

LETTER FROM RWANDA AUGUST 22, 2022 ISSUE

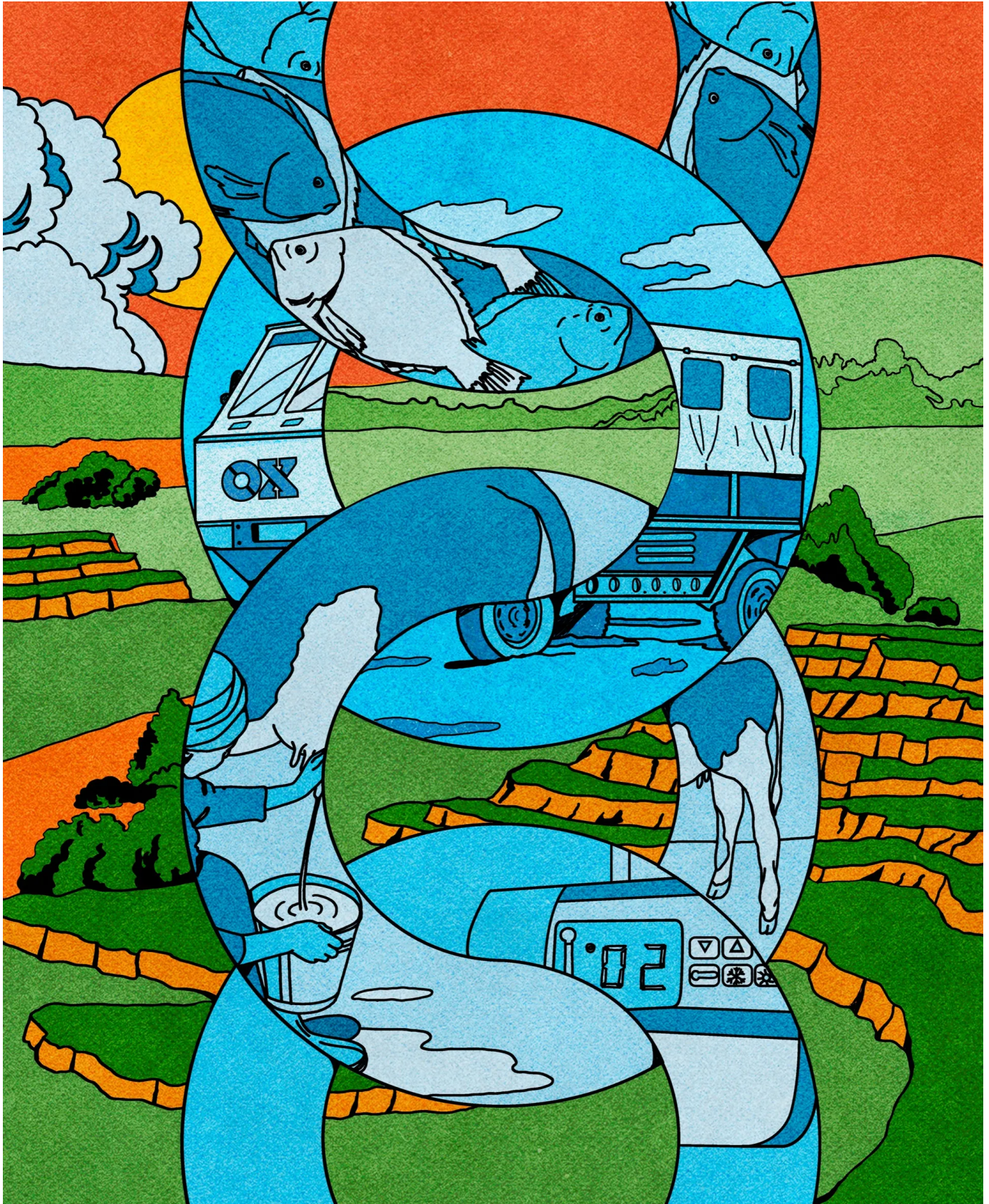
# AFRICA'S COLD RUSH AND THE PROMISE OF REFRIGERATION

*For the developing world, refrigeration is growth. In Rwanda, it could spark an economic transformation.*

**By Nicola Twilley**

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*A “cold chain” protects food as it makes its way from farm to table.* Illustration by María Jesús Contreras

