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Options for Future Climate Policy: Transatlantic Perspectives

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Foreword

For many years, climate policy has been a source of tension between the United States and Europe. Nevertheless a transatlantic dialogue organized through the International Network To Advance Climate Talks (INTACT) has provided clear evidence that the differences dividing the United States and Europe are far smaller than commonly thought. Building on the results of a series of high-level workshops and informal policy roundtables, INTACT in early 2005 launched an intensive effort to uncover new approaches for US–European cooperation in addressing the critical issue of climate change.

To explore areas of mutual interest to the United States and Europe closely linked to climate policy (technology and standards, energy security, and emissions pathways), INTACT convened three working groups, each headed by a US and European co-chair. The members of these working groups include such outstanding experts in the fields of climate, energy, and foreign policy as Brian O'Neill of the International Institute for Applied Systems Analysis (IIASA) and Chris Mottershead of BP. They were tasked with writing research papers on issues such as the impact of US socio-economic trends on climate policy and the linkages between sound energy policy and responsible climate policy.

From the papers produced through their working groups, the co-chairs distilled three synthesis reports, presented at the beginning of each chapter in this volume. The goal of these reports is to provide decision-makers with concrete options for advancing transatlantic leadership in the field of climate policy. The synthesis reports were presented to policy-makers at workshops in the United States Senate in Washington and European Parliament in Brussels in June and July 2005.

We would like to thank the authors of the working group papers and synthesis reports for their exceptional dedication to making this endeavor a success. Our thanks also go to the Robert Bosch Stiftung and German Marshall Fund of the United States, whose generous financial support has made the publication of this volume possible.

Berlin, September 30, 2005
Friedemann Müller
Alex Riechel

Emissions Pathways

Emissions Pathways to Avoid Dangerous Climate Change: A Transatlantic View

Carlo Jaeger and Michael Oppenheimer***

Greenhouse gas emissions have increased steadily on a global basis since at least the beginning of the Industrial Revolution. Other things being equal, growth in emissions would have been expected to continue for hundreds of years. But Earth's climate is now being changed in ways that are scientifically distinguishable from natural variations and in some cases even discernible by the average person. This realization has led to attempts by the global community over the past 20 years to change the expected course of future emissions in order to avert dangerous levels of climate change.

The objective of this paper is to examine the feasibility of emissions pathways that would eventually stabilize atmospheric concentrations so as to avoid dangerous interference with the climate system. This stabilization goal is defined by the UN Framework Convention on Climate Change (UNFCCC), a piece of international law that has been ratified by most nations, including the US and the nations making up the EU. We discuss the specific options open to the US and the EU in working towards global emissions pathways to avoid dangerous climate change. On the basis of global assumptions about long term global concentration and temperature goals, therefore, we take a bilateral perspective: What are reasonable objectives for the US and the EU in view of this global problem? What factors enhance or limit the ability of each to reduce emissions? How may critical obstacles be surmounted? We do not discuss other global players—Japan, China, Brazil, etc.—because we want to focus on our own regions of origin. Hopefully, this will stimulate similar reflection in other parts of the world.

We assume as a guideline that a long term global goal of limiting warming to about 2°C (see Edmonds and Smith, 2005; Hare et al., 2004; O'Neill and Oppenheimer, 2002) will eventually be viewed as a plausible guideline for coordinating national policies, either informally or formally (e.g., through implementation of Article 2 of the UNFCCC). Note that various studies use two degrees above 1990, current or pre-industrial levels as a proposed long term target, objectives which differ by as much as 0.6°C. The implications for long-term emissions, however, are basically the same: in the long run, emissions must not exceed the centuries-scale capacity of the oceans to absorb greenhouse gases from the atmosphere, i.e., about

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2 gigatons (Gt) of carbon per year. This is less than one third of today's emissions of about 7 Gt. Roughly speaking, the challenge then is to reduce emissions from today's levels by about five sevenths, i.e., about 70 percent. The challenge is compounded by the fact that emissions are rising with a long-term trend of more than 1 percent per year. The question is: how many years will it take to achieve a turnaround of this trend, and how will emissions evolve after the turnaround?

To address this question, we draw on several background papers synthesizing the relevant literature as well as on a variety of research findings concerning specific issues to be discussed. We first discuss the global perspective, next European alternatives, then American opportunities, and end by drawing conclusions for the next steps.

I The global perspective

The debate about climate change has reached a point where it is not easy to get an overview in the face of all the technicalities under discussion. A useful starting point is given by figure 1, providing a synopsis of emissions scenarios for the 21st century as discussed in the literature. The fastest growth of emissions represented in the table corresponds to a growth rate of about 2 percent. At the lower end, decreasing emissions are discussed as well, up to the point where emissions turn negative. This is the case if human greenhouse gas production is counteracted by intentional increases in absorption capacity of the Earth system.

For the purposes of climate policy, it is useful to focus on a second magnitude, represented in figure 2: the additional carbon accumulated in the atmosphere since the beginning of industrialization. Before industrialization, the atmosphere of planet Earth contained about 550 Gt of carbon. These caused the natural greenhouse effect that helped maintain the Earth's climate in a range basically hospitable to human beings. Since the beginning of industrialization, increasing use of commercial energy—mainly based on fossil fuels—has led to a situation where the atmosphere contains about 200 Gt of additional carbon. To a lesser extent, other anthropogenic greenhouse gases as well as aerosols are modifying the climate system, too. As a result, the natural greenhouse effect is amplified by human actions in ways that engender risks of dangerous climate change.

Even if emissions were stabilized at their current levels, the amount of additional carbon would keep growing for centuries—all the more so if emissions keep growing, too. Over the past decades, the additional carbon has increased at a rate of about 2 percent. There is enough economically recoverable carbon in the Earth's crust for even higher growth, say of 2.5 percent, to continue way beyond the end of this century. In many regions, this would lead to global warming of more than 10°C, and global mean temperature might keep rising for centuries until coming close to 10°C as well (Hasselmann et al., 2003). Nobody is advocating such a development, but then nobody was advocating World Wars in the past century either.

Figure 1
Emissions scenarios discussed in the literature

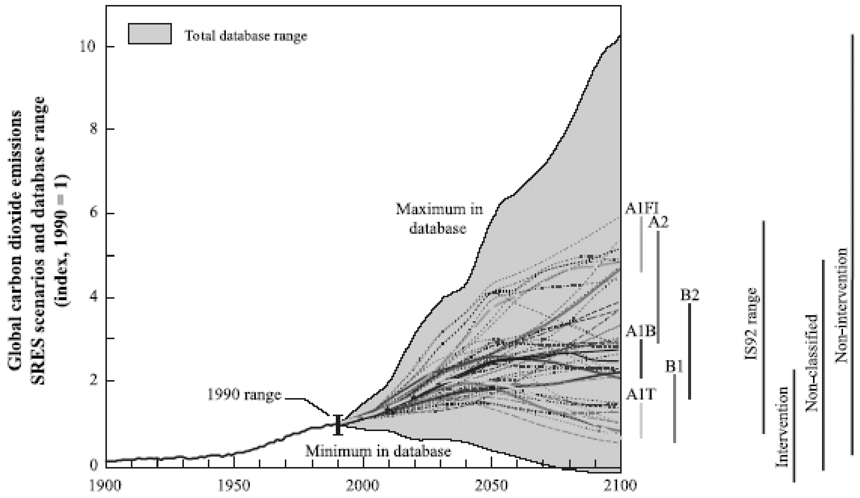
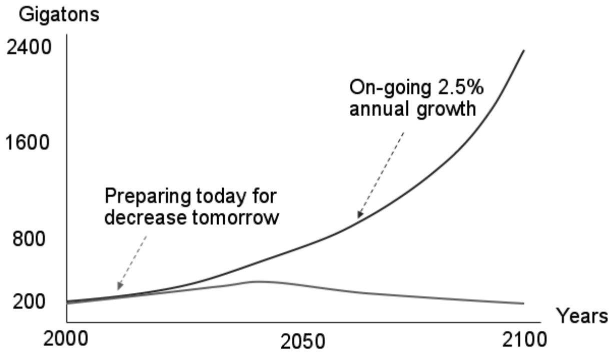


Figure 2
Upper and lower bounds for future amounts of additional carbon in the atmosphere



Source: own computations.

The lower end of plausible scenarios is given by a switch from the current increase to an actual decrease. Although some scenarios foresee such a decrease for reasons other than avoiding warming, intentional policy to reduce emissions will likely be necessary to about bring such a future while allowing for sustainable development.

A decrease of the additional carbon in the atmosphere can be achieved by combining reductions in emissions with enhancement of natural carbon absorption. The former involve consumption patterns with low content of commercial energy, highly efficient technologies for using such energy, and zero-emission technologies for generating it; the latter involve processes that take greenhouse gases out of the atmosphere. The most important such process is natural absorption by the oceans. Removal of carbon dioxide can be enhanced beyond this level and coupled to energy production in several ways, e.g., by producing commercial energy from biomass while capturing the resulting carbon dioxide, storing it in geological formations, and letting new biomass absorb additional carbon from the atmosphere. Moreover, there may be technological possibilities to capture atmospheric carbon by chemical processes. If a turnaround of global emissions is achieved in the coming decades, additional carbon may thereafter be reduced at a rate of up to 4 Gt per year. While the upper end of possible emission scenarios would lead to warming in excess of the 2° target within this century, the lower end would stabilize atmospheric concentrations at levels compatible with this target by the end of the century.

Uncertainty in climate sensitivity and in the importance of forcing by other trace constituents such as aerosol, has a very large effect on the chances of attaining the 2° target. Climate sensitivity—the increase in global mean temperature to be expected from a doubling of carbon dioxide in the atmosphere—may be as high as 4.5°C. In this case, it is virtually certain that global mean temperature will overshoot the 2° target for some time. It would then still be possible to reach the long-term target by limiting this overshooting to a period of several decades, although significant environmental consequences may result.

How can a turnaround in global emissions be achieved? To address this question, it is important to notice that commercial energy is used mainly for consumption purposes—like driving cars and regulating the temperature of dwellings. Of course, the given infrastructure along with prevailing lifestyles rather heavily constrain the options for individual choice, but at the same time they open up important options for public policy. Production of economic goods uses just about one third of total commercial energy, and this proportion is likely to decrease with the spread of the service economy. Moreover, international differences in energy use also deserve attention: while in the US commercial energy is used at a rate of about 12 KW per capita, the EU has a rate of about 6 KW, and the global average is just 2 KW. Just as the numbers of horses or typewriters per capita have ceased to be significant measures of social welfare, rates of commercial energy use may cease to be such measures in the current century.

In the long run, changes in infrastructure—like better insulation of houses, distribution networks for alternative car fuels, amenities in the midst of densely populated megacities—along with changes in lifestyles—like new status symbols and an emerging emphasis on place-based social networks connected in cyberspace—have the potential to shift a large fraction of demand for commercial energy towards other goods and services. The remaining amount of commercial energy can then by produced by a mixture of renewable sources and fossil fuels so as to respect the 2° target.

The difficulty, however, lies in the short run, i.e., the next several decades. Over this period, global population is likely to increase to 9 billion people or more, and income per capita is likely to increase by 100 percent or more. All IPCC scenarios indicate that greenhouse gas emissions will grow at least for the next 50 years absent specific policies aimed at reining them in. Developing countries are under tremendous pressure to satisfy expectations of increasing welfare, and they need to do so with technologies available now at competitive costs with a sound record of reliability. Under these circumstances, a turnaround in global emissions can only be achieved if highly industrialized countries assume leadership. The European Union has claimed such leadership by its active role in getting the Kyoto Protocol ratified and in implementing a regional emissions trading system. Therefore, we next look at options for Europe.

II European alternatives

In this section, we give a first look at alternatives for Europe over the next 10–20 years in view of triggering a turnaround in global emissions pathways. In principle, the EU can drastically reduce carbon emissions by gradually restricting the amount of emissions sold under the EU Emissions Trading Scheme (EU-ETS) while enlarging the domain of validity of the EU-ETS to those sectors not yet under its rule (mainly use of commercial energy for private consumption).

Den Elzen and Meinshausen (2005) show how the 2° target can be reached if the EU reduces its emissions by at least 15 percent by 2020 and then by at least 75 percent by 2050; similar numbers are indicated by Azar 2005. They also show—again in line with Azar (2005)—that this is feasible without prohibitive costs if North America, Japan, Oceania, and the countries of the former Soviet Union join the effort. According to these assessments, the costs would be no larger than a delay of less than a year in economic growth—the level of production that might otherwise be reached in February would be reached in August, but without the risks and damages resulting from failure to reach the 2° target.

However such a joint effort can only start after a complex process of diplomacy, opinion formation, research and development, etc. Such a process will take several years, to say the least. Can Europe support it by committing itself to the mentioned emissions reductions unilaterally? This is unlikely to happen because it would imply Europe paying the transition costs to new technological solutions and the rest of the world free-riding on the benefits. Even if at a global scale the benefits should vastly outweigh the benefits—which they may well do—this is not an acceptable alternative for Europe.

A second alternative would be for Europe to simply retreat from its rhetoric and commitments regarding climate policy and to wait for the rest of the world to become more amenable to designing and implementing global agreements for effective emissions reduction. Given the robust level of environmental concern with the European public this is hardly politically feasible even under a rather Machiavellian approach. A third alternative is to keep the rhetoric but water down the commitments in practice. Experience shows that this may well be feasible, and it may be the outcome of the political process in the coming years.

None of these three alternatives offers a realistic prospect of achieving a turnaround in global emissions. What about nuclear energy? Europe has considerable know-how in the area and has invested huge resources in fusion research. For nuclear energy to play a significant role in a turnaround of global emissions, however, in a few decades the current number of a few hundred nuclear power plants would need to increase to about 7,000. For this to happen in, say, 50 years, one would need to build an average of more than 100 nuclear power plants per year. The likelihood of serious accidents would increase accordingly (particularly with no long-term waste management strategy at hand) and the prospect of terrorist interference would also be significant. Inevitably, the media would amplify such episodes in the public sphere worldwide. As for Europe, in most countries the willingness of the public to accept, let al.one support, such a course of action has been virtually non-existent for decades, and this is not likely to change in the years to come.

A realistic alternative then must accept the fact that Europe can only build on its current leadership role in climate policy by declaring modest, but significant goals and achieving them in a verifiable way. Important opportunities to move in this direction are given by public procurement policies. Public authorities are the single largest customers for a wide range of products, in particular when it comes to buildings and transport systems. A second kind of opportunities is provided by the competence pooled in European financial markets (Jaeger and Cameron, 2004). Insurance companies have started to recognize the importance of the new risks and opportunities associated with climate change and with the need to address it pro-actively. To the extent that institutional investors take these risks and opportunities into account in the management of their portfolios, financial markets will send important signals to the entrepreneurial community in Europe and abroad. Finally, the existence of persistent unemployment in Europe means that the European economy is not operating at its efficiency frontier. Under these conditions, a well-designed climate policy can actually be Pareto-improving—in this case: achieve environmental improvements and economic gains at once—by mobilizing underutilized resources.

If Europe develops its climate policy in a realistic and credible manner, the way may then open up for more ambitious goals. Such goals could include a global emissions trading scheme of the kind advocated by a Europe-centered coalition of global business leaders (World Economic Forum, 2005). Wicke (2004) has indicated outlines of such a scheme as it might develop out of the current EU-ETS. Any such development, however, will require many years to unfold.

The key difficulty seems to be the transatlantic divide. If Europe would give in to the climate strategy of the current American administration, it would loose its leadership on the issue without any realistic prospect of achieving the needed turnaround in global emissions. On the other hand, given America's role not only in emitting greenhouse gases, but also in defining technological trajectories in many energy-related fields, any attempt by Europe to solve the problem without America would be doomed to failure. Therefore, we next look at American options.

III American possibilities

In this section we explore the realm of emissions pathways assuming that climate-driven policies will indeed be implemented, for the US as well as other significant emitters. We emphasize not only what may be accomplished, but what is unique about the US versus other countries.

Getting started: The 20–50 year timeframe

One way to examine the question of initial objectives is to focus on a near term goal of maintaining global emissions near today's levels over the next 50 years (Pacala and Socolow, 2004). Although this emissions pathway is a caricature, it does simplify thinking about some of the basic elements of any approach designed to avoid a doubling of carbon dioxide (probably a necessary component of avoiding a 2 °C warming). The key question is what such a global emissions pathway implies for the US.

A primary issue is the US' "fair share" of the global obligation. In a background paper, Greenblatt (2005) examines this question from the perspective of per capita emissions, arguing that any long term program ought to envision a decrease in the large disparities in per capita emissions among countries, particularly industrial versus developing. In fact, it is unlikely that any global emissions cap approach would succeed absent some concession by industrial countries in this regard. We do not argue that an explicit global deal on long term per capita emissions goals will be achieved; rather, adoption of emissions obligations involving developing country must result in some narrowing of this gap, or they will never be implemented.

There is an infinite number of ways to create national emissions obligations from such a 50-year objective. One extreme would keep emissions more or less constant for all countries, in many cases thereby increasing current disparities in per capita emissions. Another approach envisions equalizing per capita emissions. Neither is a plausible outcome of any foreseeable international negotiation. Greenblatt argues for a US obligation at the midpoint of these extremes. We adopt this case for illustrative purposes only.

Based on this allocation, US emissions would be restricted to about 1 GtC/yr in 2055, a 40 percent reduction from today's value. Thus, assuming a baseline scenario where CO_2 emissions rise to 3.5 GtC/yr by 2055, a reduction of 2.5 GtC/yr from the base case is needed. Again, the base case itself is subject to considerable uncertainty. The selected value is around the middle of plausible scenarios. In the following section, we discuss ways in which a no-policy base case might differ considerably from this, making emission reduction either much easier or much more difficult.

Greenblatt's down-scaling of the global analysis to the US suggests that in fact such a goal is achievable in a technical sense, and a background paper by Edmonds and Smith (2005) suggests that costs are manageable (for mid-range assumptions on uncertain factors like climate sensitivity). The options with the highest potential for success are increased motor vehicle efficiency, conversion of coal-electric base-load generation to more efficient capacity, substitution of natural gas or synthetic gas (such as hydrogen) for coal combined with various capture- and storage options, increased wind-power capacity and biological sequestration. Additional options with perhaps lesser potential (due to cost, technical, or political obstacles) include enhanced nuclear capacity, photovoltaic generation, and expanded dependence on biofuels. It is highly unlikely that changes of this scale will occur without implementation of explicit policies aimed at reducing emissions.

Longer timeframes (100–200 years) and large uncertainties

Attainment of such an objective is merely the first phase of achieving the US share of the long term goal of avoiding a 2°C warming. The subsequent 50 years must be characterized by a steady decrease in global emissions. Edmonds has viewed this problem from an alternative perspective: all scenarios incorporate an implicit technological improvement over the coming decades in the base case. How much additional technical change would be required to meet a stringent long-term goal such as 2°C? The difference between base case emissions resulting from the implicit improvement in technology and emissions needed to meet a particular long-term objective is called the technology gap.

Edmonds examines a similar set of technological changes necessary for stabilization of global mean temperature at 2°C (above pre-industrial levels) and makes two critical points. First, costs vary widely depending on assumptions made with regard to implicit improvements in technology embedded in the assumed base case, particularly during the second half of the century. An apparently small annual increment (about 0.25 percent) in end use efficiency, for example, can reduce required emissions reductions by over 10 GtC/yr by the end of the century by shrinking the technological gap that policy must close to meet the target. Second, uncertainty in climate sensitivity and in the importance of forcing by other trace constituents such as aerosol, has a very large effect on the cost of attaining such a climate goal. For example, if the climate sensitivity is 4.5°C, the possibility of reaching a 2°C target without overshooting may already be foreclosed. Given such large uncertainties in what may constitute "business-as-usual" technologies and in the climate system as well, policies that enhance rates of technological improvement have a high value.

However, considerable debate remains over the most effective approach. As Edmonds notes, "the history of technology development is nothing if not a lesson in forecaster humility. Technologies that were expected to develop have proved more difficult than expected, and technologies that were never envisioned have evolved to play a central role in the economy". This cautionary note certainly applies to US energy technology, which has a long history of large-scale "bad bets" by government. On the other hand, certain programs have certainly been effective at spurring new technologies and lower barriers to implementing existing ones. These include tax incentives for wind generation, R&D subsidies aimed at improving appliance and building efficiency, and, particularly notable in the climate context and on the largest scale, an emissions cap-and-trade system for sulfur dioxide and nitrogen oxide emissions. A combination of incentives for research combined with a sequence of emissions caps declining toward zero net emissions over this century (and completing any remaining part of this objective during the next) may be the approach most suited to the US economy.

Population and lifestyle: A case for US exceptionalism?

With or without climate policy, future emissions will depend on a variety of factors, including economic growth rates, population growth, technological development, and cultural and lifestyle factors. These are not independent variables. Rather, they are strongly linked, and many of these linkages are not even qualitatively understood. The above discussion is based on standard assumptions about population, lifestyle, and cultural factors. But the history of prognostication in these areas has been very poor, and with regard to down-scaling, there is a particular concern about arenas where trends are now anomalous. The US stands out in three ways as different from most other industrial countries, particularly Europe: its population is growing fast with a relatively young age structure, relatively high fertility rates, and high immigration (see background paper by O'Neill, 2005). Second, fuel use in the transportation sector is projected to continue to grow faster than population, reflecting particular settlement patterns and lifestyle choices. Third, the country has not yet established a political consensus articulated by national leadership, to address the climate issue.

Population distribution according to age, geographic location (e.g., coastal/inland, urban/rural) in addition to lifestyle choices and total growth rates are believed to exert a strong influence over greenhouse gas emissions. It is plausible that the US will continue to grow while the current population leaders, India and China, stabilize; the US may even surpass them. Without a substantial change in either technology or lifestyles, emissions would grow accordingly and implementation of effective policy to restrain emissions would be extremely difficult. Equally plausible over the coming 100–200 years is a slowdown of immigration (due in part to policy choices) and fertility that would simplify the task of restraining emissions. Given these uncertainties, a focus on incentives and mandates for technological progress and implementation of new or available technologies for transportation fuel efficiency may prove particularly effective at restraining emissions in the US context.

IV Next steps

It is worth noting that rapid, decade-scale shifts in lifestyle and fertility choices are not unusual, for both the US and other countries. A fast transition to a framework that facilitates emissions reduction may occur for a variety of reasons, some potentially linked to the "environmental culture" itself. The same may be said of political transitions. Small cultural and political changes on a variety of fronts can eventually cause a concatenation of change at the largest scale. While in the US the great environmental reform of the 1970s appeared to come out of nowhere, it arose in part from state level and local level initiatives to clean the air and water. With the development of statewide initiatives to regulate greenhouse gas emissions in California and among several Northeast states, and with the development of a sense of inevitability of regulation in some quarters of the business community, it is not overly optimistic to imagine that seeds are now being planted that will scale up to a comprehensive federal approach within 5–10 years. Gradual change can sometimes instigate quantum leaps in outcomes.

In climate policy, the next years will be a gestation period preparing for a turnaround in global emissions. While no global breakthroughs should be expected, they should be prepared. This requires conscious measures at four levels.

At the global level, it is essential to keep the machinery of international environmental diplomacy going, to build up competence and trust through a pattern of patient and continuous interactions. The UNFCCC has shown to be an extremely useful legal and institutional framework, as has the Kyoto Protocol. Neither of these two instruments can be expected to deliver the turnaround in global emissions that will be required a few decades from now, but both of them are essential to prepare that turnaround. Maintaining and gradually improving them is the main task at the global level.

At the regional level, a myriad of initiatives are possible and warranted. Public procurement policies can play a vital role in fostering the technological progress that will be needed for a global turnaround. This holds for single cities as for provinces and states.

At the level of the US and the EU, emission trading schemes and R&D measures seem especially promising. It is important to develop an array of experiences before trying to standardize such instruments worldwide. In this respect, the existence of the EU-ETS is an asset, not a drawback for global coordination.

Finally, interregional co-operation offers considerable opportunities in the coming years. The US and the EU have already started a joint effort on hydrogen technologies, similar efforts in other areas may be added in the years to come. There is also a need for co-operation between industrial and developing countries, say, between the US and Latin American countries, or between the EU and North Africa. Bilateral co-operation may well prove to be one of the most fruitful areas of progress in climate policy in the coming years.

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Post-Kyoto Climate Policy Targets: Costs and Competitiveness Implications

Christian Azar[*]

This paper starts with a review of climate policy targets (temperature, concentration, and emissions for individual regions as well as the world as a whole). A 20–40 percent reduction target for the EU is proposed for the period 2000–2020. It then looks at costs to meet such targets, and concludes that there is widespread agreement amongst macroeconomic studies that stringent carbon controls are compatible with a significant increase in global and regional economic welfare. The difference in growth rates is found to be less than 0.05 percent per year. Still concern remains about the distribution of costs. If abatement policies are introduced in one or a few regions without similar climate policies being introduced in the rest of the world, some energy-intensive industries may lose competitiveness, and production may be relocated to other countries. Policies to protect these industries have been proposed for that reason (in order to protect jobs, to avoid strong actors lobbying against the climate policies, and to avoid carbon leakage). The paper offers an overview of advantages and drawbacks of such protective policies.

I Introduction

The United Nations Framework Convention on Climate Change (UN, 1992) calls for a "stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." This ultimate objective of the climate convention forms the backbone of international climate politics. It calls upon us to act so as to make sure we do not cause unacceptable damage to humans, human societies, and ecosystems. Several key questions emerge:

- What level of climate change is dangerous? How does that translate into a concentration target for atmospheric greenhouse gases and ultimately emission targets in the near, medium, and long term?
- What are the costs of meeting those targets?
- How is the competitiveness of one region affected by policies that would deliver such emission reductions if other regions do not adopt similar climate policies? What policy measures are available to address these concerns, and how do they work?

This paper was initially prepared for an EFIEA workshop on EU strategies on post-2012 climate change policies with EU climate negotiators in Scheveningen, Holland on 30–31 August 2004, where I was asked to

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[*] Chalmers University of Technology, <frtca@fy.chalmers.se>. Originally published as Azar, C. (2005). 'Post-Kyoto climate policy targets: costs and competitiveness implications'. Climate Policy, 5(3), pp. 309–328. Reprinted with the kind permission of *Earthscan* <www.earthscan.co.uk>.

address these questions. Clearly, a detailed review of the literature on these broad and admittedly varying topics cannot possibly be offered in a single paper. Therefore I have attempted to offer a review of key points that have emerged in the literature, mixed with some personal viewpoints.

This paper starts off with a discussion of the concept of dangerous anthropogenic interference with the climate system and moves on to review and propose emission reduction targets required to meet a 2°C target (section II). The costs to meet these targets are assessed in section III, and it is concluded that the burden sharing of the costs rather than the total cost as such is most likely the most important obstacle to more ambitious climate policies. For that reason, section IV addresses the concerns about losses of competitiveness and ways to deal with it. Some conclusions are offered in a final chapter.

II Climate policy targets

A precise statement of what constitutes "dangerous anthropogenic interference" is not possible, since (a) the degree of harm from any level of climate change is subject to a variety of uncertainties, and (b) the extent to which any level of risk is "acceptable" or "dangerous" is a value judgment (Azar and Rodhe, 1997; Schneider et al., 2000). Science can provide estimates about expected climatic changes and associated ecological and societal impacts, but ultimately the question of what constitutes dangerous has to be settled in the political arena—given of course the best scientific assessments available about the likelihood of various potential outcomes.

Several authors have focused on thresholds in the climate system, beyond which large-scale, often irreversible, changes take place (see Rial et al., 2004, for an overview of non-linearities, feedbacks, and critical thresholds in the climate system, and Hulme, 2003, for a discussion about how human societies may cope with such changes). Examples of such threshold include a shut-down of the thermohaline circulation, a disintegration of the West Antarctic ice sheet, disintegration of Greenland ice sheet, widespread bleaching of coral reefs and disruption of other ecosystems (see Schneider and Lane, 2005, for a summary of temperature thresholds for each of these impacts).

The European Union (2005) as well as several scientists, e.g., Rijsberman and Swart (1990), the Scientific Advisory Council on Global Change to the Federal Government of Germany (WBGU, 1995; Graßl et al., 2003), Alcamo and Kreileman (1996), Azar and Rodhe (1997), and the International Climate Change Taskforce (ICCT, 2005) have argued in favor of an upper limit on the increase in the global annual average surface temperature set at or around 2°C above pre-industrial temperature levels.

