, 1992) and that consequently, R&D investment is below the socially optimal level. This problem, which is common to technology development in general, may be accentuated in the case of climate change by the risk of large innovation rents from any major breakthrough being expropriated to facilitate rapid diffusion given the potentially large welfare benefits of such diffusion (OECD, 2009).

19. A number of challenges that make the pattern of development and deployment of new technologies path dependent may temporarily aggravate underinvestment in new technologies, such as clean-energy technologies, from society's perspective. First, market-size effects encourage R&D investments in sectors where there is a relatively large market for the outputs of such investments owing to the non-rival nature of knowledge, to the detriment of green technologies (Acemoglu *et al.*, 2009). Second, learning-by-doing (LBD) effects reduce the costs of existing technologies as firms and consumers learn better how to use them, resulting in slower than socially optimal diffusion of new technologies, such as clean-energy technologies, because neither firms nor consumers take these spillovers into account when making production and consumption decisions (Arrow, 1962; IEA, 2000; McDonald and Schrattenholzer, 2001; Neij *et al.*, 2003a and 2003b); historically, costs for a particular emerging technology have declined by approximately 20% for each doubling of cumulative production volume (Major Economies Forum, 2009). Third, economies of scale and the need for inter-industry cooperation to develop new infrastructure to commercialise some new technologies, such as electric cars or renewable energy, may also slow their diffusion (Gillingham and Sweeney, 2010).

20. Hence, while pricing GHG emissions would increase GHG-emission-reducing RD&D (Research and Development and Demonstration) investments, subsidies for such investments may also be needed to increase them closer to the socially optimal level. Such subsidies should represent a larger proportion of expenditures to develop technologies that are far from commercialisation than of such expenditures to develop technologies that are near commercialisation because knowledge spillovers tend to be greatest the further a technology is from commercialisation. This is why fundamental research is typically funded mostly by government while other R&D as well as demonstration tends to be mostly financed by the private sector. Ensuring that intellectual property right (IPR) protection is strong would also help to reduce underinvestment in RD&D caused by knowledge spillovers, while establishing a fund to buyout breakthrough technologies to reduce GHG emissions could reduce the perceived risks of expropriation discussed above as well as speeding diffusion. Pricing GHG emissions through a cap-and-trade scheme could help to reduce the political uncertainty that undermines investment in RD&D by building a political constituency for continued enforcement. Both public financial support and regulatory changes can help to overcome a lack of appropriate infrastructure for the development and deployment of some low-emission technologies. For example, public subsidies and regulations are being used to adapt the US electricity network to handle increased supplies of renewable energy (see below).

21. Very large increases RD&D are likely to be required to enable backstop technologies to emerge and hence for abatement costs to fall substantially. Assuming a world carbon price scenario that targets a 550 ppm GHG concentration, OECD (2009) estimates that global energy R&D investments would need to rise approximately six-fold initially, to 0.12% of global GDP, to enable backstop technologies to emerge.[3] These technologies are estimated to reduce abatement costs substantially at longer time horizons but not to have much effect before about 2025. By 2050, abatement costs and GDP costs could be one half of the levels without such technologies; these results concord with those in other studies (Edmonds *et al*., 2007; Manne and Richels, 1992; and Clarke *et al.,* 2006). Most of the reduction in abatement costs comes from backstop technology in the non-electricity sector, where the abatement potential of currently commercially available mitigation options is comparatively smaller than in the electricity sector (which has nuclear, CCS, wind and solar energy options). Further simulations also strongly suggest that world spending on energy-related R&D alone, regardless of its magnitude, would not be able to tackle climate change. No global R&D policy of any size operating in isolation is able to stabilize the atmospheric concentration of GHG this century.

22. Using a different model that emphasizes market-size effects in the allocation of R&D, Acemoglu *et al*., (2009) find that optimal policy would entail a massive and early shift in R&D investments from GHG-emitting-technologies to clean technologies, in addition to a carbon tax, for plausible values of the elasticity of substitution between dirty-and clean-production inputs and of the discount rate. Such an approach would support the emergence of break-through technologies to reduce GHG emissions, substantially reducing future abatement costs. In this model, both the R&D subsidies and carbon tax could eventually be phased out as clean technologies became sufficiently advanced (and dominant) that research would be directed towards them without further government intervention.

23. An alternative approach to assessing the extent to which RD&D to develop technologies that reduce GHG emissions needs to increase is to identify spending gaps in the main technologies concerned between what would be needed to achieve global emission-reduction goals and what is currently being spent. The IEA (2009b) recently conducted such an exercise for the Major Economies Forum covering ten climate-related technologies that together address more than 80% of the $CO_2$ emissions reduction potential identified by the IEA: advanced vehicles; bio-energy; CCS; building-sector-energy efficiency; industrial-sector-energy efficiency; high-efficiency-low-emissions coal; marine energy; smart grids; solar energy; and wind energy. The IEA found that the total annual RD&D funding needed, for both the public and private sectors, is USD 37-74 billion. Of this total, approximately half (USD 19-37 billion) relies on public sources. The current public funding level (excluding one-time stimulus spending) is around USD 5 billion, leaving a public RD&D funding gap of USD 14-32 billion, which implies that an increase to three to six times the current level of funding is required.

## Government policies implemented thus far to reduce GHG emission have been neither ambitious nor cost effective

### *Thus far, US governments have only adopted non-binding GHG abatement objectives*

24. Prior to the recent Copenhagen Accord, the only international agreement to reduce GHG emissions that the US government had ratified was the United Nations Framework Convention on Climate Change (UNFCCC), under which the United States and other industrial countries made a non-binding commitment to return GHG emissions to the 1990 level by 2000 and to stabilise them at this level. The United States, like most non-European OECD countries, has not met this target while the EU27 + EFTA countries have, on average (see above), although only one half these countries individually met the target. The United States did not ratify the Kyoto Protocol through which other industrialised countries committed to reduce GHG emissions to 5.2% below the 1990 level by 2012; the US target would have been to reduce emissions to 7% below the 1990 level by 2012.

