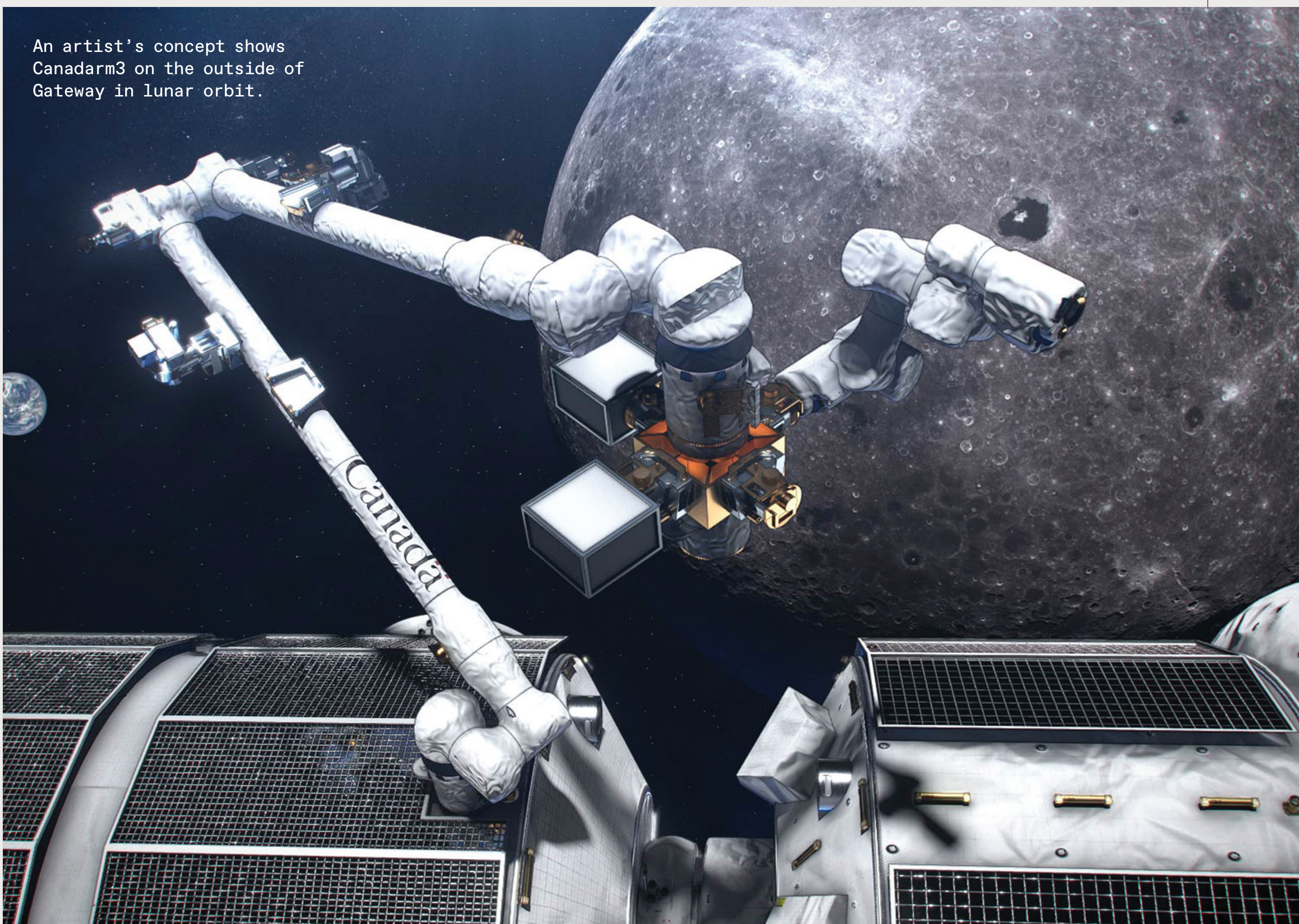
News



An artist's concept shows Canadarm3 on the outside of Gateway in lunar orbit.

