Protecting Our Biosphere:
A Comprehensive Response to Climate Change

Environment Northeast

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About Us

Environment Northeast (ENE) is a not for profit environmental research and advocacy organization focusing on the northeastern United States and eastern Canada. Our mission is to address large-scale environmental problems through policy analysis, collaborative problem solving efforts, and an advocacy program that promotes environmental sustainability. Our core staff has professional backgrounds in the areas of environmental law, energy policy, ecosystem planning and forestry.

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Acknowledgements

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The report was designed by **Jill Bock Design** and printed by **Spectrum Printing and Graphics, Inc**.

This report was made possible by the generous financial support of the **Rockefeller Brothers Fund** and in kind contributions of the **Clean Air Task Force**.

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Originally Published July, 2001
Revised January, 2002
Reprinted May, 2003

Introduction

Climate scientists have arrived at a broad consensus about air pollution and climate change. Simply put, carbon dioxide (CO_2), and other global warming emissions are heating up our planet. If this warming trend continues it could have large and potentially catastrophic impacts on human settlement and the environment.[1] And while it is true that there are uncertainties in climate science, the risks associated with global warming are so great that it would be irresponsible not to develop an immediate plan of action. The good news is that if we start now and move aggressively, we will have much better prospects of managing the problem than if we wait even 10 years.

Considerable time and resources have been committed over the past decade to a national debate on what our country should do to address the threats posed by climate change. Much of this debate focused on proposals to establish binding international emissions reduction requirements, and the prospects for and costs of meeting such requirements. We believe it is time to step back from this debate and move forward with a comprehensive plan of action on several fronts. By acting expeditiously, we should be able to prove to ourselves that the threat posed by climate change can be effectively addressed – both domestically and globally.

First, we can produce substantial, near-term reductions in domestic greenhouse gas emissions. As explained in our Plan for Near Term Reductions, we envision an aggressive, comprehensive plan of action to pursue this "low hanging fruit" – reliably producing significant carbon reductions at a reasonable cost – in three parts:

- Implementing **five proven and affordable initiatives** to produce large domestic carbon emissions reductions by 2012;
- Pursuing additional **energy efficiency and renewable energy initiatives**; and
- Establishing an aggressive greenhouse gas **cap and trade system**.

These three programs can and should begin immediately to produce significant carbon reductions by 2012. Many actions that can deliver results within the next 10-12 years take considerable time to implement and generate much greater savings over time than they do initially. Delaying implementation of certain key initiatives for even a few years can drastically reduce their potential to produce savings by 2012.

Second, we can begin now to start building the foundation for producing very deep greenhouse gas reductions well into the next several decades. Key steps, enumerated in the Plan for Longer Term Reductions, include:

- Developing action plans for significantly **reducing several non-CO_2 greenhouse emissions or concentrations** (methane and ozone formation), along with emissions of black carbon aerosols;
- Implementing projects that **capture and sequester carbon** from commercial fossil fueled energy resources; and
- Promoting **advanced fossil energy systems.**

Now is a critical time to take a fresh look at how we should respond to global warming. No political consensus exists internationally or domestically about how to deal with climate change. Meanwhile, new scientific evidence suggests that the causes of global warming are more numerous than previously understood, which presents intriguing new opportunities to limit climate warming. New technologies are emerging to limit greenhouse gas emissions, expanding the range of tools we can employ to address global warming. We find ourselves today with an excellent opportunity to step back, review long term greenhouse gas emissions trends, consider the greenhouse gas reduction targets that must be pursued and select the most promising solutions to reach those targets. From that perspective we will be positioned to re-formulate a vision for action to constrain global warming.

This report:

- Summarizes recent conclusions on global climate change science and sets targets for constraining global warming to levels that avoid unacceptable risk;
- Outlines in a comprehensive Action Plan a range of promising initiatives that can achieve these greenhouse gas reduction targets; and
- Sends a "wake up call" that the time for action is now – waiting another 10 years to address climate change will be too late.

Trends and Targets

By reviewing the climate science about trends in global climate change, we can better understand the targets we must set for reducing global warming emissions.[2]

The Framework Convention on Climate Change, signed during the 1992 Earth Summit in Rio de Janeiro and subsequently ratified by the United States and more than 180 other nations, calls for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[3]

Extensive analysis has subsequently been conducted by the Intergovernmental Panel on Climate Change (IPCC)[4] exploring a wide range of GHG reduction and climate response scenarios. Based largely on this work, we can set domestic reduction targets for GHG reductions by answering the following questions.

To avoid dangerous climate change, how much warming is too much, and how fast is too fast?

Once emitted, CO_2 persists in the atmosphere for decades to centuries. As CO_2 accumulates in the atmosphere, its concentration rises, which – along with the effects of other GHGs and certain aerosols – increases the warming of the planet.

- Constrain global warming to between 1° and 2° centigrade before 2100 by stabilizing the atmospheric concentrations of carbon dioxide at 450 parts per million;
- Reduce net domestic greenhouse gas emissions to no more than 1,250 million metric tons of carbon equivalent per year by 2012;
- Reduce domestic greenhouse gas emissions to one-quarter of today's levels by 2060.

In 1997, a group of prominent scientists called on then-President Clinton to take action to limit global warming to the "**lowest rate feasible** given emissions that have already occurred" to ensure that future climate change is limited to **a rate that allows forest and other vegetative systems to respond without severe disruption**.[5] Concerns about the disruption that may result from global warming have recently been reinforced by the IPCC Third Assessment Report, as shown starkly in **Figure 1**.[6]

The lowest atmospheric concentration of CO_2 in 2100 considered achievable in the Third Assessment Report **is 450 parts per million (ppm)**. Stabilizing CO_2 at this concentration is projected to **limit warming to**

FIGURE 1:
Global Warming -- Reasons for Concern

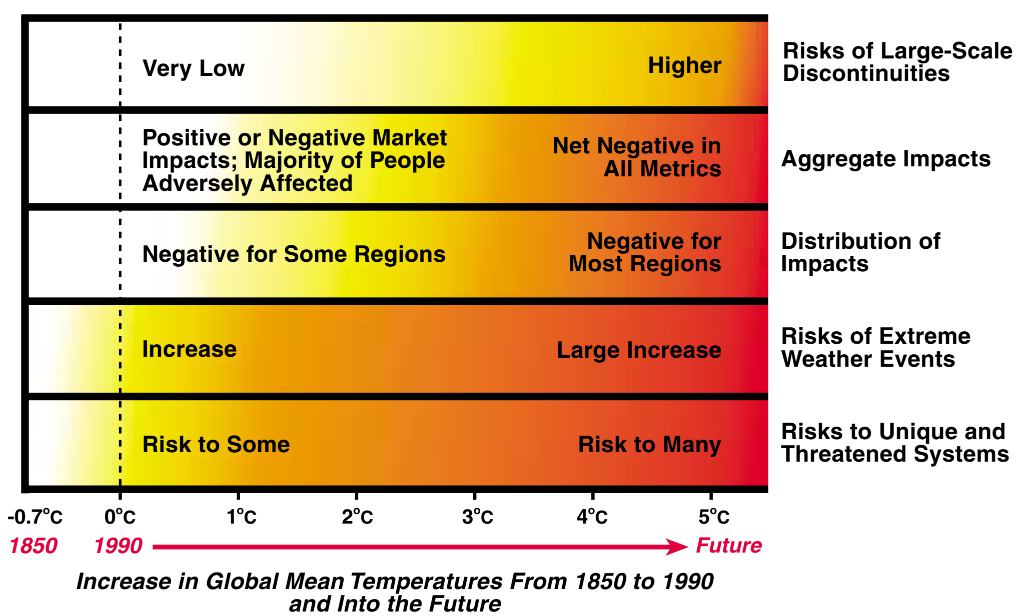


FIGURE 1 —

White means there is little or no impact or risk; yellow means modest detrimental impacts or risks; red means more detrimental impacts or higher risks. Examples of impacts are reduced crop yields, flooding, plant and animal extinctions, and exposure to diseases. "Discontinuities" means large-scale, singular events such as a shutdown of the North Atlantic thermohaline circulation.

Source: IPCC.[7]

FIGURE 2:

Effects of Delay: The Longer We Wait, The More Painful The Cuts

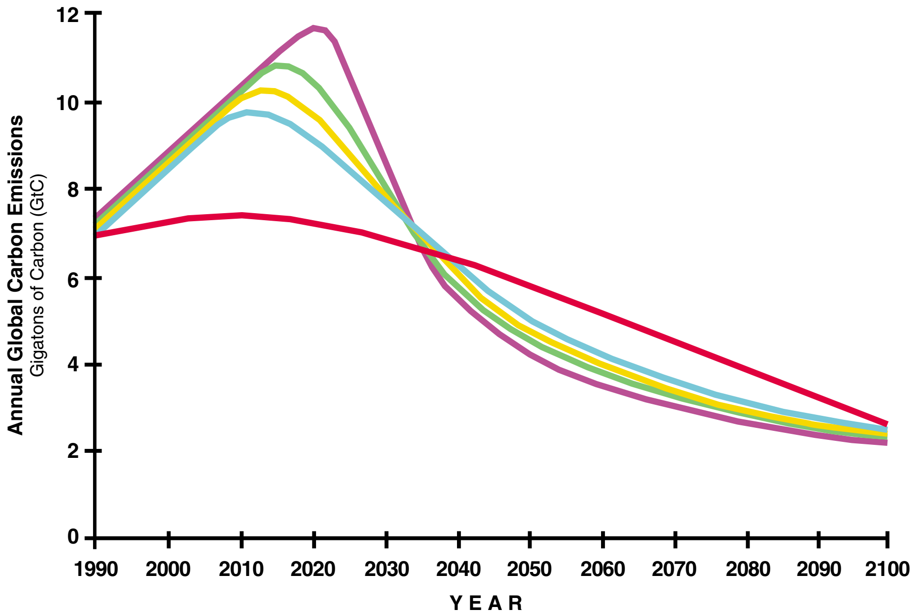


FIGURE 2 —

The path to reaching atmospheric concentrations of CO_2 at a level of 450 ppm can be gradual and affordable or it can be steep and costly. The red line shows the path of CO_2 emissions reductions (about 2% per year) had we begun in 1990. The blue, yellow, and green lines show the increasingly steep and sudden path of CO_2 emission reductions that will be required if we delay emissions reductions until 2005, 2010, or 2015, respectively. If we wait until 2020, the path will look like the purple line, requiring the precipitous and unreasonably costly cuts in CO_2 emissions approaching 5% per year.

