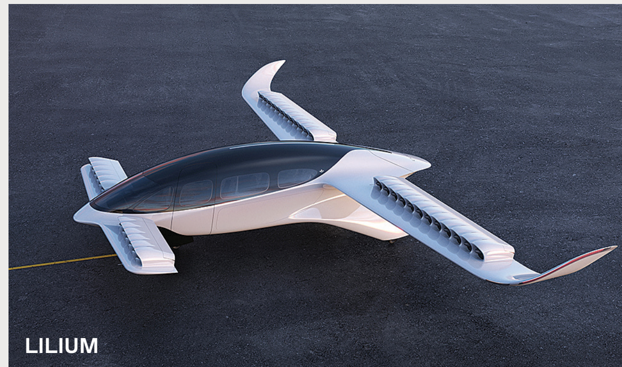
News

JOBY AVIATION

Location United States **Funding** **US $1.84 billion** **Vehicle type** Vectored thrust **Aircraft status** Full scale **Range** **240 kilometers** **Capacity** 5*



LILIUM

Location Germany **Funding** **US $938 million** **Vehicle type** Vectored thrust **Aircraft status** Tech demonstrator **Range** 250 kilometers **Capacity** 7*

VERTICAL AEROSPACE

Location United Kingdom **Funding** **US $380 million** **Vehicle type** Vectored thrust **Aircraft status** Scheduled for 2022 **Range** **160 kilometers** **Capacity** 5*

VOLOCOPTER

Location Germany **Funding** **US $376.6 million** **Vehicle type** Multicopter **Aircraft status** Certification ready **Range** **35 kilometers** **Capacity** 2*

SOURCE: SMG CONSULTING; ALL PHOTOS PROVIDED BY MANUFACTURERS

TRANSPORTATION

What's Behind the Air-Taxi Craze ›

A wave of eVTOL startups aim to revolutionize transportation

BY EVAN ACKERMAN & GLENN ZORPETTE

When entrepreneur JoeBen Bevirt launched Joby Aviation 12 years ago, it was just one of a slew of offbeat tech projects at his Sproutwerx ranch in the Santa Cruz mountains, in California. Today, Joby has more than 1,000 employees and close to US $2 billion in funding.

Having raked in perhaps 30 percent of all the money invested in electrically powered vertical-takeoff-and-landing (eVTOL) aircraft so far, Joby is the colossus in an emerging class of startups working on radical, battery-powered commercial flyers. All told, at least 250 companies worldwide are angling to revolutionize transportation in and around cities with a new category of aviation, called urban air mobility or advanced air mobility. With Joby at the apex, the category's top seven companies

*Capacity may include a human pilot.

ARCHER AVIATION

Location United States **Funding** US $856.3 million **Vehicle type** Vectored thrust **Aircraft status** Tech demonstrator **Range** 100 kilometers **Capacity** 2*

BETA TECHNOLOGIES

Location United States **Funding** US $511 million **Vehicle type** Lift + cruise **Aircraft status** Full scale **Range** 460 kilometers **Capacity** 6*

EHANG

Location China **Funding** US $132 million **Vehicle type** Multicopter **Aircraft status** Certification ready **Range** 35 kilometers **Capacity** 2*

AIRBUS

Location France **Funding** Corporate **Vehicle type** Multicopter **Aircraft status** Tech demonstrator **Range** 80 kilometers **Capacity** 4*

KITTYHAWK

Location United States **Funding** Private **Vehicle type** Vectored thrust **Aircraft status** Tech demonstrator **Range** 160 kilometers **Capacity** 1*

WISK

Location United States **Funding** US $450 million **Vehicle type** Lift + cruise **Aircraft status** Full scale **Range** 40 kilometers **Capacity** 2* together have hauled in more than $5 billion in funding—a figure that doesn't include the private firms, whose finances haven't been disclosed.

But with some of these companies pledging to start commercial operations in 2024, there's no clear answer to a fundamental question: Are we on the verge of a stunning revolution in urban transportation, or are we witnessing, as aviation analyst Richard Aboulafia puts it, the "mother of all aerospace bubbles"?

