INTERVIEW

Culture of Disruption

Researcher, Writer Jim Thomas Discusses Suite of Emerging Synthetic Biology Technologies

For 20 years, Jim Thomas has been at the forefront of international policy debates and campaigns on emerging technologies with Greenpeace International and ETC Group. Steward Brand called him "the leading critic of biotech." As a strategist and organizer working with civil society partners, Thomas has repeatedly led successful international campaigns of global importance. In the late 1990s he was one of less than a dozen leaders of a high-profile national movement to prevent the introduction of GM food and crops into the United Kingdom market. He played a major role in achieving and strengthening the United Nations moratoria on geoengineering, ocean fertilization and Terminator seeds. He also helped secure the first global UN agreement on Synthetic Biology and halt geoengineering projects in Ecuador, Philippines, UK, the United States and Canadian/Haida territory. Thomas is co-author of numerous ETC Group reports and his writing has been published in many media outlets including The Guardian, The Times UK, Slate, Huffington Post, The Ecologist, New Internationalist *and* RSA Journal. *He has been a featured speaker around the world for audiences as diverse as La Via Campesina (peasant movements) and grassroots activists to government ministers and CEOs. He has appeared in 10 documentary films. Thomas was born in Zambia, grew up in the UK, worked on several continents and now lives near Montreal, Canada.*

Jim Thomas

Interviewed by Tracy Frisch

ACRES U.S.A. Etcetera Group has been on the forefront of challenging novel technologies for many years. Please introduce *Acres U.S.A.* readers to your organization.

JIM THOMAS. We're a small organization that tracks new technological trends that impact agriculture, the food system and biodiversity. At the same time we're tracking the concentration of corporate power in the seed sector, across agriculture and increasingly in other technology sectors.

ACRES U.S.A. What does ETC stand for?

THOMAS. It's quite a mouthful – Action Group on Erosion, Technology and Concentration.

ACRES U.S.A. What does the word erosion mean for the group?

THOMAS. It refers to many kinds of erosion – the erosion of human rights, the erosion of genetic diversity, the erosion of our soils due to industrial agriculture. We look at the ways in which various things that we hold

dear are being eroded by the combination of the new emerging technologies and concentration of corporate power. That creates a theoretical framework, though it's a bit abstract.

ACRES U.S.A. Fill us in on the history of ETC Group.

THOMAS. ETC Group used to be known as the Rural Advancement Foundation International or RAFI. The Rural Advancement Foundation was set up by Eleanor Roosevelt during the Depression to support black farmers. Through the 1970s and early '80s my colleague Pat Mooney pioneered the work on concentration in the seed industry, where a few companies were beginning to buy up all the other seed companies. In studying this phenomenon he took notice of genetic engineering technologies and recognized their significance. People probably thought he was talking science fiction. He predicted that by using these new genetic engineering technologies in agriculture certain companies would gain tremendous control over the seed system. He and other colleagues introduced the idea of biopiracy, where patents would be used to control seed. RAFI went on to look at other technologies that were having similar impacts on farmers and indigenous peoples. That led us to look more broadly at other biotechnologies, nanotechnology and extreme climate technologies such as geoengineering.

ACRES U.S.A. What's the significance of being an international group?

THOMAS. We're a small group of 8 or 9 people with offices in the Philippines, the United States, Canada and Mexico City. Though we're in just a few locations, most of our advocacy and policy work is pointed toward the international level. We often work at the United Nations, for example.

ACRES U.S.A. How does ETC Group carry out its work?

THOMAS. The heart of what we do is original research and analysis. We try to understand the emerging trends and technologies and work with partners in civil society, like farmers' groups, environmental groups, indigenous groups and labor groups to understand what these new developments are going to mean for their rights and various agendas. We also try to get these groups to engage in advocacy.

ACRES U.S.A. What got you involved with this important and unusual work?

THOMAS. Before joining ETC Group, I worked on genetic engineering campaigns in many different countries for Greenpeace International. During that time I became aware of other new technologies that were just as significant as genetic engineering. I was especially interested in nanotechnology, and ETC Group was one of the only organizations taking a critical look at that.

ACRES U.S.A. Could you give readers a short tutorial on nanotechnology and how it's affecting our lives and environment?