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**A**t one in the morning, several hours before fishing boats launch, François Habiyambere, a wholesale fish dealer in Rubavu, in northwest Rwanda, sets out to harvest ice. In the whole country, there is just one machine that makes the kind of light, snowy flakes of ice needed to cool the tilapia that, at this hour, are still swimming through the dreams of the fish farmers who supply Habiyambere’s business. Flake ice, with its soft edges and fluffy texture, swaddles seafood like a blanket, hugging, without crushing, its delicate flesh. The flake-ice machine was bought secondhand a few years ago from a Nile-perch processing plant in Uganda. A towering, rusted contraption, it sits behind a gas station on the main road into the southeastern market town of Rusizi, on the border with the Democratic Republic of the Congo. Its daily output would almost fill a typical restaurant dumpster, which is considerably less than the amount required by the five fishmongers who use it.

“The first one who comes gets enough,” Habiyambere told me when I accompanied him one day in May. “The rest do not.” He said this in a tone of quiet resignation. The machine is five and a half hours’ drive south of where he lives, which is why his workday begins in the middle of the night. He rides in one of the country’s few refrigerated trucks, driven by a solid, handsome twenty-eight-year-old named Jean de Dieu Umugenga, and laden with spring onions and carrots bound for market. The route is twisty and Umugenga swings around the hairpin bends with panache, shifting in his seat with each gear change, while twangy *inanga* music plays on the radio.

Sometime after 3 A.M., cyclists start to appear. All over rural Rwanda, sinewy young men set out from their homes on heavy steel single-speed bikes that are almost invisible beneath comically oversized loads: bunches of green bananas strapped together onto cargo racks; sacks of tomatoes piled two or three high; dozens of live chickens stacked in pyramids of beaks and feathers; bundles of cassava leaves so massive that, in the predawn light, it looks as though shrubbery is rolling along the side of the road. Over the next four or five hours, as the heat of the day sets in, gradually wilting the cassava leaves and softening the tomatoes, these men will cover hundreds of miles, carrying food from the countryside to sell in markets in the capital, Kigali.

Rwanda is known as Le Pays des Mille Collines, “land of a



thousand hills,” but there must be at least ten thousand, their lush, green terraced slopes rising steeply out of a sea of early-morning mist that fills the valleys below. The cyclists coast down each hill and then dismount to push their bikes up the next. When they reach a paved road, some of them may manage to catch a ride hanging on to the back of Umugenga’s truck.

Around half past five, as the first flush of dawn appears, members of the Rulindo vegetable coöperative, a few hours northwest of Kigali, head into the fields. Rwandans are notoriously neat, I am told, and the countryside is packed with postage-stamp-size plots, like hobbit gardens, hugging the hillside contours in orderly terraces. Chili-pepper bushes and green-bean vines grow in uniform rows; the fertile red soil of the valley floor is pristine and weed-free; every square inch is meticulously cultivated.

By this time, Habiyambere and Umugenga have driven a hundred and forty miles down the entire eastern shoreline of Lake Kivu, where the fishing industry of this landlocked country is based. Its waters are dotted with rocky islands and traditional wooden canoes fishing for *sambaza*, a silvery, sardine-like fish usually eaten deep-fried, with a beer. The canoes travel lashed together in groups of three, their nets attached to long eucalyptus poles that project from the prows and the sterns like insect antennae. On arrival in Rusizi, Habiyambere and Umugenga stop first at the market to unload the vegetables, which will be sold to Congolese traders. Then they

head to the ice machine, where, after painstakingly cleaning the truck's interior, they score a small mound of precious flake ice. By

6:45 A.M., they are parked in the shade down at the dock, dozing as they wait for the fishermen to land.

Farther north, closer to the Ugandan border, Charlotte Mukandamage is wiping down the udder of a heifer that she keeps in a wooden stall behind her mud-brick home. Squatting on a plastic jerrican, Mukandamage coaxes a gallon and a half of warm, frothy milk out of the cow and into a small metal pail. Then she carefully picks her way down a steep and slippery mud path carved into the hillside, heading for a concrete marker with a picture of a cow painted on it, where a small crowd has assembled to await the milk collector.