Even by the standards of big-money tech investment, the vision of this future is giddily audacious. During rush hour, the skies over a large city, such as Dubai or Madrid or Los Angeles, would swarm with hundreds, and eventually thousands, of eVTOL "air taxis." Each would seat between one and perhaps half a dozen passengers, and would eventually be autonomous. Hailing a ride would be no more complicated than scheduling a trip on a ride-sharing app.

And somehow, the cost would be no greater, either. In a discussion hosted by the *Washington Post* last July, Bevirt declared, "Our initial price point would be comparable to the cost of a taxi or an Uber, but our target is to move quickly down to the cost of what it costs you to drive your own car."

Industry analysts tend to have more restrained expectations. Limited commercial flights will probably begin a year or two from now, and with the exception of China, all aircraft will be flown by pilots for at least the next six to eight years. (As detailed below, at least one Chinese company has already flown autonomous trials.) Costs are expected to be similar to those of helicopter trips, which tend to be in the range of $6 to $10 per mile or more. Of the 250+ startups in the field, only three—Kittyhawk, Wisk (a joint venture of Kittyhawk and Boeing), and Ehang—plan to go straight to full autonomy without a preliminary phase involving pilots, says Chris Anderson, chief operating officer at Kittyhawk.

To some, the autonomy issue is at the heart of whether this entire enterprise can succeed economically. "When you figure in autonomy, you go from $3 a mile to 50 cents a mile," says Anderson, citing studies done by his company. You can't do that with a pilot in the seat."

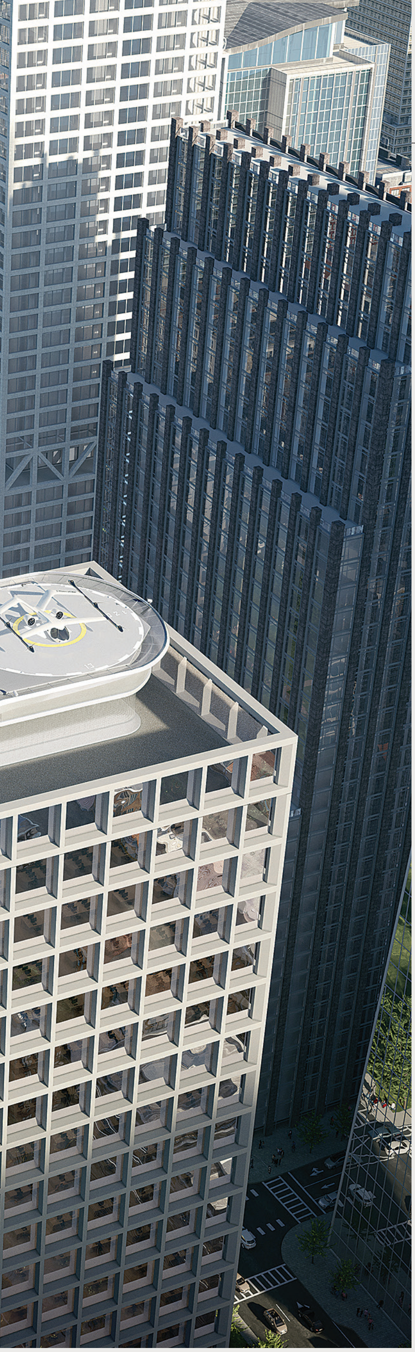
Georgia Tech professor Laurie A. Garrow agrees. "For the large-scale vision, autonomy will be critical," she says. Garrow, a civil engineer who codirects the university's Center for Urban and Regional Air Mobility, adds that autonomy presents challenges beyond technology: "We're going to have to get the consumer used to thinking about flying in a small aircraft without a pilot on board. I have reservations about the general public's willingness to accept that vision, especially early on."

Some analysts have much more fundamental doubts. Aboulafia, managing director at the consultancy AeroDynamic Advisory, says the figures simply don't add up. EVTOL startups are counting on mass-manufacturing techniques to reduce the costs of these exotic aircraft, but such techniques have never been applied to produce aircraft on the scale specified in the projections. Even the anticipated lower operating costs, Aboulafia adds, won't compensate. "If I started a car service here in Washington, D.C., using Rolls Royces, you'd think I was out of my mind, right?" he asks. "But if I put batteries in those Rolls Royces, would you think I was any less crazy?"

What everyone agrees on is that achieving even a modest amount of success for eVTOLs will require surmounting entire categories of challenges. At the

The "pinch point" in many forecasts involving eVTOL aircraft is expected to center around the sites where the eVTOLs take off and land—the so-called vertiports.

