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AICGSPOLICY**REPORT**

SHORT-TERM SOLUTIONS TO THE CLIMATE AND ENERGY CHALLENGE

Felix Chr. Matthes
Lewis J. Perelman

AMERICAN INSTITUTE FOR CONTEMPORARY GERMAN STUDIES THE JOHNS HOPKINS UNIVERSITY

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FOREWORD

This Policy Report is another significant study in the area of climate change and energy security, an important part of AICGS' research activities in 2008 and beyond. It was made possible through a generous grant from the *Daimler-Fonds im Stifterverband für die Deutsche Wissenschaft*.

In their studies, Lewis J. Perelman and Felix Chr. Matthes examine technological solutions that can make a substantial impact on climate protection and energy security today and in the near future. The crucial roles of energy efficiency, alternative energy production, and intelligent energy use are investigated for both Germany and the United States.

Avoiding climate change by developing and implementing new technologies is an attractive solution to the public and governments alike, as it is the least likely to fundamentally change our way of life. Yet, as Lewis Perelman outlines in his essay, technological developments take a considerable amount of time and cannot guarantee a satisfying solution. This is especially so as different agendas concerning energy security, economic policies, and environmental matters compete for the same financial resources. Thus, it is often most promising to design policies and measures to develop and implement technologies which combine all three competing agendas.

As Felix Matthes points out, in Germany, any improvement in the energy sector will require a basic restructuring of the infrastructure. For example, wind energy produced in northern Germany will have to be channeled to central Germany where the main energy users are located. Another area that has to be urgently addressed is energy storage, not least because of the proverbial "the wind does not always blow, the sun not always shine."

Both authors point out that any technological breakthroughs will have to be triggered by the right political, economic, and behavioral decisions. In the past, Germany has put its emphasis on regulating behavioral changes of the consumer. In the United States, the focus was rather on finding technological breakthroughs. Transatlantic collaboration in the area of research and development as well as a best-practice exchange regarding useful policies and measures could further the international debate on solutions for climate change immensely. There is no need to replicate the errors made elsewhere but in light of the short timeframe in which climate change has to be addressed, all the necessity to learn from each other.

AICGS will continue to foster the German-American dialogue on climate change and energy. We would like to thank the authors, the *Daimler-Fonds*, and Jessica Riester for her help in editing this publication.

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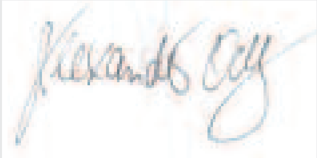

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Dr. Lewis J. Perelman is a member of the Institute of Electrical and Electronic Engineers, the Society for Risk Analysis, and is also a Senior Research Fellow of the Institute for Regulatory Science. He has over thirty years of professional experience focused on the processes of innovation, transformation, sustainability, and resilience; including strategic intelligence, policy development, planning, and assessment—as a consultant, analyst, author, publisher, and teacher. Dr. Perelman has taught at Harvard University and George Mason University, has appeared on numerous radio and television programs, and has lectured at conferences, seminars, and meetings of business, public, and nonprofit organizations throughout the world. Dr. Perelman's publications include 12 books and over 100 other publications. As an author, Dr. Perelman produced *School's Out*, a best-selling book based on Project Learning 2001, which he directed as a senior research fellow at the Hudson Institute. His first book, *The Global Mind*, was cited as one of the best scientific/technical books of the year by *The Library Journal*. Dr. Perelman was an editor and contributor to *Energy Transitions* for the American Association for the Advancement of Science, and authored *The Learning Enterprise* for the Council of State Planning Agencies. For over four years, he was Executive Editor of *Knowledge Inc.*, the leading management newsletter on organizational intelligence. He also served on the editorial board of the journal *Technology & Culture*. Dr. Perelman earned his doctorate in Administration, Planning, and Policy at Harvard following a special program of research applying cognitive science, human ecology, and welfare economics to strategies for sustainable development.

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CLIMATE-FRIENDLY TECHNOLOGIES IN THE UNITED STATES

THE NEAR-TERM POTENTIAL OF CLIMATE-FRIENDLY TECHNOLOGIES

LEWIS J. PERELMAN

Section 1: The Problem

The objective of this essay is to look at technological solutions that can make a substantial impact on climate protection and energy security today or in the near future. Here, that will mean three to eight years. Given the relatively short time horizon of this task, the roles of energy efficiency and intelligent energy usage are particularly important.

For the purposes of this report, "climate-friendly" means, in part, serving demands to reduce greenhouse gas (GHG) emissions. Clearly, climate-friendly technologies could include a variety of products and systems in domains other than energy, since GHG emissions emanate from numerous sources other than energy production or consumption—from deforestation to agricultural livestock, and so on. But since the mission of this project focuses mainly on the relationships between climate change and energy, energy technologies will be the primary focus of this study. Additionally, "climate-friendly" here includes targeting technology solutions that not only promise GHG reductions but that give top priority to human safety and security—including economic, social, and strategic security.

At the same time, it is neither appropriate nor feasible to limit the assessment of near-term technology solutions to the energy sector exclusively. In nearly all practical cases, energy systems are highly interdependent with other key resources and systems: from water and food to forests and oceans, human settlements and politics, business supply chains and management practices, etc. Indeed, the high degree of integration and complexity of today's global economic infrastructure often imposes significant limiting factors on the feasibility and safety of what, in isolation, may seem like promising technical fixes.

Precisely because of the immense complexity and dynamism of our infrastructure systems-of-systems, I will apply the phrase "energy security" very broadly and with particular prudence: that is, not just the security of energy sources but the role of energy systems in serving overall security needs.

As a corollary to this security-framed notion of climate-friendly, in assessing technological needs and opportunities, I will include some consideration of solutions that may serve the overly-neglected needs for adaptation to climate effects.

Section 2: The Allure and Limits of Technical Fixes

Most Americans and Germans and indeed most members of Western society seem to love, even need, technical fixes. The comfort of the technical fix is just that: The apparent promise to deliver gain with no pain. In reality, true technical fixes—not just marginal improvements but those that provide immense benefits at little or even reduced cost—are extremely rare. The rule of thumb among students of innovation is that over 90 percent of all inventions, new products, and other innovations fail. Technology investment analysts suggest that an innovative product must offer ten times better performance or ten times lower cost, or some combination of both, to attract venture capital interest.

But even with a great leap in quality or cost-effectiveness, the barriers to market success are imposing and numerous. The product may not be well-designed or comfortable for human use. It may violate social, religious, or cultural taboos.

Then there may be the failure of too much success: The very superiority of a breakthrough solution may be so disruptive, and thus so threatening to established economic or political interests that the latter may be motivated to use their power to quash it.

A key metric of a technical fix's success is the chart of its market penetration and diffusion. These s-shaped curves show how quickly the innovation gains enough of a market to be commercially viable and how many of the total potential users actually adopt it. They also show how long the users stick with it before they abandon it for something new, better, or just different.

Historically it often took innovations a decade or two to attain significant acceptance and several decades to be adopted by a large majority of the market and achieve market saturation. Since innovations need to be literally communicated from person to person, the advance of the capacity and coverage of modern telecommunications has tended to accelerate the pace of market penetration.

But things that more or less stand alone clearly are easier and thus usually quicker to be adopted than things that are dependent on larger-scale communication, transportation, production, supply, or service infrastructure.

Finally, but not least, the market success of even valuable innovations may be undermined by the lurking presence of shoddy or fraudulent competitors: in short, snake oil. The more urgent the need and the more lucrative the potential market, the more likely it is to attract incompetent or unscrupulous operators. And once burned by inferior or phony products, consumers are less likely to try even a first-rate new product the next time.

Section 3: Triage: Sorting Out Near-Term Energy Fixes

Because the number of potential energy technologies either on the drawing board, in development, or currently available is far too great to assess comprehensively in this survey, I am limiting it to a variety of technical solutions that have been often discussed or pointed out by experts as (a) pertinent to climate issues and (b) plausibly applicable within the relatively short time frame of the present assignment.

Nor is it possible within the limits of this study to consider every sector and subsector of energy supply, conversion, transmission, and consumption. Among areas most relevant to the subject and time frame here, electricity—including production, distribution, and consumption—warrants significant attention. The pervasive electrification of nearly all infrastructure and every process of our cybernetic society should make the importance of the electrical sector obvious. But the electrical services are inseparably interdependent with other key utilities, particularly water, telecommunications, and natural gas.

The transportation sector clearly is also a focus of great concern, since it is the major consumer of petroleum fuels which, even if atmospheric emissions were of no interest, would still be entangled in some of our most urgent national security dilemmas. Buildings of all sorts also merit serious attention: They account for about a third of total national energy consumption and over 40 percent of electrical demand. In their primal role as shelter, buildings are intimately connected to nearly all our security and safety interests, not only as isolated structures but in their locations and overall pattern of development.

While not as commonly addressed in broad energy strategy discussions, the cybersphere—the global web of computation, control, monitoring, and telecommunications—also warrants special attention here. On one hand, the cybersphere has a critical potential for enhancing energy efficiency in many other sectors. On the other, it is an increasingly hungry energy consumer as well as a critical infrastructure whose security from attack or disaster is of acute concern.

Since this report aims to find technological solutions that have a “substantial impact” on energy and climate concerns, for practicality I will sort the discussion of potential alternatives into three broad bands:

- Attractive: The most attractive—also acceptable—solutions offer positive synergies: that is, dual (or more) benefits that serve both security requirements and meet climate action demands. Within the short time frame given, there is wide agreement that cost-effective efficiency solutions are likely to be the most feasible and hence most attractive options. Efficiency solutions are particularly likely to blend technical, behavioral, and social elements. Solutions that impose low costs are obviously among the most attractive. Distributed, decentralized solutions also have an attractive advantage in the short term because they generally entail lower infrastructure costs and fewer decision points to delay initiatives.

- Potentially feasible: A larger set of potential near-term solutions have significant technical and economic promise, but face one or more substantial hurdles to overcome before they could be deployed widely or rapidly enough to make a substantial impact. Most of these solutions are more or less inherently feasible, but normally would be expected to take a longer time to achieve market penetration and large-scale adoption. However, an atmosphere of urgency or even crisis—driven by acute social, economic, political, strategic, or environmental conditions—could provide the impetus to accelerate the development and implementation of some of these candidate solutions. The particular cause of urgency would affect which of these technology options would gain a near-term boost. Because climate issues are intrinsically long-term in perspective, imminent threats to security or safety (whether physical, economic, financial, strategic, epidemic, etc.) are more likely to create the crisis atmosphere in which obstacles can be pushed aside and accelerated action undertaken. So the most attractive solutions in this category for the purposes of this Policy Report generally would be those that respond to security concerns while producing collateral benefits for the climate agenda.

■ Breakthrough: The most enticing technological opportunities for the public and policy community alike are the ones that constitute major breakthroughs, overcoming stubborn obstacles and making easy and affordable what seemed difficult and costly. By their nature, such breakthroughs are unlikely and unpredictable. But they are not impossible. Urgent efforts and crash programs may speed the achievement of a breakthrough, but offer no guarantee of a desired result. Yet when breakthroughs do occur they may well be disruptive to established systems and economic interests.

A. ATTRACTIVE FIXES

A number of studies and reports from the McKinsey Global Institute (MGI) and other organizations emphasize that energy efficiency fixes are generally the most cost-effective and rapidly available solutions both to energy security needs and GHG concerns. MGI argues that the United States should be able to increase its energy productivity—in terms of the amount of national income produced per unit of energy consumed—because, it observes, the energy productivity ratios of the economies of Northern Europe and Japan are significantly higher.[1] Yet the population density in Europe is considerably greater than in the U.S.; Japan's density is even higher. When one remembers that the span of United States territory includes Alaska and Hawaii, it should be obvious that the distances people and goods have to travel are far greater in the U.S. than in either Europe or Japan. When the energy cost of internal transportation is properly accounted for, the energy productivity of the U.S. economy is not as different from that of Europe or Japan as it might at first seem.

More relevant to the point that the U.S. could improve its economic energy productivity is that it has done so before. In particular, in the three decades since the oil "shock" of 1979, the United States has more than doubled the number of dollars of national income it produces from each unit of energy it consumes. Even in just a few weeks during the summer of 2008, U.S. energy consumption declined while the economy still continued to grow.

As energy prices soared this year, so did the number of both public-interest and private commercial appeals to buy and apply a long menu of energy-efficiency technical fixes. At least some of the decrease in U.S. energy consumption achieved earlier this year was attributable to the ability to fairly rapidly adopt some energy efficiency measures.

The efficiency chorus was matched by a similar cascade of pitches for "alternative" energy supply solutions. Some called for more use of biofuels or natural gas or even hydrogen as transportation fuels; others for shifting to plug-in hybrid/electric vehicles, pushing more "green" or even "zero-energy" buildings with photovoltaic or other onsite "renewable" power, stoking a broad enthusiasm for wind turbines, and even calls for a crash program to expand the role of nuclear power. Opening up drilling for offshore oil and gas also became something of a cause célèbre.

Most, but not all, of the latter entailed scale requirements or other hurdles that would not make them immediately attractive—that is, feasible to implement and have a significant impact with the short time frame we are considering here. The full number and variety of quick technical energy fixes that have been touted across every sector of demand is far too long to list here.

In reality, there are only a few innovations that really determine the near-term feasibility of any of such energy fixes. And their common commodity is not oil or gas or wind or even energy directly, it is only one thing: Money—and then, the particular manifestations of money in the form of pricing, purchasing power, financing, and fiscal (as opposed to environmental) "sustainability."

I will have more to say about that later. But first, let's review some examples of the "quick" energy technology fixes that recently have been proposed, and even applied already—to get a sense of which are likely to prove attractive and feasible within our limited time frame, and of some that, while eagerly touted, are improbable or even impossible.

BUILDINGS AND ELECTRICITY

1. Energy Efficiency

In another, more recent report, the McKinsey Global Institute argued that "the economics of investing in energy productivity—the level of output we achieve from the energy we consume—are very attractive," with an average internal rate of return, MGI calculated, of 17 percent. The report noted also that "Energy productivity is also the most cost-effective way to reduce global emissions of greenhouse gases (GHG)." The particular action items MGI recommended to improve efficiency included: "Setting energy efficiency standards for appliances and equipment, upgrading the energy efficiency of new buildings and remodels, raising corporate standards for energy efficiency, and investing in energy intermediaries."[2]

Another typical example, a recent report from the American Council for an Energy-Efficient Economy (ACEEE) that was one of a series on the individual U.S. states, concludes that the Commonwealth of Virginia: "can meet close to 20 percent of its electricity needs by 2025 through energy efficiency, a strategy that also would cut Virginians' utilities bills by $15 billion by 2025 and create nearly 10,000 new jobs—the equivalent of bringing almost 100 new manufacturing facilities to the state. And by reducing electricity use, Virginia can play its part in reducing global warming and contributing to a more sustainable environment."[3]

In particular, the efficiency measures the ACEEE report recommended to achieve such substantial reduction of electricity consumption included:

- In commercial buildings, replace incandescent lamps, enhance fluorescent lighting, and employ lighting control measures as well as installing new heating and air conditioning (HVAC) systems.

- In residential housing, utilize more efficient heating and air conditioning systems, improve insulation and windows, and make improvements in residential lighting.

- In industrial facilities, employ more efficient electric motors and pumps, improving duct and pipe insulation.[4]

Because the time horizon of the ACEEE report is ten to fifteen years longer than that of this study, at least some of the energy efficiency measures it recommends would require a larger scale of investment, structural deployment, and time to implement than would satisfy what we would consider "attractive" for near-term solutions. This is indicated in the following chart of cumulative savings the report includes.

The chart clearly indicates that, while the potential contribution of efficiency measures becomes substantial over a period of decades, in the near term their impact is relatively modest.

2. Compact Fluorescent Lights

Still, many of the steps suggested can be taken fairly quickly and at relatively low or modest cost. As noted in the Virginia report, one of the most popular is to shift from incandescent to fluorescent light fixtures.

According to the U.S. federal government's Energy Star program (a joint venture of the Environmental Protection Agency and the Department of Energy), if every American home replaced just one conventional, incandescent light bulb with an Energy Star certified compact fluorescent light (CFL) bulb, the energy savings would be enough to light more than 3 million U.S. homes for one year—by a rule of thumb widely cited by conservation activists, that would be equivalent to the power of one nuclear plant.

The Energy Star program further notes that qualified CFLs use about 75 percent less energy than typical incandescent bulbs and last up to ten times longer, saving about $30 or more in electricity costs over a bulb's lifetime (usually estimated at five to seven years). So the payback of the extra initial cost of a CFL bulb is pretty attractive, perhaps a year or less. With lighting accounting for roughly 16 to 33 percent of electricity use in the residential and commercial sectors, what seems like a relatively simple and low-cost technical fix—replacing incandescent bulbs with CFL light bulbs that can deliver comparable illumination with only about a quarter of the power consumption—actually has the potential for rather significant macroeconomic impact. And because it can be effected through individual initiative, requiring no large-scale infrastructure costs and few regulatory or structural barriers to implementation, it seems like something that could be done within a near-term horizon. So enticing has been the CFL fix, particularly as energy costs soared during the past year, that it gained a momentous boost when mega-retailer Wal-mart committed to use its prodigious market power to drive down the cost of CFL bulbs and aggressively push their sales.

The very elegant simplicity and attractiveness of the CFL option serves to convey a central lesson about all energy fixes: None are free of complications and virtually all entail greater complexity than may appear on the surface.

A newspaper story on the CFL marketing challenge reported that, despite the push from policy advocates, conservationists, and major companies like Wal-mart, many consumers—women consumers particularly—just didn't like the way compact fluorescent lights work.[5] They especially did not like the way CFLs don't turn on instantly, but gradually brighten as they warm up. Newer and higher quality bulbs are quicker on the draw, but the nature of the technology cannot completely eliminate some lag.

A more serious problem: CFLs contain mercury. The amount in a single bulb is small, about 5 mg, but not trivial. As CFLs were more widely promoted and marketed, worries about the toxic hazards of mercury provoked a significant backlash.[6] Many environmentalists who otherwise would favor the energy conservation and potential climate benefits of CFLs became concerned about the toxic wastes flowing from the production and disposal of millions of mercury-tainted light bulbs.

Or, consider the selling point that CFLs can replace nuclear power plants. Actually, since lighting tends to be aligned with peak demand rather than the kind of baseload power nuclear plants would provide, lights are more likely to tax peaking capacity, which often is provided by generators burning natural gas. Moreover, the nuclear industry itself, along with some environmental activists, now touts nuclear power as a "green" energy solution to climate change with "zero" (more accurately, very little) GHG emissions. For those who view nuclear power as an attractive replacement for coal-fired power plants—a major source of GHG emissions—delaying the deployment of nuclear power does not seem to be a "green" benefit.

The late environmental scientist Barry Commoner defined the essential law of ecology in lay terms as: We can never do merely one thing. Accordingly, we must keep in mind that even the simplest, easiest, cheapest technical fixes are prone to open their own particular Pandora's boxes of nettlesome aggravations. And these will commonly make even very promising potential results more complicated, difficult, and costly to achieve than our best hopes and plans anticipate.

In fact, beyond something as simple and easy as screwing in a new light bulb, many of the other relatively attractive and feasible near-term technical fixes tend to be somewhat more complicated and costly to deploy.

3. Programmable Thermostats

Getting homeowners to adopt programmable thermostats is one of the easier fixes recommended to improve the efficiency of heating, ventilating, and air conditioning (HVAC) of residential and business buildings—a major component of demand for energy generally and fossil fuels in particular (e.g., heating oil, natural gas, and indirectly, coal for electrical services). A programmable thermostat is one that, as the name suggests, can be programmed to adjust the temperature according to the time of day and day of the week. It even can automatically switch between heating and cooling as conditions change. Obviously when no one is home—typically during business/school hours—over-heating the interior space on a cold day or over-cooling on a hot day to maintain a comfortable temperature represents a considerable waste of energy and money. Similarly, at night when people normally are asleep, they can tolerate a somewhat warmer or cooler temperature than they would when awake, saving more energy.

The average U.S. household spends about $1,000 a year on heating and cooling. A programmable thermostat can reduce that cost by 25 percent to 30 percent.

If programmable thermostats could be deployed universally in the United States within a three to eight year time frame, the total energy savings could be on the order of around 5 percent of all U.S. energy consumption. That would seem to count as a "substantial" contribution from a relatively simple and inexpensive technical fix. (While the HVAC systems of commercial/business buildings tend to be more complex, at least some—such as businesses operating in office condominiums or townhouses or even conventional houses—probably could take advantage of the same fix, adding a bit to the total savings.)

One of the attractive features of energy fixes like these that can be implemented by individuals at the "grass roots" level is that the diffusion of such innovations lends itself to spreading by what we used to call "word of mouth" but is now, amplified by the reach of cyberspace, called "viral marketing." For example, a homeowner in Northfield, Minnesota, after installing a programmable thermostat in his house, collected his electric bills for a year and then posted an easy-to-understand chart on his personal blog to show how effectively the new thermostat had saved his family energy and money. (The blue line shows the year before and the red line the year after the new thermostat was put in.)

