Should plastics be a source of energy?

The plastics crisis has some asking if we should burn more plastic waste and get energy out of it

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In brief

The plastic waste problem has grown into a crisis over the past year as more people have become aware of ocean plastic litter and China shut its doors to waste plastics imports from the rest of the world. In the U.S., little plastic is being recycled, and the prospects for boosting recycling significantly and in short order are slim. Some observers are arguing for burning plastic that can't be recycled to extract its energy value. But that might be easier said than done. Burning more plastics in waste-to-energy facilities poses economic and societal challenges. Making fuels out of plastics shows long-term promise, but plants need to be built.

In Rahway, N.J., near Route 1&9, looming cooling towers and a huge white smokestack dwarf the nearby car dealerships, fast-food joints, and motels. The installation is visible for miles and is a familiar landmark to the highway's regulars, but likely few of them know what is going on inside.

The structure is the Union County Resource Recovery Facility, a waste-to-energy facility that Covanta operates on behalf of the local government. Instead of the usual coal or natural gas, it burns garbage to make electricity.

Inside, a parade of garbage trucks from all around the county tilt their loads onto the facility's floor. What comes in is the assorted dross the local citizenry throws out that isn't suited for paper, metal, and plastics recycling bins. Workers bulldoze unwanted toys, old pillows, broken furniture, and heaps of plastic garbage bags into a 10-meter-deep pit. Two steel claws the size of delivery vans mix the pile like two gigantic hands tossing a salad.

"The person running the cranes is critical," says Michael Van Brunt, senior director of sustainability at Covanta. "Coal comes in at a certain spec. You know what you are buying has consistent thermal properties. For us, it can vary by load, so we mix it for consistency."

After the operator has sufficiently homogenized the mass, the claws grab heaps of the stuff and drop it into a hopper feeding three furnaces that incinerate the trash at 1,100 °C. They can process 1,400 metric tons of waste daily. The boilers generate steam heated to 450 °C, powering turbines with a capacity of 42 MW, enough for 30,000 homes.

The plant extracts more than just energy from the garbage. Its magnets and eddy current separators recover the ferrous and nonferrous metals that end up in household trash. At the end of the process, the resulting ash, about 10% of the garbage's original volume, heads for landfills.

Two-thirds of the carbon in the trash is derived from biomass such as food and wood. Plastics compose the other third. In the U.S., discarded plastic is far more likely to end up in a landfill or a facility like Covanta's than it is to be recycled.

