hard drive available to the computer, it could handle the computation in a few days. Now, Pan Zhang, a statistical physicist at the Institute of Theoretical Physics at the Chinese Academy of Sciences, and colleagues have shown how to beat Sycamore in a paper in press at *Physical Review Letters*.

Following others, Zhang and colleagues recast the problem as a 3D mathematical array called a tensor network. It consisted of 20 layers, one for each cycle of gates, with each layer comprising 53 dots, one for each qubit. Lines connected the dots to represent the gates, with each gate encoded in a tensor—a 2D or 4D grid of complex numbers. Running the simulation then reduced to, essentially, multiplying all the tensors. "The advantage of the tensor network method is we can use many GPUs to do the computations in parallel," Zhang says.

Zhang and colleagues also relied on a key insight: Sycamore's computation was far from exact, so theirs didn't need to be either. Sycamore calculated the distribution of outputs with an estimated fidelity of 0.2%—just enough to distinguish the fingerprintlike spikiness from the noise in the circuitry. So Zhang's team traded accuracy for speed by cutting some lines in its network and eliminating the corresponding gates. Losing just eight lines made the computation 256 times faster while maintaining a fidelity of 0.37%.

The researchers calculated the output pattern for 1 million of the 9 quadrillion possible number strings, relying on an innovation of their own to obtain a truly random, representative set. The computation took 15 hours on 512 GPUs and yielded the telltale spiky output. "It's fair to say that the Google experiment has been simulated on a conventional computer," says Dominik Hangleiter, a quantum computer scientist at the University of Maryland, College Park. On a supercomputer, the computation would take a few dozen seconds, Zhang says—10 billion times faster than the Google team estimated.

The advance underscores the pitfalls of racing a quantum computer against a conventional one, researchers say. "There's an urgent need for better quantum supremacy experiments," Aaronson says. Zhang suggests a more practical approach: "We should find some real-world applications to demonstrate the quantum advantage."

Still, the Google demonstration was not just hype, researchers say. Sycamore required far fewer operations and less power than a supercomputer, Zhang notes. And if Sycamore had slightly higher fidelity, he says, his team's simulation couldn't have kept up. As Hangleiter puts it, "The Google experiment did what it was meant to do, start this race." ■

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U.S. CLIMATE POLICY

Ambitious bill leads to 40% cut in emissions, models show

But more action is needed to reach Biden's pledge to halve greenhouse gas emissions by 2030

By **Erik Stokstad**

For climate advocates in the United States, the past month felt like a roller coaster. In early July, negotiations in Congress on clean energy legislation of historic proportions collapsed, and the effort seemed doomed. But backroom talks continued and last week key senators suddenly announced an agreement on a $369 billion bill that would provide the most climate funding ever seen in the United States. "It was the best kept secret, potentially, in Washington history," says Leah Stokes, a political scientist at the University of California (UC), Santa Barbara.

The backers—Senate Majority Leader Chuck Schumer (D–NY) and Senator Joe Manchin (D–WV)—who had initially balked at the cost—announced that the draft bill would ensure U.S. carbon dioxide (CO_2) emissions would fall by 40% by 2030, compared with 2005.

Sponsors of the bill, which must still pass the full Senate and the House of Representatives, might be expected to oversell its impact. But energy and climate modelers have now scrutinized its 725 pages and concluded the 40% claim is about on target. They plugged major provisions, including subsidies for renewable energy and tax cuts for electric vehicles, as well as controversial incentives for the fossil fuel industry, into their models. Three models now agree that if the bill's provisions are carried out, U.S. greenhouse gas emissions would fall by perhaps 40% by 2030, although only part of that stems from the bill alone. One model also finds that the renewable energy subsidies will likely create 1.5 million jobs and prevent thousands of premature deaths from air pollution, especially in disadvantaged communities.

"It's a historic step, no doubt about it," says Marshall Shepherd, an atmospheric scientist at the University of Georgia and former head of the American Meteorological Society. "It really does a lot to enhance the transition to a renewable energy economy."

U.S. emissions have been falling by about 1% per year since 2005, when they peaked, largely because of replacing coal power with wind and solar, as well as natural gas, and rising fuel economy in light cars. But this pace is nowhere near fast enough to meet President Joe Biden's goal of a 50% to 52% cut in emissions by 2030 relative to 2005. Officials pledged that dramatic

A proposed bill would subsidize renewable energy sources, such as this solar farm in Florida, but also support some fossil fuel operations.

reduction as the U.S. contribution to the Paris accord's goal of holding global temperature rise to 1.5°C.

Biden's major effort had been the Build Back Better Act, which would have invested $560 billion in cutting greenhouse gases but died in the Senate after Manchin objected. The smaller new bill, called the Inflation Reduction Act of 2022, preserves much of the bang for clean energy, says energy systems expert Jesse Jenkins of Princeton University's Rapid Energy Policy Evaluation and Analysis Toolkit Project, which runs one of the models. "I think [Senate staff] did a miraculous job," he says. In particular, the bill provides subsidies to expand renewable energy and lure consumers to buy electric vehicles, solar panels, and climate-friendly home heat pumps.