Replacing a thermostat is one of the less demanding energy-saving renovations home or other building owners have been urged to undertake. While in some cases this can be a do-it-yourself project, often the aid of a contractor is needed; The cost of upgrading a thermostat may range anywhere from $30 to $300. Still, as the Northfield chart suggests, the potential money savings are often great enough and rapid enough to make the investment quite attractive.

Nevertheless, getting innovations adopted is not very productive if they are not actually used. Just as things proclaimed "sustainable" often are not actually sustained, thermostats that are technically "programmable" often do not actually get programmed to save any energy. The head of marketing for White-Rogers, a major thermostat manufacturer, notes that 25 million homes in the U.S. (about a quarter of all homes) already have programmable thermostats, but in only half of them are the residents using the features that save energy.[7]

This example underscores a broad finding from researchers who have studied the processes of innovation over many decades. A common rule of thumb from that research is that technology itself only accounts for a fraction, around 20 to 25 percent, of the productivity gains from innovation. The larger share of improvement derives from changes in human and social factors: behavior, organization, management, policy, culture, and such.

Other recommended home and building renovations aimed at improving energy performance could add further "substantial" savings within a three to eight year span. But many—adding insulation, replacing windows and doors, upgrading to the most efficient "Energy Star" appliances, heating and cooling systems, and so forth—entail greater effort, cost, and complexity to implement than the previous examples, even when proven technology is immediately available. More often than not, such substantial investments—not only of money but of time, effort, and inconvenience—will be undertaken only when they become necessary: in all-new construction, major remodeling, or simply when the heat pump dies, the old refrigerator stops working, and so on. And again, just as with thermostats, more advanced and efficient technology may require behavioral adaptations, or special skills and training for installation, service, and maintenance in order to achieve the desired benefits.

Just for that reason, tax credits or other government subsidies aimed at inducing the adoption of efficiency or alternative energy technical fixes may not achieve the macroeconomic results they aim for because they may not provide incentive or assurance to see that all of the requirements of successful application of the technology are met. In fact, there are existing tax incentives for installing programmable thermostats yet, as noted, about half are not actually saving any energy.

TRANSPORTATION

In addition to concerns within the building sector, there has been even greater concern about the particular fuels, overall energy demands, efficiencies, and technologies in the transportation sector. Broadly speaking, transportation entails far more integrated, large-scale infrastructure and systems than other sectors.

Despite the origin of the word "automobile," transportation technology exists to go somewhere, taking people and things along for the ride, and thus cannot be really autonomous. Rather, transportation depends not only on distributed thoroughfares but an elaborate infrastructure of supporting materials, resources, products, facilities, and services to keep things moving all along the way.

1. Oil Reliance

In the U.S., cars, trucks, and other motor vehicles, constitute the major means of transport. As historical experience continually demonstrates, any "substantial" change in the overall efficiency of this transportation system, or of the particular energy sources and processes on which it depends, generally demands large-scale implementation even to initiate any market penetration.

In the crisis atmosphere that existed in the oil shocks of the 1970s and shortly beyond, and then again in the past few years, tension in and about the transportation sector was especially acute—just because it is the sector most dependent on and with the greatest demand for petroleum fuels. That resource dependency was and has been increasingly seen as one of the most palpable threats to America's economic, financial, and overall national security. During the past year or so, Americans were continually reminded—by politicians, media, commercial vendors, and each other—of an acute irony: While the U.S. has been spending over $10 billion a month fighting two wars (and more on a cumbersome "homeland security" apparatus) to defend itself against terrorist and other irregular threats, the oft-cited "$700 billion a year" it spends to import petroleum not only drains its economic and financial security but often goes to help fund its enemies.[8]

Despite the sense of urgency, and sometimes desperation, the near-term measures that readily can be adopted individually or locally to reduce that dependency—and the associated pinch of rising fuel costs—are generally more behavioral than technological, as just a few of the energy-saving tips from the U.S. Department of Energy suggest:

- Aggressive driving (speeding, rapid acceleration, and hard braking) wastes gas. It can lower your highway gas mileage 33 percent and city mileage 5 percent.

- Use air conditioning only when necessary.

- Keep tires properly inflated and aligned to improve your gasoline mileage by around 3.3 percent.

- Long-Term Savings Tip: Consider buying a highly fuel-efficient vehicle. A fuel-efficient vehicle, a hybrid vehicle, or an alternative fuel vehicle could save you a lot at the gas pump and help the environment.[9]

While the savings from individual measures may seem minor, the savings are additive. Followed assiduously, the economies they offer to the individual consumer become significant. If put into practice by a sufficiently large share of the population, the macroeconomic impact would be substantial. But, except for the last item, these do not serve the craving for a technical fix. And in the 2008 election year's campaign season, politicians who dared to recommend such measures as keeping tires properly inflated to ease the recent energy crunch were often lampooned by adversaries for failing to offer a more heroic scheme to attain the holy grail of "energy independence."

Sadly but realistically, much of what appears to slake the appetite for rapid technical fixes to the country's petroleum "addiction," especially in the transportation sector, often has been an amalgam of hype and snake oil.

The more benign form of technological hype is an efflorescence of much-publicized conceptual models, working prototypes, or small-scale demonstrations of products or systems offering the tantalizing potential either to vastly improve fuel efficiency or to substitute dangerous petroleum fuels with other, more abundant, more secure, and/or more "renewable" energy sources. Or both. At the other, malignant end of the scale is pure fraud—and the more acute the sense of crisis the more abundantly the fraudulent "solutions" emerge.

Aligned with the hype spectrum, the scale of the scientific and engineering robustness of this cornucopia of technical fixes ranges from well-grounded and potentially feasible to utterly impossible. At the dark but relatively petty end of the snake oil scale, this year saw a bulge in the perennial offerings of gadgets for sale to car and truck owners that can be easily installed for "only" a few hundred dollars and that promise to improve fuel economy by 20 to 30 percent or even more. The Environmental Protection Agency has evaluated and publishes lists of scores of such devices it has found completely ineffective.

At the more benevolent end of the hype spectrum, this year saw a surge in serious, well organized advocacy of plug-in hybrid vehicles as a virtual panacea for a mélange of energy, security, and climate challenges. The blitz came from distinguished business and government leaders, stolid analysts, and legitimate policy institutes. A two-day Brookings Institution conference on the subject drew a standing-room crowd of attendees to a Washington, D.C. hotel.

Plug-in hybrid or electric vehicles certainly are technically possible and a potential long-term technical solution that merits serious consideration. But in the urgent atmosphere of last summer's soaring fuel prices, many of the speakers and most of the audience at the Brookings conference, incited by the usual samples of prototype and demonstration vehicles arrayed in the hotel lobby, seemed more inclined to perceive a potential long-term fix as an instrument of imminent salvation.

The blunt, near-term realities are less exciting. There are no plug-in hybrid vehicles currently in production or available for broad commercial sale. The number of such vehicles actually on the road is only a few dozen worldwide. They are custom-made by a few specialty shops and add $10,000 to $40,000 to the cost of the car from which they are converted.

Transportation reform activists have been, if anything, even more thrilled by the prospective debut of the all-electric Chevy Volt. The benefits General Motors touts for this radically innovative vehicle indeed seem impressive: "Chevy Volt is designed to move more than 75 percent of America's daily commuters without a single drop of gas. That means for someone who drives less than 40 miles a day, Chevy Volt will use zero gasoline and produce zero emissions. Unlike traditional electric cars, Chevy Volt has a revolutionary propulsion system that takes you beyond the power of the battery. It will use a lithium-ion battery with a variety of range-extending onboard power sources, including gas and, in some vehicles, E85 ethanol to recharge the battery while you drive beyond the 40-mile battery range. And when it comes to being plugged in, Chevy Volt will be designed to use a common household plug."[10]

General Motors promises to begin selling the Volt in the 2010 model year—certainly within the time frame of this study of options that could have a near-term impact. Yet as of October 2008, General Motors' stock is down some 85 percent from a year ago and the company seems to be teetering on the brink of insolvency. Many analysts have been expecting that the U.S. government will provide some kind of financial rescue for GM as well as for similarly ailing Ford and Chrysler, the others of the traditional "Big 3" U.S. automakers. But with the federal government now $10 trillion in debt, running a deficit of another half a trillion dollars a year, and having recently provided about another trillion dollars (and counting) to rescue failing banks and financial institutions, it cannot be taken for granted to what extent the U.S. government will have the financial capacity or political capital (public support) to provide further "bailouts." While GM likely will survive in some form, the very innovativeness of the Volt makes it also risky. And the tolerance for risk in the U.S. as well as globally right now is very low and still sinking.

These examples of hyped expectations and fraudulent exploitation may seem like marginal distractions from the valuable technical fixes urgently sought for energy, security, and climate problems. More than a few might be characterized as what is called "greenwashing" or even "greenmail," and even rationalized by some activists as means that are justified by well-intended ends. But as I suggested earlier, the potential impacts of individual innovations are determined not merely by each technology's particular performance characteristics but also—probably even more so—by the overall market, and its social and political context, in which the innovation is introduced and aims to be adopted.

Whether bad innovations are the result of innocent “irrational exuberance” or of criminal intent, disappointing results or costly failures accumulate to increase the perception of risk and uncertainty among potential investors, sponsors, customers, and adopters. Worst-case fiascos can freeze market opportunities for even great inventions for years or even decades.

And in the domains linking energy, security, and climate this project is studying, not all the instances of technological hype and exploitation have been minor. We have experienced a worst-case scenario in the form of the biofuels debacle.

2. Biofuels

Because the biofuels movement is the specific subject of a different Policy Report in this project, I will only summarize the harsh lessons we have learned from it briefly: The push for vast expansion of biofuels, particularly from corn and soybeans among other food crops, was hyped as a prolific “green” technological cure for both petroleum addiction and global warming. Generous government subsidies and protections made it an even more lucrative opportunity for farmers and producers of ethanol and biodiesel fuel stocks.

The actual impacts of the biofuels initiative—some might suggest “mania”—have ranged from counterproductive to disastrous. Diverting food production and jacking up soaring food prices, biofuels helped push an estimated 100 million people in poorer regions of the world over the brink of hunger (officially called “food insecurity”) in 2008, sparking political rebellion, social disorder, and outbreaks of violence. Rather than improving the environment, the biofuels bonanza stimulated the clearing of ever-larger swaths of forest in Brazil and Indonesia to make way for biofuel plantations. In the tri-state peninsula that borders the Chesapeake Bay, farmers enticed by the soaring prices of corn-for-fuel switched from environmentally benign crops to fertilizer-hungry corn, spewing a surge of run-off that reversed years of efforts to clean up the pollution that threatens the Bay’s fragile estuary. And scientific research revealed that rather than reducing GHG emissions, by plundering forests and soil the biofuels juggernaut was adding more GHG to the atmosphere than it was saving.

Most confounding about this fiasco is that there is a developing array of alternative biofuel technologies with the potential to provide greater benefits with far less negative impacts. Among these alternatives are some that would use advanced biotechnology to convert agricultural waste or plant matter unsuitable for food, grown on marginal land, into liquid fuel. Others would employ bioengineered microbes, bacteria, or algae, grown hydroponically and thus requiring no arable land at all.

But the recent biofuels disaster has poisoned the well in several ways that will serve to retard advancement of these more desirable alternatives. First, the “biofuels” brand has been badly tarnished and will provoke a negative response in many areas of the market. Second, the existing ill-founded biofuels industry has become sufficiently big and prosperous that it has the money and lobbying clout to politically protect its current position and practices. And that being the case, the more-benign technological alternatives’ potential to overthrow the existing food-based fuels industry gives the latter the incentive and means to quash the upstarts’ threat.

3. Efficient Vehicles

In the near term, over the next several years, the main fix in the energy/climate performance of the U.S. transportation sector will not come from any drastic shift in energy source or introduction of revolutionary technology. Rather, it will come from incremental, but still significant, improvement in the efficiency of the established internal-combustion engine technologies, combined with shifts of demand among existing products and services. This is the same pattern that we saw in the early 1980s following the energy crunch of the 1970s, and even recently again in 2008. Consumers are turning away from oversized SUVs, trucks, and other gas-guzzling vehicles in favor of smaller, lighter, more efficient vehicles. There also is growing demand for hybrid-engine vehicles, although for many consumers the payback of the extra vehicle cost through fuel-cost saving may take too long for that to be an attractive option, especially as the fuel efficiency of many conventionally powered vehicles now matches that of more-expensive hybrids.[11]

We also have seen a substantial shift of transportation demand from driving cars to other, more economical modes, especially mass transit in urban areas as well as car-pooling, motor scooters, bicycles, and even walking.

As noted earlier, the benefits of such innovations are entangled in a broader web of interdependent infrastructures and systems, often spawning collateral, unintended, or unexpected side effects, disturbances, and costs. The big shift toward more efficient vehicles has been attended by cutbacks and layoffs at some factories and urgent efforts to expand capacity of others. The very success of fuel-saving measures has reduced the fuel-tax revenues needed to construct, maintain, and repair roads, bridges, and tunnels. Most mass-transit systems were unprepared for the surge in ridership, resulting in crowding, increased delays, and accelerating wear and tear and breakdowns of equipment and infrastructure that in many cases was already aging and in need of renovation. Among other effects, the dilapidation of transportation infrastructure will tend to reduce its energy productivity and overall operational efficiency.

While the direction of the shift in transportation technology and use is toward greater efficiency, the magnitude of the macroeconomic impact over the next several years on energy conservation, national security, and climate goals is likely to be substantial but not radical. While consumers clearly want smaller and more efficient vehicles, supply capacity is yet far from matching demand. Meanwhile overall vehicle sales are down as the economy sinks into deeper recession, and credit is crunched.

As long as the economy stays depressed—which some analysts believe may be for up to two more years—turnover of the national vehicle fleet will be slow, reducing and delaying gross improvement in the average efficiency of all the cars and trucks actually on the road.

More recently, fuel prices have been sinking about as rapidly as they had been soaring earlier in the year. In this instance the rapid decline in energy costs raises the question of whether the recent shifts in demand toward more efficient options will persist.

Today's global economy generally is in uncharted territory, making any projection or prediction tenuous. But based on the pattern we saw in the 1980s, it seems likely that the current shift toward more efficient transportation options will continue for at least a few years or more. As the figure above showed, after the oil shock of 1979, even as world oil prices surprised most analysts and declined sharply through the 1980s and beyond, the U.S. steadily improved the energy productivity of its economy for more than a decade after the initial crisis.

As it did then, the current adaptation of production capacity and infrastructure already begun in response to the spike in demand for greater efficiency will take months or years to fully carry out; the commitments of resources to that restructuring would take even more years to undo if demand reverses course later. And consumer demand also tends to lag behind current conditions. The memory of pain tends to linger for some time after the source of its infliction is gone. Behavioral science bears out the old adage: Once burned, twice shy.

ENERGY MANAGEMENT

Among the potentially most attractive and feasible near-term energy fixes are an array of options that are less concerned with particular energy appliances or gadgets and more with managing the various energy systems we have. These solutions take advantage of the rapidly advancing lightness, agility, speed, and intelligence of the cybersphere.

The federal government's Energy Star program emphasizes that the need for and potential gains from good energy management are considerable. Until recently at least, the program observed that in many organizations capturing opportunities to cut energy waste was hampered by unfocused energy management practices that were decentralized, poorly coordinated, reactive, undervalued, considered capital intensive, and merely concerned with paying bills or running the powerhouse. As a result, the program observed many signs that energy waste is still prevalent, including:

- A 400 percent variation in energy use intensity of buildings in the United States exists that is not explained by age, technology, hours, size, climate.

- Little improvement of overall energy consumption has been seen although building components are 30 percent more efficient since 1980.

- Oversizing building fan systems, on average, occurs by 60 percent.

- Most chillers are oversized by 50–200 percent.[12]

The accelerating application of IT to managing energy and other resources more efficiently has begun to reverse this pattern in several ways. In a sense they take the rather simple but productive potential demonstrated by the programmable thermostat and expand it geometrically in many directions and sectors.

First, one of the most basic yet most powerful impacts of IT is to greatly expand the volume, accuracy, speed, and communication of performance metrics. Researchers discovered decades ago that simply moving electric meters from their usually hidden location in the backyard or basement to right next to the front door, where they would be continually seen by users, resulted in significant decline of household energy use. So not only is feedback necessary for control; more feedback leads to more and better control.

Because so many of our structures, tools, appliances, and processes—both in business and in the home—are getting ever more cybernetically intelligent, sensing, interactive, and connected, they are becoming ever more amenable to both proximate and remote feedback and control.

One example of not just the potential but actual application of that immersive sense-and-control capability is Cisco Systems' "Connected Real Estate" initiative. In essence, Cisco has taken the network capabilities it already has installed in many office and other buildings that support voice, video, data, and wireless mobility technologies and extended them to integrate all the systems that go into a building, including: building automation systems, video surveillance systems, security systems, and access control systems. Not only can a building's use of energy, water, and other resources be monitored and fine-tuned for optimal efficiency, but they can be coordinated and harmonized with safety, security, and all the other functions a building is meant to perform. Moreover, that resource management capability is not limited to each individual building. The energy/resource manager for a multinational organization that has many buildings and facilities dispersed all over the world can track and manage all or any of them, anytime, and from any place that provides computer access to the corporate network. As indicated from its application to some of Cisco's own buildings, a million-dollar investment in this kind of integrated information system can pay back several million dollars every year in annual savings on energy, security, and other costs.

Applying a similarly high-tech approach to building performance management, Johnson Controls' "Performance Contracting" offers its customers the opportunity to reduce their facilities' energy and other resource expenses essentially at little or no cost—by sharing their savings with the contractor.

Consider also the power in the amalgamation of global positioning systems (GPS)—which tell us exactly where people or things are—with geographic information systems (GIS)—which give us ever more detailed information about the environment in which people and things are located. Among the gains from that technical capability: The movements of trucks, cars, trains, ships, and airplanes can be tracked and managed precisely to optimize routing for maximum fuel efficiency, to reduce bottlenecks and traffic jams that waste energy and time and money, and to eliminate errors that require repeat trips or deliveries and other wasteful expenses. For example, a GPS-based replacement for America's decrepit air traffic control system, which has been stuck in the planning stage for over a decade, could have saved airlines over $5 billion of fuel costs just this year had it already been implemented.[13]

In addition, the buildingSMART Alliance of the National Institute of Building Sciences is working for the standardization and universal adoption of a computer-based technology for integrating design, planning, and construction. It is called "BIM" for Building Information Modeling. As the Alliance explains the basic concept of this technology: "In contrast with centuries-old ways of documenting facilities with two-dimensional drawings plus specifications—a process recently automated with Computer Aided Design (CAD)—new digital technology brings together owners, operators, designers, constructors, regulators and other stakeholders around a single Building Information Model (BIM), a unified tool that offers unprecedented accuracy, speed and economy."[14]

BIM offers an immense potential to improve the resource efficiency, security, and overall effectiveness of architecture, urban planning, and real estate development. The detailed digital synthesis via BIM allows alternative sites and designs to be modeled in 3D and discussed and tweaked by stakeholders before a single shovel of earth is dug or a single brick laid. But moreover, once all relevant data are integrated into the BIM model, it can be used to dynamically simulate the performance of proposed structures, including energy use, water use, ventilation, impacts of the structure on the environment and also vulnerability of the structure to threats from the environment, whether human attacks or natural hazards such as storms, earthquakes, or floods. BIM experts estimate that intensive application of BIM could reduce the costs of design, planning, and construction of development projects by 80 percent, Such savings would come through eliminating errors that now commonly bust budgets as well as delays and setbacks from late-breaking regulatory or litigation issues that could have been avoided through early coordination.

We should note that computers, the internet, data centers, telecommunications, and the other technologies that comprise the matrix of the cybersphere, and that offer such great potential to enhance resource efficiency, also are themselves significant consumers of energy—chiefly electrical—and other resources. Power use in data centers alone doubled from 2000 to 2006 to now consume 1.5 percent or more of U.S. electric power. A McKinsey & Co. report indicated that the carbon footprint of all the world's data centers is greater than Argentina's.

But current signs suggest that not just potential but actual advances in information technology will lead to significant improvements in the energy and resource efficiency of the cybersphere during the next three to eight years, and beyond. "Blade" computers and "virtualization" (or VM for "virtual machine") software have shown the ability to substantially increase the efficiency of data centers. By shrinking the physical size of hardware and utilizing it more completely, the space requirements of the servers such centers house, and thus the volume needing to be cooled, are reduced.

Companies also have found they can save energy by consolidating data centers in fewer, larger facilities that require less air conditioning. Citigroup has been constructing "green" data centers such as one in Germany that has a green (earth and plants) roof and an exterior wall covered with succulent plants that retain cooling water, reducing the air conditioning load.

Such data center innovations can lead to substantial savings. By redesigning its own computer rooms, EMC Corp. projected savings over three years of some $4 million in energy and floor space costs.[15]

The chips and other components of computers are getting more energy efficient as well. Intel's CEO recently claimed that the dual-core processors Intel introduced about two years ago had, to date, saved some 20 billion kilowatt-hours of electric energy, compared to what its earlier generation of chips would have consumed.[16] Intel's Atom and VIA's Nano systems are now competing in the market for even lower-power, energy-saving computers. More efficient chips not only reduce power demand for their operation but, because they run cooler and shed less waste heat, they save even more energy by shrinking the need for cooling.

