The great debate on CO_2 emissions

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There is a broad consensus that emissions of greenhouse gases, principally CO_2, must be reduced to minimize any adverse effects of climate change. But fierce argument attends the question 'How quickly?'.

Over the past few years, almost all of the world's leaders have acknowledged that the science telling us of long-term climate change, driven by anthropogenic emissions of greenhouse gases, is compelling, and that action is needed to reduce such emissions. In just over a week, on 1 December, parties to the United Nations Framework Convention on Climate Change of 1992 (FCCC) will convene in Kyoto* to agree upon and formally adopt the elements of just such an action. The intended outcome is legally binding commitments for industrialized (Annex I) countries and some provision to ensure that developing (non-Annex I) countries will engage in the process in the not-too-distant future.

There are, however, very different hopes and fears for what will come out of the Kyoto meeting. Leading observers from the environmental community and representatives of 'green' business groups who have followed the eight previous negotiating sessions, held over the two-and-half years preparatory to Kyoto, are not very optimistic that a thorough-going agreement to drive down emissions will emerge. If failure is inevitable, they hope that the conference will fail spectacularly. This is an all-or-nothing view, which holds that a new instrument that gives countries more time to comply with the existing commitments under the FCCC is as bad as the 'business as usual' scenario that has countries doing nothing to abate emissions. Spectacular failure, runs the argument, would result in full renegotiation.

In his paper on page 267 of this issue[1], Wigley gives a very different view, one which will encourage those who believe in conducting 'business as usual', at least for some years. This is a careful analysis, in which he outlines ways and timetables for developing countries to participate in emission reduction, set against different schemes of Annex I CO_2 abatement. But the paper has to be read with a crucial caveat in mind.

The analysis is based on a target of stabilizing atmospheric concentrations of CO_2 at roughly double the pre-industrial level — that is, at 550 parts per million by volume (p.p.m.v.). The justification advanced is that this figure is in the centre of the 350–750 p.p.m.v. range that has been emphasized in scholarly studies, and that a firmer target has yet to be specified. However, it is far from clear what the target concentration should be. Azar and Rodhe[2] suggest, for example, that greenhouse-gas concentrations should be held to 450 p.p.m.v. CO_2 equivalent (CO_2, plus other greenhouse gases such as methane and nitrous oxide), or less, to have a reasonable probability of avoiding dangerous climate change. But even at 550 p.p.m.v., assuming that such a figure meets the objective of the FCCC, Wigley's view that the burden to be shared between Annex I and non-Annex I countries could require Annex I countries to do no more than continue with 'business as usual' until the year 2010, and non-Annex I countries to do the same until 2030, is highly contentious (and to my mind misguided).

Now, Wigley may not have wished to give the impression that delay in reducing emissions is a desirable course. But there are those engaged in the negotiations who would like to see nothing done at Kyoto (for instance, the business lobbies in the United States that have spent $13 million in a mere two months to persuade people that abatement is both unnecessary and expensive). By overlooking the details, they will come away with just such a reading of Wigley's paper.

Leaving aside the immediate concerns dictated by Kyoto, such as adopting a legally binding agreement to strengthen the commitments of Annex I countries, the more serious question that this paper begs is not whether early action to reduce emissions will help (at two places in his paper, Wigley does state that it would), but whether delay in adopting implementable policies would be seriously damaging in economic terms. Again, the paper does not say that immediate practical action to reduce emission levels will be severely damaging economically; but it lends credence to all those who use such arguments.

This analysis should be read in conjunction with an earlier paper by Wigley, Richels and Edmonds[3]. There, the authors suggest that, issues of environmental damage aside, letting emissions rise in the short term before cutting them subsequently will be cheaper. Taking the two papers together, an unmistakable message emerges — that there is no urgency about emission abatement. The argument here is this. Delaying measures until technology develops to a stage where energy efficiency improvements occur in great increments would obviate costly early action that will result in loss of jobs and debilitating economic effects. In other words, this viewpoint holds that delaying now will give those engaged in reducing greenhouse-gas emissions opportunities to reduce them swiftly later on.