Source: Environmental Defense

between 1° and 2° centigrade by 2100.[8] Our first target is thus to constrain warming during this century to between 1° and 2° centigrade by keeping atmospheric concentrations of CO_2 below 450 ppm.

■ How much must global CO_2 emissions be reduced to limit global warming by 2100 to 1-2 degrees centigrade?

Globally, annual emissions of CO_2 need to eventually drop to about one-half of today's levels by 2060 to constrain atmospheric CO_2 concentrations to 450 ppm. Given limited progress to date in reducing global CO_2 emissions, a range of plausible trajectories for reductions that could achieve the 450 ppm target is shown in **Figure 2**. This figure shows that the longer global reductions are delayed, the steeper the required cuts are in the 2030 to 2050 time frame.

■ How much must domestic CO_2 emissions be reduced to meet this global reduction target?

Both highly industrialized and developing countries will need to share the burden of meeting the CO_2 emissions reduction trajectory necessary to limit atmospheric CO_2 concentration to 450 ppm. It is unrealistic to expect developing countries to move as rapidly as highly industrialized countries, but both groups will need deep reductions.

FIGURE 3:

Shared Responsibility for Reducing Carbon Emissions

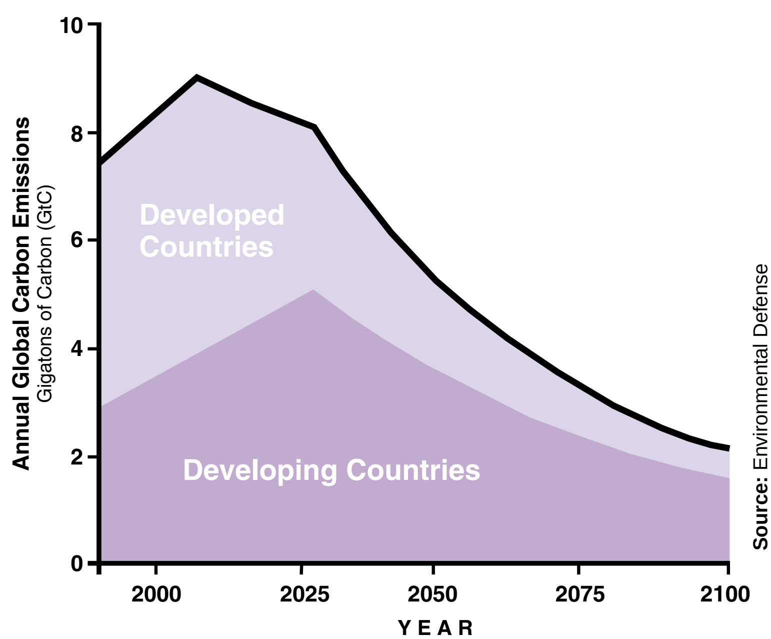
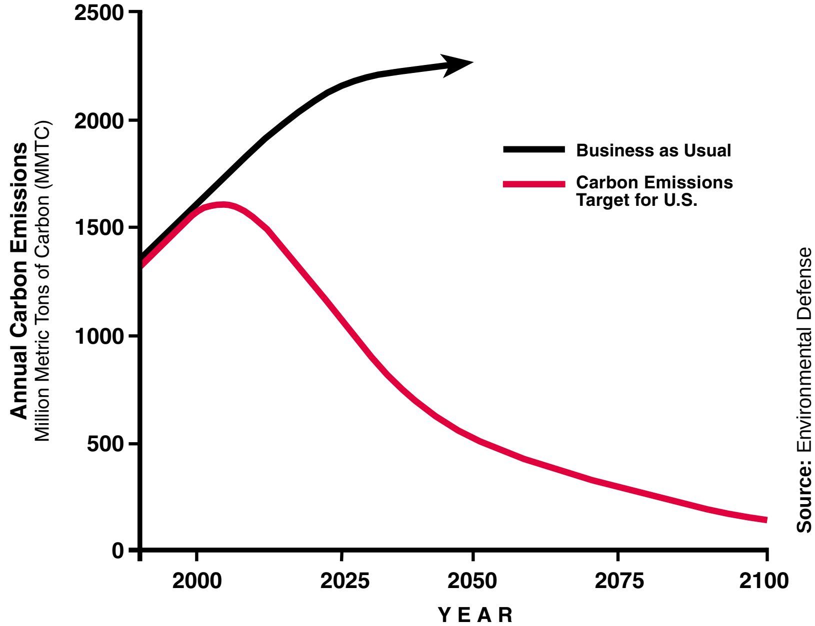


Figure 3 shows a "shared responsibility" reduction scenario that can achieve the 450 ppm concentration target. This would **require industrialized countries like** the US to reduce CO_2 emissions to about 15% below 1990 levels by 2015, dropping to about 40% below 1990 levels by

2030. Ultimately, by 2060 the U.S. (and every other industrialized nation) should expect to achieve roughly 75% reductions of CO^2 emissions from its current **(2001) levels**, as shown in **Figure 4**.

FIGURE 4:
Carbon Emissions Target For United States



■ Why do CO_2 emissions reductions need to start immediately?

Substantial reductions in global CO_2 emissions **must occur within the next 10 to 15 years** or it may be nearly impossible to limit atmospheric CO_2 concentrations to 450 ppm. This is in part due to the need for very deep reductions if cuts are delayed, as shown in **Figure 2**, and also because the sheer volume of carbon emitted before reductions occur **will preclude achieving this target if cuts are significantly delayed**, even if global carbon emissions were reduced to zero for the remainder of the century.

■ What reductions are needed in the other greenhouse gases and aerosols that impact climate?

To meet our warming limitation target, reductions will also be needed in the other GHGs besides CO_2 and in aerosol air pollution. It is difficult to set specific targets for these other pollutants until better modeling and analysis of their impacts is available from the scientific community. For the time being, it is reasonable to set a working target of reducing these other global warming emissions in the same proportions as we propose to reduce CO_2.

Looking at these trends and targets, it is clear that addressing climate change will require effort in both the international and domestic arenas over many decades. Given the long timeframe, we recognize that large future uncertainties will influence this process. Therefore, the following action plan focuses primarily on measures that can be taken over roughly the next decade and can be initiated and implemented in the U.S.

INTERNATIONAL ENERGY AGENCY

Carbon Sequestration

Renewable Energy

NREL

BALLARD POWER

Advanced Fossil Energy

Plan for Near Term Reductions

Five Proven and Affordable Initiatives

To establish a conservative “floor” for projecting domestic carbon emissions reductions that can be achieved over the coming decade, five initiatives are described below that can reliably produce significant carbon reductions within the target period at a reasonable cost:

1. Increase the **cogeneration** of electricity and useful heat;
2. Aggressively implement existing federal authority to set equipment and building **energy efficiency standards** and codes;
3. Enact **comprehensive power plant emissions reduction requirements** that include a power system **carbon cap**;
4. Enact simple-to-implement policies to expand production of electricity from **renewable sources**; and
5. Adopt either a voluntary manufacturers agreement or modified federal fuel economy standards to improve **light vehicle fuel efficiency**.

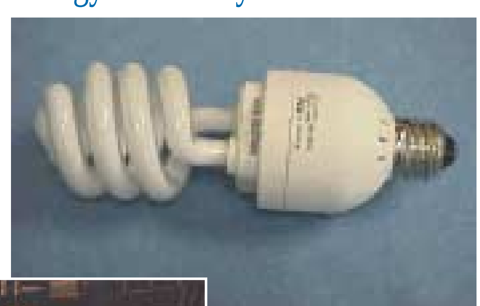
These initiatives can be accomplished without significant changes in consumer behavior and through proven mechanisms at the scale required. Projected carbon emissions reductions produced by these programs have been conservatively estimated with input from “hands on” experts and market participants[9] and may understate the savings actually produced.[10]

These initiatives clearly do not represent the full potential for near-term domestic carbon emissions reductions using other potentially feasible implementation mechanisms and less conservative analysis assumptions. **These additional mechanisms should also be aggressively pursued** and as they bear fruit, resulting carbon reductions will be substantially greater than savings projected from the initiatives described below.

