CAN **COAL** EVER BE CLEAN? | FOUND IN FRANCE: **A ROMAN BOAT**

APRIL 2014

NATIONAL GEOGRAPHIC

Wild Pets

THE DEBATE OVER
OWNING EXOTIC ANIMALS


8:45 p.m., January 20, 2014
Rio de Janeiro, Brazil
Shot with the Nokia Lumia 1020

NOKIA

Telling Rio's story like never before.

"Every day on this assignment, I woke up astounded that a place this beautiful could be real. Soccer isn't all that will amaze people in Rio this year. The Harbor is the world's largest bay; mountains rise up all around it; and wedged right between is the spectacular city. Easy to see why it's one of the Seven Natural Wonders of the World, and once again, the Nokia Lumia 1020 let me explore and shoot in a whole new way. In fact, I look at my images and can't believe they were all shot with a smartphone.

The Lumia 1020 is an absolutely incredible low-light camera. The details it captures, like the sparkling lights in this nighttime image, astonish me. I used the 1020 just like a DSLR camera, shooting aerials, action, in all kinds of light with fantastic quality. I just can't believe the pictures—and I took them!"

—Stephen Alvarez, National Geographic photographer

NOKIA LUMIA 1020

Follow my journey through the
Seven Natural Wonders of the World at
nationalgeographic.com/nokia.

NATIONAL GEOGRAPHIC
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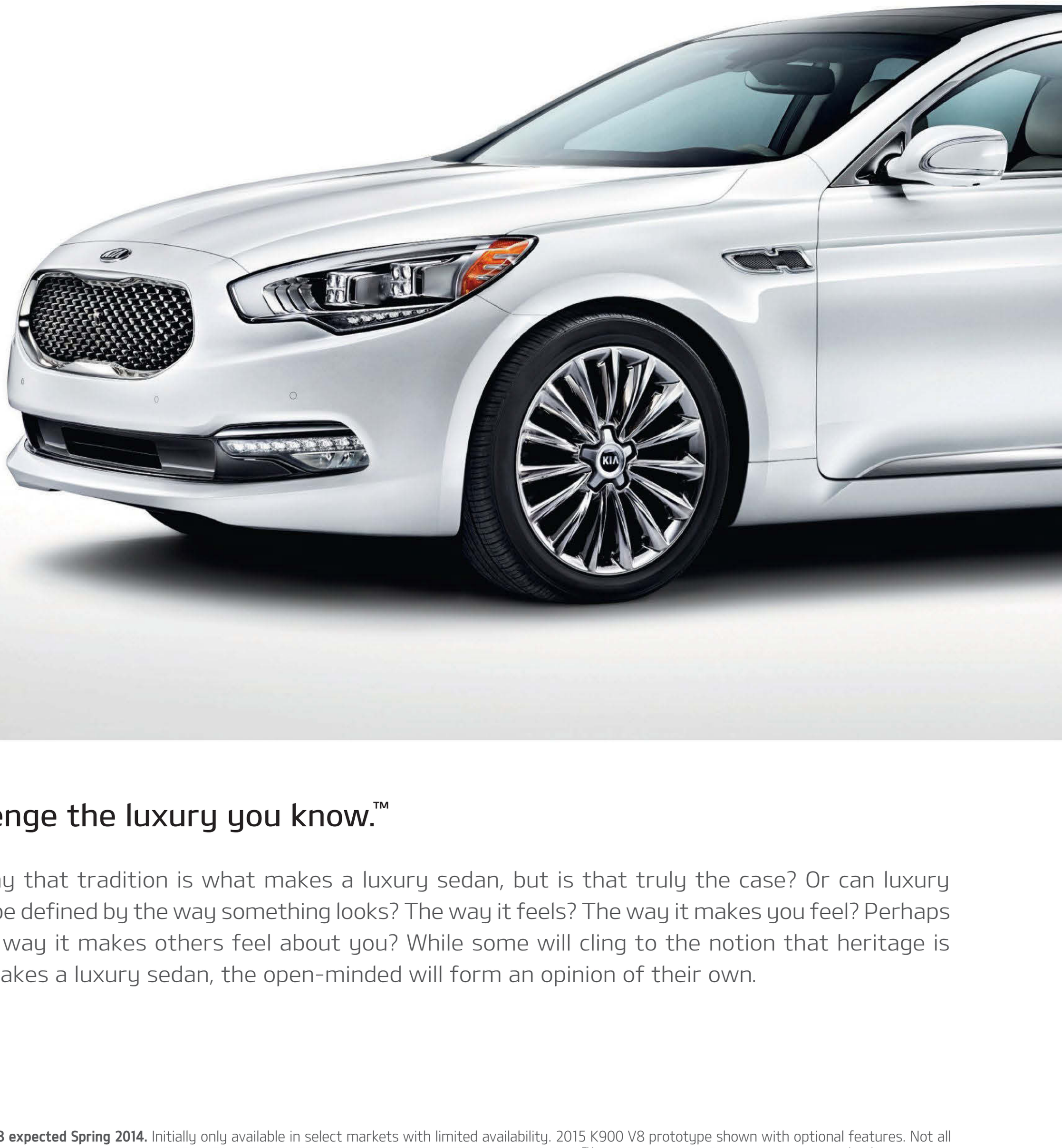
PHOTOGRAPHY | MOTION | TALENT

Introducing the K900, from Kia.



Challenge the luxury you know.™

They say that tradition is what makes a luxury sedan, but is that truly the case? Or can luxury simply be defined by the way something looks? The way it feels? The way it makes you feel? Perhaps it's the way it makes others feel about you? While some will cling to the notion that heritage is what makes a luxury sedan, the open-minded will form an opinion of their own.