THOMAS. Nanotechnology involves the manipulation of matter on the nanoscale, which is hundreds of thousands times smaller than the thickness of a human hair. That's the scale of atoms and molecules. The field of nanotechnology tries to do two things. First, it tries to build specific structures that size – mostly they're little particles and molecular structures. Secondly, nanotechnologists seek to exploit the change in properties that happens at the atomic and molecular level and use that change to produce entirely new materials. At that scale the rules of physics change, and quantum science begins to become relevant. For example, at the everyday scale, gold is tremendously inert and soft, while a nanosize piece of gold could be very reactive or a different color or hard, depending on the size of the particle. We now have an industry producing nanoparticles and other nanomaterials with all sorts of unusual properties. They're being used in products as diverse as foods, cosmetics, pesticides and packaging. Given their unusual properties, nanomaterials may also have unusual toxicities and different ways of behaving in the natural world. They can move around the human body to places where other materials couldn't get to, like across the blood-brain barrier and placenta. That raises a new set of questions about their toxicology and environmental impact. With their new properties, nanomaterials can change the way we use materials across the board. Rather than using copper to conduct electricity, we can use a nanoform of carbon. That has implications for countries that mine copper. This field has moved on to rewiring life at the nanoscale. One of the molecules you can build is DNA, and then you can start to re-engineer life forms. Nanobiotechnology takes us to synthetic biology.

ACRES U.S.A. How might we come in contact with nanomaterials?

THOMAS. While it can be difficult to know whether products are being made with nanoparticles, we do have some examples. Many sunscreens contain nanoparticles. If titanium dioxide is see-through rather than white, then it's likely nanoscale. Nanowaxes on produce are another application. Insecticides and herbicides are being turned into nano-emulsions and nanosprays that enable pesticides to more easily penetrate insects or weeds. A lot of nanotechnology is used in cosmetics to create new pigments, new dyes and new ways of getting vitamins into the skin.

ACRES U.S.A. Do nanotech products have to be labeled?

THOMAS. I'm not aware of any labeling requirement, despite increasing concern in the European Union, especially about the use of nanoparticles in foods. The European Parliament has passed resolutions calling for nanoparticles to be kept out of foods and the European Food Standards Agency has made very precautionary comments.

ACRES U.S.A. What about testing?

THOMAS. You can look for nanoparticles physically, but it requires very expensive, extremely high-powered microscopes. That's not something a consumer can do.

ACRES U.S.A. Are nanomaterials regulated, and are they being studied to determine their environmental and health impacts?

THOMAS. I don't think that federal agencies have any testing requirements, and it's not entirely clear how these things are regulated. When we started looking at nanotechnology, we quickly discovered that regulatory agencies were treating a nanosized version of a material identically to the normal-sized version of the material, even though they're very different. Given their different toxicologies, we need to establish new ways of doing safety testing. Now there's a growing field called nanotoxicology.

ACRES U.S.A. When did your group get involved with looking at nanotechnology?

THOMAS. In 2001 or 2002, just before I started working with the organization, ETC Group did a survey of the landscape and realized that nanotechnology was emerging as an important technology. At meetings ETC Group convened, nanotechnologists told us not to worry, there were no problems. In 2003 or so we produced a report called "The Big Down," our first overview of nanotechnology. While we were putting it together, we began to hear from researchers about some possible toxicity issues with the technology. Nanotech products were already coming onto the market, though nobody was addressing some very clear issues.

ACRES U.S.A. Could you point to specific toxicological issues that have been documented?

THOMAS. The nanotubes are now raising a lot of concerns. These long, thin carbon particles were seen as a miracle molecule for nanotechnology. They could deliver drugs into the body. They're stronger than steel and can carry electricity better than copper wire. However, they seem to behave very much like asbestos fibers and toxicologically they may be very similar. At this time any environmental release of nanotubes is very worrying.

ACRES U.S.A. I read in an ETC post that nanoparticles have been found in the lungs of children in Paris.

THOMAS. That's right. As toxicologists began to look at the toxicity of engineered nanomaterials, they found that industrial facilities that use high heat unintentionally produce nanoparticles. They're a major component of air pollution in automobile exhaust and incinerator and power plant emissions, and they cause significant public health impacts.

ACRES U.S.A. How are nanotubes or other nanoforms made?

THOMAS. It's usually a very high heat process. There are also ways to grind them. Sometimes lasers are used. What makes it nanotechnology is the ability to deliberately make materials in more precise sizes and shapes, whereas burning a load of garbage in an incinerator produces a random assortment of nano-sized particles.

ACRES U.S.A. Let's turn to extreme genetic engineering. As a grad student at Cornell in the late '80s, I remember hearing that sequencing genes was an extremely slow, tedious process. Where are we at present with that and what has that achievement allowed genetic technology to do?

THOMAS. There are two different things, gene sequencing and gene synthesis. Sequencing is the technique where you decode the DNA in the genome of an organism. DNA is made up of four chemical compounds called base pairs. They're referred to with the letters G, T, C and A. The ability to sequence genes has improved at an unprecedented speed.