To evaluate the climate impacts of the legislation, Jenkins and other modelers simulate the entire U.S. energy system, from the smallest electric vehicles to nuclear plants, and add the proposed policies to see how they impact CO_2 emissions. Scientists also fold in results from other models that focus on factors such as the impact of agricultural policies on two other causes of greenhouse warming: methane emissions from livestock and nitrous oxide released from fertilized fields. Modelers put everything together to forecast emissions trends, says modeler Ben King of the Rhodium Group, an independent research firm.

Just a day after the bill was released, Rhodium posted preliminary estimates on its website. The topline result: a 31% to 44% reduction in greenhouse gas emissions from 2005. Compared with current policies, that's an additional drop of 7 to 9 percentage points. Variables such as the price of natural gas account for much of the uncertainty: If gas prices drop, utilities might favor gas over renewable power, slowing the decline in carbon emissions.

This week, the think tank Energy Innovation narrowed the range, forecasting emissions reductions of 38% to 41%, with 13% to 17% from the bill alone. And the Princeton model estimated about a 42% reduction, with 15% from the bill itself.

All the analyses find the two most important factors driving down emissions are clean electricity tax credits—which the bill provides for at least a decade—and expanded tax credits for both new and used electric vehicles. The subsidies will help utilities install more capacity from wind farms and solar panels and help keep nuclear power plants financially viable as they face competition from cheap natural gas. Previous analyses had also pointed to green electricity generation and transportation as crucial to reducing emissions (*Science*, 27 May, p. 922).

Models can have difficulty predicting human behavior, cautions economist Meredith Fowlie of UC Berkeley. "I wouldn't believe any one projected number, but [key] models agree in a qualitative sense that this is going to bend the trajectory," she says.

Other provisions of the proposed bill could eventually lead to further CO_2 reductions, such as investment in technologies that directly remove carbon from the atmosphere and capture it from fossil fuel plants.

The bill also includes some climate-unfriendly provisions, apparently added at Manchin's request. It requires the federal government to offer several lease sales of offshore oil and gas resources, with more on the table if public lands are opened to renewable energy efforts like wind farms. The leases could boost oil and gas production from federal lands by an extra 50 million tons per year in 2030, according to Energy Innovation. Overall, however, climate wins out, analysts say: For each additional ton of CO_2 from fossil fuels, other provisions of the bill would reduce emissions by 24 tons.

> **"The United States is really going to be a climate leader globally if we can get this bill over the finish line."**
>
> **Leah Stokes**, University of California, Santa Barbara

The bill must still pass the Senate, where Democrats need every possible vote in their party, and then it will go back to the House. Stokes, who advised Democrats on the bill, says she's hopeful the measure will be on Biden's desk by mid-August. "The United States is really going to be a climate leader globally if we can get this bill over the finish line."

The measure won't be enough, however, for the United States to reach its Paris goal of a 50% greenhouse emissions reduction by 2030. For that, more federal regulation and state action will be necessary, King and others say. "It's all hands on deck," says energy and climate modeler John Bistline of the Electric Power Research Institute.

The ultimate—and necessary—goal is cutting U.S. emissions to zero, says Emily Grubert, a civil engineer and environmental sociologist at the University of Notre Dame. "People keep talking about this as the biggest climate investment in a generation. I can only say—I hope not." ■

DEVELOPMENTAL BIOLOGY

Mouse stem cells grown into embryo mimics

Bioreactor lets "embryoids" mature long enough for multiple organs to form

By **Mitch Leslie**

What happens in embryonic development is one of nature's best guarded secrets, unfolding deep in the mother's body. Now, researchers have opened a new window on the process. They've made artificial mouse embryos from stem cells—no sperm or eggs required—and used an innovative bioreactor to nurture their creations for longer than any previous embryo models. The simulated embryos developed anatomy that matched the real thing and "very impressive similarities at the cellular level. The right cells arise at the right time," says stem cell biologist Niels Geijsen of the Leiden University Medical Center, who was not involved in the work.

The feat, reported this week in *Cell*, may allow biologists to delve deeper into developmental mechanisms and better understand what goes wrong in birth defects. And the team's leader, stem cell biologist Jacob Hanna of the Weizmann Institute of Science, says that next, he hopes to do the same with comparable human stem cells.

Researchers have already reprised parts of early development with embryo mimics made from an assortment of mouse or human stem cells, including embryonic stem (ES) cells, which are derived from normal embryos and can form all of a body's tissues. They've mimicked the blastocyst, the simple developmental stage that implants in the uterus, and recreated gastrulation, when embryos become multilayered. These simulated embryos hit a developmental wall, however. Their cells begin to specialize but do not coalesce into organs.

One obstacle has been keeping the ersatz embryos alive for more than a few days. Last year, Hanna and colleagues unveiled a nurturing procedure that allowed them to grow standard mouse embryos outside of the mother's body for a record 11 days. (Typical mouse gestation is about 20 days.)

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