2015 K900 V8 expected Spring 2014. Initially only available in select markets with limited availability. 2015 K900 V8 prototype shown with optional features. Not all features are available on all trim levels. THE MATRIX, THE MATRIX RELOADED, THE MATRIX REVOLUTIONS: ™ & © Warner Bros. Entertainment Inc. (s14)

kia.com/K900

KIA

White-footed Tamarin *(Saguinus leucopus)*
Size: Head and body length, 22 - 29 cm (8.7 - 11.4 inches); tail, 35 - 42 cm (13.8 - 16.5 inches) **Weight:** Approx. 462 g (16.3 oz) **Habitat:** Secondary and successional lowland and pre-montane rainforest **Surviving number:** Unknown

Photographed by Cyril Ruoso

WILDLIFE AS CANON SEES IT

Look who's moving in. Some groups of white-footed tamarins have moved from their forest habitat to suburban gardens that offer orchards and small patches of forest. In their new neighborhoods, they don't have to range as far to satisfy their craving for fruit, a staple they supplement with insects, frogs and lizards. To keep mothers from being weighed down with their twins when foraging, other group members help carry the youngsters. But with forests vanishing around them and limited vacancies in the suburbs, how long can this tamarin carry on?

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.


EOS System

Canon

VOL. 225 • NO. 4

NATIONAL GEOGRAPHIC

The Romans had a serious trash problem, though it was good-looking trash.
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ROBB KENDRICK

The Shentou Number 2 power plant spews fly ash and coal dust over the countryside near Shuozhou, China. The coal-fired plant provides electricity to Beijing.

April 2014

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We burn eight billion tons a year. Demand is surging. The challenge: control the carbon pollution.
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When a star is born, the best way to take a look is with ALMA, the gigantic new telescope in Chile.
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Have you ever tried to climb into a tiny car with a 13-inch-tall column of lace on your head?
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Owners love their pet chimps, tigers, bears. Critics say it's dangerous and cruel.
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The muddy Rhône River is full of surprises: statues, luxury goods, a 102-foot-long Roman boat.
By Robert Kunzig Photographs by Rémi Bénali

April 2014

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A Veil of Eggs
The monkfish lays a million at a time, protected by a floating, gauzy film.

Commuter Science
A city-by-city breakdown of hours lost

Gallery of Gardens
Artist Fritz Haeg has helped 15 families turn their lawn into a work of art.

Reunited After 163 Years
A newfound ancient turtle bone matches up with a specimen from 1849.

Block That Meteorite
Early warnings could keep us safe.

Soylent on Rye
It's a synthesized food that does not depend on agriculture.

Sugar Solution
Fructose plus water can make tissues transparent for a clear view of organs.

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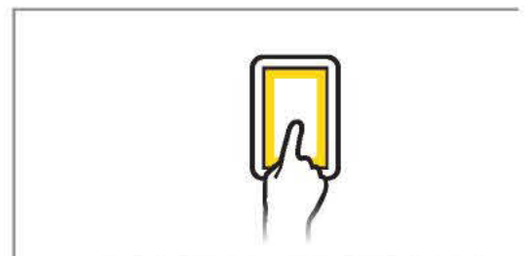

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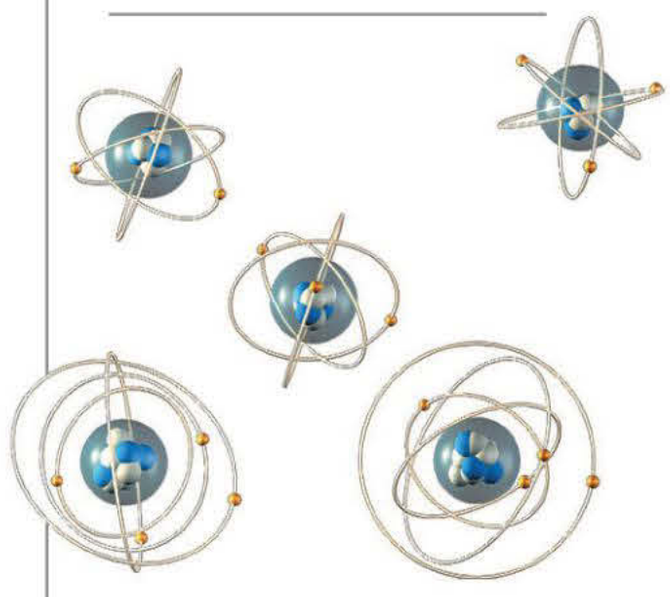
National Geographic is available on the iPad, the Kindle Fire, and the iPhone.



Cosmic Dawn
Interactive
Experience the expansion of the universe.

Deer in the Home Lights
Video
Dillie the blind deer tours her domestic digs.

On the Cover Jade the hedgehog was nearly 11 months old (and 16½ ounces) when she was photographed. South Carolinian Brandon Harley uses her as a breeder in his pet business. *Photo by Vincent J. Musi*