Advanced Fossil Energy

INTERNATIONAL FUEL CELLS, LLC

Energy Efficiency



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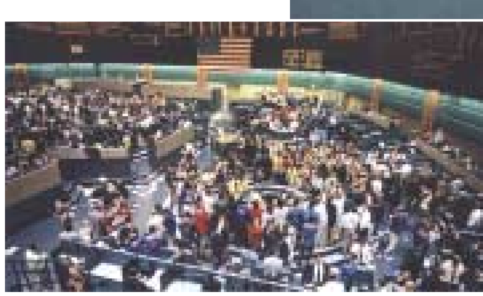
Emissions Trading



NYMEX

Initiative 1 –
Increase Cogeneration of Electricity and Heat

Cogeneration or "combined heat and power" (CHP) is power generation where waste heat from power production is captured to provide useful work. These systems make more complete use of the energy contained in fuel for CHP plants, displacing the need to burn fossil fuel to produce the heat. This in turn reduces carbon emissions. This initiative implements a group of actions to facilitate expanded use of cogeneration outlined in *Scenarios for a Clean Energy Future*,[11] a study recently published by the US Department of Energy (DOE), including:

- Increase DOE's CHP/Distributed Generation technology development budget by 50%, focusing on increased efficiency, reliability improvement, and cost reduction;
- Implement CHP tax credits included in the Clinton Administration's FY2000 Budget Proposal;
- Adopt federal tax rules allowing accelerated depreciation of CHP equipment assets;
- Expedite certification of CHP projects meeting efficiency and heat/power share criteria to qualify for tax incentives, allowing self-qualification of facilities for financial incentives;
- Provide guidance to state agencies on establishing faster CHP permitting processes, encouraging arrival of new capacity online earlier;
- Enact national interconnection standards for CHP and other distributed generation projects;
- Boost government support of advanced interconnection packages/technologies, leveraging on industrial research and development investment to realize moderate installed cost; and,
- Mandate availability of backup power at reduced cost, or spur customer "shopping" for competitively-priced backup power.

This initiative is projected to reduce domestic carbon emissions by about **14 million metric tons of carbon (MMTC) per year** and to produce savings of about **$150 million per year by 2012**.

Initiative 2 –
Advance Federal Energy Efficiency Codes and Standards

The Energy Policy Act of 1990 (EPACT) provided broad federal authority to set energy efficiency standards for buildings and equipment (lighting systems, electrical appliances, gas furnaces and water heaters, motors, etc.). While much action has been taken to exercise these authorities since EPACT was passed, this initiative assumes more aggressive implementation than is likely to occur without a serious national commitment to do so. Specific activities would include:

- **Building Energy Codes**

  Support implementation of efficient commercial and residential building codes, and offer technical support for local implementation.

- **Equipment Efficiency Standards**

  Continue development of federal energy efficiency standards for a range of equipment, including residential and commercial air conditioning, lighting, and water heating, residential appliances, fans, and reduced standby losses on electronic equipment. These standards-setting efforts rely heavily on state energy efficiency investment conservation programs to help increase technology availability, penetration, and effectiveness.[12]

This initiative would reduce domestic carbon emissions by **42 to 67 million metric tons of carbon per year** by 2012. These reductions are estimated **to save the economy from $10.8 billion to $21.0 billion per year in 2012**, as the costs of reducing energy use are substantially lower than the costs of producing the displaced energy. These carbon savings and cost estimates are based on an extensive review of DOE's detailed analyses in *Scenarios for a Clean Energy Future* of the potential savings from federal codes and standards.[13]

Initiative 3 –
Adopt National Legislation to Reduce Power Plant Emissions

This initiative envisions comprehensive power plant emissions reduction legislation that includes an appropriate power sector carbon emissions cap. No new, unproven technology is necessary to achieve these reductions and the costs of such a substitution can be calculated with confidence.[14] The main impact of the emissions limits would be a significant shift from existing coal generation, which produces the highest rates of CO_2 emissions, to new natural gas generation.[15] New gas power plants emit only about one-third as much carbon as the coal plants they would replace. Such legislation would reduce power sector carbon emissions by **80 to 160 million metric tons of carbon per year** by 2012.[16]

This range reflects uncertainties in how rapidly natural gas supplies and the necessary transportation and storage infrastructure can be developed in an environmentally sound fashion. It should also be noted that these carbon emissions reductions will occur **in addition to** any reductions driven by electricity and gas demand reduction or renewable energy production expansion. **Estimated costs of these reductions are $11 billion to $17 billion per year**[17] and include all costs of deep reductions in sulfur dioxide (SO_2), nitrogen oxides, mercury and other toxic air pollutants that would be driven by multi-pollutant power plant clean-up legislation. The SO_2 reductions alone produced by this initiative are estimated to save 18,000 premature deaths from fine particle inhalation per year.[18]

Initiative 4 –
Expand Electricity Production from Renewable Energy Sources

Source: NREL

Straightforward, proven policies should be implemented to expand electricity production from renewable energy sources. For example, federal, state and local governments could require that a substantial fraction of the energy they purchase comes from renewable sources, or the federal government could contract directly to develop renewable energy generation – as it did historically at a large scale to develop hydropower. This initiative is projected to reduce domestic carbon emissions by **5 to 9 million metric tons of carbon per year** by 2012 at **estimated costs of $0.7 billion to $1.4 billion per year.**[19]

Because of the challenges involved in estimating incremental renewable energy that could be readily produced under even such simple programs, these carbon reduction estimates are likely to understate the real potential from this initiative compared with the other initiatives in this group.[20]

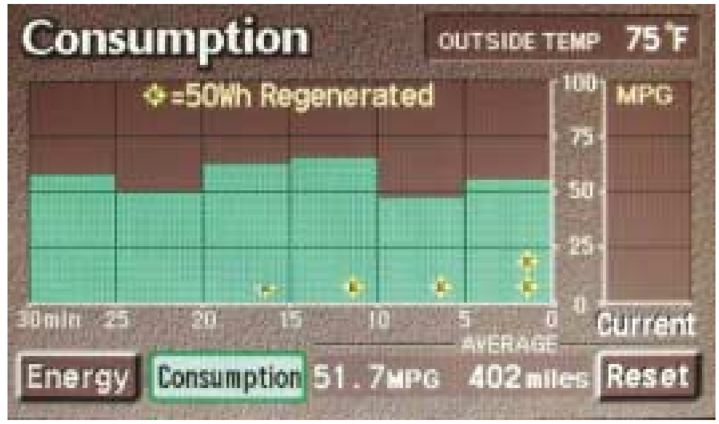
Initiative 5 –
Improve Fuel Economy of Cars and Light Trucks

Several studies, including some conducted by automanufacturers, have developed detailed and comprehensive lists of technologies available to improve fuel economy of light vehicles (cars and light trucks). A near tripling of fuel economy from current levels, while keeping size and performance constant, appears technically feasible, although the costs of such high levels of fuel economy are also very high.

This initiative would aim to improve light vehicle fuel economy to **30 to 35 miles per gallon** for new vehicles — a significant improvement over the 24.6 mpg average of all cars and light trucks sold in 1998.[21] It would be implemented either through a voluntary agreement similar to that established between the European Community (EC) and all EC auto-manufacturers to raise fuel economy by 33 percent (reduce fuel consumption by 25 percent) over the next decade or by a version of CAFÉ standards modified to minimize gaming and winner/loser issues.

Increased use of **cellulosic ethanol** would also be facilitated to reduce light vehicle greenhouse gas emissions by lowering the average fuel carbon content. Cellulosic ethanol is made from biomass feedstocks containing cellulose, such as agricultural waste or dedicated crops, that are converted to sugars and then fermented into ethanol. Ethanol currently has a motor fuel tax credit of 54 cents per gallon, declining to 51 cents per gallon in 2005. If this tax credit were extended beyond 2005, cellulosic ethanol would be very competitive. Only supply limitations will govern the rate of market penetration. Hence, policies to promote capital investment in cellulosic ethanol may be a useful adjunct to extending the fuel tax credit, and may be necessary to rapidly increase supply over the next decade.

These two initiative elements are projected to reduce domestic carbon emissions by **20 to 38 million metric tons of carbon per year** in 2012. **Estimated costs of these reductions are $0.9 billion to $4.1 billion per year.**[22]



This fuel gauge from a Toyota Prius hybrid vehicle shows the energy consumption, power regeneration, and fuel economy for this trip (51.7 mpg).

Potential carbon reductions through 2020 from these five domestic initiatives are illustrated in **Figure 5,** and also summarized in **Table 1**.

The net costs to society of these five initiatives is only about $1.0 billion to $1.7 billion per year in 2012, as the large costs savings produced by the Federal Codes and Standards energy efficiency initiative (along with the slight cost savings produced by the CHP initiative) nearly offset costs of the other initiatives.