CANADIAN SPACE AGENCY/NASA

ROBOTICS

Meet the Lunar Gateway's Robot Caretakers › With people seldom on board, the space station will rely on autonomy

BY EVAN ACKERMAN

An integral part of NASA's plan to return astronauts to the moon this decade is the Lunar Gateway, a space station that will be humanity's first permanent outpost outside of low Earth orbit. Gateway, a partnership between NASA, the Canadian Space Agency (CSA), the European Space Agency, and the Japan Aerospace Exploration Agency, is intended to support operations on the lunar surface while also serving as a staging point for exploration of Mars.

Gateway will be significantly smaller than the International Space Station (ISS), initially consisting of just two modules, with additional modules to be added over time. The first pieces of the station to reach lunar orbit will be the Power and Propulsion Element (PPE) attached to the Habitation and Logistics Outpost (HALO), scheduled to launch together on a SpaceX Falcon Heavy rocket in November 2024. The relatively small size of Gateway is possible because the station won't be crewed most of the time—astronauts may pass through for a few weeks, but the expectation is that Gateway will spend about 11 months out of the year without anyone on board.

This presents some unique challenges for Gateway. On the ISS, astronauts spend a substantial amount of time on station upkeep, but Gateway will have to keep itself functional for extended periods without any direct human assistance.

"The things that the crew does on the International Space Station will need to be handled by Gateway on its own," explains Julia Badger, Gateway autonomy system manager at NASA's Johnson Space Center. "There's also a big difference in the operational paradigm. Right now, ISS has a mission control that's full time. With Gateway, we're eventually expecting to have just 8 hours a week of ground operations." The hundreds of commands that the ISS receives every day to keep it running will still be necessary on Gateway—they'll just have to come from Gateway itself, rather than from humans back on Earth.

To make this possible, NASA is developing a vehicle system manager, or VSM, that will act somewhat like the omnipresent computer system found on virtually every science-fiction starship. The VSM will autonomously manage all of Gateway's functionality, taking care of any problems that come up to the extent that they can be managed with clever software and occasional input from a very far away human. "It's a new way of thinking compared to ISS," explains Badger. "If something breaks on Gateway, we either have to be able to live with it for a certain amount of time, or we've got to have the ability to remotely or autonomously fix it."

While Gateway itself can be thought of as a robot of sorts, there's a limited amount that can be reasonably and efficiently done through dedicated automated systems. NASA had to find a compromise between redundancy and both complexity and mass. For example, there was some discussion about whether Gateway's hatches should be able to open and close on their own, and NASA ultimately decided to leave the hatches manually operated. But that doesn't necessarily mean that Gateway won't be able to open its hatches without human assistance; it just means that there will be a need for robotic hands rather than human ones.

"I hope eventually we have robots up there that can open the hatches," Badger says. She explains that Gateway is being designed with potential intravehicular robots (IVRs) in mind, including things like adding visual markers to important locations, placing convenient charging ports around the station interior, and designing the hatches such that the force required to open them is compatible with the capabilities of robotic limbs. Parts of Gateway's systems may be modular as well; they can be removed and replaced by robots if necessary. "What we're trying to do," Badger explains, "is make smart choices about Gateway's design that don't add a lot of mass but will make it easier for a robot to work within the station."

NASA already has a substantial amount of experience with IVRs. Robonaut 2, a full-size humanoid robot, spent several years on the ISS starting in 2011, learning how to perform tasks that would otherwise have to be done by human astronauts. More recently, a trio of cubical, free-flying robots called Astrobees have taken up residence on the ISS, where they've been experimenting with autonomous sensing and navigation. A NASA project called ISAAC (Integrated System for Autonomous and Adaptive Caretaking) is now exploring how robots like Astrobee could be used for a variety of tasks on Gateway, from monitoring station health to autonomously transferring cargo. But in the near term, in Badger's opinion, "maintenance of Gateway, like using robots that can switch out broken components, is going to be more important than logistics types of tasks."

Badger believes that a combination of a generalized mobile manipulator like Robonaut 2 and a free flyer like Astrobee make for a good team, and this combination is currently the general concept for Gateway IVRs. This is not to say that the intravehicular robots that end up on Gateway will necessarily look like the robots that have been working on the ISS. But they'll be inspired by them, and will leverage all of the experience that NASA has gained with its robots on the ISS so far.