VOLOCOPTER



top of that list: certification. "The technical problems are, if not solved, then solvable," says Anderson. "The main limiters are laws and regulations."

Consider the Federal Aviation Administration, the certifying body in the United States. To clear an aircraft for commercial flight, the FAA requires three certifications: one for the aircraft itself, one for its operations, and one for its manufacturing. For eVTOLs (other than multicopters), the applicable category seems to be Title 14 Code of Federal Regulations, Part 23, which covers "normal, utility, acrobatic, and commuter category airplanes." The certification process itself is performance based, meaning that the FAA establishes performance criteria that an aircraft must meet, but does not specify how it must meet them.

Nobody knows how many eVTOL startups have started the certification process with the FAA, although a good guess seems to be one or two dozen. Joby is furthest along in the process, according to Mark Moore, CEO of Whisper Aero, a maker of advanced electric-propulsor systems in Crossville, Tenn. The certification proposals submitted by the companies for their aircraft are not public, but when one (presumably Joby's) is accepted by the FAA, it will become available through the U.S. Federal Register. Observers expect that to happen any day now.

This certification phase of piloted aircraft is fraught with unknowns because of the novelty of the eVTOL craft themselves. But experts say a greater challenge lies ahead, when manufacturers seek to certify the vehicles for autonomous flight. "If very high levels of automation are critical to scaling, that will be very difficult to certify," says Matt Metcalfe, a managing director in Deloitte Consulting's future of mobility and aviation practice.

"It's a matter of, how do you ensure that that autonomous technology is going to be as safe as a pilot?" says an official with one of the eVTOL startups. "How do you certify that it's always going to be able to do what it says? With true autonomous technology, the system itself can make an undetermined number of decisions, within its programming. And the way the current certification regulations work, is that they want to be able to know the inputs and outcome of every decision that the aircraft system makes. With a fully autonomous system, you can't do that."

Perhaps surprisingly, most experts contacted for this story agreed with Kittyhawk's Anderson that the technical challenges of building the aircraft themselves are solvable. Even autonomy—certification challenges aside—is within reach, most say. For example, the Chinese company EHang has already offered commercial autonomous flights of its EH216 multicopter to tourists in the northeastern port city of Yantai.

A more imposing challenge, and one likely to determine whether the grand vision of urban air mobility comes to pass, is whether municipal and aviation authorities can solve the challenges of integrating large numbers of eVTOLs into the airspace over major cities. Some of these challenges are, like the aircraft themselves, totally new. For example, most viable scenarios require the construction of "vertiports" in and around cities. These would be like mini airports where the eVTOLs would fly in and out and be recharged.

According to Garrow, vertiports will be the "pinch points," because at urban facilities, space will likely be limited to accommodating several aircraft at most. And yet at such a facility, room will be needed during rush hours to handle dozens of aircraft.

Despite all the challenges, Garrow, Metcalfe, and others are cautiously optimistic that air mobility will eventually become part of the urban fabric in many cities. That's not to say, though, that the vision of middle-class people being routinely whisked around cities for a few nickels and dimes per mile is a sure thing. But if it does happen, a few studies have predicted that travel times and greenhouse-gas and pollutant emissions could all be reduced.

A 2020 study published by the journal *Transportation Research Record* found a substantial reduction in overall energy use for transportation under "optimistic" scenarios for urban air mobility. And a 2021 study by researchers at the University of California, Berkeley and the NASA Ames Research Center found that in the San Francisco Bay Area, overall travel times could be reduced with as few as 10 vertiports. The benefits went up as the number of vertiports increased and as the transfer times at the vertiports went down.

Metcalfe notes that ubiquitous modern conveniences such as online shopping have already unleashed tech-based revolutions on a par with the grand vision for urban air mobility. Imagine time-traveling back to the founding of Amazon.com in 1994. Could anyone have predicted the complete upending of the consumer economy that this one company would bring about? "We never would have thought we'd be getting two or three packages a day," Metcalfe points out. "Similarly, the way we move people and goods in the future could be very, very different from the way we do it today." ■

CONSUMER ELECTRONICS

Your Digital Trash Is a Cybercrook's Treasure > Data can be the diamond discovered in a dumpster dive

BY JULIANNE PEPITONE

Many of us have obsolete devices relegated to the backs of our drawers, little museums of the technology of days long past. These forgotten laptops and phones seem like merely quaint relics, but if they're not disposed of correctly, they can leak two different but dangerous things: toxic chemicals and sensitive data.