Several other scientists have analyzed and proposed similar targets. O'Neill and Oppenheimer (2002) conclude that a 1°C target (above 1990 levels) may be required to prevent severe damage to coral reefs, a 2–3°C target to protect the West Antarctic Ice Sheet, and a 3°C target to protect the thermohaline circulation. Arnell et al. (2002) find that stabilization at 550 ppm CO_2 "appears to be necessary to avoid or significantly reduce most of the projected impacts in the unmitigated case" (in their 550 ppm CO_2 run, the global mean temperature roughly stabilizes at about 2°C above 1990 levels by year 2200).

Hare (2003) points out that certain ecosystems (in the Arctic or in alpine environments and in coral reefs) may be severely damaged also for global temperature increases below 2°C. Hansen (2005) argues in favor of a temperature increase at a maximum of 1°C above current temperatures, based largely on concerns about the risk of rapid disintegration of the Greenland and West Antarctic ice sheets. Oppenheimer and Alley (2004, 2005) offer insightful assessment of the role of the possible melting of ice sheets in determining dangerous anthropogenic interference.

Mastrandrea and Schneider (2004) and Wigley (2004) have developed subjective probability density functions for the temperature level at which dangerous anthropogenic interference takes place, based on the so-called burning embers diagram of the IPCC (2001b, chapter 19). Their median estimates lie at 2.8°C and 3°C, respectively.

Clearly, one should be careful to interpret thresholds as very sharp tipping points beyond which damages suddenly become dangerous or unacceptable for humanity as a whole. Carlo Jaeger, cited at RealClimate.org, has argued that setting such a limit is nevertheless sensible, since it is a way to collectively deal with risks. He has made the analogy with setting speed limits: when we set a speed limit at 90 km/h, no "critical threshold" exists there—nothing terrible happens if you go to 95 or 100 km/h. But at some speed, risks (the number of accidents and the impacts) would exceed acceptable levels.

Finally, this discussion should not be understood as a call for governments to initiate formal negotiations on long-term temperature targets that should be adhered to over the next hundred years. Such negotiations are likely to end up in a nightmare of complexities and problems. Perhaps even more importantly, uncertainty about the climate system, impacts, costs, baseline emissions, etc. suggest that adhering to one target over such a long time period would not be very wise. Rather, the purpose of endorsing a target, or merely thinking about a target, is that it gives guidance as to what may be required during the next couple of decades in order to make sure that we do not act now in such a way as to get locked into a future with unacceptable climate damages.

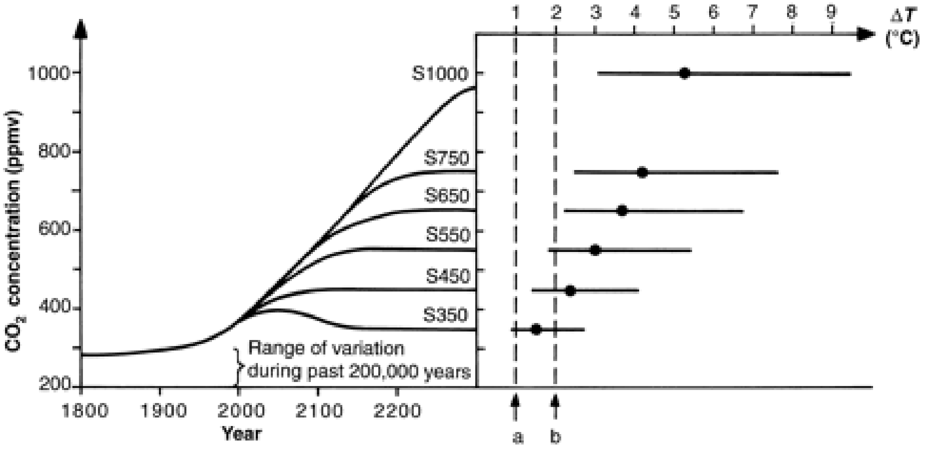
Temperature and concentration

Here I will pursue the view that a global annual average surface temperature increase of more than 2°C above pre-industrial levels should be avoided (in line with ambitions expressed by the European Union) and estimate the required concentration and emission targets.

In figure 1, the relation between atmospheric concentrations and the global *equilibrium* average annual surface temperature change is shown (see

Azar and Rodhe, 1997). In the graph, the climate sensitivity (the equilibrium temperature change for a doubling of pre-industrial CO_2 concentrations) is assumed to be 1.5–4.5°C per CO_2-equivalent doubling (IPCC, 2001a, Kerr, 2004). Further, a net contribution to the radiative forcing from other greenhouse gases and aerosols of 1 W/m^2 is assumed.[1]

Figure 1
Global average surface equilibrium temperature change for various stabilization targets



Source: Azar and Rodhe (1997). Dashed line *a)* refers to an estimate of the maximum natural variability of the global annual average surface temperature over the past millennium, and dashed line *b*) shows the 2°C temperature target. (Reprinted with permission from Science Magazine)

It can be seen from figure 1 that a CO_2 concentration of 550 ppm is expected to lead to a temperature increase in the range 1.9–5.5°C. For 350 and 450 ppm CO_2, the expected equilibrium temperature is 0.9–2.6°C and 1.4–4.5°C, respectively. Thus, in order to be relatively certain that a 2°C target is actually met, CO_2 concentrations would have to remain below 400 ppm.

There is a growing literature aiming at developing probability density functions for the climate sensitivity (Wigley and Raper, 2001; Andronova and Schlesinger, 2001; Forest et al., 2001; Gregory et al., 2002; Stainforth et al., 2005). These studies support the IPCC range in general but have tails below 1.5°C and higher than 4.5°C, in some cases much higher.[2]

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[1] Clearly, there is uncertainty about the long-run contribution from these gases, but our assumption can be compared to the median value for the total value of the contribution from all non-CO_2 gases (including aerosols) in the SRES scenarios, which as estimated by Wigley (2004) is 1.5 W/m^2 (the 90 percent confidence interval is ±1 W/m^2). The SRES scenarios are base case scenarios without any policy driven reductions in the emissions of greenhouse gases (in order to mitigate climate change). With mitigation, it is reasonable to assume that it is possible to get down to 1 W/m^2.

[2] The study by Stainford et al. (2005) reports a range of 2–11°C per CO_2 equivalent doubling, but there are rather compelling reasons to be cautious when interpreting the higher range. For instance, evidence related to changes in greenhouse gases during the

Taking these distributions into account would make it possible to estimate probabilities for the level below which the concentration of CO_2 has to stay in order to avoid any given temperature increase. Such studies have been performed by Baer (2004) and Meinshausen (2005), who both conclude that 400 ppm CO_2 equivalent (corresponding approximately to 360 ppm CO_2 only) is probably required if we are to be relatively certain to avoid a temperature increase of 2°C.

Global emission trajectories towards 2°C target

In figure 2 (p. 26), emission trajectories towards 350, 450, and 550 ppm are shown. All these concentration targets are potentially compatible with a 2°C temperature target but with very low probabilities for the 550 ppm case (as illustrated in figure 1). It can be seen that the implications for the global energy system over the next fifty years differ radically depending on the climate sensitivity. If the climate sensitivity is so low that the 550 ppm CO_2 case is compatible with the 2°C target, then global carbon emissions may increase by 20 percent until the year 2050. On the other hand, if the climate sensitivity is so high that the 350 ppm concentration target is required, then emissions need to be reduced by 75 percent over the next 50 years. The importance of the climate sensitivity for the required emission trajectory towards a 2°C target has also been highlighted by Caldeira et al. (2003).

A key question is what this uncertainty about the climate sensitivity and the ultimate temperature target implies for the near-term emission reduction requirements. This question received widespread attention with the publication by Wigley et al. (1996), who argued that delaying emission reductions compared to the IPCC stabilization scenarios (IPCC, 1994), would not only be possible but also more cost-efficient.

But the challenge now, as IPCC (1996a) writes, "is not to find the best policy today for the next hundred years, but to select a prudent strategy and to adjust it over time in the light of new information." If we follow an emission trajectory towards, say, 550 ppm and later on find out that a 400 ppm target is required, the long lifetime of carbon in the atmosphere as well as the inertia of energy capital and the political system may make it impossible to meet this lower target (see Ha-Duong et al., 1997, Schneider and Azar, 2001). Azar and Rodhe (1997) conclude that "until it has been proven that a temperature increase above 2°C is safe or that the climate sensitivity is lower than the central estimate, the projections shown in figure 1 suggest that the global community should initiate policies that make stabilization in the range 350 to 400 ppmv possible."

It is in this context interesting to reflect on the policy implications of a recent paper by Wigley (2004). He assumes a probability density functions for the temperature target, with a mean at 3°C, and combines that with a

last glacial era and the estimated temperature change suggests that it is unlikely that the climate sensitivity can be so high.

probability density functions for the climate sensitivity (Wigley and Raper, 2001). Given his mean target of 3°C, he finds that there is a 50 percent probability that the concentration of CO_2 needs to be stabilized below 536 ppm. But he also finds that there is a 23 percent probability that the concentration of CO_2 needs to be stabilized below 400 ppm CO_2. Thus also analyses with medium targets of 3°C and 536 ppm CO_2, could well justify decisions to act now so as to keep 400 ppm CO_2 within reach.

The exact reduction target in the near-term that these considerations imply depends on whether one allows for a temporary overshoot of the concentration or the temperature target. For instance, if negative carbon emissions can be obtained (through the use of air capture or biomass with carbon capture and storage, see Lackner, 2003, Obersteiner et al., 2001), then a 350 ppm concentration target by the year 2100 could be met even if atmospheric concentrations exceed 400 ppm by the middle of the century (see e.g., Azar et al., 2005). An overshoot of the temperature target might lead to irreversible changes in the climate system or in ecosystems, which means that the pathway to the target is of importance. Allowing for such temporary overshoots might thus come in conflict with the recognition in the UNFCCC that it is not only the absolute level of climatic change but also the rates of change that matter. Another factor determining how much needs to be done in the near term is the inertia in the energy system and the political system. If the maximum rate with which emissions may be reduced is assessed to be low, then relatively more ambitious policies need to be introduced in the near term (see Meinshausen, 2005, for illustrations of what delayed abatement implies for subsequent required rates of change).

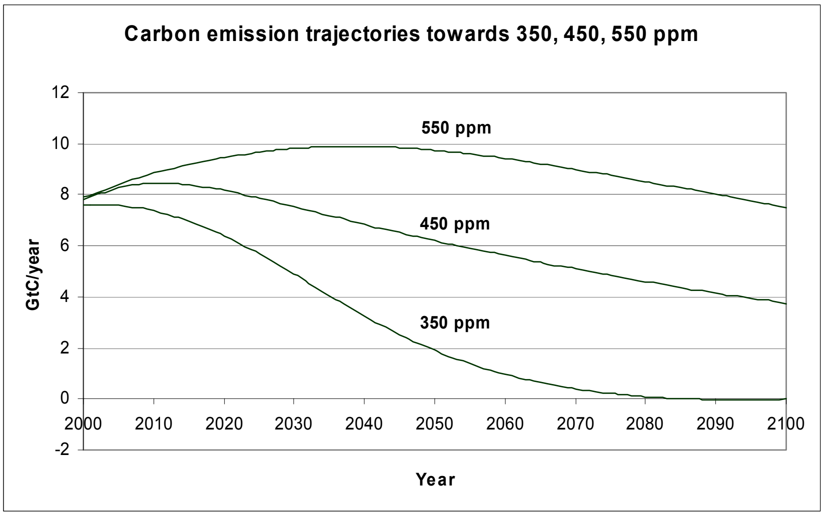
Regional emission targets

Breaking down global emission pathways into reduction targets for individual countries or regions is probably one of the more contentious challenges for climate negotiators. It should be clear that there is no single correct answer to the question of how much the EU needs to reduce the emissions in order to meet a, say, 450 ppm concentration target. The reason for this is not only that there are some degrees of freedom as to when the reductions should take place, as discussed above, but also–and perhaps more importantly–that there are several different methods that can be used to share the burden of emission reductions between countries and regions, e.g., equal per capita, contraction and convergence (Meyer, 2000), multistage, intensity targets, global triptych and multi-sector convergence (see e.g., den Elzen, 2002, Graßl et al., 2003, and Höhne, 2005).

Due to space limitation, it is not possible to review these results in detail. Instead, I will offer an illustration of the implications of one approach–contraction and convergence–by the year 2050 with a focus on CO_2 for three different concentration targets (350 ppm, 450 ppm, and 550 ppm). Results where other approaches are taken and when all the Kyoto gases are considered are discussed further down in the text.

Figure 2

Emission pathways towards 350, 450, and 550 ppm developed as the average of IPCC S350-S550 scenarios (IPCC, 1994) and Wigley et al. (1996). Each pathway may be compatible with a 2°C temperature target, but this would require a climate sensitivity of around 1.5°C/CO_2-equivalent doubling for the 550 ppm CO_2 target.



In figure 3, per capita emissions in the European Union and China over the next 50 years are shown that would be compatible with a global effort to meet these three targets. The emission pathways are developed in the following way: it is assumed that all countries receive emissions allowances for the year 2000 that represent their current emissions. For the year 2050, allowances are allocated globally on a per capita basis. For the years in between, a linear weighting scheme is assumed.[3] In addition, I have assumed that the contribution from deforestation and land-use changes drop linearly from 1.5 GtC per year at present to zero by the year 2050. The global population reaches 9.1 billion by the year 2050 (UN, 2004).

For the year 2050, the required reduction in EU lies in the range 50 percent (for a 550 ppm target) to 90 percent (350 ppm). It is worthwhile to note that there is such a sharp reduction requirement for the 550 ppm target despite the fact that global carbon emission trajectory leading to 550 ppm actually increases by 20 percent (see figure 2). The reason for this is that the contraction and convergence approach requires that emission allowances should be allocated on a per capita basis.

For the year 2020, the per capita reduction targets for the EU should be in the range of minus 20–40 percent compared to the year 2000 (for the 350 and 450 ppm targets, respectively). I am deliberately rounding numbers in order to avoid creating the impression that one can be very

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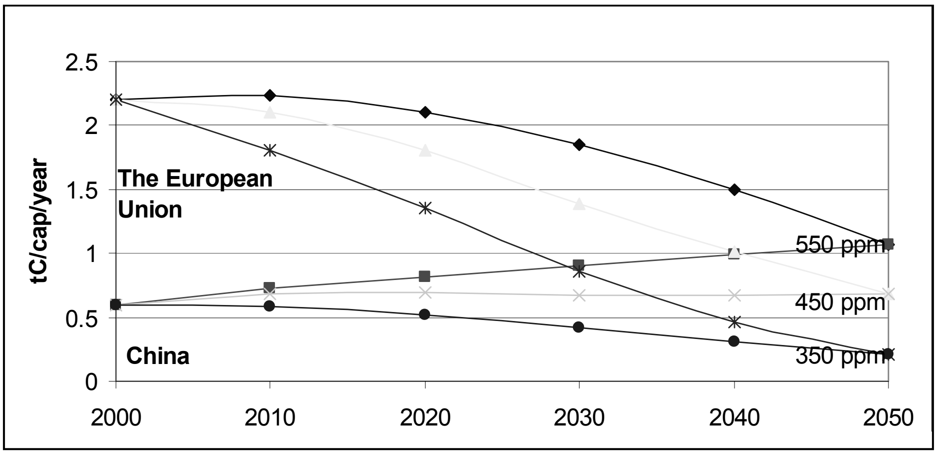
[3] A region's share, $x_i(t)$ of the allowable global emissions is given by $x_i(t) = (1-t/50) \cdot E_i(2000)/E_{tot}(2000) + t/50 \cdot P_i(2050)/P_{tot}(2050)$, where t is years after the year 2000, E and P are emissions and population in region i or in total.

precise in establishing what needs to be done in one region in the near term in order to meet a global long run target.

Other, more detailed assessments of the reduction requirements fall into this range, not only for the contraction and convergence but also for other allocation methods, e.g., triptych and various forms of multistage (see den Elzen, 2002; Nakicenovic and Riahi, 2003; Höhne, 2005; den Elzen et al., 2005; Persson et al., 2003). Den Elzen and Berk (2004), for instance, find that a reduction of all Kyoto greenhouse gases by approximately 30 percent is required over the years 1990–2025 in an "enlarged EU" in order to meet a 550 ppm CO_2 equivalent target for not only contraction and convergence by 2050 but also for triptych and for a multistage approach. The reason why their number is lower than the upper range in our estimate is that our higher value reflects a more ambitious reduction target (compatible with 350 ppm CO_2).

Cases where the allocation approach does have a significant impact on the near term reduction requirements include (rather obviously) equal per capita now, contraction and convergence by the year 2100, which gives less stringent reductions in the North (and correspondingly more stringent targets in the South), and the Brazilian proposal, which requires somewhat steeper reductions in the Annex I countries because of its focus on historical responsibility.

Figure 3
Per capita emission trajectories for China and the EU towards 350 ppm, 450 ppm, and 550 ppm, under contraction and convergence by 2050. Population scenarios are taken from UN (2004) and per capita emissions for the year 2000 from Marland et al. (2003).



For China the large difference in the 350 ppm and 550 ppm global emission trajectory (figure 3) translates into either a possibility to increase its per capita emissions by 80 percent (in the 550 ppm case) or decrease them by 70 percent in the 350 ppm case.

I chose to include only the EU and China in the graph in order not to blur the graph with too many regions, but it is worthwhile to note that the results for the EU also hold (in broad terms) for Japan, the former Soviet

Union, and South Africa. USA, Canada, Saudi Arabia, and Australia have substantially higher per capita emissions, so the reduction requirements are sharper. The results for China hold roughly also for fossil fuel related emissions from Latin America. India, Africa and Indonesia emit roughly half as much per capita as China and Latin America and may thus be allowed to increase their emissions of CO_2. On the other hand, methane and nitrous oxide emissions in India, Indonesia, and Southern Africa are larger than the emissions of fossil carbon, so taking these gases into account implies more stringent emission targets for these countries.[4] It may also be noted that there are many countries that traditionally refer to themselves as belonging to the South that emit more or much more than 1 ton carbon per capita per year (e.g., Malaysia, Iran, South Korea, Mexico, Argentina, and as already mentioned, Saudi Arabia and South Africa).

Different allocation methods yield more varying results for developing countries than for developed countries, in particular for countries with very low emissions at present. For India and sub-Saharan Africa, the choice of methods may imply differences in emission profiles (or allocated allowances) that amount to several hundred percent of their current per capita emissions (see e.g., Höhne, 2005, chapter 6, figures 4 and 6).

Finally, the actual emissions under a contraction and convergence approach, or any other allocation approach, will depend on whether trade in allowances is allowed or not. Analyses of such trade in allowances are uncertain since they depend on assumptions about baseline economic development, options to reduce emissions in different regions, political pressure to carry out most of the reductions domestically, etc. For examples of such studies, see Nakicenovic and Riahi (2003), den Elzen (2005), and Persson et al. (2005). Most studies conclude that rich countries generally end up being buyers of permits under a contraction and convergence approach by the year 2050 scheme aiming at 450 ppm, but that China also rather quickly ends up being a net buyer (because of its high growth and large coal resources).

III Overall cost of mitigation

There is much concern about the cost of meeting stringent climate targets. In the public debate claims are even made that climate policies will threaten our current standard of living. But what does the economics literature tell us? In the latest IPCC assessment, the cost of stabilizing the atmospheric concentration of CO_2 at 450 ppm, 550 ppm, and 650 ppm is estimated to lie in the range 2.5–18 trillion USD, 1–8 trillion USD, and roughly 0.5–2 trillion USD, respectively (IPCC, 2001a, chapter 8).

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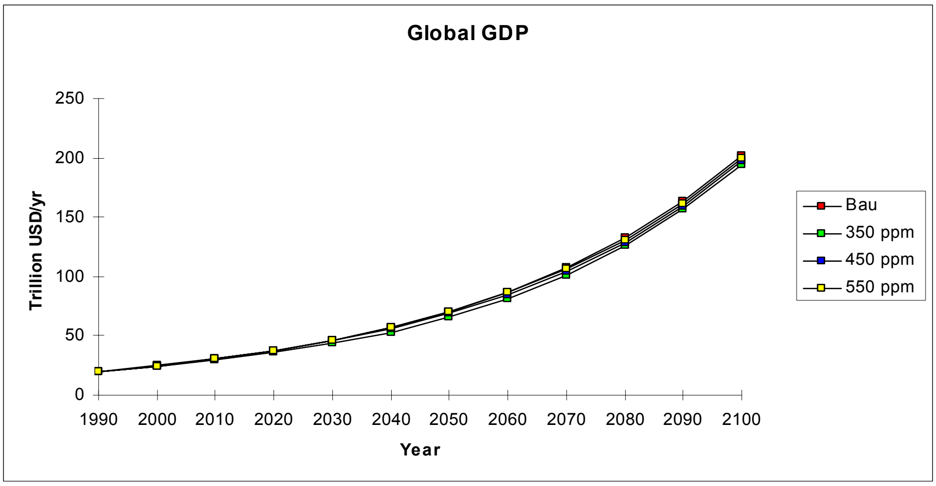
[4] Emissions of fossil carbon per capita in India, Indonesia, and sub-Saharan Africa are 0.3, 0.3, and 0.1 ton of carbon per capita per year, respectively. Emissions of greenhouse gases including fossil carbon, methane, and nitrous oxide, calculated using 100 GWPs, are estimated at 0.5, 0.7, and 0.5 ton of carbon per capita per year, respectively (see Höhne, 2005, based on UNFCCC).

In order to better understand what these numbers mean, it may be useful to view them in light of the expected overall global economic development. This is done in the graph below (Azar and Schneider, 2002). The difference between global income under a 350 ppm scenario and the business-as-usual income (a growth rate of 2.1 percent per year) represents a net present value cost of 18 trillion USD. Thus, although trillion dollar costs are large in absolute terms, they are minor compared to the expected perhaps ten-fold increase in global income over the next hundred years. Similar observations can be made for the cost of meeting near- and mid-term climate targets.

Figure 4
The development of global income, with and without climate policies.
Climate damages are not quantified and thus not included in the graph.



Source: Azar and Schneider (2002). (Reprinted with permission from Elsevier).

This graph should not be interpreted as if we were trying to argue that it is inexpensive to meet low stabilization targets. The point is to reject the rather widespread misperception that climate policies are not compatible with continued economic development. If policymakers and the general public would understand that the cost amounts to a few years delay in becoming 10 times richer by the year 2100 or as a difference in growth rate of on average less than 0.05 percent per year—hardly noticeable even in retrospective!—the willingness to accept climate policies would probably be higher.

It would also be wrong to conclude that the minor difference in growth rates between a stringent climate policy and business as usual implies that the low carbon future will materialize by itself. On the contrary, major efforts are required to achieve the almost complete transformation of the energy system that is required (see chapter 19 in IPCC, 1996b, or Azar et al., 2003, for examples of energy scenarios meeting stringent climate targets). There is in particular a need for (i) introducing and continually increasing the cost of emitting CO_2 (through the use of a tax, or a cap-and-trade system), (ii) for standards for energy efficiency improvements, and (iii) for a concerted effort to enhance technology development (not only through more R&D spending but also through the creation of niche markets for emerging more advanced carbon-free energy technologies, see Sandén and Azar, 2005).

IV Some perspectives on climate policy and the implications for competitiveness

The difficulties in achieving agreements on climate policies stem from many factors, for instance the fact that costs of climate change and of emissions abatement will not be shared equally across countries, that there is not enough public awareness and support from climate policies, that there is widespread misperceptions that the costs of dealing with climate change will threaten overall economic welfare levels, and that the cost of the policies will fall on people living now whereas benefits will accrue to future generations.

An additional key obstacle is opposition from sectors or industries that would be heavily affected by climate policies. This aspect becomes particularly relevant if the policy ambitions differ across countries.[5] Climate policies would then, it is often argued, lead to relocation of production which could be costly in terms of premature closure of industrial facilities and losses of jobs, and lead to increases in carbon emissions in other countries (sometimes referred to as “carbon leakage”).

The mere expectation that such competitiveness losses may occur is sufficient to set strong interest groups in motion against climate policies. The most well-known example is probably the Byrd-Hagel Resolution in the US Senate in 1997, which explicitly stated that the US should not accept any outcome in Kyoto unless it mandated “specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period.” Competitiveness concerns also partially explain why the EU chose to “grandfather” permits and why countries have been very generous when it comes to the total amount of allowances allocated in the EU Emissions Trading Directive (Grubb et al., 2005).

Thus, it is worthwhile to better understand the concerns about competitiveness and what governments may possibly do about it. Whether they should introduce protective policies is a political question that will not be

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[5] Such differences are built into the Kyoto framework–the rich countries will have to take the lead–but similar problems can be expected for decades ahead since different countries view climate change differently and the alternative–to wait until everybody agrees that something should be done–would probably imply a rather long period of waiting. One approach could be to include all countries in a cap-and-trade system and distribute permits generously to those who resist so that they may up being winners of the climate policy. This is roughly what happened with Russia in the Kyoto negotiations, but it has so far–for good and bad reasons–not received sufficient support to bring other countries on board in this manner.

addressed here. Rather, I will review insights from the literature and offer perspective on questions such as: what are the consequences of protecting, or not protecting, sensitive industries, and what are the pros and cons of different protective policies?

Loss of nationwide competitiveness—or not?

It is misleading to speak of losses of competitiveness at the country level as a result of climate policies. In fact, nationwide competitiveness is not even a well-defined concept in economics (see Krugman, 1994; Babiker et al., 2003). Households and transportation do not "compete" with their likes in other countries. Further, according to the theory on international trade, an economy should specialize more in producing goods it is comparatively better at, regardless of whether or not it has an absolute advantage over its trading partners. Implementing a uniform carbon price will shift advantage from carbon-intensive industries toward less carbon-intensive industries (compared with trading partners that do not implement such policies).

At the micro level, however, competitiveness is a useful concept. A company could be said to be competitive if it can produce goods at or below the prevailing market price. Energy and carbon-intensive industries that face competition from regions without climate policies may lose competitiveness if the cost of energy and carbon increases.

But it should also be recognized that most industries have low energy costs compared to their turnover, and these may even gain competitiveness and increase output (this is a common result in computable general equilibrium models, which even suggest that output in manufacturing industries may increase, see e.g., Bergman, 1996). The way this could operate at the international market is as follows: a drop in the exports (or increased imports) of energy and carbon-intensive goods would eventually lead to a slight depreciation of the exchange rate (ceteris paribus). This depreciation would improve the competitiveness of manufacturing industries etc. whose lower production costs (in international currency) would outweigh the impact of higher energy prices.[6] Thus, although it is not correct to talk about nationwide losses of competitiveness, a slight depreciation of the currency implies higher import prices, i.e., a slight loss in real income.

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[6] The mirror image of this argument goes under the name the "Dutch disease", i.e., the fact that countries that experience an export boom in one sector (e.g., as a result of a discovery of petroleum) will see more resources drawn to that sector. The increase in export leads to an upward pressure on the exchange rate and to higher salaries in this sector, which leads to losses of competitiveness in other sectors.

Competitiveness of energy-intensive industries

Energy and carbon-intensive industries include steel, aluminium, chemicals (e.g., fertilizers), cement, and refineries.[7] Producers of these products have limited opportunities to pass on increases in production costs to consumers, since the price is often set by international markets (where producers do not face the same carbon price). Electricity generation from fossil fuels is clearly also energy and carbon-intensive, but if there is no trade in electricity with non-abating regions, then electric utilities can obviously not lose competitiveness to producers in these regions.[8] For many of these companies, competitiveness, measured as their production costs compared to competitors outside the climate abating regions, is at stake. Figure 5 below shows estimated increases in production costs for a 10 USD/tCO_2 tax on various energy-intensive industries (assuming constant production technology). The cost increase includes the tax on on-site emissions and the higher electricity prices that result from the carbon tax.

In the EU Emissions Trading Scheme (EU-ETS), the increase in average production cost is much smaller because of the grandfathering of emission permits. Energy-intensive companies are basically given as many permits as they need for this first phase, 2005–2007, and may chose to “consume” these permits in order to keep the price impact down. For that reason, Carbon Trust (2004) concludes that the EU-ETS is not likely to pose any significant threat to energy-intensive industries in Europe, expect possibly for aluminium industries which will face a higher electricity price but will not receive any grandfathered permits. The impact on the aluminium sector thus depends on the extent to which the electric utilities are successful in passing through the opportunity costs of the permits to consumers.