25. Domestically, the previous Administration unilaterally adopted the non-binding target of reducing the GHG emissions intensity of the economy by 18% over 2002-12, a reduction four percentage points greater than was projected to occur on a BAU basis (minus 14%) at the time (2002) (IEA, 2008). The previous Administration also gave some indications that the United States was prepared to agree binding emission reduction targets for the post-2012 period in international negotiations provided that other major economies did likewise, with developed countries expected to bear a greater share of the abatement burden than developing countries. The targets referred to in this regard were to stop the growth in US missions by 2025 (a unilateral declaration made on 16 April, 2008) and for global emissions to be reduced by 50% by 2050 (G8 declaration, 8 July, 2008). Based on recent OECD projections of GHG emissions (Duval and De la Maisonneuve, 2010) and economic growth (OECD, 2010b), the United States is on track to meeting the 2012 emissions intensity target but has not yet implemented policies to achieve the longer-term targets.

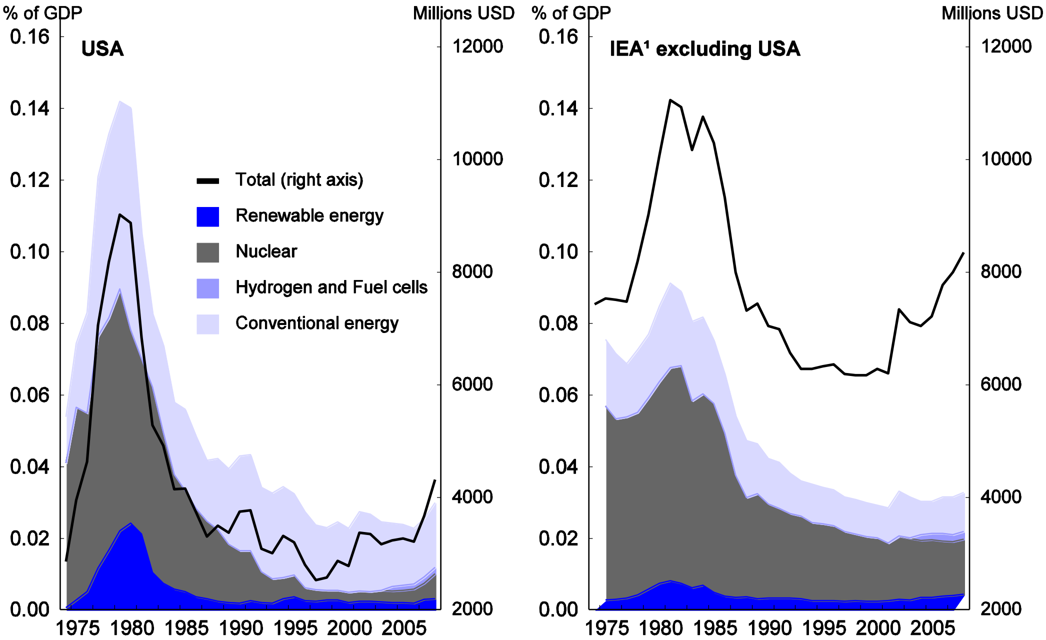
***Thus far, the main policy instruments deployed have not been cost effective***

26. Rather than price GHG emissions – the cornerstone of a cost-effective approach to reducing GHG emissions – the previous Administration focused on voluntary agreements (VA) with industry, which accounted for around one half of the estimated mitigation impact of measures reported in the fourth US Climate Action Report (United States Department of State, 2007), and on supporting the development and dissemination of technologies to reduce GHG emissions, notably through measures in the Energy Policy Act of 2005. This Act introduced or expanded tax breaks to accelerate market penetration of advanced, clean-energy technologies, provided loan guarantees for a variety of early commercial projects that use advanced technologies that avoid, reduce or sequester anthropogenic GHG emissions, and offered standby default coverage for certain regulatory and litigation delays for the first six new nuclear power plants to be constructed. To reduce emissions in the longer term, the Energy Policy Act of 2005 authorised the Climate Change Technology Program (CCTP). This is a multi-agency planning and coordinating entity whose purpose is to accelerate the development and deployment of technologies that can reduce, avoid, or capture and store greenhouse gas emissions. CCTP conducts analysis, provides strategic direction, and makes recommendations for strengthening the Federal portfolio of investments in related R&D.

27. While public spending on energy-related RD&D did increase, both the increase and the level attained were modest, especially compared with the period following the first two oil-price shocks (Figure 12); spending on nuclear and renewable sources, in particular, is now far lower than at that time. This increase and the level attained are comparable to those in other IEA member countries. The United States focuses much more of its public spending on energy-related RD&D on conventional energy sources (energy efficiency, fossil fuels, other power and storage technologies, and other technologies or research) than other IEA member countries, and much less on nuclear RD&D. While no comprehensive data exist on private sector RD&D, available evidence suggests that its share in overall private RD&D spending is low compared with other sectors and has been decreasing over the past two decades (OECD, 2009). Disaggregated sectoral analysis (Alic *et al.*, 2003) suggests that R&D spending in power generation as a share of total turnover is much lower than in manufacturing.

**Figure 12. Public spending on energy-related RD&D has increased in recent years but remains low**

2008 PPP prices




1. Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom.

*Source*: International Energy Agency, RD&D Budget - Edition 2009; OECD, Economic Outlook database 87 (May 2010).

28. None of these policy instruments is cost effective as a substitute for emissions pricing. They do not internalise the costs that GHG emissions impose on others. Accordingly, there is no reason for abatement to be the least costly. Moreover, the absence of pricing weakens incentives for induced technical change to reduce emissions. Rather, such policies have the potential to work best as complements to emissions pricing. For example, voluntary agreement (VA) programmes can contribute to information gathering and diffusion of best practice. Similarly, support for RD&D to reduce emissions complements emissions pricing by addressing other market failures, such as the inability of investors in innovation to appropriate all social returns from these investments owing to the public-good nature of knowledge. Another problem with proposing support for RD&D as a substitute for the pricing of GHG emissions is that this pushes back the timing for achieving emission reductions. Yet timing is important because irreversible environmental damage could occur before the hoped-for emission-reducing technologies materialise. Moreover, as noted above, even much higher levels of support for RD&D in the absence of pricing of GHG emissions could not stabilise GHG atmospheric concentrations.