When I tagged along with Mukandamage one morning, we were joined by a half-dozen others, including an elderly man in a fedora toting a large pink plastic bucket, and a skinny seven-year-old hauling a yellow tin pail nearly half her size. The morning sun was glittering on the tin roofs of nearby homes, and wisps of smoke from woodstoves mingled with mist rising off the hills. Soon, a balding man wearing black gum boots came into view: Pierre Bizimana, a farmer and a part-time milk collector. He pushed a bike, over which were slung two battered steel cans, each capable of carrying a little more than thirteen gallons of milk. For the next



two hours, in the gathering humidity, Bizimana, his assistant, and I trudged uphill from one station to another, picking up a gallon here and a half gallon there from a few dozen farmers. Then we headed to the nearby town of Gicumbi, where there is a milk-collection center with an industrial chiller.

By 9:30 A.M., Bizimana is heading home, to tend to his own cow and a small plot on which he grows sorghum, corn, and beans. Hundreds of miles away, François Habiyambere and Jean de Dieu Umugenga have embarked on the drive back north with a truck full of fresh fish for the Rubavu market. Some of the sweaty cyclists are already making their return journeys, too, often with a passenger perched on the cargo rack where the cassava or the chickens had been. And the Rulindo farmers are back from their fields bearing crates of freshly picked peppers and beans. The next morning, the harvest will be loaded onto a RwandAir flight bound for the United Kingdom, where it will be sold in supermarkets. In the meantime, the crates are stacked in a solar-powered cold-storage room, which, at sixty-five degrees Fahrenheit, is about twenty degrees warmer than it should be.

**T**he International Institute of Refrigeration estimates that, globally, 1.6 billion tons of food are wasted every year, and that thirty per cent of this could be saved by refrigeration—a lost harvest of sufficient abundance to feed nine hundred and fifty

million people annually. In a country like Rwanda, where fewer than one in five infants and toddlers eat what the World Health Organization classifies as the minimum acceptable diet, such wastage is a matter of life and death. Rwanda is one of the poorest countries in the world: the gross per-capita income is currently \$2.28 a day, and more than a third of children under five are stunted from malnutrition. Although it is difficult to calculate the precise contribution of unrefrigerated bacterial reproduction to rates of food-borne illness, according to the most recent data diarrhea alone is estimated to have reduced Rwanda's G.D.P. by between two and a half and five per cent. Nonetheless, President Paul Kagame's government has pledged to transform Rwanda into a high-income country by 2050; recently, it has come to realize that this goal cannot be achieved without refrigeration.

In 2018, Rwanda announced a National Cooling Strategy, the first in sub-Saharan Africa, and, in 2020, it launched a program known as the Africa Centre of Excellence for Sustainable Cooling and Cold Chain, or ACES. A collaboration between the Rwandan and U.K. governments and the U.N. Environment Programme, ACES is designed to harness expertise from within Africa and beyond it. Several British universities are involved, as is the University of Rwanda, in Kigali, where the new institution has its campus. ACES' mission is wide-ranging and encompasses research, training, and business incubation, and also the design and certification of cooling systems; once construction is complete, early next year, its



campus will have the country's first advanced laboratory for studying food preservation and a hall to demonstrate the latest refrigeration technology.

Among people involved in international development, Rwanda is considered a good place to do business. There is little corruption; Kagame, though an autocrat, is credited with enforcing discipline in the public sector and promoting governmental accountability and transparency. And the country's small size—it is not much larger than Vermont—makes it an ideal testing ground for initiatives that, if successful, can then be deployed across sub-Saharan Africa. ACES has plans to expand from its Kigali hub with spokes across the continent, and the team is also working with the southern Indian state of Telangana to build a similar center there.

In Kigali, I met the world's first professor of cold economy, Toby Peters, from the University of Birmingham, who has spent much of the past three years working to launch ACES. When I told him about my journeys alongside Rwanda's slowly broiling milk, fish, meat, and vegetables, he defined the problem in systemic terms. "There is no cold chain in Rwanda," he said. "It just doesn't exist."

In the developed world, the domestic refrigerator is only the final link in the "cold chain"—a series of thermally controlled spaces through which your food moves from farm to table. The cold chain is the invisible backbone of our food system, a perpetual mechanical winter that we have built for our food to live in.