This observation is similar to the conclusions drawn from studies about the relocation of industries facing unilateral regulations of other environmental problems, e.g., sulphur, emissions of metals etc. The general result from the literature on this issue is that it has proven difficult to demonstrate a strong case for such relocation (Jaffe et al., 1995; Persson, 2003; Cole, 2005). It would be premature, however, to conclude that this would be the case for stringent climate policies, since the costs of dealing

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[7] Most of the carbon in the crude oil remains in the product, but there are some emissions in the refineries that, if taxed, would increase production costs and might lead to relocation of the refinery. It is in this context also worth observing a related problem: if ethanol, methanol, dimethyl ether (DME), or Fischer-Tropsch (FT) diesel from biomass would become competitive in Europe because of its carbon policies or the biofuels directive, it is important to make sure that other regions do not produce the same fuels from fossil fuels (since that would be a lot cheaper, in particular for methanol and DME) and sell it as if it were fossil carbon free. Although the chemical composition of the fuels is the same regardless of the energy source, the isotopic content is different.

[8] This is the case for large markets or islands (e.g., Australia, the EU, North America, and Iceland). But competition could also occur, e.g., if, say, Turkey and Ukraine would start to sell large amounts of electricity to the EU as a result of climate policies in the EU; then countervailing measures would also have to be considered.

with the CO_2 problem per unit of output in energy-intensive industries is significantly higher than the cost of dealing with many other environmental problems.

Figure 5
The impact of a 10 USD/tCO_2 carbon tax on the production cost of energy-intensive products[a]

	Steel basic oxygen furnace	*Steel (electric arc furnace)*	*Cement*	*Newsprint*	*Aluminium*
Cost increase (%)	7.7	1.5	18.6	3.9	2.4
Total cost increase (USD/ton)	20.6	3.4	8.7	4.5	28.6

a Reinaud writes that these numbers are rough estimates of the *upper* boundary of the costs since they do not include options to lower carbon emissions or electricity use in these industries. In addition the cost number refers to the average plant. Further, the author has chosen to use the average carbon emission factor (gC/kWh) for electricity generation in Europe when estimating the impact on the electricity price. But if the emission factor of the marginal electricity source would determine the impact on the electricity price, the cost increase for aluminium could be more than twice as high, since it is the change in electricity price that is the most crucial parameter for aluminium.

Source: Reinaud (2004).

In the longer term, e.g., if the EU aims at reducing emissions by 20–40 percent by the year 2020, carbon prices might be several times higher than 10 USD/tCO2. Bollen et al (2004), for instance, estimate that a permit price of 58 EUR/tCO2 by the year 2020 would reduce emissions in EU-25 by 31 percent compared to 1990. Although the authors also emphasize that there is a lot of uncertainty about the exact value of the permit price, it is nevertheless likely that the required permit price will be in the tens of euros per ton of CO2 and such high permit prices would likely lead to severe competitiveness problems for energy-intensive industries from companies that do not face similar carbon penalties.

Higher cost of climate policies if industries are protected—or not?

Economic assessments generally find that the cost to meet a *domestic* carbon target increases if protection of sensitive industries takes place, see e.g., Böhringer and Rutherford (1997), Babiker et al. (2000, 2003), Bye and Nyborg (2003).[9] For instance, Böhringer and Rutherford (1997) find that the cost to meet a 30 percent reduction target for Germany would increase from 0.6 percent of its GDP to 0.8 percent of GDP if energy-intensive industries are protected. The fundamental reason for the expected increase in cost is that lowering the tax, or in general the effort to reduce the

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[9] Bergman (1996) is an exception who finds that differentiated taxes will lead to lower costs to meet a domestic carbon target. He even concludes that “differentiated taxes seem to be an almost perfect substitute to internationally coordinated taxes.”

emissions, in one sector, means that more costly options have to be employed in other sectors.

However, let us assume that the aim of the unilateral climate policy is to meet a global emission target (defined as the sum of the domestic emissions plus the impact on the emissions in the rest of the world). Then, the cost is typically lowered if some form of protection of heavy industries takes place, see Hoel, 1996, Bergman, 1996, Böhringer and Rutherford, 1997).

These results are all obtained with the use of general equilibrium models, which typically are poor at capturing non-equilibrium effects, such as unemployment.[10] For that reason they may underestimate social costs associated with rapid closures of large industries.[11] In addition, these models are rarely, if ever, run under the assumption that other countries will eventually also initiate carbon abatement policies. If they do, it could be argued that it would be economically inefficient to pursue a policy that leads to relocation of industries away from Europe if it is believed that these industries would be competitive in a near future with similar carbon constraints in the rest of the world. Such considerations could offer an argument in favor of temporary protection, but they also imply the risk for relocation of industries is lower than what one may conclude from static analysis. Companies are, of course, aware of the fact that other countries may introduce climate policies.

Losing or gaining markets?

Even if there is some risk that energy-intensive industries relocate to other regions if Europe unilaterally pursues more ambitious climate policies, it should also be kept in mind that such policies would likely enhance the development of carbon-efficient technologies in Europe. This may be economically positive for Europe in the longer term since it is most likely that other countries will eventually start to abate carbon. European industries may at that time gain a competitive advantage on these new markets. Danish export of wind power is an example worth noting. This perspective is sometimes referred to as the Porter hypothesis (Porter and van der Linde, 1995).

Further, technology development that leads to more efficient technologies in Europe (say in the automotive industry, in electric appliances, etc.) may set the standard also in other countries regardless of their climate ambitions. This would, in turn, lead to reductions in carbon emissions in their countries, i.e., a reversed form of carbon leakage (see Grubb et al., 2003).

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[10] They are also incapable of capturing non-equilibrium effects on energy markets, e.g., opportunities to increase energy efficiency and thus reduce carbon emissions at no costs (see e.g., Ayres, 1994).

[11] Further, costs are almost exclusively measured in monetary terms, but the social costs of high unemployment rates in certain regions may also need specific attention.

Options for protection

There are several different policy options that may be employed to protect the energy-intensive industries from climate policies. Example include:

- allocating carbon emission allowances freely on the basis of past emissions (grandfathering);
- introducing so-called border tax adjustments (BTA), i.e., import taxes and export subsidies that level the playing field with countries outside the carbon abating region;
- different levels of mitigation efforts between sectors (different carbon tax levels, full tax exemptions, trading schemes that only cover certain sectors, as is the case with EU-ETS, etc.);
- direct subsidies to compensate industries that lose competitiveness.

These options all have in common that there will be methodological problems in the implementation phase and that protective policies may come in conflict with basic ambitions of achieving free trade and non-distorted markets. There have already been complaints about unfair allocations to companies in different countries in the case of the EU-ETS. Another problem is that there would be a risk that these protective policies would be self-reinforcing in the sense that industries, once protected, will continue to claim the right to protection even when the carbon abating efforts of other countries increase. The coal subsidies in Germany are a case in point, where subsidies amount to 82,000 euros per job in 2001 (see press release from the German Federal Environmental Agency [FEA] 2003). Yet another problem is that there is a risk that one introduces policies to protect industries that really do not need protection. This would be the case for energy-intensive industries that plan to remain in the country but manage to get subsidies by threatening that they would relocate unless some form of compensation is given. Another example could be firms that would move abroad regardless of the climate policy but stay only to get the subsidies (e.g., aluminium industries in search of low cost electricity options—that may be found in regions with large hydro resources compared to the electricity consumption).

A difference between these policies is that some leads to the protection of the continued operation (e.g., direct subsidies that match the extra cost faced by the industries), whereas others aim at protecting the interests of the capital owners (e.g., grandfathered permits that could be sold and generate revenues to the capital owners even if the plant were taken out of operation).

Below, we will discuss some of these protective policies in some more detail.

Cap-and-trade with grandfathering of emissions allowances

“Grandfathering” permits, i.e., the free allocation of permits based on historical emissions rather than auctioning (or the use of taxes), has several drawbacks or features worth paying attention to. First, grandfathering is expected to increase the cost of meeting any given target substantially (see IPCC, 2001a). The reason for that is that the loss of government revenues that a tax or auctioned permits would have generated could have been used to offset distortive taxes.

A second important feature is that grandfathering based on historic emissions fails to offer protection to *electricity*-intensive industries (e.g., aluminium smelting, see Reinaud, 2004; Carbon Trust, 2004). This has already caused concern amongst electricity-intensive industries in Europe.[12] For that reason, complementary measures may nevertheless be needed, e.g., direct subsidies to electricity-intensive industries that cannot pass on increases in production costs to consumers. Spain and Ireland have introduced legislation that prevents electric utilities from raising the electricity price (Reinaud, 2004).

A third potential problem is that if grandfathering of emission permits becomes the norm in environmental policy, the incentive to be proactive and reduce emissions in advance of environmental policy breaks down.

Fourth, energy-intensive industries often argue in favor of grandfathering so as to ensure continued operation in the face of “unfair” competition from regions without (similar) climate policies. However, whether grandfathering offers such protection or not depends on how allocation decisions are made in subsequent commitment periods and whether firms are behaving as profit maximizers or not. Permits allocated based on past emissions can be seen as a one-time donation to the capital owners. Whether the firm would continue to operate or not would then depend on the relation between the expected profits from selling the permits and the expected profits of continued operations. The time span over which permits are allocated are an important factor here that determines the relative profitability of closing versus continued operation. Regardless of whether the plant closes down or not, such a policy would offer effective incentives to reduce the emissions, at least as long as the updating of the allowances for subsequent periods does not depend on the emissions in the preceding period.

If emission allowances are continually updated based on the emissions in the preceding period, then there would be incentives to increase emissions so as to get more permits. If commitment periods are short, it is rather unlikely that it would be profitable to close down the firm, and under these conditions the policy would look more like a subsidy. This would protect the firm from closing down but in its extreme version imply that there would be no climate policy at all. It may be noted that the decision on how to update allowances for the next period in the EU-ETS is yet to be taken, so this is not simply an academic observation.

Finally, grandfathering to industries that may pass on most of the opportunity cost of the permits to consumers may see their profits increase as a result of climate policies. The value of the permits allocated to coal-

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[12] Recently, they urged EU governments to block windfall profits from EU Emissions Trading Scheme. See <http://www.pointcarbon.com/article.php?articleID=4212&categoryID=279>.

fired power plants may actually be of the same order of magnitude as the value of the entire plant.[13] The fact that a carbon policy might lead to increased profits for a carbon-intensive industry might be difficult to digest, at least from the perspective of the "polluter pays" principle.

One possible compromise would be to employ selective and partial grandfathering, selective in the sense that auctioning would be the norm but with grandfathering for the energy-intensive sectors. And, partial in the sense that the companies would at most be grandfathered to the extent that profit levels do not increase (see Kågeson, 2000). Goulder (2005) reports that only a small share of the allowances need to be grandfathered in order to maintain profit levels in the US economy, the exact level depends on how much of the price increase that may be passed on the consumers. He concludes that "major stakeholders can be compensated without significantly increasing the overall policy costs."

Border tax adjustments

An interesting, but also complicated and, for some, contentious approach might be to introduce import taxes (and possibly export subsidies) for carbon-intensive products from (and to) countries in which there is no carbon abatement policy. The import tax would carry the benefit that it would be close to equivalent (for European consumers) to a tax on production in other countries aimed for European markets, and the export subsidy should be set so as to level the playing field in regions outside Europe (and all the other regions that have taken on climate policies).

The introduction of such border tax adjustment would almost certainly lead to problems with WTO rules (National Board of Trade, 2004), but pursuing this approach would in addition to its immediate climate benefits have the benefit of sending a message to other countries as well as people not directly involved, interested, or engaged in climate affairs that the EU takes the threat of climate change seriously. Clearly, any country that would take on commitments with similar carbon prices as those that prevail in the EU would automatically be exempted from border tax adjustments, and the EU may argue that any country that has a problem with these tariffs can simply join the climate treaty (see also Hoel, 1996).

One problem with this approach is that it is very difficult, if not impossible, to calculate the correct level of the tariff on all products (just imagine keeping track of the embodied carbon emissions in each product entering the EU). For that reason, the only reasonable approach would be

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[13] A coal-fired power plant is estimated to emit 225gC/kWh (40 percent efficiency). At 100 USD/tCO$_2$, this amounts to 0.8 USc/kWh. At a capacity factor of 75 percent the power plant would produce 6570 kWh/year per installed kW. Thus, if the price increase can be passed on to consumers and the plant owner gets permits that correspond to its emissions, then the additional revenues is 53 USD/kW of capacity/year. Assuming that the permit price increases with the discount rate, then 25 years of permits would be equal to 1330 USD/kW of installed capacity, more than the cost of building a coal fired power plant!

to include only a few products, e.g., steel, aluminum, some other metals, and fertilizers etc. The tax could be set based on some form of benchmarking, e.g., the best available technology so as to make sure not to discriminate against any foreign producer who is very efficient. But even this approach would not be free from problems. In the case of aluminium, the emissions associated with its production would depend very much on whether coal or hydro is the marginal electricity source, and that choice (or property of the electricity system) has nothing to do with the best available technology to produce aluminium. Thus, it will not be possible to completely avoid the problem of site-specific emission factors. There is also a border line problem: if energy-intensive materials (e.g., steel) are faced with an import tax, then what about manufactured goods (car bodies, cars, etc.)?

Differentiated efforts: Including the European transport sector in the EU-ETS

The EU-ETS only includes emissions from large point sources. Calls have been made to include other sectors as well, e.g., the transportation and residential sectors. This could be done by requiring that importers and refineries need to hold permits for emissions that will be generated by users of gasoline and fuel oil. But such a decision would have implications, as we will see, for the competitiveness of energy-intensive industries.

There are basically two arguments in favor of inclusion. First, it would improve cost-efficiency of European climate policies (equalize carbon prices across a wider range of emission sources). Secondly, since the current EU-ETS only covers some 40 percent of the overall CO_2 emissions in the EU, it has proven difficult to relate the target for the trading sector to the overall Kyoto target for the EU. By claiming that emissions will be reduced substantially in the non-trading sectors, it has been possible for several countries to allow for generous, perhaps too generous, allocations for the trading sectors.

The key argument against including other sectors is that a sufficiently strong target to comply with the Kyoto targets would imply that one of these sectors, the transportation sector, which probably has the largest willingness and capacity to pay for permits, would drive the price of the allowances to levels that would be difficult to deal with for the energy-intensive industries (The “transportation sector would buy all the permits,” exclaimed a frustrated representative for energy-intensive industry to me recently). In this context, it is worth observing that the Swedish carbon tax on households and transportation is currently around 100 USD/tCO_2, whereas the permit price in the EU-ETS was, in February 2005, around 10 EUR/tCO_2.

Such prospects could make it politically very difficult to introduce a sufficiently stringent cap in the trading sector because of lobbying from energy-intensive industries. In addition, including the transportation sector under the cap means that other measures to reduce the emissions in this sector will not lead to lower emissions, because the overall cap is already set.[14] Thus there is a risk that the overall abatement will become less stringent if these sectors are also covered in the EU-ETS.

V Summary and conclusions

In this paper, targets for the global average annual surface temperature, atmospheric concentration of CO_2, and emissions of CO_2 have been reviewed and proposed. It is concluded that the EU needs to reduce emissions by 20–40 percent by the year 2020 compared to the year 2000 if we want to stabilize atmospheric concentration of CO_2 in the range 350 to 450 ppm CO_2 and pursue an approach based on contraction and convergence by the year 2050. For many developing countries, per capita emissions are already above the per capita targets by the year 2050, in particular for targets lower than 450 ppm. For developing countries with lower emissions per capita, there is still room for substantial increases in emissions.

The paper then assesses the cost of stabilizing the atmosphere at these levels. It is found that models that are generally perceived as being pessimistic find that the costs are compatible with continued impressive growth in global GDP. The reduction in growth rates, averaged over the entire century, is less than 0.05 percent per year. A key conclusion is that overall costs to meet stringent climate targets do not seem to be large enough to explain the strong resistance to the introduction of climate policies. Rather, it is the fact that the reductions will create winners and losers that probably cause the most severe opposition. This problem is aggravated by the fact that countries do not all move ahead with climate policies at the same speed, and they are not likely to do so in the near future either.

It is concluded, however, that energy-intensive industries are not likely to lose competitiveness to any large extent under the current first phase of the EU-ETS. For stricter emission reduction targets, as those envisaged above, many energy-intensive companies would most likely lose competitiveness under the assumption that there would be no climate policies in major producer countries. If the rest of the world follows the EU in its climate ambitions, which is of course necessary for the EU climate policies to be meaningful, there would not be any need to introduce protective climate policies. Under such conditions, it would be clearly be economically more efficient if the full cost of carbon would be reflected also in the

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[14] This view is only partly valid. Policies to improve energy efficiency in cars or buildings, for instance, would not lead to lower emissions in a trading scheme in the current phase–that is true!–but it would lower the permit price, which in turn would make it possible for policymakers to adopt more stringent targets in subsequent periods.

price of energy-intensive goods, since that would lead to substitution away from these materials.[15]

But as long as there are large differences in the climate ambitions across countries, there will be discussions about unfair competition and carbon leakage. Two contrasting positions may be taken regarding on whether protective policies are attractive or not. One view would be to suggest that the EU moves ahead with uniform carbon prices in all sectors of the region of concern, aiming primarily at meeting the domestic carbon target at the lowest possible cost, and hope that leadership inspires followers in the rest of the world and creates incentives for the development of more advanced technologies that can be exported. The second view would be to argue in favor of the introduction of some forms of protective policies so as to protect jobs or capital owners, or both. This paper has reviewed some policies that aim at achieving these goals. Buying acceptance for climate policies might be important and necessary, but the policies used protect the industries may be costly and may be difficult to get rid of (as demonstrated by the history of the Common Agriculture Policy, introduced after the Second World War to secure food production in Europe and still in place today). It is beyond my aim to propose any solution to this trade-off, but it seems clear that more research is needed to develop policies that combine the conflicting objective of being cost-efficient and politically feasible.

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[15] This would not only lower the cost of meeting the climate target but also bring about other environmental benefits associated with the reduction of mining and metals refining, see Kåberger et al. (1994).

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US Socio-Economic Futures

Brian O'Neill[*]

US socio-economic trends will be important determinants of future energy demand, land use, and greenhouse gas emissions, as well as determinants of the impacts of climate change. These trends include demographic changes, trends in economic growth and its distribution across different sectors of the economy, and shifts in consumption patterns associated with changing lifestyles. Here I focus on demographic and lifestyle factors, highlight plausible alternative outcomes, and comment on their potential significance for future emissions. The timescale of focus is the next 20–100 years. In general, there is little that can meaningfully be said about these trends more than a century into the future, and the literature that attempts to do so is extremely sparse. It is taken as understood that none of these trends by themselves, nor even socio-economic factors considered together, would completely determine future emissions or vulnerability to impacts. Changes in technology, as well as political and institutional factors, in combination with socio-economic factors will co-determine emissions and vulnerability outcomes.

First, I discuss potential demographic outcomes in terms of population size, age structure, living arrangements (e.g., household size), and spatial distribution. Next, I discuss two ways in which demographics could affect future energy demand and emissions in the US: through impacts on macro-economic growth and through lifestyle-related compositional effects on aggregate consumption patterns. Finally, I discuss a few selected additional lifestyle factors that may be important over the next century.

Demographic trends

Currently (i.e., in 2005) the US population is about 295 million and growing at approximately 1 percent per year. By 2020, population size is likely to be in the range of 300–350 million, based on projections from the United States Census Bureau (USCB); by 2100, this range expands to an astonishing 280–1200 million.[1] There are several points regarding this

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[1] Unless otherwise noted, I use the US Census Bureau projections to represent the demographic outlook for the US, rather than projections from the UN or IIASA, primarily because the Census Bureau considers a wider range of future migration trends (both the UN and IIASA assume migration is zero beyond the middle of the century). I use Census Bureau projections made before data from the 2000 census were available (USCB, 2000), since this is the most recent set of projections available that gives a high and low range of

outlook that are worth considering. First is that the range of uncertainty in population size is relatively narrow over the next few decades and widens substantially only toward the middle of the century and beyond. Population size uncertainty grows slowly because growth is subject to substantial inertia built into the present size and age structure of the population.

Second, the large range for 2100 is driven by a wide range of migration assumptions, as well as alternative assumptions about fertility (assumptions about life expectancy vary as well but have a smaller effect on population size outcomes). Current net migration into the US is at a historic peak of about 1.3 million per year. The Census Bureau foresees the possibly that it could rise to 3.6 million per year by the end of the century, or fall to less than half the current rate at 560,000 per year. Few other major countries in the world currently anticipate migration to have such a substantial potential influence on future population size. In addition, fertility rates in the US continue to hover around replacement level of about 2 births per woman, substantially above the very low levels (below 1.5) prevalent in Europe. While demographers generally consider it extremely unlikely that countries in which fertility has already reached replacement level will see it rise substantially above 2 births per woman, a sustained fertility increase of only half a birth per woman or so can have a large effect on future population size. The Census Bureau uses a range of long-term fertility assumptions of 1.6–2.7. To put the high end of this range in perspective, during the post-World War II baby boom, total fertility rates in the US rose to over 3 births per woman (although it should be noted that this was a temporary change driven largely by changes in the timing of childbearing). For comparison on the low side, a fertility rate of 1.7 is below replacement level but, averaged across Europe, fertility is below 1.5, and in some countries as low as 1.1, so it is not unthinkable that the US will experience lower fertility rates (and therefore smaller population) than projected in the Census Bureau low scenario.

Third, it is worth putting the range of population size outcomes in perspective as well, because it is a reflection of the status of the US as a demographic anomaly in the developed world. While about 50 countries are expected to have smaller populations in 2050 than they do today, and while the populations of Russia and most of the states of the former Soviet Union are already shrinking (UN, 2004), the US is currently the third largest country in the world and is growing faster than developing countries such as China, Iran, and Thailand. If the US follows the high growth scenario from the USCB, its population could equal or exceed that of both China and India by the end of the century (depending on whether these countries follow either the UN medium or low projections). Even if the US follows the low scenario, its population will remain larger than it is

outcomes, and that extends to 2100. In 2004 the Census Bureau released an interim result for a single, middle projection to 2050 with base year data from the 2000 census (USCB, 2004), but has yet to release a longer term projection or high and low variants based on the 2000 census.

today until nearly the end of the century, in sharp contrast to the many European countries that face immediate or impending population declines.

Finally, it is worth noting that this range of population outcomes for the US is not well represented in IPCC emissions scenarios (SRES), for two reasons: first, the high scenario used in SRES was based on a projection from IIASA that assumed (as do all IIASA and UN projections) that migration would go to zero by the middle of the century, excluding the possibility of continued high migration as foreseen by the USCB. Second, the SRES scenarios do not include any low population scenarios for industrialized countries at all; this is an outcome that is simply not included in the SRES scenario set. As a result, the range of outcomes for the North America region (currently the US accounts for about 90 percent of the population of this region) in SRES is about 400–700 million, substantially smaller than the Census Bureau range.

Changes in age structure also span a substantial range. Currently, about 12 percent of the US population is aged 65 or older. Aging in industrialized countries, including the US, will accelerate temporarily over the next 30 years as the large baby boom cohorts age into the elderly age groups. By 2050, the USCB projects a range of 18–23 percent for the 65+ age group, and by 2100 the range expands to 19–30 percent. Thus in all plausible futures (including those with very high in-migration) the population becomes older, and the proportion of the population aged 65 and older could more than double by the second half of the century. Aging is most substantial in the low population growth scenario, due mainly to its assumption of relatively low fertility. It should be noted that more substantial aging than occurs in this scenario is possible, both because lower fertility is a possibility (as discussed above), and because this scenario assumes life expectancy at the low end of its projected uncertainty range. Pairing a low fertility assumption with the high end of the life expectancy range would produce greater aging, and there is no theoretical reason to prefer one pairing of these assumptions over another.

Another anticipated demographic change is shifts in living arrangements, including in particular a shift toward smaller household size (i.e., smaller number of members per household). As discussed below, several studies have pointed to changing numbers of households as an important driver in environmental change. Detailed projections of future living arrangements have only recently been carried out by demographers, and only for selected countries (e.g., Zeng et al., 1998; Prskawetz et al., 2001). A recent study aimed at identifying plausible bounds for future household size in the US (Jiang and O'Neill, 2005) finds that a range of 2.0–3.0 persons per household represent plausible extremes, compared to a current average size of 2.6. Most of this uncertainty range develops by 2050, and grows slowly thereafter. At the low end of this range, outcomes are driven by aging (fewer children as compared to adults leads to smaller households) as well as decreasing union formation rates (e.g., marriage, cohabitation) and increasing union dissolution rates (e.g., divorce). Whether this range of outcomes is sufficient to drive important changes in consumption patterns remains to be tested, but it should be noted that this change is likely to be much smaller than those anticipated in many developing countries where household size is substantially higher.

Finally, the spatial distribution of the US population could also plausibly undergo substantial shifts over time, but it is the demographic trend that has been least explored in terms of potential long-term outcomes. One way to structure thinking about this issue is to focus on two key components of spatial distribution trends: shifts in the relative growth rates of particular geographic regions, and shifts in the growth rates of urban vs. rural areas. Over the past several decades, the US has experienced net internal migration from the Northeast and Midwest to the South and West (Rogers and Henning, 1999). Historical urbanization trends are less straightforward. The US underwent rapid urbanization in the 19th and early 20th centuries. However, in the 1970s demographers were surprised to discover what came to be known as a "counter-urbanization" trend not only in the US but in other industrialized countries as well; i.e., growth in non-metropolitan areas began to outpace growth in metropolitan areas (Mitchell, 2004), and migration into rural areas was greater than migration into urban areas. This trend turned out to be short-lived; during the 1980s growth in urban areas again predominated. However, the 1990s saw a resumption of the counter-urbanization trend in the US, with migration into rural areas again outpacing migration into urban areas (Fulton et al., 1997; Fuguitt and Beale, 1996).

There is no consensus on the most likely pattern of spatial growth in the future. While over the shorter term a trend toward continued growth of the south and west seems likely, in the longer term uncertainty is high. The potential role of counter-urbanization in the future is also unclear. Geographers and economists have proposed two broad types of explanations for counter-urbanization trends: that they are driven by changes in residential preferences, or that they are driven by changes in spatial distribution of employment opportunities (Renkow and Hoover, 2000). Residential preferences for less urban lifestyles, perhaps driven by urban disamenities such as crime and crowding, could prolong recent deconcentration trends. Economic activity could move to less densely population areas if structural shifts favor activities that have less to gain from the benefits of agglomeration in cities. For example, shifts toward services, information technology development, and international competition in a globalizing world have been offered as explanations for restructuring-driven spatial deconcentration in the recent past.

In summary, there are a number of possible scenarios for future demographic change in the US. By the end of the century the US could have a population of more than 1 billion, have surpassed India and China, and still have less than 20 percent of its population above age 65. This quadrupling of the population, driven by high immigration and relatively high fertility, would be associated with substantial shifts in the racial and ethnic mix in the population and could plausibly be associated with a growing number of coastal mega-cities. In contrast, by the end of the century the population could be somewhat smaller than it is today, with a third or more of its population 65+. It is also possible that an increasing counter-urbanization trend could lead to a greater dispersal of the population over the land.

Macro-economic growth effects

Aging could have substantial impacts on economic growth (and therefore, all else equal, on emissions). There is considerable evidence that, in general, age structure can be an important determinant of economic growth rates under some conditions. For example, the so-called Asian economic miracle, during which high growth rates have been sustained in many East Asian countries over the past decade or two, has been convincingly shown to have been driven in part by a "demographic window" of opportunity (Bloom and Williamson, 1998). Rapid declines in fertility temporarily create an age structure with a labor force that is large relative to the size of dependent age groups (children and the elderly), providing favorable conditions for both household and public savings rates. Later, continued low fertility and lengthening life expectancy leads to a shift in age structure toward large old-age dependency ratios. A corresponding decrease in labor productivity (for the population as a whole), savings, and possibly consumption could lead to substantial decreases in economic growth rates, as well as challenges to intergenerational transfer schemes such as pay-as-you-go pension systems and public health care.

Research on this issue has been largely confined to economics and economic demographers, and environmental implications have rarely been considered. Dalton et al. (2005) have recently introduced age structure into an energy-economic growth model of the US economy and found that in the long-term (50–100 years) aging in the US could reduce CO_2 emissions by a third relative to an identical scenario that does not account for the effects of aging. In fact, the aging effect on emissions can, under some conditions, be larger than the net effect of technological change. This result is preliminary in the sense that it does not yet account for the potentially ameliorating effects of international capital flows and of extensions to working life-spans. However, historical trends in industrialized countries have been toward decreasing, not increasing, working lifespan (MacDonald and Kippen, 2001). In addition, rising educational enrollment rates have decreased labor force participation at young ages, and falling retirement ages have decreased participation at older ages, leading to a steady decline in lifetime hours of work (Ausubel and Gruebler, 1995). It cannot blithely be assumed that this trend will be easily reversed; less work and more leisure has been the preferred direction in industrialized countries for 150 years.