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The Bear in the Backyard

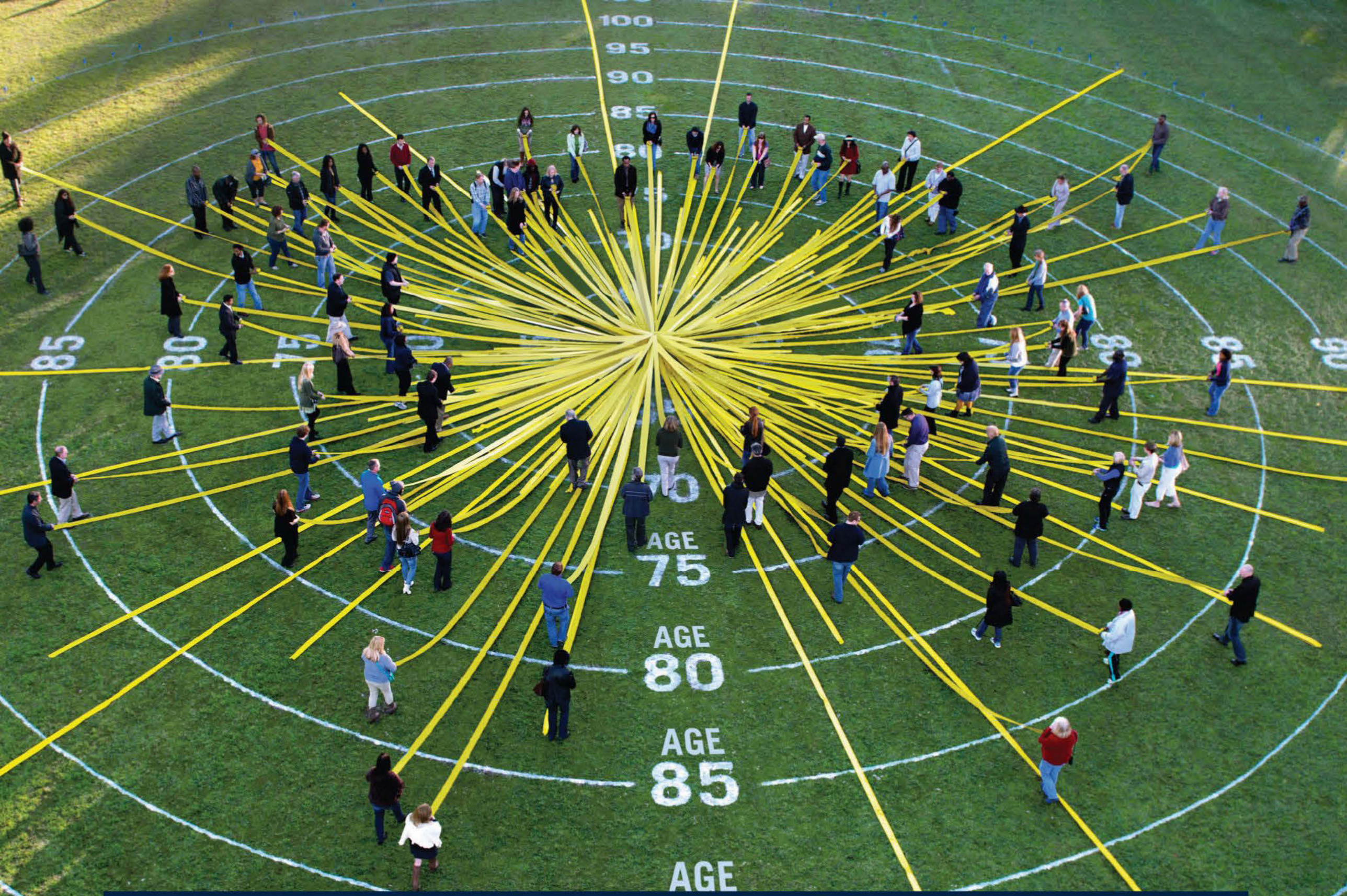
About 15 years ago I had an assignment to photograph wild dogs in Botswana's Okavango Delta. A pack had hunted down an impala and dragged the carcass near my Land Rover. I crawled under the vehicle so I would be as inconspicuous as possible while photographing the scene, but an adult male trotted over to me, sniffed my face, and started tugging at my leg. I stayed absolutely still, heart racing, hardly breathing. It was an intimate encounter with one of Africa's most endangered carnivores but was completely on the animal's terms, not mine.

Turning a wild animal—a lion, a lemur, a bear—into a pet creates a different dynamic. The relationship exists on the terms of the human owner, and I question the wisdom of that for both sides. In this month's story on exotic pets, writer Lauren Slater and photographer Vince Musi take us into living rooms and backyards shared with animals whose natural habitats lie far from the suburbs. Undoubtedly, their owners feel an attachment no less profound than what you or I feel for the domestic dogs and cats in our lives. "All my life people have let me down," a woman who keeps three kangaroos told Slater. "My animals never have."

It's said that the morality of a nation can be judged by the way it treats its animals. But treatment is not just a matter of providing food, shelter, and care. It's whether the animal in question ought to be a pet at all.

Boo Boo lived in John Matus's Ohio backyard for nine years before her relocation to a Colorado sanctuary in 2013. "I miss her a lot," says Matus, who raised her from a cub.

PHOTO: VINCENT J. MUSI



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Inspiring people to care about the planet

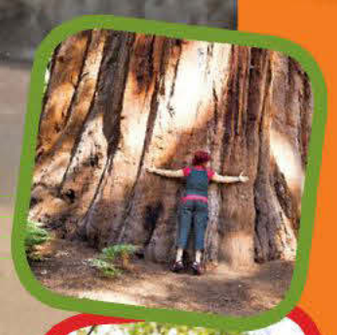
The National Geographic Society is chartered in Washington, D.C., as a nonprofit scientific and educational organization "for the increase and diffusion of geographic knowledge."

Coulda, Woulda, Shoulda

As we all know you're only young ONCE. If you do the math, that means about 6,570 days from the time you're born until you're considered an adult. So help the young people in your life do as much fun, cool stuff as they can while they're still KIDS. These two amazing books are packed with hundreds of creative ideas on how kids can best spend their oh-so precious leisure time.