29. The Energy Policy Act of 2005 also mandated an increase in the bio-fuel content of gasoline sold in the United States – to 4 billion gallons in 2006, 6.1 billion gallons by 2009, and 7.5 billion gallons by 2012. This programme has been a particularly costly way of reducing GHG emissions. Abstracting from indirect land use effects (ILUE), corn-based ethanol, which is a first generation bio-fuel and the dominant one in the United States, is estimated to reduce GHG emissions by 20-30% (Wang, 2009); another widely quoted study, however, puts the reduction at only 13% (Farrell, 2006). Assuming that the reduction in GHG emissions is 10-20%, the OECD (2008b) estimates abatement costs of at least USD 1 000 per tonne

of $CO_2$, making this a very expensive way of reducing GHG emissions; by way of comparison, emission permit prices in the European Trading Scheme have generally been less than EUR 20 per tonne of $CO_2$-equivalent. This programme has also taken land out of production of food for (direct or indirect) human consumption, pushing up food prices slightly, and increased the cyclical volatility of global food prices because subsidies for corn-based bio-fuels are positively related to oil prices, which are positively correlated with the global business cycle.

30. The Renewable Fuels Standard (RFS) was substantially revised in the Energy Independence and Security Act of 2007 (EISA) to give increased weight to bio-fuels that are more effective in reducing GHG emissions, allowing for direct emissions and significant indirect emissions such as from indirect land use changes. EISA established new renewable fuel categories, setting mandatory life-cycle-GHG-emissions thresholds for them in relation to average petroleum fuels used in 2005. It grandfathered existing corn-ethanol plants but requires a 20% reduction in life-cycle GHG emissions for any renewable fuel produced at facilities for which construction started after 19 December, 2007, a 50% reduction for a renewable fuel to be classified as biomass-based diesel or advanced bio-fuel, and a 60% reduction for a fuel to be classified as cellulosic bio-fuel. EISA requires a gradual increase in the use of bio-fuels by American fuel producers from 9 billion gallons in 2008 to 36 billion by 2022 and requires them to use an increasing proportion of advanced bio-fuels – they are required to rise from nothing in 2008 to 21 billion gallons (16 billion gallons of which must be cellulosic bio-fuel) by 2022.[4] The Act also created a USD 1.04 per gallon subsidy for cellulosic bio-fuel and reduced the ethanol subsidy from USD 0.51 to USD 0.45 per gallon. The requirement in EISA to take account of ILUE when setting the revised renewable fuel standard (RFS2) is a major improvement on the original RFS that should not be sacrificed, as would occur were the provision in the American Clean Energy and Security Act of 2009 (ACES, see below) prohibiting the EPA from taking this factor into account to be retained in final climate-change legislation. This provision was not included in the American Power Act (Kerry-Lieberman) subsequently submitted to the Senate but not voted on owing to insufficient support in the Senate.

31. To implement RFS2, the EPA has had to estimate the life-cycle GHG emissions effects of bio-fuels, allowing for significant ILUE. Based on its modelling, peer-review comments and new studies and public comments, the EPA issued its final ruling on RFS2 in February 2010 (Table 1). Taking a 30-year time horizon and a zero per cent discount rate, the EPA concluded that corn-based ethanol produced under certain conditions (notably, not using a coal-fired dry mill plant) just met RFS2. Sugarcane ethanol and cellulosic ethanol are much more effective, qualifying as advanced bio-fuels under the ruling.

**Table 1. Sugarcane ethanol and cellulosic ethanol are more effective for reducing GHG emissions than corn ethanol** )

Life cycle Year 2022 GHG emissions reduction results for RFS2 final rule (includes direct and indirect land use change effects and a 30 year payback period at a 0% discount rate)

| Renewable fuel Pathway (for US consumption) | Mean GHG emission reduction(1) | GHG emission reduction 95% confidence interval(2) | Assumptions/comments |
|---|---|---|---|
| Corn Ethanol | 21% | 7-32% | New or expanded natural gas fired dry mill plant, producing 37% wet and 63% dry Distiller's Grains and Soluables (DGS), and employing corn oil fractionation technology |
| Corn butanol | 31% | 20-40% | |
| Sugarcane ethanol(3 | 61% | 52-71% | Ethanol is produced and dehydrated in Brazil prior to being imported into the U.S. and the residue is not collected. GHG emissions from ocean tankers hauling ethanol from Brazil to the U.S. are included. |
| Cellulosic ethanol from switchgrass | 110% | 102-117% | Ethanol produced using the biochemical process. |
| Cellulosic ethanol from corn stover | 129% | No ILUE | Ethanol produced using the biochemical process. Ethanol produced from agricultural residues does not have any international land use emissions. |
| Biodiesel from soybean | 57% | 22-85% | Plant using natural gas. |
| Waste grease biodiesel | 86% | No ILUE | Waste grease feedstock does not have any agricultural or land use emissions. |

1. Per cent reduction in lifecycle GHG emissions compared to the average lifecycle GHG for gasoline or diesel sold or distributed as transportation fuel in 2005.
2. Confidence range accounts for uncertainty in the types of land use change assumptions and the magnitude of resulting GHG emissions.
3. A new Brazil module was developed to model the impact of increased production of Brazilian sugarcane ethanol for use in the US market and the international impacts of Brazilian sugarcane ethanol production. The Brazil module also accounts for the domestic competition between crop and pasture land uses, and allows for livestock intensification (heads of cattle per unit area of land).

*Source.* US Environmental Protection Agency (EPA, 2010a), Tables 2.6 -1 to 2.6 -12

32. The EPA's analysis thus supports earlier evidence that sugarcane-based ethanol has much lower GHG emissions abatement costs than corn-based ethanol, even when the latter is produced under conditions that minimise GHG emissions (using natural gas instead of coal to power dry mill plants). However, agriculture and trade policies discourage the use of sugarcane-based ethanol, which would be imported from Brazil, by setting high import tariffs on sugarcane-based ethanol. Abatement costs could be reduced by eliminating subsidies for bio-fuels with lower life-cycle GHG emissions reductions than sugarcane-based ethanol – *i.e.,* corn-based ethanol and biobutanol, including from plants currently grandfathered – and by abolishing the import tariffs on sugarcane-based ethanol. These measures could also be used to help to negotiate lower barriers in Brazil against imports of technologies to reduce GHG-emissions. Removing the barriers to sugarcane-based ethanol could also make it easier to meet the advanced bio-fuels requirements in EISA as there are still considerable technical barriers to overcome before commercialisation of other such fuels. Even so, the blend wall – current federal regulations stipulate that gasoline should not contain more than the current 10% ethanol-fuel blend because higher concentrations could damage engines – is a major technical barrier to meeting RFS2. It has been suggested that raising the permissible blend to 15% (E15) could ease this constraint. However, it is debatable whether recent vehicles as a group can use E15, older vehicles (pre-2001) cannot do so, and use of intermediate blends in gasoline-powered non-road engines can create serious safety issues. Moreover, using E15 in motors not adapted for this fuel may damage emissions-control equipment. The blend wall is particularly

problematic for the development of cellulosic ethanol envisaged in EISA because any incremental additions to the already saturated ethanol market would have to be absorbed by Flexible-Fuel-Vehicles (FFVs) that receive E85 through a new, parallel fuel distribution infrastructure. In view of these problems, it would be preferable to replace the bio-fuels mandate with the pricing GHG emissions, which would be a more cost-effective means of reducing them. Were the various actors presented with prices that internalized the external impacts of GHG emissions, it is quite possible that altogether different approaches (such as electric or hybrid-electric vehicles) would displace crop-derived liquid fuels. Moreover, proper pricing could help reveal whether bio-fuels truly are less carbon intensive than conventional fuels (corn, in particular, requires a great deal of energy to grow, harvest and process even before it appears at a bio-refinery).

