two months later, Congress blocked any marketing of the salmon by ordering the FDA to establish labelling requirements for genetically engineered meat.

The agency has not released those requirements, nor finalized guidelines for regulating gene-edited livestock. "The FDA is excited about the promise of some of these newer technologies and the products being developed, including genome-edited animals," an agency spokesperson said. "While helping to bring innovative products to market, the FDA also needs to ensure they are safe and have consumer confidence."

Meanwhile, researchers and companies are hesitant to wait for US approval. "Nobody wants to do it based on what's happened to us," says Sylvia Wulf, chief executive of AquaBounty Technologies, the company in Maynard, Massachusetts, that developed the fish.

That leaves US researchers in a bind. Federal funding for genetically engineered or edited livestock is in short supply. Geneticist Kevin Wells at the University of Missouri in Columbia can recall only one such grant in the past 30 years. To pick up the slack, researchers have leant on industry funding — but this, too, might run dry if companies can't bring their animals to market.

AquaBounty's salmon predates genome editing, but the company has since used the technique to develop another fish, a fast-growing tilapia. But instead of trying for FDA approval, AquaBounty sought to bring the fish to market in Argentina. In December, the company announced that Argentina would not regulate the tilapia as a genetically modified animal. Instead, the fish would fall under regulations governing new plant and animal breeds — a significantly shorter regulatory pathway.

Recombinetics, an animal-biotechnology company in St Paul, Minnesota, has also decided to look beyond the United States. The company's gene-edited dairy cattle do not have horns, which could be a boon to both animal welfare and dairy farmers, who surgically remove the horns from conventional cattle to prevent the animals from hurting each other or their handlers.

In 2016, Recombinetics petitioned the FDA to declare its gene-edited cattle "generally recognized as safe", a designation that would have largely freed the animals from regulatory oversight. Hornless cattle also occur naturally, the company argued, noting that it used genome editing to turn off only one gene.

"We don't need the United States. It's just a reality."

The FDA declined the petition, but the company has since received a green light from Brazilian regulators. The firm is focusing on Brazil and other markets — including Argentina, Australia and Canada — to market both its hornless cattle and its genome-edited heat-resistant cattle. "We don't really need the United States," says Recombinetics chief scientific officer Mitch Abrahamsen. "It's just a reality."

HAVE RESEARCH, WILL TRAVEL

It isn't always easy to move a research project to a different country. About 10 years ago, difficulties finding funding for his research drove animal geneticist James Murray to relocate his transgenic goat project from the University of California, Davis, to Brazil. The goats were engineered to produce milk that contained lysozyme, an enzyme with antibiotic properties. Murray hoped that the milk could help to protect children from diarrhoea.

But Brazil bans the import of goats and even goat eggs or sperm. Murray and his collaborators then tried to clone their goats from cells that they were able to legally import. This proved unexpectedly difficult in the semi-arid climes of northern Brazil, says Murray, who thinks that the problems arose because of differences in the goats' diet.

The team eventually sorted out its cloning problems and created a herd of transgenic, lysozyme-producing goats. Then the researchers' grant ran out, and Murray's collaborators moved to a different university. "At present, we are on hold," he says.

And not everyone is convinced that it will be so easy to dismiss the powerful US market. Wells is working with a company called Genus to develop disease-resistant, gene-edited pigs. "To up and go to Brazil — that doesn't help you at all in reality," he says. "Anyone who claims that they're going to get their animal into agriculture by moving to Brazil doesn't understand where they're going to be selling their product."

Genus, which is based in Basingstoke, UK, is working with the FDA to gain approval for its pigs in the United States.

AquaBounty's Wulf also doesn't discount the value of the US market, which imports US$3-billion worth of salmon every year. "It's big to us," she says. "But we're not going to be put in a box just because we have a regulatory process that doesn't work."

Last October, the FDA pledged to finalize its guidance on genome-edited animals that will be used as food. But the announcement did nothing to dissuade Long from making his trip to Brazil.

"They move at the pace of molasses in January," he says. "Why would I sit around and wait?" ■

SPACE FLIGHT

First private Moon lander sparks new lunar space race

Israeli craft heralds era of national and private cooperation to exploit lunar resources.

BY ELIZABETH GIBNEY

Israel is heading for the Moon — and a milestone. If all goes well, a lander that launched on 21 February will become the first privately funded craft to touch down on the Moon. The feat seems set to kick off a new era of lunar exploration — one in which national space agencies work alongside private industry to investigate and exploit the Moon and its resources.

The craft, named Beresheet — 'in the beginning' in Hebrew — was built by an Israeli non-profit company called SpaceIL that raised US$100 million for its mission, much of it through philanthropic donations. Beresheet lifted off on a SpaceX Falcon 9 rocket from Cape Canaveral, Florida, and should reach Mare Serenitatis, a basaltic plain on the northern hemisphere of the Moon, in April (see 'Moon shot'). There, it will study the presence of magnetism in lunar rocks, a phenomenon that is puzzling, given the satellite's lack of a global magnetic field.