The world generated a record 53.6 million tonnes of electronic waste in 2019, up more than 21 percent over five years, according to the United Nations' most recent assessment.

Only about 17 percent of that e-waste was recycled, and what happens to the rest can be detrimental for both human health and privacy. A new systematic review by the *Lancet* found that "people living in e-waste exposed regions had significantly elevated levels of heavy metals and persistent organic pollutants," and it advocated for "novel cost-effective methods for safe recycling operations… to ensure the health and safety of vulnerable populations."

John Shegerian couldn't agree more. He's the cofounder and CEO of ERI, one of the largest electronics recycling-and-disposal providers in the world, and the coauthor of ERI's 2021 book *The Insecurity of Everything: How Hardware Data Security Became the Biggest Issue Facing the World Today.*

We spoke with Shegerian about e-waste's effect on the future of our world and our privacy, and the role engineers can play in solutions. The conversation has been edited for length and clarity.

The conclusion of the *Lancet* study surely isn't a shock to you, but others might be surprised about the kinds of pollutants inside our old computers, phones, and TVs—and the danger they present when not handled responsibly.
John Shegerian: When we got into the industry [in 2002], Al Gore had not yet won his awards for *An Inconvenient Truth.* There was no iPhone or Internet of Things. But [e-waste] was still already the fastest-growing solid-waste stream in the world. Now, in 2022, electronic waste is the fastest-growing waste stream by an order of magnitude.

The magnitude of the problem grossly outstrips the amount of solutions. We have so, so, so many devices. And when [e-waste isn't disposed of correctly], it can get put into a landfill, thrown into a river or a lake, or just buried. Sadly, it could also be sent to a country where they don't have the right tools or expertise to dismantle old electronics.

Eventually the linings [of devices] break, and when they're rained upon, the very toxic materials [they contain]—mercury, lead, arsenic, beryllium, cadmium—come out. If they get back into the land and water, it has very negative effects on the health of our vegetation, our animals, and our people. So, unfortunately, no, I'm not surprised [by the *Lancet* study].

You founded ERI because of the environmental concern, but you and your team quickly came to realize the cybersecurity risk as well: Many of these tossed-out devices contain sensitive personal or professional data.
J.S.: Yes, we saw these little breadcrumbs about data and privacy throughout the 2000s: the birth of Palantir [Technologies], the founding of LifeLock, and what we were seeing ourselves at ERI. Really, in 2012, I started speaking to companies about the need to "shred" data the way they shred sensitive papers. They looked at us like we were green Martians. Over the years, I spoke about it at conferences anyway, and at one of these in 2017, Robert Hackett from *Fortune* asked for an interview and wrote an article that ended with this line: "Turns out e-waste isn't just an environmental menace, but a cybersecurity one too." Five years of banging the drum, and thanks to this article, we were finally off to the races…comparatively.

Comparatively. Because you find that people, both as individuals and on the enterprise level, aren't taking the data risk seriously enough. How did that inspire *The Insecurity of Everything*?
J.S.: Technology is so ubiquitous that this is a societal problem we all have to reckon with. It's much more serious than just affecting your family or your company. This is a problem of international magnitude, that has homeland-security risks around it. That's why we wrote the book: The vast majority of our clients still were not listening. They just wanted us for environmental work, but they weren't really sold on the hardware data-destruc-

GETTY IMAGES

tion part of the work yet. We wanted to write this book to share some examples of serious consequences—that this isn't some remote, theoretical concern.

Can you share some of those anecdotes?
J.S.: I once had a big, big bank call me up: "John, we've had a breach, but we don't believe it's phishing or software. We think it came from hardware." I go out there, and it turns out one of their bankers threw his laptop in the trash in Manhattan and someone fished it out. On that laptop was information from the many clients of the entire banking firm—and the bank's multibillion-dollar enterprise. The liability, the data...God, just absolutely priceless. If it got into the wrong people's hands, the ransom that could have been extracted was truly of huge magnitude.