***Some states are introducing measures to reduce GHG emissions***

33. In the face of weak measures at the national level to reduce GHG emissions, a number of states have set emission-reduction targets and have introduced or plan to introduce emissions trading schemes to achieve these targets cost-effectively (Table 2). The only such scheme already in place is the Regional GHG Initiative (RGGI), which covers 10 North-eastern and mid-Atlantic states (Box 2). Other major regional schemes are scheduled to begin in 2010. There is also a voluntary emissions trading scheme (the Chicago Climate Exchange, CCX) which operates at a national level. CCX emitting members make voluntary but legally-binding commitments to meet annual emission-reduction targets, which are modest. A major aim of the scheme, in common with the RGGI, is to build experience with GHG emissions trading schemes. In the event that a national emissions trading scheme is created (see below), it could pre-empt regional systems, although no decisions in this regard have yet been taken. It could also provide some allowances or other “carrots” for early action, giving states incentives to move forward with their ETS in the meantime. Permits from the regional systems could be converted into national permits at the average market price for regional permits in the year of their vintage.

**Table 2. A number of state/regional or voluntary GHG emissions trading schemes are getting underway**

| **United States** | | | |
|---|---|---|---|
| Regional GHG initiative (RGGI), covering ten North-eastern and Mid-Atlantic states | In place | 2009 | $CO_2$ emissions from the power sector have to be reduced by 10% by 2018.<br>The majority of allowances are auctioned.<br>Offsets can be used but are limited to a number of projects within states participating in the scheme and outside the capped electric power generation sector. |
| Voluntary Chicago Climate Exchange (CCX) | In place | 2003 | CCX is a voluntary cap and trade system, CCX emitting members make a voluntary but legally-binding commitment to meet annual GHG emission reduction targets. Those who reduce below the targets have surplus allowances to sell or bank; those who emit above the targets comply by purchasing a CCX carbon financial instrument.<br>In Phase I (2003-06), members committed to reduce emissions by at least 1% a year, for a total reduction of 4% below the baseline. In Phase II (2007-10), CCX members commit to a reduction schedule that requires 2010 emission reductions to be at least 6% below the baseline. |

| | | | |
|---|---|---|---|
| California | Planned | 2010 | The Global Warming Solutions Act signed in 2006 caps GHG emissions at 1990 levels by 2020. Against this background, California has released plans for the introduction of an emissions trading scheme in 2010 and is working closely with other states and provinces in the Western Climate Initiative (WCI) to design a regional cap-and-trade programme (see below).<br><br>Regulations to implement the cap-and-trade system would need to be developed by the beginning of 2011. |
| Western Climate Initiative (WCI)[1] | Planned | 2010-20 depending on state | The target is to lower GHG emissions by 15% from 2005 levels by 2020.<br><br>When fully implemented in 2015, the programme is expected to cover nearly 90% of the GHG emissions in WCI states and provinces.<br><br>Each member state/province has the flexibility to decide how best to allocate allowances. At least 10% of allowances at the start of the programme, increasing to at least 25% by 2020,will have to be auctioned.<br><br>Offsets can be used under certain conditions. |
| Midwestern Regional GHG Reduction Accord[2] | Planned | | The target and design of this ETS has yet to be decided. However, the Advisory Group recommends a 20% emission cut by 2020 relative to 2005 levels, and a 80% cut by 2050. |

1. The Western Climate Initiative includes seven US states and four Canadian provinces: Arizona, California, Montana, New Mexico, Oregon, Utah, and Washington; and British Columbia, Manitoba, Ontario, and Quebec.

2. The accord involves 9 Midwestern governors and 2 Canadian premiers, who have signed on to participate or observe in the *Midwestern Greenhouse Gas Reduction Accord*.

*Source:* OECD (2009, Table 7.2)

**Box 2. Regional Greenhouse Gas Initiative (RGGI)**

The RGGI, which got underway in 2009, is a cap-and-trade scheme covering the electricity sector in 10 North-eastern and mid-Atlantic states.[1] This scheme sets caps that stabilize electricity sector GHG emissions at their 2009 level over the first compliance period (2009-14) and reduces them by 10% over the second period (2015-18). Ninety per cent of RGGI emission permits are auctioned and 70% of the auction proceeds are invested in promoting energy efficiency, including by supporting R&D. The RGGI has not had a great effect on emissions to date because emissions have turned out to be much lower than anticipated when the cap was set; concomitantly, emission-permit prices have collapsed to just above the price floor (banking between compliance periods is permitted). The sharp drop in emissions occurred because of mild weather, a large switch out of oil-based electricity since 2005, and the severe recession. The cap will need to be adjusted down for the next compliance period to allow for the lower than anticipated BAU level of emissions.

1. The 10 participating states are: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.

34. States have taken a variety of other actions to reduce GHG emissions (United States Department of State, 2010, Table 4-2). In some cases, the efficiency of these measures is undermined by the lack of co-ordination between states. An important example in this regard is renewable (energy) portfolio standards (RPS) (IEA, 2008). Twenty-five states and the District of Columbia have established such standards using different design principles and goals. The lack of consistency between these standards increases the cost of meeting renewable energy standards by limiting cross-border trade in such energy. These problems could be overcome by the federal government establishing a federal electricity RPS covering those parts of the country in which cross-border trade in electricity is feasible, as is proposed in ACES (see below), although the efficiency of such an instrument would depend on its interaction with a national carbon pricing instrument.