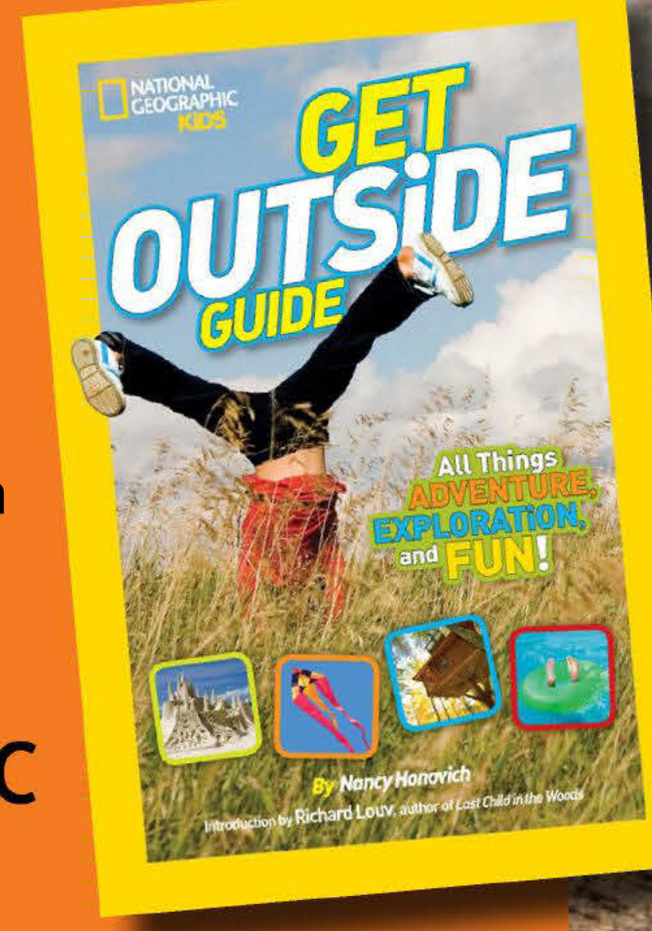
For starters...

- Learn how to take a great photo
- Build a fort
- Canoe, kayak, or float down a river



The sky's the limit...

- Explore a national park
- Make a telescope
- Build a solar oven



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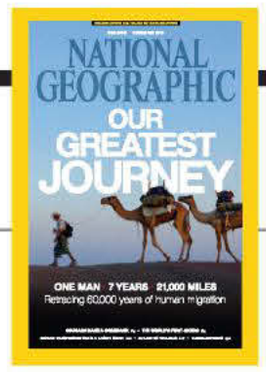

Our Greatest Journey

On my wall I have a Buckminster Fuller Dymaxion map of the world. Many times I have gazed into it, fantasizing about (someone) taking the walk from the southern tip of Africa to the southern tip of South America. Given the right weather conditions, even the small gap between Cape Dezhneva in Russia and Cape Prince of Wales in Alaska could perhaps be crossed. I'm really looking forward to finally taking that walk, albeit from the comfort of my armchair, thanks to the next seven years of what I'm sure will be adventurous reporting from Paul Salopek.

GEOFF SYKES
Eagle Rock, California

Paul Salopek has the eye of an artist, the insight of a philosopher, and the candor of a poet. What better way to understand what it means to be human than to walk among us?

MARTIN LEIF
Roswell, New Mexico

From the first time I sang "It's a Small World" as a Brownie, I have tried to remember that we are all in this together. I will be interested not only in the geographic journey and the physical wonders this man will see but also in his discovery of the many ways we human beings are alike and connected. Wow. What a ride!

LYNNE MILFORD
Fort Worth, Texas

Tumbleweeds

When I was a child growing up on the northern edge of the San Fernando Valley, tumbleweeds were playthings. We chased them when the Santa Ana winds blew and watched them jump down our dirt road and pile up against the fences. When the wind stopped, we built forts and houses out of them in the field next door. At Christmas my mother always used three to make a snowman and painted it white. It was the closest we'd get to snow. But my father always yelled at us when we'd pull a tumbleweed over the fence and into our yard. Now I know why.

JAN GANDY
Palo Cedro, California

This article was an eye-opener. Although I've lived in the West nearly all my life, I had never learned that tumbleweeds were an invasive species. Kudos to author George Johnson and your magazine for an article that had the perfect blend of history, science, sci-fi thriller, and sardonic wit.

MARIE KEEHN
Discovery Bay, California

Corrections

DECEMBER 2013, "ENGLISH BY THE BOOK" The catalog of the history of words referenced on page 60 was begun in 1857, not 1859.

FEEDBACK *Readers sent in word of suspected cougar sightings around the U.S.*

EMAIL comments to ngsforum@ngm.com; for subscription help, ngsline@customersvc.com. **TWITTER** @NatGeoMag
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ART: KIRSTEN HUNTLEY

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LETTERS

First Skiers

I already knew the fate of the two bull elk before I finished reading. Any wildlife biologist can tell you that the stress brought on by such an exhausting ordeal doomed the elk even before they were freed. The wolves only made quick work of what were already near-dead beasts.

RUFUS BAUR
Council, Idaho

Ghost Cats

I was thoroughly enjoying the article on cougars, until I read the claim that California has "an abundance of deer" and "one of the lowest rates of cougar conflicts with humans." Though the golf course at Pebble Beach may have an abundance of deer, populations in northeast counties and the Sierra Nevada have been decimated. I live in Shasta County, in the heart of the deer's winter range, and it is all too easy to find a fresh kill. Livestock depletion must not count as "conflict with humans" either, because we sure have a lot of dead sheep gone to feed cougars.