ACRES U.S.A. The Human Genome Project cost $2.7 billion. What are the costs of sequencing today?

THOMAS. Sequencing costs for the human genome have dropped to something on the order of a thousand dollars – for superfast sequencing. You can put a piece of biological material on a computer chip and it will instantly read out its genetic code. And the price continues to drop as the speed increases. Turning to gene synthesis, since the mid-1960s it has been possible to build DNA. Initially it would take thousands and thousands of hours to produce just a few letters of a genome. Now a number of companies are producing ever-faster genome synthesis technology. We consider that the driving force behind this area of synthetic biology. We can now produce any DNA sequence we want, up to the length of a bacteria or even a chromosome. In time we'll be able to print out the DNA sequence of a plant or an animal, even a human.

ACRES U.S.A. What do you mean by "print out?"

THOMAS. There's a machine called a DNA synthesizer. It's a large printer with four bottles containing each of the four chemicals – G, T, C and A – that constitute DNA. You connect the synthesizer to a computer and it hooks together the base pairs in the order you want and prints the sequence of DNA that you asked for. Currently, synthetic biology labs aren't using DNA synthesizers much because they can order DNA sequences online from large DNA foundry companies. Internet sites like DNA 2.0 will send them to you by FedEx. That kind of making-life-to-order industry undergirds this new area of biotechnology.

ACRES U.S.A. On ETC Group's website I read about Craig Venter, who you've called "the Donald Trump of the biosciences." In 2011

he announced that he had created the first self-replicating species on the planet whose parent is a computer. What was he talking about?

THOMAS. Craig Venter is very much a showman and a businessman. He led the race to decode the human genome. He did it faster than the National Institutes of Health and sold all the data to private pharmaceutical companies. He was also the first person to attempt to take out patents on human genes. Now he is on the forefront of synthetic biology. He and his team tried to identify the shortest DNA sequence of a living organism and then they built it using a DNA synthesizer. The DNA sequence is for *Mycoplasma genitalium*, a small bacterium found in the human genital tract. They kind of made it come to life by putting that synthetic DNA sequence into an existing cell. They actually changed a few parts of the DNA to include Craig Venter's name in it, which they call a watermark. It's basically genetic graffiti. While they claimed it was the first synthetic cell, they really just copied something in nature and manufactured it.

ACRES U.S.A. I read that he's up to Synthia 3.0, which he describes as "a basic technology platform upon which apps can be attached."

THOMAS. Venter named his synthetic organism *Mycoplasma laboratorium*, but we called it Synthia, which he didn't like very much! Much of what goes on in synthetic biology involves creating new sequences to engineer existing organisms, usually an *E. coli*, yeast or algae. Synthetic biologists think of the DNA sequence as the basic operating instructions for a cell. When you add extra bits of synthetic DNA, they think of them as programs that you would run on the basic operating system. Venter wanted to create his own model organism. He understood what he was doing as creating the equivalent of Windows or OS X. He decided he wanted to be the "Microbesoft" of the new synthetic biology world and is still moving ahead with that.

ACRES U.S.A. How do practitioners of extreme genetic engineering like synthetic biology think about life?

THOMAS. That's very interesting. The core assumptions of synthetic biology are that life is a sort of computer program, that DNA is like a code and that a cell or living organism is like a computer or a machine. As long as you can "reprogram" the DNA – the instructions – then you can engineer the machine to do whatever you want it to do. Synthetic biologists bring a reductionist, machine-like view of nature and the living world. They use all sorts of metaphors. A cell is called a chassis, like in a car. The bits of DNA that they invent are called programs or pathways.

ACRES U.S.A. How do you see things differently?

THOMAS. The linear assumptions about DNA as a code that can be broken up into discreet units and instructions aren't the way that genetics actually works. There's all sorts of communication between different parts of the genome and between DNA and other parts of cells, as well as the communications outside of the cell, which is called epigenetics. You can't turn this into some neat programming language! Synthetic biologists have come up with a number of neat tricks. By putting a piece of DNA in a living organism, they can make it glow green or make it produce a compound like vanilla flavor. But then evolution often gets the better of them, and it will stop working or do something unexpected. That's the worry.

ACRES U.S.A. How big is the synthetic biology industry now?

