A coal-fired power station in Tongling, China.

QILAI SHEN/BLOOMBERG/GETTY

FOSSIL-FUEL RESERVES MUST REMAIN UNTAPPED TO HIT 1.5 °C GOAL

Many planned coal, oil and gas extraction projects will not be viable if the world hopes to hit climate targets.

By Bianca Nogrady

Nearly 90% of economically viable global coal reserves must be left in the ground to have even a 50% chance of hitting internationally agreed climate-change goals. That's according to an updated model of limits on fossil-fuel extraction, published in *Nature* (D. Welsby *et al. Nature* **597**, 230–234; 2021).

For a 50% chance of remaining below 1.5 °C degrees of global warming – the more aspirational of the two targets set by the 2015 Paris agreement – the world must not emit more than 580 gigatonnes of carbon dioxide before 2100, report the authors.

Under this scenario, researchers led by environmental and energy economist Dan Welsby at University College London calculate, 89% of coal reserves, 58% of oil reserves and 59% of gas reserves must remain unextracted (see 'Resources off limits').

The authors stress that although the scenario already looks "bleak" for the global fossil-fuel industry, even tighter limits on extraction will be needed to improve the chances of constraining warming to 1.5 °C above pre-industrial levels.

The research "makes the fundamental point that the majority of known economic reserves will not be able to be used", says Frank Jotzo, an environment and climate-change economist at the Australian National University in Canberra.

Never see the light of day

The study builds on a 2015 model that examined how much fossil fuel must remain unused to limit global average temperature increases to no more than 2 °C compared with pre-industrial times (C. McGlade and P. Ekins *Nature* **517**, 187–190; 2015).

Updating the model was important because the entire debate has now moved beyond 2 °C being acceptable, says Welsby. "Actually, 2 °C is incredibly significant warming."

The model captures key primary energy sources, such as fossil fuels, biomass, nuclear and renewables. It takes into account demand, economic factors and the geographical distribution of resources and emissions, and examines how these change over time. It also incorporates negative-emissions technologies, such as CO_2 removal.

Welsby and his co-authors calculate that oil and gas production must decline by 3% each year from now until 2050, which means fossil-fuel production must peak within the next decade – and that most existing and planned fossil-fuel projects would be unviable as a result.

Regional variations

However, the study reveals significant regional differences in limits on fossil-fuel extraction, based on the carbon intensity and cost of exploiting different resources.

For example, the modelling suggests that 84% of Canada's oil sands must remain untapped, as well as all undeveloped oil and gas resources in the Arctic. Australia must leave 95% of its coal reserves in the ground, and both Russia and the United States will need to walk away from 97% of theirs.

Under the new model, only the most cheaply exploited fossil-fuel reserves will be viable, says Michael Jakob, an economist at the Mercator Research Institute on Global Commons and Climate Change in Berlin. "Others, like the Canadian tar sands, of course would be completely uncompetitive because you would never go in this area of expensive oil production."

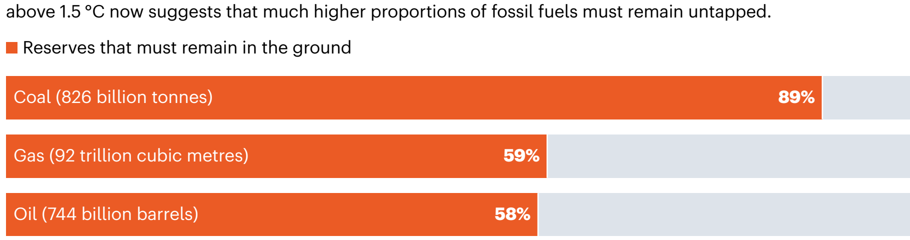
The model also assumes substantial use of CO_2 removal and carbon capture and storage, because if they aren't included or are included at a smaller scale, "that target is unfeasible", Welsby says.

This mirrors the approach taken in a major Intergovernmental Panel on Climate Change (IPCC) report, published last month (see go.nature.com/3iu12nn). It allowed a 40% increase in greenhouse-gas emissions while still remaining below 1.5 °C by including negative-emissions technologies, says Pep Canadell, chief research scientist at the CSIRO Climate Science Centre in Canberra, who has contributed to IPCC assessment reports.

Canadell says the inclusion of CO_2 removal

RESOURCES OFF LIMITS

A 2015 study found that, if the world is to stay below 2 °C of warming, then one-third of oil, half of gas and 80% of coal reserves must remain in the ground. Updated modelling to avoid dangerous warming above 1.5 °C now suggests that much higher proportions of fossil fuels must remain untapped.



D. WELSBY *ET AL. NATURE* 597, 230–234 (2021) acknowledges the likely scenario that "we blow out our carbon budget", but then remove enough CO_2 from the atmosphere to bring the temperature back down to, or even below, 1.5 °C above pre-industrial levels.

However, this strategy is risky, says Nebojsa Nakicenovic, energy economist and former chief executive of the International Institute for Applied Systems Analysis in Vienna.

Overshooting emissions targets and then removing the carbon from the atmosphere "means we are postponing the problem to the second half of this century", and CO_2 removal technologies have a long way to go before they are scalable, he says.

It is clear, based on evidence such as the results of the new modelling, that achieving the deep fossil-fuel emissions reductions needed to keep warming below 1.5 °C will be a "Herculean task" and we must start immediately, Nakicenovic says. "It's not enough to have promises for 2050."