Artificial refrigeration was introduced in the United States in the second half of the nineteenth century, but the term “cold chain” gained currency only in the late nineteen-forties, when European bureaucrats rebuilding a continent shattered by war studied and copied American methods.

Today, in the United States, a green bean grown in, say, Wisconsin will likely have spent no more than two hours, and often much less, at temperatures above forty-five degrees on its way to your fork. As soon as it is harvested, it is rushed to a packhouse to have its “field heat” removed: it is either run through a flume of cold water, known as a hydrocooler, or put in a forced-air chiller, where a gigantic fan pushes refrigerated air through stacked pallets of beans. These processes “pre-cool” the bean, lowering its internal temperature from more than eighty degrees down to the low forties in just a couple of hours. After that, a bean can happily hang out in cold-storage facilities, travel in refrigerated trucks, and sit on chilled supermarket shelves for up to four weeks without losing its snap.

The cold chain is more than the sum of its parts. What if the tepid cold-storage room I saw in Rulindo had been running at the correct temperature, in the low forties? Without the rest of the cold chain in place, the benefits would be marginal. In a forty-degree storage room, a bean takes about ten hours to reach the same temperature that pre-cooling achieves in just two. And in the



whole of Rwanda there is only one forced-air chiller. It's at a government export facility near the airport in Kigali and is almost never used, because it costs too much to run.

For the green bean, the difference between being chilled in two hours and in ten is absolute. Fruits and vegetables are still alive, metabolically speaking, after they are harvested. A bean cut off from the support of its parent plant will start to consume itself, and the hotter the temperature the faster it does so. Any perishable fruit or vegetable that is not cooled within a few hours of harvest will have already burned through much of its bounty of complex sugars, chlorophyll, Vitamin C, and other nutrients. It will be shrivelled and yellow-tinged, having lost a tenth of its weight in water alone. And, in its weakened state, it will then likely succumb to microorganisms that cause rot and disease.

“The integrity of the cells starts to be compromised and they break, and then the enzymes are, like, *Wahey! Happiness!*” Natalia Falagan, one of ACES' co-designers, told me. “And, as soon as there is softening in the tissue, then the bacteria and fungi will think, *Oh, now it's my time!*” We met in her lab at Cranfield University, in the U.K., where we conversed surrounded by racks of rotting fruit and vegetables, hooked up to sensors and monitors like critically ill patients in an I.C.U. A cold-storage room, she confirmed, is of little use without pre-cooling. “And then farmers will say temperature-controlled rooms don't work,” Falagan

lamented. “No! It’s that the fruit you put in there is already mush.”

Quite aside from the long-term costs of such spoilage in terms of health and nutrition, there is also an immediate economic impact on the prices that farmers can charge for their harvest. Given that produce is sold by weight, diminished water content immediately reduces earnings and, if quality falls below a certain level, the vegetables will no longer be export-grade and must instead be sold locally, at a discount of about ten cents on every pound. The consequences are even more dire for unrefrigerated milk and flake-ice-deprived fish: on average, thirty-five per cent of the milk painstakingly gathered on bicycles by people like Pierre Bizimana is sufficiently spoiled by the time it reaches the country’s dairy-collection centers that it fails quality-control tests and is rejected outright. Meanwhile, unsold, uniced fish is typically offloaded to Congolese traders for pennies on the dollar at the end of the day. Between thirty and fifty per cent of all food produced in developing countries is lost—discarded, unsold and uneaten, thanks to weak or nonexistent cold chains. For farmers surviving on less than a couple of dollars a day, the effect of these losses is substantial; for sub-Saharan Africa as a whole, they are estimated to add up to hundreds of billions of dollars each year.

**B**ecause the ACES team was assembled during the COVID-19 era, many of its members had not met in person until this May, when Rwanda hosted a U.N.-sponsored forum on



sustainable energy, which showcased ACES, among other initiatives. When President Kagame gave an opening address to the forum's delegates—an international assortment of politicians, civil servants, aid workers, entrepreneurs, and academics—ACES served as his example of Africa's potential for insuring sustainable, equitable development globally. "I was in the room, and I felt like jumping out of my chair," said Juliet Kabera, the ranking Rwandan member of the team, who also heads up the country's Environment Management Authority.