LAWRENCE J. RIVARD
Falls River Mills, California

Those mountain lions (we still call them mountain lions where I live) crossing the meadow were photographed near my home. The comeback is a heartwarming story to some. But to others it is simply the return of a serious competitor.

JEFF VAN FLEET
Kalispell, Montana

As an active hunter, conservationist, and pragmatist raised in the American West, I was encouraged to read about the rebound of the cougar and the science behind it. Now attention needs to be turned to repatriating and managing another of our long-neglected apex predators: the jaguar.

JARED ZAUGG
Sandy, Utah

For patients 12 years and older whose asthma is not well controlled on a long-term asthma medicine or whose disease severity warrants

IF YOU THINK ASTHMA "COMES AND GOES" THINK AGAIN.

IT'S MISUNDERSTOOD.
ASTHMA DOESN'T COME AND GO.
Inflammation, the root cause of asthma, is always there, making you more vulnerable to triggers. So, while it's important to avoid triggers, it's also important to treat this inflammation. SYMBICORT helps reduce that underlying inflammation, which can mean improved lung function, and better breathing all day and night, when taken twice daily. Once your asthma is well controlled with SYMBICORT, your doctor may switch you to a long-term asthma control medicine such as an inhaled corticosteroid.

Ask your doctor about SYMBICORT.

Important Safety Information About SYMBICORT

SYMBICORT contains formoterol, a long-acting beta$_2$-adrenergic agonist (LABA). LABA medicines such as formoterol increase the risk of death from asthma problems. It is not known whether budesonide, the other medicine in SYMBICORT, reduces the risk of death from asthma problems seen with formoterol.

- **Call your health care provider if breathing problems worsen over time while using SYMBICORT. You may need different treatment**
- **Get emergency medical care if:**
  - o Breathing problems worsen quickly, and
  - o You use your rescue inhaler medicine, but it does not relieve your breathing problems

SYMBICORT should be used only if your health care provider decides that your asthma is not well controlled with a long-term asthma control medicine, such as an inhaled corticosteroid, or that your asthma is severe enough to begin treatment with SYMBICORT.

If you are taking SYMBICORT, see your health care provider if your asthma does not improve or gets worse. It is important that your health care provider assess your asthma control on a regular basis. Your doctor will decide if it is possible for you to stop taking SYMBICORT and start taking a long-term asthma control medicine without loss of asthma control.

Children and adolescents who take LABA medicines may have an increased risk of being hospitalized for asthma problems.

SYMBICORT does not replace rescue inhalers for sudden symptoms.

Be sure to tell your health care provider about all your health conditions, including heart conditions or high blood pressure, and all medicines you may be taking. Some patients taking SYMBICORT may experience increased blood pressure, heart rate, or change in heart rhythm.

Do not use SYMBICORT more often than prescribed. While taking SYMBICORT, never use another medicine containing a LABA for any reason. Ask your health care provider or pharmacist if any of your other medicines are LABA medicines.

SYMBICORT can cause serious side effects, including:

- **Pneumonia and other lower respiratory tract infections.** People with COPD may have a higher chance of pneumonia. Call your doctor if you notice any of the following symptoms: change in amount or color of mucus, fever, chills, increased cough, or increased breathing problems
- **Serious allergic reactions** including rash, hives, swelling of the face, mouth and tongue, and breathing problems
- **Immune system effect and a higher chance of infection.** Tell your health care provider if you think you are exposed to infections such as chicken pox or measles, or if you have any signs of infection such as fever, pain, body aches, chills, feeling tired, nausea, or vomiting
- **Adrenal insufficiency.** This can happen when you stop taking oral corticosteroid medicines and start inhaled corticosteroid medicine
- **Using too much of a LABA medicine** may cause chest pain, increase in blood pressure, fast and irregular heartbeat, headache, tremor, or nervousness
- **Increased wheezing** right after taking SYMBICORT. Always have a rescue inhaler with you to treat sudden wheezing
- **Eye problems including glaucoma and cataracts.** You should have regular eye exams while using SYMBICORT
- **Lower bone mineral density** can happen in people who have a high chance for low bone mineral density (osteoporosis)
- **Slowed growth in children.** A child's growth should be checked regularly while using SYMBICORT
- **Swelling of blood vessels** (signs include a feeling of pins and needles or numbness of arms or legs, flu like symptoms, rash, pain or swelling of the sinuses), decrease in blood potassium and increase in blood sugar levels

Common side effects in **patients with asthma** include nose and throat irritation, headache, upper respiratory tract infection, sore throat, sinusitis, stomach discomfort, flu, back pain, nasal congestion, vomiting, and thrush in the mouth and throat.

Approved Uses for SYMBICORT

SYMBICORT 80/4.5 and 160/4.5 are medicines for the treatment of asthma for people 12 years and older whose doctor has determined that their asthma is not well controlled with a long-term asthma control medicine such as an inhaled corticosteroid or whose asthma is severe enough to begin treatment with SYMBICORT. SYMBICORT is not a treatment for sudden asthma symptoms.

Please see full Prescribing Information and Medication Guide and discuss with your doctor.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch or call 1-800-FDA-1088.

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IMPORTANT INFORMATION ABOUT SYMBICORT

Please read this summary carefully and then ask your doctor about SYMBICORT.

No advertisement can provide all the information needed to determine if a drug is right for you or take the place of careful discussions with your health care provider. Only your health care provider has the training to weigh the risks and benefits of a prescription drug.

WHAT IS THE MOST IMPORTANT INFORMATION I SHOULD KNOW ABOUT SYMBICORT?

People with asthma who take long-acting beta$_2$-agonist (LABA) medicines, such as formoterol (one of the medicines in SYMBICORT), have an increased risk of death from asthma problems. It is not known whether budesonide, the other medicine in SYMBICORT, reduces the risk of death from asthma problems seen with formoterol.