Overall then, energy management systems, and the IT technologies they run on, may be among the technical fixes with the greatest near-term potential to contribute to energy and security needs while serving climate goals.

B. POTENTIALLY FEASIBLE FIXES

In the discussion above, I have already mentioned examples of technical fixes that, in contrast to some that seem attractive and feasible in the near term, face more difficult hurdles or complications that probably will delay their potential impact until farther in the future. Here, I will summarize some of the dark-horse or wild-card technologies that have been talked about as possible solutions to energy, security, and climate issues, and that have some chance (more or less) to come into play in the near future.

RAIL/MASS TRANSIT

We've known for a long time that rail and mass transit systems are generally more energy efficient than traveling, particularly commuting, in cars on highways. The surge in shifting trips to these rails systems we see when fuel prices spike, or sometimes when other events like a bridge collapse or ice storm constrain highway use, do not represent a sustainable shift in travel behavior. As noted above, the infrastructure of rail and transit is not elastic enough to rapidly respond to big shifts in demand. In the short run some measures like adding more cars or tweaking train routes and schedules or "bus rapid transit" can adapt service capacity somewhat. But substantially shifting travel from road to rail usually takes extensive construction and time.

TELEWORK

The upside benefits of telework and telecommuting are immense. Indeed they are probably the most positive of all the options noted here, offering almost ideal synergy across the agendas of energy, security, and climate. The Telework Coalition lists just some of the energy and environmental benefits of telework:

- It reduces toxic gases and dust particles spewed into our atmosphere,

- It reduces chemicals washed into our waterways, wells, rivers & estuaries,

- It reduces the need to have to find new sources of oil.[17]

Telework saves energy and slashes emissions. (No vehicle has greater energy efficiency and lower emissions than the one that stays parked in the garage.) Telework serves economic security, adding over $300 billion to the economy's bottom line through greater worker productivity. Telework also contributes to homeland security by dispersing assets and work centers, facilitating redundancy and continuity of operations in case of attack and disaster.

The benefits and feasibility of telework have been available and well known for a long time. Yet adoption remains only marginal. The barriers to telework's huge potential are chiefly in the category of organizational behavior and management: in particular, the tendency of middle managers to resist surrendering line-of-sight control over employees, despite much research-backed evidence that telework increases productivity. This barrier needs a strong push from top management, and perhaps public policy, to be overcome.

SMART GRID

One of the potentially most important applications of IT to energy management is the "smart grid" which extends the cybersphere's growing capability to sense and control to allow fine-tuned managing of supply and demand on the electric grid. With the crude level of grid management that generally exists now, in times of high demand and limited supply of power, whole neighborhoods may experience reduced voltage—"brownouts"—or be shut off altogether in a "blackout." Putting intelligent sensors and switches into each electric meter—or even individual appliances such as furnaces, air conditioners, water heaters, refrigerators, stoves, clothes washers/dryers, etc.—can give grid managers the ability to monitor and manage demand in much more nuanced detail. With permission of customers, utility managers can remotely control the electric load from particular equipment at times of peak demand, perhaps adjusting heating or cooling, turning down the water heater, and so on, rather than cutting off a whole building.

The smart grid also permits demand-based pricing, charging more for power used during periods of peak demand—usually during daylight business hours—and less at off-peak times, generally at night.

And the smart grid also works in reverse, allowing homes and buildings with photovoltaic or other on-site electric generating equipment to sell surplus power back to the utility. This two-way control and finance capability of the smart grid is critical to the potential large-scale deployment of plug-in hybrid or electric vehicles.

Among several utilities beginning to test smart-grid solutions, Xcel Energy is already building a smart grid pilot project in Boulder, Colorado. So the smart grid fix is likely to start penetrating a number of local areas of the U.S. within the next several years. But because of the sheer scale and complex integration of the nation's whole electric grid, this innovation probably will not make a "substantial" impact on the country's energy budget until farther in the future.

SOLID STATE LIGHTING

A more attractive fix for illumination needs will be solid state lighting (SSL). The principal technology in this category is the light-emitting diode (LED), well-known and increasingly common in a wide range of consumer products, from cell phones to computers, music players, kitchen appliances, automobiles, flashlights, and such. A typical LED package includes a tiny electronic chip fused to a plastic lens.

An emerging technology in the category is organic LEDs (OLEDs). Unlike LEDs, which are rigid and produce a focused beam of light, OLEDs are based on chemical potions that can be painted onto broad sheets, such as display screens, or even flexible films.

LEDs are extremely energy-efficient, needing only 33 percent to as little as 3 percent of the amount of power to produce light of comparable intensity to incandescent or CFL light bulbs. LEDs also run cool, producing little waste heat. Unlike CFLs, LEDs are essentially break-proof and contain no toxic mercury. LEDs are extremely durable, lasting ten times longer than CFLs—decades rather than years. And LEDs are aesthetically appealing: they turn on instantly and the color of the light they emit can be adjusted. Because of these technical advantages, industry analysts broadly expect LEDs eventually to replace both CFL and incandescent lights. The question is when.

The principal hurdle to the adoption of LED lamps for general area illumination is cost. LEDs currently cost about ten times as much as CFLs of the same illumination. Because LEDs also last at least ten times longer, and are less prone to break or fail, that already makes them a competitive option for some commercial/industrial users for whom maintenance costs are a significant consideration. The production costs of LEDs are steadily coming down, but to some extent so are those of CFLs as the latter have been ramped up to mass-market use.

Overall, most industry analysts do not expect LEDs to significantly penetrate the market for residential general lighting until after 2013. But that certainly is within the edge of our near-term time frame. Whether LED use will disseminate rapidly enough to add up to a “substantial” impact in the near future is uncertain, but possible.

ALTERNATIVE ENGINES

As noted above, substantial gains in transportation energy efficiency in the near term are mostly likely to come from refinements and adaptations of engines that burn more or less conventional fuels to generate locomotive power. Just cutting vehicle weight immediately improves fuel economy. Besides just shrinking size, making greater use of lighter plastic or composite materials in place of metal and replacing iron or steel components with aluminum alloys are already happening and will increase in vehicle manufacturing.

But traditional internal-combustion-engine power trains are terribly inefficient in converting the energy from burning fuel into motion, leaving much room for improvement. Using the computers that already saturate modern vehicles to turn off half the cylinders in six or eight cylinder engines at highway cruising speed can improve economy of even large vehicles. It is an innovation already on the market that is likely to spread to more cars and trucks.

Diesel engines—ignited by compression rather than spark plugs—have been around since the dawn of the automotive age and have about 30 percent better fuel economy than normal (Otto cycle) gasoline engines, and also emit about 25 percent less carbon dioxide. Diesel-powered vehicles are common in Europe, accounting for more than half of new car sales. Americans have been less interested in diesel cars for various reasons—noise, smell, performance, fuel availability, pollution regulations. Cars with a new generation of cleaner, more efficient, and high-performing diesel engines from Daimler, Honda, and other manufacturers will begin entering the U.S. market during the coming year. Because diesel-powered vehicles have penetrated the U.S. fleet so little to date, their potential to have an impact on fuel and emissions efficiency in the next several years is considerable. However, availability of the ultra-low-sulfur fuel the new engines require, and possibly more stringent pollution regulations as well as the uncertainty of consumer acceptance, all could limit the potential gains.

A number of alternative engine designs have been proposed over the years, but always confront the looming hurdle of being adopted at a large enough scale by an industry dominated by a few giant manufacturers that is accustomed to a limited class of well-established and highly refined technology. External combustion engines, chiefly steam, competed seriously in the early days of the automobile age. While they had some advantages, the quality of the technology of that time was not as attractive as that of the gasoline-powered internal combustion engine which quickly came to dominate. Using far more advanced technology available today, some recent prototypes of external-combustion, closed-cycle steam, or Stirling engines have shown the potential for great gains in engine efficiency and cleanliness. But getting a radically different engine concept adopted at a mass-market industrial level remains a huge challenge.

A new, 6-stroke engine design recently patented by Bruce Crower offers an intriguing potential to increase fuel economy by 40 percent yet without requiring drastic changes in current manufacturing. Compared to the complexity and high cost of hybrid or electric alternatives, Crower's innovation mostly uses the components of the existing engine architecture, adding only a few relatively low-cost parts, modest alteration of engine-control software, and a readily available common substance, water.[18] Rather than requiring sweeping change in vehicle manufacturing, it seems feasible to retrofit to existing engines.

The Crower innovation confronts the usual, prodigious hurdles even the simplest creations of independent inventors face when tackling the monolithic auto industry.[19] But perhaps with the impetus of another fuel-price spike, this fix potentially could have a notable impact on transportation efficiency in the next several years.

PLUG-IN HYBRIDS

As discussed earlier, despite the flourish of publicity and policy pitches for plug-in hybrid and electric vehicles, they demand such high marginal costs and large-scale infrastructure transformation that they are unlikely to make a major impact in the near term. And the substantial infrastructure demands they pose are not just in vehicle manufacturing, service, and parts.

In addition, the smart grid electric infrastructure would have an important impact on the potential for the effective, safe adoption of plug-in vehicles on a large scale. If many such vehicles were plugged in for recharging during daylight hours of peak demand they at least would surge the demand for costly peaking power and potentially could increase the risk of crashing the whole grid. On the other hand, recharging such vehicles at night when demand is low would make for more efficient utilization of baseload power generators, lowering overall costs.

The smart grid's demand-based pricing would provide a financial incentive to vehicle owners to recharge them during off-peak hours. Its remote load management capability further would allow utility operators to turn off plug-in vehicles to maintain load stability. Indeed, some analysis suggests that large-scale deployment of plug-in vehicles could then help make the electric grid more stable, providing back-up power to the grid from the batteries of thousands or millions of cars and trucks.[20]

SUPERCONDUCTORS

Ever since their discovery in the late 1980s, so-called "high temperature" superconductor (HTS) materials—which can carry electricity with virtually no resistance and hence energy loss—have intrigued engineers, energy planners, and policymakers with the tantalizing potential to drastically improve the efficiency with which electric power is generated, transmitted, and used. As it is, because of the resistance of the copper wires used from one end of the electrical system to the other, most of the system's energy is dissipated as waste heat before it produces any useful result.

Unfortunately, "high temperature" so far still means at the brutally frigid temperature of liquid nitrogen, a couple of hundred degrees below zero Celsius, requiring means for the production, containment, and insulation of the liquid gas. Nevertheless practical applications of superconductors have begun to appear which promise some significant potential energy and other resource savings.

In June of this year, American Superconductor Corp., the U.S. Department of Energy, and the Long Island Power Authority (LIPA) celebrated the commissioning of the world's first HTS power transmission cable system in a commercial power grid in LIPA's Holbrook, New York, transmission right-of-way. This new system uses hair-thin ribbons of HTS material that conduct 150 times more electricity than copper cables of comparable size. At full capacity, the HTS cable system can transmit up to 574 megawatts of power, enough to serve 300,000 homes.

Because of the energy needed to cool the cryogenic fluid HTS systems require, the net energy savings from their greater conductivity is not yet huge. But they offer other collateral benefits that may add up to substantial value, including reduced risk of fire. By making far more efficient use of existing rights of way, they may reduce the need to build new transmission corridors, saving on construction costs, the need to clear forests, and the delays of political and litigation battles with constituents who want more power but "not in my backyard" (NIMBY).

DISTRIBUTED SOLUTIONS

Distributed solutions are those that are more of less independent of large-scale integrated architectures. On-site, "renewable" electric power technologies—including photovoltaics, wind, geothermal, or small-scale hydropower—generally depend on the electric grid for backup. The economics of such installations also may benefit from or even depend on the ability to sell surplus power back to the utility. But in principle such systems can operate more or less autonomously for some period of time. With some facility for on-site energy storage or similar design features, autonomous "zero-energy" houses or buildings are possible. In fact a number already exist. Other features of "green" architecture also can help habitats become more self-reliant, including: active or passive thermal design elements that use incident solar radiation to contribute to space heating or cooling, rainwater capture and water recycling, and composting or similar forms of on-site waste treatment.

While it is unlikely that such solutions can or will be adopted in the near future at a large enough scale to make a major macroeconomic difference in U.S. resource use, they do enjoy and confer some significant advantages. First, just because they are distributed, they face lower hurdles to being initiated than solutions that require large-scale infrastructure changes. Homeowners association covenants or local ordinances may present some barriers, but those obstructions also can be addressed and overturned locally.

A notable benefit of distributed solutions is that, if they are designed to be less vulnerable to the hazards of utility failures, accidents, attacks, or natural forces, etc. (which is not always the case), they can contribute significantly to disaster resilience and operational continuity—enhancing community safety and security.

HABITAT ADAPTATION

This final category is a catch-all for a range of measures—of varying cost and difficulty—aimed at (and needed to) adapt the architecture and settlement patterns of our human habitats. The sort of distributed solutions just mentioned may spill over into this category but the number of situations in which they can or will be chosen is, as noted, probably limited.

There are simpler, more obvious and even conventional adaptations of American habitats that can and arguably should be adopted to make the nation's infrastructure more efficient, more secure, and in a realistic sense more "sustainable." That they may be simple and obvious does not, however, imply that they are easy.

One is the sheer size of American homes, which has grown apace with the debt binge that is now unraveling. Over the three decades between 1970 and 2000 the average size of new single-family homes increased from 1,500 square feet to over 2,200 square feet. But during the same period the average size of U.S. households declined from 3.1 people per household in 1970 to 2.6 people per household in 2002.[21]

At the margin, the movement toward more compact, higher-density, more urban settlement patterns already is noticeable. But it's clearly easier and less costly to switch to a smaller, more efficient car than to a smaller, more efficient home.

That might seem even more so when the housing market is in the dire straits that currently exist. However there may be an ironic silver lining of the dark cloud of the current housing distress: People who no longer can afford to live in the "McMansions" spawned in the over-leveraged housing bubble may wind up seeking and moving to more "affordable" housing, which is thus also more compact and efficient in resource use.

Under normal conditions, it would seem highly unlikely that basic changes in the architecture, infrastructure, and settlement patterns of our human habitats would happen rapidly enough to show a substantial macroeconomic impact over a time horizon of only a few years. But the current conditions are anything but normal. We seem clearly to be in the midst of a major "system break" in the U.S. and world economies. Policy initiatives that only weeks ago would have been considered wildly radical now seem to be almost daily routine.

It appeared at the beginning of the U.S. political campaign season early this year that the coming election might result in a choice for "change." But now we see that this election is bound to be, rather, a response to change that no longer is a matter of choice but of necessity. So while we may debate—indeed are debating—the form and direction, it now seems likely that the shape of America's physical, financial, and political infrastructure five or so years from now will be notably different from what we have been used to.

C. BREAKTHROUGH

The more dire the circumstances, and thus the more acute our discomfort or anxiety, the more we seem to be tantalized by the hope of the technological breakthrough—the deus ex machina that, in defiance of probability and sober expectation, suddenly appears to deliver painless salvation and raise our spirits.

In this last band of the technology triage, I will briefly summarize a few examples of the leading-edge (or "bleeding-edge") technological breakthroughs that offer the potential for technical fixes which, while improbable, just might have some notable impact on America's energy and resource budgets in the near future. Again, this list like those above does not pretend to be exhaustive but only suggestive.

WAVE POWER

Since the oceans cover over 70 percent of the earth's surface, there is, unsurprisingly, recurring interest in finding practical ways to harness the energy that courses through them. One of the seemingly more feasible options, which has garnered growing recent interest, is wave power. Wave power may have even greater potential than wind power, because waves are nearly constant while wind is more intermittent. Several potential candidate systems are now in the prototype or early demonstration phases of development. Pelamis, a Scotland-based company, recently announced the launching of "the world's first wave farm" at Aguçadoura on the coast of Portugal. And England's South West Regional Development Authority is planning a project called Wave Hub, now scheduled to debut in Spring 2010 off the north coast of Cornwall. Wave power technology offers a potential dual benefit: It also can be used for desalination of sea water, helping to alleviate a global fresh water crisis that may be more acute than the energy crisis.

STORAGE

Means for storing energy, particularly electrical energy, are a key factor limiting the potential of "renewable" and other alternative energy solutions. Wind power, in particular, is inherently erratic and unreliable. Sunlight-powered solutions such as photovoltaics are only productive when the sun is shining. Hybrid or electric vehicles require batteries that are expensive, bulky, and less than ideally durable, reliable, or even safe.

Advanced hybrid/electric vehicles are migrating from lead-acid and nickel-metal-hydride batteries to the kind of lithium-ion batteries commonly used in portable computers. The latter are lighter and more efficient but also more expensive; and they entail a risk of potentially explosive combustibility. More advanced lithium-based battery technology aimed at alleviating these disadvantages is in development.

Vanadium redox batteries use bulky tanks of liquid chemicals that, because of their relative simplicity and low cost, potentially could provide cost-effective backup storage for wind or solar power stations.

The so-called "hydrogen economy" is essentially a storage solution, using gaseous or liquid hydrogen to store and transport energy produced through electrolysis by some electrical power source. Its extremely large infrastructure costs hinder its potential.

Beta batteries potentially could use the beta particles—energetic electrons—emitted by certain radioactive materials to provide a very long lasting (possibly decades) package of stored energy. The particles have little penetrating power—they can be stopped by aluminum foil—and so pose little danger. A recent advanced design uses tritium, an isotope of hydrogen, as the radiation source and a kind of porous silicon to capture the radiation and convert it to electric power. The basic materials are abundant, but costs so far are prohibitive. However, some view the beta battery as a more feasible alternative to the hydrogen economy.

Finally, ultracapacitors have the potential to provide a portable, rechargeable electric power storage solution superior to chemical batteries. Capacitors store electric energy purely with the power of electrostatic force. Electrons can move in and out of a storage capacitor at far higher speed than with chemical batteries. The recharging cycles of capacitors are not only much faster but can be repeated a virtually unlimited number of times, unlike batteries using chemical reactions that, with each repeated cycle, gradually decay until they eventually wear out and need to be replaced.

The science and technology of capacitors have been known for decades, and they are a common component of nearly all electronic technology. Now, driven by advanced nanolaminate and polymer technology, the potential exists to create a new generation of capacitors that can store large amounts of energy in a smaller, lighter, and more durable package than chemical batteries provide.

NANOANTENNA PV

Even as the cost of conventional photovoltaic products becomes more affordable, the existing technologies still depend on the visible light from sunshine to generate useful power. A new class of photovoltaic technology uses extremely tiny, nanoscale gold spheres as antennas that can capture the infrared radiation emitted by any heat source and convert it to electric power. Such nanoantenna arrays could work to generate power not only from the heat of sunlight during daytime but also the heat from the earth, buildings, etc. that is radiated at night. Researchers at the Department of Energy's Idaho National Laboratory recently developed an inexpensive way to produce plastic sheets containing billions of nanoantennas that could be manufactured as lightweight "skins" able to provide power for a wide range of objects, with a higher efficiency than traditional solar cells.

BIOTECH

Steadily advancing biotechnology offers many potential ways to revolutionize our energy systems. As noted earlier, bioengineering is now aimed at developing bacteria, algae, or other microbes that could produce biofuels without the current biofuel technology's disruptive impacts on agriculture, forests, and so on. Indeed, major advances in agricultural production that would be a boon to the world's increasing food-insecure populations also might help alleviate some of the conflict between food and fuel production.

On the security agenda, the U.S. is sometimes called the "Saudi Arabia of coal," with coal resources sufficient to meet its needs for several centuries. But coal also entails a large number of environmental liabilities. Biotechnology offers the potential to make coal resources cleaner, safer, and more useful while eliminating many of the hazards of mining and burning coal in the existing manner.

A perennial danger in coal mining is the presence of methane gas, which can trigger explosions and fires. The methane is produced by indigenous bacteria that live by consuming coal. Advanced bacteria, engineered to convert coal to methane more aggressively and productively, potentially could be injected into coal seams and the resulting "natural gas" piped out and used as a cleaner energy source. Similar biotechnology potentially could be used to extract and convert the immense energy trapped in the kerogen deposits (often called oil shale) in the Bakken and other large formations in the U.S. northern plains and mountain states.

If such advanced technology could provide a cost-effective means of extraction, it potentially could provide the U.S. with fossil-energy resources equivalent to several times the total oil reserves of Saudi Arabia.

While this solution could substantially enhance U.S. national security, it would not satisfy the demands of some climate activists to end the use of fossil fuels entirely. However, because burning natural gas yields considerably less GHGs than burning oil or coal, it would confer some relative advantage for climate goals.

HIGH TEMPERATURE SUPERCONDUCTORS

While superconductor materials, as noted above, are beginning to have some practical application in electrical transmission, their current need for cryogenic cooling substantially limits their contribution to energy efficiency. Through over twenty years of research, the Holy Grail sought by scientists in this field is the discovery of a material that can be superconducting at much higher temperature, closer to normal ambient conditions. If and when such a breakthrough occurs, the impact on the electrical sector of our energy economy would be immense, even revolutionary.

LOW-ENERGY NUCLEAR REACTIONS

Probably the farthest-out of potential breakthrough opportunities I will mention here rests on the inchoate science of low-energy nuclear reactions (LENR)—phenomena misleadingly called “cold fusion” when they were first discovered two decades ago, with the untoward consequence that both their discoverers and the subject were soon not only discredited but assailed. (Whatever else, this history may stand as one of the more acute examples of the toxic effect of hype on potential technology development.)