SUCCESS! MARS ROVER FINALLY COLLECTS ITS FIRST ROCK CORE

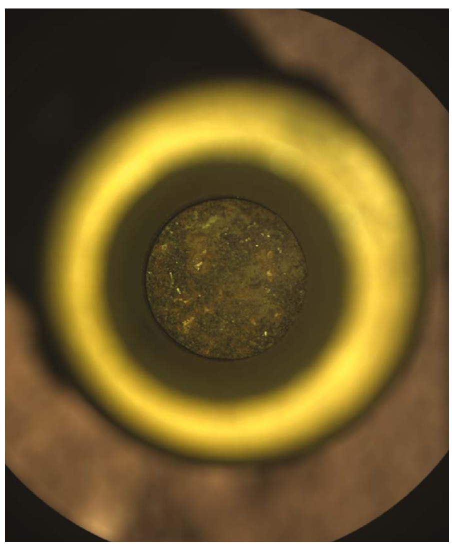
NASA's Perseverance rover lives up to its name, drilling into Martian rock after a misstep in August.

By Alexandra Witze

After a failed attempt last month, NASA's Perseverance rover has successfully drilled, extracted and stored a sample of Martian rock — the first ever Mars sample destined to be flown back to Earth for study.

"This is a momentous achievement," said NASA administrator Bill Nelson in a statement.

When the rover first attempted the manoeuvre, on 6 August, the rock it was trying to sample crumbled into powder before making it into a sample tube. The second attempt, on 1 September at a different location several hundred metres away, went smoothly: the drill bit pulled a slim cylinder out of a 70-centimetre-long rock named Rochette. Engineers then paused the process so that they could photograph the core in its sample tube, to ensure it was intact, before sealing the specimen inside days later.



NASA/JPL-CALTECH

Perseverance's first intact rock core, visible inside its sample tube, on 6 September.

The core from Rochette now rests in Perseverance's belly, hermetically sealed and ready to wait many years until future spacecraft can retrieve it and any other cores the rover manages to collect. The goal is to gather about 35 cores representing the geological history of Jezero Crater, Perseverance's landing site — which was home to a river delta billions of years ago and might contain evidence of ancient Martian life.

How Rochette fits into that history isn't yet clear. Early investigations by the rover suggest that it is a rock type known as basalt, and might have been part of an ancient lava flow that makes up the ridge where Perseverance is parked, says Kenneth Farley, a geologist at the California Institute of Technology in Pasadena and the mission's project scientist. Rochette shows reddish patches and staining, as well as small cavities filled with salts, all of which suggest it interacted with water over a period of time — perhaps at the bottom of the ancient lake that once filled Jezero.

Rochette turned out to be a much better rock to drill into than the one the rover first attempted to sample — a rock named Roubion that lay elsewhere on the crater floor. Roubion also showed signs of interacting with water long ago, but in its case the water seems to have physically weakened the rock, because it turned to dust when Perseverance hammered in its drill bit. The rover might try drilling into another rock similar to Roubion later in its mission, says Farley, if it can find one that looks more robust.

If further studies confirm that Rochette is basalt, that would be scientifically exciting because, once it has been returned to Earth, researchers could use the decay of radioactive elements in the rock to date its formation precisely. This has never previously been possible for a Martian rock because no samples have ever been brought back from the planet.

NASA's previous Mars rover, Curiosity, which landed in a different crater in 2012, came across rocks that were, unexpectedly, too hard for it to drill — the opposite of Perseverance's initial problem. And a 2008 Mars lander, Phoenix, had trouble collecting grains of dirt until mission managers worked out that the dirt needed to be kept out of direct sunlight so that ice between the grains didn't melt, refreeze and cement them together. "Mars is a real planet, with surprises," says Raymond Arvidson, a planetary scientist at Washington University in St. Louis, Missouri, who has worked on a number of Mars rover missions, although not Perseverance.

Crunch time

Now the pressure is on for Perseverance to start collecting cores more efficiently. It landed in Jezero in February, so it has taken more than six months to collect its first sample. It is supposed to gather its first suite of cores from the crater within one Mars year of landing (a little less than two Earth years). And because the rover landed slightly over 2 kilometres from its main sampling target, Jezero's ancient river delta, it probably won't even reach that formation until early next year.

But Arvidson says he's not concerned about the pace of the mission so far. The first three months were used, among other things, to test and fly a miniature helicopter, which has made a dozen flights so far and is helping mission scientists to pick interesting directions for the rover to travel. The rover itself has driven 2.17 kilometres, south and then west from its landing site, surveying the terrain and doing experiments that don't involve drilling, such as using ground-penetrating radar to probe beneath the planet's surface.

Following its successful sample collection, Perseverance will drive a few hundred metres north-west, into a region known as South Seítah, full of sand dunes, ridges and other rocks and boulders. Mission planners will soon have a brief break, from 2 October to 14 October, when it will not be possible to communicate with the rover because Mars will move behind the Sun relative to Earth.

NASA and the European Space Agency are planning a complex set of future robotic missions that would travel to Jezero, pick up the samples collected by Perseverance and fly them back to Earth for scientists to study. It will be at least 2031 by the time the samples arrive on Earth.