The 2 °C dream

Countries have pledged to limit global warming to 2 °C, and climate models say that is still possible. But only with heroic — and unlikely — efforts.

BY JEFF TOLLEFSON

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The year is 2100 and the world looks nothing like it did when global leaders gathered for the historic climate summit in Paris at the end of 2015. Nearly 8.8 billion people now crowd the planet. Energy consumption has nearly doubled, and economic production has increased more than sevenfold. Vast disparities in wealth remain, but governments have achieved one crucial goal: limiting global warming to 2 °C above pre-industrial temperatures.

The United Nations meeting in Paris proved to be a turning point. After forging a climate treaty, governments immediately moved to halt tropical deforestation and to expand forests around the globe. By 2020, plants and soils were stockpiling more than 17 billion tonnes of extra carbon dioxide each year, offsetting 50% of global CO_2 emissions. Several million wind turbines were installed, and thousands of nuclear power plants were built. The solar industry ballooned, overtaking coal as a source of energy in the waning years of the twenty-first century.

But it took more than this. Governments had to drive emissions into negative territory — essentially sucking greenhouse gases from the skies — by vastly increasing the use of bioenergy, capturing the CO_2 generated and then pumping it underground on truly massive scales. These efforts pulled Earth back from the brink. Atmospheric CO_2 concentrations peaked in 2060, below the target of 450 parts per million (p.p.m.) and continue to fall.

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That scenario for conquering global warming is one possible — if optimistic — vision of the future. It was developed by modellers at the Joint Global Change Research Institute in College Park, Maryland, as part of a broad effort by climate scientists to chart possible paths for limiting global warming to 2 °C, a target enshrined in the UN climate convention that will produce the Paris treaty.

Climate modellers have developed dozens of rosy 2 °C scenarios over several years, and these fed into the latest assessment by the Intergovernmental Panel on Climate Change (IPCC). The panel seeks to be policy-neutral and has never formally endorsed the 2-degree target, but its official message, delivered in April 2014, was clear: the goal is ambitious but achievable.

This work has fuelled hope among policymakers and environmentalists, and it will provide a foundation for debate as governments negotiate a new climate agreement at the UN's 2015 Paris Climate Conference starting on 30 November. Despite broad agreement that the emissions-reduction commitments that countries have offered up so far are insufficient, policymakers continue to talk about bending the emissions curve downwards to remain on the path to 2 degrees that was laid out by the IPCC.

But take a closer look, some scientists argue, and the 2 °C scenarios that define that path seem so optimistic and detached from current political realities that they verge on the farcical. Although the caveats and uncertainties are all spelled out in the scientific literature, there is concern that the 2 °C modelling effort has distorted the political debate by obscuring the scale of the challenge. In particular, some researchers have questioned the viability of large-scale bioenergy use with carbon capture and storage (CCS), on which many models now rely as a relatively cheap way to provide substantial negative emissions. The entire exercise has opened up a rift in the scientific community, with some people raising ethical questions about whether scientists are bending to the will of politicians and government funders who want to maintain 2 °C as a viable political target.

"Nobody dares say it's impossible," says Oliver Geden, head of the European Union Research Division at the German Institute for International and Security Affairs in Berlin. "Everybody is sort of underwriting the 2-degree cheque, but scientists have to think about the credibility of climate science."

Modellers are first to acknowledge the limits of their work, and say that the effort is designed to explore options, not predict the future. "We'll tell you how many nuclear power plants you need, or how much CCS, but we can't tell you whether society is going to be willing to do that or not," says Leon Clarke, a senior scientist and modeller at the Joint Global Change Research Institute. "That's a different question."

ONE TRILLION TONNES

The idea of limiting global warming to 2 °C dates back to 1975, when economist William Nordhaus of Yale University in New Haven, Connecticut, proposed that more than 2 or 3 degrees of warming would push the planet outside the temperature range of the past several hundred thousand years. In 1996, the EU adopted that limit, and the Group of 8 (G8) nations signed on in 2009. The parties to the UN convention on climate change affirmed the target in 2009 at their Copenhagen summit, and then formally adopted it a year later in Cancún, Mexico.

The move caught scientists off guard. Before 2009, most modellers had focused on scenarios in which atmospheric CO_2 concentrations stabilized around 550 p.p.m. — double the pre-industrial level — which would probably limit warming to a little less than 3 °C. But as political interest in the 2 °C target grew, a few started exploring the implications. In April 2009, a team led by Myles Allen, a climate scientist at the University of Oxford, UK, published[1] a study concluding that humans would have to limit their total cumulative carbon emissions to 1 trillion tonnes — more than half of which had already been dumped into the atmosphere — to maintain a chance of limiting warming to 2 °C. This trillion-tonne carbon budget provided a scientific baseline for what was now a politically important target, and many modellers shifted gears.

"There were very few scenarios with stringent targets such as 2 °C, and then sponsors started demanding it," says Massimo Tavoni, deputy coordinator of climate-change programmes at the Eni Enrico Mattei Foundation in Milan, Italy.