It might also be useful to have a limited number of specialized robots, Badger says. "For example, if there was a reason to get behind [an equipment] rack, you may want a snake type of robot for that."

While NASA is actively preparing for intravehicular robots on Gateway, such robots do not yet exist. The agency will not be building these robots itself, instead relying on industry partners to deliver designs that meet NASA's requirements. At launch, and likely for the first several years at least, Gateway will need to be able to take care of itself without internal

An astronaut holds Bumble, one of three Astrobee robots on the ISS.

JSC/NASA

Robonaut 2 prepares for manipulation tests in front of its task board on the ISS.

JSC/NASA

robotic assistants. However, one of the goals of Gateway is to operate completely autonomously for up to three weeks without any contact with Earth at all. The purpose is to mimic the three-week solar conjunction between Earth and Mars, in which the sun blocks any communications between the two planets. "I think that we will get IVR on board," Badger says. "If we really want Gateway to be able to take care of itself for 21 days, IVR is going to be a very important part of that. And having a robot is absolutely something that I think is going to be necessary as we move on to Mars."

Intravehicular robots are just half of the robotic team that will be necessary to keep Gateway running autonomously long-term. Space stations rely on complex external infrastructure for power, propulsion, thermal control, and much more. Since 2001, the ISS has been home to Canadarm2, a 17.6-meter robotic arm, which is able to move around the station to grapple and manipulate objects while under human control from either inside the station or from the ground.

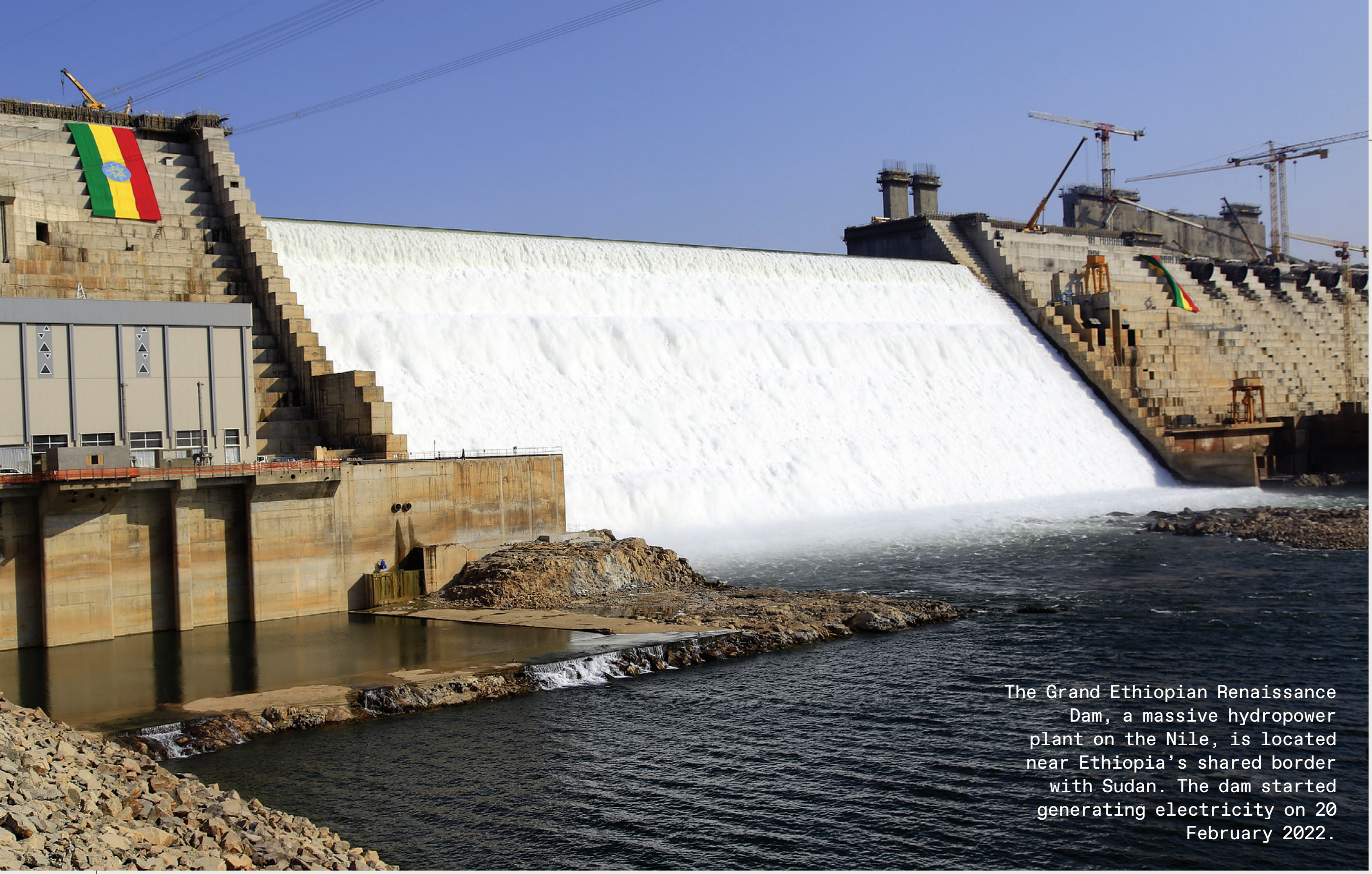
The CSA, in partnership with the Canadian company MDA, is developing a new robotic-arm system for Gateway called Canadarm3, scheduled to launch in 2026. Canadarm3 will include an 8.5-meter-long arm for grappling spacecraft and moving large objects, as well as a smaller, more dexterous robotic arm that can be used for delicate tasks. The smaller arm can even repair the larger arm if necessary. But what really sets Canadarm3 apart from its predecessors is how it's controlled, according to Daniel Rey, Gateway chief engineer and systems manager at the CSA. "One of the very novel things about Canadarm3 is its ability to operate autonomously, without any crew required," Rey says. This capability relies on a new generation of software and hardware that gives the arm the ability to react to stimuli.