You also have situations like the federal government—I won't say what branches—telling us: "We have all of these old electronics that are potentially data-heavy, and when companies like yours gave us quotes [for responsible recycling], it seemed kind of expensive. We were told to save money and we found someone to do it for free."

Free? Yeah, no. What happens is that a guy will pick up the devices for free, put them in a container, and sell them wholesale to the highest bidder. Lots of those buyers are harvesting the precious metals and materials out of old electronics—but there are also people adverse for homeland security who want to pull out the hard drives and find a way to harm us here in the United States or hold corporate data for ransom. From those examples you can see how you need to protect your financial and personal data on an individual level too.

What do people need to know—and do—to avoid becoming one of these stories?
J.S.: It is crucial to make sure that if you're giving [your device] to a retailer who has a take-back or trade-in program, vet them and make sure they're using responsible recyclers. Make sure they guarantee you that all your data will be destroyed before they take your phone and resell it. If they won't tell you, with radical transparency, who the vendor is handling the materials or where they're going to go? Pass.

For the engineers of today and tomorrow who are interested in this work, how can they be part of the solution?
J.S.: Engineers have been such important partners for us, whether it's creating e-waste shredding machines or things like glass-cleaning technology that helps us recycle materials. They've also helped us be the first to develop AI and robotics in our facility. So, they could come to work for someone like us and answer questions like: How do we recycle more of this material in a faster and better way, with less impact to the environment?

On the other side, engineers are still going to be hired by great original equipment manufacturers, whether tech or auto companies, and that's beautiful because now they could design and engineer for circular economy behavior. They could create new products made of recycled copper, gold, silver, steel, plastics—keeping them out of our landfills.

Engineers have a huge opportunity to help leave the world a better, safer, and cleaner place than we inherited. But everyone on Earth is a stakeholder in this. We all have to be part of the solution. ■

COMPUTING

Novel Sonic Transistors: The Shape of Tomorrow's Electronics?

> Topological acoustic transistor points the way to dissipationless electronic circuits

BY CHARLES Q. CHOI

Potential future transistors that consume far less energy than today's devices may rely on exotic materials called topological insulators, in which electricity flows across only surfaces and edges, with virtually no dissipation of energy. In research that may help pave the way for such electronic topological transistors, scientists at Harvard have now invented and simulated the first acoustic topological transistors, which operate with sound waves instead of electrons.

Topology is the branch of mathematics that explores the nature of shapes independent of deformation. For instance, an object shaped like a doughnut can be deformed into the shape of a mug, so that the doughnut's hole becomes the hole in the cup's handle. However, the object couldn't lose the hole without changing into a fundamentally different shape.

Employing insights from topology, researchers developed the first electronic topological insulators in 2007. Electrons

HOFFMAN LAB/HARVARD SEAS

Topological transistors could someday be the key component of computers that consume much less energy and generate a lot less heat. The type shown here conducts sound waves instead of electricity.

zipping along the edges or surfaces of these materials are "topologically protected," meaning that the patterns in which the electrons flow stay unchanged in the face of any disturbances they might encounter—a discovery for which these innovators were awarded the Nobel Prize in Physics in 2016. Scientists later designed photonic topological insulators, in which light is similarly protected.

However, creating electronic topological transistors in which the dissipationless flow of electrons can get switched on and off in topological materials requires dealing with complicated quantum mechanics. By using sound instead of charge, the Harvard scientists were able to sidestep this complexity to create acoustic topological transistors.

Still, designing an acoustic topological transistor wasn't easy. "We knew our approach to topological logic could work, but we still needed to find a viable selection of materials where it actually did work," says study lead author Harris Pirie, currently at the University of Oxford. "We took a fairly brute force approach: There was one summer where we were running calculations on about 20 computers at the same time to test thousands of different materials and designs."

The design the Harvard researchers settled on consists of a honeycomb lattice of steel pillars anchored to a plate made of another substance, all sealed in an airtight box. The plate is made of a material that expands greatly when heated.

The steel lattice has slightly larger pillars toward one end and slightly smaller ones toward the other. These differences in the size and spacing of the pillars govern the lattice's topology, which in turn influences whether sound waves can flow through a particular subset of pillars or not. For instance, at 20 °C, ultrasound cannot pass through the device, but at 90 °C, it can zip unimpeded along the device's edges. In essence, heat can switch this device from one state to another, much as electricity does with conventional transistors.