The flurry of modelling efforts that followed split into two main camps: pay early or pay late (see 'Two paths to 2 °C'). In the former, nations need to slash greenhouse-gas emissions immediately; in the latter, they can buy time for a slower phase-out by developing a massive infrastructure to suck CO_2 out of the air.

"Models that have these negative emissions really do let you continue to party on now, because you have these options later," says John Reilly, co-director of the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology (MIT) in Cambridge.

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In the pay-later approach, most models rely on a combination of bioenergy and CCS. The system starts with planting crops that are harvested and either processed to make biofuels or burnt to generate electricity, which provide carbon-neutral power because the plants absorb CO_2 as they grow. The CO_2 created when the plants are processed is captured and pumped underground, and the process as a whole eats up more emissions than it creates. A consortium sponsored by the US Department of Energy has tested such a system at one facility that produces bioethanol fuel in Illinois, but neither bioenergy nor CCS has been demonstrated on anywhere near the scales imagined by the models.

"It's just simple arithmetic: the carbon budget is so small that you need to go negative, or at least you need to offset some of your emissions in order to get to zero," says Tavoni. "We tried to be honest, and pretty agnostic about whether these transformations are easily achievable."

On the basis of those models and other information, the IPCC estimates that climate mitigation would reduce the projected global consumption in 2100 by 3–11% — a relatively modest amount that would allow the global economy to keep growing overall. But remove either bioenergy or CCS from the scenarios and the costs increase substantially. If mitigation is delayed or bioenergy and CCS are constrained, most models simply can't limit warming to 2 °C.

The question is whether any of those models accurately reflect technical and social challenges. MIT has a model that tends to project costs two or three times the average reported by the IPCC, in part because it tries to reflect difficulties in scaling up any technology, such as the availability of skilled labour and natural resources in different regions. And then there are the technical hurdles. Capturing CO_2 from power plants has proved more difficult and expensive than many had hoped. Just one commercial project is currently operating, at the Boundary Dam Power Station in Saskatchewan, Canada.

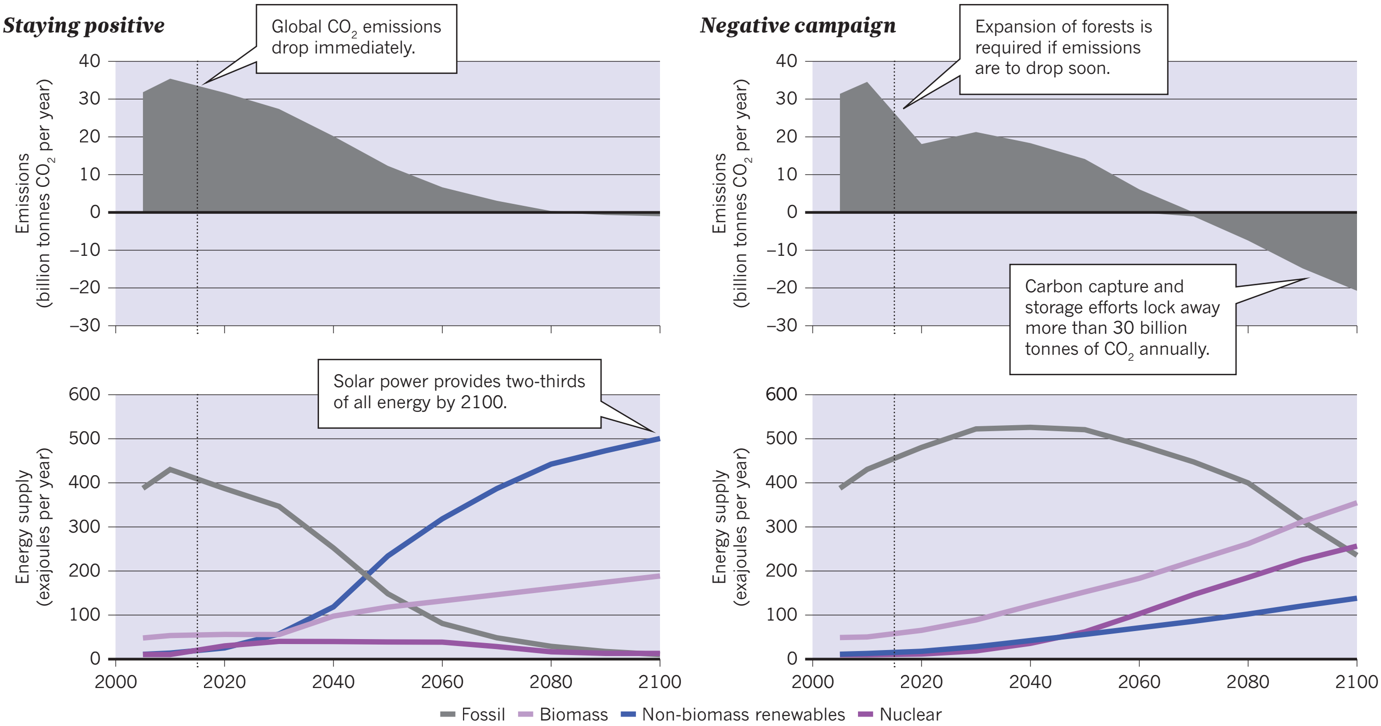
Moreover, Reilly says, the number of models that actually completed 2 °C scenarios remains relatively small, and they probably project lower mitigation costs than those that are not able to generate these low-emissions scenarios. "It's a very self-selecting set of models."