ACES was to host an open day for delegates at its new campus at the culmination of the forum. The weekend before, I accompanied the team on a tour of Rwanda's existing refrigeration infrastructure. Because of the pandemic, some of the Europeans were making their first visit to a country whose assets and needs they had been studying for three years. Our first stop was a pair of cold-storage rooms built with European Union funding, in 2019, thirty miles south of Kigali, on the road to Tanzania. A member of a local farming coöperative walked us over to a low-slung brick structure; inside, the first things that caught my eye were cobwebs lining the walls. One of the rooms was not functioning, our guide said; the other contained two lonely crates of chili peppers, and the cooling seemed to have been switched on purely in honor of our visit. The spotlessly clean floor certainly did not suggest frequent use. It was also made of wood, a poor choice of material because it

is hard to sanitize, so any squashed produce lingers, providing a perfect substrate for fungi and bacteria to grow. Judith Evans, one of the world's leading refrigeration experts, quietly pointed out other design flaws, including the lack of an air curtain at the door, as well as dozens of nails driven through the walls, which would allow heat to bypass the insulation.

"I'm freaking out about this," Falagan whispered, as the farmer described how the room worked. "There's no humidity control, no fans for air circulation!" While the team quizzed the unfortunate farmer, I stepped outside and wandered around the corner to see other members of the coöperative loading crates of chilis that had been stored outdoors, under an open-walled shade structure, into the back of a pickup truck. Later, Issa Nkurunziza, a Kigali-based cold-chain expert with the U.N. Environment Programme, told me that the farmers had confessed to him that the refrigeration unit was simply too expensive for them to run.

Since 2015, when the United Nations issued a call to halve per-capita global food loss by 2030, N.G.O.s, overseas-development agencies, and philanthropic foundations have rushed to fund refrigeration projects in the developing world. "But people don't understand how to use it," Evans told me. "It's generally not well maintained or serviced." Cold storage alone, without training and a viable business model, risks becoming a white elephant. The World Bank, which has funded ten cold-storage rooms in Rwanda in the past few years, has estimated that at least ninety-six per cent

of nearby farmers don't use them at all.



*"I've made peace with my demons."*



Cartoon by P. C. Vey

Such largesse can also trigger unintended consequences. Catherine Kilelu, a food-security researcher in Kenya who is leading the development of an ACES-backed cooling hub there, told me that.

in one remote community, there was some evidence that the quality of children's diets diminished after the Bill and Melinda Gates Foundation helped fund chilling plants as part of a larger investment in commercializing the country's dairy industry. Previously, Kilelu explained, the yield from evening milking sessions was consumed at home rather than being taken to market. Once a dairy farmer was able to keep this milk salable overnight, however, that source of nutrition disappeared. "You might think, Well, if they make more money, they can spend that on feeding their kids, but that's not necessarily the case," she said. "People use it to repair their roofs or buy smartphones or other things they need."

Later on, we visited a far more well-resourced facility, a packhouse run by Rwanda's National Agricultural Export Development Board, but here a different kind of problem was evident. The facility, built in 2017 with World Bank assistance, was stuffed with plastic crates full of vegetables, stacked twelve-high to the ceiling. "Right now, it's just big enough, but, with the production plan we have, in six months it will not be," Innocent Mwalimu, a soft-spoken cold-chain specialist, said, as he showed us around. As Rwanda emerges from COVID-19, it faces a spiralling balance-of-payments deficit, and the government has set a target to double the country's perishable exports by 2025. By way of stimulus, companies that use the packhouse are charged less than seven



cents per kilo exported, effectively subsidizing the cold chain for agribusiness entrepreneurs. Similar models have been pioneered successfully in Kenya—to the extent that, recently, fruit, vegetable, and cut-flower exports overtook the traditional mainstays of tea, coffee, and tourism to become the largest source of overseas revenue for the Kenyan government.