Even though Gateway will be 1,000 times as far from Earth as the ISS, Rey explains that the added distance (about 400,000 kilometers) isn't what really necessitates Canadarm3's added autonomy. "Surprisingly, the location of Gateway in its orbit around the moon has a time delay to Earth that is not all that different from the time delays in low Earth orbit when you factor in various ground stations that signals have to pass through. With Canadarm3, we realize that if we want to get ready for Mars where that will no longer be the case, more autonomy will be required."

Canadarm3's autonomous tasks on Gateway will include external inspection, unloading logistics vehicles, deploying science payloads, and repairing Gateway by swapping damaged components with spares. Rey tells us that there will also be a science logistics airlock, with a moving table that can be used to pass equipment in and out of Gateway. "It'll be possible to deploy external science, or to bring external systems inside for repair, and for future internal robotic systems to cooperate with Canadarm3. I think that'll be a really exciting thing to see."

Even though it's going to take a couple of extra years for Gateway's robotic residents to arrive, the station will be operating mostly autonomously (by necessity) as soon as the Power and Propulsion Element and the Habitation and Logistics Outpost begin their journey to lunar orbit in November 2024. Several science payloads will be along for the ride, including heliophysics and space-weather experiments.

Gateway itself, though, is arguably the most important experiment of all. Its autonomous systems, whether embodied in internal and external robots or not, will be undergoing continual testing, and Gateway will need to prove itself before its technology is deemed trustworthy enough for deep-space travel. In addition to being able to operate for 21 days without communications, one of Gateway's eventual requirements is to be able to function for up to three years without any crew visits. This is the level of autonomy and reliability that we'll need, to be prepared for the exploration of Mars and beyond. ■



The Grand Ethiopian Renaissance Dam, a massive hydropower plant on the Nile, is located near Ethiopia's shared border with Sudan. The dam started generating electricity on 20 February 2022.