Essentially, the LENR phenomena entail the observation that when current flows through electrodes composed of very particular types of materials immersed in water, surplus energy appears to be generated beyond what would be expected from chemical reactions alone. The first guess, which proved unfortunate, was that some kind of nuclear fusion was occurring at temperatures astronomically lower than seemed theoretically possible.

More recent research, notably by Lewis Larsen and Allan Widom, based on experiments that were continued over the subsequent decades, indicates that the phenomena are real but entirely different from the kind of atomic fusion reaction that occurs at immensely high temperatures inside the stars or in a hydrogen bomb. Or in the gigantic machines called tokomaks that a few research centers have been trying to develop for decades in the attempt to harness the fusion genie in a magnetic bottle.

According to the Larsen-Widom analysis, the tabletop, LENR reactions involve what’s called the “weak nuclear force,” and require no new physics.[22] Larsen anticipates that advances in nanotechnology will eventually permit the development of compact, battery-like LENR devices that could, for example, power a cell phone for five hundred hours.

Obviously, such an application would not offer any significant macroeconomic impact on the nation’s energy budget. But as we now see lithium batteries migrating from just such small-scale applications to soon powering cars and trucks, it is imaginable that a breakthrough in LENR technology might eventually lead to products capable of making a substantial dent on energy use.

Section 4: The Ultimate Fix: Money

As suggested at the outset of this essay, despite the dazzling array of possible technical fixes to our energy, security, and climate concerns—a list that could be far longer than the one surveyed here—by far the most important and influential is also the most elemental. That is, money, and the diverse ways we create, acquire, use it, and also lose it.

While perhaps we are not accustomed to think of money as technology, it takes only slight reflection and historical recollection to realize that indeed money is a social invention that is over 4,000 years old. It also is one that has undergone continual mutation and evolution—from literally “hard” currency to paper proxies and now to digital symbols.

As touched on several times above, the dynamics of money and its use have a powerful effect on whether and how other innovations get developed, and whether and how particular innovations get adopted in popular use.

Real answers to the question of which technical fixes may affect America’s energy, security, and climate interests in the near term, and how, inevitably depend on at least four key financial issues.

PRICE

In the wake of the oil crises of the 1970s, and the rapid escalation of the price of oil, there was a popular view among government, business, and the general public that “alternative,” more secure sources of energy not only were needed but with a bit of government stimulus could soon be developed to compete economically with increasingly expensive petroleum. President Jimmy Carter proclaimed a bold plan aimed at energy “independence” that included the goal of obtaining 20 percent of America's energy needs by the year 2000 from "renewable" sources—meant to include such now-familiar options as solar and wind as well as conservation and efficiency.

Many entrepreneurs, including both major corporations and small start-ups, jumped into the fray with plans to develop and commercialize a broad menu of new, solar and renewable technical fixes. Both public and private sources made substantial investments in the emerging alternatives, based on the assurance by nearly all authoritative analysts that world oil prices would continue to rise. But in fact, the price of oil began a progressive and long decline from the 1980s through the following decade. The growing gap between the production costs of the alternative technologies and of ever-cheaper oil demanded ever greater subsidies to have any chance of marketing products at competitive prices. But the administration of Ronald Reagan which took over in 1981 had very different priorities from Carter's, an avowed faith in market forces, and a determination to cut government spending—especially on civilian energy programs.

Many of the alternative energy startups foundered for lack of investment or viable markets; some hung on in a prolonged cycle of long-term R&D projects. As noted earlier, improving energy efficiencies of various sorts, particularly in industrial processes, did gain traction and had a significant impact that fulfilled some of the Carter goals. But the alternative and renewable supply options made only a minor contribution to national energy consumption by the turn of this century.

If it had not been clear enough before it certainly became understood that price matters. To overcome natural risk aversion, investors, developers, and entrepreneurs crave assurance that market conditions will be sufficiently stable and predictable that by the time their innovations are ready to take to market they will be able to compete and grow profitably.

But energy prices have proven fickle and erratic in the past. And recently they have again. The steady and accelerating ramping up of crude oil prices from February 2006 to August of this year goaded a waxing crowd of both policymakers and entrepreneurs to launch a cascade of bold alternative energy initiatives. But since then prices of oil, along with other previously inflating commodities, and then the stock market, have been crashing. Gasoline, whose price soared to over $4/gallon in the U.S. during the summer, is now selling in some areas for less than $3/gallon.

The yo-yo cycling of fuel prices since the major interruption in domestic supply and distribution networks caused by Hurricane Katrina in 2005 was a kind of "natural experiment" that seemed to convey a key finding to economists, policymakers, and businesses alike: Namely that a major shift in consumption behavior would not occur at gas prices below $3.50 or so, but at around $4.00 a gallon a threshold of pain was crossed that unleashed a wave of demand for alternatives.

As noted, there is something of a ratchet effect in this shift in preferences and supply commitments that is likely to endure for some time despite the recent price slide. But the price effects are not the only factor affecting the prospects for new technologies.

PURCHASING POWER

When fuel prices soared last summer, an exasperated business executive posted a desperate question on a social networking website: "When gas hits $5.50 a gallon will we still be able to afford to drive to work?"

The query elicited a cascade of nearly a hundred answers. Most were variations on "no," followed by diverse appeals and recommendations for action, ranging from ways to quickly increase supplies to price controls, rebates to consumers, or various attacks on oil companies. More than a few made insightful points. But none recognized an essential fact: The price of fuel is not the same as its cost.

Among the respondents, Europeans who were then paying the equivalent of up to $9 a gallon for motor fuel were stridently unsympathetic to Americans complaining about the strain of $4-a-gallon gas. Overlooked was that European countries imposed much higher taxes on fuel than the U.S. does.

On the other hand, at the same time, the value of the U.S. dollar was low and sinking in relation to the euro and British pound. Because the world crude oil market is priced almost universally in U.S. dollars, the cost of oil to European consumers was relatively less because of their stronger purchasing power, despite their higher prices "at the pump."

So the answer to a question such as whether "we" can "afford" gas at $5.50 or any other price depends not only on the price in dollars, but also on what a dollar costs, and how many dollars "we" have. Now that the price of gas has fallen to $3 or less, it does not follow that "we" necessarily can "afford" to fill up any better than we could last summer—given that a growing number of "we" have lost jobs, savings, homes, and/or credit.

The same concept applies to the prospects for new technical fixes to succeed in the market in the coming few years. Price aside, depending on how long and deeply the economy declines, a poorer society may have fewer customers with the interest and means to buy the "next big thing." The pace of introduction of even useful products is likely to slow or stall.

FINANCING

As became painfully clear in the autumn of 2008, the mechanisms of debt and finance are essential lubricants for the smooth functioning of the economic machine—especially at the microeconomic level of discrete transactions among individuals and firms.

The mechanics of financing are particularly important to the market prospects of many of the alternative energy solutions we have reviewed here. Many of these alternatives have higher up-front costs than the conventional devices, systems, or services they aim to replace. That partly is so simply because they are new and have not had time to build economies of scale and experience. But often they are intrinsically more expensive because of more sophisticated technology, costly materials, special installation requirements, and so on.

The economic promise of many of these fixes is that they lower operating costs. Over the total lifecycle of the product, they offer lower cumulative costs of ownership.

But sales of most products are not structured to integrate lifecycle costs. Individual customers have to be willing to choose to pay a higher price now in exchange for the promise of a payback on their investment in the future.

Making that choice faces two hurdles. The first is having confidence that the price of the operating costs projected in the future is reliable—as noted earlier, price volatility undermines that. But even if consumers believe that the energy or other resources they would use in the future will cost no less than what they would expect to save with the new product, they still face the problem of being able to pay its price now, when they have other options available at a lower price.

If the total cost of the new product is fairly low and/or if the expected payback of the initial investment through operational savings is fairly quick—a couple of years or even a matter of months—many customers will be able to pass these hurdles and make what rationally looks like a good deal. But for big-ticket items like a new home heating/AC system or even a new car or business equipment, many customers simply will not have the extra money now to pay the higher price for the most "climate-friendly" choice.

In business and other organizations, too, capital budgets and operating budgets usually are handled separately, often by different managers. The person in charge of capital acquisitions has little or no incentive to bust his budget to help the person in charge of operations cut her expenses.

To overcome these obstacles, financial innovations are needed. And in fact they have been developing. As in the example of the Johnson Controls program mentioned above, there are new financing arrangements emerging where a third party integrates the up-front and operating costs. Instead of having to pay the full or even any initial purchase cost, the consumer instead buys some sort of leasing or rental contract that amortizes lifecycle costs and shares savings with the contractor.

ECONOMIC SUSTAINABILITY

The meaning of the word "sustainability" often has been muddied if not convoluted by its use for ideological or public-relations purposes. In the context of environmental politics or "corporate social responsibility" the term "sustainable" often has been applied to things that are not really durable or resilient, and may not even be sustained.

In this situation I use the word "sustainability" in its more literal and common-sense meaning of durability or just survivability—at a time when the financial and economic arrangements that have governed the global economy for several decades suddenly and acutely have proven unsustainable.

At the time I write, things are very dynamically in flux, and it is difficult if not impossible to foresee what new financial, fiscal, monetary, etc. arrangements will emerge from the current upheaval.

However, in regard to this task's mission—to forecast the potential of various technical fixes to energy and other problems in the next several years—recent events certainly underscore that the unfolding evolution of the global economy's financial and structural architecture will have an immense influence on what is possible and what actually occurs.

Again: uncertainty, volatility, and risk aversion have a chilling effect on innovation in general, and on the particular innovations discussed here.

Coincidentally, in regard to the theme of "climate-friendly," it is evident that heightened immediate anxiety about financial, economic, and national security overwhelms and trumps any worries about long-term climate issues among most of the populace. Even Yvo de Boer, head of the UN climate office, recently acknowledged that "the financial crisis is going to make it more difficult for industrialized countries to make public resources available for cooperation with developing countries," setting back prospects for a new international agreement to replace the Kyoto Protocol.[23]

Section 5: Conclusions

Answering the strategic questions posed by this project and the particular task of this report only can be done effectively in the context of the larger forces contending to reshape the national and global environments in which they occur.

In particular, the objectives of this project are immersed in the clash of three powerful policy agendas that increasingly compete and often conflict. For clarity, we can think of the challenge of managing the contending demands of these agendas as a problem in three colors: green vs. blue vs. red.

The "green" agenda identifies itself with "Sustainability." The green movement, as is widely understood, advocates environmental protection, resource conservation, "renewable" resources, and "green" buildings and infrastructure, among other things, especially "climate protection." Its notion of "sustainability" commonly is associated with "corporate social responsibility" (CSR) as indicated by such metrics as the "triple bottom line" (meant to merge economic, environmental, and social welfare goals in corporate accounting).

The "blue" agenda is primarily focused on "Security," including "Safety." It embraces the demands for national and homeland security. Its mission starts from preventing or protecting against various hazards or threats against human security and extends to responding to attacks or disasters when they occur, and recovering from their consequences. The menu of blue concerns spans the spectrum of human anxieties, including: war, terrorism, violent crime, industrial accidents, infectious disease, and economic, social, or political disasters as well as all sorts of natural disaster.

The "red" agenda is that of the harsh financial and fiscal realities that determine "Solvency" or, more urgently now, its opposite. The color of this agenda aptly reflects the "red ink" of the ocean of debt in which America and many of its global partners are now drowning. Across a span of years past, exponents of the red agenda sounded alarms about the impending threats of rising deficits and national debt, unfunded liabilities, excessively easy money and cheap credit, overleveraging, opaque accounting, lax regulation, and the house of cards built of synthetic financial "derivatives." Now the day of reckoning has arrived and the alarms that were ignored, and the corrections that were postponed, no longer can be avoided. The situation of the United States is particularly onerous. In addition to its current $10 trillion national debt, soaring deficit, and sprawling burden of private debt, including a trillion dollars of credit-card debt, the government faces the imminent drain of over $50 trillion of unfunded liabilities for retirement and health-care entitlements.

The clash of these importunate agendas is now seen in almost every critical policy issue from the global to the national levels and down to the grass-roots level of local development, business, and consumer decisions. Increasingly these issues entail difficult tradeoffs or zero-sum conflicts. To cite just a few examples:

■ The drought that has afflicted the southeast United States over the past year at times left the 4 million people in metropolitan Atlanta with only enough water to last about ninety days. Yet the U.S. Corps of Engineers was required to release a billion gallons of water a day from the city's main Lanier reservoir to protect an endangered species of fish downstream in Florida. The clash also entailed energy: the water also is needed to cool the Farley nuclear power plant in Alabama.

■ The big push for plug-in hybrid/electric vehicles points toward an inevitable clash between environmental "sustainability" and national security priorities. While shifting the major source of transportation energy from conventional fuels to electricity offers benefits both for energy security and emissions reduction, it leaves unresolved the question of what source of energy will produce the needed electric power. The U.S. has abundant coal and an established infrastructure to provide a secure and affordable solution, but one that poses environmental hazards. Nuclear power is proposed as a cleaner and more "climate-friendly" solution, but one with high capital costs that further depends on costly government subsidies and poses serious security threats from virulent wastes, vulnerability to disastrous accident or attack, and the festering risk of weapons proliferation. Various "renewable" energy sources are currently inadequate to the scale of the task, are unreliable, demand government subsidies to cover their high costs and needed technology development, and also entail environmental impacts that may be unacceptable.

■ The EPA has an assertive "Smart Growth" program aimed at promoting a pattern of community development designed to have lower environmental impacts and greater efficiency in the use of energy and other resources. The pattern emphasizes compact, dense, pedestrian-oriented clusters of homes, shops, and offices. Yet police, fire, and other public safety officials continually criticize and oppose such developments because their narrow streets hinder access by emergency vehicles. And Prof. Philip Berke of the University of North Carolina has shown that many of the new "Smart Growth" developments have been built in hazardous locations such as areas of the U.S. Gulf Coast that were scoured by Katrina and other major hurricanes that assaulted the region in 2005. The locations of these "sustainable" communities, and their general absence of disaster-mitigation measures, puts them in the crosshairs to be obliterated and washed away by the rising tides and future tempests that are bound to come.[24]

A study of the connections between water and energy resources by scientists at the DOE Oak Ridge and Los Alamos national laboratories examined alternative scenarios for electric power development in the western states. The study was particularly interested in seeing how a major push to expand the use of wind-generated power in the region over the next thirty years or so would affect the use of water as well as the performance of the electric-supply system. The computer simulations showed that while the increased use of wind power would indeed help conserve the copious water resources demanded to cool conventional power plants, it also would substantially increase the risk of major failures, and blackouts, of the regional electric grid. The reason basically is that the existing electric grid does not go to the usually remote areas where wind resources are richest. Extending the grid to these new areas not only would impose considerable capital costs in addition to those of the wind farms themselves—they would also tend to overload the grid's "circuit breakers," needed to prevent the kind of regional power failure that disastrously blacked out the entire northeastern U.S. in the summer of 2003.[25]

Ideally, most of the stakeholders in these issues would like to come up with initiatives and solutions that skirt the conflicts among the tricolor agendas—benefiting both blue and green goals without breaking the bank. And in fact there is a zone at the crossroads of the agendas where such synergies are sometimes possible.

I mentioned some of these multi-benefit opportunities earlier: Telework reduces emissions and saves energy and other resources, moreover not only saving money but improving productivity, and on top of that enhancing security and disaster resilience. Zero-energy buildings could enable police or fire stations, shelters, hospitals, communications facilities, embassies, and such to keep functioning in the wake of a disaster even when electrical or fuel supplies are interrupted.

And while it may not serve everyone's priorities, even the Defense Department has an increasing, practical interest in green solutions. The Marine Corps is looking to apply solar, renewable, and recycling technologies on the sites of operations in places like Iraq or Afghanistan, to reduce the need for vulnerable truck convoys to supply fuel and water. And the Air Force, which is as pinched by high fuel costs as airlines or anyone else, is making a serious effort to develop and use biofuels, synthetic fuels, or other alternatives.

Moreover, when green and blue solutions can be blended, there may be collateral benefits for financing. One of the difficulties in selling security or hazard-mitigation measures is that, somewhat like insurance policies, they tend to be just-in-case investments that don't pay back any return unless and until something bad happens. But one of the nice features of many of the efficiency and/or green solutions we have looked at here is that they begin paying back a stream of savings (or sometimes revenue) as soon as they are installed. When the design features of both can be integrated in the same product, system, or infrastructure (as was the case in the Cisco and Johnson Controls examples), the economics of hazard mitigation could become more attractive, while "sustainability" could become more truly equivalent to "survivability."

But as "The Clash" chart implies, the zone of happy synergy between green and blue agendas is limited. In far more cases the green and blue agendas compete for resources and design requirements. Up until the recent past, rather than tradeoffs being reconciled in some kind of rational design process, the conflicts often were simply fudged, with extra green and blue baubles heaped on groaning architectural Christmas trees to appease separate constituencies, and the bloated costs paid through separate line items. In the past that was wasteful; from now on it will be increasingly impossible.

The tide of red ink rising from below the black line of solvency in the chart already limits the comfortable zone of synergy. The prodigious financial demands of either the blue or the green agendas already has begun to seem infeasible.

Based on estimates from the American Society of Civil Engineers and others, it seems that the U.S. needs to spend at least $2 trillion over a period of five years or so just to moderately mitigate the danger to public safety posed by America's crumbling, brittle, and hazardous infrastructure.

Meteorologists calculate that there is a 25 percent chance of a major—category 3 or higher—hurricane striking New York City within the next fifty years. Analysis by Columbia University scientists indicates that, when that occurs, the economic cost to the city from wind damage alone will exceed $350 billion. (The economic cost to the city of the 9/11 attack has been estimated as about $3 billion.) So while the cost of reducing America's growing vulnerability to disaster may be deferred, the cost of the consequences will not be.

While the real costs and potential benefits of the green agenda just for "climate protection"—mitigating the expected future impacts of global warming—are debated, the estimated costs to the U.S. are on a similar scale of hundreds of billions to more than a trillion dollars.

Many people have been impressed with the potential future hazards of climate change, which certainly are not trivial. Yet fewer may yet have grasped the peril in our immediate economic quandary. Future economic losses from global warming, cumulative over several decades, have been estimated at some $45 to 76 trillion. Yet consider that global sales of one class of derivative securities, credit default swaps, (much of which are now considered "toxic") totaled over $60 trillion just in the last year.

So, urgent yet costly blue and green demands both occur in a context now where the U.S. and other governments have been feeding trillions of dollars of bailouts, backups, and insurance to pacify the debt beast in just a matter of weeks.

Meanwhile, the bill for the over $50 trillion of unfunded liabilities from the entitlements owed to the retiring (or would-be-retiring-but-can't-afford-to) Baby Boom generation is fast coming due. As former Comptroller General David Walker repeatedly has warned, with the first of America's 70 million baby boomers now starting to retire, the country faces the prospect that 70 percent of the federal budget by 2030 will be spent on Medicare, Medicaid, Social Security, and other entitlement programs. By 2034 those programs will consume 20 percent of the nation's entire gross domestic product. Add in the growing interest payments on the national debt (already twice as much as the Defense Department budget) and there would be virtually no money left for just about anything else the government is expected to do.

WHAT TO DO

The tri-color dilemma of importunate but competing agendas fits the category that systems scientists call "wicked problems" or what one of them, Russell Ackoff, simply labeled a "mess": Problems are connected to other problems; and solutions either may be absorbed with little effect or may cascade, through side effects or unintended consequences, to do more harm than good.

So, within the context of this project's mission, what can be done?

At least since the energy crisis of the 1970s, policy planners have been inclined to propose government interventions aimed at managing the price of oil and/or other fossil fuels to make it more attractive for investors, entrepreneurs, and consumers to commit to "alternative" energy fixes. For over thirty years many analysts have argued that the most transparent and efficient mechanism to achieve that result would be some kind of simple, adjustable tax on such fossil fuels.[26]

Nevertheless, under the conditions likely to persist for the foreseeable future, it may be very difficult to implement a fiat mechanism which is at once economically efficient, reasonably resistant to political/criminal corruption, and politically acceptable. That is especially so given the relatively low level of public trust in government, and other institutions as well, both in the U.S.[27] and elsewhere in the world.[28]

So again, the most feasible and attractive energy technology fixes in the near term will be those that are least dependent on government subsidies or mandates.

The survey in this essay showed that, in the efficiency category at least, a number of practical solutions are available now—or have some potential to be in the near term—that can offer positive synergies: saving energy and other resources while improving or at least preserving security and providing collateral climate benefits, and at an affordable cost requiring little or no subsidy.

In regard to the "climate-friendly" theme of this task, the synergy zone among the competing agendas could be expanded by increasing the too-neglected focus on adaptation to the potential conditions of climate change. This was a key recommendation of a report on climate-change strategy by a panel of scientific experts for the United Nations Foundation, as its subtitle emphasized: "Avoiding the unmanageable and managing the unavoidable."[29]

Because nearly all the hazards from global warming projected to the next century already exist to some extent, investments in infrastructure needed to increase the nation's resilience to "all hazards" also will help serve the needs for climate adaptation. As it is, rather than working to reduce our vulnerability to disaster, the U.S. has been encouraging patterns of architecture, land use, community development, and infrastructure construction that actually are increasing risk. For instance, through flood insurance and other policies, we subsidize ever more expensive development in coastal zones and flood plains that are already at risk from storms and flooding and bode to be more so as sea levels rise, protective estuaries are destroyed, and (on top of that) land sinks under the sheer weight of construction.