FIGURE 5:
Carbon Emissions Reductions -- Five Initiatives

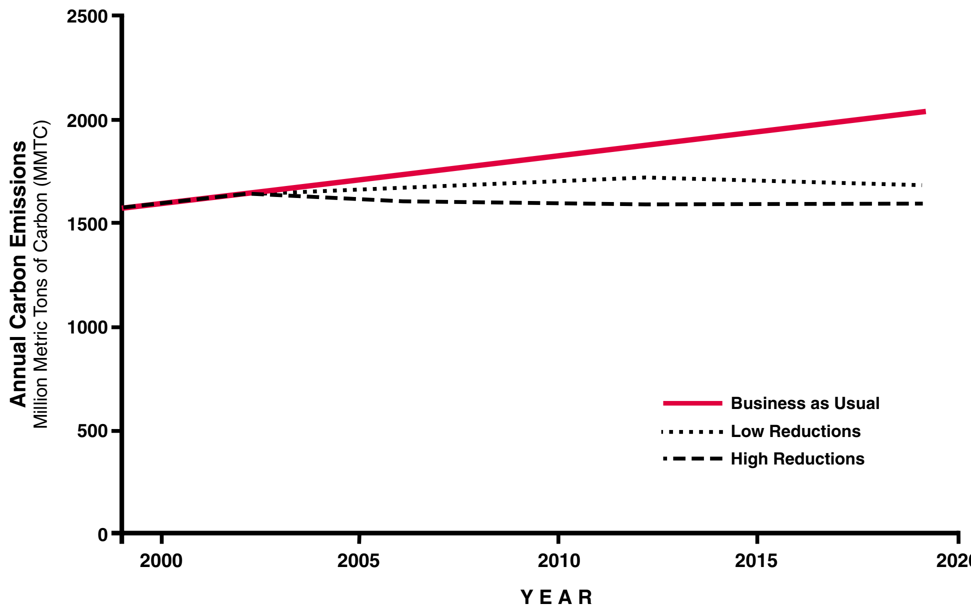


TABLE 1:
Estimated U.S. Carbon Reductions from Five Initiatives (MMTC/year)

Initiative	2012 Carbon Reductions Low to High	2020 Carbon Reductions Low to High
Cogeneration of Electricity and Heat	14	14+
Efficiency Codes and Standards	42-67	120-181
Power Plant Emission Limits	80-160	160+
Renewable Energy	5-10	20+
Fuel Economy of Cars and Light Trucks	20-38	37-69
TOTALS	161-289	351-444+

Additional Energy Efficiency and Renewable Energy

Many other market-based and policy initiatives should be implemented to improve energy efficiency and expand renewable energy production in parallel with the above initiatives. Many such initiatives are described in the U.S. DOE's *Scenarios for a Clean Energy Future* and in several recent advocacy reports.[23] While carbon savings estimates and costs for such parallel initiatives are not estimated in this study for reasons described above, their potential carbon reductions could be significant.

Greenhouse Gas Cap and Trade System

Substantial near-term greenhouse gas emissions reductions can also be produced by enacting a broad greenhouse gas cap and trade system. Any action that reduces GHG emissions or removes carbon from the atmosphere (into carbon "sinks") through agricultural and forestry activities or through durable geologic storage would receive credit.

The debate on climate action has suffered because little observable information exists on the extent and costs of the great range of potential actions that could reduce GHG emissions or increase the size of carbon sinks. In the absence of real market information, such costs are typically projected through engineering and other forms of analysis. These analyses and their results vary across a wide range (from those that suggest large reductions are possible at very low costs to those that suggest few reductions are available, and that they come at a very high cost).

Establishing a broad GHG cap and trade system in conjunction with even a modest reduction requirement may be the only quick and reliable way to find out what opportunities exist and what they cost. This would provide essential information for making progress on climate change. Several firms have already entered the GHG trading market,[24] largely due to trading driven by Canadian companies and European government and company activities. Their experience is beginning to expose some preliminary market-driven information on the availability and price of greenhouse gas reduction credits. Recent discussions with GHG traders suggest that large GHG reductions are probably available in a range from $20 to $40 per metric ton of carbon. Most traders also appear to believe that the GHG reduction market might eventually clear below this range.

A broad GHG cap and trade system will drive diverse reductions, many of which will be beyond the scope of the numerous proposed "categorical" programs advocated to reduce GHG emissions. Some examples include:

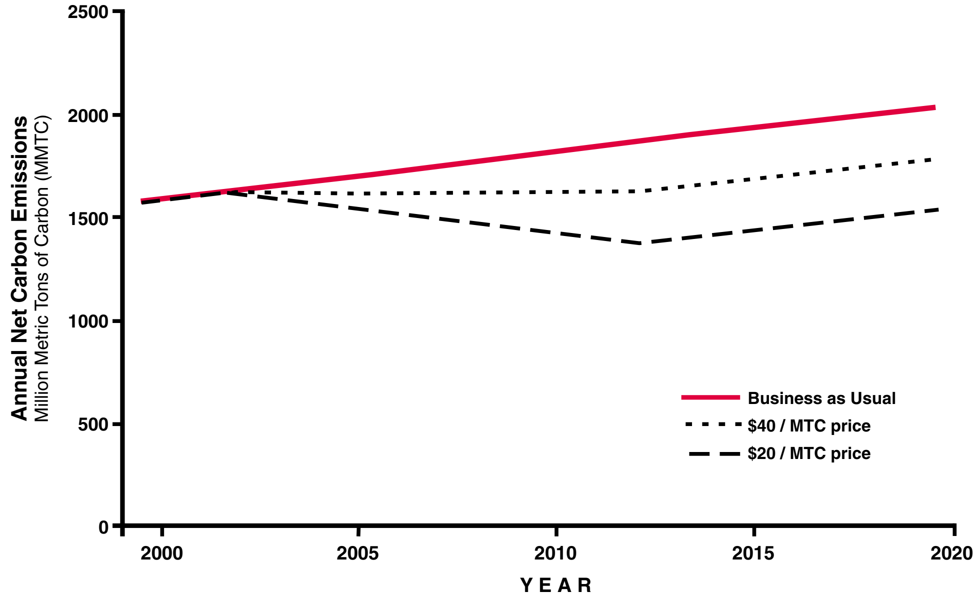
- Methane capture from coal mines, natural gas production, transport and distribution systems, and land fills;
- Agricultural waste management and increased agricultural soil carbon resulting from changes in farming practices;
- Increased storage of carbon in forest vegetation and soils resulting from changes in forest management practices;
- Industrial process changes that reduce or eliminate emissions of N_2O and other GHGs (beyond CO_2 and methane);
- Capture and sequestration of carbon dioxide currently emitted to the air by natural gas development operations.

We will probably only learn how large such potential savings may be, as well as what they will cost, by establishing a broad GHG trading system.

One approach to implementing a GHG trading system would be to establish a cap and trade program for the power sector as part of multi-pollutant power plant clean up legislation (as proposed in Initiative 3 above) or to establish an economy-wide cap and trade system. These systems offer the best opportunity to minimize GHG reduction costs and they could be quickly established given the experience gained under the successful U.S. sulfur dioxide (SO_2) cap and trade program enacted in 1990 under the first Bush Administration. For example, under that program, U.S. electric power generators already report CO_2 emissions on a continuous basis, so their progress towards meeting a CO_2 cap would be easy to track and verify.

FIGURE 6:

Net Carbon Emissions Reductions -- Greenhouse Gas Reverse Auction

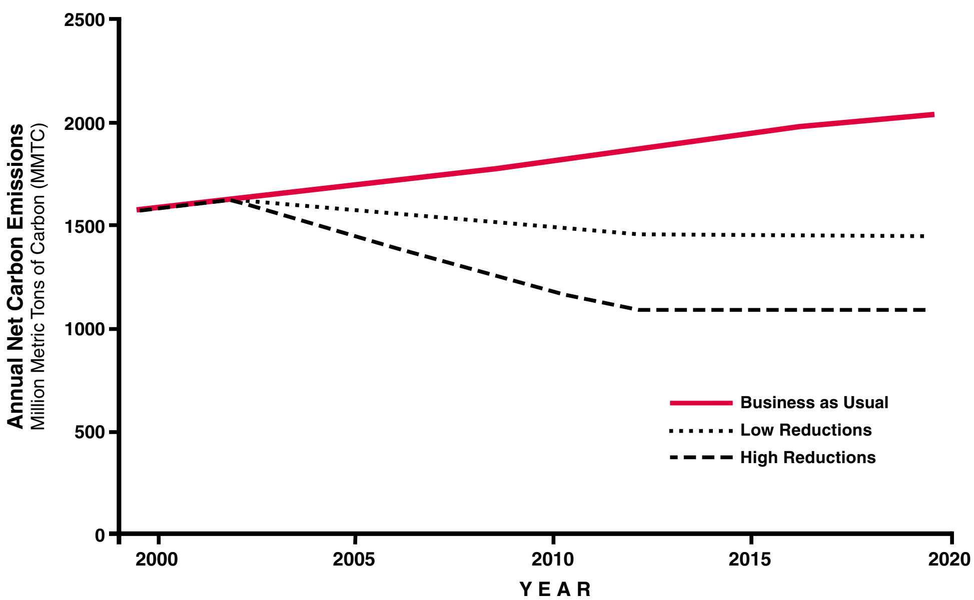


Another approach is to establish a federal "reverse auction" to purchase GHG reductions. A reverse auction system must ensure that each ton of reduction bought produces a true net-reduction from emissions that would have occurred absent the purchase. Such an auction could be set up in 2002 (for initial purchases in 2003) and might start with a budget of $1.0 billion per year. In each year's auction, participating parties offer (or bid) the number of tons of GHG emissions they will reduce and the price at which they will do so. The government buys the lowest cost reductions offered until the annual budget is used up. If the auction amount were to be increased by $1.0 billion each year through 2012, and assuming the $20 to $40 per metric ton price range, this auction could produce net GHG emissions reductions of **250 MMTC to 500 MMTC** by 2012, as illustrated in **Figure 6**.