ENERGY

East Africa's Grand Dam Generates Strife › Doubling Ethiopia's electricity supply threatens neighbors' use of the Nile

BY RAHUL RAO

In the eyes of Ethiopia's government, the future is a 145-meter-tall monument of rolled concrete and Francis turbines that spans the Blue Nile River within shouting distance of the Sudanese border.

That future shifted from vision to reality on 20 February, when Ethiopian prime minister Abiy Ahmed (a Nobel Peace Prize winner who has since come under fire for alleged war crimes in the country's ongoing civil conflict) pressed a virtual button that turned on the Grand Ethiopian Renaissance Dam (GERD), by far Africa's largest hydropower project to date.

That moment notwithstanding, the project isn't complete just yet. The dam's reservoir is still filling, and the full force of both its power and its downstream effects is yet to be seen. And when you zoom out, Ethiopian authorities' lack of transparency about the whole project is only clouding its future.

The GERD project is truly monumental, and not just because the structure is taller than the Great Pyramid of Giza. When the dam is fully operational, its generating capacity will exceed 5,000 megawatts—enough, at least in theory, to double Ethiopia's electricity supply.

So, it's not hard to see why the Ethiopian government is keen on seeing the project through. Right now, less than half of the country's population has access to electricity; most of Ethiopia's energy comes from biomass, in the form of traditional sources such as firewood and animal dung. The use of those materials is linked to deforestation and respiratory illnesses.

Now, with the GERD operational, Ethiopia might fully electrify itself by the 2030s, without much fossil fuel in its energy mix.

MINASSE WONDIMU HAILU/ANADOLU AGENCY/GETTY IMAGES

To be sure, there has been progress in the nation's energy distribution program: Ethiopia's electrification has given an additional tenth of the country's population access to electricity since the Ethiopia Electrification Program kicked off in 2018. Most of that electricity comes from relatively clean hydropower; the country has considerable hydro potential, and it has begun to harness it with other dams such as Tekezé and Gilgel Gibe.

Now, with the GERD operational, Ethiopia might fully electrify itself by the 2030s, without much fossil fuel in its energy mix. There's even talk of selling power to neighboring countries—though the dam is located hundreds of kilometers from any major city, and it's not clear if Ethiopia's grid can handle the GERD's peak power, let alone transmit current to Sudan or Djibouti.

Before any of that happens, the 74-billion-cubic-meter reservoir in the dam's wake needs to fill up. Filling began in 2020, but the glass is still not even half full. It will be several more years before the reservoir fills up. As the reservoir level rises, it could eventually choke off the Blue Nile that feeds it, shutting off the flow that joins the Nile at the Sudanese capital of Khartoum.

The region's monsoon-driven climate will ultimately control how much water gets through. The throttle will be the amount of rain that falls during the wet season, between June and September. In 2021, for instance, the region saw more rain than average, minimizing the downstream effects.

But suppose the region is hit by drought; suppose Ethiopia closes the dam gates to force the reservoir to fill more quickly. Either, or both, could cut off the Blue Nile's flow and could impact hydropower plants like Sudan's 280-megawatt Roseires Dam and Egypt's 2,100-MW Aswan High Dam. "They have to think how to adapt the operation of the dam," says Hisham Eldardiry, an energy and water security researcher at Pacific Northwest National Laboratory, in Richland, Wash.

The Nile is much more than a hydropower resource. For millennia, people have relied on it for things like irrigating fields, and less water could harm environmentally sensitive breadbaskets downstream, such as the region around Khartoum and Egypt's Nile Delta. Farmers might be forced to avoid crops with high water needs. (Rice, for instance, could be eliminated as a crop.)

Eldardiry's research has found that the effects will be dependent on how long the reservoir takes to fill. If it's rapid (three or four years), then the downstream impacts will be more severe than if the Ethiopians slow down the filling (letting it crest in closer to seven years).

But Ethiopia isn't setting a firm target—at least not one that it's revealing publicly. For water managers downriver, that's a problem. "They need to know how much water is coming so they can plan ahead for the irrigation season or for the production of hydropower," says Eldardiry.