One costly result of this imprudence is that both insured and other economic losses to storms and other disasters have been increasing over recent decades in the U.S. faster than national income. So neglecting preparedness, mitigation, and adaptation for the range of physical disasters further compounds the risk of financial disaster.

Beyond these useful but inadequate steps, we need a far more thoughtful and disciplined effort to navigate through the mess we face to find effective solutions to energy, security, climate, and others of the wicked tangle of problems. As things stand, we lack any coherent doctrine and code of practices for reconciling these competing demands and devising integrative solutions.

We need, first, to analyze and understand better how to identify and take advantage of the attractive opportunities for synergy. We need to see how particular design, engineering, construction, and other elements can produce benefits both for security/safety and environmental efficiency within budget limitations.

Second, in the more common cases where easy synergy is not possible, we need to study and understand better how planners, architects, engineers, and other professionals resolve conflicts and establish priorities between demands for security/safety and demands for environmental efficiency, again within budget limitations.

In both cases, the powerful new capabilities for analysis and simulation provided by BIM and other software tools can help greatly. But they need to be applied more widely and consistently. And designers, engineers, builders, planners and other stakeholders need to share the data needed to create a comprehensive picture of how systems work and can be improved.

And finally, we need to undertake more thorough and balanced assessment of the relative risks, benefits, and costs of the range of possible hazards or threats we face, as well as of the policies and actions proposed to solve them.

In times of crisis, Winston Churchill counseled, it is not enough to do our best—we must do what is required.

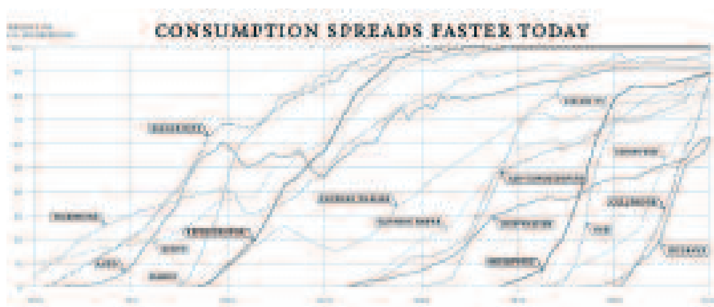

__Figure 1:__ Consumption Spreads Faster Today

Source: The New York Times[30]

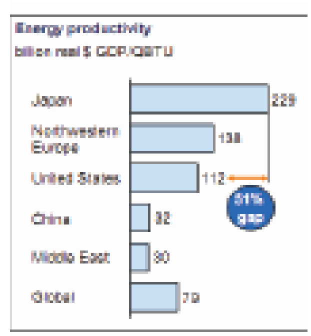

__Figure 2:__ Energy Productivity

Source: MGI[31]

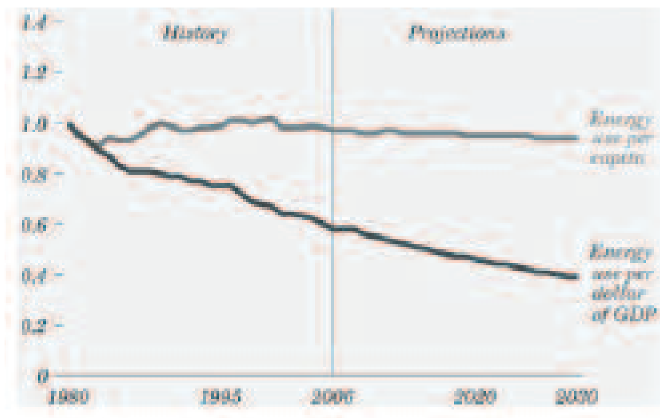

Figure 3: *Energy Use Per Capita and Per Dollar of Gross Domestic Product, 1980-2030 (index, 1980 = 1)*

Source: U.S. Energy Information Administration[32]

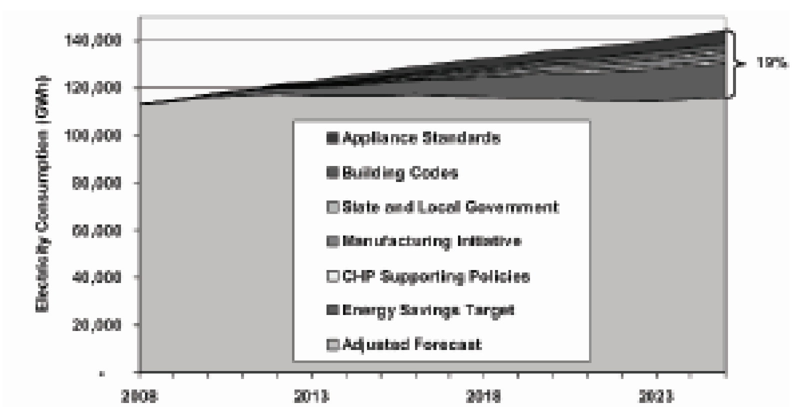

Figure 4: *Share of Projected Energy Use Met by Energy Efficiency Policies - Medium Scenario*

Source: American Council for an Energy-Efficient Economy[33]

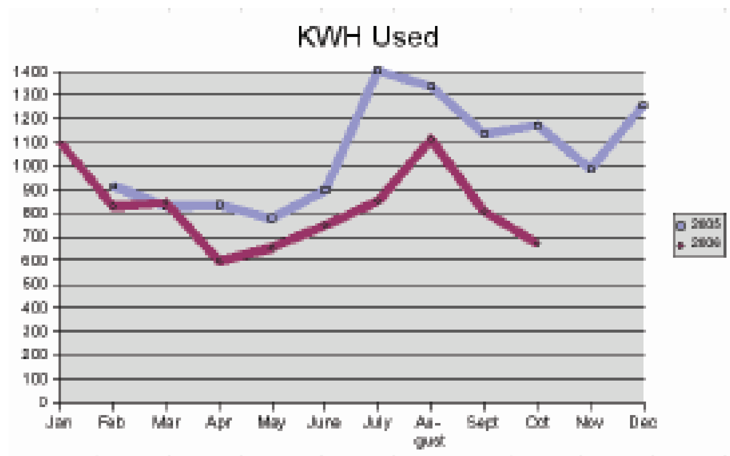

Figure 5: *Programmable thermostat: Northfield home's savings*

Source: Adam Gurno[34]

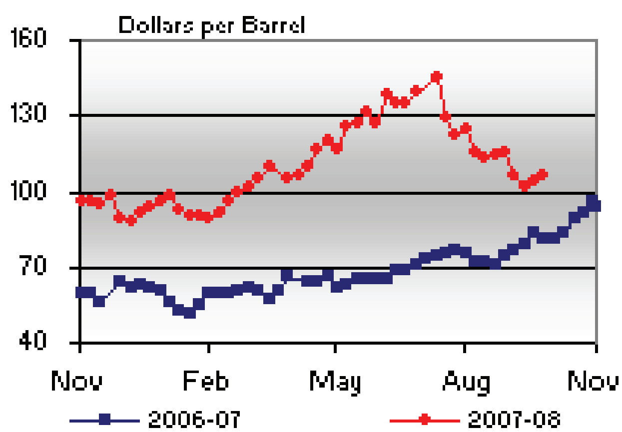

Figure 6: *Spot Crude WTI Prices, Dollars per Barrel*

Source: US Energy Information Administration[35]

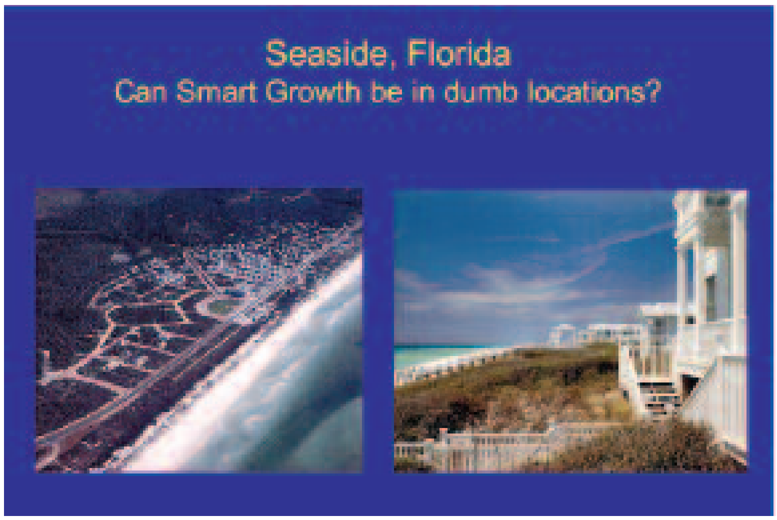

Figure 7: *Example of Smart Growth*

Source: Berke et al.[36]

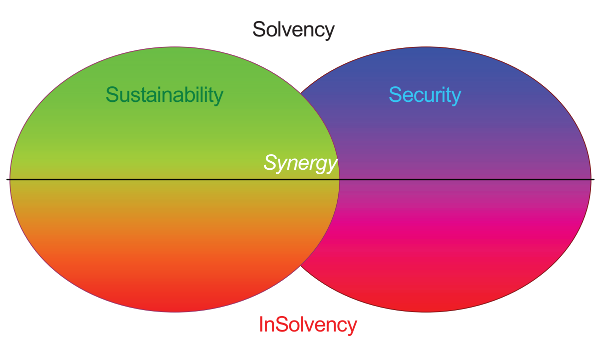

Figure 8: *The Clash of Agendas*

NOTES

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18 Basically, the Crower design combines the advantages of the steam engine with the structure of the traditional gasoline engine by adding two water strokes to the Otto cycle's 4 gasoline strokes. On the fifth stroke, after the Otto cycle's exhaust stoke (which ejects combustion gases), water is injected from an external tank into the hot (over 1000 degrees) cylinder. The water explodes into superheated steam, expanding into another power stoke. Then on the sixth stroke the steam is vented to a condenser to be recycled back to the water tank.

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02

CLIMATE-FRIENDLY TECHNOLOGIES IN GERMANY

THE NEAR AND MEDIUM-TERM POTENTIAL OF CLIMATE-FRIENDLY TECHNOLOGIES: EXPERIENCES AND LESSONS FROM THE GERMAN DEBATE AND POLICIES

FELIX CHR. MATTHES

Section 1: Introduction

Combating dangerous climate change is one of the most significant challenges for policymaking across the world today and in the future. Even if the most dynamic growth of greenhouse gas emissions can be observed for emerging economies like China or India in recent years and in the foreseeable future, industrialized countries face a special responsibility with regard to the phase-in of a global policy to avoid dangerous global warming. If we consider global warming as a result of an increased concentration of greenhouse gases in the earth's atmosphere and reflect on the long atmospheric lifetime of the most significant greenhouse gases, cumulative greenhouse gas emissions from the beginning of the industrial age are sufficient metrics for responsibility in the framework of global warming. In 2005 the share of the European OECD countries in the global cumulative carbon dioxide emissions (CO_2) from energy since beginning of the nineteenth century was 27 percent in 2005, the respective share of the North American OECD countries amounted to 32 percent. Other OECD countries and the eastern European countries with economies in transition (EIT) were responsible for another 20 percent of the global cumulative emissions since 1800. The share of emerging economies with recently high growth rates of CO_2 emissions was 8 percent for China and 2 percent for India in 2005. If the global carbon dioxide emissions follow a business as usual trajectory, global CO_2 would double compared with recent levels, the largest share of the emissions increase coming from India and China. Therefore, the source pattern of the cumulative emissions would show no radical change. The European OECD countries would make up a 17 percent share, the North American OECD countries 24 percent, other OECD and EIT countries 16 percent, China 19 percent, and India 7 percent.

In this context, fast and strong action to decrease greenhouse gas emissions from the OECD countries will be an indispensible effort to enter a national, regional, and global emission trajectory, allowing for global warming to be limited to a level which avoids unacceptable and potentially disruptive consequences deriving from global warming for nature, economies, and societies.

Limiting the increase of the global mean temperature to a level below 2°C compared to pre-industrial levels is increasingly seen as a robust target for climate policy. With respect to the special responsibility of the industrialized countries this global target can be translated into indicative emission reduction targets in the range of 80-95 percent for the middle of this century. This transition of the economies toward a near-zero carbon economy will obviously require action that addresses different time frames. The key determinants for differentiating between short- and long-term policy objectives are maturity of technologies and necessary structural changes with regard to lifetime of the capital stock, the lead time for the adjustment and the roll-out of infrastructures, the necessary time frame for non-disruptive changes of economic and socio-economic structures and pattern, etc. Emission reduction targets for the next twenty to thirty years must mainly rely on technologies which are available and matured in general today and on policies and measures which fit into the existing political and legal framework. Longer-term climate targets will require the adjustment of infrastructures, e.g., for electricity, gas, and CO_2 (sequestration) which could last for one to two decades. The change of structures of urban developments and new structures for creation of value added and/or trade structures will require a much longer perspective.

A well founded and comprehensive climate policy has to address these different dimensions and must reflect the near-term effects of policies and measures as well as the potential long-term implications of the implemented measures. The increased use of market-based instruments like cap-and-trade schemes for greenhouse gas emissions will increase the urgency of such integrated assessments.

These significant interactions between short-term action and its long-term implications for sufficient climate policies should be considered carefully within the reflections on more near-term policies and technologies.

The change of emission trajectories will and must result from changes in technologies. However, technological changes are driven by economics; political interventions; preferences and uncertainty assessments of consumers and investors; availability of infrastructures; and many other factors. Against this background, the following analysis of near- and medium-term options for emission reduction will combine technological aspects, related policies and measures, and the underlying socio-economic trends.

In order to avoid inconsistencies it is useful to aggregate the singular analysis of certain technological changes and political interventions to consistent scenarios. In this context, the analysis presented in this study does not focus on isolated technological or other options for greenhouse gas emission reductions.

Within the climate policy framework of the European Union (EU), all member states must report so-called policy scenarios every two years which contain greenhouse gas emissions projections for the years 2020 and 2030, the underlying socio-economic trends, and an impact assessment for the different policies and measures which were already implemented or could be implemented in the future, either within the scope of national policies or as European policies. Every member state must compile three different scenarios. The without measures scenario (WOMS) requires an emission projection which reflects the absence of those policies and measures which were already implemented. The with measures scenario (MWS) is a projection which reflects all policies and measures that were already implemented. A supplementary with additional measures scenario (WAMS) lays out the effects from additional policies and measures and as such the potential for further political action. The comparison of these scenarios provides a consistent overview of the potentials, the achievable implementation of technologies and other options, and the respective political and economic framework. Based on some background information on the German situation (Section 2) which could be important for understanding the following analysis, we present some key results on the policy scenario exercise undertaken in 2007 (Section 3). As a supplementary analysis we also present some additional sensitivity analysis in this chapter from a research project that addressed the impact on high energy prices on emission trends and the implications for climate policies. In Section 4 we summarize the most significant emission mitigation options and policies and measures and add some results of an analysis on the economic dimensions of the recent Integrated Energy and Climate Package (*Integriertes Energie- und Klimaprogramm*, IEKP) in Germany. Some concluding remarks (Section 5) outline some of the key lessons on near-term climate strategies. This essay is mainly based on three studies which analyzed the potentials, the policies and measures, and the costs of ambitious climate policies for Germany. A bibliography of these studies is provided.

Section 2: Selected Background Data and Information on Germany

DEMOGRAPHIC AND SOCIO-ECONOMIC DRIVERS FOR GREENHOUSE GAS EMISSIONS

Germany is the largest member state of the European Union with about 82 million inhabitants and a gross domestic product of about €2.423 billion in 2007 (about $3.321 at 2007 exchange rates). It is the industrial heartland of Europe; the gross value added created in industry represents about one-fourth of the gross domestic product. The total employment was 39,768 in 2007, of this 25.5 percent in industry, 72.4 percent in the private and public service sector, and 2.1 percent in agriculture. The industrial basis for the German industry is characterized by specialized and innovation-intensive industries even in more traditional branches (mechanical engineering, vehicles, chemicals, etc.). Furthermore, most of the industrial sectors rely heavily on the export of goods and capital equipments.

The general demographic trend is characterized by a more or less stagnating population since the early 1990s and for the next fifteen years. A slight decrease beyond 2020 to about 79 million inhabitants in 2030 is expected. The share of employment in industry shows a steady decrease and the role of the service sector will increase in the foreseeable future.

The aging population and other socio-economic trends result in significantly changing patterns of household structures. In the last two decades and also for the next two to three decades, the share of one and two person households shows significant growth; in 2030 the number of one or two person households could be about 2.5 million higher than in 2005. This has significant implications for the average living space per capita. In 2005 the German average was 38 square meters per capita; recent projections see an increase to 45 square meters per capita by the year 2030. The living space in buildings which existed in 2005 will remain stable at a level of 3 billion square meters over the next three decades. Living space in new buildings erected between 2005 and 2030 is assumed to be about 500 million square meters. In other words, the capital stock in residential buildings in 2030 will be mainly characterized by the 85 percent share of living space in buildings which already existed in 2005 and climate policy must anticipate the increase of the respective energy services. About 60 percent of the total living space in Germany is covered by one- and two-family dwellings and the remaining 40 percent in buildings with three or more apartments. Recent forecasts do not assume a significant change in this general pattern.

Apart from the material structure of the building stock in Germany, the ownership structure is a key determinant for policies and measures related to residential buildings. In about 42 percent of cases, the apartments are owned by the residents; all other residents are tenants. The structure of self-owned living space differs significantly for the different types of buildings. For one- and two-family dwellings the share of self-owned apartments amounts to about 66 percent; for other apartments this share is only 17 percent. This situation is a relevant factor with regard to many policies and measures for the building sector because there is a complex set of regulations in Germany which protect tenants from rent increases exceeding certain thresholds. In this context the user-investor dilemma is a key determinant for any policy that addresses investment in the building sector.

With regard to the transport sector, the capacity for passenger transport is characterized by a large share of individual road transport. About 80 percent of the total passenger transport capacity is provided by individual automobile traffic, about 7 percent by railways, and 10 percent by other public transport. For the next two to three decades the growth of passenger transport is projected to grow from about 1,000 billion person kilometers to 1.150 billion person kilometers in 2030. This moderate growth for the passenger transport is contrasted by a significant increase of the projected freight transport which is assumed to grow from 500 billion ton kilometers to 820 billion ton kilometers in 2030. Presently the share of road transport in the total freight transport capacity is about 70 percent which could increase to 74 percent by 2030 in the business as usual scenario. The recent shares of rail transport and inland navigation are about 17 percent and 14 percent, respectively.

The analysis of emission reduction potentials for the different time frames must reflect these key socio-economic and demographic drivers:

- The existing industrial structures require a careful assessment of policies and measures regarding the impacts on the competitiveness of these industries on the one hand. However, on the other hand environmental pressure and other drivers leading toward intensified investments in Germany or abroad can build new market opportunities.

- Significant changes in the demographic structures and the consequences for energy consumption patterns and other trends which have significant impacts on energy demand and emission trends (smaller households, increase of living space, etc.). The interactions between an aging population and the need for fast penetration of innovative technologies will require careful analysis and flexible approaches of energy and climate policies.

- The small share of new investments in the housing sector and the dominant role played by the existing building stock, combined with complicated ownership structures, require complex approaches if the buildings sector shall be addressed by energy and climate policies and measures.

■ The different dynamics for passenger and freight transport will require a balanced approach to dealing with the different patterns of road transport and the different policies and measures to address both, the change of modal-split, as well as the efficiency of vehicles and the use of less carbon-intensive fuels for transport.

Among the wide range of socio-economic and economic drivers for the energy system and the other sectors which are highly relevant to greenhouse gas emissions these issues should be considered as key challenges for the assessment of potentials in the near, medium, and long term and the related policies and measures. Last but not least, these key drivers are significant determinants for the status quo of energy use and greenhouse gas emissions in Germany.

PAST AND PRESENT STRUCTURE OF ENERGY SUPPLY AND CONSUMPTION AND GREENHOUSE GAS EMISSIONS

The primary energy supply for Germany is characterized by more or less stable primary energy consumption for the last fifteen years and some significant changes in the structure of the energy supply. The most interesting trend can be observed for the consumption of mineral oil. After German unification the share of mineral oil in the total primary energy supply increased from 35 to about 40 percent. However, since the end of the last century this trend has reversed and the share of oil fell back to 36 percent in 2006. In contrast to this non-uniform trend, the use of coal has decreased steadily since the 1990s. Since 1990 the share of lignite and hard coal in the total primary energy consumption in Germany has decreased more than 10 percentage points. However, in recent years the share of coal in the energy supply stabilized at a level of 24 percent. Nuclear energy provided about 12 percent of the primary energy for most of the last fifteen years. The share of natural gas increased over the period from 1990 to 2006 from 15-23 percent but has shown no significant dynamics over the last four years. The most dynamic growth among the different primary energies can be observed for renewables energies. However, the base level of the contribution of renewable energies to the primary energy supply was very low, amounting to only 2.1 percent in 1990. From 1990 to 2007 the share of renewable energies increased to 6.7 percent. The most significant growth for renewables was from 2002 to 2007 with an increase from 3.0 to 6.7 percent.