Figure 7 shows the combined impact of the five carbon reduction initiatives plus the GHG reverse auction through 2020. It illustrates that these initiatives would enable the United States to decisively "turn the corner" from increasing to declining GHG emissions at a reasonable cost. The net projected costs of the proposed initiatives and the reverse auction are between $11.0 billion and $11.7 billion per year in 2012.

FIGURE 7:

Net Carbon Emissions Reductions -- Five Initiatives Plus Auction



Plan for Longer Term Reductions

Reason for Optimism

Looking beyond our ten year plan to "turn the corner" in U.S. domestic GHG and aerosol emissions, much larger GHG and aerosol reductions can be achieved over the following several decades. This reduction potential is large enough that a comprehensive climate action program could reduce domestic GHG and aerosol emissions to levels necessary to achieve climate stabilization by mid-century. These opportunities include making deep reductions in a broader range of air pollution emissions and deploying energy systems that remove and sequester carbon from fossil fuels.

Expand the Scope of Targeted Emissions

Climate change is driven by many air pollutants – not just by carbon dioxide. Most of these air pollutants and their estimated "radiative forcing"[25] are shown in **Figure 8**. This figure shows the relative estimated radiative forcing of these myriad pollutants, and reminds us that there are large uncertainties measuring the magnitude and identifying the sources of the non-CO_2 GHGs and aerosols.

Emerging climate research suggests that substantial near-term (10-40 year) cooling opportunities exist by reducing emissions of non-CO_2 gas and aerosol air

FIGURE 8:

The Global Mean Radiative Forcing of the Climate System for the Year 2000 - Relative to 1750

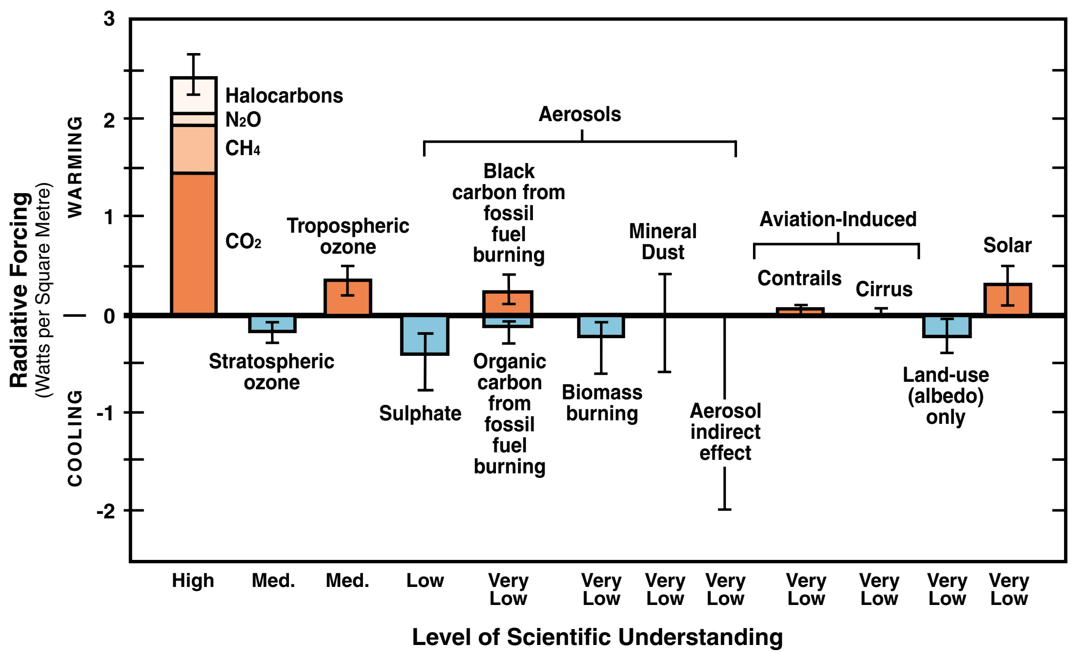
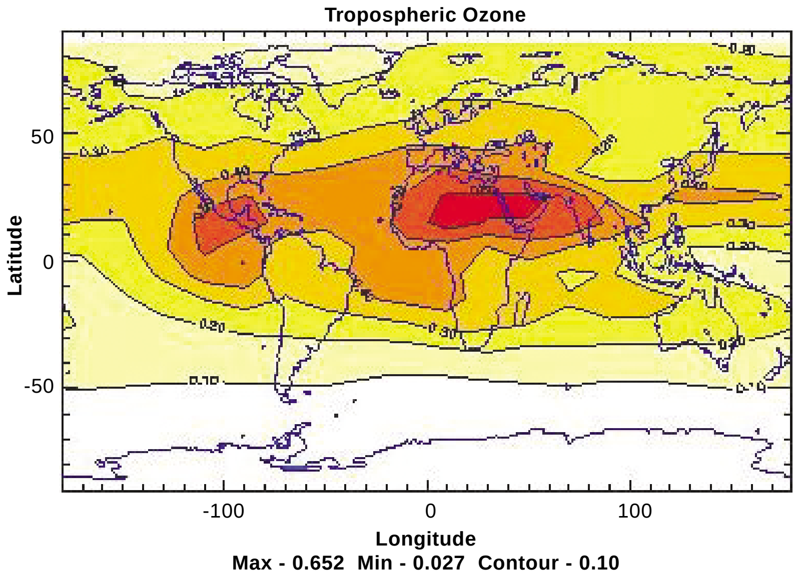


FIGURE 8 —

These radiative forcings arise from changes in the atmospheric composition, alteration of surface reflectance by land use, and variation in the output of the sun. Rectangular bars represent estimates of these forcings – some yielding warming, and some cooling. The indirect effect of aerosols shown is their effect on the size and number of cloud droplets. A second indirect effect of aerosols on clouds, their effect on cloud lifetime, which would also lead to cooling, is not shown. The vertical line above the rectangular bars indicates a range of estimates, guided by the spread in published values of forcings and physical understanding. Some forcings possess a much greater degree of certainty than others. A vertical line without a bar represents a forcing for which no best estimate can be given due to large uncertainties.[26] **Source:** IPCC

FIGURE 9:
Where Ozone Warms



■ **FIGURE 9 —**
Spatial pattern of estimated warming from tropospheric ozone in watts per square meter of earth surface area.[27]
Source: Shine and Forster

Ozone

Tropospheric ozone is one example of a non-CO_2 greenhouse gas. The IPCC estimates that ozone is the third most important greenhouse gas, having a warming effect that is about 28% as large as that of CO_2. Recently published research suggests that ozone's warming effect might be considerably higher.[31] Ozone formation is driven primarily by the emissions of nitrogen oxides (NO_X) and volatile organic carbon (VOCs), which react with sunlight in the atmosphere to create ozone. Ozone levels are also influenced by emissions of methane (CH4) and carbon monoxide (CO). Ozone has a very short lifetime (hours or days), which means that if emissions of ozone precursors (NO_X and VOCs) are reduced, the warming effect of this gas will be immediately reduced – unlike CO_2, which has an atmospheric residence "life" of up to several hundred years. The estimated distribution of climate warming from ozone is shown in **Figure 9**. Several Clean Air Act regulations have recently been enacted – including the NO_X SIP Call and the On-road Diesel Emissions Rule – that will dramatically reduce domestic formation of tropospheric ozone over the coming several decades. While these rules have been implemented to help achieve the national air quality standard for ozone, they will also have a beneficial impact on climate.

pollutants that cause warming.[28] The reasons for placing a high priority on non-CO_2 emissions are several. First, large reductions in nearly all of these gases and aerosols are achievable. The technology for making reductions is commercially available and affordable, and there should be no serious political barriers to implementing necessary policies. Second, the human health and environmental benefits of non-CO_2 reductions are significant.[29] Although significant reductions of many of these air pollutants will occur in the future from traditional "clean air" programs,[30] recognizing their climate impacts will facilitate deeper and quicker reductions in these emissions. Third, some important air pollutants (notably SO_2) that are currently cooling the climate are already being reduced (for reasons related to health and acid rain). As the cooling effect from reduced SO_2 is diminished, comparable cuts must be made in emissions of other warming agents to avoid losing ground. Finally, reducing non-CO_2 air pollutants will be rewarded with a more immediate cooling effect than for reductions in CO_2 , since non-CO_2 pollutants have shorter atmospheric lifetimes (lasting from hours to decades) than does CO_2. This timely effect can buy precious time for us in the near-term to slow overall warming to a rate that will allow the climate system and ecosystems to adapt to temperature and weather changes.

To capture this large opportunity, our climate change "agenda" must be broadened to encompass all air pollutants that impact climate. Key steps include:

1. Developing reliable estimates of the climate benefits associated with reducing all air pollutants that impact climate (beyond the Framework Convention on Climate Change GHGs): black carbon, carbon monoxide,

nitrogen oxides, volatile organic compounds and methane.[32]

2. Developing reliable estimates of the sources of air pollutants impacting climate – particularly within developing countries.

3. Exploring and evaluating domestic opportunities for deep and immediate reductions in ozone formation, as well as elemental carbon and methane emissions. Several obvious examples include:
   - Tough off-road diesel particulate emissions rules (including locomotives, marine diesel propulsion and aircraft);
   - A program to retrofit portions of the mobile diesel vehicle fleet with particulate and NO_X emissions controls before the fleet ultimately "turns over" to new vehicles meeting recent on-road diesel rules (and similar potential rules for off-road diesel vehicles);
   - Developing and implementing measures to reduce methane leakage from landfills equipped with methane collection systems; and
   - Reducing leakage from natural gas extraction, transmission, distribution and use.