This is not to say that the US economy will inevitably come under substantial pressure from aging. Dalton et al. (2005) find substantial aging effects only in the demographic scenario with the most aging. In mid-range demographic scenarios, the US outlook for labor force is one of the most favorable of any industrialized country; one study (MacDonald and Kippen, 2001) finds that across a range of scenarios, the absolute size of the US labor force increases at least through 2050, while in many European countries, it falls in almost all scenarios, even accounting for immigration.

Demographics, lifestyles, and consumption patterns

Both the level and composition of household expenditures differ across households of different type (Paulin, 2000; Deaton et al., 1999; Bosch-Domenech, 1991). Characteristics such as household size, age of the householder, composition (measured as the number of members in particular age classes), and urban/suburban/rural status have been shown to be important for certain goods in particular contexts. For example, energy studies literature has identified household characteristics as key determinants of direct residential energy demand (Schipper, 1996; Poulsen and Forrest, 1988; Schipper et al., 1989). Household size appears to have an important effect, not only on energy use per household but on a per capita basis as well, most likely due to the existence of substantial economies of scale in energy use at the household level (O'Neill and Chen, 2001). Research focusing specifically on transportation has found substantial differences in travel demand across households that differ in the age and gender of the householder, household size and composition, and family type (Prskawetz et al., 2001; Carlsson-Kanyama and Linden, 1999). The lifecycle concept has been used as a framework for capturing variation in travel demand across households that differ by some combination of family size, family type, age of the householder, and marital status (Greening and Jeng, 1994). It has also been suggested that gender-specific cohort effects may be important, since younger generations, and women in particular, have different travel habits than previous generations (Buettner and Gruebler, 1995; Spain, 1997).

These types of differences across households can be thought of as arising from lifestyle differences associated with households that differ in their demographic characteristics. In general, lifestyle is taken to mean a specific pattern of activity and consumption; usually, lifestyle is assumed to involve factors above and beyond the influence of income and prices. For example, lifecycle variations in travel demand can be though of as arising in part from the fact that members of young, middle-aged, and elderly households generally have different lifestyles: different patterns of daily activity involving work, leisure, trips for children, etc.

The existence of lifestyle differences across households with different demographic characteristics raises the possibility that as the US population shifts in composition across these categories of household types, aggregate consumption could be substantially affected, with consequences for energy demand and emissions. However, only a few studies have tested this hypothesis within medium to long-term energy and emissions scenarios. Prskawetz et al. (2001) focus on personal vehicle use in Austria, and demonstrate that over the next 40 years, projections that do not account for the effect of the aging of the baby boom cohort, and an associated shift toward smaller household size, could miss a possible peak and subsequent decline in travel demand anticipated from an age-structured model. Dalton et al. (2005) project total energy demand for the US accounting for the age structure of the population, and find substantially less demand in scenarios with relatively rapid aging. They find that this effect is largely driven by changes in the level of aggregate consumption, not by changes in the consumption mix across different categories goods. It is plausible that other demographic trends, such as changes in spatial settlement patterns, could have substantial implications for energy demand (particularly in transportation), but this has not yet been tested within longer term scenario analysis.

Other lifestyle changes

Aggregate consumption can change not only due to shifting population composition, but also due to changes in lifestyles (activity and consumption patterns) within population groups or across the population as a whole. A number of such "lifestyle changes" have been considered as socio-economic scenario elements; two—diet and travel—are briefly discussed here.

Diet is a key factor driving future land and energy use scenarios. Typically, the proportion of calories from meat increases with rising incomes, but future trends in industrialized countries that have already transitioned to more meat-based diets are unclear. Since production of meat is more land- and energy-intensive compared to production of staples, shifts in dietary preferences are one of the most important determinants of future land use and emissions from agricultural sectors (Fischer and O'Neill, 2005). Studies that find that global land use by the agriculture sector could decline in the coming decades are driven in part by optimistic dietary assumptions, along with assumed increases in technology-driven agricultural productivity (e.g., Waggoner and Ausubel, 2001).

Travel-related behavior is a second important example. Energy use per person per unit of time is much higher for travel than for other activities (Schipper, 1989), and therefore future trends in travel activity are likely to be an important determinant of energy use and emissions. While income and prices are important determinants of travel behavior, lifestyle choices also play an important role. Approaches to scenario building that used a time-based activity approach have been advocated as a means of capturing the potential for lifestyle choices to be incorporated in projections (Schipper, 1989). One global scenario (Schaefer and Victor, 1997) has taken an activity-based approach, positing a fixed fraction of time and income devoted to travel, and foresees mobility (distance traveled per year) per person in the US more than doubling by 2050, as incomes rise and travel shifts toward faster modes of transport (including air travel). However, scenarios based on alternative time budgets for travel—reflecting different lifestyle choices—were not tested.

Transportation behavior is also a good example of how technological and lifestyle changes can be intertwined. For example, changes in information technology may play an important role in residential locations (discussed above), in the division of work between home and place of employment, and in commuting patterns. However, it is unclear whether the net effect will be toward increasing or decreasing energy demand (Allenby and Unger, 2001). Energy use at home could be greater than energy use at a place of employment. It is also possible that, rather than decreasing travel by reducing the need for commuting, information technology could increase travel demand by facilitating the development of larger and more spatially diverse networks of colleagues and customers.

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A Vision of US Wedges

Jeffery B. Greenblatt[*]

In this paper, I adopt the "stabilization wedges" framework from Pacala and Socolow (2004)[1] for the US, examining the question of which wedge technologies would be have the greatest opportunity for success in the US. I further define one US wedge as a linear ramp of avoided carbon emissions from zero today to 0.25 GtC/yr in 2055, with an integrated area of 6.25 GtC.[2] This is precisely one-fourth of a wedge as defined in Pacala and Socolow (and shifted forward one year, which is inconsequential). This smaller wedge measure is needed in order to frame the problem reasonably for the US, who are projected to emit 1.64 GtC/yr of CO_2 in 2005, or approximately 24 percent of the projected global CO_2 emissions of 6.89 GtC/yr.[3]

Using the Energy Information Administration (EIA) projections for US emissions through 2025, I extrapolate these estimates to 2055 using the average projected growth rate from 2002–2025 of 1.52 percent/yr.[4] This results in emissions of 3.49 GtC/yr in 2055, or slightly more than double the 2005 level. Doubling of US emissions is consistent with doubling of global emissions by 2054, as laid out in Pacala and Socolow.

In order to achieve stabilization at less than a doubling of atmospheric CO_2, Pacala and Socolow argued that global emissions must be held fixed for the next fifty years, with further reductions in the future. Recognizing that this is merely a qualitative description of any number of possible emissions pathways that could result in atmospheric stabilization, it is only applicable to the globe as a whole. For each nation, emissions could follow even more varied emissions pathways; so long as the global total remains fixed, it is permissible, for instance, for the emissions from some nations to grow, while others could shrink. However, the equitable distribution of "emissions rights" remains among the most challenging issues still to be resolved in global climate discussions. For instance, the US population is projected to grow to 409 million by 2050, or 4.6 percent of a

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[1] Pacala, S. and Socolow, R. (2004) Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. Science 305, 968–972.

[2] This is similar to the "US wedge" defined by D. A. Lashof, 2005 (U.S. Stabilization Wedges. Unpublished manuscript, Natural Resources Defense Council Climate Center) of a linear ramp to 0.25 GtC/yr between 2010 to 2050, integrating to 5 GtC.

[3] Energy Information Administration (2004) International Energy Outlook 2004. US Department of Energy. <http://www.eia.doe.gov/oiaf/ieo/environmental.html>. Accessed 7 June 2005.

[4] Energy Information Administration (2004) Annual Energy Outlook 2005. US Department of Energy. <http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html>. Accessed 6 June 2005.

projected global population of 8.92 billion.[5] If the international community adopts an equal per capita emissions target, then assuming a global emissions target of 7 GtC/yr in 2055, the total emissions from the US must fall precipitously to 0.32 GtC/yr to be consistent with a globally flat emissions trajectory. On the other hand, if a flat emissions policy is adopted for all countries, then US emissions would be limited to 1.64 GtC/yr, but numerous poor nations who possess very small emissions today would experience severe constraints on their economic growth due to these emissions restrictions.

I feel that the correct target for the US lies somewhere in the middle, so I adopt a 2055 target of 0.98 GtC/yr, a 40 percent reduction from today's value. Thus, assuming a baseline scenario where CO_2 emissions rise to 3.49 GtC/yr by 2055, a reduction of 2.51 GtC/yr, or 10 US wedges, is needed.

I now turn to the question of which wedges would be most advantageous to develop on US soil. What follows are brief descriptions of each of the fifteen wedges enumerated in Pacala and Socolow, but scaled to the US wedge unit size, followed by a discussion of the feasibility of each wedge succeeding in the US:

1. *Efficient vehicles*. Pacala and Socolow require doubling of the fuel economy from 30 mpg to 60 mpg to achieve one wedge. The current US fleet of light-duty vehicles is approximately 175 million, and is expected to increase to 285 million by 2050,[6] or about 14 percent of the estimated 2 billion cars in 2054. Thus, doubling the fuel efficiency of US cars would reduce CO_2 emissions by 0.14 GtC/yr, or about 0.6 US wedges. Achieving approximately 50 percent reductions in fuel use would require advanced technology hybrid gasoline, diesel, or fuel cell engines,[7] which are certainly feasible to implement in the US, especially if there is a strong demand worldwide for the technology. However, to achieve an entire US wedge is virtually impossible, requiring an average fuel efficiency of 280 mpg, beyond that of even the most advanced concept hydrogen fuel cell.

2. *Reduced use of vehicles*. An alternative way to reduce vehicle emissions is to use them less. As above, reducing the distance traveled per vehicle by half (from 10,000 to 5,000 miles per year) is equal to 0.6 US wedges. However, it is less likely that such deep reductions in vehicle use would be achieved without fundamental restructuring of the US transportation model. For example, widespread, enthusiastic support for public transportation, strong incentives for ride-sharing, popularization of telecommuting and teleconferencing, or rethinking of urban and suburban designs could achieve such reductions or possibly more.

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[5] United Nations Population Division (2003) World Population Prospects: The 2002 Revision. Annex Tables. United Nations Publishing, New York.

[6] Fulton, L. and Eads, G. (2004) IEA/SMP Model Documentation and Reference Case Projection. World Business Council for Sustainable Development Sustainable Mobility Project. <http://www.wbcsd.org/web/publications/mobility/smp-model-document.pdf>. Accessed 7 June 2005.

[7] ibid.

3. *Efficient buildings*. It is estimated that there are ample opportunities to achieve the 25 percent reductions in building and appliance emissions required by Pacala and Socolow for 2054.

4. *Efficient baseload coal plants*. The US currently emits 0.54 GtC/yr of the 1.71 GtC/yr globally, from 305 GW of coal power producing 2000 TWh/yr. Extrapolating the projected growth in power output from 2002–2025 of 1.80 percent/yr, the resulting demand is 4900 TWh/yr in 2055; at 90 percent capacity factor, this is 620 GW. Using Pacala and Socolow's assumed baseline efficiency of 40 percent in 2054 results in emissions of 1.14 GtC/yr; increasing the efficiency of these plants to 60 percent reduces emissions by 0.38 GtC/yr, or 1.5 US wedges. Thus, an efficiency increase to 51 percent is sufficient to achieve one US wedge of reductions; more than one US wedge is possible.

Overall energy efficiency. The EIA's own "high technology" case (1.9 percent/yr energy intensity decline versus 1.6 percent/yr in the reference case) affords reduction of 0.41 GtC/yr by 2050, or about 2 US wedges.

5. *Gas baseload power for coal baseload power*. Replacing 50 percent efficient coal power with 60 percent efficient (combined cycle) natural gas power results in roughly half the carbon emissions. One US wedge is equivalent to replacing 350 GW of baseload coal with baseload natural gas; thus, replacing just over half of the 620 GW of projected baseload coal capacity with gas power results in one US wedge. For context, the baseline case projects 460 GW of combined cycle natural gas in 2055, based on 126 GW in 2005 and an average growth of 2.63 percent over 2002–2025,[8] so displacing one US wedge of coal power with natural gas would inflate this capacity by 76 percent.

6. *Capture of CO_2 at baseload power plants*. For one US wedge, 200 GW of baseload coal power or 400 GW of natural gas baseload power must be built with carbon capture and storage (CCS) technology. This is equivalent to replacing one-third of the projected 2055 coal capacity (620 GW) with CCS technology, or virtually all of the projected 2055 natural gas capacity (460 GW). It is believed that both technologies will become economically viable worldwide, with strong markets in the US. The US is poised to become a world leader in developing CCS technology, as well as the requisite underground storage expertise.

7. *Capture of CO_2 at a hydrogen plant*. One US wedge is equivalent to 62.5 MtH_2/yr from coal or 125 MtH_2/yr from natural gas.

8. *Capture of CO_2 at a coal-to-synfuels plant*. One US wedge is equivalent to 7.5 million barrels per day from coal.

Geological storage. To store one US wedge of CO_2 underground would require 875 Sleipner-scale (0.3 MtC/yr) projects, a vast scale-up for any country as compared to current activity.

9. *Nuclear power for coal power*. Nuclear power has undergone almost no growth in recent years; the EIA projects virtually no growth through 2025,

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[8] EIA (2004) Annual Energy Outlook 2005.

remaining essentially at the current level of 100 GW.[9] To displace one US wedge of baseload coal power requires an addition of 175 GW, almost twice the current capacity. A revival of nuclear power in the US is possible with strong government support and an industry that seriously addresses public concerns over reactor safety, nuclear weapons proliferation, and nuclear waste storage. Indeed, progress on climate change mitigation may require a compromise wherein nuclear power is given a strong push forward in exchange for equally strong support for renewable energy and carbon capture and storage technology. Note, however, that only approximtely 600 GW of coal power are at stake in the baseline scenario, so that if several of the above strategies targeting coal power are implemented simultaneously, expanding nuclear power may not also be needed to reduce carbon emissions.

10. *Wind power for coal power*. Because of the low capacity factor (about 30 percent) of wind turbines, three times the installed capacity of wind is needed to displace the same number of kWh of coal power. Thus, one US wedge is equivalent to 525 GW of new wind power (1050 GW if natural gas is being displaced). This capacity would displace 75,000 km^2 of land, though most (more than 95 percent) of it could still be utilized for other purposes (grazing, farming, etc.). The US installed capacity of wind power in 2004 was 7 GW, with a global capacity of 48 GW.[10] It is estimated that the near-offshore generation potential of the US, excluding protected areas, is about 900 GW,[11] and the potential in the interior of the country (mainly the Great Plains region), excluding protected areas, exceeds 1200 GW.[12] Therefore, there is the potential to build one or more US wedges of wind power.

11. *Photovoltaic (PV) power for coal power*. Like wind power above, displacing coal requires about 525 GW of PV assuming a capacity factor of 30 percent. The current world total of installed PV is 3 GW. The scale-up to one US wedge, however, is enormous regardless of the assumed installed base. As for potential, one US wedge would require 5,000 km^2 of land area (possibly shared with another function such as roof covering, etc.) which is a minute portion of the US land area of over 9,600,000 km^2. As adequate power can be generated during daylight hours even in cloudy northern US latitudes, PV is much less limited by the intrinsic resource than e.g. wind power, which is extremely dependent on the availability of high average wind speeds. Presumably, several US wedges of PV are achievable.

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[9] ibid.

[10] BP Consult ApS (2005) International Wind Energy Development-World Market Update 2004. Ringkøbing.

[11] Musial, W. and Butterfield S. (2004) Future for offshore wind energy in the United States. Conference paper preprint. National Renewable Energy Laboratory. Report number NREL/CP-500-36313. Golden, Colorado.

[12] Elliott et al. (1991) An assessment of the available windy land area and wind energy potential in the contiguous United States. US Department of Energy and Pacific Northwest Laboratory. Report number PNL-7789. From Table 10. Assumes “moderate exclusion” scenario and class 3+ winds in contiguous US.

12. *Wind-generated hydrogen in fuel-cell cars for gasoline in hybrid cars*. One requires double the installed wind capacity as in (10), or 1050 GW. Again feasible, but the required capacity does begin to interfere with the available wind power resource, if significant amounts of wind power are also used, e.g., to generate electric power.

13. *Biomass fuel for fossil fuel*. One US wedge requires 625,000 km^2 of cropland, or 6.5 percent of US land area. It is likely that utilizing land area of this size begins to interfere with other cultivation uses.

14. *Reduced deforestation, increased reforestation/afforestation, and new plantations*. Deforestation is not a significant activity in the US, and reforestation is already taking place by itself as abandoned farmland is returning to its natural state. It is estimated that 1,500,000 km^2 of tree plantations, or 16 percent of the US area, would be required to absorb one US wedge's worth of CO_2 emissions. Like the biofuel requirement above, this would be an exceedingly tall demand on the available land resource, and so would be unlikely in the US.

15. *Conservation tillage*. About 4,000,000 km^2 of cropland are required to be converted to conservation, or "no-till," agricultural practice for one US wedge. While this amount probably exceeds the amount of farmed land in the US, it is certainly feasible that the no-till method could be extended to all available US cropland, resulting in a significant portion of a US wedge. It is not known what percentage of US farmland is currently managed by conservation tillage, but it is probably small; thus, the potential carbon savings are quite large.

In conclusion, options with the highest potential for success in the US are efficiency improvements, including motor vehicle fuel efficiency, building efficiency, and generation efficiency in, e.g., coal electricity plants; substitution of natural gas or hydrogen (produced from fossil fuel coupled to CO_2 capture and storage) for coal electricity, wind electricity, and biological sequestration. Additional options with lesser potential due to cost, technical, or political obstacles include increased nuclear electricity, solar photovoltaic electricity, and increased biofuel production. In all cases, it is unlikely that the necessary scale-ups will occur without explicit policies aimed at reducing emissions.

Technology and Standards

Using Technology to Bridge the Emissions Gap

Dirk Forrister[*] and Michael Wriglesworth[**]

Developing and deploying clean technology will be an essential part of any successful strategy responding to concerns about climate change. The objective of stabilizing concentrations of greenhouse gases (GHG) in the atmosphere, which is at the heart of the United Nations Framework Convention on Climate Change (UNFCCC), is potentially so challenging that major technological change will be required to bridge the gap between the stabilization objective and current trends in GHG emissions.

The rate of technology change over the last century—and its capability to accelerate into broad market acceptance—gives reason to be optimistic about its future scope. But fundamentally important will be drivers that are capable of ensuring that the pace of technology change needed is actually achieved and that this change occurs on a global basis. Past experience also suggests that new environmental and energy technologies will make their greatest impact in markets where there are clear price signals to stimulate their use by business and consumers.

The global nature of the technology change needed to address rising greenhouse gas emissions underlines its role as a key area for dialogue and action by the US and EU to give this issue global leadership in working towards an international regime.

Objectives

- To explore how existing and innovative cost-effective technologies can bridge the gap between meeting coherent economic and energy policy goals and realizing the UNFCCC objective of stable atmospheric greenhouse gas concentrations.
- To identify policies that will be needed to ensure a range of competing cost-effective technologies can be promoted that give a high probability of success.
- To examine how promoting technically equivalent standards based on available technology can remove barriers to trade and encourage convergence of policies.
- To note policy interactions between trends in greenhouse gas emissions, scope for technology and standards to contribute, and implications for energy security.

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- To explore the role of technology as a critical area for EU and US co-operation on climate policy, and the basis for an action plan aiming to demonstrate how economic growth may be combined with a transition to low carbon economies.

Links to other Issues raised in the INTACT process: Emissions pathways and energy security

- **Emissions pathways:** Economic analysis shows a need to deploy wide ranges of technologies to close the challenging gap between economic aspiration with increasing energy needs in both developed and developing countries and the UNFCCC objective of stabilizing atmospheric greenhouse gas concentrations.
- **Energy security:** Energy security can be viewed differently, but, for both the US and EU, having more options to use cost-effective technology will increase security by allowing choice of fuel and energy source from diversified supply. At the same time, energy needed to meet economic aspirations will be reduced. A key objective for new technologies will be to increase efficiency of energy use and ultimately to seek to decouple economic growth from energy intensity.

The Technology Revolution needed to address climate change

- Energy, largely from fossil fuels, drove a remarkable transformation of the global economy in the 20th century. Projections of future GHG emissions show large increases during this century, despite major improvements in energy technology, including large penetration of renewable technology, both because of increasing energy needs and the low cost and convenience of fossil fuels.
- Therefore increasing energy needs, especially in developing countries, are likely to be met by both fossil and alternative fuels, with developing country emissions predominating globally by around 2030, unless new technologies are also deployed globally.
- Meeting the UNFCCC objective of stabilizing GHG concentrations implies both a trend of implementing business-as-usual technology improvements and deploying a range of new technologies needed to close the gap to stabilization.
- Closing the gap will be so challenging that a technology revolution is needed across a wide range of technology options, with the goal of making that range of technologies cost-effective for broad market deployment.
- Changing the emissions trajectory will require new technology and, crucially, a way of fairly evaluating society's interest in stabilizing GHG concentrations.
- With appropriate valuation, technologies like carbon capture and storage (CCS), hydrogen and advanced transport systems, and biotech-

nology offer hope for stabilizing GHG concentrations in the atmosphere by near to the end of this century.
- Given the general lack of economic signals for carbon mitigation from markets, these new technologies will need to be developed through a combination of public and private investment; their widespread deployment depends not only on technical feasibility being demonstrated, but also on their commercial viability.
- It will be challenging to introduce motives of climate technology into agendas already focused on energy security, health, safety, and environmental concerns and the objective of inexpensive energy supply.
- A flexible working relationship between public and private sectors will be essential for the success of the revolution in the technology of energy supply that simultaneously meeting these objectives implies. Public and private sector roles must be clear to avoid a muddle that could strand resources inefficiently.
- Analysis suggests the period to 2050 needs to be a “warm up” phase for massive deployment of technologies able to continuously lower emissions towards zero for GHG stabilization to be achieved.

Need for policy coherence: Technology linkages needed between climate change and energy policies

- The EU Kyoto policy response to climate change fits with its energy policy of power and gas market liberalization, and current natural gas supply advantages.
- Weak EU competence in energy policy and supply also encourages emphasis on energy efficiency, conservation, and alternative energy as consistent with supply security. Post-2012, the EU gas advantage will gradually weaken, needing to be replaced by developing and deploying new and existing technologies. The US already faces a similar situation and will likely depend more heavily on coal in the future.
- As future strategies for both the US and EU converge on technology options, both can increase security of supply from diverse energy and supply sources.

Technology and standards to promote sustainable mobility, focusing on technical equivalence

- A major challenge in coming decades will be to satisfy aspirations for mobility of an increasing proportion of a growing global population. This implies major increases in the use of transport fuels and therefore of CO_2 emissions unless oil-based fuels can be displaced over time by fuels from alternative sources.
- There is considerable scope to use biofuels, such as bio-diesel and ethanol, in conventional engines, but these are not seen as suitable for global use.

- Vehicle constructors such as DaimlerChrysler consider hydrogen to be among the most promising fuel options taking global trends and policies into account.
- A transition from fossil, to renewable, to low-carbon fuels is expected, with an initial phase focused on integrating bio- and synthetic with conventional fuels.
- Promoting of traditional and synthetic biofuels in the short to medium term should be based on lifecycle analysis of what is most economic and energy efficient.
- Hydrogen-based fuel cells show strategic promise in the medium to long term, provided hydrogen can be derived from low-carbon sources. Sound long-term frameworks will need to be agreed with authorities, for fuel cell vehicles to be launched that are fully competitive with diesel and gasoline-powered vehicles.
- Such long-term frameworks should include regulated standards that encourage clean technologies but without being prescriptive about choice of technology.
- The 2004 World Business Council on Sustainable Development (WBCSD) report “Mobility 2030” sees the need for a downward trend in the transport-related GHG emissions curve by 2030 and to afterwards complete the task of limiting transport-related emissions of GHGs to sustainable levels. For these goals to be achieved, technological foundations for the eventual elimination of the deleterious effects of fossil carbon from transport fuels must be laid.
- To develop sustainable mobility that will contribute towards GHG stabilization, optimum technological solutions will need to become deployed globally. The close links between emission control standards and cost-effective technological solutions can be exploited most effectively by passing standards that are technically equivalent. This will minimize barriers to trade, whilst promoting convergence of policy aims towards a common objective to stabilize GHG concentrations.

Incentive for clean coal technology opportunities

- Clean coal technologies have been demonstrated in US over the last two decades. Integrated gasification combined cycle (IGCC) plants look promising for high-grade coal, whereas ultra-supercritical (USC) pulverized coal or fluidized bed combustion technologies appear more cost-effective with lower grades of coal.
- IGCC offers scope for power production with very low emissions of sulphur, particulates, and mercury as well as low emissions of CO_2 if combined with carbon capture and storage. In a US context promoting usage of CCS will require both market and financial incentives. Syngas from IGCC can be treated with steam to give relatively pure streams of hydrogen and CO_2, offering this alternative fuel with carbon capture and storage.

- Use of clean coal technologies would fulfil environment and energy security objectives in the EU and US by simultaneously reducing emissions and need for imported fuels.
- A combination of incentives will be needed to make IGCC competitive for initial commercial deployment. This early phase of deployment also offers an important strategic opportunity to combine IGCC with carbon capture and storage. Coal, the most abundant US energy resource, could be used as a source of power with very low emissions, potentially producing hydrogen for future fleets of fuel cell powered vehicles.

Carbon capture and storage: A major mitigation option

- Increased energy needs in both developed and developing countries will have to be met mainly by fossil fuels for several decades. The option to capture and geologically store CO_2 will become a key way of reducing emissions whilst continuing to use fossil fuels. Its cost-effectiveness will depend on the energy efficiency of the capture process and on the assessment of risks associated with long-term storage.
- BP is demonstrating potential for capture and storage technology at the In Salah natural gas production project in Algeria, where natural gas can contain up to 9 percent CO_2.
- At present, costs of carbon capture technology and commercial risks involved remain too high for economic viability in the power or industrial sectors where potential economies of scale exist in capturing CO_2 emissions.
- A strategic opportunity exists for policy makers to enable economic deployment of carbon capture and storage in the power sector, as part of a portfolio of CO_2 emission reduction options. Carbon pricing, e.g., through emissions trading, is one option to provide the economic signal needed to build carbon capture and storage into companies' long term commercial and environmental strategies.

Role of technology in US–EU climate change debate

- The widely held view that technology will play the decisive role in ultimately achieving stabilization of GHG concentrations at politically acceptable levels has become the focus of cooperation, aiming to rebuild transatlantic relations.
- Unfortunately that cooperation brings a tension between views of the need for *technology push* versus the importance of *market pull*.
- The *technology push* approach depends on publicly supported R&D programs, which will develop the technology that will lower costs for subsequent actions.
- *Market pull* depends on technology being developed by business and industry, induced by market signals from regulatory frameworks, including financial incentives.

- There is a growing consensus that both approaches are needed and that neither is sufficient by itself. IEA sees energy efficiency having the greatest potential during the period until 2030, but breakthrough technologies will be needed in the long term. During both phases the use of market signals will be necessary, by which abatement and innovation will be inexorably linked.
- A converging focus on technology is a critical area for EU and US cooperation on climate policy, based on a common sense of urgency and direction. Choices about technology depend on a judgment on the urgency of climate action. The debate on post-2012 international climate policy is an opportunity to move this political agenda forward.
- The UK used its G8 Presidency to try to build a partnership with rapidly developing countries and to develop an action plan of practical measures to reduce emissions based on developing and deploying technology to demonstrate ways of combining economic growth with the transition to low carbon economies.
- A crucial element of UK G8 strategy was to gain confidence of stakeholders, notably business, which needs to build low carbon investment into strategies.