The consumption pattern of primary energy in Germany has been quite stable since 1990. About 30 percent of the total energy consumption was used in the energy sector (power plants, refineries) and about 64 percent was consumed by industry, service sector, households, and transport. The non-energetic use of energy resources represents a difference of about 7 percent.

The level of final energy consumption in 2006 was approximately the same as in 1990 and only small variations occurred. The structure of final energy consumption is balanced between the sectors. Each of the sectors industry, transport, and private households represented about 28 percent of the total final energy consumption in 2006. The share of final energy consumption in the service sector was about 15 percent at this time. The trends in the final energy sector follow the general variations of the primary energies. Coal, heating oil, and motor fuels lost market shares; the consumption of natural gas, electricity, and district heating grew. The consumption of electricity was especially driven by industry and private households and to a much lesser extent by the service and the transport sectors.

Besides the sectoral breakdown of final energy consumption, the structure of energy use is another important starting point for the analysis and design of appropriate strategies to decrease greenhouse gas emissions in the near and long term.

About 60 percent of the total final energy is used for heating in Germany, about 30 percent for space heating, 5 percent for warm water, and 23 percent for other process heat. The use of oil and gas for space heating dominates the consumption pattern in the residential sector where space heating represents about 74 percent of the total energy consumption. The major drivers of energy consumption in industry are process heat and mechanical energy and mechanical energy for the transport sector. The consumption pattern for electricity is characterized by a large share of motors which require 50 percent of the total electricity in the end-use sectors. 20 percent of electricity is consumed for process heat. Lighting; information and communication technologies; space heating; and warm water represent 9 percent, 7 percent, 6 percent, and 8 percent, respectively.

The changing structure of energy supply as well as the structural change of the economy (e.g., with a continuing decrease of agricultural production) have significantly affected the past trends of greenhouse gas emissions (Figure 1). The trend in the 1990s is characterized by a significant decrease of greenhouse gas emissions, mainly caused by the sharp change in industrial activities in the eastern part of the country following the reunification of Germany and a major decrease in coal consumption. Emissions from the energy industries, agriculture, and the waste sector dropped while emissions from the transport sector and private households increased. Since the turn of the century this pattern changed. Emissions from transport and the residential sector decreased and emissions from the energy sector (i.e., the power sector) started to increase again. This is mainly a result of the dramatic changes in energy prices which incentivized the more efficient energy consumption in the end-use sectors on the one hand and improved the competitive position of CO_2-intensive energy like hard coal and lignite in the power sector on the other hand.

In this context, the analysis of the drivers for the past trends of greenhouse gas emissions from energy use leads to interesting insights (Figure 2).

If the structure of fuels and the intensity of energy use would not have changed since 1990, the emissions from energy use in Germany would have increased by about 130 million tons because of economic growth and changed demography by the year 2005. These driving forces behind a potential emissions increase were overcompensated by the increased efficiency of energy use, the increased contribution of CO_2-free energy sources (i.e., renewable energies), and the decreasing carbon-intensity of the fossil fuels. The illustration also indicates that most of the progress regarding energy efficiency was made in the first half of the 1990s and then after the year 2000. The increasing role of renewable energies is a more or less steady process whereas the oil price driven increase of the CO_2-intensity of fossil fuels in recent years caused a change of trends.

Although a major share of the emissions reduction was achieved by the structural change in the eastern part of the country (an in-depth analysis of the emission trends in the 1990s attributed 50 percent of the emission reduction during this period to German reunification), energy and climate policy had a significant impact on the emission trends since the early 1990s.

The analysis of the past emission trends and the recent patterns of energy consumption lead to the following starting points for the analysis of options for a decrease of greenhouse gas emissions as well as the design of climate policy strategies:

- The progress of an increased energy productivity, a decreased carbon-intensity of fossil fuel use, and the expansion of fossil-free energy sources lead to a stabilization of total energy consumption and a significant reduction of greenhouse gas emissions in Germany. However, without the unique situation of structural change and intensified modernization in eastern Germany it would be impossible to extend this trend to the necessary emission reductions for the next two to three decades. Additional efforts will be needed to meet the challenges of an ambitious energy and climate policy.

- The energy sector—and within this sector, power generation—is one of the key sources for greenhouse gas emissions. Without a significant decrease of these emissions no ambitious climate policy can be designed. The necessary options and measures must address power generation on the one hand and the use of electricity on the other hand.

- Greenhouse gas emissions from transport and especially the passenger and freight road transport represent another key source. Changes in the modal-split, significantly less emission intensive vehicles, and transport fuels must be addressed.

- Space heating is the third major source of greenhouse gas emissions for Germany. Against the background of the long-lasting building stock, activities in this sector will require a combined strategy, strong efforts in terms of the renovation of existing buildings to achieve emission reductions in the near- and medium-term, and, at the same time, the implementation of innovative technologies to low-carbon standards for new buildings to ensure a low-carbon building stock in the long-term.

The need for a broad range of activities for very different sectors which must take into account a wide range of special circumstances leads to an intelligent policy mix. However, the design of such policies must reflect a complex political and legal framework.

POLITICAL AND LEGAL FRAMEWORK

Political interventions to improve energy efficiency and to limit greenhouse gas emissions have a long tradition in Germany. From 1990 onward, Germany has set ambitious targets for reduction of greenhouse gas emissions. The original target of a 25 percent reduction of CO_2 emissions by 2005 was substituted by Germany's commitment within the EU burden-sharing agreement to the Kyoto Protocol of a 21 percent reduction of all greenhouse gas emissions compared to 1990 levels. For the longer term, Germany has defined a 40 percent emission reduction target by 2020. Since the introduction of these targets a series of policy packages was approved and implemented to initiate emissions reduction measures. These programs cover a wide range of measures for a wide range of sectors that vary from command and control policies to voluntary agreements and from measures to improve transparency and raise awareness to market-based instruments such as environmental tax reform or emissions trading.

Nevertheless, various policies existed for a long period of time that caused effects which were and are counterproductive from the perspective of climate change policies. The domestic production of non-competitive hard coal was heavily subsidized over decades and tax breaks gave strong incentives to develop urban structures which create the need for transport and lead to non-optimal structures of urban development.

For a long time the monopolistic structures and the insufficient regulation of the energy sector led to a wide range of barriers for innovative power generation technologies (distributed generation, cogeneration, etc.) as well as to a lack of incentive structures for the efficient use of electricity (tariff structures, etc.).

However, Germany was among the first countries to define greenhouse gas emission reduction targets and implement early policy packages to address greenhouse gas emissions in the energy sector, in certain industries with process emissions, as well as in the waste sector. As mentioned earlier, for a share of the emissions reductions which were achieved in the past these policies were essential.

As a result of European integration the legal and political framework for national climate policies is in the process of a fundamental change. Whereas climate policies during the 1990s were subject to national policymaking, to a large extent this changed significantly after the turn of the century. The majority of emissions reduction initiatives now come directly or indirectly under the control of the European Union:

- The European Union initiated climate policies for a broad range of comprehensive measures, from the EU greenhouse gas reduction commitments and the European Union Emissions Trading Scheme (EU ETS) to mandatory targets for the use of renewable energies and performance standards for cars and electric appliances and other special regulations (non-CO_2 greenhouse gas emissions from industry, carbon capture and storage, etc.).

- The use of direct subsidies and other means of state aid (tax breaks, etc.) is subject to strong restrictions under European state aid legislation which are based on the efforts to eliminate distortions and barriers in the internal market of the EU. Furthermore, strong efforts are being made to eliminate distortions from taxation policies.

- The internal market for energy is one of the key projects of the European Union. The EU member states had to liberalize their electricity and gas markets and establish regulatory schemes to enable third party-access to infrastructures and unbundling of infrastructures. Although the EU has no formal competences on energy policy the design of the framework for the internal market for energy has shifted an enormous amount of factual energy policy decisions toward the EU institutions.

- The development and the regulation of energy infrastructures is to a significant extent subject to European programs, regulations, financial mechanisms, and other policies and measures.

- Last but not least, the EU undertakes strong efforts to develop strong external relations and neighborhood policies in the energy sector to improve energy security but also to initiate complementary climate policies and measures which could make additional contributions to a global climate policy on the one hand and limit competitiveness distortions for the European Union industries which are subject to climate policy regulations on the other hand.

As a consequence the focus of national climate and energy policies changed significantly during the last decade. Implementation of EU policies and measures plays a very important role in many fields of action. The design of national policies and measures must increasingly fit into the EU legal and regulatory framework (state aid, taxation, other competition distortions, energy market liberalization, etc.).

However, there is still a significant margin for climate policies and measures in terms of policies at the national, regional, and local level. German policymakers at the federal and regional levels have continued to implement policy packages to decrease greenhouse gas emissions during the last years. The key foci of these policies is currently:

- focused support of certain technologies (e.g., research and development; lead markets and early market penetration for renewable energies in power generation; heating, and cooling, and transport; support of cogeneration; demonstration projects; and phase-in of carbon capture and storage);

- comprehensive measures to improve the energy standards for buildings and to decrease the respective greenhouse gas emissions;

- public information and awareness-raising activities for the wide range of climate-friendly technologies;

- implementation of energy management systems and other means to improve energy efficiency and decrease greenhouse gas emissions from the business sector;

- measures to change the modal-split of transport in favor of public transport, rail transport, etc.; and

- restructuring of the waste management sector to achieve major emission reductions of non-CO_2 greenhouse gas emissions.

A series of these policies and measures and their impacts on the greenhouse gas emission trends will be discussed in the following chapters.

In addition to these policies with a focus on climate change issues, some policies must be taken into account which address other risks but nevertheless have an impact on greenhouse gas emissions. Based on an agreement with the German nuclear operators the German Bundestag has approved legislation to legally ban new nuclear power plants and to phase-out the existing nuclear power plants by the year 2025. In this context, the assessment of climate-friendly technologies and policies must not only consider the targets for emission reductions but also the substitution of a risky but low-carbon energy source.

Section 3: Greenhouse Gas Emission Reduction Potentials in Germany and the Related Policies and Measures

OVERVIEW AND AGGREGATE ANALYSIS

In the following chapters we will describe a series of emission reduction potentials and the existing or future policies and measures which will be needed to achieve these emission reductions. With regard to the metrics of emission reductions it should be considered that the recent level of greenhouse gas emissions in Germany is about 1,000 million tons of CO_2–equivalent (mln t CO_2e). In other words: an emission reduction of 10 mln t CO_2e equals an emission reduction of one percentage point.

Figure 3 indicates the results for the three scenarios described in Section 1. Had all measures already in place not been implemented, the level of total greenhouse gas emissions in Germany would increase by about 50 mln t CO_2e from 2000 to 2020. The emission reduction effects which are attributable to the implemented measures amount to 110 mln t CO_2e in 2020. If additional measures are undertaken the emission level in 2020 could drop by another 155 mln t CO_2e. In the longer perspective the effects of climate policies could amount to more than 400 mln t CO_2e, compared to 2000 levels, which equals an emission reduction of about 50 percent compared to 1990.

Figure 4 shows the results of an aggregate analysis for the contribution of different mechanisms to the emission reduction in the energy sectors, which is the most important source of greenhouse gas emissions. The policies and measures described in the following chapters address energy efficiency (energy productivity), higher shares of renewable energies (lower shares of fossil fuels), and a decarbonization of the fossil fuel use (carbon intensity of fossil fuels). The overview in Figure 4 indicates that with the policies and measures which are already in place the total greenhouse gas emissions from energy could be decreased by about 126 mln tons of CO_2e. Economic growth would have increased the emissions by more than 270 mln t CO_2e if the role of all other components would have been stable in the 2005-2020 period. However, the growth trend is overcompensated by higher efficiency of fuel use, a higher share of renewable energies, and an intensified decarbonization process for the fossil fuels. With the existing policies and measures the increased use of renewable energies would deliver the biggest share of emission reductions (about 200 mln t CO_2e), whereas a contribution of about 100 mln t CO_2e each could be assigned to higher energy efficiency and lower CO_2-intensive structure of fossil fuels.

With the help of more ambitious and additional policies and measures the contribution of energy efficiency could be nearly doubled to about 180 mln t CO_2e in the period 2005 to 2020. Another increase of energy production from renewable energies could increase the contribution to these energy sources to about 240 mln t CO_2e. The biggest additional contribution in the additional measures scenario could result from a further decarbonization of fossil fuels and increase the respective emission reduction to 240 mln t CO_2e from 2005 to 2020.

In the longer-term perspective, the contribution from an increased use of renewable energies and a further shift to low-carbon fuels and/or technologies could lead to additional emission reductions which would allow for an over-compensation of the effects of economic growth, and for ambitious greenhouse gas emissions to be reached by 2030.

The results presented in this aggregate analysis are assigned to specific existing and future policies and measures and less to the existing potentials for emission reductions. However, additional potentials could be raised by other and new political means.

BUILDINGS, SPACE HEATING, AND WARM WATER

The German building sector is characterized by a long-living buildings stock. Most buildings have a lifetime of about one hundred years and the duration of the renovation cycle is about forty years. The exchange of significant building equipments like heating systems takes place every twenty years on average. In other words, emission reductions from the building sector can only be achieved with policies and measures which are designed to address long-term processes:

- In thirty years, 85 percent of the living space and more than 95 percent of the energy consumed for space heating can be assigned to those buildings which already exist today.

- The energy demand from buildings that will be newly erected in the next two to three decades will determine the energy demand and the greenhouse gas emissions for the second half of this century.

The technical potentials of greenhouse gas emissions reductions from the building sector are significant:

- Insulation and new heating equipment for existing buildings can reduce the specific energy consumption up to 85 percent. Demonstration projects show that with comprehensive renovation measures an energy demand of 30 kilowatt-hours per square meter (kWh/m2). Further pilot projects exist to reach passive-house standards (defined as having an energy demand for heating that is less than 15 kWh/m2) also by renovation of existing buildings. Usually these buildings need ventilation equipment.

- High-grade insulation, including high-efficiency windows, ventilation, and heat recovery enable new buildings to have very low or near-zero energy consumption standards.

- High-efficiency heating equipments (condensing boilers) or the use of renewable energies for heating and warm water (i.e., solar collectors, modern wood pellet heating systems, heat pumps, energy-storage equipment) allow significant emission reductions from buildings.

With the policies and measures that are in place, the greatest savings are achieved by means of monetary support programs. These are the program of the German promotional bank KfW and the market incentive program. Furthermore, two regulatory measures—the Amendment of the German Building Energy Conservation Ordinance (*Novellierung der EnEV;* BECO; *Deutsche Energieeinsparverordnung*, EnEV) and the German Energy Label (*Energieausweis*)—are important in this context. Complementary effects result from public relations and consultancy. Monetary and ordinance measures together bring about an annual saving of 15 mln t CO_2 in 2030 (excluding double counting). The most successful individual measure in this regard is the KfW CO_2 Building Renovation Program (*KfW-CO_2-Gebäudesanierungsprogramm*), which produces a saving of 5.3 mln t CO_2 annually. The second most successful measure is the German market incentive program for biomass, which generates a saving of 4.6 mln t CO_2 annually in the building sector. Other measures, which are not individually quantifiable, bring about a saving of 14 mln t CO_2 collectively.

District heat and electricity use for heating are also included in the representation of energy consumption development. With the existing measures, these savings amount to around 16 percent up to 2030 compared to 2006 when electricity and district heat are taken into account.

In the non-residential building sector, the CO_2 emissions will be reduced by the existing policies and measures (see above) by 36 percent up to 2030 in relation to 2006. This considerable reduction is achieved by boiler replacements, rehabilitation effects on the building envelope, and the increasing use of solar-powered installations and biomass furnaces. Moreover, a considerable share of the reduction is due to demolition. Old buildings, which are generally poorly insulated, are most likely to be replaced by new buildings. The replacement cycles are substantially shorter than in the residential building sector. The reduction in energy consumption amounts to around 29 percent in the same time period.

Beyond the existing policies and measures, further measures can be taken into account which aim at substantial improvement of plant efficiency, promotion of thermal insulation in old buildings, and an increase in the use of renewable energies as well as an increase in public relations, consultancy, training, and quality campaigns.

Condensing boiler technology is by far the most efficient and marketable technology in terms of the energy supply to buildings. By means of promoted introduction, it is intended that only condensing boilers will be used up by the end of the time horizon. The combination of the highly-efficient, cost-effective condensing boiler technology and solar thermal energy represents a suitable installation mix. Within the scope of the with measures scenario, it is therefore intended that the share of these combi-installations will increase from 8 percent today to 80 percent by 2020 and 100 percent by 2030.

The combustion of solid biofuels, the use of solar thermal energy and the use of ambient heat via heat pumps are particularly suited to delivering a sustained contribution to heat supply in the buildings sector. By means of the “Increasing the use of renewable energies” measure, the volume of renewable energies could more than double by 2030. Alongside a significant expansion in biomass use, the contribution of solar energy increases by a factor of 13 and of other renewable energies by a factor of 20.

In order to resolve the modernization backlog with regard to thermal insulation, it is assumed that the potential utilization can be doubled from 32 percent to 65 percent by additional performance standards and incentive programs. This shall be achieved by means of the following individual measures: instead of repeatedly repairing defective and over-aged components in a provisional manner, an exhaustive rehabilitation shall be initiated in such cases. In this way, the quantity of rehabilitations is increased. In order to improve the quality of the rehabilitation, roofs and facades should not be rehabilitated without thermal insulation; the ordinance’s requirements also need to be complied with during the realization of thermal insulation.

The latter measure shall be supported by tightening the German Building Energy Conservation Ordinance by 25 percent for new and old buildings as of 2012. However, the achievable savings by 2030 for old and new buildings amounts to only half that of the savings achieved by improving the level of potential utilization. It is thus more effective to first improve the implementation of the present German BECO instead of making the ordinance stricter. The latter undertaking will, however, ultimately be unavoidable in the long term in order for stringent reduction targets to be met.

The energy savings brought about by the measures within the with additional measures scenario amount to around 32 percent by 2030 for residential buildings compared with 2005 when electricity and district heat are taken into account. For fuel oil and natural gas, the savings reach a level of around 44 percent in comparison with those of 2005. This corresponds to approximately 23 percent of the total German consumption of natural gas and fuel oil in 2006. With additional incentive programs, the share of renewable energies can be expanded to 25 percent by 2030; this corresponds to almost double the value reached with the measures which are already in place. With these additional measures, the CO_2 emissions fall by around 44 percent up to 2030 compared to the 2006 level.

The total final energy consumption of non-residential buildings could fall by 49 percent in the with additional measures scenario compared to 1990 (2006). The decline in gas consumption is more considerable than in the with measures scenario. In both scenarios, the fuel oil use decreases substantially more than the gas use. Due to the high level of savings, a decline in electricity consumption arises. Renewable energies in the form of biomass and solar energy increase relatively substantially, while always remaining at a low level in absolute terms. Subsequently, a reduction of 27 mln t CO_2e can be expected up to 2030 in the with additional measures scenario.

The total emissions in the sectors where space heating is the most significant source of greenhouse gas emissions (residential and commercial sector) could be reduced with the implemented and the additional policies and measures about 50 percent in 2020 and 65 percent in 2030.

ELECTRIC APPLIANCES

Electric household and office appliances (without lighting) represent a share of 25 percent of the total electricity consumption in Germany, lighting about 10 percent, and electric motors in the industry about 30 percent. One third of the electricity consumption is for heating; of this about 10 percentage points is for space heating in the residential, commercial, and industrial sectors. Ventilation and air conditioning play recently only a minor role in the German electricity consumption.

The total reduction potential for electricity is assumed to be 10 percent compared to recent levels. Considering the growing penetration of electric appliances and equipment, the main strategies for increasing the efficiency of electricity use are as follows:

- For many electric appliances and equipments efficiency potentials of 30 percent to 50 percent exist; for some applications like lighting the efficiency potentials are above 70 percent. Improving market transparency and performance standards are key policies of Germany and the European Union.

- For many heating applications, there are options for substitution of electric heating by natural gas, district heating, and other innovative systems. Due to high electricity prices in Germany, electric space heating is increasingly leading to social problems for tenants who live in buildings equipped with such systems.

Within the existing measures, electricity savings are essentially achieved by means of the German Energy Consumption Labelling Ordinance (ECLO; *Energieverbrauchskennzeichnungsverordnung*, EnVKV) and the German Energy Consumption Maximum Value Ordinance (ECMVO; *Energieverbrauchshöchstwerteverordnung*, EnVKH). Up to 2030, an overall saving of 9.4 TWh is expected. To be sure, this is largely due to the German ECLO and ECMVO; however, there are further factors of influence such as autonomous progress in energy technology and a wide range of information and transparency measures via energy labeling, most notably the German Energy Efficiency Initiative.