***State and local government land-use regulations need to integrate housing development and public-transport infrastructure decisions***

35. Another government policy weakness from the point of view of combating climate change is that local and state land-use regulations often do not integrate housing development and transport infrastructure decisions. The result is that the United States has many urban areas that are not adapted for public transport. For this to change in the long term, land-use regulations should integrate housing development and public transport availability. This could result, for example, in more housing redevelopment in already built-up areas, which are often better suited to public transport than the alternative green-field sites. In making this change, policymakers could learn from the experiences of Germany and the Netherlands, which have successfully implemented such policies.

**The current Administration's preferred climate-change policy would yield large cost-effective reductions in emissions if implemented**

***The Administration is endeavouring to establish a comprehensive climate-change policy***

36. The current Administration is endeavouring to establish a comprehensive climate-change policy, the main planks of which are pricing GHG emissions and supporting the development and deployment of innovative technologies to reduce GHG emissions. As discussed above and emphasized in OECD (2009), this is the right approach to deliver cost-effective abatement. Pricing emissions provides incentives to reduce emissions at least cost. It also provides incentives to invest in RD&D to develop and deploy clean technologies, although public support for RD&D and deployment is still needed to bring them up to socially optimal levels owing to a number of market failures (knowledge spillovers, political uncertainty, market-size effects, and learning-by-doing effects). Public support for the development and deployment of such technologies has been increased, and further increases are planned. And the Administration has proposed pricing GHG emissions through a cap-and-trade scheme that would reduce emissions in line with the conditional commitments made at Copenhagen and would reduce emissions from covered emissions sources (82.5% of the total by 2016) by 83% from the 2005 level by 2050. To prepare the ground for such a scheme (or regulation of GHG emissions if a cap-and-trade scheme is not implemented – see below), the United States will begin collecting data in 2010 on greenhouse gases from large emitters. The federal government's technology strategy to reduce GHG emissions, which is supported by these policy instruments, is summarised in Box 3.

**Box 3. The federal government's technology strategy to reduce GHG emissions**

| Key Technology Elements | Supporting Policies |
|---|---|
| • Coal | • Financial Incentives |
| – De-Carbonize the Grid | – Value Avoided GHG Emissions |
| – Nuclear Power | – Technology Investment Incentives |
| – Low-Emission Coal Power | – Loan Guarantees to Address Risk |
| – Renewable Power | – Fuel Mandates |
| • Cars | – Codes, Standards, Labelling |
| – Transform Vehicles To New Fuels | – Transparent Means for Measuring Progress |
| – Hybrid and Electric Vehicles | **R&D Strategy** |
| – Alt. Fuel Vehicles and Bio-Based Fuels | • Mobilize US Research Enterprise, incl. private |
| – Alternatives, including Other Modes | • Boldly Innovate with New Research Approaches |
| • Efficiency (All Sectors) | • US Climate Change Technology Program |
| • Other GHGs | – Strengthen Federal R&D Portfolio |
| • Enablers | – Prioritize Investments |
| – $CO_2$ Capture and storage | • Expand R&D Co-operation and Collaboration |
| – Modernized Grid | – Include non-Federal Entities |
| – Energy Storage | – Encourage International Co-operation |
| » Large Scale, Utility-Scale | • Seek Sustained Increases in R&D Investment |
| » Small Scale, Vehicle-Scale | |
| – Strategic and Exploratory Research | |

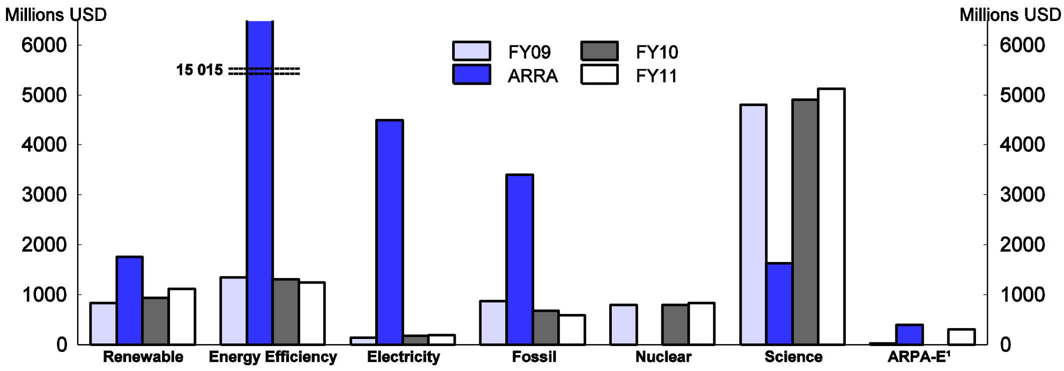
*Source:* Marlay (2010)

***Public support for RD&D and deployment of technologies to reduce emissions is rising***

37. The Administration gave a substantial boost to public funding for Research, Development and Deployment (RD&D, which includes expenditure to speed the spread of a given technology (deployment), in addition to traditional R&D, which is focused on creating new technologies) to reduce GHG emissions through the American Reinvestment and Recovery Act of 2009 (ARRA), which boosted such funding by about USD 26.7 billion according to US Department of Energy (DOE) estimates (Marlay, 2010) (Figure 13). Almost one half of this total was allocated to measures to increase energy efficiency, such as subsidies for improving building insulation. ARRA included USD 400 million of funding for the DOE’s Advanced Research Projects Agency – Energy (ARPA-E), which promotes and funds research and development of advanced energy technologies that might not otherwise occur because of a high risk of failure. Such funding could also help to overcome underfunding of such R&D caused by the risk of high innovation rents from breakthrough technologies being expropriated, as discussed above. There was also a considerable boost to funding to improve the electric grid so that it is better adapted to receiving and managing renewable energy and an additional USD 6.0 billion of loan guarantees offered through the Innovative Technology Loan Guarantee Program. The Department of Energy is aiming to have committed all of these ARRA funds by the end of FY 2010 and to have spent 35-40% of the total by then.

**Figure 13. The Department of Energy's (DOE's) innovation budget ("science") is steadily rising**

DOE Energy RD&D by Program Office (Total $9.4 B)




1. Advanced Research Projects Agency-Energy.

*Source*: Marlay (2010).

