transmit it back to the brain with the greatest speed and resolution.

Specifically, the program is seeking technologies that can read and write to brain cells in a 50-millisecond round trip and also interact with at least 16 locations in the brain at a resolution of 1 cubic millimeter (an area that encompasses thousands of neurons).

The four-year N3 program will consist of three phases, says Emondi. In the first phase, teams will have one year to demonstrate the ability to read (record) and write to (stimulate) brain tissue through the skull. Teams that succeed will move to phase 2. Those groups will have 18 months to develop working devices and test them on living animals. Any group left standing will proceed to phase 3—testing their device on humans.

Four of the teams are developing totally noninvasive technologies. A team from Carnegie Mellon University, for example, wants to use ultrasound waves to guide light into and out of the brain to detect neural activity. The researchers plan to use interfering electrical fields to write to specific neurons.

The three other teams proposing noninvasive techniques include Johns Hopkins University's Applied Physics Laboratory, Thyagarajan's team at PARC, and a team from Teledyne Technologies, a California-based industrial company.

The two remaining teams are developing what DARPA calls "minutely invasive" technologies, which require no incisions or surgery but may involve technology that is swallowed, sniffed, injected, or absorbed into the human body in some way.

Rice University, for example, is developing a system that requires exposing neurons to a viral vector to deliver instructions for synthetic proteins that indicate activity in neurons. The Ohio-based technology company Battelle is developing a brain-machine interface that relies on magnetoelectric nanoparticles injected into the brain.

> "This is uncharted territory for DARPA, and the next step in brain-machine interfaces."
> —Al Emondi

"This is uncharted territory for DARPA, and the next step in brain-machine interfaces," says Emondi. "If we're successful in some of these technologies...that's a whole new ecosystem that doesn't exist right now."
—MEGAN SCUDELLARI

A version of this article appears on our Human OS blog.

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WHERE DOES GRAPHENE GO FROM HERE?

Experts weigh in on whether the EU's €1 billion Graphene Flagship can get the "wonder material" past the Valley of Death

Six years ago, the European Union embarked on an ambitious project to create a kind of Silicon Valley for the wonder material of the last decade: graphene. The project—called the Graphene Flagship—would leverage €1 billion over 10 years to push graphene into commercial markets and make Europe an economic powerhouse for graphene-based technologies.

To this day, the EU's investment in the Graphene Flagship represents the single largest project in graphene research and development (though some speculate that graphene-related projects in China may have surpassed it). In six years, the Graphene Flagship has spawned nine companies and 46 new graphene-based products. Still, there remains a sense among critics that the material has not lived up to expectations.

Graphene's unique properties have engendered high hopes for its use in advanced composites and new types of electronic devices. While graphene can come in many forms, its purest form is that of a 1-atom-thick layer of graphite. This structure has provided the highest thermal conductivity ever recorded—10 times as high as in copper. Graphene also has one of the highest intrinsic electron mobilities (the speed at which electrons can travel through a material): approximately 100 times as great as that of silicon.

The Graphene Flagship is now more than halfway through its 10-year funding cycle. To many observers, the project's achieve-

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ments—or lack thereof—are a barometer for the commercial status of graphene, which was first synthesized at the University of Manchester, in England, in 2004. When it was founded, the Flagship wrestled with a key question that it still faces: Would the project support "fundamental" or "applied" research in its quest to make Europe the "Graphene Valley" of the world?

Jari Kinaret, director of the Graphene Flagship, says it's the latter: "From the very beginning, our plan has been to take graphene and related materials from academic laboratories to society." Over time, he said, the project has intentionally funded more applied research. The consortium was originally made up of mostly academic groups, whereas today about 40 percent of its members are companies.

However, other experts are not convinced that the Graphene Flagship is in the best position to lead graphene into commercial markets.

"There's absolutely nothing wrong with funding fundamental research," said Tim Harper, founder and former CEO of G_2O Water Technologies, which uses graphene for water filtration systems. "But when this type of project is dressed up as commercialization and run by people with little interest in or experience with commercializing anything—but with a major interest in securing research funding—then it becomes more problematic by promising much more than it can likely deliver."

Other industry observers echo this sentiment. Terrance Barkan, executive director of the Graphene Council, an association of researchers, producers, developers, and consumers of graphene, believes the Flagship has been a boon for the academic community but hasn't had much impact on the material's commercialization. [Editor's note: The author has worked for the Graphene Council.]

"For the money applied and for all the resources rallied, the Graphene Flagship is underperforming from a commercial development perspective," Barkan said. The Flagship does claim to have helped develop several dozen commercial products based on graphene, including a flexible wireless sensor for measuring a wearer's heart rate and a graphene-coated motorcycle helmet.

Kinaret does not see a sharp line between fundamental and applied research in the Flagship's projects. Nonetheless, in the project's next phase, known as Core 3, there is a growing emphasis on bringing technologies further along the development cycle. In this phase, the Flagship has allocated €45 million (US $50.5 million) for projects that should result in prototypes that function in realistic environments.

Harper at G_2O believes this effort may be counterproductive. "Forty-five million euros isn't much," he said. "Getting a hard-tech idea to market for one company takes tens of millions of euros."

Another problem, according to both Harper and Barkan, is that the Graphene Flagship has been pursuing a "technology push" rather than a "market pull" strategy for commercialization. "The Graphene Flagship projects seem to be in the process of developing a solution that's in search of a problem," said Barkan.

One of the key problems in the commercialization of any emerging technology is bridging the "Valley of Death"—the gap between a technology that researchers have developed and the rollout of a commercial product. To help graphene make it through, another project, called the Graphene & 2D Materials Eureka Cluster, is currently seeking EU funding.

Antonio Correia, president of the Phantoms Foundation, a European organization that coordinates nanotechnology innovation, is now spearheading the Eureka project. Correia believes this new effort is needed to take up the slack in the graphene-development value chain. Although he would agree that the Graphene Flagship has played an important role in combining fundamental research with industrial concerns, he thinks the industry should guide how graphene is commercialized in the future. According to Correia, this focus on industry interests will be necessary if graphene is to bridge the Valley of Death.

Barkan of the Graphene Council offered another take on this strategy: "At the end of the day, the question should be, 'What kind of a problem are you trying to solve where graphene unlocks new solutions?' " he said. "Not 'What type of innovation have you created that you are trying to push into a product?' "
—DEXTER JOHNSON

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