SYMBICORT should be used only if your health care provider decides that your asthma is not well controlled with a long-term asthma control medicine, such as an inhaled corticosteroid, or that your asthma is severe enough to begin treatment with SYMBICORT. Talk with your health care provider about this risk and the benefits of treating your asthma with SYMBICORT.

If you are taking SYMBICORT, see your health care provider if your asthma does not improve or gets worse. It is important that your health care provider assess your asthma control on a regular basis. Your doctor will decide if it is possible for you to stop taking SYMBICORT and start taking a long-term asthma control medicine without loss of asthma control.

Get emergency medical care if:

- breathing problems worsen quickly, and
- you use your rescue inhaler medicine, but it does not relieve your breathing problems.

Children and adolescents who take LABA medicines may be at increased risk of being hospitalized for asthma problems.

WHAT IS SYMBICORT?

SYMBICORT is an inhaled prescription medicine used for asthma and chronic obstructive pulmonary disease (COPD). It contains two medicines:

- Budesonide (the same medicine found in Pulmicort Flexhaler™, an inhaled corticosteroid). Inhaled corticosteroids help to decrease inflammation in the lungs. Inflammation in the lungs can lead to asthma symptoms
- Formoterol (the same medicine found in Foradil® Aerolizer®). LABA medicines are used in patients with COPD and asthma to help the muscles in the airways of your lungs stay relaxed to prevent asthma symptoms, such as wheezing and shortness of breath. These symptoms can happen when the muscles in the airways tighten. This makes it hard to breathe, which, in severe cases, can cause breathing to stop completely if not treated right away

SYMBICORT is used for asthma and chronic obstructive pulmonary disease as follows:

Asthma

SYMBICORT is used to control symptoms of asthma and prevent symptoms such as wheezing in adults and children ages 12 and older.

Chronic Obstructive Pulmonary Disease

COPD is a chronic lung disease that includes chronic bronchitis, emphysema, or both. SYMBICORT 160/4.5 mcg is used long term, two times each day, to help improve lung function for better breathing in adults with COPD.

WHO SHOULD NOT USE SYMBICORT?

Do not use SYMBICORT to treat sudden severe symptoms of asthma or COPD or if you are allergic to any of the ingredients in SYMBICORT.

WHAT SHOULD I TELL MY HEALTH CARE PROVIDER BEFORE USING SYMBICORT?

Tell your health care provider about all of your health conditions, including if you:

- have heart problems
- have high blood pressure
- have seizures
- have thyroid problems
- have diabetes
- have liver problems
- have osteoporosis
- have an immune system problem
- have eye problems such as increased pressure in the eye, glaucoma, or cataracts
- are allergic to any medicines
- are exposed to chicken pox or measles
- **are pregnant or planning to become pregnant.** It is not known if SYMBICORT may harm your unborn baby
- **are breast-feeding.** Budesonide, one of the active ingredients in SYMBICORT, passes into breast milk. You and your health care provider should decide if you will take SYMBICORT while breast-feeding

Tell your health care provider about all the medicines you take including prescription and nonprescription medicines, vitamins, and herbal supplements. SYMBICORT and certain other medicines may interact with each other and can cause serious side effects. Know all the medicines you take. Keep a list and show it to your health care provider and pharmacist each time you get a new medicine.

HOW DO I USE SYMBICORT?

Do not use SYMBICORT unless your health care provider has taught you and you understand everything. Ask your health care provider or pharmacist if you have any questions.

Use SYMBICORT exactly as prescribed. **Do not use SYMBICORT more often than prescribed.** SYMBICORT comes in two strengths for asthma: 80/4.5 mcg and 160/4.5 mcg. Your health care provider will prescribe the strength that is best for you. SYMBICORT 160/4.5 mcg is the approved dosage for COPD.

- SYMBICORT should be taken every day as 2 puffs in the morning and 2 puffs in the evening.
- Rinse your mouth with water and spit the water out after each dose (2 puffs) of SYMBICORT. This will help lessen the chance of getting a fungus infection (thrush) in the mouth and throat.
- Do not spray SYMBICORT in your eyes. If you accidentally get SYMBICORT in your eyes, rinse your eyes with water. If redness or irritation persists, call your health care provider.
- Do not change or stop any medicines used to control or treat your breathing problems. Your health care provider will change your medicines as needed
- **While you are using SYMBICORT 2 times each day, do not use other medicines that contain a long-acting beta$_2$-agonist (LABA) for any reason. Ask your health care provider or pharmacist if any of your other medicines are LABA medicines.**
- SYMBICORT does not relieve sudden symptoms. Always have a rescue inhaler medicine with you to treat sudden symptoms. If you do not have a rescue inhaler, call your health care provider to have one prescribed for you.

Call your health care provider or get medical care right away if:

- your breathing problems worsen with SYMBICORT
- you need to use your rescue inhaler medicine more often than usual
- your rescue inhaler does not work as well for you at relieving symptoms
- you need to use 4 or more inhalations of your rescue inhaler medicine for 2 or more days in a row
- you use one whole canister of your rescue inhaler medicine in 8 weeks' time
- your peak flow meter results decrease. Your health care provider will tell you the numbers that are right for you
- your symptoms do not improve after using SYMBICORT regularly for 1 week

WHAT MEDICATIONS SHOULD I NOT TAKE WHEN USING SYMBICORT?