38. The DOE's innovation budget ("Science" in Figure 14) has increased steadily in recent years, to USD 5.1 billion in the FY 2011 budget request. The largest budget allocations in this category, which represents about one half of DOE's RD&D budget, are for basic energy sciences, high energy physics, and biological and environmental research. The government plans to double investment in basic research over the next five years. The main categories in the remainder of the DOE's energy RD&D budget are for energy efficiency, renewable energy, nuclear energy, and fossil energy (advanced coal-fuelled-systems, and CCS). To further deployment, the DOE has requested funding authority to support loan guarantees of USD 36 billion for new nuclear power plants and USD 4.4 billion for renewable energy and electricity transmission. These guarantees are intended to enhance access to finance for these projects as they may otherwise have difficulty being financed owing to their high risk, high capital intensity, and high degree of sunk costs (which reduces the collateral value of such assets). The Administration has also proposed in the FY 2011 Budget to eliminate most fossil-fuel subsidies by ending tax credits worth USD 39 billion over the next decade, in line with the agreement among G-20 countries in September 2009 to phase out such subsidies.

39. While the actual and planned increases in public support for RD&D and deployment of technologies to reduce GHG emissions are laudable, still larger increases are likely to be required to have a good chance of developing breakthrough technologies that greatly reduce abatement costs (see above). To avoid an inadequate supply of scientists being a constraint on such a large expansion in both public- and private-energy RD&D - there is evidence that R&D subsidies can drive up wages of scientists enough to prevent significant increases in R&D (Goolsbee, 1998) – it will probably be necessary also to substantially increase investments in training scientists.

40. As noted above, the United States cooperates with other members of the Major Economies Forum on Energy and Climate to promote innovation, deployment and information sharing in low GHG-emissions technologies. Action plans have been developed in the technologies considered to be the most important for reducing emissions. The United States is leading the action plans on energy efficiency in the buildings sector and industrial sector energy efficiency.[5]

***Energy-efficiency regulations are contributing to cost-effective abatement***

41. Regulation can also be a cost-effective approach to reducing emissions where information and other barriers prevent market-based instruments from working efficiently. For example, the Administration has been proactive in establishing minimum energy efficiency standards for motor vehicles and a wide variety of consumer products and commercial equipment. In the case of motor vehicles, the Corporate Average Fuel Economy (CAFE) regulation issued in 2001, which stipulated an increase in new vehicle fuel economy standards to be achieved by 2007, was one of the programmes estimated to have made the greatest contribution to abatement over recent years (United States Department of State, 2007). The EPA and the Department of Transport (DOT) recently issued new joint regulations to reduce GHG emissions and increase fuel economy of new passenger cars and light trucks sold in model years 2012 through 2016. The EPA projects that $CO_2$ emissions per mile of the average new light-duty vehicle will be 23% lower by 2016 than in 2011 and that fuel savings associated with the more efficient GHG technologies will far outweigh the higher initial vehicle costs (by 2020, fuel savings (at pre-tax fuel prices) amount to 35.7 billion USD, compared with vehicle compliance costs (excluding fuel savings) of 15.6 billion USD (US Environmental Protection Agency, 2010b)). These estimates do not, however, allow for the loss of consumer welfare from requiring consumers to purchase more fuel economy than they would absent the regulation. This loss is likely to be significant given that consumers are not already flocking to fuel efficient models for which extra technology costs are more than compensated by fuel savings (this phenomenon is sometimes referred to as the "Energy Paradox"). President Obama also issued an Executive Order in 2009 requiring federal agencies to set and meet strict GHG reduction targets by 2020. He also called for more aggressive efficiency standards for common household appliances and put in motion a programme to open the outer continental shelf to renewable energy production.

***Legislation along the lines of the American Clean Energy and Security Act of 2009 (ACES) would provide a sound basis for achieving cost-effective abatement***

42. The House of Representatives has passed legislation (the American Clean Energy and Security Act of 2009, ACES) that contains a cap-and-trade programme covering 85% of US emissions by 2016 that would deliver the GHG-emission reductions signalled in Copenhagen (17% below the 2005 level by 2020 and 83% below by 2050), and the Senate introduced a new climate bill (the American Power Act, sponsored by Senators Kerry and Lieberman) in May 2010 that is broadly similar, although it has not been passed owing to insufficient support in the Senate. Extensive analyses of ACES highlight a number of lessons that can inform legislators as they decide whether or not to support future climate-change legislation. The economic costs of reducing GHG emissions are modest when a comprehensive approach is adopted, the centrepiece of which is the pricing of GHG emissions. The CBO (2009) estimates that GDP would be 1.1% to 3.4% lower in 2050 than on a BAU basis were ACES to be passed (Table 3), which corresponds to a tiny reduction in annual GDP growth.[6] CBO (2009) also concludes that annual workforce turnover caused by comprehensive climate-change legislation would be small compared with what normally occurs because there are few workers in energy-intensive sectors and change occurs over a long period. Competiveness- and employment impacts in energy-intensive and/or trade-exposed sectors (which account for 10% of emissions and 0.5% of non-farm employment) are minimal if they are given output-based allocations of emission permits free of charge (Inter-Agency Report, 2009). Finally the border-tax-adjustment (BTA, import fees levied by countries that price GHG emissions on goods manufactured in countries that do not) provisions in the ACES legislation passed by the House of Representatives would be costly to the economy, administratively burdensome to implement, are unlikely to be successful at protecting domestic industries from competiveness impacts, and may not be the most effective means of addressing leakage (OECD, 2009). The Senate bill has much more flexible language on this front, although as noted above, there has not been enough support in the Senate to pass this bill.

**Table 3. The economic costs of reducing GHG emissions are modest when a comprehensive approach is adopted**

Projected Changes in Gross Domestic Product in Selected Years from the Implementation of H.R. 2454

| Year | Percentage Change |
|---|---|
| 2020 | -0.2 to -0.7 |
| 2030 | -0.4 to -1.1 |
| 2040 | -0.7 to -2.0 |
| 2050 | -1.1 to -3.4 |

*Source:* Congressional Budget Office (2009).