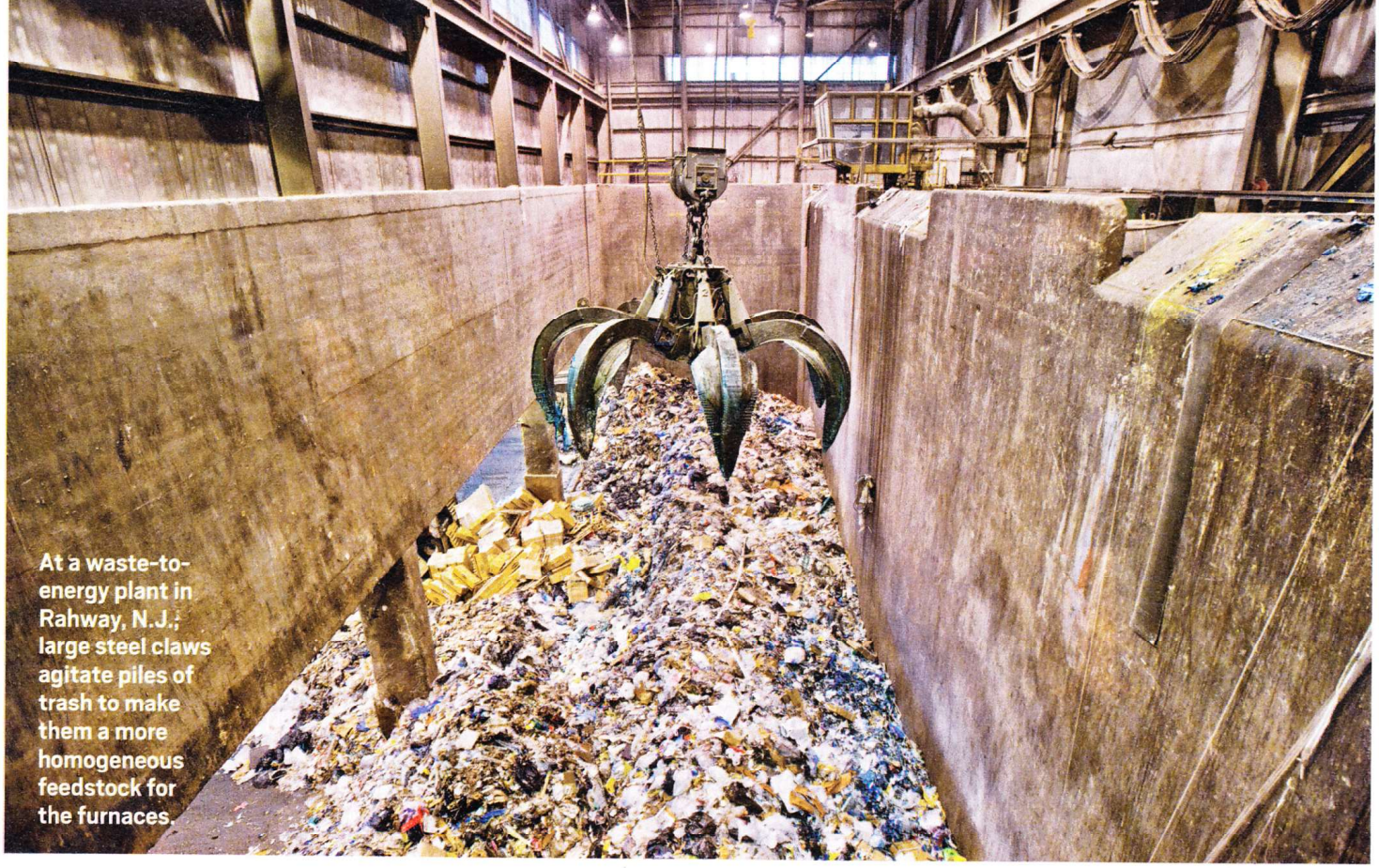
According to the Environmental Protection Agency, Americans recycled only 9.1% of their plastics in 2015. Waste-to-energy facilities combusted 15.5%. But the most likely destination for the plastics discarded in the U.S. is the landfill. It is the final resting place for three-quarters of it.

The public is fed up with plastic waste. It's haunted by pictures of tropical beaches littered with plastic bags and tortoises entangled in six-pack rings. And most people realize that we are growing more and more dependent on plastics, especially hard-to-recycle varieties such as single-use flexible food packaging.

Adding to the crisis, the Chinese government has shut down imports of waste plastics, breaking the U.S. and Europe of their habit of baling up garbage and sending it out of sight and out of mind across the sea. The plastic is piling up.

In response, municipalities are installing equipment to sort waste better. Industry is trying to improve the recycling system to handle more plastic and fold the results into more new products. Desperate to look responsive, politicians are resorting to bans of single-use plastics such as straws, cutlery, and polystyrene foam containers.

Yet despite good intentions, recycling



At a waste-to-energy plant in Rahway, N.J., large steel claws agitate piles of trash to make them a more homogeneous feedstock for the furnaces.

and banning won't keep enough plastic out of the landfill to solve the plastic waste problem. Some people involved argue that extracting energy from plastic—in both waste-to-energy facilities and plastics-fed fuel refineries—will need to be part of a solution that keeps our old plastics out of the landfill.

Marco Castaldi, director of the Earth Engineering Center at the City College of New York, says improving recycling will be tough and probably can't address all the plastic waste piling up. He points out that the U.S. municipalities leading the pack are still achieving only a 30% recycling rate. Waste-to-energy furnaces, pyrolysis plants, and other energy extraction schemes are needed to finish the job. "Thermal conversion processes are going to have to be engaged," Castaldi says.

Even some environmental activists agree that supplementing mechanical recycling with such technologies is worth considering. The Ocean Conservancy, for example, recommends energy recovery as part of a strategy for tackling ocean waste in Southeast Asia. And the Ocean Plastics Charter that five G7 leaders signed earlier this year calls for "working with industry towards 100% reusable, recyclable, or, where viable alternatives do not exist, recoverable, plastics by 2030."