Additional measures could further reduce the energy consumption of large electrical household devices. Mandatory performance standards for further electrical household devices and other equipment or the tightening of existing mandatory product labels for electrical household devices are options to reach an addition reduction of electricity consumption. A fundamental pre-requisite for the success of both measures is their dynamic adaptation, i.e., the regular adaptation of threshold values to progress in energy technology. This could follow the example of the “Top Runner approach” practiced in Japan, in the framework of which the most energy-efficient product is determined in each case for individual product groups. After a certain pre-defined time, the products of all manufacturers and importers have to meet this energy efficiency value on average. Under these conditions, it is estimated that an increase in mandatory minimum efficiency standards brings about electricity savings of around 11 billion kWh (i.e., Terawatt hours, TWh) by 2030. Alternatively, in the case of the tightening and dynamic adaptation of mandatory product labels for electrical household devices, the saving would be smaller, amounting to around 8 TWh. Furthermore, measures are considered which can contribute to a greater tapping of existing technology-related saving potentials of the "standby consumption" of electrical and electronic household devices. The electricity consumption when the device is switched off, which comes about as a result of electrical devices not being completely disconnected from the power grid upon being switched off, can be avoided in the medium term if the manufacturers were obliged to fit switches to enable disconnection from the power grid. The saving potential of this measure is estimated to be around 1.5 TWh. A possible measure to reduce electricity consumption in the standby operation mode is mandatory labeling of the electricity consumption of the devices when they are in this operation mode. Due to this measure, savings can be achieved of around 7 TWh by 2030. An alternative measure is the setting of minimum efficiency requirements of consumption in the standby operation mode. In this way, the present saving potentials can also be tapped—and possibly in a shorter period of time. As a general rule, all measures to reduce the energy consumption of electrical devices should be accompanied by information campaigns, the effect of which is already included in the impacts of measures.

The key instrument for the future will be European performance standards. Recently such standards are under development for fifteen groups of electric appliances, ranging from lighting systems to electric motors and cooling equipment.

With such standards alone for household appliances, net electricity savings of around 18 TWh are expected. Around 60 percent of this total stems from the electricity consumption of electrical devices covered in the above measures; the remainder is due to energy consumption for cooking as well as electrical appliances for warm water preparation in residential buildings, auxiliary energy for the operation of oil and gas boilers, and for air conditioning and ventilation. Compared to the recent levels, electricity consumption could decrease by around 33 TWh up to 2030 by existing and additional measures. Another 30 TWh electricity could be saved by substitution of electric heating systems by more efficient equipment on the basis of natural gas or district heating.

TRANSPORT

The existing measures for the transport sector address different dimensions of transport:

- mandatory standards for blending of biofuels (8 percent by 2015) shall decrease the carbon-intensity of motor fuels and achieve a (net) emissions reduction of 18 mln t CO_2 by 2015;

- voluntary agreements with the car manufacturing industry should increase the efficiency of cars (140 g CO_2/km) which equals an emissions reduction of about 7 mln t CO_2;

- increased excise duties (eco-tax) for gasoline and diesel shall incentivize more efficient vehicles which could lead to an emissions decrease of 2 mln t CO_2 annually by 2015;

- road-pricing for heavy duty vehicles (introduced in 2005) shall increase the incentives for a shift of freight transport to rail transport and lead to an emissions reduction of 3 mln t CO_2 by 2015; and

- changing the tax breaks for commuters shall remove incentives for long-distance commuting, the respective emission reduction is assumed to be 2 mln t CO_2 annually.

In total these existing measures could achieve an emission reduction of 34 mln t CO_2 by 2030. However, the automotive industry will not comply with the voluntary agreement and the effective emission reduction for the transport sector will decrease to about 25 mln t CO_2 by 2015.

As a result, additional policies and measures could be implemented to lower the emissions from the transport sector in the next two to three decades. A key role in this policy mix will be the introduction of mandatory standards for cars. If the existing voluntary agreement is transformed into mandatory standards and the standards are set at 130 g CO_2 per km in

2012 and 100 g CO_2 per km in 2030 this would lead to an emissions reduction of additional 16 mln t CO_2 in 2030. Such mandatory standards for the first step (2012/2015) will be decided by the EU at the end of 2008 as part of the EU's climate and energy package.

An increase in the mandatory blending of biofuels to 12.5 percent in 2020 and 25 percent in 2030 equals a (net) emission reduction of about 14 mln t CO_2 in 2030. Such mandatory standards are heavily debated in the EU as well as in Germany. In any case, sustainability standards for those biofuels which are accepted for compliance with the blending standards are an indispensible complementary measure for these kinds of policies.

A doubling of tolls for trucks and the expansion of road pricing to the total highway system could decrease the German greenhouse gas emissions by about 20 mln t CO_2 in 2030.

One of the most cost-sensitive transport sectors is national and international air transport. New policies and measures are discussed and planned to decrease the emissions from the segment of the sector. Air transport will be included in the EU Emissions Trading Scheme from the third trading period of the scheme. However, this related emission reduction of about 2 mln t CO_2 in 2030 is relatively small compared with a full taxation of jet fuel at the level of the excise duty for diesel fuel. Such level of taxation could decrease the emissions from air transport by about 18 mln t CO_2.

A series of other measures could account for an additional emissions reduction of about 10 to 15 mln t CO_2 by 2030, ranging from mandatory use of fuel-efficient engine oils and low-resistance tire to structural changes in taxation of motor fuels and car purchases.

The additional measures could achieve a further decrease of greenhouse gas emissions of about 70 mln t CO_2 in 2030. With all implemented and additional measures the greenhouse gas emissions from transport could be reduced by 40 percent in 2020 and 55 percent in 2030.

ELECTRICITY GENERATION FROM RENEWABLE ENERGIES

In Germany, the electricity production from renewable energies is substantially shaped by support provided by the German Renewable Energy Sources Act (RESA; *Erneuerbare-Energien-Gesetz*, EEG), which is in accordance with European policy (Directive 2001/77/EC). In Germany, a share of the electricity consumption amounting to at least 12.5 percent ought to be achieved by 2010. Furthermore—in line with the target set by the 2004 amendment of the German RESA—a share of at least 20 percent is aimed for 2020. An amendment to the RESA is planned following the RESA review in 2007; this will be effective as of 2008. In the process, shifts of emphasis have been contemplated but not an increase in overall support in comparison to the current state of affairs. Moreover, measures in research and development are in place, as are flanking regulatory and energy-economic measures.

With the implemented measures, the minimum target of 12.5 percent will be significantly overachieved in 2010 and the target of 20 percent in 2020 will more or less be achieved. Up to 2030 the share of renewable energies increases to almost 27 percent. This development is due unambiguously to the increasing use of wind power; indeed, almost half of the renewable electricity production in Germany in 2020 stems from wind power.

With the comprehensive revision of the German RESA, combined with additional regulations to ensure and finance the network connection of new generation facilities (which is a relevant factor for offshore wind power plants), the total electricity production from renewable energies could amount to 154 TWh and 224 TWh in 2020 and 2030, respectively. In addition, the increasing import of renewable electricity should also be considered (around 2 TWh in 2020 and 25 TWh in 2030). In 2020 this expansion would equal a share of 26 percent and more than 40 percent in 2030 in terms of the total power generation in Germany.

The most significant source of electricity generation in all cases will be wind energy, followed by power generation from biomass.

ELECTRICITY GENERATION FROM FOSSIL FUELS

A wide range of measures was implemented to increase the share more efficient and less CO_2-intensive power generation options in the heavy coal- and nuclear-based power sectors.

Key measures to be addressed are high efficiency gas-fired power plants (combined cycle power plants), combined heat and power production (CHP/cogeneration), and distributed electricity generation plants for public power production as well as industrial and other autogeneration of electricity. Key political measures to support these technologies are:

- abolition of natural gas tax for electricity production from high efficiency condensing power plants;

- introduction of the EU Emissions Trading System (EU ETS), but with the allocation scheme of the first trading phase;

- incentive payments for existing and new CHP plants under the German CHP Protection Act (*KWK-Vorschaltgesetz*) and the German CHP Act (*KWK-Gesetz*) of 2002; and

- bonus payments for avoided network use for distributed power generation facilities.

These measures lead to a certain increase of power generation from CHP plants because of the direct incentives from the measures mentioned above and the preferential allocation regime in the first phase of the EU ETS. As a result the CHP-based electricity production increases slightly from 55 TWh (2000) to 63 TWh (2030).

The abolition of the natural gas tax for natural gas-based power generation improved the competitive position of gas-fired power plants on the one hand. On the other hand, the implementation of the EU ETS changed the merit order of the existing power plants significantly, which led to a certain reduction in emissions but did not incentivize gas-fired plants compared to coal-fired plants because the free allocation of allowances to new entrants was dependent on the emission levels of the new plants (more free allowances were allocated to new coal-fired power plants than to new gas-fired plants).

As a result the decrease of greenhouse gas emissions from the EU ETS in the specification of the first phase was rather limited alongside the effects of lower electricity consumption and the increase of power generation from renewable energies from the existing policies and measures. Operational effects from the EU ETS at a CO_2 allowance price of €15-30 per allowance amount to 10 mln t CO_2 and the abolition of the natural gas tax for power generation leads to an emissions reduction of another 10 mln t CO_2.

The revision of the EU ETS with tighter caps and a shift toward full auctioning at least for the power sectors is one of the key instruments to accelerate the modernization of the power sector, improve the competitive position of low-carbon power generation from fossil fuels, and to enable the phase-in of power generation with carbon dioxide capture and sequestration (beyond 2020).

Two additional policies and measures are of key importance for additional emission reductions in the German power sector:

- The revision of the EU ETS, eliminating the distortions of the CO_2 price signal from free allocation to new entrants, a compensation for the heat production in CHP plants, and the introduction of more stringent climate protection targets (increasing the allowance price €5/EUA by 2030);

- Increased support of CHP plants to meet the target of doubling CHP-based electricity production by 2015 and trebling it by 2030 in relation to the 2000 level. To this end, the existing German CHP Act is extended and the criteria for CHP plants that are entitled to receive bonuses are broadened.

OTHER GREENHOUSE GAS EMISSIONS

Greenhouse gas emissions from processes other than combustion make up a lower—but nevertheless significant—share of the total greenhouse gas emissions.

Some greenhouse gas emissions will decrease in the future as a result of other policies. The phase-out of subsidies for the non-competitive hard coal mining in Germany will lead to a reduction of methane (CH_4)

emissions of about 5 mln t CO_2e in the period from 2005 to 2020.

Emissions trends for other sources are strongly affected by policies and measures which are already implemented and effective. Additional measures are already under discussion and could lead to further emission reductions.

For the waste sector, far-reaching and effective measures were implemented to significantly decrease CH_4 emissions from landfills. According to a range of policies and measures for the waste sector, the disposal of bio-degradable waste has been prohibited since 2005. As a result, the methane emissions from landfills will decrease by 8 mln t CO_2e from 2005 to 2020 and by 10 mln t CO_2e from 2005 to 2030.

The emissions from hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulphur hexafluoride (SF_6) would increase significantly if no policies are implemented for these source categories. If the recent patterns continue, the emissions from HFC, PFC, and SF_6 would double in the next two to three decades from 15 mln t CO_2e in 2005 to more than 33 mln t CO_2e in 2030. A wide range of implemented measures (standards, voluntary agreements, etc.) addresses especially the emissions of HFC from stationary and mobile air conditioning systems, PFC emissions from the semiconductor industry, and SF6 emissions from disposal of soundproof windows. In total, this package of measures will allow for HFC, PFC, and SF_6 emissions to be stabilized at current levels. However, strengthening these regulatory activities could lead to more abatement in this sector which would allow for emissions to be decreased by 5 mln t CO_2e compared to recent levels.

Nitrous oxide (N_2O) emissions from industrial processes are a significant source of greenhouse gas emissions which represent annual emissions of about 14 mln t CO_2e in Germany. Significant reductions of about 80 percent were achieved for N_2O emissions from the production of adipic acid in recent years. Additional policy measures which are already in the pipeline will help to further decrease these emissions as well as the N_2O emissions from the production of nitric acid. The extension of the scope of the EU ETS to N_2O emissions from adipic and nitric acid productions could lead to a more than 90 percent reduction, given the fact that the abatement costs in these sectors are low (less than €1 per ton of CO_2e) compared to the foreseeable allowance price (higher than €15) in the EU ETS.

All in all, the emissions from non-energy and especially non-CO_2 greenhouse gas emissions are a field for target-oriented political measures to raise additional low-cost abatement potentials of up to 40 mln t CO_2e. However, many of these measures tend to be very technology-specific and will rely on command-and-control policies. For only some large point emission sources the inclusion into the EU ETS is increasingly seen as an appropriate approach, also in the case of non-CO_2 gases.

THE IMPACT OF HIGH ENERGY PRICES

High energy prices significantly change the economic framework for climate policies and the assessment of different categories of greenhouse gas mitigation options. However, a careful analysis is necessary to identify the need for a revision of policies and measures in the context of very high energy prices (e.g., at a level of $150 per barrel of crude oil).

Different aspects must be taken into account to assess the impact of very high energy on greenhouse gas emission mitigation. The first aspect is the effect of very high prices on the international fuel markets in terms of the price levels faced by different groups of decision-makers:

- For motor fuels the impact of high prices on the global fuel markets is rather limited because the share of excise duties is rather high in Germany. In 2007, 50 percent of the retail price for unleaded gasoline (without value added tax, VAT) was the excise duty; for diesel fuel it was 40 percent. If the VAT of 19 percent is considered, the share of taxes for motor fuels is from 60-70 percent. As a result, price increases in the global fuel markets only translate to a much lesser increase in retail prices (which are the reference for the economics of emission reduction measures).

- For natural gas and heating oil the link between international energy markets and retail prices is much more direct. The prices for heating oil and natural gas follow the global market prices very closely. This might change for natural gas after the effective liberalization of the EU natural gas market. In a competitive market only the import prices for natural gas will follow the global market price for petroleum products; the difference between import and retail prices, which is two-thirds of the residential retail prices for network access, structuring, and trading, will be subject to competition and regulation and should not follow the reference prices for oil very closely.

■ From the empirical evidence, the prices for imported hard coal to Germany follow the dynamics in the global markets for oil and natural gas. However, the relative competitive advantage for hard coal compared to natural gas increases significantly with growing oil prices. This is even more true for domestic lignite production where the price is more or less constant. For the very price-sensitive power market this change in relative prices is a key issue for investments and operation.

The second aspect concerns the changing economics of different mitigation measures and its implications for political measures:

■ The general economics for energy efficiency measures in the building sector will be much more favorable in the case of high energy prices. However, non-economic barriers like the user-investor dilemma for rented apartments (the owner must pay for the investment but the cost savings benefits the tenant and only limited potential exists to shift investment costs to the renter) will not be affected by increasing energy prices. For electric appliances such structural barriers do not exist; the problem here is mostly the lack of transparency. Renewable energies for heating are more attractive if there is a competitive market for renewable energies. If the degree of competition is too low the prices for renewable energies will follow the price trends for fossil fuels.

■ For the transport sector the investment in more efficient vehicles will be attracted but only to the extent that the retail prices increase (see above). However, the demand for low fuel-consuming trucks will increase in the very cost-sensitive freight transport sector. Another effect of high energy prices in the transport sector is a shift between transport modes (from road to railways, from individual to public transport).

■ For the power sector high energy prices will change the economics in favor of coal-based power generation. Even the competitive situation of natural gas-fired cogeneration could be worse if gas prices rise. The economics of renewable energies will improve, but in the context of the German support scheme (guaranteed prices for feed-in of electricity from new renewable power generation) this will have an impact on the costs of the support scheme but not on the expansion of renewable energies.

The third dimension regarding the effects of rising energy prices on emission reduction potentials is awareness raising and behavioral changes. The analysis of the energy market trends and the consumption and investment patterns show clearly that high price levels have changed attitudes toward energy efficiency investments on the one hand and behavioral changes. If lowering the indoor temperature by 2°C leads to a decrease in fuel-use (and costs) of about 10 percent this is clearly an option for many energy consumers. The share of high-efficiency appliances was at least higher in commercial advertisements. Future analysis will show if this has also led to significant changes in purchasing patterns. For one sector the changing purchasing patterns can already be clearly seen: downsizing within new car purchases is significant.

As a result, the reduction of greenhouse gas emissions in the residential, commercial, and transport sectors, and to some extent in the industrial sectors, will be cheaper at significantly higher energy prices in general. However, the different dynamics of retail price increases as well as the structural barriers to the implementation of abatements measures will not eliminate the need for ambitious policies. Still, the amount of public money to be involved in the policies and measures could decrease when the energy prices remain at high levels.

The analysis for the power sector as the largest source for greenhouse gas emissions shows a different result. Fuel shifting from high CO_2-intensive fuels (lignite, hard coal) to natural gas and even the expansion of cogeneration will be much more expensive if energy prices are high. Very high CO_2 prices from the EU ETS will be needed to compensate the change in relative prices between low and high CO_2-intensive fuels. Nevertheless, the competitive position of renewable energies will profit from higher energy and CO_2 prices. Figure 5 indicates the price trends for hard-coal, CO_2 allowances, and electricity compared to the levels of guaranteed prices within the German support scheme for power generation from renewable energies. A comparison of the electricity price trend with the hypothetical level of marginal costs of an older hard coal-fired plant clearly shows that hard coal-based power generation sets the wholesale market price in the German power market. The increase of hard coal and CO_2 allowance prices drove the electricity prices to levels where some options of power generation from renewables are going to be competitive (landfill gas, biomass, onshore wind). However, in the context of the guaranteed price scheme for renewable energies the increase of fossil fuel prices will lead to a lower need for (indirect) subsidies within the guaranteed prices rather than an increased power generation from renewables.

The significant increase will not only have effects for the competitive position of lignite, hard coal, or gas-fired power generation or electricity production from renewable energies. High energy prices will also change the economics of emerging technologies like CO_2 capture and storage (CCS), which is assumed to be available on a commercial basis after 2020. The main share of abatement costs of CCS is the energy penalty from reduced net efficiency of the plants because of the energy demand for the capture process. If hard coal prices follow the dynamics of the global oil market as it was observed for the last thirty years, the economic value of the energy penalty and, as such, the abatement costs will be higher if oil and hard coal prices increase significantly. The phase-in of CCS for hard coal-based power generation will be challenged by such price trends; for lignite-based electricity production the situation is much less complicated in this regard.

All in all, high energy prices will have some positive effects for greenhouse gas emission mitigation strategies in the residential, commercial, and transport sectors as well as some industrial sectors. High energy prices will create a much more complicated situation in the power sector which is the largest single emission source of greenhouse gas emissions in Germany. As a result, some policies for emission reduction will require less public money or other transfers. Paradoxically, in the context of the structural barriers for the building sector and the changing economics in cost-sensitive and heavily coal-based sectors like power generation, the level of necessary efforts for climate policies will not decrease in case of high energy prices. Even a higher intensity of political intervention will be necessary for sectors like the energy industries.

THE CRUCIAL ROLE OF INFRASTRUCTURES

Many of the fundamental changes in the energy system on the track to a low-carbon economy have significant implications for the infrastructure, its adjustment, roll-out, and regulation:

- Many low-carbon options of energy supply will lead to a decentralization of production. Cogeneration plants must be built close to heat sinks; some renewable energies are only available locally.

- The inclusion of the demand side as a more active part of the energy system will require smart grids which allow interactions between energy supply and energy demand. Load management, grid control, and optimization will no longer be only an issue at the level of the transmission grid.

- The increasing share of intermitting power generation (renewable energies) and must-run electricity production (cogeneration) will require much more efforts on load and grid management and optimization.

- Some options of sustainable energy supply will need a strong relocation of production sites. Onshore and especially offshore wind power generation, power plants with CCS, etc., will lead to a significant different geography of power supply (in Germany this is the "northern drift" to production sites at the Baltic and the North Sea, where the wind energy potentials are large, the coal and gas deliveries are cheap, and the distances to future CO_2 storage sites are short). Unfortunately this relocation of production does not go along with the main locations of energy consumptions.

- For some decentralized options of sustainable energy (e.g., biomass gasification) it could be more efficient to feed-in bio-methane into the grid and use it at different locations and in more efficient plants and/or at sites where heat sinks allow cogeneration at a larger scale.

■ If CCS shall play a significant role in the future energy system, an infrastructure for transport and storage must be created which is available on a non-discriminatory basis.

The implication of this new geography of the energy systems is that infrastructures play a much greater role. Electric networks must be designed differently and much more intelligently in order to integrate decentralized and centralized power generation as well as power supply and consumption. Heat networks will be crucial in order to exploit the potential of cogeneration and biomass for heating. Gas networks must be able to manage decentral feed-in of bio-methane.

Although these issues are to some extent medium- and long-term topics in terms of technology, infrastructure is a short-term issue regarding the necessary investment and regulatory decision. If the lead time for many infrastructure expansions and adjustments is fifteen years (as is often the case in Germany), significant decisions have to be made rather quickly. However, many decisions about infrastructures face a wide range of uncertainties. Large-scale infrastructure decisions (offshore wind, CCS) must be made under significant uncertainty. This raises the question of what role public policy must play in these long-term adjustments of infrastructures; the regulation of infrastructures is a major issue. Together with the emerging internal energy market in the EU, a regulatory framework for the infrastructure was developed which addresses primarily non-discriminatory access to infrastructures and especially to push down the user cost of infrastructure. The latter target of network regulation must not necessarily be consistent to the long-term needs of infrastructure. The integration of energy (network) regulation and climate policies is certainly one of the biggest near- and medium-term challenges of policy integration in the EU which is indispensible for an effective climate policy.