Conclusions

- Increasing energy needs of developed and developing countries imply a major gap between greenhouse gas emission trends and the UNFCCC stabilization aim that will require a wide range of technology options to be deployed globally.
- Both “technology push” and “market pull” approaches will be needed to ensure the development and deployment of technology needed. Energy efficiency has greatest potential in the short to medium term, but breakthrough technologies will be needed in the long term.
- The global nature of technology change needed underlines that this is a key area for dialogue and action by the US and EU, who will need to give this issue global leadership in working towards an international regime.
- Deploying similar technology options globally can be promoted by technically equivalent standards that can also help to promote convergence of policy aims.
- EU and US policies to control greenhouse gas emissions will tend to converge on developing and deploying technology, particularly as EU natural gas advantages weaken.
- Use of clean coal technology can address both US environment and energy security objectives by simultaneously reducing emissions and need for imported fuels.
- A combination of incentives will be needed to make IGCC competitive. IGCC with carbon capture and storage makes it feasible to use coal as a source of power with very low emissions while also producing hydrogen for future fleets of fuel cell powered vehicles.

- Carbon capture and storage can become a major enabling technology to mitigate emissions if market signals allow sufficient value to be secured to cover costs.
- Carbon capture and storage will create a strategic opportunity in the power sector as part of a portfolio of CO_2 emission reduction options. Carbon pricing, through emissions trading, would give the signals needed to build carbon capture and storage into companies' long-term commercial and environmental strategies.
- A converging focus on technology is a critical area for EU and US cooperation on climate policy, based on a common sense of urgency and direction.
- A crucial element of G8 strategy should be to gain confidence of stakeholders, notably business, which needs to build low carbon investment into its strategies.

Recommendations

The set of technology and standards issues that were reviewed in this working group provided a valuable set of insights regarding the role of technology in addressing greenhouse gas emissions. The co-chairs drew together these insights into a focused set of policy recommendations, which follow. These recommendations do not represent official positions of the working group contributors.

- *A global standard for R&D expenditure should be pursued, using an appropriate level from US and Japanese experience as possible a benchmark.*

  Global research and development on advanced energy technologies that mitigate greenhouse gas emissions should be increased substantially. The US has taken a lead in appropriately elevating the importance of this policy, and more leadership from other G8 nations is essential to ensure that technological solutions will be found.

Action: Europe should consider adopting an enhanced commitment to R&D, matching, for example, US or Japanese levels of R&D spending, as part of its post-2012 climate change strategy.

- *A global standard to create market value for greenhouse gas mitigation should be pursued, using EU policies as the benchmark.*

  Markets for greenhouse gas emissions reductions should be broadened globally to establish the proper economic signals that will stimulate private sector investment in technologies. The EU leadership through its Emissions Trading Directive has established the importance of this policy, and more leadership is needed from other G8 nations in the form of establishing greenhouse gas market-based instruments and/or other clear economic signals for greenhouse gas mitigation.

Action: The US should consider adopting measures to match the EU controls of greenhouse gas emissions from large factories and energy facilities with a view to creating economic stimuli to reduce emissions.

- *Climate technology solutions should be applicable, in terms of economic and societal benefit, to mitigation opportunities existing in every major emitting nation.*

  The EU and the US should agree on an approach to future policy that identifies opportunities to mitigate GHG emissions from every major emitting country for the next decade, to ensure that the business community globally has the long-term certainty needed to guide investment decisions.

Action: Negotiations on a future GHG mitigation regime should begin soon, with all major emitting nations engaged to share best practice.

- *Climate-friendly technology solutions should focus initially on clear winners that are worthy of coordinated global action.*

  Governments should provide an expedited focus on strategies to promote "big hitter" technology classes that business and environmental NGOs broadly agree could offer particular benefits, including IGCC, carbon capture and storage, and advanced biofuels.

Action: A G8 Task Force should identify specific, coordinated national policies to spur near-term market acceptance, given the long-term importance of these technologies in meeting multiple energy, economic and climate change objectives.

- *A crucial element of G8 strategy should be to gain confidence of stakeholders, notably business, which needs to build low carbon investment into strategies.*

Achieving Sustainable Mobility

Ulrich Müller[*]

One of the greatest challenges in the coming century will be the global transformation towards sustainable development. The conservation of fossil energy resources and the protection of climate will have high priority in this context. DaimlerChrysler aims to make an active contribution to future mobility through its fuel strategy and the introduction of advanced automotive powertrains.

In the following paper five key questions with respect to the DaimlerChrysler fuel strategy will be raised and answered:

- Are alternative energy sources a realistic option for the transport sector?
- What direction is DaimlerChrysler taking in its efforts to foster sustainable mobility?
- What path will hydrogen and fuel cells be taking in the years ahead?
- Are the targets set in the EU biofuels directive viable?
- What are the advantages of synthetic biofuels?

Figure 1
DaimlerChrysler fuel strategy

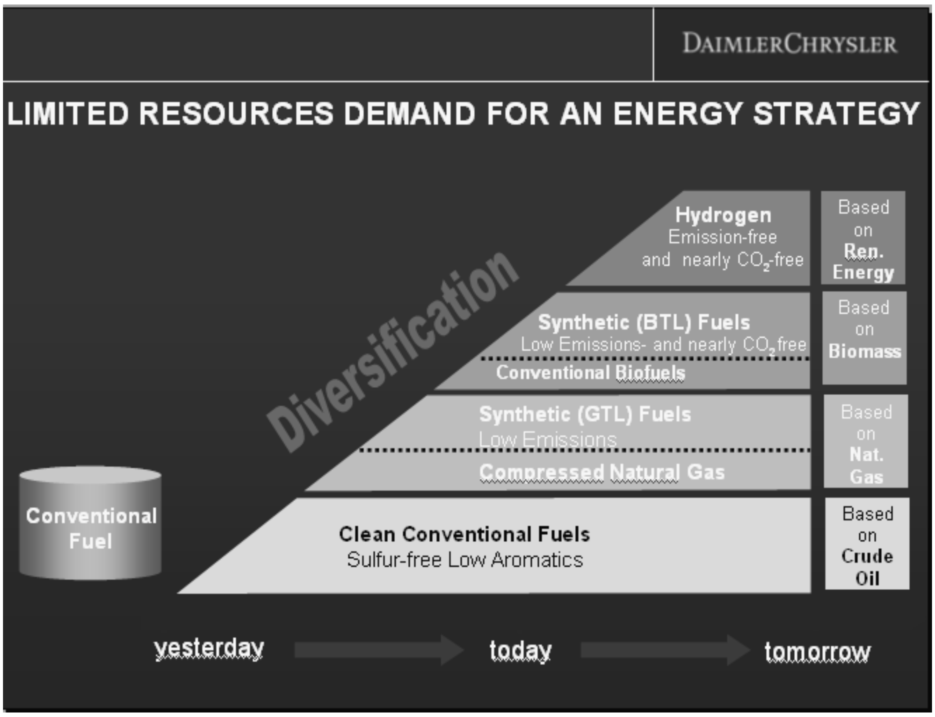

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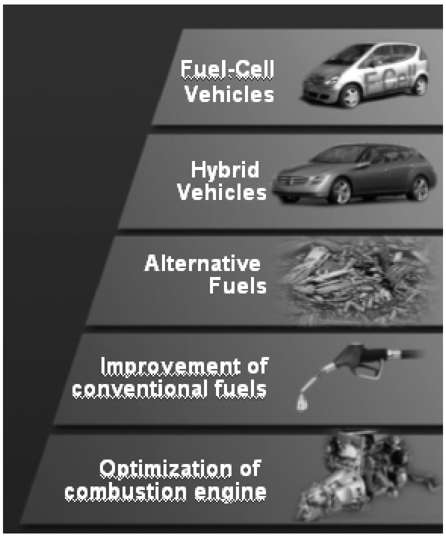
Figure 2
DaimlerChrysler 5-step approach to sustainable mobility



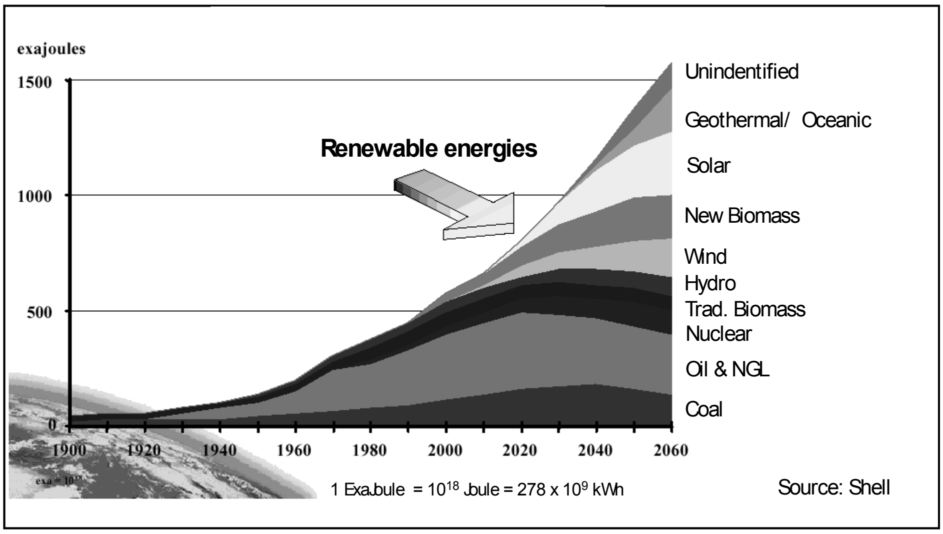
Alternative energy sources in the transport sector

Only a small number of alternative energy sources are currently used in traffic. Among those used are biofuels such as ethanol and bio-diesel, which are usually blended with conventional fuels. In some countries, natural gas is used for operating on-road vehicles. None of these alternative energy sources is currently expected to become suitable for global use.

The volume potentials of the most important alternative fuels (natural gas, biofuels, and hydrogen) will be a major factor in determining their future importance to sustainable mobility, especially if one assumes that alternative fuels will increasingly have to be produced from renewable resources. In the United States, for instance, natural gas is so scarce and expensive that any significant use in transportation would be inefficient. A similar development is to be expected in the medium term for the EU. By contrast, the share of biofuels in the fuel market will grow strongly in the coming years. Different analyses forecast a share of 15 percent in the EU. Although hydrogen has to be seen as a long-term alternative, it has the advantage of being producible from different forms of primary energy.

For reasons of economic efficiency, concentration on a few primary energies for transportation is recommended for the initial stage. For example, in Europe, wind power, biomass, and few, still undeveloped hydropower capacities can be utilized as renewable energy sources. In the case of biomass, waste biomass (e.g., wood chippings and straw) is already being considered for short and medium-term use—as is the cultivation of energy-supplying plants. The latter is an interesting option especially with the new EU member countries from East Europe. For environmental reasons, the use of entire plants (e.g., for the production of synthetic fuels) should be preferred to the use of fruits only (e.g., rape seed oil methyl ester).

Figure 3
World Enegy Supplies 2060



1 ExaJoule = 10^{18} Joule = 278 x 10^9 kWh

Source: Shell

Wind power appears to have a great potential, still to be developed, in Europe in the medium term. Several studies, especially for offshore areas, indicate significant resources in the order of current European electricity consumption. Additional regenerative primary energy potential lies in solar-thermal energy and photovoltaics in the very long term.

DaimlerChrysler advocates preparations for the large-scale use of environment-friendly and affordable energy options in joint projects with government, the energy industry, and its competitors in the transport sector. In the short and medium term, using biofuels in conventional combustion engines seems a promising option. In the long term, DaimlerChrysler considers hydrogen to be among the most promising fuels, taking worldwide industry and government activities into account.

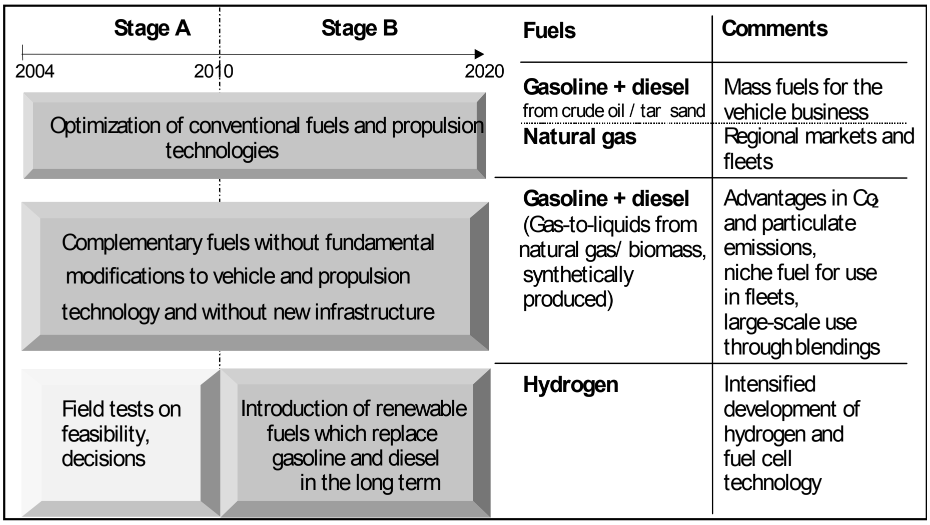
The DaimlerChrysler fuel roadmap

Climate protection and ever more stringent demands for reductions in CO_2 emissions in road traffic cause vehicles to become more expensive. In addition, the long-term safeguarding of fuel supplies is gaining in importance. For instance, industrialized countries' dependence on oil imports from oil-exporting countries with latently unstable political structures is growing significantly. Accordingly, volatile price developments have to be expected, with adverse effects on business activity. Against this background, the DaimlerChrysler approach to conventional and alternative fuels has been reviewed and further elaborated.

One of the main targets outlined in the fuel roadmap is to safeguard business interests in harmony with existing energy and environmental resources. Another major goal is to play an active part in bringing about the evolutionary transition to sustainable mobility.

Gasoline and diesel will remain the basis of the vehicle business for a long time to come (two decades, at least). For this reason, conventional propulsion systems—including hybrid technology—have to be improved still further.

Figure 4
DaimlerChysler fuel roadmap



Fuels	Comments
Gasoline + diesel from crude oil / tar sand	Mass fuels for the vehicle business
Natural gas	Regional markets and fleets
Gasoline + diesel (Gas-to-liquids from natural gas/ biomass, synthetically produced)	Advantages in CO_2 and particulate emissions, niche fuel for use in fleets, large-scale use through blendings
Hydrogen	Intensified development of hydrogen and fuel cell technology

Despite technical and, in particular, financial problems, hydrogen is widely regarded as a long-term solution to the CO_2 and supply problems. Other alternatives—for instance natural gas—are rated as niche fuels because of limited resources or insignificant CO_2 advantages (as compared to diesel). Hydrogen can reach a higher level of market availability only in the long term. Hence, in the short and medium term, all possibilities have to be exploited to complement conventional fuels by the addition of biofuels or synthetic fuels made of natural gas or biomass (e.g., synthetic diesel) and/or to improve their ecological properties by means of blendings.

DaimlerChrysler considers the safeguarding of fuel supply and the reduction of CO_2 emissions to be a community task which can only be solved by the concerted action of automotive and energy industries, government, society, and customers. To this end, the European Automobile Manufacturers Association (ACEA) is working towards identifying the most efficient measures and strategies within the context of an integrated policy framework.

DaimlerChrysler is determined to play an active part in shaping the transition from fossil to renewable and low-carbon fuels. In this decade, further development will focus on conventional fuels and the integration of biogenic and synthetic fuels. To master the challenges of using hydrogen, DaimlerChrysler is taking an active part in fuel projects throughout the world.

Hydrogen and fuel cells: What are the next steps?

With its benchmark position in technology, DaimlerChrysler has also adopted a pioneering role in the development of alternative propulsion systems, having grouped these activities under the heading of “Energy for the Future.” In particular, these activities include the further improvement of combustion engines and fuels, the promotion of biofuels which are CO_2-neutral to the greatest possible extent, the development of hybrid vehicles and, in the long term, the development of fuel cell vehicles.

In a fuel cell, electrical energy is directly generated from hydrogen in an electrochemical reaction and used to drive an electric motor. With this technology, it is possible to overcome a number of the disadvantages of battery-electric vehicles, (e.g., lengthy charging times, high weight, and a rather short range) with one “tank filling.” A fuel cell is considerably more efficient than an internal combustion engine, and it does not emit carbon monoxide, soot particulates, nitrogen oxides or CO_2.

From September 2001 until June 2003, a fuel cell Sprinter was operated in daily delivery service by the Hermes mail-order shipping company. It covered a distance over 25,000 km and delivered more than 7,800 parcels.

Technical data:
- Fuel cell system: 75 kW
- Fuel: gaseous hydrogen (350 bar)
- Top speed: 120 km/h
- Range: 150 km
- Max. climbing ability: 33 percent

In Europe, two vehicles were successfully operated by UPS until May 2004. Since the fall of 2004, two Dodge Sprinters have commenced delivery service in the US.

After successful individual tests of highly diversified fuel cell vehicles, practical experience is now being gained in everyday operations. This includes a European field test with a total of 30 Citaro buses in 10 European cities from 2003 until 2005 and worldwide fleet tests with F-Cell cars by customers in Germany, the US, Japan and Singapore. Another three Citaro buses were supplied to Australia in the fall of 2004, and three will be supplied for local public transport in Beijing in 2005.

System properties, e.g., cold-start behavior, were improved through parallel research activities. Other necessary steps still need to be taken in improving the durability and reliability of fuel cell systems, in reducing costs, in promoting projects for the establishment of climate-friendly hydrogen infrastructures, and in raising the acceptance of fuel cell and hydrogen technologies. Prior to a market introduction, reliable long-term framework conditions need to be agreed with the political institutions with the aim of launching fuel cell vehicles that are fully competitive with diesel and gasoline-powered vehicles.

Biofuels as a first step to alternative fuels

The European Union is seeking to reach a 23 percent market share for alternative fuels by 2020—with a particular focus on biofuels. To this end, the EU passed a directive for the promotion of biofuels in the transport sector, setting out promotion options for ten different biofuels.

In Germany, biofuels have been exempted from mineral oil tax since 1 January 2004; this exemption will remain in force until 2009. Fuels made in part from biomass are rated as biofuels for tax purposes to the extent of their biomass proportion.

The European Commission has proposed the target shares of alternative fuels in the fuel market (see figure 5).

Figure 5
Target shares in fuel market

Year	*Biofuels %*	*Natural gas %*	*Hydrogen %*	*Total %*
2005	2			2
2010	5.75	2		8
2015	7	5	2	14
2020	8	10	5	23

Despite intensive consultations, binding market shares for the individual member states have not yet been specified. Instead, recommended values for biofuels—two percent for 2005 and 5.75 percent for 2010—were put forth. In addition, the EU has demanded an analysis of ecological, economic, and social impacts to ensure that only those biofuels are used that have advantages over conventional fuels.

DaimlerChrysler welcomes the goal of the EU directive, namely to reduce CO_2 emissions and to secure fuel supply through the introduction of alternative fuels. The target market shares are, however, seen differently. From DaimlerChrysler's perspective, an even higher market share for biofuels appears to be possible until 2020 if synthetic biofuels can be efficiently produced on an industrial scale in the coming years. Promotion beyond the year 2009 will be required to ensure the security of investments for biofuel producers. This should also include a grading according to environmental advantages.

In contrast, a ten-percent share of natural gas in the fuel market by 2020 is unrealistic since the natural gas reserves in the EU are limited and imports from distant natural-gas deposits in Siberia and the Middle East are restricted. Apart from this, no additional advantages in CO_2 emissions as compared to the diesel engine are achieved when the energy input and the methane losses during transport over long distances are taken into account. To the extent to which this is expressly requested by political institutions, natural gas can therefore only be used for fleets in most countries, for regionally limited applications, or as a raw material for the production of synthetic diesel.

Due to the significant investment required for the construction of a production and distribution infrastructure, a market share for hydrogen of five percent by 2020 appears to be too high. In spite of this, DaimlerChrysler sees hydrogen as one of the most promising fuels for the future and is engaged in intensive development work within the framework of an experimental design project on alternative propulsion systems.

Synthetic biofuels

In numerous scenarios on the development of energy requirements, special significance is attributed to energy and fuel generation from biomass. The reasons for this emphasis are the comparatively easy handling of the energy carriers generated from biomass, involving the application of proven technologies, the availability of raw materials in virtually all regions, the CO_2 advantages, and the rather low additional costs compared to conventional energy carriers.

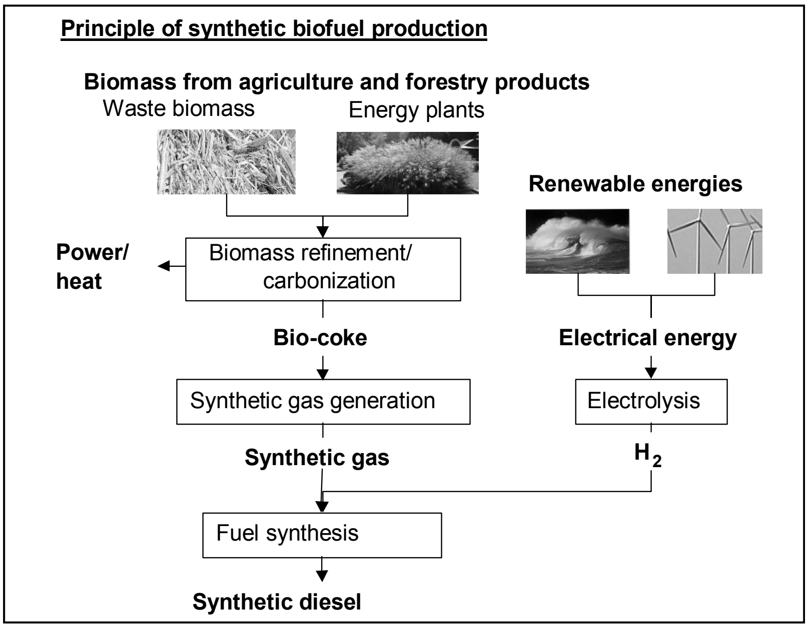
The energetic, technical, and economic aspects of fuel produced through the gasification or fermentation of biomass are currently being investigated in several projects. One possibility for producing synthetic fuels from biomass is provided by a process developed by Choren Industries, outlined in simplified terms in figure 6 (p. 78). DaimlerChrysler is actively cooperating with Choren Industries in research, strategy development, and in the political field.

Depending on the production process used, synthetic biofuels can have the following advantages:

- Reduced emissions, analogous to synthetic fuels made of natural gas (by 90 percent in the case of HC and CO and by 30 percent in the case of particulates)
- Additional reductions in CO_2 emissions by between 61 and 91 percent depending on the process
- No problems for engines and filling stations of the kind presented by other biofuels (e.g., RME, ethanol, methanol)
- Marketable fuel prices through exemption from mineral oil tax until 2009
- High volume potential since different types of biomass can be processed

- Reduced areas taken up in agriculture since complete plants are processed
- Contribution to the solution of the waste disposal problem

Figure 6
The "Choren" Process



When it comes to selecting the best suited biofuels and processes, reliable data concerning energy, materials, and costs as well as economically efficient facility concepts are required. These concepts must combine decentralized biomass generation with fuel production that should be as centralized as possible. The relevant data is elaborated in a lifecycle analysis and verified in field tests. The results show that synthetic biofuels are a promising option. Consequently, DaimlerChrysler promotes these fuels by engaging in pilot projects and policy discussions.

The Role of Technology in the EU–US Climate Change Debate: The (Only) Way Forward?

Christian Egenhofer[*]

It is a widely held view that technology will play the decisive role in ultimately achieving stabilization of greenhouse gas (GHG) emissions at politically acceptable levels. Furthermore, international cooperation to promote the development and diffusion of new breakthrough technologies has appeared as the single most important initiative to rebuild transatlantic relations. Unfortunately, the EU and the US have found themselves supporting two polar views: “technology push” versus “market pull.”[1]

The technology push approach argues that the principal emphasis should be on technology development, financed through typical public R&D programs. Proponents argue that it would be preferable to invest in the short term in R&D and to adopt emissions limitations later, when new technologies will have lowered the costs of limiting GHG emissions.[2] The market-pull approach argues that technological change is an incremental process emanating primarily from business and industry, induced by government incentives. Profit-seeking firms would respond with technological innovation.[3]

There is a growing consensus that neither technology push nor market pull on its own will be able to meet the climate change challenge. The International Energy Agency, for example, argues that energy efficiency improvements offer the greatest potential to reduce GHG emissions in a 2030 perspective. Such improvements depend critically on government incentives.[4] At the same time, it is increasingly accepted that new and technically unproven (i.e., breakthrough) technologies need to be devel-

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[1] See Galeotti, M. and Carraro, C. Traditional environmental instruments, Kyoto mechanisms and the role of technical change. In: Carraro, C. and Egenhofer, C., eds. (2003) Firms, Governments and Climate Policy—Incentive-based Policies for Long-term Climate Change. Edward Elgar, Cheltenham; Grubb, M. and Stewart, R. (2004) Promoting Climate-Friendly Technologies: International Perspectives and Issues. INTACT Project Paper; Goulder, L. (2004) Induced Technological Change and Climate Policy. Report for the Pew Center on Global Climate Change, Arlington.

[2] See Humphreys, K. (2001) “The Nation’s Energy Future: The Role of Renewable Energy and Energy Efficiency.” Testimony to the Committee on Science of the US House of Representatives, 28 February 2001; Edmonds, J. (2003) Toward the Development of a Global Energy Technology Strategy to Address Climate Change. Paper prepared for a strategic roundtable at the Global Energy Scenarios of the World Gas Conference.

[3] Grubb, M., Koehler, J., and Anderson, D. (2002) Induced Technical Change: Evidence and Implications for Energy-Environmental Modelling and Policy. Annual Review of Energy and Environment 27, 271–308.

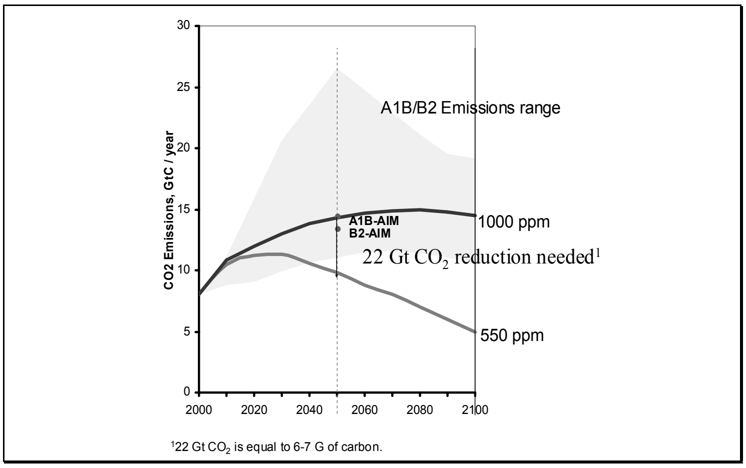
[4] International Energy Agency, op. cit.

oped in the long term to meet the stabilization objective of the United Nations Framework Convention on Climate Change (UNFCCC).

The meaning of meeting the global climate change challenge

To illustrate the climate change challenge, the World Business Council for Sustainable Development, using scenarios developed by the UN-sponsored Intergovernmental Panel on Climate Change (IPCC), estimates that, in order to achieve stabilization of GHG concentrations, there is a need to reduce global CO_2 emissions by 22 billion tons of CO_2 per year by 2050—almost as much as today's total global emissions[5] (see Figure 1). This may require a peak of global emissions by around 2020, since GHG emissions stay in the atmosphere for a long time.[6]

Figure 1
Achieving an acceptable CO_2 stabilization



Source: World Business Council for Sustainable Development (2004) Facts and Trends to 2050—Energy and Climate Change. WBCSD, Geneva. Retrieved from <http://www.wbcsd.ch>.

To illustrate the scale of the task, a reduction of just 3.3 billion out of 22 billion tons of CO_2 (or 1 gigaton out of 6–7 gigatons of carbon) would necessitate increasing current global wind power capacity 150 times, bringing into operation 1 billion hydrogen cars to replace conventional 30-miles-per-gallon cars, boosting current nuclear capacity five-fold, or using half of the agricultural area of the US for biomass production.

Although there are different opinions on whether or not the 2050 goals can be reached with technically proven technology, there is a broad consensus that there is a need for real breakthrough technology beyond 2050. Pacala and Socolow and the IPCC argue that current technologies could solve the climate problem for the next 50 years, while Hoffert et al. believe that new and revolutionary technologies will be needed.[7]

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[5] 22 Gt CO_2 equals 6–7 Gt of carbon.

[6] CO_2, the most important GHG, for example, stays in the atmosphere for 100 years.

[7] Pacala, S. and Socolow, R. (2004) Stabilization Wedges: Solving the Climate Problem for

Figure 1
The challenge: 3.3 billion tons of CO_2 emissions reduction per year requires...