But just burning plastic isn't as easy as it might sound. Waste to energy might be up to the task technologically; the economics are a different story.

The waste-to-energy facilities that dot the U.S. are already processing as much plastics as they can. Building new facilities—at least in the U.S.—is fraught with challenges. Technologies that make fuels from plastics hold promise, but they still must be proved and scaled up further before they can make a difference.

China shuts the door to plastic

The Chinese government forced the world to rethink how it manages plastics when it adopted its National Sword policy earlier this year. China banned 24 categories of scrap materials, including plastics.

Many U.S. municipalities leaned heavily on China to handle their plastic waste. This was especially true for towns that told residents to toss all their plastics into recycle bins. In reality, municipal materials recovery facilities (MRFs) want only three of these plastics: rigid polyethylene terephthalate, high-density polyethylene, and polypropylene containers—plastics number 1, 2, and 5, respectively, according to recycling coding that consumers may be familiar with. The other plastics that end up in the recycling stream—multilayer pouches, vinyl pipe, polystyrene cups, and the like—are seen as contaminants.

Some municipalities didn't even bother sorting. They just baled up all the unsorted plastics and tried to sell it. Chinese recyclers were ready buyers. In China, they would mostly pluck out the same three valuable plastics and then discard the rest—not always in a proper landfill.

The West Coast, with its cheap freight rates to China, was particularly addicted to this system. In a letter to local officials this May, Scott Smithline, director of California's Department of Resources Recycling & Recovery, acknowledged that two-thirds of the recyclables collected in California were being sent abroad, more than 60% of that to China.

"All they were doing was transferring the landfill from their state to a foreign country," says Scott Saunders, general manager of KW Plastics, based in Troy, Ala. KW calls itself the largest high-density polyethylene and polypropylene recycler in the world, processing about 450,000 metric tons of material annually.

For Saunders, the Chinese buyers were a bad influence on recycling in the U.S. Because they were willing to buy anything, the quality of plastic bales was low; half of them could be contaminants. But U.S. buyers like KW felt forced to take the bales because the plastics would otherwise slip through their fingers and get sold overseas.

Over the next two years, Saunders predicts, MRFs will increasingly do the sorting themselves. But for now, the ban has created a backlog.

Some jurisdictions have temporarily suspended recycling programs. In other places, recyclables are piling up and even being landfilled. And even if MRFs even-

tually manage to do a better job of sorting, residuals such as plastic film will still need a home.

The effect of the new Chinese policy may add up. According to a study led by Amy L. Brooks at the University of Georgia's College of Engineering, the Chinese policy will displace 111 million metric tons of plastic worldwide by 2030 (*Sci. Adv.* 2018, DOI: 10.1126/sciadv.aat0131). China had been getting about 10% of its recycled plastics, about 700,000 metric tons per year, from the U.S.

Just burn it

It might seem that this is waste to energy's moment to shine—to charge in and solve the plastic waste problem. The industry does see itself as an environmentally friendly alternative to landfilling. Covanta says waste-to-energy facilities reduce CO_2 emissions by about a ton for every ton of waste that's not landfilled. This is because fossil fuels aren't being burned for energy, methane isn't being generated in a landfill, and metals are being collected for recycling.

But the sober reality is that today's waste-to-energy plants simply can't start burning all the plastics that are piling up. The plants have the capacity to make only the amount of energy per day that they were designed to produce. Plastics have a higher energy content than most trash. If a waste-to-energy facility processes more plastics, it has to take in less waste overall.

That's a problem because the facilities generate most of their revenues from the so-called tipping fees that they get from municipalities for getting rid of waste. Covanta, which operates two-thirds of the waste-to-energy facilities in the U.S., generated 70% of its income in 2017 from such fees. Only 19% came from the electricity it sold. Another 5% came from the metals it recovered. Energy and metals alone would cover only a third of the operating expenses of Covanta's plants.