The mission is not wholly private, because it involves government partners. And although the craft is little more than a demonstrator — its scientific mission is simple and the lander is expected to last just two days on the surface — the mission is symbolically important. It is Israel's first Moon mission, and would be the first privately backed craft to 'soft land' on the Moon's surface — until now, the preserve of an

PAUL HENNESSY/NURPHOTO VIA GETTY

A SpaceX Falcon 9 rocket launched on 21 February, carrying the Israeli Beresheet Moon lander.

elite club of the space agencies of the United States, China and Russia.

SpaceIL's success would be a milestone, says Robert Böhme, chief executive and founder of PTScientists in Berlin, a private company also shooting for the Moon. "It would be a big proving point, because right now the only one with soft-landing capability is China," he says.

The Israeli success could herald a new crop of landers, and flip the business model for lunar exploration to one in which private firms essentially sell a delivery service. Customers could buy room on landers to ferry their cargo — from communications technology and scientific instruments built by space agencies and universities to urns from companies promising to put loved ones' ashes on the Moon. In the long term, firms might want to put technology on the Moon to mine for water, which could be turned into fuel to power rockets or sustain a lunar settlement.

Lunar scientists are set to benefit from a commercial fleet of landers. Aside from China's Chang'e craft — the latest of which landed last month and is the Moon's only active robotic resident — the last surface missions were in the 1970s, says Barbara Cohen, a planetary scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "This generation of lunar scientists hasn't been able to do anything robotically," she says. "We're really excited."

XPRIZE LEGACY

SpaceIL is the first former competitor for the now-defunct Google Lunar XPRIZE to launch its mission to the Moon. But at least five other companies that competed for the prize plan to launch missions by the end of 2021. All the firms are vying to be the first fully commercial mission to make it.

The Google Lunar XPRIZE deserves credit for the Moon's popularity today, says Bob Richards, chief executive of Moon Express in Cape Canaveral, another former competitor. Launched in 2007 to spur affordable and commercial access to the Moon, the project offered $20 million to the first team to land a craft on the surface and perform basic tasks. The competition was cancelled in January 2018 when no firm looked set to meet the March launch deadline. At the time, the XPRIZE Foundation in Culver City, California, put the failure down to teams' difficulties in raising funding, as well as technical and regulatory challenges.

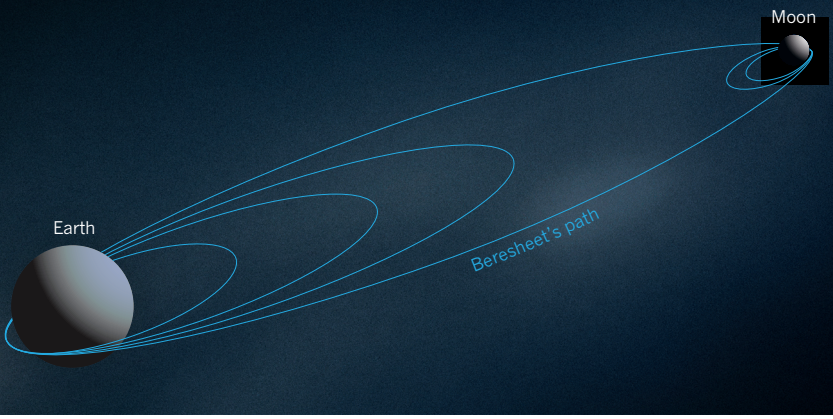
The landscape for private Moon landers has changed dramatically since then — thanks to falling launch costs and a growing pool of customers willing to pay for a trip to the Moon, say firms.

SpaceIL's lead in this new space race is largely down to its funding, says Richards. Three young engineers founded the firm in Tel Aviv in 2011, but it has drawn $43 million from Morris Kahn, a South African software billionaire who is now the firm's president. The mission has become a national project, involving the Israel Space Agency — which chipped in $2 million — and Israel Aerospace Industries in Lod, the country's major satellite firm, which assembled the craft. The project has also kept costs down by hitching a ride on the Falcon 9 along with other cargo.

Fresh government interest is also spurring Moon missions. NASA and the European ▶

MOON SHOT

The privately built Israeli craft Beresheet headed to the Moon on 21 February. After disengaging from its SpaceX rocket, the craft entered Earth's orbit. It will travel in elliptical loops until it is close enough to the Moon to be captured by lunar gravity, before landing in April.



Space Agency (ESA) are looking to fund private firms to ship scientific instruments to the lunar surface, in the hope that the agencies will eventually be among many customers using the service.

NASA, which turned its sights back to the Moon after a 2017 US presidential directive, aims to provide a training ground for Mars missions and to study lunar resources that could sustain a human presence on the Moon, for example by mining oxygen and hydrogen for fuel, as well as purely scientific studies.

To help reach these goals, the agency launched the $2.6-billion, 10-year Commercial Lunar Payload Services (CLPS) programme in 2018. Last November, NASA picked nine consortia that it deems eligible to fly its payloads to the Moon. Each is led by a US firm and includes multiple partners to cover launch, lander and operations capabilities. Scientists are currently submitting proposals to NASA for instruments or technologies that could make up the payloads to be shipped commercially.