The dam's anticipated generation capacity has fluctuated a great deal over the years, from 6,500 MW down to 5,000 MW, amid criticism that those high numbers only described the peak capacity during the wettest part of the rainy season. The dam's Italian builders also allegedly conducted the dam's feasibility study, a potential conflict of interest.

Still, the GERD is a remarkable energy project in an especially deprived part of the Global South. Situated near an international border and directly impacting one of the world's major river systems, its situation is unique and delicate. But Eldardiry says that there are a few lessons it can teach planners of other hydropower projects.

For one, he says, it's important for governments to come together and reach agreements over resources—especially when it comes to projects like the GERD, whose effects ripple across multiple countries. "Reaching an agreement would have solved a lot of the problems," says Eldardiry.

Another takeaway: There are few things as important as what Ethiopia hasn't done—share data. ■

JOURNAL WATCH

Robots Rock What They Can't Roll

People around the world have long been captivated by the Moai, a collection of statues that stand sentry along the coast of Easter Island. The statues are well known not just for their immense size and distinct facial features, but also for the mystery that shrouds their geographic location. The question that piques everyone's curiosity is: How did ancient Rapa Nui people move these ginormous rocks—some weighing as much as 80 tonnes—across distances of up to 18 kilometers?

In 2011, a group of archaeologists made some progress in potentially unraveling this mystery. They conducted an experiment in which they tied three hemp ropes to the head of a Moai replica. Using two of the ropes angled at the sides to rock the statue back and forth and the third rope for guidance, they were able to "rock and walk" the replica forward. In the experiment, 18 people were able to move the 4.4-tonne replica 100 meters in just 40 minutes.

More recently, a group of researchers sought to use robots to employ this rock-and-walk technique further. Jungwon Seo, an assistant professor at the Hong Kong University of Science and Technology, and his team devised a rock-and-walk technique suitable for machines and implemented it four different ways. They describe their work in a study published 21 January in *IEEE Transactions on Robotics.*

In all the scenarios, the researchers used an object that had features like those of the Moai, such as a low center of gravity and a round edge along the bottom, which facilitate the dynamic rolling maneuvers. Seo foresees these rock-and-walk techniques being helpful when helicopters or other machines can't get the job done.