Jeremy O'Brien, director of applied research for the Solid Waste Association of North America (SWANA), says waste-to-energy plants exist to dispose of waste. Sanitation is their first job. "Materials and energy recovery are secondary benefits," he says.

To incinerate more plastics, the U.S. would need to build more waste-to-energy plants so they could process more trash overall. But it has yet to embrace the technology as some countries do. Only about 13% of U.S. garbage is burned for energy. In the European Union, the figure is double. Germany incinerates about a third of its waste for power; Norway and Sweden, more than half.

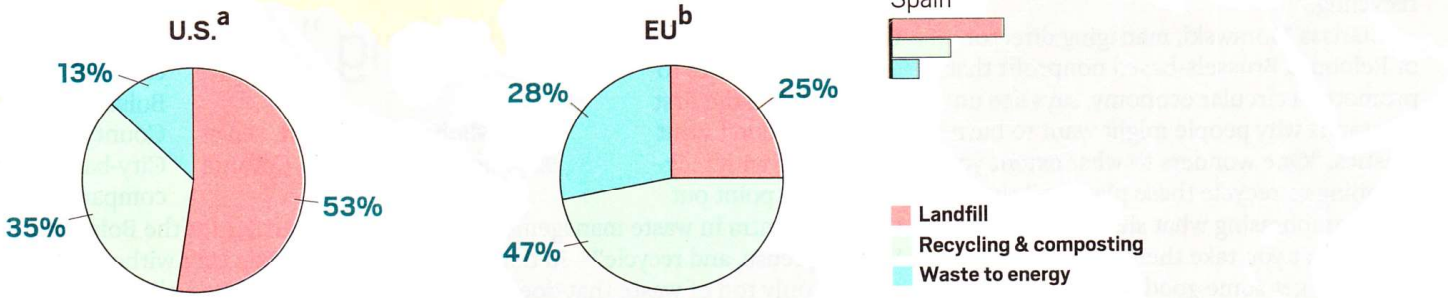
"The biggest impediment for us is cheap landfilling, particularly in the middle part of the country," Covanta's Van Brunt says. Tipping fees can be as low as $20 per metric ton in land-rich states like Oklahoma. More densely populated coastal regions tend to have more waste-to-energy facilities because of their landfills' relatively high tipping fees—more than $70 in parts of New Jersey, for instance.

In Europe, the incentives line up against landfills. For 20 years, the European Union has lived under the Landfill Directive, which requires that biodegradable waste be treated so it is biologically and chemically stable before it is disposed. "That is what drove the implementation of waste-to-energy facilities," O'Brien says.

European officials favor waste-to-energy methods because they are more likely than their North American counterparts to see it as a way of making waste safer, O'Brien

Different methods

Waste to energy is more common for trash management in Europe than in the U.S.



Note: Numbers may not add to 100% due to rounding and data collection methods. **a** Data are for 2015. **b** Data are for 2016.
Sources: Confederation of European Waste-to-Energy Plants, Eurostat, EPA

notes. It gets rid of hazardous materials and pathogens while yielding energy and metals.

EU countries levy high taxes on landfills. Belgium, for instance, charges a tax of more than $100 per metric ton of waste landfilled. Germany, Sweden, and some other nations have landfill bans on the books.

Not everyone is on board

The European embrace of waste to energy doesn't sway some activists, who consider the technology a step backward. Ahmina Maxey, U.S. and Canada regional coordinator for the Global Alliance for Incinerator Alternatives, opposes new waste-to-energy facilities and wants to see existing ones close.

Atop her list of grievances is emissions.

Relatively clean

Waste-to-energy plants emit less than coal- and oil-based energy plants but more than natural gas plants.

	EMISSIONS, kg/(MW·h)		
FUEL	CARBON DIOXIDE	SULFUR DIOXIDE	NITROGEN OXIDES
Municipal solid waste	560.45	0.23	1.50
Coal	1,022.27	5.91	2.73
Oil	760.00	5.45	1.82
Natural gas	515.91	0.05	0.77

Source: Jeremy O'Brien, director of applied research, Solid Waste Association of North America

"We are really just converting waste from solid garbage into air pollution and creating a landfill in the sky," she says.