4. Expand current climate-based GHG emissions trading programs to appropriately include all air pollutants that impact climate.

Source: Ed Jackson, © Carl Vinson Institute of Government, The University of Georgia, http://www.cviog.uga.edu/Projects/gainfo/photogallery/htmpages/truckpollution.htm

Near-term benefits of an expanded climate action agenda could be substantial. For example, a 60 to 80 percent reduction in ozone formation, elemental carbon emissions and methane emissions – which may well be achievable and affordable over the next forty years with concerted action – would (very roughly) reduce climate warming forcing by **about two thirds as much as the cumulative warming effect of all the global CO_2 emissions to date.**[33]

Capture and Sequester Carbon Emissions

Energy systems are being developed that can remove and geologically sequester the carbon contained in fossil fuels. Environmentally sound deployment of these systems could dramatically reduce future domestic carbon dioxide emissions.[34] It thus appears feasible to contemplate **replacing our power and transportation fuels systems over a roughly 40 to 50 year period with advanced systems incorporating carbon capture and geologic sequestration.** Minimizing demand for power and transportation services through improved energy efficiency and expanding development of renewable energy would minimize costs of transitioning to these advanced energy systems.

In advanced fossil energy systems, fossil fuel is chemically processed to produce a hydrogen-rich gas called "syngas" from which the carbon dioxide can be removed. The syngas is then used to produce power. Once removed, this "captured" carbon dioxide can be transported and injected into several types of geologic formations to contain or "sequester" it from the atmosphere for the foreseeable future.

Estimates of the volume of carbon that could be geologically sequestered are large relative to current global carbon emissions of about seven gigatons of carbon per year (GtC/yr) – as shown in **Table 2.**[35] If even a small fraction of this potential were to be used, geologic carbon sequestration could clearly play a major role in addressing climate change over the next century.[36]

TABLE 2:
Worldwide Capacity of Potential CO_2 Storage Reservoirs

Sequestration Option	**Worldwide Capacity in gigatons of carbon (GtC)** (orders of magnitude estimates)
Ocean	1000s
Deep Saline Formations	100s-1000s
Depleted Oil & Gas Reservoirs	100s
Coal Seams	10s-100s
Terrestrial	10s
Utilization	<1 GtC/yr

1 GtC = 1 billion metric tons of carbon equivalent. Ocean and land-based sites together contain an enormous capacity for storage of CO 2. Worldwide total anthropogenic carbon emissions are approximately 7 GtC per year. Among these options, the world's oceans have by far the largest capacity for carbon storage. **Source:** *Environmental Science and Technology*

Advanced energy systems are not “science fiction.” Coal-fueled power plants with carbon capture and sequestration **could be developed over the next several years using commercially available equipment and techniques**.[37] All components of such advanced coal power plants with carbon capture and sequestration system are operational today but have not yet been integrated in a single operational system. Examples of individual system elements include:

■ Coal Gasification: Tampa Electric’s Polk Station

Polk Station is a 250 megawatt integrated coal gasification combined cycle (IGCC) power plant owned and operated by Tampa Electric that began operation in 1996. This power plant uses gasification technology commercially available from Texaco, and GE Frame 7F gas turbines. Relatively pure CO_2 is produced at pressure by the Polk gasifier, and is then emitted to the atmosphere, along with CO_2 produced from the combustion of the syngas.[38]

■ CO_2 Transport and Injection: Weyburn Oil Fields

The oil extraction industry today mines carbon dioxide (through wells), compresses and transports it long distances through CO_2 pipelines and injects it into oil fields to enhance recovery of oil. In 1998, a total of about 43 million metric tons of CO_2 (or about 11.7 million metric tons of carbon) was injected at 67 different commercial oil recovery operations.[39] Thus all elements of the technology necessary to transport and sequester CO_2 (once captured at an energy production facility) are mature, having been applied in the field for many years as part of this industry.

One recent commercial example is a North Dakota project that is removing CO_2 from a gasification plant that produces natural gas from lignite coal. The “captured” CO_2 is then shipped over a newly-constructed 204 mile CO_2 pipeline to the Weyburn oil field in Saskatchewan, where it is injected to enhance recovery of oil. The injected CO_2 is then left in place as a sequestration project.[40]

Polk Station with Gasifier; **Source:** Tampa Electric

In 1998, a total of about 43 million metric tons of CO_2 was injected at 67 different commercial oil recovery operations.

Information

Information on advanced fossil energy systems incorporating carbon capture and sequestration can be found on the following websites:

- The International Energy Agency’s Greenhouse Gas R&D Programme – **www.ieagreen.org.uk**
- The National Energy Technology Lab’s Carbon Sequestration Products – **www.netl.doe.gov/products/sequestration/index.html**
- The Gasification Technology Council – **www.gasification.org**
- MIT Energy Lab Sequestration Reports – **http://web.mit.edu/energylab/www hjherzog/publications.html**
- US Department of Energy’s First Carbon Sequestration Conference – **www.netl.doe.gov/events/carbseq/carbseq01.htm**

Carbon Sequestration: Statoil's Sleipner Project

Statoil and its partners operate a natural gas recovery platform above the Sleipner natural gas reservoir off the coast of Norway. CO_2 must be removed from this natural gas to make it marketable. This project first removes CO_2 from the gas (at considerable cost) and then compresses the CO_2 and injects it into a saline formation under the North Sea. The incremental cost of compressing and injecting this CO_2 stream is about $75/ton of carbon. Statoil has identified significant economies of scale for compression and injection, and projects that at 4 million tons per year (about four times the current flow), costs would be reduced to about $26/ton of carbon.[41] At these early costs, full sequestration (which can capture about 90% of emitted carbon) would add about 2 cents/kWh to new IGCC coal plant production costs. These costs are projected to drop to about 1.5 cents/kWh by 2012.[42]

Carbon Sequestration: Acid Gas Injection

Natural gas often contains impurities that must be removed before the natural gas can be transported in pipelines and sold to customers. In some gas production areas, excess CO_2 and hydrogen sulfide are stripped from the gas being produced and then disposed of by injecting them into geologic formations. For example, 22 of these "acid gas injection" (or AGI) projects are operating in Canada, with the CO_2 fraction of the injected gas ranging from 14 to 88 percent. A large domestic AGI project is under development in LaBarge Wyoming. When it begins operating in 2003, this AGI project will be equivalent in size to the Sleipner project.[43]

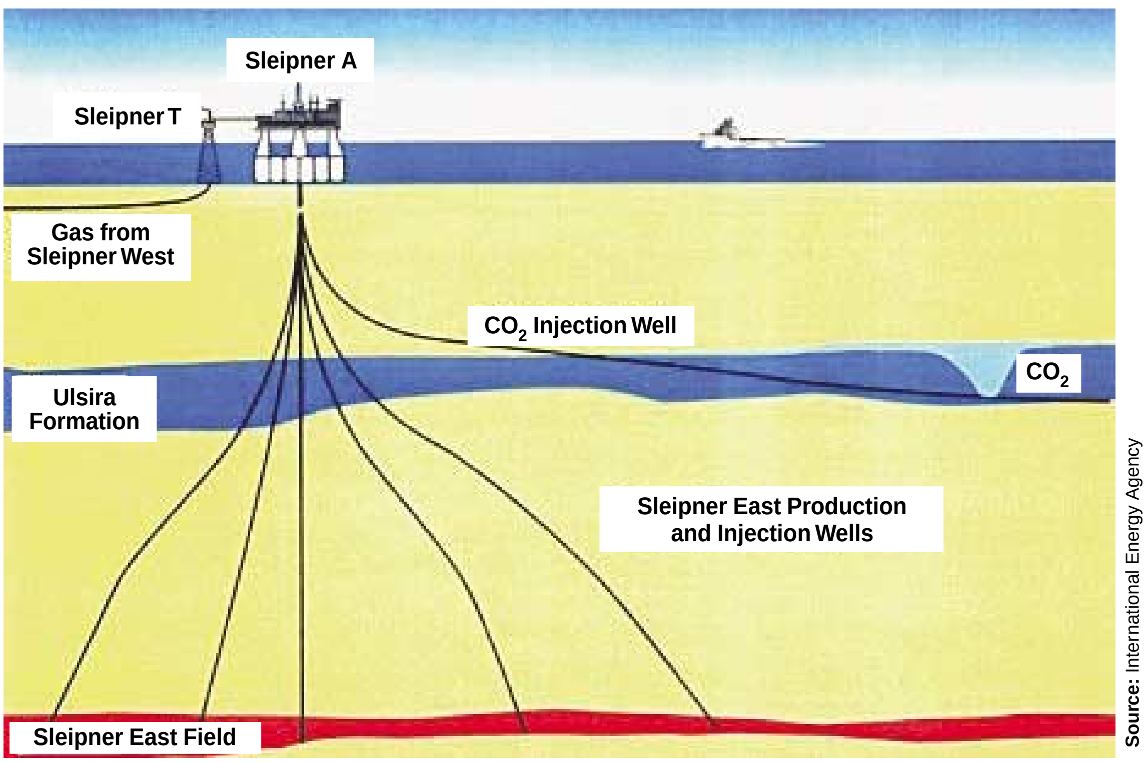


Diagram of Statoil's Sleipner Carbon Sequestration Project.