THOMAS. The industry is probably around $16 or $18 billion at this point. There are forecasts that the synthetic biology-derived market will reach just under $40 billion by 2020, though those numbers seem a bit overhyped. Synthetic biology is rapidly building an industry funded by Silicon Valley venture capitalists that think that it will be the next programming technology, an extension of the Internet boom. Suddenly a lot of fragrance and flavor companies and industrial chemical and food ingredient companies are producing their products using synthetic biology. We've also seen a rise in the very closely allied area of genome editing.

ACRES U.S.A. Watching ETC Group's excellent 10-minute video, *What is Synthetic Biology*, it is clear that synbio organisms like yeast or algae need to be fed. It is reminiscent of the false promise that by manufacturing meat in a laboratory, we could eliminate livestock in agriculture, pollution from manure and the problem of animal cruelty on factory farms, ignoring the fact that there needs to be a source of energy and nutrients to do that.

THOMAS. Absolutely.

ACRES U.S.A. What kinds of feedstuffs are being used to feed these synbio organisms?

THOMAS. Most synthetic biology companies are using cane sugar to produce foods, flavors, fragrances, oils and other products, though some are using corn syrup from the Midwestern United States as their feedstock. Many of those companies have built large fermentation facilities in Brazil because it tends to be the cheapest, easiest place to get straight sugar. Sugar production in a place like Brazil depletes water resources, is linked to slave labor and other horrible labor practices and carries real concerns around agrochemicals. But ultimately, for the synthetic biologist, the problem is simply that it ties their industry to the price of sugar. If the price of sugar goes up, then their prices go up, so they've been looking for other feedstocks. One of them is algae. Strangely enough, most of the synthetic biology algae are still being fed on sugar! But they're really interested in farming the ocean to grow large quantities of algae or seaweed. Cellulose obtained by breaking down woodchips was also considered, but that doesn't seem to have gone anywhere. And it would still be competing for land. The synthetic biology industry has also gotten very interested in natural gas. Bacteria that

consume natural gas instead of sugar can be engineered to produce fuels or plastics and potentially food, flavors and fragrances. The synbio industry is buddying up very closely with the fracking industry and larger oil and gas industries.

ACRES U.S.A. Is that really in development?

THOMAS. Very much so. A lot of that work is around turning fracked and flared gas into petroleum substitutes, like fuel and plastics. They're also working on making it into fish food, which then could be the basis of food, in other words, turning gas into food.

ACRES U.S.A. What could possibly go wrong?

THOMAS. We have about 40 years experience with genetically engineered organisms in which originally only a single "gene" was moved from one organism to another. We learned that almost every time you engineer an organism, you get unexpected results. As you make the engineering more complex, as with synthetic biology, you're going to get more unexpected results. Let's say you have an organism engineered to break down cellulose. If it got out into the environment, there is plenty of cellulose in our houses, clothes and fields to survive on. And we don't know how it would change with evolution or whether it would produce toxins. Those are some of the worrying scenarios.

ACRES U.S.A. Wasn't there a genetically engineered soil organism that happened to produce alcohol?

THOMAS. That's right. *Klebsiella planticola* was a bacterium genetically engineered to break down cellulose. Fortunately, a couple of researchers looking at its impacts in the soil found that it would produce an alcohol that would kill plant roots and they were able to halt the release before it happened. In fact, a lot of the initial work in synthetic biology sought to engineer organisms to break down cellulose into alcohol for ethanol production. If instead you break down cellulose and turn it into vanilla and that gets into the soil, we don't know if that's a problem. And that's assuming that it's going to do the thing it's expected to do. These are living systems that evolve and have a will to live.

ACRES U.S.A. Is this being regulated at all?

THOMAS. Governments will say that synthetic biology is regulated in the same way as any genetic engineering. In the United States, that's very poorly and hardly at all. We're in the midst of a major fight to determine whether synthetic biology and other new technology, such as gene editing, actually fit under the definitions of genetic engineering. The biotechnology industry is making the legal argument that technically they're not GMOs and therefore don't have to go through the GMO approval process. In the United States, a group of biohackers decided to use synthetic biology to make weeds glow green. They wanted to mail the seeds of these glowing green weeds to thousands of people across the United States so they applied to the USDA to find out if they needed to be regulated. The USDA said it didn't really fit under their regulations, which is a very worrying precedent.

ACRES U.S.A. What happened?

THOMAS. Those guys were only able to make a very weakly glowing plant so the company switched its focus. Now it's working on a genetically engineered moss that smells like patchouli to gently fragrance your home. They call it "fragrant moss."

ACRES U.S.A. Sounds very socially useful.

THOMAS. Exactly – it's a gimmick. And moss is something that could survive in the wild.

ACRES U.S.A. Evidently they also don't realize the importance of odor in communication between various species.