Moreover, waste-to-energy technology is expensive, she says, and a burden to the communities that plunge into it. Detroit sunk $1.2 billion into its incinerator, she points out. Harrisburg, Pa., spent more than $360 million upgrading its plant. This kind of spending locks communities into waste to energy, Maxey argues, and prevents them from pursuing other types of waste reduction, composting, and recycling.

Clarissa Morawski, managing director of Reloop, a Brussels-based nonprofit that promotes a circular economy, says she understands why people might want to burn plastics. "One wonders to what extent you are going to recycle these plastics," she says, paraphrasing what she often hears. "Why don't you take them all and burn them and get some good energy out of them?"

But the approach isn't a reasonable solution long term, Morawski argues. "While the world is getting off fossil fuels, it seems counterproductive to be saying 'Let's just burn all plastics.'"

Even Europe, Morawski says, is shifting away from waste to energy as a plastics strategy, focusing instead on boosting recycling. This can mean forgoing multilayer packaging or flame retardants where they aren't needed, so the resulting stream is simpler to recycle. It can also mean redesigning packages to incorporate more recycled resin.

"If we can get plastic into a state where it is more recyclable, then we can achieve tremendous gains," she says.

Proponents of waste to energy say the technology is cleaner than other power sources. According to SWANA's O'Brien, waste-to-energy plants emit less CO_2, sulfur dioxide, and nitrogen oxides than coal-fired power plants do per unit of power.

And waste-to-energy plants have cleaned up their act over the years, Covanta's Van Brunt says. "Arguably, one of the best things that happened to our industry is the Clean Air Act Amendments of 1990," he notes.

The law forced the industry to install advanced pollution control equipment. For example, to clean up the flue gases coming out of its Rahway plant, Covanta uses a baghouse to remove particulates, calcium hydroxide to neutralize acids, ammonia to reduce nitrogen oxides, and activated carbon to adsorb mercury, dioxins, and other contaminants.

From 1990 through 2005, the U.S. waste-to-energy industry lowered its own SO_2 emissions by 88% and NO_x by 24%, according to EPA. It has reduced emissions of lead, cadmium, mercury, and particulates by 96%. The industry went from emitting 58% of the dioxins in the U.S. in 1986 to less than 0.1% in 2012, according to a study by the Earth Engineering Center at Columbia University.

Backers of waste to energy will be the first to say they don't want to interfere with recycling. They point out that the mantra in waste management is "reduce, reuse, and recycle"—in that order.

"The only ton of waste that doesn't have an impact is the ton that you don't generate," Covanta's Van Brunt says. "But then the next best thing is to recover energy to the extent that we can, and that is where we fit, right below recycling."

According to EPA, recycling metals, paper, and plastics recovers roughly 16 billion J of energy per metric ton of material. Burning that same ton for energy saves about 7 billion J.

Just burn it, sort of

Companies developing pyrolysis, another technology to extract energy from plastic waste, hope that their processes will evolve into something better than waste to energy for those plastics that can't be recycled.

Pyrolysis takes mixed plastic waste and treats it at 350 to 800 °C in a low-oxygen environment so it breaks into shorter-chain hydrocarbons. Small companies have been operating demonstration plants for years to make crude-oil-like fuels. Pyrolysis also has the potential to make chemical feedstocks that could be fashioned back into polymers, creating a closed loop.

"Neither of these options would be available if all the trash were sent to a waste-to-energy facility," says Jeff Wooster, global sustainability leader for Dow Chemical's packaging business.

A backer of pyrolysis, Dow partnered with Reynolds Consumer Products on the Hefty EnergyBag program. The companies set up the first pilot for the program in Citrus Heights, Calif., in 2014. There, residents throw hard-to-recycle plastics like disposable forks, potato chip bags, and drink pouches into special orange Hefty bags.

Sanitation trucks collect the bags and send them for energy recovery. Most of the plastic goes to pyrolysis plants, but it's burned to fuel facilities such as cement plants when capacity is unavailable. Over the past four years the program has collected more than 150 metric tons of plastics, Dow says.

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>
> **—Michael Van Brunt,** senior director of sustainability, Covanta

The partnership subsequently nabbed Omaha as the first major metropolitan area to participate in the program at a large scale. Dow has also awarded grants to establish programs in Boise, Idaho, and Cobb County, Ga. Salt Lake City-based pyrolysis company Renewlogy is Dow's partner for the Boise program.