The downside is that the benefits of this kind of cold-chain investment are not distributed equally. In Kenya, one study found that three-quarters of the country's fruit and vegetable exports are sourced from just seven large, mostly white-owned farms, because they have the capital and the resources to implement stringent international food-safety standards and are perceived as easier to work with and audit. Even companies specifically founded with a mission to install off-grid, affordable cooling systems to reduce post-harvest losses and support rural communities have found it challenging to work with Kenya's smallholder farmers. "From an economics point of view, you're forced into bigger systems to make it work," Julian Mitchell, the C.E.O. of one such company, InspiraFarms, told me. "And that excludes the poorest of the poor"—the farmers who grow more than ninety per cent of Kenya's fruit and vegetables, who are left losing half of everything they harvest.

The primary difficulty, as Selçuk Tanatar, the principal operations officer at the World Bank's International Finance Corporation, explained to me, is that operating a cold chain costs the same, if

not more, in Nairobi as it does in New York City: five to fifteen cents per kilo of produce. In other words, refrigeration adds about one per cent to the cost of a tomato in the developed world, but about thirty per cent to its cost in the developing world. “Nobody is going to pay that,” Tanatar said. As a result, the financially viable way to build a cold chain is to work with farmers who grow fruits and vegetables that the developed world wants—blueberries, mangoes, French beans. “But then it doesn’t really help the local people with food security,” Tanatar continued. “You’re just getting cheaper and better products to the developed market.”

In Rwanda, six million people—nearly half the population—are small-scale farmers, tending an average of less than an acre and a half of land. A solution that does not work for them is not much of a solution at all: a trickle-down cold chain in which the rich grow richer, the poor become poorer by comparison, and, all the while, the former colonists enjoy cheap superfood smoothies.

**I**n March, 2021, a small, peculiar-looking truck began transporting fruit and vegetables from fields to markets in western Rwanda. From the front, the truck resembles a tank, wider and squatter than you’d expect, and oddly square. It looks the way you might imagine a truck from IKEA to look, and in a sense that’s what it is. The cab is made of lightweight wood-composite panels that can be shipped in flat packs and then assembled in a day,

without any special tools. Named the OX, the truck was developed in England specifically for emerging markets. It's about half the weight of a standard pickup but able to carry double the load. The windshield and the skid plate meet at a snub-nosed angle, which means that its tires hit steep slopes before the bumper does, and that it can ford streams that are up to thirty-five inches deep—both essential for negotiating Rwanda's many severely rutted unpaved roads.

Francine Uwamahoro, OX's managing director for Rwanda, introduced me to a woman with short, orange-dyed hair named Louise Umutoni, saying that she was the company's best driver. "New customers are surprised," Umutoni said. "They don't believe their truck driver is a woman." She took me for a ride as she made her rounds of local farmers. Rwandan roads make for a bone-jarring experience that several drivers described to me as "an African massage." As we drove, Umutoni fielded customer calls on her mobile. The demand for OX trucks is so high that the company currently has to turn down eight in ten requests for transportation.

OX's global managing director, Simon Davis, who left Jaguar Land Rover to take the job, told me that, as innovative as the truck's design is, the secret to its success is the company's business model—the cargo equivalent of a bus service. Most prospective customers can't afford to buy a truck, but they can afford to rent space in a truck operated by OX. "We built our first business

model around fifty dollars a day in revenue, total,” Davis said. “On our best day so far, we’ve earned two hundred and twenty dollars from a single truck.”

Umutoni’s first customer of the morning was a woman waiting by the side of the road with several baskets of green bananas that she wanted us to take to the nearest city, twelve miles away. She told me that, though OX’s rates are higher than those of the men with bicycles, the increased cost is more than covered by the additional income she can make by getting more produce to market faster. Her only complaint about OX was that sometimes when she called there wasn’t any space left in the truck; she wanted to start selling to Congolese traders and expand her business further, but first she had to be sure that transportation would be available.

Almost as soon as the first OX truck started rolling around Rwanda, the company began thinking about the next iteration. It sought feedback from drivers like Umutoni. One thing she asked for was better visibility. In rural Rwanda, the roadside is a busy place: goats graze, women sell fruit and vegetables, and children run back and forth, kicking footballs made from inflated condoms wrapped in banana leaves. The new model, which is still at the prototype stage, is, Davis said, “a bit like driving a conservatory.” More important, OX 2.0 is an electric vehicle—its predecessor was diesel—and, as an optional extra, it will be available with a solar-powered refrigeration unit. It thus goes some way toward meeting

the need that Innocent Mwami and Delçuk Tanatar had pointed out to me: a cold chain with lower operating expenses. OX can power its new truck for less than half the cost of the first-generation diesel prototype.