THOMAS. No, and the same issue may hold around light. If you start introducing weeds that glow in the dark, how does that affect communication? That kind of ecological complexity isn't the sort of thing synthetic biologists deal with very well. Besides the unpredictable effects of genetically engineered organisms spreading and changing, there are other more predictable threats. If sugar becomes the key feedstock for making a lot of our food, flavors, fragrances, plastics and chemicals, then large swaths of farmland and forestland would be turned over to produce feedstocks for the industry. We've already seen problems with that in the first wave of biofuels, with so much corn production going into ethanol and its effect on food prices. Vanilla flavor produced by yeast through synthetic biology displaces and disadvantages natural forest-based production of vanilla. Farmers producing a high-value forest product also protect the biodiversity of the agro-ecological landscape. If companies can source the same product from a genetically engineered organism fed on a batch of sugar or methane, all of that is threatened. A key issue around the flavors and fragrances is how they're described. The company behind this has said they think that their synbio vanillin should be labeled as natural because fermentation is natural! Such a claim allows it to compete with real natural vanilla. Vanilla presents a complicated situation because it's one of the only ingredients with a legal standard of identity. You can't use the word vanilla for anything else. But for patchouli or citrus flavors, you apparently can just call it 'natural' and directly compete with truly natural production.

ACRES U.S.A. There's a lot of linguistic confusion.

THOMAS. Intentionally so. The synbio industry originally planned on making large amounts of biofuels and chemicals. With the glut in the energy market, those plans collapsed and they rushed into the highest value sector they could find, which is flavors and fragrances. This idea that they can pass them off as natural is very attractive to the big food and cosmetic companies.

ACRES U.S.A. Maybe they could make marijuana, too.

THOMAS. At least two companies are actually making synbio cannabinoids, mostly CBD (Cannabidiol). Companies in Colorado and other places where marijuana has been legalized are aggressively marketing CBD, which gives you a lot of energy. Synthetic biology companies could argue that if they can provide ingredients such as CBD without growing marijuana plants, then there's no reason to legalize it.

ACRES U.S.A. Most people concerned about genetically engineered foods remain focused on crops that are genetically engineered to be resistant to herbicides or producing Bt insecticide, despite the new forms of genetic engineering on the horizon. What should we know about gene editing?

THOMAS. Rather than introducing an extra piece of DNA, whether synthetic or natural, in gene editing you change some of the letters in an organism's genome. You can either knock them out one at a time or add in extra letters. Various tools have been used in gene editing, but the tool that changed everything is called CRISPR/cas9. CRISPR is already being hailed as the biggest, most profitable biotech breakthrough of the 21st century.

ACRES U.S.A. Is CRISPR naturally occurring?

THOMAS. It's a mechanism within a bacterium that allows the organism to change its own DNA. That mechanism is now being applied intentionally to a range of other life forms, and it's being built into organisms as a gene drive. Genetic engineers are so excited about CRISPR because it makes the process faster and easier. And they think it creates a good argument for saying that it's not a GMO. If you edit the genome rather than bring in additional DNA, somehow that's different from genetic engineering up until now. One after another companies are putting this forth as a legal argument and getting the USDA to agree that they won't regulate it. The large biotech companies like DuPont and Monsanto see it as a way to get around the existing laws and labeling regulations for GMOs.

ACRES U.S.A. Don't they also claim that CRISPR is very precise?

THOMAS. That claim is being made because they're changing one DNA-based pair at a time. But with CRISPR, off-target effects seem to occur elsewhere in the genome. It's unpredictable where they will be.

ACRES U.S.A. It sounds like the same fallacy that one gene results in one protein and we can control the whole thing.

THOMAS. Exactly. The simplistic idea that a single stretch of DNA equals one instruction is laughable at this point, but that's roughly the assumption upon which synthetic biology is being built. DNA doesn't come in a straight line, but all wound up on itself. If one part of DNA touches another part of DNA, then those parts are probably communicating as well. Even the way in which DNA is folded can be seen as part of the code. By knocking out one DNA-based pair in one place, you can have effects throughout the genome.

ACRES U.S.A. I had never heard of gene drives until I started preparing for this interview.