EnergyBag isn't without controversy. The National Recycling Coalition last year wrote a letter to Dow asking it not to refer to the program as recycling.

"We agree. It is not recycling," Wooster says, but he notes that it is a step on the

Workers unload discarded polystyrene for use at an Agilyx depolymerization unit in Tigard, Ore.

way to a sustainable plastics system. "Our long-term goal is to expand the use and acceptance of energy recovery technologies to the point where they are able to produce a chemical feedstock at the scale and quality that would allow us to create new plastics."

This is Agilyx's goal, too. The Tigard, Ore.-based company has been involved with pyrolysis of hard-to-recycle plastics since it started up 14 years ago with backing from the trash collection firm Waste Management.

For a while, Agilyx converted mixed plastics at its plant in Tigard into an oil that was further refined into jet fuel. The company has processed plastics into about 19,000 barrels of the product.

In 2015, Agilyx had to switch gears when oil prices fell below $40 per barrel. "We had a little bit of an issue when the commodity markets fell," CEO Joe Vaillancourt recalls.

Pondering their next step, Agilyx managers struck on polystyrene. It was easier for their process to make styrene from polystyrene than to make the oil from mixed plastics. Styrene is more valuable. And polystyrene is extremely difficult to sort and clean in a mechanical recycling process.

Agilyx retrofitted its plant to produce 10 metric tons per day of styrene monomer to be sold to the polystyrene makers Americas Styrenics and Ineos Styrolution. The latter firm is considering using Agilyx technology to build a styrene plant near one of its facilities.

Though Agilyx converted its plant, it hasn't abandoned the plastics-to-oil approach. Vaillancourt notes growing interest in the technology because of the plastic waste problem and because oil prices are rising again. Even under the best of circumstances, he says, 60% of plastics—notably films—will end up in the landfill because they are not recoverable. "We can take 90% of that and put it through a chemical recycling process," he says.

City College's Castaldi says it makes sense that pyrolysis is getting more attention now as municipalities look for ways to manage the overflow of plastic waste. "Pyrolysis is something that can handle it," he says.

Pyrolysis companies are already working toward the longer-term dream of making plastic from plastic. Agilyx announced last month it will use pyrolysis to produce naphtha, which chemical plants crack to make polymer building blocks such as ethylene and propylene.

Another pyrolysis firm, RES Polyflow, is hitting on the same idea. It is planning a facility in Ashley, Ind., that will process 100,000 metric tons of plastic per year into 380,000 barrels of diesel and naphtha. In March, BP signed a deal to buy the plant's output when it opens next year.

The future is ... cement?

Other schemes for dealing with the plastics problem abound. Cement kilns—which power cement manufacture and burn at more than 1,400 °C—might offer the quickest fix, SWANA's O'Brien says. "Cement kilns are always needing energy resources," he says. "If I had to get rid of a million tons of nonmarketable recyclables this next year, they would be the first on my list."

Castaldi agrees that cement kilns are intriguing. "Cement kilns, they love those plastics," he says. He notes that plastic has a high heating value and doesn't produce as much ash or sulfur as coal, the most common kiln fuel, does.

A $25 million project, dubbed Entsorga West Virginia, seeks to capitalize on cement kilns' need for fuel. Its plant, nearing completion in Martinsburg, W.Va., will take municipal waste and lay it down in rows for up to 14 days. This composts some of the food waste in the mixture.

When that step is finished, Entsorga will take out the metals, rocks, and other materials that don't belong. It will shred the rest into an EPA-approved fuel called solid recovered fuel. "It is basically dried-out municipal waste," says Emily Dyson, R&D director at BioHiTech Global, one of the partners in the project.

When the plant starts running early next year, it will process about 100,000 metric tons of material per year. A nearby cement kiln will substitute this plastic-rich fuel for 30% of the coal it has been using.

The more solutions, the merrier, Agilyx's Vaillancourt says. There is plenty of plastic waste to go around because recycling, and even processes like his, won't be able to dispose of everything. "There is no one silver bullet that will deal with all of this," he says. ■