While you are using SYMBICORT, do not use other medicines that contain a long-acting beta$_2$-agonist (LABA) for any reason, such as:

- Serevent® Diskus® (salmeterol xinafoate inhalation powder)
- Advair Diskus® or Advair® HFA (fluticasone propionate and salmeterol)
- Formoterol-containing products such as Foradil Aerolizer, Brovana®, or Perforomist®

WHAT ARE THE POSSIBLE SIDE EFFECTS WITH SYMBICORT?

SYMBICORT can cause serious side effects.

- Increased risk of pneumonia and other lower respiratory tract infections if you have COPD. Call your health care provider if you notice any of these symptoms: increase in mucus production, change in mucus color, fever, chills, increased cough, increased breathing problems
- Serious allergic reactions including rash; hives; swelling of the face, mouth and tongue; and breathing problems. Call your health care provider or get emergency care if you get any of these symptoms
- Immune system effects and a higher chance for infections
- Adrenal insufficiency–a condition in which the adrenal glands do not make enough steroid hormones
- Cardiovascular and central nervous system effects of LABAs, such as chest pain, increased blood pressure, fast or irregular heartbeat, tremor, or nervousness
- Increased wheezing right after taking SYMBICORT
- Eye problems, including glaucoma and cataracts. You should have regular eye exams while using SYMBICORT
- Osteoporosis. People at risk for increased bone loss may have a greater risk with SYMBICORT
- Slowed growth in children. As a result, growth should be carefully monitored
- Swelling of your blood vessels. This can happen in people with asthma
- Decreases in blood potassium levels and increases in blood sugar levels

WHAT ARE COMMON SIDE EFFECTS OF SYMBICORT?

Patients with Asthma

Sore throat, headache, upper respiratory tract infection, thrush in the mouth and throat

Patients with COPD

Thrush in the mouth and throat

These are not all the side effects with SYMBICORT. Ask your health care provider or pharmacist for more information.

NOTE: This summary provides important information about SYMBICORT. For more information, please ask your doctor or health care provider.

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Nalini Nadkarni

National Geographic Grantee

EXPERTISE
Forest Ecologist

LOCATION
Costa Rica

Caught Up I've studied the plants and animals that live in forest canopies for 30 years. It's like climbing mountains—there's always some danger in moving up and down a tree. When you climb day after day, though, sometimes for months on end, you forget that you're up more than a hundred feet. Eating a sandwich and an apple up there can seem like having a picnic on the ground.

I used to wear my long hair in two braids that I kept tied up behind my head to keep them out of the way. One day I forgot to tie them back. I noticed a tugging on my rappelling gear a few feet down. Within seconds the rope was so taut that my chin was pressed against it. There is a metal clip called a whale's tail that the rope loops through to create friction to help you control your slide. My braid was caught in it—and it was getting tighter and more painful.

I tried pulling myself up, tried yanking my braid out. It was futile. After five minutes I thought, I'm going to have to cut this thing off. I had always identified myself as someone with long hair. My father was from India, and hair is a source of beauty and honor there. Somehow my ancestral motivation wasn't quite as strong when I was strung up.

Holding myself up with one hand, I reached into my pocket and pulled out a penknife and starting sawing. When the last hairs were cut, my weight went back into the harness and my braid dropped to the ground. I made my way back to the forest floor and snatched it up. We had a museum of odd things we'd found in the canopy. I put my braid on display as a reminder that every moment—like this one, 150 feet above the forest floor—you have to be fully aware.

ART: ISTVAN BANYAI. PHOTO: LAWRENCE BOYE, UNIVERSITY OF UTAH

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This is a LOT of machine for not a lot of money. The ***Stauer Centurion Hybrid*** sports a heavy-duty alloy body, chromed and detailed with a rotating bezel that allows you to track direction. The luminous hour and minute hands mean you can keep working into the night. And the dual digital displays give this watch a hybrid ability. The LCD windows displays the time, day and date, includes a stopwatch function, and features a bright green electro-luminescent backlight. We previously offered the ***Centurion*** for $199, but with the exclusive promotional code it's yours for **ONLY $59**!

No matter what, this watch can keep up. Thanks to the Stauer 30-day Money Back Guarantee**,** you've got time to prove it. If you're not totally satisfied, return it for a full refund of the purchase price. You also get a 2-year replacement guarantee on both movements. But I have a feeling the only problem you'll have is deciding whether to keep the Stauer ***Centurion*** on your dresser or tucked inside your toolbox.

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VISIONS

Bosnia and Herzegovina
In Mostar a competitive diver holds torches as he jumps from the Old Bridge into the Neretva River. The 78-foot-tall limestone span—completed in 1566, destroyed by war in 1993, reopened in 2004—is a World Heritage site.

PHOTO: DADO RUVIC, REUTERS

Spain
During the Descent of the Angel festival in Peñafiel, seven-year-old Pablo Leal Requejo “flies down” to remove the Virgin Mary’s veil of mourning. The Easter celebration may have evolved from medieval plays. It draws about 2,500 people each year.

PHOTO: DANIEL OCHOA DE OLZA, AP IMAGES

Russia
Lit by a torch, an ice cave in a Kamchatka glacier glows like an entrance to the underworld. The pocked walls and ceiling are layers of compacted snow—more than 20 feet thick—carved by hot springs from the Mutnovsky Volcano.

PHOTO: DENIS BUDKOV

This page features two photographs: one chosen by our editors and one chosen by our readers via online voting. For more information, go to *yourshot.nationalgeographic.com.*

Your Assignment

When senior photo editor Sadie Quarrier and photographer Cory Richards launched this assignment for Your Shot members, "Explore Our Changing World," they looked for images that captured what the eye can't always register. These two shots did just that. Find more from this assignment online.