Section 4: Most Significant Greenhouse Gas Emission Reduction Measures and Their Costs

The in-depth analysis of greenhouse gas emission reduction potentials and, more importantly, the respective policies and measures show four main findings:

■ In the context of German demographic and economic development, ambitious emission reduction targets can be met, even in the case of a phase-out of nuclear power by 2025. A decrease of emissions of about 30 percent from 2005 to 2020 and approximately 40 percent from 2005 to 2030 is possible from the perspective of potentials and implementation policies. However, additional policies and measures will be necessary for this; the implemented policies and measures will only deliver emission reductions of about 10 percent in 2020 and 20 percent in 2030 compared to 2005 emission levels. The latest German energy and climate policy package (*Integriertes Energie- und Klimaprogramm*, IEKP) addresses a major share of these additional policies and measures.

■ The aggregate analysis underlines that increasing the share of renewable energies is of very special importance to ambitious climate policies. Nevertheless, a major improvement of the energy productivity—as well as the ambitious decarbonization of the remaining fossil fuel use—are strategic approaches which are of comparable relevance in the framework of a 30-40 percent greenhouse gas emission reduction strategy.

■ Most of the necessary technologies for these emission trajectories are already available and matured. This is a matter of fact for most of the efficiency technologies (insulation, modern heating equipments and electric appliances, etc), a wide range of technologies for the use of renewable energies (wind power, biomass, solar collectors, etc.) as well as modern and low-CO_2 power generation technologies (combined-cycle power plants, centralized and distributed cogeneration). Further support will improve these technologies but must primarily address cost reductions for these technologies. For a smaller range of technologies (CCS, photovoltaics, new engines and vehicle concepts, second generation biofuels, drilling technologies for geothermal energy, etc.) major technological and cost improvements must still be achieved. However, these emerging technologies will play a more significant role beyond 2020.

■ For many technologies major adjustments of infrastructures will be necessary (roll-out of additional transmission capacities for electric power, smart grids to integrate distributed power generation and demand side management, CO_2 infrastructure for CCS). The long lead time for this infrastructure development must increasingly be seen as a major potential bottleneck for ambitious climate policies.

■ The key policies and measures are available at an advanced stage or are already in place. The key challenge in Europe is to design a comprehensive and harmonized set of policies and measures which fits into the political and legal framework of the EU as well as the member states.

With regard to the existing policies and measures the greatest contributions to the emissions reduction up to 2030 are made by the following:

■ increased use of electricity production from renewable energies (62 mln t CO_2 e);

■ introduction of the mandatory biofuels blending for motor fuels in Germany (*Beimischungspflicht*; 18 mln t CO_2 e);

■ various measures to limit the HFC, PFC, and SF6 emissions (16 mln t CO_2 e)

■ electricity savings by means of various measures (14 mln t CO_2 e);

■ introduction of the EU emissions trading system (10 mln r CO_2 e);

■ various measures in the waste sector (10 mln t CO_2 e);

■ abolition of the natural gas tax for electricity generation (9 mln t CO_2 e);

■ support programs for increasing energy efficiency in the buildings sector (around 7 mln t CO_2e);

■ reduction of the fleet consumption of passenger cars within the scope of the self-commitment of the European Automobile Manufacturers' Association (ACEA) (7 Mt CO_2e);

■ the German Energy Saving Ordinance (6 Mt CO_2e); and

■ the market incentive program for biomass and solar energy (5 Mt CO_2e).

In addition to the effects of these policies and measures, an extended set of policies could achieve much more ambitious emission reductions. The greatest additional contributions to the emissions reduction up to 2030 are due to the following measures:

■ An increased use of electricity production from renewable energies could deliver an additional emission reduction of 50 mln CO_2e. The key instrument for this would be a revision of the actual support scheme for power generation from renewables. This revision is part of the recent climate and energy policy package (IEKP). The cost for this measure is estimated to be in the range of €27-44 per ton of CO_2 abated (€/t CO_2).

■ The revision of the EU ETS could deliver from 40 to 50 mln t CO_2 for Germany at allowance prices of between €30 and €45 in 2030. The respective revision is estimated to be approved in December 2008. However, the emission abatement mentioned above will only by achieved in the framework of the multilateral emission reduction target of the EU (30 percent compared to 1990 levels), which will apply if an appropriate international agreement is approved. The inclusion of industrial processes with large N_2O emissions can deliver significant emission reductions (about 10 mln t CO_2e and more) for abatement costs of less than €1/t CO_2e.

■ Increased efforts to achieve electricity savings (including substitution of electric heating) could deliver 20 mln t CO_2 at (negative) costs of -€80 to -€195/t CO_2. The mandatory performance standards for key electric appliances are recently under negotiation within the EU, the substitution of electric heating is part of the German IEKP. However, a adjustment of these measures on a regular basis will be probably necessary.

■ An expansion of the support scheme for CHP which leads to a 25 percent share in total power generation could achieve an additional 20 mln t CO_2. The abatement costs for this measure are about €6/t CO_2. A revision of the German CHP support scheme is part of IEKP and will come into force in 2009. An adjustment of these regulations will be probably needed after 2010 to reach the target mentioned above.

■ The introduction of kerosene taxation could mitigate about 20mln t CO_2. This measure is not on the agenda at the moment either at the EU or on the national level.

■ The implementation of ambitious standards for the CO_2 emissions of passenger cars could achieve abatements of 16 mln t CO_2. The first stage of standards for 2012/2015 has recently been under negotiation. A next step will be necessary for 2015 and beyond. The (negative) abatement costs for higher efficiency standards are estimated at -€100/t CO_2.

■ The increase of mandatory blending of biofuels could deliver 14 mln t CO_2 by 2030. Estimates for the specific abatement costs range from €100 to €200/t CO_2. The respective measures are under strong discussion at the moment.

■ A range of standards and incentive programs to improve the insulation of old buildings and to increased use of modern heating systems could achieve an emission reduction of about 20 mln t CO_2 by 2030. The abatement costs for such measures are estimated at €47/t CO_2.

■ The mandatory use of renewable energies in buildings could achieve an emission reduction of 11 Mt CO_2 at specific costs of €67/t CO_2. The respective obligation (for new buildings) is part of the recent German energy and climate package IEKP.

■ The extension of the toll for trucks to both motorways and other roads of the highway system as well as to trucks with a maximum permitted vehicle weight of 3.5 tons or more could deliver an additional emission reduction of 10 Mt CO_2 in 2030. This measure is partially implemented with the recent energy and climate package IEKP; the abatement costs are estimated at the level of €71/t CO_2.

In view of the additional measures mentioned above, it should be pointed out that they are essentially aimed at a comparatively durable capital stock (buildings and power plants).

The sectoral analyses have demonstrated very clearly that clear perspectives and definite statements on the future incentive signals and framework conditions are attributed particular importance with regard to the necessary investments in these sectors (long-term support programs for the buildings sector, stable general conditions for renewable energies, full consideration of CO_2 costs during decisions regarding new entrants within the scope of emissions trading, etc.). However, should such clarity not—or not soon—be established (or only be provided with regard to incentive signals that are counterproductive in terms of climate protection policy), the emissions path described above shall remain illusory.

Section 5: Conclusions

A sufficient climate policy which shall effectively contribute to avoiding dangerous climate change must address deep cuts of greenhouse gas emissions compared to the business as usual trends as well as to historic emission levels. Recent modeling shows that a more or less complete decarbonization of the economies in industrialized countries will be necessary to limit the increase of the global mean temperature to levels below 2°C compared to the pre-industrial situation.

Germany and the EU have set interim goals for emission reductions by 2020 (20 or 30 percent for the EU and 40 percent for Germany, compared with 1990 emission levels) which are not yet sufficiently in line with these long-term challenges but are a first step to increase significantly the level of ambition.

The detailed analysis of technologies and the related policies and measures leads to the following key lessons:

■ The amount and the size of quick fixes for greenhouse gas emission reductions are rather limited. Behavioral changes for space heating and in the transport sector (in case of high prices) and operational adjustments in the power sector and some energy-intensive industries after the phase-in of a CO_2 price delivered by the EU ETS can contribute only a small portion of the necessary emission reductions.

■ Three sectors are crucial for ambitious climate policies. The building sector is characterized by an extremely long-living capital stock. Emission reductions from the existing buildings stock take a long time and delayed measures are highly problematic because only small windows exist for the necessary and sufficient renovation measures. The standards for new buildings will have no significant impact on the emission levels in the next two or three decades but will determine the long term emission levels. The power sector is the biggest source of greenhouse gas emissions and is also characterized by an extremely long-living capital stock. As a result, measures in the power sector, including efficiency measures at the demand side, must reflect the long-term perspective. The substitution of coal-fired power generation is a key strategy of climate policy, as long as CCS is not available. Fast and comprehensive innovation strategies (renewable energies, CCS, roll-out and adjustment of infrastructures) are indispensible for the power sector. The transport sector is characterized by a less long-living capital stock on the one hand but by extremely complex demand structures, growth patterns, and individual preferences on the other hand. A significant shift between transport modes will be necessary and a diversification of engine technologies and fuels seems to be unavoidable.

■ The cost of those greenhouse gas mitigation options which can be implemented by additional policies and measures are in the low- and medium-cost range. Many options for energy efficiency are available at negative costs but face significant structural barriers (ranging from the user-investor-dilemma to asymmetric information). Early implementation of some higher-cost options can achieve significant cost reduction over a short time period (as demonstrated by the phase-in of wind energy in Germany).

■ For a wide range of emissions reduction potentials the technologies and also the policies and measures to implement these options are available and matured. For all measures which could contribute to ambitious emission reductions by 2020 the technology is commercially available and the practical implementation experiences exist for the respective policy tools. For the time beyond 2020 a series of emerging technologies (CCS, photovoltaics, new engines and vehicle concepts, second generation biofuels, drilling technologies for geothermal energy, etc.) is in the pipeline. The innovation process regarding these technologies can and must be accelerated. The emerging options will not require a new type of political instruments. The only significant new challenge for political strategies is dealing with the infrastructural aspects of these new technologies (roll-out and major adjustment of existing infrastructures, smart grids, CO_2/CCS infrastructure) within the framework of liberalized energy markets with an increasingly strong network regulation. Major adjustment of infrastructures for electricity, gas, and heat, as well as CO_2, under significant uncertainties and with long lead times will be a major challenge for the future regulation of infrastructures.

The implementation of comprehensive climate policy strategies which must also fit into other political strategies (energy security, competitiveness, etc.) will require comprehensive political approaches. There is not a unique political measure which can comprehensively address the different technological, structural, and political dimensions of an ambitious climate policy. The creation of an intelligent, innovative and flexible policy mix with a long-term horizon is crucial. Having said that, it should be pointed out that carbon pricing (with emissions trading as the political measure of choice) and focused innovation policies are fundamental and indispensible parts of an effective policy mix.

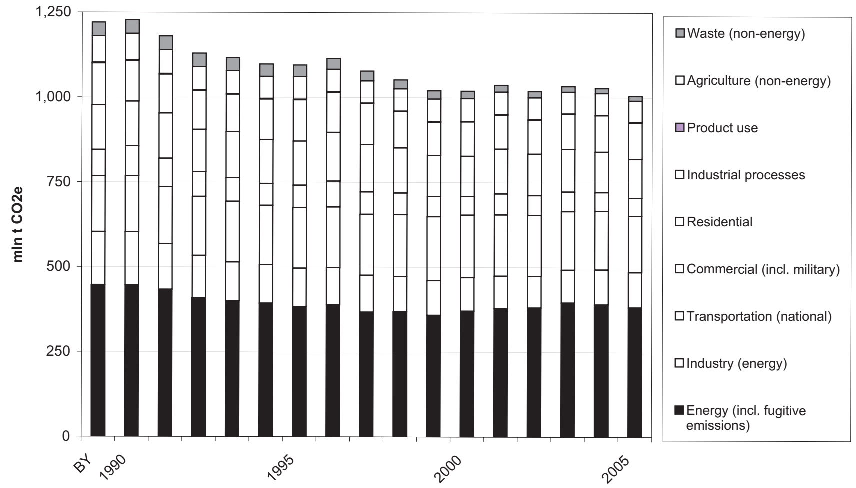

Figure 1: *Greenhouse gas emission trends in Germany, 1990 to 2005*

Source: German Federal Environmental Protection Agency, Matthes et al. (2008a)

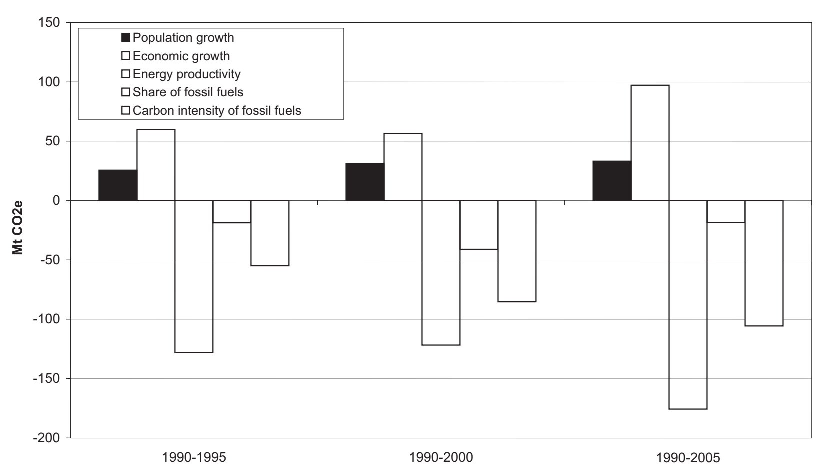

Figure 2: *Driving forces for greenhouse gas emissions from energy use in Germany, 1990 to 2005*

Source: Matthes et al. (2008a)

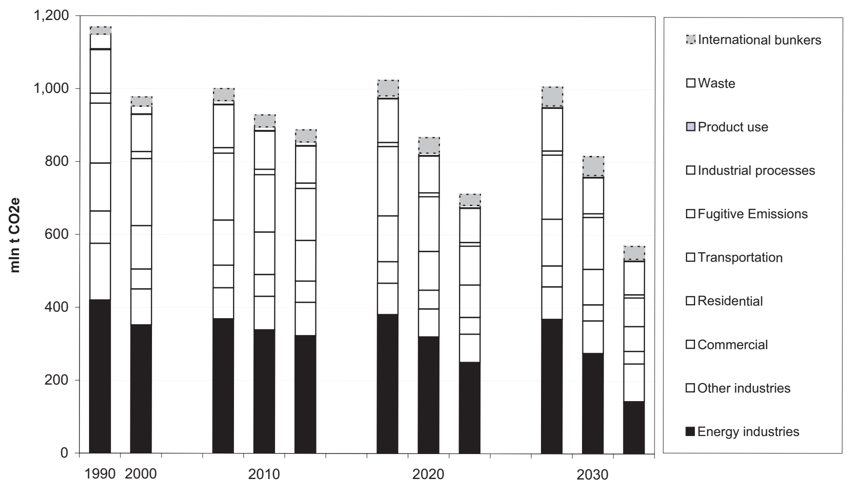

Figure 3: *Greenhouse gas emissions (w/o agriculture and land use (land use change) in different scenarios for Germany, 1990 to 2030*

Source: Matthes et al. (2008a)

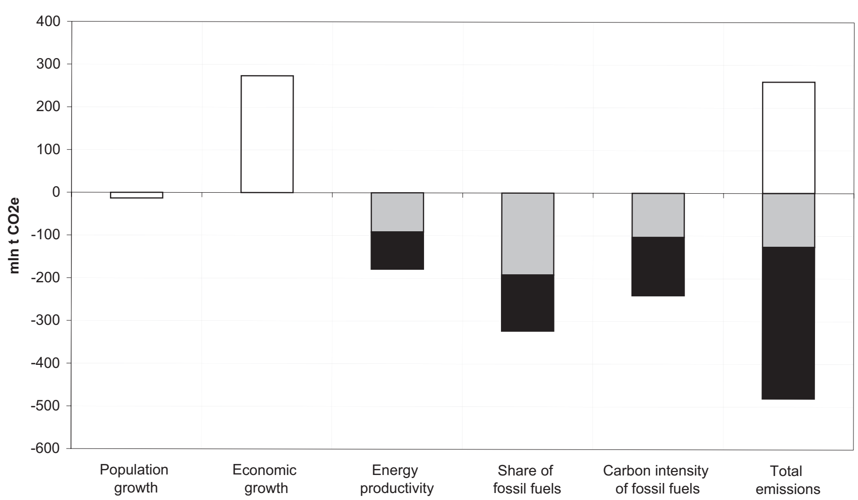

Figure 4: *Driving forces for greenhouse gas emissions from energy use in Germany, 2005 to 2020*

Source: Matthes et al. (2008a)

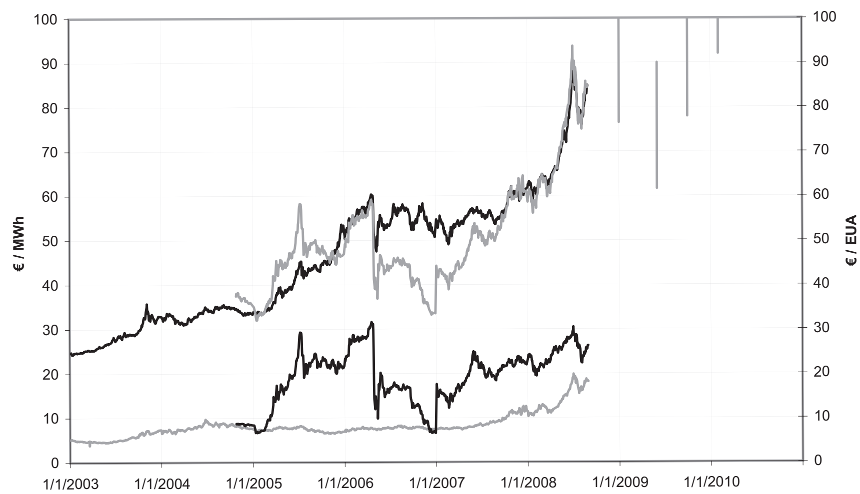

Figure 5: *Future prices for hard-coal, CO_2 emission allowances and electricity on the German wholesale market and guaranteed prices for electricity generation from renewables in the German support scheme*

Source: Öko-Institut

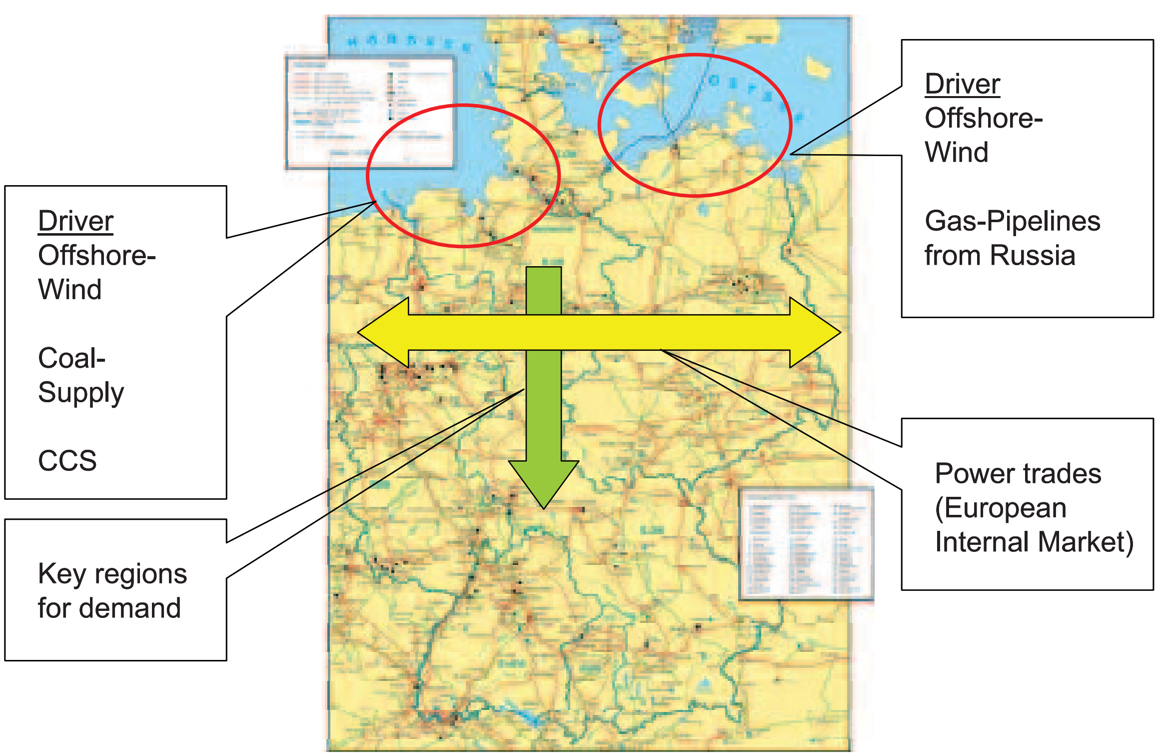

Figure 6: *Drivers of electricity network restructuring in Germany*

Source: Öko-Institut

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