mutated *Mut6* gene—are present only at low levels in wild-type *Chlamydomonas* but are abundant in the *Mut6* algae.

The molecular basis of the recognition of aberrant single-stranded RNAs is not well understood. However, it is likely that an RNA-dependent RNA polymerase plays an important part by converting the aberrant single-stranded RNA into a double-stranded form. In the plant *Arabidopsis*, an RNA-dependent RNA polymerase encoded by the *Sde1* locus is required for the induction of RNA silencing by a transgene. This enzyme is not required when RNA silencing is activated by viruses that replicate their nucleic acid through a dsRNA intermediate (*6*).

The core of the RNA silencing mechanism, irrespective of whether the foreign RNA is single- or double-stranded, is likely to be the processing of dsRNA into short 21- to 23-nucleotide segments (see the figure) (*7*, *8*). These short RNA species are thought to be incorporated into a ribonuclease (RNase) complex (which is now being characterized in fruit fly extracts) (*9*). The current thinking is that the short RNA species form Watson-Crick base-paired structures within the complex that guide the RNase to the target molecules (foreign dsRNA and cellular RNAs of similar sequence) in the cell, which are then degraded. If true, this model would provide an explanation for why introduction of a foreign RNA into a cell results in degradation not only of that RNA but also of other RNAs with a similar nucleotide sequence (*10*).

The RNA helicase encoded by the *Mut6* gene is similar to the PrP16 protein of human cells that is necessary for the splicing of messenger RNAs (mRNAs) after transcription. It also resembles the worm protein MOG-1, which helps to destabilize an RNA (*fem-3*) that promotes development of male reproductive organs. MUT6 is the second RNA helicase–like protein to be implicated in RNA silencing. Just last month, Domeier *et al.* reported that the worm *smg-2* gene encodes a helicase required for persistent RNA silencing (*11*). SMG-2 and its close homolog in yeast, UPF-1, are necessary for degradation of nonsense mRNAs containing premature stop codons.

SMG-2 is a helicase of superfamily I, most members of which are encoded by RNA viruses, whereas MUT6 is a member of the DEAH-box helicase superfamily II (*12*). Differences between SMG-2 and MUT6 make it unlikely that these proteins operate at the same stage of RNA silencing. However, the involvement of both of these proteins in RNA silencing does suggest that this process is part of the normal molecular network that regulates RNA processing and stability in eukaryotic cells. This network is distinct from the well-characterized cellular machinery that governs the transcription of DNA into RNA.

One reason for the intense interest in RNA silencing (*1*) is that this process is apparently unique to eukaryotic cells. Now, with the discovery of proteins in the RNA silencing pathway (*4*, *13*) that are similar to proteins in other pathways regulating RNA, it is likely that RNA silencing is merely a variation on a well-established cellular theme. But even if it is, for the true RNA connoisseur, there is genuine interest in a process that borrows known protein components to carry out unknown reactions. Whether one is a connoisseur or not, there is no question that the report by Wu-Scharf *et al.* provides a tantalizing clue that should facilitate the unwinding of RNA silencing.

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PERSPECTIVES: CLIMATE

A New Route Toward Limiting Climate Change?

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The upcoming sixth meeting of the Conference of the Parties to the Framework Convention on Climate Change (FCCC) from 13 to 24 November in The Hague has refocused attention on climate change policy. The debate has recently been stimulated by Hansen *et al.* (*1*), who have suggested an "alternative scenario" for mitigating climate change. In their proposed mitigation strategy, the increase in carbon dioxide (CO_2) concentration over the next 50 years is limited to an additional 75 parts per million by volume (ppmv) (*2*), equivalent to a radiative forcing increase of 1 W/m^2. (Radiative forcing is the energy imbalance caused by changes such as rising atmospheric CO_2 concentrations. A net positive forcing will cause a warming.) So far, this is rather traditional. But their strategy departs from previous ideas by proposing to enhance aerosol cooling and to limit the total forcing from non-CO_2 greenhouse gases, including tropospheric ozone, to today's level by 2050. The proposed Kyoto Protocol already includes non-CO_2 greenhouse gases such as methane (*3*), but Hansen *et al.*'s inclusion of ozone and aerosol effects—both of which are short-lived local and regional air pollutants—would be a new addition to global policy. Is this proposal viable?

To evaluate the plausibility of any climate policy, one must first analyze reasonable baseline scenarios from which the policy is meant to depart. Such scenarios represent future demographic, social, economic, technological, and environmental developments that may occur in the absence of a dedicated climate policy. The most up-to-date scenarios are those in the Intergovernmental Panel for Climate Change (IPCC) Special Report on Emissions Scenarios (SRES); they represent a wide range of possible future emissions paths (*4*). The estimated change in radiative forcing over 2000 to 2050 ranges from 1.5 to 3.7 W/m^2 from the entire set of SRES scenarios; CO_2 is responsible for 1.1 to 2.7 W/m^2 depending on the scenario (*5*).

The baseline from which the Hansen *et al.* policy would be easiest to implement is the relatively optimistic SRES B1 scenario family. The B1 family assumes low population growth and, as noted by Hansen *et al.*, "improved energy efficiency and a continued trend toward … increased use of gas instead of coal" [p. 9878 (*1*)]. Even in the B1 family with its optimistic assumptions, the CO_2 forcing increase ranges from 1.1 to 2.2 W/m^2. Meeting the net 1 W/m^2 forcing target of Hansen *et al.* (*1*) is thus likely to require some, possibly substantial, efforts (*6*). Even larger efforts may be required if future developments follow one of the other SRES scenarios.