43. One aspect of achieving modest abatement costs is the availability of a large supply of international offsets (*i.e.*, emission reductions from foreign sources not subject to emission caps that can be used by a covered entity towards its emission permit requirements) provided that they are subject to strict oversight and are verifiable to ensure that they represent genuine reductions from business-as-usual (a concern with offsets is that they may be subject to fraud and double counting). For example, ACES permits a large supply of international offsets to enter the system each year (up to 1.5 $GtCO_2$-equivalent, discounted by 25% from 2017)[7]. The US EPA (2010c) projects that covered entities would make substantial use of them (accounting for 33% of cumulative abatement over 2012-50) but would not hit the usage constraint during the first half of the century. Consequently, permit prices would equal international offset prices (USD 14 per tonne of $CO_2$ eq. in 2012, rising to USD 70 in 2050 in 2005 prices) adjusted for the discount factor. In the absence of international offsets, however, permit prices would be up to 150% higher by 2050; on the other hand, simply delaying international offsets has a much more modest impact. This makes it important for the US government to support multilateral efforts towards strengthened emissions monitoring in developing countries and to develop sectoral or even country-based approaches to ensure that a large supply of genuine offsets is available if comprehensive climate-change legislation is passed. There would also be much to gain from working with foreign governments to harmonise national cap-and-trade programmes so that they can eventually be linked. All of these measures would help to ensure that abatement occurs where it is cheapest rather than where it is being paid for. In the presence of an adequate supply of international offsets, the bringing on-stream of Carbon Capture and Storage (CCS) electricity generation capacity and/or of more nuclear power is not a critical factor in containing abatement costs (the EPA estimates that permit prices would only be 15% higher than otherwise). However, in the absence of international offsets, these technologies make a large difference to abatement costs (permit prices would be 80 percentage points higher by 2050, bringing the total increase to 230% above the reference scenario). Regardless of whether or not there are international offsets, ACES would represent a relatively low-cost approach to reducing emissions.

44. Another issue for legislators to consider if they adopt a cap-and-trade scheme is the extent to which permits will be issued free of charge. The more permits that are given away, the less scope there is to use revenues from allowance auctions to reduce other taxes that distort economic activity more, increasing the overall economic costs of reducing GHG emissions. In view of the need for budget consolidation, it would be wise to keep the free allocation of permits to a minimum so that funds raised from permit auctions can be devoted to deficit reduction, once low-income households have been compensated and more funds made available for energy RD&D. Insofar as this reduces the need for increases in other taxes, which distort economic activity, this use of the funds raised reduces the excess burden of taxation (*i.e*., the costs to economic efficiency of taxation) compared with what it otherwise would have been.

45. If climate change legislation is not passed, the EPA will progressively extend regulation to reduce emissions from motor vehicles to all other sectors. This would not be as cost-effective an approach to abatement and would be unlikely to be sufficient to enable the United States to achieve the emissions reduction targets communicated at Copenhagen. In this scenario, such regulation should be complemented by increases in gasoline and other fossil-fuel taxes.

**Summary of recommendations for achieving cost-effective abatement of GHG emissions**

46. The main recommendations for reducing GHG emissions cost effectively are summarised in Box 4.

**Box 4. Summary of recommendations for achieving cost-effective abatement of GHG emissions**

- Implement comprehensive pricing of GHG emissions, as in ACES or the American Power Act.
- Support multilateral actions to strengthen emissions monitoring in developing countries and work with other countries to ensure that a large supply of genuine offsets is available, e.g. through sectoral or even country-based approaches. Work with other countries to harmonise national cap-and-trade programmes so that they can eventually be linked.
- Limit the free allocation of emission permits as much as possible so that revenue can be applied to budget deficit reduction once low-income households have been compensated and more funds have been made available to energy RD&D. Increase the energy RD&D budget to increase the probability of developing breakthrough technologies that substantially reduce abatement costs and take steps to increase the supply of scientists working in the field.
- Remove import barriers against sugarcane-based ethanol and eliminate subsidies for domestic producers of corn-based ethanol.
- In the event that it is not possible to pass legislation pricing GHG emissions, reduce emissions using the next most cost-effective instruments available, such as energy taxes and regulation.

## NOTES

1. The regional time profiles of local air pollution (LAP) substances in the BAU scenario follow OECD (2008a) for SO2, NOx, and $NH_3$, and Bollen *et al.*, (2007) for $PM_{2.5}$.

2. The pathway set forth in pending legislation would entail a 30% reduction by 2025 and a 42% reduction by 2030, in line with the goal to reduce emissions by 83% by 2050.

3. This estimate comes from the WITCH-model, which incorporates a detailed representation of the energy sector into an inter-temporal growth model of the economy and, in contrast to most of the literature, does not assume that backstop technologies emerge without dedicated investments. The way in which the impacts of R&D (and learning-by-doing) on the costs of these "backstop" technologies are incorporated into the model relies partly on past experience with solar, wind and nuclear power.

4. EISA's volume requirements are denominated in ethanol equivalent gallons (i.e., indexed to the relatively low energy density of ethyl alcohol). As a gallon of diesel contains approximately twice the energy of a gallon of ethanol, the drop in diesel fuels currently projected to satisfy the bulk of the cellulosic fuel requirements is a far smaller number of gallons than the rise in the number of ethanol equivalent gallons.

5. The other action plans are: advanced vehicles (led by Canada); bio-energy (led by Brazil and Italy); carbon capture, use and storage (led by Australia and the United Kingdom); high-efficiency-low-emissions coal (led by India and Japan); marine energy (led by France); smart grids (led by Italy and Korea); solar energy (led by Germany and Spain); and wind energy (led by Germany, Spain, and Denmark).

6. By way of comparison, current environmental regulation in the United States is estimated to cost about 2 - 2½ per cent of GDP (Portney, 1998).

7. In other words, an international offset of 125 tonnes of $CO_2$-equivalent gives a covered entity an emission permit credit of 100 tonnes of $CO_2$-equivalent.

# BIBLIOGRAPHY

Acemoglu, D. P. Aghion, L. Bursztyn, and D. Hemous (2009), "The Environment and Directed Technical Change", *NBER Working Paper* 15451.

Alic, J., D. Mowery and E. Rubin (2003), "US technology and innovation policies: lessons for climate change", *Report for the Pew Center on Global Climate Change*, Arlington, VA.

Arrow, K. (1962), "The Economic Implications of Learning by Doing," *Review of Economic Studies* 29, 155-173.

Bohi, D. and M. Toman (1996), *The Economics of Energy Security*, Kluwer Academic Publishers, Massachusetts.

Bollen, J., B. van der Zwaan, C. Brink, H. Eerens (2007), "Local Air Pollution and Global Climate Change: A Combined Cost-Benefit Analysis", Netherlands Environmental Assessment Agency MNP Report 500116002/2007.

Bollen, J., C.Brink, H. Eerens, and A. Manders (2008), "Co-Benefits of Climate Policy", PBL Report No. 500116005, PBL, Bilthoven, the Netherlands.

Bollen, J., B. Guay, S. Jamet, and J. Corfee-Morlot (2009), "Co-benefits of Climate Change Mitigation Policies: Literature Review and New Results", *OECD Economics Department Working Papers*, No. 693, Paris.