THOMAS. ETC Group is probably more concerned about gene drives than almost any other technology. A gene drive is a genetic element that will reliably get passed on from one generation to another. It has been thought that there are natural gene drives where a particular genetic trait is encoded in the genome in such a way that it will more likely or always get passed on to the next generation. With the CRISPR gene drive, which is what we're interested in, it's possible to engineer a particular genetic trait into an organism so that it *always* gets passed onto the next generation. If you engineer a fruit fly with a gene drive that makes it have red eyes, then all its offspring will have red eyes, as will all their offspring, so the entire fruit fly population will have red eyes. In normal Mendelian genetics you could assume that a trait will get passed on 50 percent of the time and 50 percent of the time it won't. With this gene drive, 100 percent of the time the trait gets passed on. What's significant about gene drives is their ability to relentlessly spread a genetically engineered trait through a population until ultimately you change or destroy an entire species. A lot of gene drive research aims to render a species of mosquito or parasite extinct.

ACRES U.S.A. Sounds like deliberate extermination.

THOMAS. That's right. The application that gets talked about most involves eradicating mosquitoes that carry malaria, Zika or dengue fever. Or maybe it would be possible to engineer a mosquito so that it couldn't carry a particular parasite. They could also be used though in many other areas. Gene drive developers say that this technology will end up in agriculture.

ACRES U.S.A. Many people would be thrilled to get rid of a mosquito species that carries the Zika virus. What are some of the problems to anticipate before releasing a gene drive?

THOMAS. First, there are the ecological implications of taking out or changing an entire species. While mosquitoes are problematic for a

number of reasons, they also are important as pollinators and as elements in the food chain. Bats, birds, fish and other animals eat them. The disease might well move to other vectors. Initially only one species of mosquito seemed to carry Zika, but it turns out other mosquito species can carry it, too. Ultimately, it's also likely that organisms will develop resistance to gene drives and then gene drives will have a limited effectiveness. What you're doing is launching these weapons into the wild against the mosquito or the parasite and fighting its evolution. Evolution will win every time with who knows what side effects. Then there are a bunch of social and ethical questions. If a northern hemisphere organization decides to release gene-drive mosquitoes across Africa, they'd be carrying out a very controversial experiment with a potentially ecologically disruptive technology over a whole continent. Since it's a health application and mosquitoes bite humans, you would need the consent of all the subjects in that experiment – .i.e. all Africans. That's a very big political decision. But the debate about gene drives won't just be about mosquitoes and malaria or Zika. That's just the case that the developers want to talk about.

ACRES U.S.A. Who stands to gain from gene-drive technology?

THOMAS. It's interesting to look at where the funding comes from. Currently there seem to be three big players. The Gates Foundation is putting $75 million into developing gene drives because of malaria. A big Indian industrialist's philanthropy just threw in $70 million. And the Pentagon would say they're funding gene drives because they're potentially a terrible biological weapon and they want to know how to remove gene drives from the environment should they end up being released with belligerent intentions. In the process, of course, the Pentagon is learning exactly how to create and optimize these bio-weapons. One could imagine a number of hostile uses, from engineering a parasite to decimate a human population to releasing a gene drive to destroy a food crop on an island nation. Agricultural biotech companies are extremely interested in gene drives. There's been much talk about a gene drive to overcome glyphosate resistance in weeds, like Palmer amaranth (pigweed), which would give Monsanto's market for Roundup a very healthy bounce. Another agricultural application getting attention involves putting a gene drive in pests like fruit flies that attack soft fruit, the objective being their eradication. The idea of gene drives is very attractive to agricultural input companies. Gene drive developers are now talking about developing "local" gene drives that would spread for a certain number of generations and then stop. That would enable corporations to sell gene drives as a service, for instance to eradicate pests or make the weeds on your farm susceptible to herbicides.

ACRES U.S.A. So that explains some ways that gene drives could generate a profit.

THOMAS. Gene drives are very new. The first proof of principle – the first working gene drive – wasn't announced until late 2014 or early 2015. Since then, there has been a frenzy to get on top of the implications of gene drives and a steady increase in the numbers of labs developing them. Gene drives are also being developed for supposed conservation uses. For example, a consortium of five universities, government agencies and an NGO are building a gene drive mouse that could be released to eradicate mice on islands.

ACRES U.S.A. And those mice are not going to stow away in someone's luggage?

THOMAS. We don't even know whether gene drives can jump species! Yet an NGO called Island Conservation that works internationally and is based in Santa Cruz already has gene-drive organisms ready for field trials. They want to be ready to release gene-drive mice by 2020, but no agency could possibly have regulations ready by then, and we won't have a good understanding of the implications.

ACRES U.S.A. I really enjoyed the ETC Group article about the conference in Britain at which conservation biologists and biotech geeks were courting each other. It was appalling and hysterical.