“For me, having given up on cold chain, these technologies that can get the operating expenses down—they mean that it’s going to maybe be a different story now,” Tanatar told me. He noted that part of the value of ACES will be in providing a venue to showcase innovations like this to Rwandan farming coöperatives, entrepreneurs, and trainee technicians. When ACES held its open day in Kigali, an OX truck was parked prominently out in front.

The ACES campus currently consists of several single-story brick buildings set around a central lawn filled with mauve-flowered jacaranda trees. These will serve as classrooms for teaching future refrigeration technicians. Qualified technicians are in such short supply that, when the flake-ice machine I saw in Rusizi breaks down, a mechanic has to be summoned from Uganda to repair it. At the northern edge of the twelve-acre site are a handful of cottages: some are to be office space for refrigeration companies, both local startups and established international corporations; others will provide student housing and a day-care center, intended to encourage female students to train as technicians and entrepreneurs. To the west, land has been set aside for the next phase in ACES’ development: a smart farm, to study how pre-harvest treatments affect post-harvest quality, and



also to test novel field pre-cooling equipment.

Rwanda is full of would-be food, agribusiness, and technology entrepreneurs. Africa's "youth bulge" means that young Rwandans are continually warned that there will probably not be jobs waiting for them upon graduation, and that they should be prepared to create their own. It seemed as though on any street corner in Kigali one could encounter someone like Donatien Iranshubije, a confident and prepossessing twenty-one-year-old wearing a crisp button-down shirt accessorized with a thin gold chain. Iranshubije co-founded a startup that offers next-day delivery of fresh fruit and vegetables from rural farming coöperatives to two dozen Kigali families. At the moment, he told me, the company gets around the need for refrigeration by using motorbike couriers to move the food fast, but, as the business expands, he expects to invest in cold storage. For him, as for thousands of others, refrigeration is a prerequisite for growth. The challenge for ACES is to insure that the urgent need for cold chains in countries like Rwanda is met in a sustainable fashion.

Cold chains present a double bind; both their absence and their presence have huge ecological costs. The U.N. Food and Agriculture Organization estimates that if global food waste were a country its greenhouse-gas emissions would be the third largest in the world, right behind China and the U.S. On the other hand, the chemical refrigerants and the fossil-fuel energy used to

produce cooling already account for more than seven per cent of global emissions—just one per cent less than food loss. As countries like Rwanda refrigerate, those emissions are increasing rapidly. Toby Peters, the ACES co-founder, has done the calculations and arrived at a terrifying conclusion: if every country were to have a cold chain similar to the ones the developed world relies on, these emissions would increase fivefold. Seen from that perspective, helping Rwanda develop an energy-efficient cold chain looks less like altruistic development aid and more like enlightened self-interest.

In development literature, much has been made of Africa's ability to "leapfrog" richer countries. In Rwanda, a country in which a national network of telephone cables was never laid, cell phones became central to daily life far more quickly than in the U.S. The same is true for mobile banking and electronic payments. The hope, then, is that Rwanda and its neighbors can do something similar with refrigeration, bypassing inefficient and polluting technologies in favor of more sustainable solutions and leading the way for supposedly developed countries.

Not only is the way food is refrigerated in the developed world not sustainable; the resulting supply chain isn't even particularly resilient, as the sight of empty supermarket shelves during the past couple of years has revealed. Meanwhile, the food losses that plague the developing world occur at almost the same rate in the developed world. In the United States, where maintaining the cold

chain is the domain of private enterprise, between thirty and forty per cent of the country's food supply goes to waste in supermarkets, at restaurants, and at home. Leapfrogging in refrigeration will require more than adopting new technology; the cold chain needs to be reinvented from the ground up.