Promote Advanced Fossil Energy Systems

Substantial **research** on advanced fossil energy systems is underway within the US (by the DOE and industry) and several other developed countries.[44] The goals of DOE's advanced fossil technology program are to move very efficient, high-tech fossil energy systems with full carbon sequestration and no conventional air pollution emissions into the commercial marketplace by 2015 (assuming net carbon capture and sequestration costs of $50/ton of carbon). DOE further aims to achieve capture and sequestration costs of $10/ton or lower per ton by 2035.[45]

The economic benefits of this research could be large. A recent National Energy Lab study has estimated that achieving DOE's CO_2 capture and sequestration cost targets could reduce the net present value (NPV) of total global costs of constraining atmospheric CO2 concentrations to 450 ppm in this century by about $4.3 trillion. To illustrate the significance of these potential savings, consider that US domestic costs would be reduced by about $800 billion (NPV), and China's costs would drop by about $1.1 trillion (NPV).[46]

The potential for sequestering fossil energy system carbon is so large – and potentially so critical to meeting our mid-century carbon emissions targets – that **commercial scale projects** should move forward within the next several years in parallel with aggressive research programs. Commercializing such systems within the U.S. may also be critical to making such technology economically available to countries like China and India who are likely to remain reliant on coal to fuel much of their energy systems for the foreseeable future.

We are mindful that several significant barriers must be addressed before these promising technologies will significantly improve the overall environmental "footprint" of coal for use in power generation. Persistent areas of concern, including the impacts of mining, air pollution emissions and solid or liquid waste streams, must be reduced to acceptable levels.[47]

Transition to Hydrogen Economy

Advanced fossil energy systems – like IGCC plants – can produce hydrogen on a large scale that can be used to generate electricity or fuel vehicles. When carbon capture and sequestration is added to these systems, they produce hydrogen with only small amounts of carbon emissions to the atmosphere. Some advanced technologies under development would use coal and carbonate minerals as feedstock, producing pure hydrogen and binding the coal's carbon content into a mineral byproduct that could potentially be safely landfilled or used for purposes like road bed construction.[48]

To achieve our domestic target of reducing domestic carbon dioxide emissions 75% by 2060, our **transportation system must be fully transitioned to hydrogen fuel** – produced from sources with little or no carbon emissions to the atmosphere. There appears today to be no other practical path for transportation systems that can reduce carbon emissions sufficiently, while providing our necessary transportation services.[49] Advanced fossil energy systems could soon be producing large volumes of hydrogen and are thus likely to play a critical role in transitioning our transportation and other energy systems to hydrogen fuel.

Hydrogen filling station at Munich airport provides fuel for a fleet of buses and BMW Model 750hL hydrogen cars.

Sources: *Hydrogen and Fuel Cell letter* - June 1999 - Feature and National Hydrogen Association, *Hydrogen Newsletter,* August 2000.

Summary

Very deep greenhouse gas and aerosol reductions are needed to avoid severe risks to global ecosystems. The "good news" – as shown in **Figure 10** – is that a comprehensive plan of action to reduce global warming, combined with a targeted action plan to significantly reduce projected GHG emissions within this coming decade can reach – **and probably exceed** – these deep reductions and do so without significant economic or social dislocation.

We must move expeditiously to minimize future energy demand by improving the efficiency with which we use energy and by transforming our energy system capital stock to renewable forms of energy, high-efficiency natural gas systems and fossil-fuel systems that capture and sequester the carbon in these fuels. We must also move quickly to deeply reduce all air pollution contributing to global warming and to increase carbon storage in soils and plants through agricultural and forestry practices.

One cannot project with any certainty what technology mix will deliver the reductions in long-term GHG and other air pollutants necessary to achieve our climate protection target. Technology evolution and market forces will combine in ways we cannot predict today to shape our mid-century energy systems. Thus, we must ensure all potentially useful – and environmentally acceptable – technologies are being aggressively pursued, so that we have the broadest set of options for reducing pollutants that impact climate and transitioning to low-carbon energy systems by mid-century.

FIGURE 10:

Turning the Corner on U.S. Global Warming Emissions: Impact of the Plan of Action

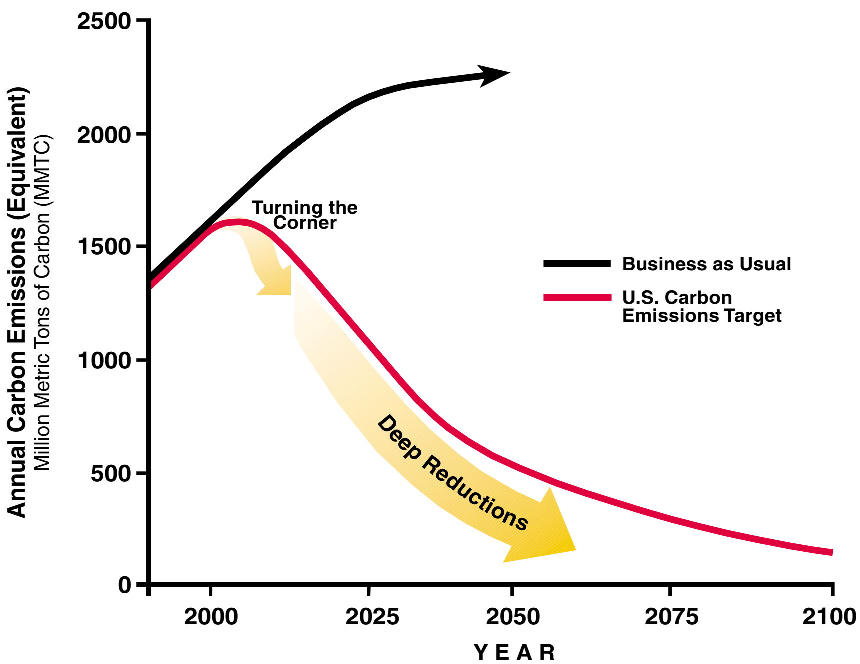


FIGURE 10 —

The "Turning the Corner" arrow shows the range of reductions achievable by implementing the Five Initiatives plus a GHG cap and trade system from the Plan for Near Term Reductions. The "Deep Reductions" arrow illustrates the deep savings that could be achieved by a comprehensive GHG reduction strategy that combines ongoing improvements in energy efficiency, development of renewable resources, transitioning fossil energy systems to those incorporating carbon capture and sequestration, and programs to expand carbon sinks and to reduce all GHGs and aerosols that increase warming.

Endnotes

1 See, Intergovernmental Panel on Climate Change, *Summary for Policymakers, A Report of Working Group I of the Intergovernmental Panel on Climate Change,* January, 2001. This report is available at www.usgcrp.gov/ipcc.

2 The author wishes to thank Environmental Defense staff for their generous assistance in understanding the relationships among the scientific conclusions that we review here.

3 www.unfccc.de/resource/convkp.html.

4 www.ipcc.ch.

5 Letter from Harold Mooney, Paul S. Achilles Professor of Biology, Stanford University, dated May 21, 1997.

6 IPCC, *Summary for Policy Makers, Climate Change 2001: Impacts, Adaptation and Vulnerability, A Report of Working Group II of the Intergovernmental Panel on Climate Change,* page 5, www.usgcrp.gov/ipcc/.

7 *Id.*

8 See, IPCC, *Technical Paper III, Stabilization of Atmospheric Greenhouse Gases: Physical, Biological and Socio-Economic Implications,* 1997, Appendix I. The report is available at http://www.ipcc.ch/pub/techrep.htm. If all greenhouse gases are considered, concentrations should be limited to about 475 ppm of CO_2- equivalent. See, ibid., page 25, Figure 12. Concentration of CO_2 is the average amount of CO_2 within the atmosphere. See also, IPCC, *Third Assessment Report, Working Group I, Technical Summary,* 2001, page 76.

9 Carbon emissions reduction estimates assume a formal commitment to proceed by 1/1/02, reasonable post-commitment program implementation periods and they generally rely on conservative assumptions. For example, all marginal electricity displaced by electrical energy efficiency is assumed to be relatively low-carbon electricity produced by new, combined cycle natural gas plants.

10 The conservative approach taken to estimate carbon reductions from the five initiatives (as detailed in the note above) suggests that actual savings produced by these initiatives will most likely be higher than projected here.

11 Interlaboratory Working Group 2000, *Scenarios for a Clean Energy Future* (Oak Ridge, TN: Oak Ridge National Laboratory and Berkeley, CA: Lawrence Berkeley National Laboratory), ORNL/CON-476 and LBNL-44029, November, 2000, http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm .

12 Existing levels of local programs in portions of the country (California and several northeastern states) are sufficient to provide the momentum to move standards forward on a reasonable track. A higher level of local program activity would accelerate standard setting by creating further market acceptance of efficient equipment.

13 Technical appendices from *Scenarios for a Clean Energy Future* containing calculations of projected future impacts of federal codes and standards programs, as well as key assumptions underlying these projections, were extensively reviewed by energy efficiency experts with substantial "hands on" experience. This review adjusted impacts projections to account for delayed implementation of aggressive implementation and to reflect field experience. Projected carbon reductions were further (conservatively) adjusted to assume that new natural gas plants having relatively low carbon dioxide emissions rates would produce all displaced electricity generation. See, Interlaboratory Working Group 2000, *Scenarios for a Clean Energy Future*, Op.Cit.