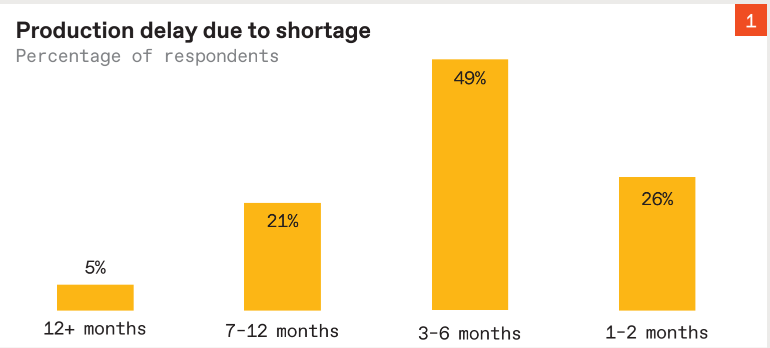
—Michelle Hampson

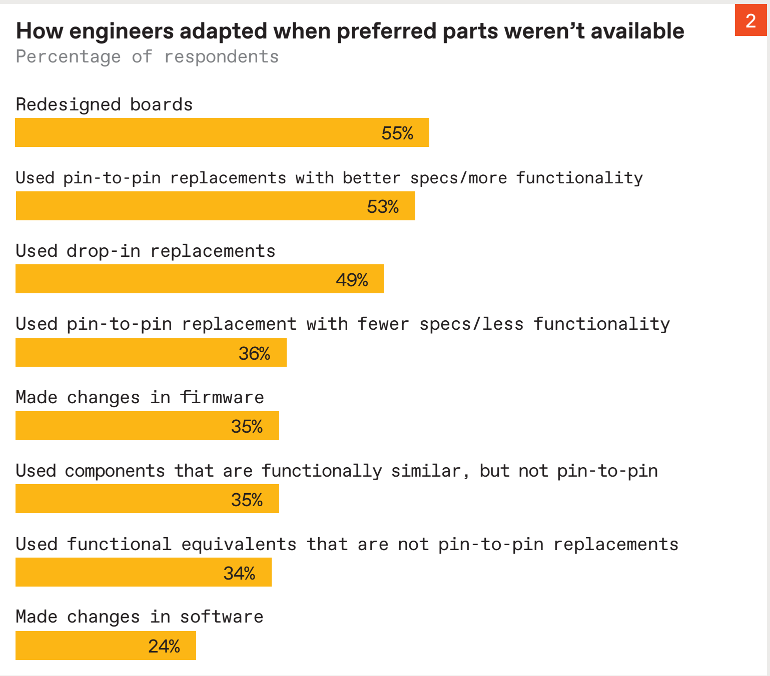
SEMICONDUCTORS

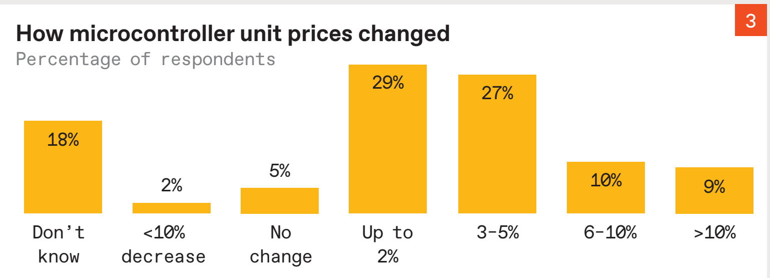
5 Ways the Chip Shortage Is Rewiring Tech

> Broken supply chains prompt companies to redesign products

BY JULIANNE PEPITONE







SOURCE: AVNET

The global chip shortage's effect on today's products is clear in just about every consumer market in the developed world; it's reflected in half-empty car dealership lots and shuttered manufacturing lines. COVID gets a lot of the blame—and it sure didn't help—but the fact is, the disruption of the semiconductor market's supply-demand balance has long been looming due to the proliferation of gadgets basic to everyday life.

The end of the shortage, unfortunately, is not near. Yuh-Jier Mii, R&D chief at the world's largest contract chip manufacturer, Taiwan Semiconductor Manufacturing Co., recently told *IEEE Spectrum* that he believes it will take two to three years to get enough new chip fabrication facilities online to adequately address the shortfall.

So, the shortage isn't just affecting the availability of today's gadgets. The lack of chips is already fueling changes in the design of future products and delaying the next generations of devices. It is also forcing engineers to devise all manner of Plan Bs, according to a new survey from Avnet.

Sixty-four percent of the global engineers polled for the study say their companies are increasingly designing products based on the availability of components, rather than just following their preferences. This finding and others highlight how the chip shortage will alter technology—and tech jobs—for years to come.

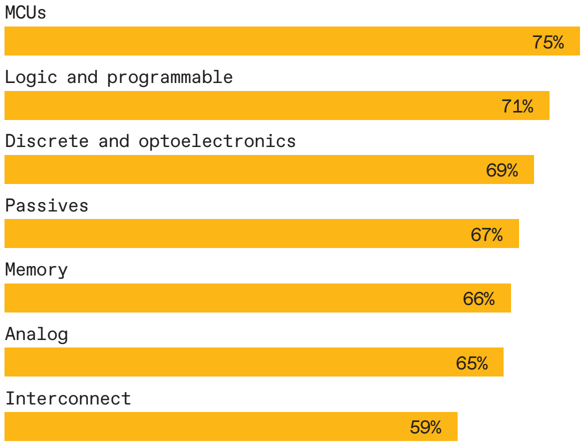
"Just as [technologists] have had to think about manufacturability and testability, we need to start thinking about 'procurability,'" says Samuel Russ, an associate professor of electrical engineering at the University of South Alabama. "It's got to become part of the engineer's lexicon, and we've got to figure out better ways to be more agile."

Russ stresses that tech workers shouldn't view the crunch as a temporary problem to work around when designing. It's a real-world component of the landscape that's fundamentally altering how technologists, designers, and engineers work—and could become elemental to what tech is made, by whom, and when.