THOMAS. At the UN Convention on Biological Diversity, the issue of synthetic biology has become a topic for international discussion among 198 countries. Given the level of concern, synthetic biologists want to attract some allies in that forum, so they've made a deliberate effort to come up with ways in which synbio could be used to conserve biodiversity. That explains this crazy idea of using gene drives in conservation. Thirty leading conservationists like Jane Goodall and David Suzuki have signed a letter declaring that gene drives have no place in conservation. When the International Union of Conservation and Nature recently held its big World Conservation Congress, the developers of gene drives and other synbio promoters tried very hard to get a statement supporting the use of synthetic biology in conservation. Instead the IUCN approved a moratorium statement on gene drives. The pro-synbio countries and the organizations associated with that were horrified.

ACRES U.S.A. ETC Group's report "Reckless Driving" asserts that gene drives pose a grave threat to the environment, food security, peace and security on par with nuclear power.

THOMAS. I really think so. Gene drives are probably the highest leverage technology I've ever seen except maybe for nuclear power. The idea that releasing a single mosquito or fly could thereby change an entire species and by extension entire ecosystems – that kind of leverage is unparalleled. The ability to release something small and change something big offers a tremendous amount of power. That's why militaries and corporations are so excited about it.

ACRES U.S.A. This is very sobering.

THOMAS. It's hard to know how it will go. Developers are saying that CRISPR is so easy to do (gene drives basically work on CRISPR) that any fairly smart high school or undergraduate biotech student could do this. It would be difficult to detect in the first instance. That makes for very serious challenges. We're calling for the United Nations through its biodiversity convention to enact a moratorium on gene drives, but even knowing how to do that is going to be very difficult.

ACRES U.S.A. We haven't heard much about Terminator seeds lately, but isn't that one new technology that has not been commercialized?

THOMAS. In 2001 the UN Convention on Biodiversity agreed to a moratorium on the use of Terminator, which was strengthened in 2006. As far as we know, the biotechnology industry has not used Terminator in seeds, but there's been a very strong push to overturn that moratorium. Brazil currently has a national ban on the use of Terminator, but two bills before the Brazilian government would overturn the ban. After Brazil's recent coup by agribusiness-friendly interests and impeachment of the country's elected president, one of those bills will probably pass. We believe the biotech industry wants to overturn that ban in Brazil so that they can overturn the moratorium at the United Nations. There is somewhat of a link between Terminator and gene drives. Terminator would force sterile seeds on farmers. Gene drives would take Terminator a step further by spreading sterility across entire species.

ACRES U.S.A. Do you have any insight into how scientists, entrepreneurs and investors can think this is OK?

THOMAS. The only explanation I can come up with for how relaxed people can feel about gene drives – and synthetic biology broadly – is that they think that they're working with a predictable, reliable technology. They see it as bringing engineering to life sciences. They believe they know what's going on and that they can control it.

ACRES U.S.A. What gives you the skepticism and the sensitivity to care about the technological frontier?

THOMAS. It comes from watching one emerging technology after another and seeing their social ramifications. This also goes back to your previous question. Particularly in places like Silicon Valley, there is a strong culture of "disruption." Investors ask, "Can we create the next disruptive technology?" They mean a technology that will create a multi-billion dollar market that wasn't there before. What they don't see is that the disruption is real for people's lives, and what they're disrupting are existing economies, existing livelihoods and existing cultures. There are piles of evidence that any powerful new technology brought into our society ends up doing its disrupting in ways that tend to benefit the powerful and really disadvantage those who are already disadvantaged. What motivates us at ETC Group is seeing the recurring pattern where new technologies introduced by the powerful drive further inequality and the further erosion of rights and the environment.

ACRES U.S.A. I'm hearing your strong sense of the urgency about gene drives.

THOMAS. This is a very crucial moment for gene drives because the technology is so new. Companies and governments are rapidly organizing themselves to make this into a viable technological platform. Yet, the threats are extremely clear. The sane thing is to call a halt right now and think long and carefully about the implications. Instead, most people aren't even aware of this. By the time they know about gene drives, it will be too late. But we still have a window to hold this technology back.

ACRES U.S.A. This is happening on a level that is not accessible to most of us. What should individuals do?

THOMAS. For anyone involved in agriculture in any capacity, it is really important to quickly wrap your head around gene drives because they're going to transform agriculture. If you're part of an organization where you can analyze it and speak out, please do so sooner rather than later. At this point it may sound abstract, but within 5 or 10 years it's not going to be.

ACRES U.S.A. Another set of powerful new technologies falls under the category of geoengineering. What are some of the geoengineering schemes for addressing climate change?