Technology	*Required for 3.3 Gt CO_2/yr (1 GT carbon)*
Coal-fired power plant with CO_2 capture/ storage	700 x 1 GW plants
Nuclear power plants replace average plant	1500 x 1 GW (5 x current)
Wind power replaces average plant	150 x current
Solar PV displace average plant	5 x 106 ha (2000x current)
Hydrogen fuel	1 billion H_2 cars (CO_2-free H_2) displacing 1 billion conventional 30 mpg (7.84 liters per 100 km) cars
Geological storage of CO_2	Inject 100 mb/d fluid at reservoir conditions
Biomass fuels from plantations	100 x 106 ha (half of US agricultural area)

Source: Egenhofer, C. and van Schaik, L. (2004) Towards a Global Climate Regime: Priority Areas for a Coherent EU Strategy. Report of a CEPS Task Force, Centre for European Policy Studies, Brussels. Based on presentation by ExxonMobil to a CEPS Task Force meeting on 22 October 2004. Available at <http://www.ceps.be/Article.php?article_id=375>.

EU and US differences political economy perspectives on technology

The EU's short-term policy response to climate change has been to embrace the Kyoto Protocol, which can be explained by the largely synergistic relationship between the EU's natural gas supply situation and other EU policy objectives, such as power and gas market liberalization. Moreover, weak EU competencies in the areas of energy policy and security of supply in combination with relatively strong competencies in the fields of market liberalization and the environment have forced the EU to frame climate change responses in the context of energy efficiency and conservation rather than in energy policy logic.[8] Climate change policy has been coined as a "win-win" situation with regards to security of supply, higher efficiency, more competition,[9] and co-benefits through reduction of local

the Next 50 Years with Current Technologies. Science 305, 968–972; Intergovernmental Panel on Climate Change (2001) Third Assessment Report: Summary for Policy-makers. United Nations, New York; Hoffert, M. I. et al. (2002) Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet. Science 298, 981–987.

[8] See Wriglesworth, M. and Egenhofer, C. (2005) Security of Energy Supply and Climate Change in the EU: Setting the Stage. Background Paper for the INTACT Project on "Transatlantic Dialogue on Climate Change," Sub-group on "Technology & Standards."

[9] Market liberalization and integration have transformed the traditional notion of security of supply in the EU and elsewhere. Within competitive markets, firms in principle invest in those technologies that promise the highest return on capital, which has meant that the power generation sector favors the solution with minimum capital investment and the fastest returns. A result of EU electricity and gas market liberalization has been a dash for gas, mainly in the form of CCGT and CHP, to the detriment of more

pollution. In a short-term perspective, understandably technology did not play a major role. The relatively modest Kyoto Protocol target helped as well.

More important, however, is the EU's security of supply position with regard to natural gas and its transformation through gas and electricity market liberalization. The strategic positions of the EU and the US in natural gas are profoundly different: according to European Commission data, 80 percent of global gas reserves are located within an economically transportable distance to the EU, compared with around 10 percent for the US. These reserves could cover Eurasian demand for 50 years. Hence, switching from coal to gas is a viable, cost-effective short-term policy for the EU but less so for the US, where the share of coal in power generation is expected to remain stable and continue to account for about half of all fuels.[10] Climate policy will put pressure on coal. Any US alternative short of deploying carbon capture and storage would increase concerns about security of supply.

Against the background of minimal trade-offs in the EU—at least in a short-term perspective—between climate change, security of supply, and market liberalization, it should not come as a surprise that the energy sector has been broadly supportive of EU climate policy approaches and the EU Emissions Trading Scheme (ETS). A modest carbon constraint, especially when implemented through the EU emissions trading scheme and based on free allocation, has been seen in business circles as enhancing efficiency and even security of supply, as many energy savings measures come at a low or even negative cost.[11] In addition, as long as allowances are given for free ("grandfathering"), the competitiveness effects on industry are minimized.[12]

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capital-intensive generation technologies. The EU emissions trading scheme is another driver behind the use of gas.

[10] According to the International Energy Agency, the share of gas in power generation is projected to more than double in the period from 2002 (15 percent) to 2030 (35 percent). The European Commission does not rule out the possibility that 40 percent of total electricity will be produced from natural gas by that time. See International Energy Agency (2004) World Energy Outlook 2004. IEA, Paris. For US figures, see US Energy Information Agency (2003) Annual Energy Outlook—With projections to 2025. EIA, Washington, DC.

[11] European Commission (2001) European Climate Change Programme, Final Report, Brussels. Retrieved from <http://www.europa.eu.int/comm/environment/climat/eccpreport.htm>.

[12] See Carbon Trust (2004) The European Union Emissions Trading Scheme: Implications for Industrial Competitiveness. Carbon Trust, London; Renaud, J. (2004) Industrial competitiveness under the European Union emissions trading scheme, International Energy Agency Information Paper. Washington, DC; Quirion, P. and Houcarde, J.-Ch. (2004) Does the CO_2 emissions trading directive threaten the competitiveness of European industry? Quantification and comparison to exchange rate fluctuations. Presented at the EAERE Conference, Budapest, June 2004. Retrieved from <http://eaere2004.bkae.hu/download/paper/quririonpaper.pdf>; Egenhofer, C., Fujiwara, N. and Gialoglou, K. (2005) Business Consequences of the EU Emissions Trading Scheme, Report of a CEPS Task Force, Centre for European Policy Studies, Brussel.

It should equally not surprise that the US situation gives a more heterogonous picture.[13] At the federal, or national, level there is a focus on research and technology programs as well as on voluntary measures. The sub-federal level is characterized by a plethora of state and local government initiatives, including trading schemes. There are advocates for federal regulation, mainly in Congress, as exemplified by the bipartisan McCain-Lieberman cap-and-trade legislation. The business community remains largely divided. Corporations participate in numerous voluntary initiatives, but most oppose mandatory emissions limits.[14] A majority of US public opinion tends to favor stronger climate change policies than those advocated by the Bush Administration,[15] as also do a number of religious organizations and churches.

One result of the impasse over climate change policies at the national government level has been increased activism and cooperation among state and local governments at the sub-national level. It is often noted in this regard that there is a tradition of some states (especially California) taking the lead on environmental issues, with the national government eventually adopting policies that have been developed at the sub-national level. To some extent, this may yet happen with climate change policies.

A growing coalition of members of Congress—in both the Senate and the House of Representatives—supports a policy of mandatory domestic limits on GHG emissions. Although the coalition is composed predominantly of Democrats, it includes a number of Republicans, and its bipartisan leadership includes Senator John McCain, a prominent Republican. Both the congressional coalition and activist state and local governments tend to hail from the West Coast and the Northeast. The economic and political significance of fossil fuel industries in many Midwestern and Southern/Southwestern states is likely to prevent them from following the trend toward increased mitigation efforts in the far Western and Northeastern regions of the country. But they will be open to technology approaches.

Beyond Kyoto... at last: Technology in a post-2012 perspective

With the entry into force of the Kyoto Protocol, there finally may be an opportunity to move the political agenda beyond Kyoto into the "post-2012" period. While this will necessitate first an answer to how urgent the problem is, at the same time it raises the questions, what to be done next and what role technology policy will play?

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13 See Pew Center on Global Climate Change (2004) Climate Change Activities in the US: 2004 Update, Pew Center on Global Climate Change, Arlington; Brewer, T. (2005) The Political Economy of US Responses to Climate Change Issues (working title; forthcoming).

14 Some electric power companies have, however, publicly advocated a mandatory cap-and-trade system or a carbon tax.

15 For a detailed review of public opinion data from 1989–2005, see Brewer, T. (2005) US Public Opinion on Climate Change Issues: Implications for Consensus-Building and Policymaking. Climate Policy 5, 1, 2–18.

Let us look back to answer the second set of questions. In the aftermath of the Kyoto Protocol negotiations, and especially after the US rejection of Kyoto, numerous alternative proposals to the Protocol have been put forward (see figure 2).[16] When assessing these different approaches against environmental, economic, or equity criteria, it quickly becomes apparent that there is no magic solution to the climate change challenge. It will take many years to reach a global consensus. This conclusion should not be surprising. An effective response to climate change requires nothing less than aligning the national energy policies of more than 150 countries.[17] Rather than "reinventing the wheel," however, one would assume that a global agreement will have to build on parts on the Kyoto Protocol structure, while at the same time accommodating a number of additional

Figure 2
Different approaches to the climate change challenge post-2012

- An international agreement with *absolute—Kyoto style—targets*, but with modifications such as a safety valve, i.e., a maximum price on allowances.
- *Energy* or carbon-*intensity targets* to improve energy efficiency; the ultimate target can be an equal per capita emissions target.
- *Linkages*, i.e., linking participation to R&D cooperation or financial transfers.
- *Environmental conditionality* in which emissions trading is linked to environmental "progress," e.g., the Green Investment Scheme, or trade-and-back approaches.
- *Sector-specific targets*, i.e., a coordinated approach for domestic policies.
- Co-ordinated *global carbon taxes.*
- *Technology development* and international cooperation on R&D activities.
- A *combination* of different instruments, such as a combination of the intensity targets, sector-specific domestic measures and technology development in the so-called "triptych approach."
- *Orchestration of treaties* focusing on different co-existing commitments under different legal frameworks.

Source: Egenhofer and van Schaik, op. cit.

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[16] For an overview, see Torvanger, A., Twena, M. and Vevatne, J. (2004) Climate policy beyond 2012—A survey of long-term targets and future frameworks, CICERO Report 2004:02, Center for International Climate and Environmental Research, Oslo. Retrieved from <http://www.cicero.uio.no>; Aldy, J. E., Barrett, S. and Stavins, R. N. (2003) Thirteen plus one: A comparison of global climate policy architectures. Climate Policy 3, 373–397; Bodansky, D. (2004) International Climate Efforts Beyond 2012: A Survey of Approaches, Pew Center on Global Climate Change, Arlington. Retrieved from <http://www.pewclimate.org>; Kameyama, Y. (2004) The Future Climate Regime: A Regional Comparison of Proposals. International Environmental Agreements: Politics, Law and Economics 4, 307–326; see also figure 2.

[17] Ashton, J. and Burke, T. (2004) The Geopolitics of Climate Change. SWP Comments 5/04. Stiftung Wissenschaft und Politik, Berlin.

components, including technology. It is reasonable to expect that we will continue to live in a differentiated world.

The next priorities in a technology perspective

Most scholars and analysts attribute the EU–US climate change disagreement to divergent views on climate science, the role of domestic versus international action, technology, costs, the role of developing countries, and the Kyoto Protocol process itself.[18] In order to overcome the climate divide, there is a need for some convergence in all of these areas. This will take time, however.

In the meantime, we have argued on other occasions that the EU and the US (governments and stakeholders) should concentrate on three areas likely to be critical for the EU–US climate change agenda: (i) a (common) sense of direction, (ii) a determination to make the EU climate change policy work, and (iii) convergence on technology.[19] Progress in these areas is a prerequisite for a more constructive transatlantic dialogue.

A (common) sense of direction

The first important step is to forge a common understanding between the US and the EU on the urgency of climate change and to demonstrate together the will to achieve more ambitious reductions and technological innovation. The EU has tried to provide direction after EU heads of governments in March 2005 endorsed a target to limit the global average temperature increase to 2°C and indicated a willingness to explore with other countries the possibility of a reduction target for industrialized countries of 15–30 percent for GHG emissions by 2020 on a 1990 basis.

The UK has used its G8 presidency to develop a package of practical measures to cut emissions, focusing largely on technology as well as building a partnership with rapidly developing economies to find a way to combine economic growth with a low-carbon economy. This is an opportunity to inject fresh political momentum toward a new global consensus. The focus on technology and developing countries as the keys to tackling climate change has been a key US demand for some time. It is important,

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[18] See Cline, W. R. (1992) The Economics of Global Warming. Institute for International Economics, Washington, DC; Nordhaus, W. D. (1994) Managing the Global Commons: The Economics of Climate Change. MIT Press, Cambridge; Nordhaus, W. D., ed. (1998) Economics and Policy Issues in Climate Change, Resources for the Future, Washington, DC; Harris, P. G., ed. (2000) Climate Action and American Foreign Policy, St Martin's: New York; Purvis, N. and Mueller, F. (2004) Renewing Transatlantic Climate Change Cooperation. The Brookings Institution, Washington, DC; Michel, D., ed. (2005) Climate Policy for the 21st Century: Meeting the Long-Term Challenge of Global Warming. Johns Hopkins University, Center for Transatlantic Relations, Washington, DC.

[19] Egenhofer, C. (2005) Could a Transatlantic Greenhouse Gas Emissions Market Work?. In: Hamilton, D. S. and Quinlan, J. P., eds. Deep Integration: How Transatlantic Markets are Leading Globalization, CEPS Paperback published jointly with the Center for Transatlantic Relations of Johns Hopkins University.

however, that this new strategy not only responds to the concerns of the current US Administration, but also to those of other stakeholders, notably business, as reflected in the following remark by a representative of Tony Blair's government: "Business and the global economy need to know that this isn't an issue that is going to go away."[20]

Making EU climate change policy work

It is now up to the EU to show that climate change policy can be undertaken without ruining the economy. Implementation of the EU-ETS has already given strong signals to the US. Successful EU performance can help change the minds of US stakeholders. The EU-ETS has attracted increasing interest, globally and not just by Kyoto Protocol countries. US scholars are watching the EU-ETS intensively. The total value of current EU allowances of permits stands at around 50 billion EUR, as the allowance price has risen to almost 20 EUR recently. This might be too big a market to ignore. It is often forgotten that climate change policy can have important benefits beyond climate policy objectives. Such co-benefits of climate change measures are the reduction of local pollution caused by NO_x or SO_2, less congestion or noise from transport, innovation and technological leapfrogging and employment.[21] In fact, most studies assume that the benefits of reducing local air pollution are higher than the costs of reducing greenhouse gas emissions.[22] In short, climate policy is likely to have significant benefits that are not yet explicitly acknowledged. The examples of BP, Entergy, Toyota, or Rio Tinto show that reducing GHG emissions can yield net profits.[23] Finally, as the case of the Kyoto Protocol has shown, when the US is absent, other countries will proceed to define the international agenda as they deem most appropriate. A global or even transatlantic GHG emissions market may hold the best hope for a less fragmented business environment.[24]

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[20] Derwent, H. (2005) The G8 and the Post-2012 Agenda. Presentation at the 2005 Third Annual Brussels Climate Change Conference. Centre for European Policy Studies, Brussels & EU Conferences Ltd.

[21] Jochem, E. and Madlener, R. (2003) The Forgotten Benefits of Climate Change Mitigation: Innovation, Technological Leapfrogging, Employment, and Sustainable Development, OECD, Paris.

[22] See Organization for Economic Cooperation and Development (2002) Ancillary Costs and Benefits of GHG Mitigation: Policy Conclusions, ENV/EPOC/GSP(2001) 13/FINAL of 17.4.2002. OECD, Paris.

[23] BP calculated that reducing GHG emissions by 10 percent below its 1990 level had a net benefit of 650 million USD. See Browne, J. (2004) Beyond Kyoto. Foreign Affairs 83, 4, 20–32.

[24] If one believes leading global business associations, there is a growing concern about an increasingly fragmenting or even disintegrating regulatory framework. One of the recurrent themes of business responses is the creating of a greenhouse gas emissions market. According to Steve Lennon, chair of the environment and energy commission of the ICC, which includes major US companies, business sees a "global system of emissions trading as inevitable." See Harvey, F. (2005) Business pushes G8 on global warming. Financial Times, June 24, 2005.

Convergence on technology

Given that medium-term targets will be more constraining than the current ones from the Kyoto Protocol, the EU will require more radical changes. This is likely to lead to greater distributional consequences and we should expect the relative consensus among stakeholders in the EU to come under pressure. This effect can already be observed in during the emerging discussions on the post-2012 EU strategy, as well as on the future of the EU Emissions Trading Scheme.[25]

Since longer-term targets can only be met by the development of new technologies and the massive diffusion of both new and existing technologies, the EU also needs a greater focus on technology. This will become increasingly apparent after 2012, when the modest sacrifices that have had to be made among EU countries until now give way to starker distributional trade-offs and harder political choices. Such trends may prod the EU toward greater convergence in thinking with the US, where the strong emphasis on technology is already apparent.

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[25] See two CEPS multi-stakeholder Task Force reports that analyze these issues: Egenhofer, C. and van Schaik, L. (2005) Towards a global Climate Regime: Priority Areas for a Coherent EU strategy; and Egenhofer, C. and Fujiwara, N. (2005) Reviewing the EU emissions trading scheme: Priorities for short-term implementation of the second round of allocation. Part I. Available at <http://www.ceps.be/files/TFReport_EU_ETS_Part_I.pdf>.

Energy Security

Energy Security and Climate Change: Parallels and Policy

Friedemann Müller[*]

In recent times both energy security and climate change have received increasing public attention as well as higher priority on national agendas (energy security) and the international and G8 agendas (climate policy). The coincidence of these political developments is not surprising, since both problems are inherently related.

The most obvious aspect of this relationship lies in the ties of these issues to the exhaustion of resources critical to human society. According to numerous expert assessments, oil and natural gas, the most attractive primary energy sources, will be more or less exhausted by the second half of this century. While optimistic assessments place the peak of global oil production at sometime within the coming thirty years, the majority of experts expect it to occur as soon as during the next decade. The absorptive capacity of the atmosphere towards greenhouses gases is also limited, as is implicitly stated in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC). This convention, ratified nearly globally, including by the United States and the European Union, defines the "ultimate objective" as the "stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

The necessity to reduce the share of oil and, in the long run, of natural gas in overall energy consumption links both policy fields. Energy security is threatened through

- The increasing role of China, India and other developing countries in a market that has been dominated on the demand side by OECD countries over the past decades. As a result of their preponderance in this market, OECD countries have, until now, to a large extent determined the rules of the energy game. Now it is obvious that this market has not only come under pressure due to the massive demand increase—2004 was the year with the highest global energy demand growth in twenty years—but also is becoming more and more politicized. China, for instance, now defines quite a number of energy-rich regions as vital to its security of supply, making it more difficult to establish stable rules and stabilizing policies. As an example, a coherent UN Security Council policy towards Sudan was hampered by China, which sees Sudan as one of its potential energy suppliers for the future;

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- The increasing proportion of oil and natural gas resources within the so-called Strategic Ellipse. The extension of this Ellipse includes the Persian Gulf, the Caspian Sea region and the main energy fields of Russia. The production of oil in all other areas worldwide can be expected to peak within the near future. As shown in figure 1, the Middle East, with its more than 60 percent share in world oil reserves, can bide its time until other oil regions exhaust their reserves while having not only the trump card of a much longer life expectance of its own reserves but also the advantage of much lower production costs and thus higher profits per barrel. However, in spite of skyrocketing profits that ever increasing dependence on its oil and gas supplies will bring this region, it is questionable whether the perennially shaky Middle East will gain stability.

Figure 1

	Reserves	*Share in World Reserves*	*R/P* years*
Middle East	727	63%	88
Latin America	118	10%	31
Africa	102	9%	33
Russia	69	6%	21
Asia/Pacific	48	4%	17
USA/Canada	48	4%	13
Europe	18	2%	7.5
Caspian Region	17	2%	26
World	1148	100%	41
of which OPEC	882	77%	80

*R/P = Reserves per yearly production (2003).

Climate policy also requires new ideas. Neither a peak in global greenhouse gas emissions, a necessary precondition for the stabilization of greenhouse gas concentration in the atmosphere, nor even a reduced growth of global emissions can be expected unless radical changes take place in our consumption of fossil fuels. On the contrary, emission growth will certainly be higher during the current decade than in the previous one due to the rapid recovery of economies in transition such as Russia, whose industry collapsed during the 1990s. Longer-term projections also do not show a significant reduction in global emission growth rates.

Taken as a whole, industrialized countries produced no emission growth during the 1990s—growth in the United States and countries such as Australia was offset by a decline in economies in transition. At the same time, though, a huge additional amount of greenhouse gases (more than 3 billion tons annually or one eighth of the total global emission) was emitted in developing countries in 2002 as compared to 1990. The International Energy Agency expects further growth in global CO_2 emissions of 62 percent between 2002 and 2030, with more than two thirds of this growth taking place in developing countries. Notably, it is precisely this region that neither feels responsible for the problem of climate change due to its much lower per capita emissions (emissions per capita are about one sixth of those in industrialized countries) nor has the technologies required to reduce emissions at its disposal by either changing the energy mix to non-fossil energies or by improving its extremely low energy efficiency.

At least with regard to China and India, the energy security and climate problems closely parallel each other. While per capita oil and natural gas consumption and per capita greenhouse gas emissions are still low in China and India, as in other developing countries, the growth rates of both energy consumption and greenhouse emissions are extremely high. This growth is related to the inefficient use of energy in these countries. If China improves its energy efficiency (energy consumption per GDP on an exchange rate basis) between 2002 and 2030 in a linear fashion such that its efficiency coincides with the EU level of 2002 at the end of this period, it will demonstrate no growth in energy consumption during the whole period and can maintain an annual GDP growth of 7.8 percent. This energy efficiency improvement offers a huge potential for mitigating both the energy security and climate problems.

Is there a parallel solution to both problems?

Stabilizing and reducing greenhouse gas emissions requires, most of all, a reduction of carbon dioxide emissions from fossil fuels. These emissions are responsible for about three quarter of all greenhouse gas emissions. In order to achieve such a reduction the most important options are:

- increasing energy efficiency (for instance by increasing the mileage of automobiles)
- shifting the energy mix to less carbon-intensive energy sources

Both approaches require improvements in applied technologies. The increase of energy efficiency in industrialized countries is steadily making progress, however with a declining rate of improvement in Europe and Japan, where the energy efficiency is already the highest. In the years to come, global efficiency improvement rates will likely be lower than GDP growth so that the overall emissions will increase if the second option is not exercised. The reason for this overall decline in efficiency improvement lies in the fact that largest potential for energy efficiency improvement is present in developing countries, where the allocation of the necessary investment is difficult to organize.

A shift in the energy mix can be brought about through a number of schemes described in figure 2 (p. 94), each with a different impact on energy security and global climate.

As described in figure 2, a number of alternatives to the current energy supply can be envisioned that have an impact on either climate and energy security (or both). Two of the options—coal/natural gas liquefaction and import diversification—can have a positive effect on energy security but not on climate change. Substitution of coal and oil by natural gas—for instance in power stations and heating systems and possibly in the transport sector—will have a limited positive effect on climate-relevant emissions. If taken on its own, this option has no real effect on energy security because natural gas is not obviously better in terms of diversity of supply than oil or coal. In combination with an import diversification strategy, it could, particularly in Europe, have a positive effect on energy security. In the special case of power stations, though, this effect will not be achieved even through combination of these options, since imported natural gas will substitute domestic coal in both Europe and the United States.

Figure 2

Energy option	*Technology required*	*Impact on*		*Major obstacle*
		climate	*energy security*	
Clean coal	Carbon sequestration	+	+	Cost, possible leakage
Renewables	No new technology: improvement of production costs and efficiency	+	(+)	Cost, shortages in key resources (silicon)
Hydrogen	Efficiency enhancements	(+/–)	(+)	Requires large energy input: not an energy source, per se implementation difficulties in the transport sector
Nuclear power (fission)	No new technology: Reduction of nuclear fuel required and waste produced, safety improvements	+	+	Proliferation, waste disposal, scarcity of uranium
Nuclear power (fusion)	Contained fusion technology with lower energy input than output	+	+	Long lead-time expected before working fusion reactors can be introduced
Coal/natural gas liquefaction	No new technology	–	+	Extremely high carbon emissions
Substitution of oil and coal with natural gas	No new technology	+	(+/–)	Large investment with little effect on carbon emissions or dependence on foreign energy sources
Import diversification	No technology required	none	+	Limited option

Nuclear power (fission) clearly serves both energy security and climate objectives. Doubts, however, are widespread whether the share of nuclear power in overall energy will be increased. The combination of problems—the proliferation issue, long-term nuclear waste disposal problems and the scarcity of uranium, but also acceptance among the voting population—

will probably only lead to more nuclear capacities in a minority of states. Whether they will offset the reduction of capacities in other countries is doubtful. The US and the EU as a whole will probably not significantly increase the share of nuclear energy in their corresponding electricity production.

The most interesting and promising alternatives to the current energy structure will be provided by *clean coal, renewables, hydrogen and nuclear fusion*. While renewables are increasing their market share slowly, on a low level, clean coal could become a breakthrough technology within the next twenty years. Hydrogen and, to an even larger extent, nuclear fusion represent technologies that will hardly provide a tangible contribution to the energy mix in the foreseeable future. Both, however, could play an enormous role in the energy supply at the end of the century.

Coal sequestration or better "carbon capture and sequestration" (CCS) is an advanced technology with still some uncertainties about its long-term safety. The application, particularly in power station could definitely bring about both increased energy security and reduced carbon emissions. Energy security will be improved because coal is the most widespread energy source. It is available in all major regions in the world. The costs of CCS—currently about 70 USD per ton of CO_2 (Edenhofer, 2005)—can be made economically competitive if an ambitious emission cap internalizes the external costs resulting from the damage caused to the climate system by greenhouse gas emissions. While an ambitious climate policy would require carbon extraction of no more than 1200 GtC, a business-as-usual-scenario projects emissions of about 2200 GtC (Edenhofer, 2005). One fifth of the necessary reduction could be provided by CCS at minimum risk.

The advantage of *renewables* can be best represented through its steep learning curve, which indicates that costs associated with renewable energy technologies have been reduced significantly and will also probably be reduced further during the years to come. They are already competitive in areas where the infrastructure for large scale electricity production and transportation is non-existent and its establishment economically not feasible. Therefore their largest future market may be located primarily where large energy efficiency improvement potential is located: in developing countries.

The *"hydrogen economy"* is generally understood to refer to a decentralized network of power stations providing hydrogen primarily to the transport sector. Insofar as that it can be produced wherever electricity is available, it can provide a major contribution to energy security. With respect to climate policy, it only makes sense if the electricity is produced on the basis of low or zero emissions. Large solar power stations might not necessarily only be profitable in industrialized countries.

The same source of energy that powers the Sun, *fusion* is an ideal energy source since its fuel consists of resources that are abundantly available. In practice, producing electricity efficiently from fusion, however, has proven to be a huge challenge. The accumulated experience of decades of research encourages us to believe that the problem is solvable but will require an increased R&D effort. Further, even under optimal conditions, best estimates tell us that it will take at least four decades before this source of energy is economically viable. Optimistic assessments indicate that, by the end of the century, nuclear fusion could provide enough electricity so that large-scale production of hydrogen could also benefit from it. If thus power production and the transportation could be organized on the basis of fusion and hydrogen, this would be the major step to the solution of the energy supply and the carbon emission problem.

Political instruments

There is a clear transatlantic consensus that political intervention into energy supply and usage should not neutralize market forces but make the market work efficiently. Further, national or even international political interests can be satisfied through R&D that includes government-funded financial incentives and, through these incentives, moves the market in a specific direction. Major policy instruments might create either a push or a pull effect:

- Government support of R&D can bring about a *push effect*. This support is provided in order to promote the development of an advanced technology designed to serve stated political goals such as the improvement of energy security or the prevention of "dangerous interference with the climate system."
- Regulatory measures such as emission caps produce a *pull effect.* Such measures could also include rules prohibiting the importation of more than a quarter of oil supplies from a single region. The pull effect forces particular actors to contribute to the realization of alternatives to existing structures.

Effectively combined, push and pull effects can provide the necessary framework to achieve a certain political objective. Thus, for instance, caps on carbon emissions might drive the implementation of technologies developed through government research initiatives. If the push and pull instruments can be coordinated in a way such that both energy security and climate security can be improved, readiness to make use of both of these instruments might be strengthened.

Transatlantic strategies

While the climate issue is unarguably a shared global one, energy security is a problem generally associated with national interests. While on the consumer side, energy policy is presently organized almost exclusively on a national basis, it is obvious that joint efforts may be part of the optimization process in supporting energy security. Joint efforts in this direction might be even more attractive if the climate problem can be solved at the same time.

Transatlantic leadership will be indispensable in organizing international climate policy. Developing countries cannot be relied on to take the lead in this field due to a lack of technology options and their general refusal to invest into a solution of a problem which they are convinced that others have created, as described above. Russia also will not accept a leadership role although it has very much contributed to the climate problem, since its energy waste and resulting greenhouse gas emissions are worse than those of countries like China and India. Apart from the fact that it is still struggling to overcome its transition problems, Russia lacks the required technologies to improve its energy efficiency.