In addition to limitations in CO_2 forcing, the largest potential forcing decrease in the Hansen *et al.* strategy would result from changes in aerosol composition. The domi-

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nant anthropogenically produced aerosols, sulfate aerosols, are conventionally believed to cool the atmosphere by reflecting sunlight (the direct effect) and by making clouds more reflective (the indirect effect). Recent observational and modeling studies have indicated that aerosols with substantial black carbon (soot) content (see the figure) offset some of this cooling (*7*). The global magnitudes of these effects are uncertain, however, adding risk to any strategy that relies on modifying aerosols.

Haze isn't cool. This photo from the recent Indian Ocean Experiment (INDOEX) shows polluted air masses. It has recently been shown (*7*) that soot-containing aerosol pollution can reduce cloud cover, thus offsetting the expected aerosol-induced cooling of the atmosphere substantially. The magnitude of the effect is, however, uncertain.

Hansen *et al.* propose to reduce the black carbon content of aerosols in order to increase the cooling effect of aerosols. In the absence of changes in net sulfur dioxide (SO_2) emissions, less black carbon as a result of pollution controls would, indeed, lead to increased cooling. The technology for reducing soot emissions is widespread, and it is reasonable to assume that future efforts to control local air pollution will result in a decrease in these emissions. Efforts to control SO_2 and other aerosol precursor compounds will, however, also be taken. It is extremely unlikely that reduced soot emissions would, or even could, occur in isolation.

Furthermore, any strategy that limits CO_2 emissions will limit fossil fuel use and will therefore also reduce emissions of aerosol precursors that usually accompany fossil fuel use. This effect is demonstrated in the SRES B1 scenarios, in which CO_2 emissions increase relatively modestly over the next 50 years and, in all but one scenario, global SO_2 emissions fall. Adding a CO_2 mitigation policy to meet the 1 W/m^2 target is likely to decrease SO_2 emissions even further. Such a decrease in SO_2 emissions is most likely to result in a net decrease in aerosol cooling. To convert this to an increase in cooling, a nearly global removal of soot would be required (*8*), and even then the strategy would only work if the soot forcing effect is strong (its magnitude is highly uncertain).

Some SRES scenarios have constant or increasing emissions of SO_2 through 2050, which might allow soot reductions to cause an increased cooling effect. These scenarios generally have, however, CO_2 emissions that are much higher than those required to meet a 1 W/m^2 target. They are therefore unsuitable for the Hansen *et al.* strategy.

Even if selective reduction of the soot component of aerosol forcing were practical, it would only provide temporary relief (*9*). This approach does not address the long-term effects of greenhouse gas emissions. SO_2 emissions decline from 2050 to 2100 in all SRES scenarios. By the last half of this century, radiative forcing will be increasingly dominated by long-lived greenhouse gases such as CO_2 and nitrous oxide. In addition, much of the infrastructure related to the emissions of these gases has a long lifetime, and plans to stabilize radiative forcing by the end of the next century must be well in place by 2050. A policy that relies on a temporary aerosol cooling offset, even if successful, is likely to shortchange the longer term goal.

The goal of the FCCC is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (*10*). Much of the ongoing discussion has therefore focused on the long term. An additional focus on limiting shorter term increases in radiative forcing, as suggested by Hansen *et al.*, should also be considered, particularly if further research shows that increases in the rate of climate change are likely (*5*). Reducing emissions that lead to local air pollution may, indeed, help contribute to reducing climate forcing. Pollution controls, however, rarely reduce a single constituent, and as discussed above, this will limit the overall magnitude of any pollution-control–derived forcing reduction. Economic considerations and the nature of the climate target can change the emphasis on CO_2 relative to other radiatively important substances (*11*), but the primary focus must remain on CO_2.

References and Notes

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2. Stated by Hansen *et al.* as keeping the CO_2 concentration growth rate "about the same as in the past two decades." Note that a constant rate of concentration growth requires a decreasing rate of emissions increase.
3. See www.cop4.org/kp/kp.html
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PERSPECTIVES: PLANETARY SCIENCE

Nitrogen on the Moon

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A continuous stream of atoms and electrons flows from the sun's surface into the solar system. This solar wind has left its signature in the lunar "soils" (the residue of rocks broken down by impacting meteorites) that cover most of the moon's surface. The solar wind has implanted itself into the surfaces of individual soil grains to depths of tens of nanometers. For elements such as carbon, nitrogen, and the noble gases, whose normal abundance is very low in lunar rocks, the solar component can be distinguished from the indigenous lunar contribution, allowing insights into the elemental and isotopic composition of the solar wind over time.

The lunar surface is thus a potential source of information on changes in the sun over its lifetime. For the element nitrogen, however, the lunar record may reflect more than just solar processes. Almost from the first soil analyses for nitrogen, we have known that $^{14}\text{N}/^{36}\text{Ar}$ in lunar soils is elevated by a factor of about 10 relative to the sun, that $^{15}\text{N}/^{14}\text{N}$ ratios vary from sample to sample by more than 30%, and that this isotopic variation is related to the time when the nitrogen was introduced to the moon (*1*). Understanding these observations could shed light on lunar surface processes, solar system history, or the origin of the material from which the solar system formed. Nevertheless, after some 25 years we are still trying to make sense of them. The measurement of elemental and isotopic depth profiles in individual grains of lunar soil, as reported by Hashizume *et al.* on page 1142 of this issue (*2*), may bring us closer to an understanding.

Initially, the isotopic ratios seemed

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