The programme is intended to "jump-start" a private Moon-lander industry, says Richards, and mirrors NASA's effort more than a decade ago to encourage development of commercial space-flight firms such as SpaceX. The agency is now among many clients that use these commercial services to send cargo to space.

RAILWAY TO THE MOON

Böhme says that NASA is likely to pick dozens of payloads as part of the CLPS programme, giving several firms a shot at the Moon, probably from 2020. "We're creating the railroad, a DHL delivery service to the Moon," says John Thornton, chief executive of Astrobotic, based in Pittsburgh, Pennsylvania, another firm hoping to land the first commercial lunar craft.

ESA is planning a single lander mission that would launch in 2025, aimed at demonstrating the feasibility of harvesting water or oxygen from soil at the lunar poles. Last month, the agency contracted PTScientists (which was created in direct response to the XPRIZE), rocket-makers ArianeGroup of Paris and aerospace firm Space Application Services of Brussels to explore the viability of such a mission. Böhme says that the agency hopes to secure the roughly €250 million (US$283 million) it would need from member states in November. Unlike in the CLPS programme, for which commercial partners will cover launch costs, ESA would pay for the mission's launch and operations, as well as for room on the lander, says Böhme.

Today, Richards estimates, a mission to the Moon's surface could cost about $50 million, half of what it cost a decade ago. Economies of scale for subsequent missions could bring the price of individual payloads down to just hundreds of thousands of dollars, he says. ■

BIOTECHNOLOGY

Life's genetic alphabet doubled

Synthetic, eight-letter DNA behaves like the real thing.

BY MATTHEW WARREN

The DNA of life on Earth stores information in just four key chemicals — guanine, cytosine, adenine and thymine, commonly referred to as G, C, A and T, respectively. Now scientists have doubled the number of life's building blocks, creating for the first time a synthetic, eight-letter genetic language that seems to store and transcribe information just like natural DNA.

In a study published on 22 February in *Science*, researchers led by Steven Benner, who established the Foundation for Applied Molecular Evolution in Alachua, Florida, suggest that an expanded genetic alphabet could, in theory, support life (S. Hoshika *et al. Science* **363**, 884–887; 2019). "It's a real landmark," says Floyd Romesberg, a chemical biologist at the Scripps Research Institute in La Jolla, California. The study implies that there is nothing particularly 'magic' or special about those four chemicals that evolved on Earth, says Romesberg. "That's a conceptual breakthrough," he adds.

Normally, as a pair of DNA strands twist around each other into a double helix, the chemicals on each strand pair up: C bonds with G, and A bonds with T. For a long time, scientists have tried to add new pairs of such chemicals, also known as bases, to the genetic alphabet. For example, Benner first created 'unnatural' bases in the 1980s, and Romesberg's laboratory inserted a pair of unnatural bases into a living cell in 2014. But the latest study is the first to systematically demonstrate that the complementary unnatural bases recognize and bind to each other, and that the double helix they form holds its structure and information.

"There is nothing particularly 'magic' or special about those four chemicals that evolved on Earth."

Benner's team created the synthetic letters by tweaking the molecular structure of the regular bases, which pair up by forming hydrogen bonds. Each contains hydrogen atoms, which are attracted to nitrogen or oxygen atoms in their partner. Benner says that it's a bit like Lego bricks that snap together when the holes and prongs line up.

By adjusting these holes and prongs, the team has come up with several new pairs of bases, including a pair named S and B, and another called P and Z, all of which are similar to the natural four (M. M. Georgiadis *et al. J. Am Chem. Soc.* **137**, 6947–6955; 2015). In the *Science* paper, the researchers describe how they combine these four synthetic bases with the natural ones.

The team then conducted a series of experiments to show that its synthetic sequences share properties with natural DNA that are essential for supporting life. The researchers created hundreds of molecules of the synthetic DNA, and found that the letters bound to their partners predictably, which is important for the reliable storage of information. They then showed that the structure of the double helices remained stable, no matter what order the synthetic bases were in, which is important for evolution because DNA sequences need to be able to vary without the structure falling apart. This is a substantial advance, says Philipp Holliger, a synthetic biologist at the MRC Laboratory of Molecular Biology in Cambridge, UK, because other methods of expanding the genetic alphabet are not as structurally sound.

Finally, the team showed that the synthetic DNA could be faithfully transcribed into RNA — a key step for translating genetic information into proteins. "The ability to store information is not very interesting for evolution," says Benner. "You have to be able to transfer that information into a molecule that does something." To demonstrate transcription, Benner's team created synthetic DNA that codes for an aptamer, an RNA sequence that binds and activates specific molecules rather than serving as a protein template. The transcribed RNA was able to bind and activate a fluorescent molecule.

Benner's team has also developed further pairs of new bases, opening up the possibility of creating DNA structures with 10 or even 12 letters. But the fact that the researchers have already expanded the genetic alphabet to eight is in itself remarkable, notes Romesberg. "It's already doubling what nature has."

Holliger says that the work is an exciting starting point, but that there is still a substantial distance to go before a true eight-letter genetic system is reached. One key question, for example, will be whether the synthetic DNA can be replicated by polymerases, the enzymes responsible for synthesizing DNA inside organisms during cell division. ■