THOMAS. Climate geoengineering that is going ahead or being researched falls broadly into two areas. The first would be techniques for removing greenhouse gases like carbon dioxide and methane from the atmosphere. There are various proposals. Ocean fertilization, which has been largely discredited, involves seeding iron in the ocean so that the ocean would grow more plankton, which would supposedly draw down carbon dioxide. There have been a number of such ocean fertilization tests to determine its feasibility. Other experiments looked at altering ocean chemistry, trying to make it more alkaline so it would soak up more carbon dioxide. There are proposals for big machines that would suck up carbon dioxide out of the air. The other main type of geoengineering is called "solar radiation management." We know that the emission and accumulation of greenhouse gases is what causes climate change. Solar radiation management aims to reduce the amount of heat reaching our atmosphere. If you could just block out the sun or reflect back more sunlight, then we could physically alter the heat thermostat of the planet. There are many ideas in the solar radiation management bucket. Can we put

small particles of sulfur into the upper atmosphere, a bit like simulating a volcano's eruption, to reflect sunlight back out into space? Or make extra clouds, or make clouds whiter so that they reflect more sunlight? Such ideas were considered crazy only about eight years ago. Now they're creeping to the edges of international debate and slowly becoming an acceptable part of the discussion around climate change. That's very worrying. The idea that you would change the thermostat of the planet has massive physical implications. Dimming the amount of light hitting one part of the planet can create monsoons in another part of the planet and other enormous changes. It's really unprecedented.

ACRES U.S.A. Less than a couple degrees of global warming has already resulted in record flooding, heat waves and droughts.

THOMAS. The geoengineers would say there is a proof of principle here, too. Throughout history very large volcanoes have briefly brought down the overall temperature of the planet as all the debris and dust from the eruption reflected light back out into space. That's what happened when Pinatubo erupted in 1991. If things get too bad, geoengineers propose that we create artificial volcanoes to mimic that. But volcanologists who have studied eruptions of large volcanoes have shown that's when droughts occur in sub-Saharan Africa or the monsoon fails in India. So geoengineering the planet would only serve to increase the unpredictably of our weather system – even more than climate change has already done. Another worrying aspect of geoengineering is the context. The international community has been unable or unwilling to deal with man-made climate change. Some leading industries and even some governments want to stall real action. This makes the idea of a quick fix very attractive to them.

NEED MORE INFORMATION?
For more information, visit *etcgroup.org*, *synbiowatch.org* and *geoengineeringmonitor.org*.

ACRES U.S.A. Isn't the fight against quick fixes a unifying principle for your work?

THOMAS. Unfortunately, it is.

ACRES U.S.A. You're alerting civil society all over the world and advocating against quick fixes, which have all kinds of unintended consequences that those doing the fixing don't want to see.

THOMAS. This techno-fix mentality cuts across a whole range of different technologies and also over many different policy areas, whether we have a techno-fix for malaria in gene drives or for climate change in geoengineering. It used to be that governments understood that it takes slow, difficult social policy to make real change. But increasingly now they're hoping to find the "killer app" or silver bullet for whatever the problem is. We live in an era of ever-accelerating innovation. Technologies are appearing faster and faster, coming all at once. Underlying technologies like nanotechnology are making things possible that weren't before. Government and society are very easily dazzled by the promises and generally lack the tools to assess the problems.

ACRES U.S.A. Where do we need to look for the solution?

THOMAS. For a few years we've been pointing out the need for an international capacity to do technology assessments. Initially we advocated for an international treaty requiring technology assessment that we called the International Convention for the Evaluation of New Technologies. Since then we came to believe that there needs to be some mechanism or body in the United Nations with the ongoing task of tracking all of the new emerging technologies, like nanotechnology, geoengineering, synthetic biology and robotics, and doing really good social assessments involving those most affected. The good news is that's beginning to happen. A few years ago, the United Nations agreed to create a technology facilitation mechanism. In New York, in conjunction with the UN's Science and Technology Innovation Forum, people are establishing that mechanism. That could become the global mechanism for assessing new technologies. But it needs to be met by a greater capacity in civil society to track these same technologies and try to understand their implications.

ACRES U.S.A. Are there any other organizations such as yours?

THOMAS. In a diffuse way there are. For every area of emerging technologies, whether nuclear, agricultural or big data, for example, there usually are small watchdog groups. Social movements have a lot of knowledge for understanding the implications of new technologies. What we need to do is hook them together. In Latin America we just started our first regional technology assessment platform. We're bringing together groups to scan the horizon of the new technologies and assess which ones will have implications for society. This needs to happen in North America, Europe, Africa and Southeast Asia. Such a network of technology assessment platforms could develop an early warning monitoring system for civil society. That's very necessary and doable.