Even if one ignores environmental issues, however, there is no consensus that delaying emission abatement is the cheaper route to stabilization of CO_2. For instance, a study[4] sponsored by the US Department of Energy concluded that the United States "could reduce annual emissions of carbon dioxide and other greenhouse gases by as much as 20% from the 1990 level by 2010 at no net cost to the economy". Also, a group of distinguished US economists[5] have pointed out that "there are many potential policies to reduce greenhouse gas emissions for which the total benefits outweigh the total costs" and that "there are policy options that would slow climate change without harming American living standards and these measures may in fact improve US productivity in the longer run".

Here, then, are powerful voices who say that early steps to reduce emissions in the United States are both warranted and need not be painful economically.

But even if one ignores these voices, and assumes that heavy costs are associated with immediately reducing greenhouse-gas emissions, there are still good reasons for early action. One is legal, as enshrined in a principle in the FCCC, which states that parties to the convention are to take "precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects". Another is scientific. Take the Dutch IMAGE 2 model[6], which consists of three fully linked sub-systems (energy–industry, terrestrial environment, and atmosphere–ocean), unlike other models which concentrate on single aspects or spatial scales. The IMAGE 2 analysis showed that early action is critical when taking environmental and economic goals into consideration. As the authors pointed out, "if global emissions are too high in the year 2010, there is little chance afterwards to make a course correction which avoids climate-related impacts".

What, though, are the chances of our being able to make such a course correction? According to Ha-Duong, Grubb and Hourcade, the authors of another paper in this issue[7] (page 270), they are low. Ha-Duong *et al.* observe that integrated assessment models under-represent socioeconomic inertia, the time lag between deciding to take

*See other contributions to this topic in Briefing on page 215 and Commentary on page 225.

action to reduce emissions and actually doing so; moreover, they consider that "higher adjustment costs" to correct the situation make it best to spread emission reduction over several generations. Their bottom line is that if we acknowledge that there is a significant risk that we need to stay below a particular level, then, given the socioeconomic inertia in energy systems, delay in abatement will prove costly. So Ha-Duong and colleagues' conclusion is that there is a pressing case for limiting CO_2 emissions now.

In all, this is far more than a scholarly debate between proponents of 'act now' with practical action to abate emissions, or 'delay until later'. What countries agree at Kyoto and then proceed to do will have a profound impact on the various possible future outcomes discussed by Wigley and Ha-Duong *et al.* If Annex I countries now take on legally binding commitments to abatement, it will send a strong signal to the private sector of the necessity of investing in cleaner energy sources. Moreover, the non-Annex I countries that are beginning to question the commitment of industrialized nations to greenhouse-gas reductions will be reassured that it is not a problem that only they need to cope with. In the end, the combined action of government regulation and private-sector involvement in Annex I countries will give a powerful impetus to non-Annex I countries to adopt similar emission-reduction measures. □

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4. US Department of Energy *Potential to Reduce CO_2 Emissions in the U.S.* (US Dept Energy, Washington, 1997).
5. *Statement of Over 2000 Economists Including Six Nobel Laureates* (Redefining Progress, San Francisco, Feb. 1997).
6. Alcamo, J. (ed.) *IMAGE 2.0: Integrated Modeling of Global Climate Change* (Kluwer, Dordrecht, 1994).
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Developmental biology

The worm keeps turning

Bruce Bowerman

Who scapes the lurking serpent's mortal sting? Not he that sets his foot upon her back. Even the smallest of worms will turn, when trodden on[1].

The roundworm *Caenorhabditis elegans* is one of the most important models for the study of animal development. It is unique in that the generation of all 558 cells of a newly hatched roundworm larva from a few embryonic founder cells is invariant. The description of this process, a monumental effort undertaken by Sulston and colleagues[2], required seven years of patient peering through a microscope, repeatedly observing embryonic cell divisions and carefully recording the positions of nuclei — as small as 1 μm in diameter — in hundreds of embryos. The way that the embryonic founder cells generate all the different cell lineages of an entire roundworm is truly invariant: every division axis, every slight asymmetry in cell size and every contact made with another cell is indistinguishable from one embryo to the next, with very few exceptions. On page 294 of this issue Kaletta *et al.*[3] provide the first genetic evidence that a single mechanism may operate throughout the *C. elegans* embryo to maintain the invariance of all cell lineages.