The researchers noted that these acoustic topological transistors are scalable. This means the same design could also work for the gigahertz frequencies commonly employed in circuitry that is potentially useful for processing quantum information, Pirie says.

"More generally, the control of topologically protected acoustic transport has applications in a number of important fields, including efficient acoustic-noise reduction, one-way acoustic propagation, ultrasound imaging, echolocation, acoustic cloaking, and acoustic communications," he says.

The design principles used to develop acoustic topological transistors could be adapted for use in photonic devices in a fairly straightforward manner, "at least in principle, because the acoustic wave equation mathematically maps onto its photonic counterpart," Pirie says. Meaning: The physics of sound waves and light waves are similar enough that the lessons of a topological transistor of one variety easily translate to a topological transistor of the other kind.

However, Pirie says, "this mapping doesn't exist in electronics," which makes it more challenging to develop an electronic topological transistor from this work. "It's still likely we could follow the same general scheme in electronics—we just have to find the right materials to use," he notes.

The scientists detailed their findings online earlier this month in the journal *Physical Review Letters*. ■

JOURNAL WATCH

Can Autonomous Cars Show Pedestrians Their Intentions?

Judging whether it's safe to cross the open road involves a complex exchange of social cues between pedestrian and driver. But what if there's no one behind the wheel? Autonomous-vehicle company Motional thinks that making the vehicles more expressive could be the key to maintaining those crucial signals.

When he's waiting at a crosswalk, Paul Schmitt, chief engineer at Motional, engages in what he calls the "glance dance"—a rapid and almost subconscious assessment of where oncoming drivers are looking and whether they're aware of him. "With automated vehicles, half of that interaction no longer exists," says Schmitt. "So what cues are then available for the pedestrian to understand the vehicles' intentions?"

To answer that question, his team hired animation studio CHRLX to create a highly realistic virtual-reality experience designed to test pedestrian reactions to a variety of different signaling schemes. Reporting their results in *IEEE Robotics and Automation Letters*, Schmitt and his team showed that exaggerating the car's motions—by braking earlier or stopping well short of the pedestrian—was the most effective way to communicate its intentions.

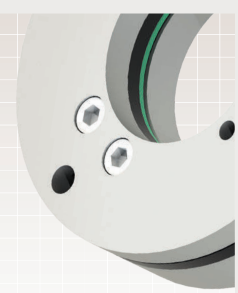
The company is now in the process of integrating the most promising expressive behaviors into its motion-planning systems, and it has also open-sourced the VR traffic environment so that other groups can experiment.

The study tested various expressive behaviors meant to implicitly signal to pedestrians that the car was stopping for them. These included having the car brake earlier and harder than the baseline, stopping the car a vehicle's length away, adding exaggerated braking and low-revving sounds, and finally combining these sounds with an exaggerated dipping of the nose of the car, as if it were braking hard.

The team measured how quickly the participants decided to cross the roadway, and also gave them a quick survey after each trial to find out how safe they felt, how confident they were of their decision to cross, and how clearly they understood the car's intention. The car stopping short elicited the highest ratings for sense of safety and intention understanding.

The fact that stopping short elicited the best response isn't surprising, says Schmitt, as this approach was inspired by the way human drivers behave when slowing down for pedestrians. What was surprising, he adds, was that there was little difference between the reactions to the baseline scenarios with and without a driver, which suggests pedestrians are paying more attention to the movement of the vehicle than to the driver behind the wheel. —Edd Gent

ROBOTIC END-EFFECTORS



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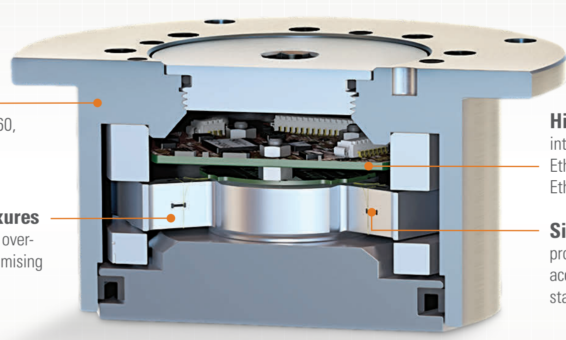

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