"In the past, design was separate from procurement. It was based on the technology—you pass it to the sourcing organization, you move that into production," says Peggy Carrieres, Avnet's vice president of global sales enablement and supplier development. These days, she says, " 4

Which category of components has been the most significantly impacted overall?

Percentage of respondents



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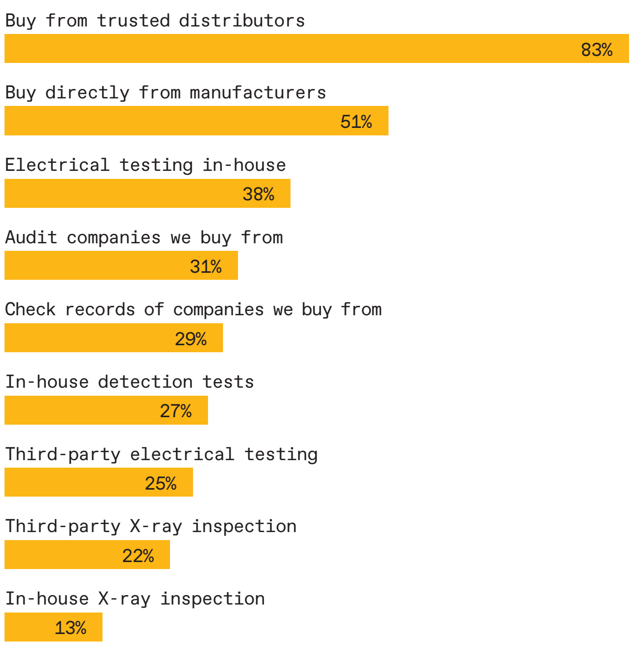
How engineers are managing risk of counterfeit parts

Percentage of respondents



you have to think about [component] availability from day one."

Availability is particularly low for microcontrollers (a.k.a. microcontroller units, or MCUs), Avnet found (see Chart 4). Russ noted that unlike in the CPU world, which has Intel and AMD and then "scenery-chewing extras," the MCU space comprises a dozen different companies of roughly equal size. "The problem with MCUs is that it's not one or two parts; it's like 100 different parts that are low-volume products," Russ says. "So it's a lot harder to keep those in stock, especially if fab lines are starting to have to decide how to allocate. They're obviously going to want to focus on the high-volume stuff."

The supply-demand imbalance has helped to push MCU costs significantly higher, but that's not the only reason for price spikes. Also moving the needle, Carrieres notes, are macro factors affecting the economy at large: inflation, higher labor costs, intermittent shutdowns, and soaring prices for materials like palladium, which topped US $3,000 per ounce in March.

"It takes a while to rebalance that whole supply chain, and we've got these megatrends happening," Carrieres adds. "There's ever more demand, and the cost to manufacture has gone up, so that has to be reflected in the selling price."

Engineers are being forced into "behavioral" changes when it comes to design and product-generation road maps, Carrieres says: "They're delaying the next-gen projects and extending the marketing cycles for products already in production, because they may have already [worked out the sourcing for] the mix of materials for that previous production. It's pushing out the addition of new innovations—or forcing the removal of features in the current production cycle—because they've got to focus on, 'Well, what do we have available to build?'"

Design engineers have limited alternatives when faced with so many headwinds. "None of the options are great—if you can find a pin-to-pin replacement, that's the easiest. But that may or may not be possible," Russ says. "You've either got to redesign the board or come up with some kind of adapter. You have to start making those considerations: How easily can the board be redesigned? How high is the volume of production for your board?"

Russ adds: "In a situation like this, where the industry is throwing you curveballs, you have to have a 360-degree view of your product. Is it manufacturable? Is it procurable? What does it do to the cost? What does it do to the performance? [Tech designers and engineers] especially have got to keep the procurement organization and the manufacturing organization on speed dial."

While engineers have always needed a strategic view to some extent, Carrieres notes that "the forces that are at play today are so much more complex. So, when you start your design, even from the first sketch, [you have to] look beyond the board. It's tempting to go deep into that design and stay focused on the technology, but you have to look beyond the board in order to ultimately be successful." ■