The embryonic cells of *C. elegans* not only make studies of development at a single-cell resolution possible but also pose an intellectual challenge. The one-cell-stage embryo undergoes a series of asymmetric and asynchronous divisions to generate five somatic founder cells, each of which subsequently divides to produce descendants that together form all the somatic cells of the roundworm larva. Two of these founder cells, D and E, each give rise to either 20 muscle or 20 gut cells, respectively, whereas another three — AB, C and MS — produce the remaining 518 somatic cells that have many different fates, constituting all tissues apart from the germ line. It is difficult to imagine how the lineages derived from these three founder cells can be so invariant.

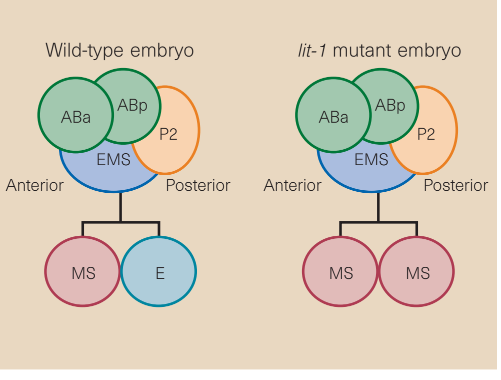

Figure 1 **Transformation of embryonic cells from a posterior to an anterior fate in *lit-1* mutant embryos. The first lineage defect in *lit-1* mutant embryos occurs at the 4-cell stage. In wild-type embryos the most ventral blastomere EMS becomes polarized to produce a posterior daughter called E and an anterior daughter called MS. E makes the intestine (endoderm) whereas MS makes body-wall muscle and pharynx (mesoderm). In *lit-1* mutant embryos, the polarization of EMS is lost and both daughters adopt the anterior MS fate.**

Ironically, Sulston's conclusion that the embryonic lineage in *C. elegans* is invariant led even most 'worm people' to dismiss the roundworm embryo as an extreme case of lineage-dependent development, seemingly irrelevant to more complex animals, where the generation of a large number of cell lineages that vary from embryo to embryo depends on intricate interactions between cells, and complex signalling pathways, rather than a predetermined destiny.

In 1987, however, this smallest of worms first turned for Jim Priess, an early disciple who found the embryo appealing in its elegant simplicity. Not impressed with the logic that invariance implies irrelevance, he interchanged the positions of the two daughters of the AB founder cell (AB for anterior blastomere), which produces 389 of the 558 cells in a hatched larva[4]. To everyone's surprise the rearranged embryo developed normally in spite of the ultimately very different fates of the two AB daughters. This one simple experiment conclusively demonstrated that more than half the embryo depends extensively on cell interactions for the development of different lineages. Subsequent genetic and molecular studies showed that widely conserved cell-signalling pathways are required to properly specify some of the most complex lineages in the *C. elegans* embryo[5], deepening even further the mystery of invariance.

Now the worm has turned yet again, this time in the laboratory of Ralf and Heinke Schnabel, who, with Titus Kaletta, show that eliminating a gene called *lit-1* results in mutant roundworm embryos with massive lineage defects[3]. The first defect becomes apparent at the 4-cell stage, where the parent of two somatic founder cells divides to produce a posterior daughter called E that makes gut (endoderm) and an anterior daughter called MS that makes body-wall muscle and pharyngeal cells (mesoderm). In *lit-1* mutant embryos, both daughter cells adopt an anterior fate (see Fig. 1). This results in an excess of mesoderm and a complete *l*oss of *i*n*t*estine (hence the gene name *lit-1*).

The investigators go on to show that in these mutant worms many embryonic cells that divide along the anterior–posterior axis similarly produce daughters that adopt anterior fates at the expense of posterior fates. These posterior-to-anterior fate transformations are observed in lineages that develop without the help of other cells (autonomously), and in lineages that require signals from other cells. For example, during normal development the MS founder