14 Power system compliance with a comprehensive emissions reduction requirement – including a power sector carbon emissions cap – would include some mix of reduced electricity consumption, installation of emissions controls, reduction in generation from existing coal plants and development of both renewable power resources and new natural gas power plants.

15 If new integrated gasification combined cycle coal plants with carbon capture and sequestration enter the market over the next several years, existing coal generation could be replaced by a combination of new natural gas plants and new coal IGCC's (with carbon sequestration) to produce similar carbon emissions reductions.

16 These figures assume that from about one-quarter to one-half of the projected year 2012 electricity generation from our existing fleet of coal-fired power plants is replaced by electricity produced at new natural gas plants.

17 These estimates are conservatively high as they include the full cost of reducing power plant SO_2, NO_x, and mercury emissions well below current levels, even though a large portion of these reductions will occur – absent such legislation – on a less predictable schedule over the next ten to fifteen years under current Clean Air Act requirements.

18 Clean Air Task Force, *Death, Disease and Dirty Power,* October, 2000, page 5, www.clnatf.org.

19 Potential savings result from expanded development of wind and biomass power. Biomass power estimates are taken from *Scenarios for a Clean Energy Future,* but adjusted to reflect implementation delays (as this study assumed policy initiatives began in 1998). Wind power estimates are derived from a series of recent interview with active, large scale wind developers – and are substantially larger than estimates contained in *Scenarios for a Clean Energy Future.*

20 Most potential for such expansion over the next decade is through wind power and biomass power. In the case of wind power, questions about the location of suitable wind power sites, potential limits on volume of intermittent wind energy within power markets, and the ability of wind manufacturers to expand production to meet domestic US expansion – which may be competing with other wind power markets – are factors rendering reliable estimates difficult. In the case of bio-mass power, questions about the availability and costs of advanced, high-efficiency biomass gasification technology – which has not yet been commercialized – potential environmental impacts of energy crop production, and conditions under which biomass power can be considered to have no net carbon emissions render reliable estimates of expanding this resource challenging.

21 1998 average fleet miles per gallon taken from Robert Bamberger, CRS Report for Congress, *IB90122: Automobile and Light Truck Fuel Economy: Is CAFE Up to Standards?,* National Council For Science And The Environment, April 4, 2001.

22 These cost estimates are an annualized cost based on lifetime savings produced by the cumulative investments through 2012 (cumulative costs through 2012 divided by lifetime savings produced by this investment times cumulative annual tons of carbon reduction in 2012).

23 See, Interlaboratory Working Group, *Scenarios for a Clean Energy Future*, Op.Cit. See also, *Clean Energy Blueprint,* prepared recently by the Union of Concerned Scientists, that projects results of an aggressive set of energy efficiency and renewable energy programs through 2010. This report is available at www.ucsusa.org.

24 Examples include CO2e.com and Natsource.

25 The term "radiative forcing" has been defined by the IPCC as "an externally imposed perturbation in the radiative energy budget of the Earth's climate system. Examples of such forcings – which can be positive (generally causing warming) or negative (generally causing cooling) include increased absorption of solar radiation (and resulting warming) caused by black carbon aerosols, or reflection of solar radiation by clouds (and associated cooling) formed as a result of sulfate aerosols. See Chapter Six of Volume One of the IPCC's *Third Assessment Report* for a detailed discussion of radiative forcing.

26 IPCC, *Summary for Policy Makers, A Report of Working Group I of the Intergovernmental Panel on Climate Change,* January, 2001, page 8. Additional details for this figure follow. Except for solar variation, some form of human activity is linked to each. Forcing due to episodic volcanic events, which leads to a negative forcing lasting only for a few years is not shown. Effects of aviation on greenhouse gases are included in individual bars. The overall level of scientific understanding for each forcing varies considerably, as noted. Some radiative forcing agents are well mixed over the globe, such as CO2, thereby perturbing the global heat balance. Others, such as aerosols, represent perturbations with stronger regional signatures because of their spatial distribution. For this and other reasons, a simple sum of the positive and negative bars cannot be expected to yield the net effect on the climate system.

27 Shine and Forster, "The effect of human activity on radiative forcing of climate change: a review of recent developments," *Global and Planetary Change 20*, 1999, pages 205-225.

28 James Hansen, Makiko Sata, Reto Ruedy, Andrew Lacis and Valdar Oinas, "Global warming in the twenty-first century: An alternative scenario," *Proc. Natl. Acad. Sci*. 97, 2000, pages 9875-9880; Keith P. Shine and Piers M. de F. Forster, "The effect of human activity on radiative forcing of climate change: a review of recent developments," *Global and Planetary Change 20,* 1999, pages 205-225; James Hansen and Makito Sata, Trends of measured climate forcing agents", *Proc. Natl. Acad. Sci*. 98, 2001, pages 14778 – 14783 and Mark Z. Jacobson, "Control of fossil-fuel particulate black carbon and organic matter, the most effective method of slowing global warming", *Jour. Geophys. Res*., in press .

29 Aerosols that form as a result of sulfur dioxide emissions appear to have substantial cooling effects as noted in Figure 8. As sulfur emissions are reduced in response to their large adverse impacts on public health and the environment, the cooling effect from the aerosols will also be reduced. This potential reduction in cooling is an additional reason for aggressive action to reduce non-carbon emissions that have warming effects.

30 Domestic actions are already being taken – for non-climate reasons – that will reduce emissions of several of these gases and aerosols, including ozone and black carbon. Examples include EPA's NOx "SIP Call" Rule that requires large reductions in NOx emissions from eastern power plants and EPA's On-Road Diesel Rule that will significantly reduce NOx and black carbon emissions from on-road diesel engines over the next 30-40 years.

31 Mickley, Loretta and Jacobs, "Uncertainty in pre-industrial abundance of tropospheric ozone: Implications for radiative forcing calculations," Journal of Geophysical Research, pages 106 (D4) 3389-3399, 2001.

32 Methane levels impact ozone formation through several mechanisms, in addition to having a direct forcing effect. In this case, the climate effects of methane levels as they impact ozone would be estimated.

33 This estimate assumes the current IPCC estimates for warming induced by black carbon, ozone and methane (CH4).

34 See, US DOE, *Vision 21, Clean Energy for the 21st Century,* for a broad vision laying out the potential evolution of advanced coal energy systems incorporating carbon capture and sequestration. This can be found at www.netl.doe.gov/publications/brochures/pdfs/vision21.pdf.

35 Table 2 is taken from Howard J. Herzog, "What Future for Carbon Capture and Sequestration?," *Environmental Science and Technology,* Volume 35 , Issue 7 / pages 148 A – 153 A, April 1, 2001. A more detailed discussion of geologic carbon sequestration potential estimates is contained at in Howard Herzog and Neda Vukmirovic, "CO2 Sequestration: Opportunities and Challenges," MIT Energy Lab, June 1999 and at pages 22 – 32 in Howard Herzog, Elisabeth Drake and Eric Adams, "CO2 Capture, Reuse and Storage Technologies for Mitigating Global Climate Change – A White Paper," MIT Energy Lab, January, 1997.

36 Herzog and Vukmirovic, Op.Cit.

37 Howard Herzog, *An Introduction to CO2 Sequestration and Capture Technologies,* MIT Energy Lab, August, 1999.

38 A detailed description of this project is contained in DOE's fact sheet "Tampa Electric Integrated Gasification Combined Cycle Project" at www.lanl.gov/projects/cctc/factsheets/tampa/tampaedemo.html.

39 Herzog and Vukmirovic, Op.Cit.

40 Ray P. Hattenbach, Dakota Gasification Company, "Carbon Management – CO2 For Enhanced Oil Recovery," The Energy Council's 2001 Annual Meeting, Anchorage, Alaska, September 2001.

41 US DOE, Workshop Summary Report, *CO2 Capture and Geologic Sequestration: Progress through Partnership*, 1999, page 9.

42 Herzog, Op. Cit., page 6.

43 David Keith, "CO2 Capture and Storage in Canada," MIT Carbon Sequestration Forum II, November 2001.

44 Most notably Japan – which has the largest and longest running carbon capture and sequestration technologies research program and several EU countries.

45 Kim, S. H. and J. A. Edmonds, *Potential for Advanced Carbon Capture and Sequestration Technologies in a Climate Constrained World*, Pacific Northwest National Laboratory, February 2000, page 5.

46 Id., page 24.

47 The full range of environmental problems associated with use of coal in conventional power plants has been recently summarized in *Cradle to Grave: The Environmental Impacts from Coal,* Clean Air Task Force (CATF), June 2001. IGCC technology characteristics suggest that such advanced coal technology, combined with attention to coal mining and solid waste management issues **if properly developed and regulated** has the potential to avoid or mitigate many environmental problems associated with conventional coal power production as described in the CATF report.

48 Los Alamos National Laboratory, *Zero Emission Coal to Hydrogen*, www.lanl.gov/energy/est/zec/index.html.

49 Personal conversation with Malcolm Weiss, MIT Energy Lab. Electric vehicles might provide an alternative to hydrogen fuel but they would require significant breakthroughs in battery technology capability that cannot be assumed.

Dedication

ENE dedicates this report to the late Carlton Bartels, a greenhouse gas trader for Cantor Fitzgerald. Carlton generously provided assistance to us in estimating the greenhouse gas reduction allowance prices used in this report. Carlton perished in the World Trade Center on September 11th.

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