The United States and Europe have the option to invest into technologies that can help to solve both the challenges on the field of energy security and climate change. Additionally they possess the resources to organize national and international regulatory systems that few others have. Building on these strengths, the following strategy options are recommended:

- a much stronger joint US–European effort to support R&D in the fields of carbon capture and storage, hydrogen technology, nuclear fusion, and renewable technologies such as biomass
- an emissions cap organized in such way that national emission trading markets can be linked to international or regional markets like the European Emission Trading Scheme (ETS). Ultimately such a system should be structured in such a way that it can be made attractive to those who have a big potential for efficiency improvement such as China, India and other still developing countries.

While a joint US–European R&D effort provides direction to energy research, it will not mobilize the investments necessary to bring products of this research to the market. As a result, financial incentives must be offered through a legal framework that internalizes costs resulting from securing energy supply and from environmental damage caused by greenhouse gas emissions. Placing a cap on emissions can achieve this result in such a way that the market will choose the least-cost option for implementing the necessary measures.

The era of oil and natural gas as major sources of the global energy supply will, in any case, come to an end within this century. The sooner we are prepared to make use of alternatives, the more both energy security and the climate will profit. Thus we must be guided by the need to choose the technology options that help to deal with both challenges.

Beyond Petroleum: Energy and Environmental Security

Chris Mottershead[*]

The well-being of world's six billion people is underpinned by secure access to affordable and clean energy—making energy and environmental security an issue for us all. The following essay does not try to argue for a particular outcome but rather is a personal view of some of the drivers that will shape the future of energy supply and use.

Energy security is a complex concept, made up of a number of individual but connected concerns, each with its own technical, economic and political dimensions:

- *Availability*—is the primary source of energy physically available in material volumes and can it be technically produced?
- *Access*—is the resource open to exploitation, and can the necessary political, technical, and financial resources be applied?
- *Demand competition*—will increased demand from growth areas increase concerns about energy availability?
- *Physical security*—can the energy be accessed and transported to market without fear of physical interference by theft, terrorism, or war?
- *Reliability*—can the energy be made available upon demand?
- *Cost*—can the energy be produced and sold at a competitive price?

Environmental security is about the health of people and the biosphere, while these two areas are interdependent in a way that we are only starting to fully understand, it could be considered to be made up of three individual but connected concerns:

- *Well-being*—does the availability of energy enhance access to food, water, and other needs associated with human well-being?
- *Health impact*—what is the direct health impact from local emissions or the indirect impact upon health from global changes to the climate?
- *Ecological damage*—how is the world's biosphere impacted by the production and consumption of energy?

Ethics of energy provision

The provision of clean and affordable energy is a global concern, as it underpins the availability of basic necessities like food, water, sanitation, and shelter and fuels the provision of heat, light, and mobility that are the foundation of economic growth and social progress. However, its provision

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does raise ethical issues, for example, concerning fair and equitable access to energy for the world's poorest and most vulnerable people.

Energy provision is a global issue, but consumption is local; managing it therefore requires collective understanding and local action. Local needs and culture will dictate many pathways from energy production to use, with many diverse stakeholders, each with their own objectives. The diversity of social, economic, and environmental drivers is a rich source of differentiation between stakeholders in a world that cannot wait for full understanding and ideal solutions.

Rich economies benefit from fossil fuel consumption, but the impact of the associated carbon emissions affects some of the world's most vulnerable people in the least developed countries. Very reasonable arguments around fairness and equality can too quickly descend into assertions about economic inequality and differing definitions of social justice. This cannot be ignored, but neither can it be resolved for energy without reference to the broader journey of human progress and development. A journey that will be enriched for sometime by our common concern for things like fuel poverty and climate change, but a journey whose breadth encompasses so many other things, and which will continue long after our current concerns have become part of history.

Steve Pacala and Rob Socolo from Princeton University have shown that the necessary technical solutions to climate change already exist, at least for what needs to be done over the next 50 years. The question is whether we choose to take the necessary action to make climate change an integral part of the journey. Learning to mitigate and adapt to climate change, like all journeys, has a past, present and future. The past provides us a rich pool of personal experience and shared knowledge from which we create understanding about what is possible. The future provides hope and is most effective when focused by a shared aspiration. Only the "present" provides us with the space to take action. However, these actions need to consider competing objectives such as poverty alleviation, so action needs to be thoughtful, paced, and purposeful. It should not be gestures based on shifting ethical fashion, or worse the overreaction to alarmist predictions of doom, but enduring, confident, and timely action where we all:

- are open to what needs to be done,
- avoid asserting priorities between equally valid ethical propositions,
- do not prescribe solutions but let them emerge through experimentation,
- embrace a willingness to learn and adapt as understanding emerges.

Real progress has been made over many decades in providing energy and environmental security, to which the issue of climate change is a recent addition. Further progress can be made, as long as we are not deflected by unhelpful competition between "ideal" solutions and accusations of responsibility.

Society needs to consider the impact of its demand for energy, and the place to start is by being open about the probable impacts from consumption. These impacts are uncertain predictions about an unknown future, based on our evolving scientific understanding. We need to be cautious about being too certain about the future, but we need to take action; indeed we take action every time we choose to switch on a light or drive a car. The place to start is with an understanding of the impacts, so societies can allocate resources and make strategic choices, based on its best current understating of competing needs.

The World Health Organization (WHO) estimate 150,000 deaths were the result of climate change in the year 2000, of which just fewer than 80,000 were caused by malnutrition, around 50,000 were caused by diarrhea, and a little fewer than 20,000 caused by malaria. This demonstrates that the impacts of climate change are neither directly attributable nor are they unique, but rather climate change is an additional stress to existing major problems. In many of these areas solutions already exist, but are not fully implemented. For example, if we take the additional 80,000 estimated to have died during 2000 from climate impacts upon food production, then this has to be placed in the context of 840 million people in the world who are malnourished, of whom 24,000 die each day of starvation, despite there being enough food in the world to feed everybody. In fact, 1,100 million people are overweight. We need to ensure that we are realistic in our objectives, and that we are solving the highest priority problems.

There is reason to believe that greater collective concern and action is emerging, and this can be accelerated by improved cooperation between business, governments, and civil society. The creation and growth of clean energy businesses is dependent upon the willingness of consumers to purchase these solutions, either individually or through collective political agreement for action.

Energy and environmental security

According to the IEA, fossil fuel supplied 79 percent of primary energy in 2002 (coal 23 percent, oil 35 percent and gas 21 percent) and is again in a state of flux, as is the energy industry more broadly. A sustained higher oil price creates new competitive options, both from non-conventional fossil fuels and other sources of primary energy. Nuclear power is again becoming a real option for some countries, and there is renewed commitment to energy efficiency, renewables, and bio-fuels by many governments. While this flux reflects a broad range of concerns, energy security is at the core for many countries, along with the impact of environmental emission.

Energy security—Availability

There is no fundamental shortage of energy to meet the world's aspiration for economic growth and social progress. There are at least 40 years of proven oil reserves at current consumption, 60 years of gas, with considerable unexplored upside potential, and at least 200 years of coal supply. There are vast quantities of non-conventional oil and gas, such as heavy oil and gas hydrates. The power sector uses around 40 percent of all primary energy from a diverse set of sources, while transport uses around 20 percent but is nearly wholly dependent upon oil.

People have worried about the finite nature of oil reserves for many years, although they continue to grow each year to offset production. Current proven oil reserves are around 1,200 billion barrels, which will last at least another 40 years at present rate of consumption, slightly less allowing for growth. However, the volume of reserves is very dependent upon both price and the rate of technological innovation. It has been argued that since 1973 the oil price has been set by OPEC, or rather Saudi Arabia as the swing producer. It also represents on a long-term basis the marginal cost of non-OPEC production and particularly that of production by international companies, i.e., at the market cost of capital using the best available technology.

However, vast qualities of non-conventional oil and gas exist, as well as coal, all of which could provide liquid transport fuels. The wide geographical distribution of these resources counterbalances the increasing reliance in future decades upon the Middle East for conventional oil. Some non-conventional sources have demonstrated that they are economic at modest oil prices, for example, existing Canadian and Venezuelan heavy oil production. However, heavy oil, gas-to-liquids, and potentially coal-to-liquids become much more competitive at oil prices of around 35 USD per barrel, vastly increasing the effective reserves for liquid fuels. Having an alternative to conventional oil is important to provide sustainable security, even if you choose not to use it at scale. As a result, oil—conventional or synthetic—will probably remain the fuel of choice for transport for many decades.

Energy security—Access

While a great deal has been written about oil in the Middle East and other OPEC countries, its market share is only around 35 percent. Most growth during this decade is likely to occur from non-OPEC sources, but the IEA predicts that OPEC share will then rise, reaching 53 percent in 2030, just above the historic peak of 1973. Russia is the world's second largest oil exporter and the largest gas exporter. It has prided itself on providing sustainable access to its resources, particularly gas, over several decades of political change.

Over 96 percent of the world's transport requirements are met by oil, and the advantages of oil mean that there is no real alternative at present. Neither gaseous fuels, nor electric vehicles, are currently a viable alternative in most applications—although they do have successful niche markets. With the potential for sustained higher prices then there will be more diversity of supply, with biofuels and gas-to-liquid fuels or hydrogen becoming real options, as well as an increasing potential for coal-to-liquids, particularly if their production can be optimized by being associated with power production.

The overall increase in transparency around energy issues will increase awareness of where fossil fuels come from, allowing customers to be "resource conscious," potentially allowing them to make purchases dependent upon the social and environmental acceptability of certain resources. While price will probably remain the principal decision criteria, consumers may start to discriminate between supplies based on social and environmental ethics, at least when they have alternatives at the same price.

Energy security—Demand competition

Energy demand has grown due to both increases in population and per capita wealth. The world had 2.6 billion people in 1950, which grew to 6 billion in 1998, while gross world productivity increased by 583 percent between 1950 and 1999, from 6 trillion USD per year to 41 trillion USD (real 1998), with average per capital GDP increasing from 2,500 USD to 6,750 USD.

The increasing importance of Russian supply in providing global diversity of supply, and therefore security, is counterbalanced by increases in demand in China, which doubled its oil needs during the nineties to become the third largest consumer in the world at nearly 5 million barrels a day. This growth in demand looks as if it will continue.

The recent high oil prices have been caused by high levels of Chinese demand and continued economic growth in the OECD, as well as a lack of swing capacity in the Middle East. While additional capacity will be added, some countries are uncomfortable to simply rely upon the market to meet their particular demands in competition with others and are again seeking special relationships between producers and consumers.

Demand growth is driven by increasing need for basic services such as mobility, for example, in the US the miles driven increased by two thirds between 1982 and 1995, from 1.5 to 2.5 trillion miles per year. It can also be seen in the large increases in the ownership of energy-intensive goods, for example, the degree of global car ownership increased tenfold from 1950 to 1999, from 53 million to 520 million. Although there have been energy efficiency gains in most of these goods, they have often been used to improve the overall quality of the basic service, for example, improvements in vehicle efficiency have largely been offset by increases in size and weight of vehicles, delivering consumer preferences for vehicle performance, comfort, and safety.

Energy security—Physical security

Physically securing access to energy has long been a prime concern of governments, not least because access to reliable energy is an essential component of a nation's defense capacity. The emergence of a global commercial market for many forms of fuel and energy technology has reduced the degree to which conflict is motivated by securing physical access to energy. This is reinforced as countries become more dependent upon trade, with an increasing interdependence between countries for access to raw materials and markets.

However, there are a number of “choke points,” where physical interruption would have an impact, e.g., 15 million barrels a day of oil pass through the Straits of Hormuz, and 10 million through Strait of Malacca, 3 million each for Bab el Mandab and Suez Canal, 2 million for the Bosporus.

Many people are concerned about the security of fissile materials associated with nuclear power; this concern has increased recently because of the potential use of dirty bombs by terrorists. Others argue that the danger can be limited by the use of the right processes and technology, such as pebble bed containment.

Energy security—Reliability

The provision of energy upon demand is essential at many levels within a modern economy: consumer, business, industry, and critical services. The most important sources of failure are weather, equipment, underinvestment, poor maintenance and physical attack—such as vandalism, terrorism, or war. Beyond adequate investment and good maintenance, the key tools for managing the more uncertain events are redundancy and storage.

Liquid transport fuels can be stored, and various mechanisms exist for ensuring sufficient supplies are available, particularly for key services during periods of shortage. However, it is not economically viable to store electricity; in fact, one of the prime ways reliability is delivered for key facilities is to install standby generation that makes use of liquid fuels, which can be stored.

The failure of a power system can happen in the distribution, transmission, generation, or fuel systems. The increasing use of renewables extends concerns about fuel security because of the intermittency of many renewable sources. One way to deal with this is to extend the idea of “spinning reserve” through some level of capacity mandate, used to manage the need to constantly ensure supply and demand are balanced. However, there may be other and complementary routes that focus more on the inherent distributed nature of some forms of renewables, or other forms of distributed generation, for example, making more use of intelligent networks.

The interconnected nature of large power grids can provide economically efficient ways of delivering reliability, but they can also introduce exposure to the possibility of cascading failure, with the potential for wide spread disruptions. A key challenge in delivering reliability is to ensure that not only is power availability guaranteed, but that other key parameters are also delivered, for example, voltage, frequency, and reactive power. These parameters can change quickly, and the system needs to be able to manage them, so distributed generation does not introduce new sources of unreliability—a concern for some regulators when considering distributed generation concepts like net metering.

Energy security—Cost

There is much debate about how responsive overall demand is to price changes. According to the International Monetary Fund, at a macroeconomic level, large changes in oil price have a demand elasticity of around 0.5, while more modest changes are much more inelastic.

Oil consumption grew at 4 percent per year during the seventies, despite the large price increase of 1973–74, and eventual peak in 1979. This was partly caused by the utility sector and other users switching from fuel oil, with 5 million barrels a day reduction in demand, i.e., 10 percent of total oil demand, and a 50 percent reduction in fuel oil demand. Since that time, and through a 5-fold range in oil price, from 10 USD to 50 USD per barrel, oil demand increases have be around 2 percent per year.

Much of this inertia in demand is caused by equipment choice, not fuel choice. Price changes often impact equipment choice, on a timescale determined by capital stock turnover, rather than overall demand reduction for the primary energy needed for heat, light and mobility, and with direct fuel switching often having technical limits. However, demand can be suppressed by overall economic decline, demonstrated most clearly during the mid-nineties in Russia.

The price of energy often is not a conventional commercial return based on open market pricing; it is often regulated, for example, by public service commissions or through the imposition of producer and/or consumer taxation. The commercial cost of production in the Middle East is estimated by the IMF to be 2.6 USD per barrel for finding and development and 2.6 USD per barrel for production, providing a significant margin at higher oil prices for the resource owner.

International oil and gas companies also have an important role, for example, BP paid 76 billion USD in taxes during 2004 on revenues of 285 billion USD, 67 billion USD in consumption taxes, 6.4 billion USD in income tax, and 2.2 billion USD in production taxes. The future economics of energy needs to consider these, as they are an important source of revenues for governments, which are placed under threat if material increases in the cost of production or transformation of energy in needed to respond to concern of energy or environmental security.

Equally, some forms of energy attract direct or indirect financial support, such as renewable portfolio standards, rural support programs that encourage biofuels, assistance with public liability for the nuclear industry, and subsidies to the coal industry in some countries to protect employment.

Environmental security—Well-being

Energy is a prerequisite to social progress and economic development. It services basic human needs for water, food and shelter; it provides heat, light, mobility, and motive power that underpins social progress by enabling jobs, education, and health care. Energy has undoubtedly had a positive role to play in extending global life expectancy from 46 to 63 years over the last 50 years. The lack of access to clean energy means unnecessary poverty for billions. The IEA estimates that 1.6 billion people in developing countries are without any electricity in their homes.

There is a clear relationship between per capita energy consumption and measures of development, such as the Human Development Index (HDI), a measure of life expectancy, education and standard of living. Countries who consume less than 2 tons of oil equivalent per capita per year have a low HDI. Large gains in HDI can be achieved for relatively modest increases in energy use up to this level, with modest gains in HDI above this number, despite large increases in energy consumption. A similar result is obtained for electricity consumption, with a rapid rise in HDI for developing countries up to an inflexion point of between 3 or 4 MWhr per capita per year. The developed countries all exist above this inflexion point, and have much more modest increases in HDI despite large increases in consumption, up to the 20MWhr per capita per year in Canada. There is also a similar relationship with the availability of commercial energy, where penetration is below 20 percent then life expectancy is reduced by 10 years.

Urbanization is also a key driver. Over the last century the world experienced unprecedented growth in urbanization. In 1900 only 14 percent of the world’s population lived urban areas, by 1950 it was 30 percent, and in 2000 it was 47 percent–2.8 billion people. It is expected that by 2030 this will have risen to 60 percent. Most of the increase will be in developing countries, and much associated with the rise of megacities, i.e., larger than 5 million people. There were 5 megacities in 1950, all in the developed world, this rose to 41 megacities in 2000, and is expected to rise to 59 by 2015, of which 48 will be in developing countries. Supplying the necessary energy to fuel these cities will be a key challenge for the future, as will their demand on a whole range of key resources, such as water, arable land, minerals, and timber.

Environmental security—Health impact

Historically there have been two principle concerns about the impact of energy use upon human health. Firstly, the positive benefits associated with access to modern energy. Secondly, the negative impacts associated with the operational safety of energy production, and the public health impacts associated with emissions, particularly local air quality. Increasing focus is now being placed upon the human impact of climate change from the emissions of greenhouse gases, in particular the carbon dioxide emissions associated with the consumption of fossil fuels.

It is estimated that a quarter of all ill health is to some degree associated with poor environmental conditions. Currently 1.7 million people die each year from unsafe water, sanitation, and hygiene. While 0.8 million die from poor outdoor air quality and 1.6 million die each year from the inhalation of smoke from solid fuels. However, this is not just a developing country issue; there is evidence that 2 percent of all US deaths are associated with poor air quality, and 5.5 million children are affected by asthma. A recent health impact assessment for Austria, France, and Switzerland revealed that vehicle-related pollution kills more people than car accidents.

Another recent European study has estimated the combined cost of health externalities from the consumption of coal and oil to be in the range 0.02 to 0.07 euros per KWhr, i.e., broadly similar to the cost of generation. This cost is twice that associated with gas, while nuclear is half that of gas, and renewables half that of nuclear.

The change in regional weather due to climate change effects temperature, precipitation and the impacts of extreme weather, and is estimated to cause around 150,000 deaths per year. The principal health effects are upon malnutrition, water, and food-borne diseases, vector and rodent-borne disease, allergies, temperature-related illness, physical impact of extreme weather events, and air quality related health impacts. These impacts will combine with existing trends, for example, increasing cardiovascular disease associated with aging population, but some of the additional burden can be avoided by behavioral changes. Other impacts such as diarrhea will the reduced through improved living standards, where the recovery rate is nearly 100 percent once GDP per capita reaches 6,000 USD per year. There will also be geographical disparities as the deaths associated with climate change are highest in India and sub-Saharan Africa, while North America and Europe may actually see a reduction in deaths—as winter extremes become less frequent. As well as mitigating for the impacts of climate change by reducing emissions, some level of adaptation will be needed, e.g., improved weather warning systems, and the extension of existing strategies such as provision of clean water and oral dehydration for diarrhea or impregnated bed nets for malaria prevention.

Increasingly the health burden from energy consumption will be associated with urbanization in the developing world, where 13 of the 15 most polluted cities in the world are in Asia. The US adopted their first significant air pollution regulations during the 1950s, when per capita income was around 13,000 USD per year. Japan adopted modern regulations during the early 1970s, when incomes were around 11,000 USD per year. However China and India started to regulate emissions during the 1990s, when average incomes were only 1,500 USD per year, and in some respects these regulations have surpassed those of the developed countries; for example, recently China announced auto emission standards that are more stringent than in the US.

However, concern about such apparent modern concepts as urbanization and sustainable mobility are not new; in fact oil and the internal combustion engine were part of a previous solution to similar concerns. Despite horses being only half as energy efficient as humans, their greater power made them essential. In 1898, 25,000 tons of manure was being “emitted” each day from horses in Manhattan alone, creating an enormous health hazard and an expensive waste disposal problem. This was just as much a supply problem as one of pollution; by 1920, a quarter of US arable land was used to grow oats to fuel these horses.

Nitrous oxides (NO_x) emissions are the product of combustion with air, and play an important part in driving four key sources of damage: $<2.5\mu m$ particulates, ozone, acidification and eutrophication. The natural carbon cycle is not the only one being perturbed by human activity, so is the global nitrogen cycle. The impacts upon increased food production are wide recognized, but there also systematic negative impacts which are global in scale, for example, through increased respiratory and cardiac problems, as well as ecological damage.

Sulphur emissions from the combustion of coal and conventional petroleum fuels are important sources of both particulates and acidification, but the emissions are more controllable, either through removal of sulphur from the fuel in oil refineries, or through post-combustion process like flue gas desulphurization (FGD) on coal-fired power plants.

While in the past there has been a clear distinction between local air quality and the global impact of green house gas emissions, the boundary is starting to blur. In South Asia, air pollution is no longer focused upon emission “hot spots” but is an increasing regional haze. The result of forest fires, fossil fuel consumption, and the burning of conventional biofuels. The effects are not simply those direct impacts from conventional air pollutants but give rise to semi-global changes, e.g., a reduction in the level of sunlight reaching the earth’s surface and changes in the level of regional precipitation.

Environmental security—Ecological impact

The potential for ecological impacts occurs both from the production and consumption of energy, although the balance between these, the nature of the potential damage and geographical location of the impact varies dependent upon the particular supply chain from source to use. This makes comparisons between supply chains very difficult, not least because of different cultural expectations, even within a given supply chain. Of course, these different cultural expectations are not limited to different values placed on ecological impacts but also to broader ethical considerations. Thus, for example, there are legitimate differences in perspective on the benefits and costs associated with nuclear power. How do you assess the climate benefits from greater use of nuclear power against increased threat of nuclear terrorism?

Of course, energy is only one of a number of key resources where there are limits to their exploitation, for example, water, arable land, minerals, timber, as well as fossil fuels. The limits on exploitation may not always simply be about resource availability, for example, the limit to conventional fossil fuel consumption is probably more limited by the effects of climate change than they are the availability of fossil fuels.

Access to these key resources is also interdependent; both in a technical and political sense, for example, energy can be used to overcome fresh water limitations through desalination. Only 3 percent of world's water is fresh water, and most of this is locked in ice caps or glaciers. Of the available freshwater it has been estimated that half has already been appropriated for human use. At times the competition for this water and its quality gives rise to tension, particularly the impact on downstream users, e.g., between the countries that share the Danube, Nile, Jordon and Euphrates. At current consumption rates, 100 percent of freshwater will be appropriated by humans in 2050. Similar interdependences exist between energy and other key resources, such as the ecological, agricultural, and health benefits of making available modern fuels to those who still rely upon "sticks and dung" for cooking.

Environmental security—Costs

Over the last decade there has been much talk of "internalizing the environmental externality," and the emergence of emission trading as an economically efficient tool for achieving this. This in effect is a regulated cap on emissions, chosen to deliver some overall environmental benefit, but where the cost of compliance is optimized over the entire portfolio of emissions and sometimes from outside it through the purchase of offset credits. It is a market-based tool for making emission reductions required by regulators—who create a new property right, the right to emit—and people then trade this right. However, this is not the product of a conventional market—a tradable carbon product does not have the inherent ability to delight and engage consumers.

Of course, there is a small market for environmentally aware companies and consumers who will purchase carbon tradable products for their own satisfaction, particularly where their marginal cost is low, and therefore does not reflect the real cost of the externality. There is no evidence of a material market emerging for carbon tradable products outside those created by regulation, in fact, most of us still "talk thin and buy fat."

Emission trading markets price the marginal cost of abatement, and because the property right is for only a limited period, it should probably be the considered as the marginal cost of "doing nothing" on existing infrastructure, since the lack of enduring and legally binding caps means they cannot be used to justify major capital investment. Too many people incorrectly take the marginal cost within the trading system and multiply it by total volumes to establish the overall carbon market; this is erroneous as it misses two key facts. Firstly, in systems like the EU Emissions Trading Scheme most allowances are allocated free. Secondly, many companies will find many efficiency gains within their existing operations, where the net cost of emission reduction is net present value (NPV) positive. It is only the minority of carbon emissions that are priced within the trading scheme and then based on the assumption that there is an equilibrium between people buying and selling. Such an equilibrium does not necessarily exist, as there is a disparity between those with an absolute need to buy allowances to conduct their business and those who can generate allowances to sell but who may rightly choose to focus their limited efforts upon adding value in their core business.

Specific transitionary incentives are probably required to induce the necessary technological change required to stabilize atmospheric concentrations of carbon dioxide at acceptable levels. With such transitionary incentives it should be possible to achieve the level of sustained cost reduction seen in other energy technology, for example, both deepwater and photovoltaic technology has sustained a 5 percent per year cost reduction over many years, wind and liquefied natural gas 3 percent per year.

Increasingly governments will need to use a broad suite of policy measures to meet environmental objectives, including:

- Emissions *cap-and-trade* schemes to drive efficiency into existing major infrastructure,
- *Transitional incentives* to encourage the commercial deployment of near-to-market technologies like renewables and carbon capture and storage,
- *Investment criteria* to ensure that all new energy infrastructures are competitive against cost and emission benchmarks,
- *Public awareness* to create acceptance of public policy and an increasing customer base for clean and secure energy,
- *Regulation* where there is clear market failure, for example, energy efficiency in buildings.
- *Tax and trade consistency* to remove inconsistencies and barriers, for example, to allow the creation of an open global market for biofuels.

Conclusion

The next decade will lay the foundation for resolving the apparent contradiction between continued energy growth and the real carbon constraint—which is the atmospheric concentrations of CO_2, not the availability of fossil fuels.

Private sector energy companies continue to respond to new opportunities and increased competition. There is also evidence that shifts are taking place within public sector companies, as some transform themselves into hybrid companies, retaining overall state ownership and control but having a degree of private sector activity, which can access finance from international investors. However, this international finance increasingly comes with conditions of social and environmental performance associated with the private sector.

There are also an increasing number of well informed customers, including consumers, who favor clean and secure energy, and a minority of these who are willing to pay a premium.

A range of technology solutions to both supply security and environmental concerns exist, and are broadly economically viable. Energy efficiency, renewables, coal-fired generation with sequestration, and nuclear power clearly have advantages to both energy and environmental security. Others, such as heavy oil or gas/coal-to-liquids, will provide greater security but with increased emissions. However, even these emissions can be managed with some loss of overall energy efficiency.

While there is considerable uncertainty and complexity, solutions do exist, and ultimately, all that is required is a commitment to take action.

Climate Policy and Energy Security

Ottmar Edenhofer and Kai Lessmann***

Energy policy is faced with at least four crucial challenges. It has to balance climate protection, energy security, socio-economic acceptability, and equity. Balancing energy policy between these four goals is likely to be a challenging puzzle, much like finding a solution to the fabled magical squares. Between the four cornerstones of energy policy, trade-offs have to be made, but at the same time, pursuing the individual goals may yield strong synergies.

To date, the goals of energy policy are focused on the triangle of security, socio-economic acceptability, and climate protection. Equity is completely neglected in most social cost-benefit analyses of global energy policy. Admittedly, we are not in a position to undertake a comprehensive social cost-benefit analysis according to the proposed magical square ourselves. With this paper we want to broaden the scope of the discussion and shed some light on necessary extensions of the present framework. In the first section, we will discuss the relationship between climate protection and economic growth. This discussion derives crucial criteria for sustainability of the energy system and allows an identification of vital energy security issues in section II. In the third section, we discuss policy instruments for improving international risk management.