Bosetti, V., E. Massetti and M. Tavoni (2007), "The WITCH Model: Structure, Baseline, Solutions", *FEEM Working Paper Series* No. 10-2007, Fondazione Eni Enrico Mattei, Milan.

Bosetti, V., C. Carraro, E. De Cian, R. Duval, E. Massetti, and M. Tavoni (2009a), "The Incentives to Participate in and the Stability of International Climate Coalitions: A Game Theoretic-Analysis Using the WITCH Model", *OECD Economics Department Working Papers* No. 702, Paris.

Bosetti, V., C. Carraro, R. Duval, A. Sgobbi, and M. Tavoni (2009b), "The Role of R&D and Technology Diffusion in Climate Change Mitigation: New Perspectives using the WITCH model", *OECD Economics Department Working Papers* No. 664, Paris.

Clarke, L. E., M. Wise, M. Placet, C. Izaurralde, J. lurz, S, Kim, *et al*., (2006), *Climate Change Mitigation: An Analysis of Advanced Technology Scenarios*, Pacific Northwest National Laboratory, Richland, WA.

Carlson, C., D. Burtraw, M. Cropper and K. Palmer (2000), Sulphur Dioxide Control by Electric Utilities: What are the Gains from Trade?", *Journal of Political Economy*, December.

Congressional Budget Office (2009), "The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions", September, Washington D.C.

Duval, R. (2008), "A taxonomy of instruments to reduce greenhouse gas emissions and their interactions", *OECD Economics Department Working Papers*, No. 636, Paris.

Duval, R. and C. De la Maisonneuve (2010), "A Long-Run Growth Framework and Scenarios for the World Economy", *Journal of Policy Modeling*, Vol. 62.

Edmonds, J., M. A. Wise, J. J. Dooley, S. H. Kim, S. J. Smith, P. J. Runci *et al.*, (2007), *Global Energy Technology Strategy: Addressing Climate Change*, Joint Global Change Research Institute, Battelle Pacific Northwest National Library, College Park, MD.

Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare and D. Kammen (2006), "Ethanol can contribute to energy and environmental goals", *Science* 27 January 2006: Vol. 311, No. 5760, pp 506-508.

Gillingham, K., and J. Sweeney (2010), "Market Failure and the Structure of Externalities", in (eds. forthcoming) A. Jorge Padilla and Richard Schmalensee, *Harnessing Renewable Energy*.

Goolsbee, A. (1998), "Does government R&D policy mainly benefit scientists and engineers?" *American Economic Review* 88: 298-302.

Griliches, Z. (1992), "The search for R&D spillovers", *Scandinavian Journal of Economics,* 94:S29-S47.

Hoel, M. and L. Karp (2001), "Taxes and Quotas for a Stock Pollutant with Multiplicative Uncertainty", *Journal of Public Economics*, Vol. 82, No. 1.

Inter-Agency Report (2009), "The effects of H.R. 2454 on international competitiveness and emission leakage in energy-intensive trade-exposed industries".

Intergovernmental Panel on Climate Change (2007), *The Fourth Assessment Report (AR4)*.

IEA (2000), *Experience Curves for Energy Technology Policy*, Paris.

IEA (2008), *Energy Policies of IEA Countries: The United States 2007 Review*, Paris.

IEA (2009a), *$CO_2$ Emissions from Fuel Combustion*, *2009 Edition*, Paris.

IEA (2009b), "Global gaps in clean energy, research, development and demonstration", Paris.

McDonald, A. and L. Schrattenholzer (2001), "Learning Rates for Energy Technologies", *Energy Policy* Vol. 29 No. 4, pp 255-261.

Major Economies Forum (2009), "Technology Action Plan".

Manne, A. and R. Richels (1992), *Buying Greenhouse Insurance*, MIT Press, Cambridge.

Marlay, R. C. (2010), "Changing Landscape of DOE's Research Enterprise", US Department of Energy, Washington D.C.

Neij, L., and P. Andersen and M. Durstewitz (2003a), The Use of Experience Curves for Assessing Energy Policy Programmes", in IEA (eds), *Experience Curves: Tool for Energy Policy Analysis and Design*, Proceedings of joint European Union/International Energy Agency Workshop, Paris.

Neij, L., *et al.*, (2003b), "Experience Curves: A Tool for Energy Policy Assessment", *Environmental and Energy Systems Studies*, Lund University, Sweden.

Newell, R. and W. Pizer (2003), "Regulating Stock Externalities Under Uncertainty", *Journal of Environmental Economics and Management*, Vol. 45, No. 2.

Nordhaus, W. D. (2007), "The Challenge of Global Warming: Economic Models and Environmental Policy".

OECD (2008a), *OECD Environmental Outlook to 2030*, Paris.

OECD (2008b), *Biofuel Support Policies: An Economic Assessment*, Paris.

OECD (2009), "The Economics of Climate Change Mitigation: Policies and Options for Global Action Beyond 2012", Paris.

OECD (2010a), "Interim Report of the Green Growth Strategy: Implementing our Commitment for a Sustainable Future", Paris.

OECD (2010b), *OECD Economic Outlook No. 87*, Vol. 2010/1, Paris.

Pizer, W. (2002), "Combining Price and Quantity Controls to Mitigate Global Climate Change", *Journal of Public Economics*, Vol. 85, No. 3.

Portney, P. (1998), "Counting the Cost: The Growing Role of Economics in Environmental Decision-making", *Environment Magazine*, at 3.

Stavins, R. (1998), "What can we learn from the Grand Policy Experiment? Lessons from $SO_2$ Allowance Trading", *Journal of Economic Perspectives*, Summer.

Stavins, R. (2005), "Lessons Learned from $SO_2$ Allowance Trading", *Choices*, 20(1).

United States Department of State (2007), *US Climate Action Report 2006, 4th ed.*, Washington D.C.

United States Department of State (2010), *US Climate Action Report 2010, 5th ed.*, Washington D.C.

US Environmental Protection Agency (2010a), "Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis", Washington D.C.

US Environmental Protection Agency (2010b), "Light Day Vehicle Rule Regulatory Impact Analysis", Washington D.C.

US Environmental Protection Agency (2010c), "Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009", 1/29/10, Washington D.C.

Wang, M., M. Wu and H. Huo (2007), "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types", *Environmental Research Letters* 2 (2007) 024001, IOP Publishing Ltd, United Kingdom.

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