Although the caveats are listed in the IPCC assessment, the report does not adequately highlight economic and technical challenges or modelling uncertainties, says David Victor, a political scientist at the University of California, San Diego, who participated in the IPCC assessment. Victor does not place all the blame on scientists glossing over the problems: when researchers drafted the assessment's chapter on emissions scenarios and costs, he says, they included clear statements about the difficulty of achieving the 2 °C goal. But the governments — led by the EU and a bloc of developing countries — pushed for a more optimistic assessment in the final IPCC report. "We got a lot of pushback, and the text basically got mangled," Victor says.

For all of the concerns and criticisms, however, modellers say that the

Two paths to 2 °C

Modellers have explored various scenarios for limiting global warming to 2 °C. One (left) immediately slashes fossil-fuel use while ramping up renewable-energy use. Another strategy (right) allows continued use of fossil fuels, but bioenergy supplies a growing share of energy. Carbon from the bioenergy industry is captured and stored, driving overall emissions below zero.



SOURCE: IIASA/IPCC

exercises have illuminated important research questions, such as how much bioenergy and CCS will cost and what effects they will have on land use, food systems and water availability.

One 2014 study[2] in *Earth's Future*, for instance, found that it would be difficult to grow enough bioenergy crops, even with second-generation cellulosic biofuels, which are made not only from a plant's sugars but also from the carbon in its stem and woody materials. The effort would require significant boosts in crop yields and the use of 77% more nitrogen fertilizer by 2100. The bioenergy would also need to be produced in centralized facilities that capture the bulk of the emissions. Unless everything goes right, scaling up to the level projected in many models would be difficult without significantly reducing food production or clearing large swathes of natural ecosystems for farmland.

"If we need to ramp up such a large infrastructure, we need to investigate what that implies," says Sabine Fuss, an environmental scientist at the Mercator Research Institute on Global Commons and Climate Change in Berlin.

Fuss led a commentary[3] in *Nature Climate Change* in October 2014 calling for a transdisciplinary research agenda on negative emissions. One of the first outgrowths of that work, led by co-author Peter Smith, a biologist at the University of Aberdeen, UK, is an upcoming assessment of carbon-negative strategies and potential limitations. Strategies include bioenergy with CCS, as well as other ways of absorbing carbon, such as planting forests, using chemical scrubbers to capture CO_2 directly from the air and crushing rocks to enhance geological weathering that consumes the gas.

"The science behind these technologies is probably a bit behind the models," Smith says. "This sort of provides a road map for where we need to go in the next two or three years."

RISK FACTOR

Modellers are also digging into real-world complexities. Most models assume that participation in climate mitigation will be global, that countries will put a common price on carbon, that technological solutions will be widely available and that this combination will drive investment towards relatively cheap mitigation options in developing nations. But the reality could be more complicated. A team at the Joint Global Change Research Institute worked with Victor and others to investigate the risks of making investments in developing countries due to political instability and the relatively poor quality of many public institutions there. Their model showed[4] that investors would probably shun developing countries and pour money into developed ones, driving up costs and making it harder to curb rapidly rising emissions in developing nations.

"The models have taught us that with unrealistic assumptions anything is possible, and with realistic assumptions it will be very hard to cut emissions to meet goals like 2 degrees," Victor says. "That's an important result because it forces — or should force — some sobriety about what can be achieved."

One message that modellers have delivered quite clearly is that without collective and aggressive action by all countries, costs invariably increase, and the chance of hitting the 2 °C goal plummets. This is precisely the situation heading into the Paris summit. Most countries, and all of the major greenhouse-gas emitters, have submitted pledges to reduce their emissions, but these vary widely in ambition.

As it stands, the world is on a path to nearly 3 °C of warming by the end of the century, and even that assumes substantial emissions reductions in the future. If nations do not go beyond their Paris pledges, the world could be on track to use up its 2 °C carbon budget as early as 2032. If the models are correct, world leaders may have to either accept extra warming or plan for a Herculean negative-emissions campaign. In the event that they choose the latter — and succeed — the entire debate will change.

"It's a completely different game," says Nebojsa Nakicenovic, an economic modeller and deputy director-general of the International Institute for Applied Systems Analysis in Laxenburg, Austria. "If that is technically possible, then we could also go below 2 degrees."

Fast-forward to 2100 once more. The bioenergy industry is now one of the largest and most powerful on Earth. People are pulling roughly as much CO_2 out of the atmosphere as they were emitting at the time of the historic Paris conference. Humanity has asserted control over the atmosphere, and governments face a new and difficult question at the 108th anniversary of the UN climate convention: how low should they set the global thermostat? ■

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