I Climate protection and economic growth

There is an emerging international consensus about the necessity of climate protection. Preventing the global mean temperature from rising faster than 0.2°C per decade and above 2°C relative to pre-industrial levels is one ambitious formulation of this challenge. Such constraints are necessary if dangerous perturbations of the climate system are to be avoided during the next decades. Otherwise impacts such as increased probability of extreme weather events, disturbances of the global water circulation, loss of biodiversity, or sudden shifts in monsoon dynamics will likely have to be dealt with. The imperative to avoid such impacts has been adopted as a “guardrail” by the German Scientific Advisory Council on Global Change (WBGU), which emphasized its importance again in its latest survey.[1]

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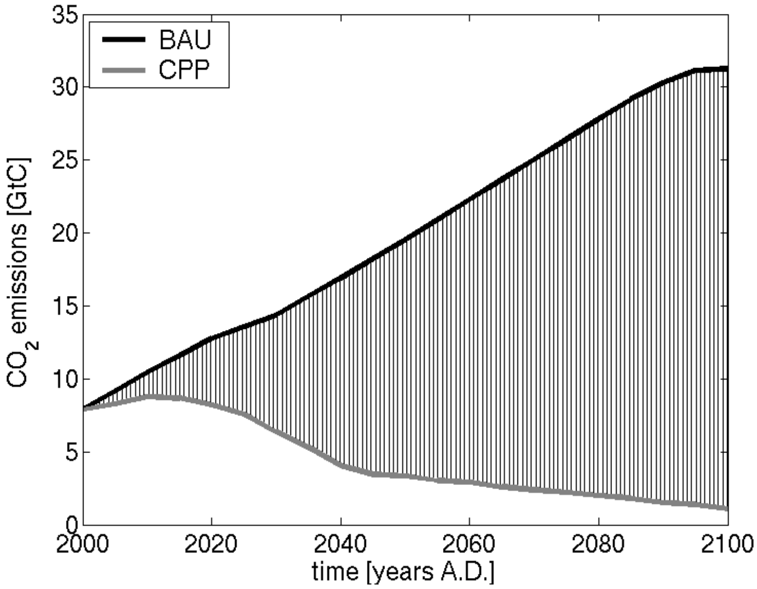
[1] German Scientific Advisory Council on Global Change (2003), World in Transition: Towards Sustainable Energy Systems. Earthscan, London and Sterling, 107.

Our calculations show that cost-effective climate protection according to this guardrail requires stabilization of greenhouse gas emissions within the next two decades in order to approach zero emissions at the end of the century. The gap between the business-as-usual (BAU) scenario of CO_2 emissions and the climate protection path (CPP) (see figure 1) shows the technical, economical, and political challenges with which humankind is confronted: a largely emissions-free economy at the end of the 21^{st} century in order to avoid dangerous climate change requires a profound change in the worldwide energy system. The world economy is about to face a new energy crisis, probably lasting longer and being a greater challenge than both of the oil crises of the 1970s. The reason for this new crisis is the need to overcome the mitigation gap and therefore transform the worldwide energy system.

Figure 1
The mitigation gap. The area between the climate protection path (CPP) and the business-as-usual path (BAU) is referred to as the mitigation cap. This amount of carbon emissions must be mitigated over the next century.



Unfortunately, many economists believe that overcoming this mitigation gap will be quite costly. Figure 2 shows estimated costs from several different studies. Stabilizing CO_2 concentration at a level below 450 ppm leads to increasing mitigation costs. The fact that in virtually all macroeconomic models losses in gross world product (GWP) surge when a target of less than 550 ppm is set demonstrates just how ambitious this goal of climate protection is.[2]

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[2] For a comparison see Morita et al. (2000) Overview of Mitigation Scenarios for Global Climate Stabilisation based on the New IPCC Emissions Scenarios (SRES). Environmental Economics and Policy Studies 3, 65–88.

Figure 2
The mitigation costs in different macroeconomic models

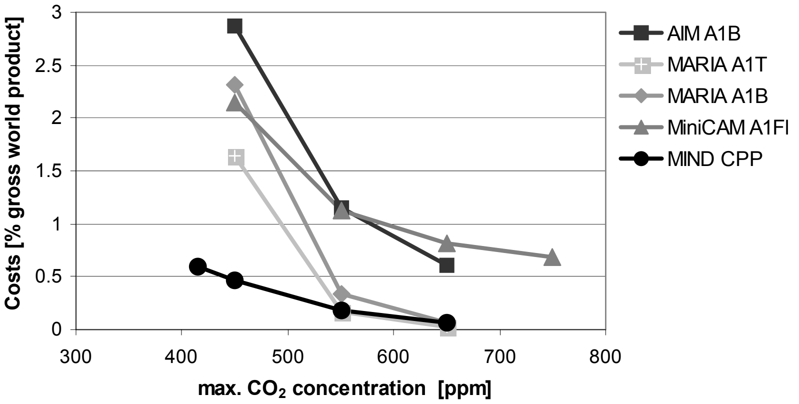

Figure 2 shows that the mitigation costs of scenarios calculated by the MIND model are significantly lower than cost estimates from comparable models used in the Third Assessment Report of the IPCC, in which similar socio-economic scenarios are assumed.[3] The calculations show that 0.6 percent of GWP is required to reach the WBGU endorsed climate protection goal of a maximum 2°C temperature rise, for which CO_2 concentration peaks at approximately 420 ppm. This is mainly due to the potential of technological change, and therefore the capacity of businesses and investors to react flexibly to the specifications of climate protection, which was included in the MIND model.[4] In the next section we explore whether a path of transformation can be found that exhibits such low costs and in addition has a positive effect on energy security.

II Energy security within the magical square

Within the next century, the energy requirements of humankind will likely increase four to five times relative to current demand in order to facilitate appropriate economic growth for the less developed countries as well as for the newly industrialized ones.

Energy scenarios in accordance with the aforementioned climate guardrails show that the share of renewable energy in the overall energy consumption needs to be increased substantially in the next decades—not only to achieve the ambitious climate targets defined by the WBGU (figure 3a, p. 114) but also for a mere stabilization of CO_2 concentration at 450 ppm (figure 3b, p. 114). Nevertheless, coal, crude oil, and natural gas continue play an important part within the global energy mix: figure 3a shows how a substantial reduction in the use of fossil energy resources is

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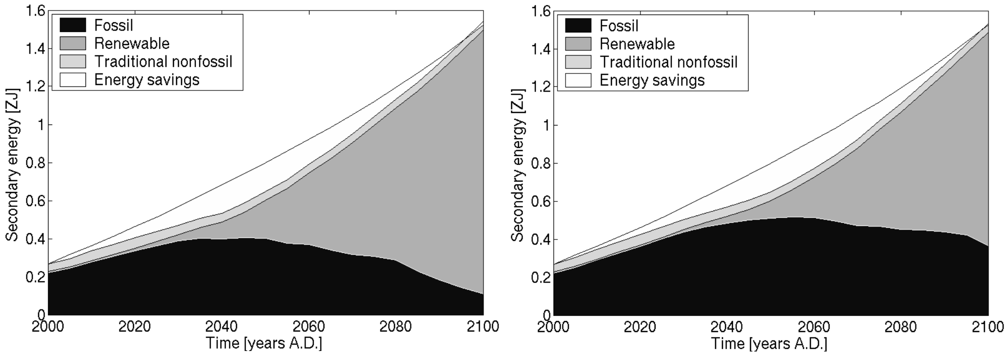
[3] Metz, B., Ogunlade, D., Swart, R., and J. Pan (2001) Climate Change 2001: Mitigation. Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

[4] Edenhofer, O., Bauer, N., Kriegler, E. (2005) The Impact of Technological Change on Climate Protection and Welfare: Insights from the MIND Model. Ecological Economics 54: 277–292.

necessary if the climate protection target put forward by the WBGU is implemented. In contrast, figure 3b indicates that fossil fuels can be used to their current extent, even if CO_2 concentration are stabilized at 450 ppm. In either case, fossil fuels can only be used to the extent shown if parts of the resulting carbon can successfully be captured from large power plants and be sequestered in geological formations. Despite the relatively high costs of carbon capturing and sequestration (CCS)—currently about 70 USD per ton of CO_2—this option could become economically viable if ambitious emission caps were agreed on and implemented in the next few decades. The reason is the considerable technical progress in exploration and extraction of fossil resources.

Figure 3
Two scenarios for the global energy system with respect to different climate protection goals are shown. On the left-hand side, the climate window of the WBGU is imposed on the economy, on the right-hand side, a stabilization of CO_2 concentration at 450 ppm is to be achieved.



The option of capturing CO_2 from huge coal power plants and storing it in geological formations offers the possibility of using the fossil energy resources without destabilizing the climate system any further. Likewise, this option could be of great importance for international climate negotiations: a climate policy stimulating this possibility would facilitate the entry of the US and other countries, such as China and India, into climate negotiation, because their income from coal, crude oil, and natural gas would be diminished less than by following climate policy without this option.

Above all, the US is increasingly discussing the possibility of “Industrial Carbon Management,” 50 percent of emissions in industrialized countries are produced by point sources, such as power plants and are therefore in principle accessible for CCS. However, the permeability of the geological formations, which critically determines the leakage of CO_2 from the sequestration site, has not been adequately investigated to date. Still, even at high rates of leakage of around 0.5 percent, sequestration of 160 gigatons of carbon (GtC) in geological formations by 2050 would still be of advantageous for the world economy, mainly to “buy some time” by postponing parts of the expensive transformation of the energy system to a later date. Leakage rates can be particularly "critical" in determining the costs of mitigation, as will be demonstrated below.

There is no global shortage of exhaustible resource likely during the 21st century. Reserves of traditional commercial fuels—oil, gas, and coal—will suffice for decades to come. It is assumed that once conventional oil resources are depleted, the huge unconventional oil and gas reserves will be tapped for extraction and clean generating technologies mature. Coal reserves are especially abundant: the resource base is more than twice that of conventional and unconventional oil and gas. The presently known reserves of these resources (coal, crude oil, natural gas) amount to approximately 5000 GtC.[5] Since the beginning of industrialization about 283 GtC have been used up.[6] In our business-as-usual-scenario we calculate that 2200 GtC will be extracted by the economy. If CO_2 concentration was stabilized at 450 ppm only 1200 GtC would be extracted; about 400 GtC would then be captured and sequestered in order to achieve climate protection.

In the scenarios considered, renewable energy resources are needed to provide approximately 20 percent of the worldwide secondary energy in 2050 and 80 percent by the end of the century. But these renewable energy resources are thought to be too costly by some energy economists. Consequently, they often favor a renaissance of nuclear energy in order to fulfill demands raised by climate protection. However, nuclear energy based on nuclear fission as a global solution is very problematic if not infeasible. The following estimates outline why.

In today's worldwide electricity production the share of nuclear power is 16 percent. The International Energy Agency (IEA) recently estimated that the worldwide electricity production will double by 2030.[7] In order to maintain the nuclear energy share at current levels, approximately 500 new pressurized water reactors would have to be built. In order to raise the share to 32 percent, approximately 1500 new nuclear power plants would be necessary. Not only would this increase the use of uranium and in turn drastically shorten the reach of this resource, but it would also intensify the problem of ultimate disposal of nuclear waste—not to mention the overall problem of proliferation. The reach of the known resource base for nuclear power may be increased by meaningful improvements in uranium breakdown technology and by deployment of reprocessing facilities. In the light of necessary governmental and technical security standards, however, the chances are that not many states outside the Organisation for Economic Cooperation and Development (OECD) could or should want to

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[5] Rogner, H.-H. (1997) An Assessment of World Hydrocarbon Resources. Annual Review of Energy and Environment 22, 217–262.

[6] Marland, G., Boden, T. A., and Andres, R. J. (2003) Global, Regional, and National CO_2 Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge.

[7] International Energy Agency (2004) World Energy Outlook 2004. IEA, Paris. 191–204.

apply them. Moreover, it is questionable whether nuclear fission will be able to compete with other mitigation options in the long run because of its relatively high investment costs.

On the other hand, the poor reputation of allegedly costly renewable energy is not justified: it is commonly recognized that at present renewable energy is more expensive than fossil energy, but it is also indisputable that its costs can be reduced through learning-by-doing. In fact, such reductions are already observed.[8] The potential to reduce costs is expressed by the so-called learning rate, which indicates the percentage cost reduction per unit of power for every doubling of the installed capacity. The higher the installed capacity, the lower the price per kilowatt. The overall costs for the transformation of the energy system depends crucially on this learning rate.

During the transition stage, we observe rising demand for energy related services in our scenario, due to the building up of a regenerative infrastructure. During this time, energy efficiency improvements keep emissions from rising along with energy consumption. Only by means of higher energy efficiency can the share of renewable energy be augmented without defying the climate protection goal. Further results from the energy scenario described above show that efficiency gains alone are not sufficient in the long run. Nevertheless, the short to medium-term potential to save energy is substantial.

Still, the high share of fossil fuels even in the climate protection scenarios implies that the dependence on oil and gas remains an important geopolitical risk for Europe, US and China. In the medium-term this dependence can be reduced by increasing energy efficiency and by diversifying oil and gas imports. However, the increased energy efficiency in industrialized countries will be overcompensated by a rapid growing oil demand in China and India substantially increasing global oil demand and oil prices. Because of this growing energy demand, energy security cannot be further increased for these countries by diversification of their oil and gas imports alone beyond 2020. The issue is amplified by the fact that 70 percent of conventional oil and 40 percent of natural gas resources are concentrated in the so-called Strategic Ellipse comprising countries like Iran, Iraq, Saudi Arabia, and Russia.[9] The countries in the Strategic Ellipse are for the foreseeable future neither politically nor economically low-risk suppliers of oil and gas. Besides the diversification of imports and an increased energy efficiency, the most efficient ways to reduce the dependence on oil and gas further are by promoting renewable energy technologies and by developing new coal strategies. These options do not only comprise low-emission power plants but also the opportunity for providing alternative

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8 International Energy Agency (2000) Experience Curve for Energy Technology Policy. IEA, Paris.

9 Rempel, H. (2000) Geht die Kollenstoff-Ära zu Ende? Vortrag auf der DGMK/BGR-Veranstaltung “Geowissenschaften für die Exploration und Produktion: Informationsbörse für Forschung und Industrie,” Hannover. Available at <http://www.bgr.de/b123/kw_aera/kw_aera.htm>.

sources for feeding the transport sector with hydrogen, biofuels, or gas-to-liquids. The urgent need for OECD and emerging industrialized countries like China and India for reducing supply side risks will be a powerful driver for the transformation of the energy system.

Beyond 2030, the economic and technical development of renewable energy technologies is the central option not only for climate policy but also for reducing geopolitical risks. This conclusion remains valid if nuclear power becomes a more important option than in our scenarios. Even the most optimistic nuclear power scenarios predict only a 20 percent share on the primary energy consumption in 2030. A reasonable strategy for promoting renewable energy technologies is a not only crucial for climate protection but also a medium-term requirement of energy security.

This transformation for the energy system has also important implications for equity. It is a well-known fact that hydrocarbon-exporting countries suffer from their exports because of the misuse and inequitable distribution of rents from the energy trade. A clear symptom of the "Dutch disease" can be diagnosed if resource abundance in general or resource booms in particular shift resources away from sectors of the economy that have positive externalities on growth. In essence, Dutch disease leads to decreasing growth rates, because countries possessing abundant natural resource tend to have a larger service sectors and smaller manufacturing sectors than resource-poor economies.[10] Therefore, economists believe that a comparative advantage in resource exporting is in many cases not a blessing but a major cause for an economic slow-down.[11]

The transformation of the global energy system requires an increased share of renewable energy technologies, mainly in the developing countries in Africa because the efficiency of wind and solar energy is ten times higher there than in Europe. Now the crucial question emerges, whether Africa benefits from exporting electricity to Europe or not. Exporting electricity does not necessarily imply an infection with Dutch disease because investment in electricity infrastructure has positive externalities on economic growth and even on human capital. Moreover, electricity can be traded on markets and therefore induce revenues from export which can be invested in the domestic economy. It is worthwhile to check to what extent trading electricity could be part of an export-oriented growth strategy for developing countries especially in Africa.

The International Energy Agency predicts an investment for energy-supply infrastructure worldwide of about 16 trillion USD in the period 2001–2030. Almost 10 trillion USD will be spent on power generation, transmission, and distribution alone. Developing countries will require almost half of global investment in the energy sector as a whole. Invest-

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[10] Sachs, J. D. and Warner, A. M. (1997) The Big Push, Natural Resource Booms and Growth. Unpublished working paper.

[11] Sala-i-Martin, X. and Subramanian, A. (2003) Addressing the Natural Resource Curse: An Illustration from Nigeria. IMF Working Paper WP/03/139.

ment needs amount to 1.2 trillion USD in Africa.[12] Financing the required investment in developing countries is a challenge because domestic saving and investment shares in Africa are too small, so that a huge inflow of foreign direct investments is needed for enhancing the capacities for electricity production. Therefore, poorly developed domestic financial markets and high investment risks for foreign investors are the most important reasons for low investment shares and low economic growth rates. But some calculations show that renewable electricity from Africa would be competitive even without further reduction of costs by learning-by-doing. A prerequisite of such an investment strategy are instruments for reducing the risk of foreign direct investment. We will discuss this aspect in the next section.

III How do we deal with risks?

In this last section we conclude that, according to the magic square, promotion of renewable energy technologies is crucial in the long run. Fossil fuels, in particular gas and coal, will be the predominant source for primary energy until the middle of this century. In this section, we will discuss the instruments for implementing such a strategy. These instruments do not represent a comprehensive global energy policy architecture. The discussion of these two pillars should only launch a debate that will hopefully lead to a more complete architecture.

Creating a global market for renewables

It is a common belief in economics that with the introduction of tradeable permits for CO_2 *(black trading)*, subsidies for renewable energy can no longer be justified.[13] This argument would hold if the market for renewables was an example of "perfect competition." Unfortunately, it is not: for technical reasons, there is a failure of the market for renewable energy. Energy technologies exhibit increasing returns to scale: the higher the volume of production (or the installed capacity), the lower the cost per kilowatt-hour. As renewable energy resources have so far only taken initial steps in their development, whereas fossil energy resources have long been established in the market, investors will still not invest in renewable energy resources, even though costs below those for energy from fossil fuel are likely to be achieved in the long term. The reason for this is that the fossil energy system has already written off its high initial investment costs, whereas capital costs in the renewable energy sector are relatively high. Innovators who investigate new techniques in the initial stage reduce costs through "learning-by-doing." Subsequent imitators benefit from these advances at no additional costs. Hence, in markets showing

[12] International Energy Agency (2003) World Energy Investment Outlook, IEA, Paris. 25–29.

[13] Wissenschaftlicher Beirat beim Bundesministerium für Wirtschaft. Zur Förderung erneuerbarer Energien. Stellungnahme vom 16. Januar 2004.

economies of scale, there is an incentive *not* to be a pioneering firm. But if all firms are waiting to follow a pioneering firm, none can do so. This effect becomes more pronounced when the entrepreneurs have shorter time horizons. It is economic common sense that internalizing this externality requires policy intervention. Whether renewable energy resources have the potential to compete with fossil energy resources with regard to price is still uncertain. With the introduction of a policy instrument to cure this market failure, renewable energies get a chance to prove their potential. However, one needs to be cautious when introducing a subsidy to remedy this market failure: subsidies are known to provoke mismanagement, hence it is important to design the subsidy system well in order to prevent it from being inefficient.

The Kyoto Protocol could be further developed by obliging the engaged countries to create a certain part of their energy production in the regenerative sector. This "green energy" should be traded at an international level in order to encourage companies to reduce costs by selecting the most appropriate locations. For example, the Annex I countries could agree to increase the share of renewable energy resources in overall energy production by 10 percent by 2010. Network operators in the power supply system would be obliged to use a certain quota of the produced renewable energy in their networks. At the same, time a yet-to-be-further-defined department of environment should provide producers/vendors of regenerative power with tradeable *green energy certificates*, which would correspond to the amount of regenerative power supplied. The network operators could receive the certificates either through production and supply of regenerative power or by purchasing them on the market. Both are viable ways to fulfill their obligations. Thus, competition takes place in the power market as well as in the certificates market. A network operator that produces more than its share of "green energy" could sell certificates. On the other hand, one that provides less than its share will be forced to buy certificates because fulfillment of the obligation is measured by the possession of certificates.

It is likely that the installation of such markets will enable solar thermal plants, biomass, and wind energy to be competitive with fossil energy resources within the next decade. Vendors of regenerative energy will be encouraged to reduce costs quickly in order to increase market share and profit. The share of regenerative energy share in the overall energy mix could be regulated via national stipulations—prices and selection of the technique will be determined by the market.

Finally, application of the subsidy must cease and renewables must enter unprotected competition alongside fossil energy in order to determine the long-term cost structure of the energy mix. Thus *green energy certificates* do not distort competition in favor of renewables, but in the first place they instantiate competition, through which the most cost-effective alternative will be unveiled. Without this subsidy there is no guarantee that the best alternative will prevail.

Setting up a market for "green energy" requires that quotas are valid in the long run and that a "stop-and-go" policy is avoided to offer security for long-term investments. Provided these conditions hold, entrepreneurs will invest in technology with high initial costs and late profitability. The crucial point will be that trade in green energy certificates takes place at an international level, giving investors incentives to select the best locations anywhere in the world. The market for renewables suffers from regional fragmentation. International trade for energy certificates could be a first important step to globalize the market for renewable energy.

It is likely that a market for green energy certificates would not attract enough capital for financing a network allowing Africa to export electricity. Therefore, public-private partnerships may be required for building up the required infrastructure for transmitting electricity. In order to finance such a network, a coalition of Annex I countries could issue tradable contracts, securities, or bonds entitling their owners to a fixed income expressed as an interest rate. In exchange for the security, investors on the capital market contribute their capital to the electricity network. After building up the electricity network, the access to the network and the supply of electricity could be auctioned. The profits from this auction are used to pay the contracted fixed income. This scheme will channel foreign direct investments in African countries and will also avoid—as already outlined above—infection with Dutch disease. These securities are tradable and can be sold even before the profits are realized. The purpose of securitization is to attract financing without using the international credit market for African countries itself in which these countries would have to pay relatively high interest rates. Because of this mechanism, the risks of investments in developing countries can substantially be reduced. A European-African electricity network would improve energy security for both regions and allow access to low-emission electricity.

Energy security and CCS–Carbon sequestration bonds

The way to a sustainable energy system must be bridged by fossil energy resources. Hence the use of geological formations is of great importance. The sequestration of 200 Gt of carbon in exploited gas and oil fields according to the WBGU proposal is possible at minimum risk.[14]

For sustainable use of geological formations, two institutional problems must be solved. First, because of limited storage capacity one must levy a *deposit price* for using storage capacities such as saline aquifers and exploited gas fields. CO_2 may then be "emitted" either into geological formations or into the atmosphere. As long as deposit price plus costs for transport and control is lower than the atmosphere's usage price—for instance expressed in the permit price for CO_2—storage in geological formations will be used. If it were certain that no CO_2 would leak from

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[14] German Scientific Advisory Council on Global Change (2003) World in Transition: Towards Sustainable Energy Systems. Earthscan, London and Sterling.

geological formations, tradable permits and the deposit price would provide all the necessary precautions for a sensible use of a sparse commodity. But, second, there is the risk of leakage.

Leakage as such is not a catastrophic event from a climate point of view, as long as not all storage sites leak CO_2 to a great extent at the same time. The probabilities of such accidents may not be known yet, but the maximal economic damage cost is easy to calculate: it equals the leaked amount of CO_2 times the permit price for emissions at the time of the leakage. The leaked CO_2 would then use the atmosphere as storage, of course without the permit price paid. In this case, the sequestration company must purchase the appropriate number of permits. Nevertheless, this strategy alone will not prevent the misuse of sequestration in geological formations. Firms could speculate that CO_2 will start to leak beyond their existence, that the permit price will fall in the long run, or that a later management will be confronted with the consequences. If the time horizon of risk-seeking investors and managers is shorter than the presumed event of leakage, storage in geological formations will pay because the risks can be passed on to later generations. Hence it is of foremost important to provide incentives to store CO_2 in formations that are as secure as possible in their own interest.

The implementation of carbon sequestration bonds offers the possibility of reasonable risk management: every firm willing to store CO_2 in geological formations must buy a predefined amount of bonds from an environmental authority.[15] From the firm's point of view, these bonds are an asset as long as the CO_2 remains in the geological formation. If this is the case indeed an interest rate will be paid. However, the bonds will be devalued every three years or so by the environmental authority *unless* the firm can prove without doubt that no CO_2 has leaked. Otherwise, the bonds must be partially written off.

The authority can use the money generated by leaked carbon to subsidize renewables not yet ready for the market. This liability should compensate the market penalties of the renewables arising from the fact that, without sequestration, they would have become profitable more quickly. If stored CO_2 leaks from geological formations precious time required for a cost-effective transition of the energy system will be wasted.

Carbon sequestration bonds must be tradable on markets: a firm can sell its bonds in order to increase its cash flow. But firms will be able to sell their bonds only if they can offer buyers a higher return on investment than a risk-free asset can. The magnitude of this risk surcharge will depend on how buyers assess the risk of a devaluation of the bonds. The firm can

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[15] An analysis of carbon sequestration bonds in two variations (including the one presented here) can be found in Edenhofer, O., Held, H., and Bauer, N. (2005) A Regulatory Framework for Carbon Capturing and Sequestration within the Post-Kyoto Process. Accepted for publication in: Rubin, E. S., Keith, D. W., and Gilboy, C. F., eds., Proceedings of 7th International Conference on Greenhouse Gas Control Technologies. Volume 1: Peer-Reviewed Papers and Plenary Presentations. IEA Greenhouse Gas Programme, Cheltenham. Forthcoming.

obtain high prices only if buyers are convinced of the storage site's security. Hence there are incentives for the whole branch of business not to undermine confidence in the bonds. Because of the threat of devaluation, the security standard for geological formations will emerge to a market-ready commodity. Namely, firms will face incentives to employ high-performance checks to ensure that the CO_2 remains in the geological formations. The better this can be proved, the higher the value of the bonds. Because carbon sequestration bonds are tradable, investors, analysts, and customers can show their confidence by buying the bonds, even at high prices. Accordingly, the public participates in the decision about the extent to which sequestration should be applied. Risk assessment for this technique is thus out of reach of the technocrats alone: more democracy concerning its employment and investments is guaranteed.

IV False Dichotomies

So far the discussion about climate policy has been shaped by falsely posed alternatives—growth of energy supply without climate protection or climate protection without economic growth, energy security without equity or equity without economic growth. However, wrong alternatives constantly narrow the set of options. Tragic decisions are induced by a limited set of options. Therefore, what seems to be a dilemma can also hint at a wrongly posed problem—scientists, politicians, statesmen, and entrepreneurs are always in danger of having their decisions dictated by false alternatives.

On the basis of our model calculation, we have shown that even ambitious climate protection goals can be achieved without substantial losses in economic growth if the share of renewable energy is increased, energy efficiency is enhanced, and CO_2 is captured at point sources and stored in geological formations. We argue that this strategy will also improve energy security for developing and developed countries. Nobody can predict exactly how the energy system will evolve through the 21st century. Hence what is necessary is a stable political framework that allows entrepreneurs, investors, and consumers to investigate the most efficient techniques by trial and error.

At the same time only techniques that do not cause irreversible damage should be used. Kyoto must come back to its most prominent task: the design and implementation of markets from which the optimal solutions will emerge by trial and error. A market for green energy certificates not only increases the efficiency of renewable energy, but also opens up opportunities for development in Africa, which can provide the proper sites for solar power generation. Carbon sequestration bonds could allow for moderate and controlled use of carbon capturing and sequestration. Today, the magical square seems to the majority to be an infeasible challenge. But tomorrow, the magical square could be a synonym for a sustainable, equitable, and efficient market economy. In that way the next energy crisis can be managed by a newly designed energy policy.

Abbreviations

ACEA	European Automobile Manufacturers Association
BP	British Petroleum
BTA	Border Tax Adjustments
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCS	Carbon Capturing and Sequestration
CEPS	Centre for European Policy Studies
CHT	Combined Heat and Power
CICERO	Center for International Climate and Environmental Research
CO_2	Carbon Dioxide
EFIEA	European Forum on Integrated Environmental Assessment
EIA	Energy Information Administration
ETS	Emission Trading Scheme
EU	European Union
EU-ETS	EU Emissions Trading Scheme
FGD	Flue Gas Desulphurization
G8	Group of Eight
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Gt	Gigatons
GtC	Gigatons of Carbon
GW	Gigawatt
GWP	Gross World Product
HDI	Human Development Index
ICCT	International Climate Change Taskforce
IGCC	Integrated Gasification Combined Cycle
IIASA	International Institute for Applied Systems Analysis
INTACT	International Network To Advance Climate Talks
IPCC	Intergovernmental Panel on Climate Change
KW	Kilowatt
kWh	Kilowatt-hour
NO_x	Nitrous oxides
NPV	Net Present Value
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
ppm	parts per million
R&D	Research and Development
SRES	Special Report on Emissions Scenarios
TWh	Terrawatt-hours
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USCB	United States Census Bureau
USD	US Dollar
WBGU	Scientific Advisory Council on Global Change to the Federal Government of Germany (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen)
WHO	World Health Organization
WTO	World Trade Organization
yr	Year