The more time I spent with the ACES team, the more acutely I felt both their excitement and their anxiety about Rwanda's unbuilt cold chain: get it right, and enter a promised land of food security, prosperity, and sustainability; fail, and wave goodbye to a livable planet, while accelerating inequality and exacerbating hunger. "These are the kind of problems that hadn't really even been recognized as problems or challenges before—they were just consequences," Philip Greening, another member of the ACES team, told me. Greening is currently constructing a computer model of Rwanda—a digital twin in which all the possible variants for preserving and moving its food can be implemented, costed, and evaluated, in order to answer such pressing and essential questions as: Where should cooling hubs be placed to be most useful for the communities that need them the most? What will happen if, as currently planned, slaughterhouses are built in rural areas, so that the live chickens I saw, transported on bicycles and slaughtered at home, are replaced by carcasses that need to be moved, stored, and sold under refrigeration? How will exporting ten per cent more fresh produce affect a farming family's

nutritional and economic status? Is it worth improving the road network before investing in farm-level pre-cooling facilities?

The use of computer modelling to make such decisions is new, and there are limitations. Inevitably, there will be simplifications, and some data are likely to be unobtainable. And, of course, humans remain somewhat unpredictable. During the COVID-19 pandemic, Greening and Peters, realizing the importance of the cold chain in delivering vaccines, worked with the Bangladeshi government to figure out the most effective possible allocation of the country's refrigerated assets. But Bangladesh's actual vaccination campaign departed significantly from the model's recommendations, as Greening ruefully explained. "In the end, the challenge wasn't so much 'Can we get the vaccine to the right places?' as 'Can we get people to want to be vaccinated?'"

Meanwhile, in Rwanda, as Alice Mukamugema, an analyst at the country's Ministry of Agriculture, pointed out to me, consumers believe that refrigerated food isn't fresh. (Americans in the early twentieth century expressed similar fears.) "Traders who sell the rejects from the National Agricultural Export Development Board packhouse on the local market even have to put them in the sun for a while, so that they don't feel cold," she said.

**T**ate one afternoon, I had an appointment to see Christian

Benimana, a Kigali-born, Shanghai-trained architect who has been working with ACES on the design of its campus. I'd been riding in cars and trucks all week, so I decided to walk to his office, an hour and a half across Kigali from my hotel. Since the Rwandan genocide, the city's population has exploded, growing from just under three hundred thousand people in 1994 to more than 1.2 million today, but its streets are surprisingly quiet, lacking the chaotic energy of most cities in the developing world. The city is so hilly that all but the poorest people make even short journeys on one of its ubiquitous motorcycle taxis, so for stretches of the walk to Benimana's office I was the only pedestrian.

The lack of bustle on the streets seemed boring at first but gradually became its own source of fascination. The sidewalks were spotless (plastic bags have been banned since 2008), women in high-visibility vests weeded perfectly groomed flower beds and median strips, and there was not a single homeless person to be seen. (The homeless are reportedly moved to what the Rwandan government refers to as "rehabilitation transit centers," but which Human Rights Watch calls prisons.) Between anonymous glass office buildings and tidy single-story houses, there were huge expanses of open space: a flock of ibises screeched from an enormous tulip tree; an African spoonbill waded on fuchsia legs along the edges of a muddy river; birds of prey circled above me, riding thermals. Only the smells—sooty diesel fumes and the smell of hot bodies crammed together on bicycles and moto-taxis



at every intersection—reminded me that I was in a desperately poor country.

Benimana, a reserved but commanding forty-year-old man, told me that, in 2007, the Rwandan government announced a visionary master plan to transform Kigali into “an important center of stability and development for the entire continent of Africa.” It quickly became clear that the plan was seriously flawed, and there was a public outcry. But the government, rather than pressing on regardless or just giving up, took stock of the complaints and produced a major revision of the plan, which it has since continued to update and implement with considerable success. Some of the results can lack character, Benimana admitted—the city center is a giant roundabout, and its new hotels, malls, and industrial zones are a series of generic boxes—but other aspects are impressive. Wetlands take up a quarter of Kigali’s surface area and they are now protected habitats—a distinct improvement on the glorified sewers that the rivers of London and Los Angeles became as those cities urbanized.

“After the genocide, the process of rebuilding was not optional,” Benimana said. “And the decision was made early on to set the bar really high—to see whether we can solve some of the structural, societal problems that we have, and to become a place that people can learn from.” For Benimana, the ambition of ACES is entirely in

keeping with his country's embrace of experimentation and innovation. "We are able to dream things that are beyond what is imaginable, and then act on them," he told me. "Or at least try." ♦

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