EDITORS' CHOICE

Klaus Priebe Santa Fe, New Mexico

After Priebe saw storms predicted over Utah's Canyonlands National Park, he hopped in his truck—where he'd also slept four nights—to snap this bolt, using a lightning trigger that detects rapid changes in light intensity.

READERS' CHOICE

Juan Carlos Osorio
New York, New York

Osorio wanted to photograph this solar plane, which was the first to fly at night. He used an eight-second exposure. "This plane runs on no fuel," he says. "Amazing!"

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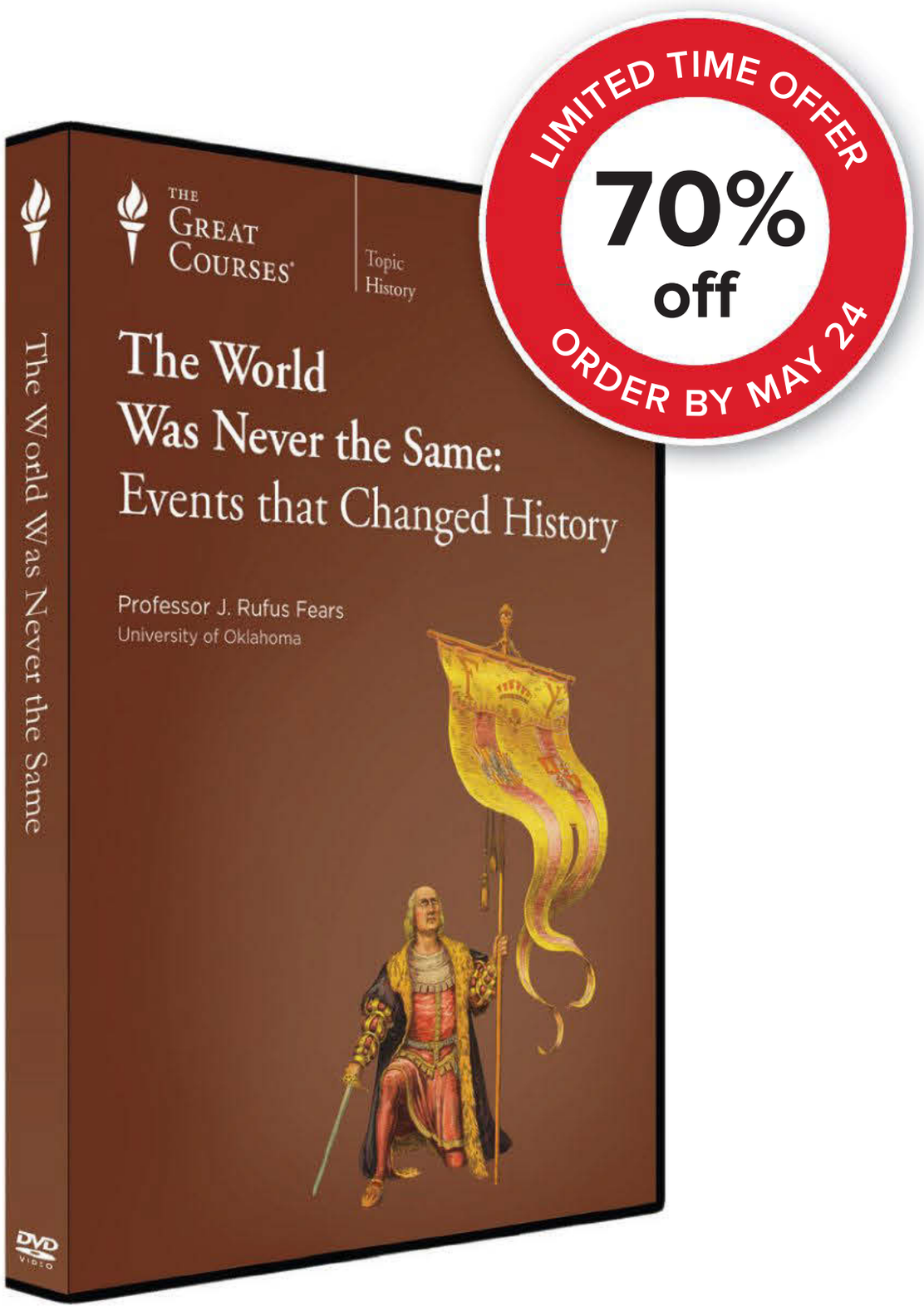

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6. Marathon—Democracy Triumphant (490 B.C.)
7. Hippocrates Takes an Oath (430 B.C.)
8. Caesar Crosses the Rubicon (49 B.C.)
9. Jesus—The Trial of a Teacher (A.D. 36)
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11. Muhammad Moves to Medina—The Hegira (A.D. 622)
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13. Dante Sees Beatrice (1283)
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NEXT

Protecting monkfish populations may depend on an egg hunt.

MONKFISH ARE VORACIOUS PREDATORS. They also happen to be among the most commercially valuable finfish in the northeastern United States. Yet despite the fish's importance, researchers don't know crucial details about it, including whether it lives in distinct populations.

To find out more, National Oceanic and Atmospheric Administration scientists have set up the Monkfish Egg Veil Sighting Network. Adult monkfish (below) lurk on the ocean bottom, but their eggs—which can emerge a million or more at a time, knitted together in a gauzy veil—float near the water's surface. People who spot the veils, which may measure up to 40 feet, are encouraged to record their sightings on the network's website. "The veils are buoyant. They're built for dispersal," notes researcher Anne Richards. Tracking them, she says, "will help us understand how monkfish move throughout their lives." *—Rachel Hartigan Shea*

This veil was photographed at the New England Aquarium in Boston. As the monkfish larvae develop, the veil's appearance darkens to purple, and it becomes harder to see in the water.

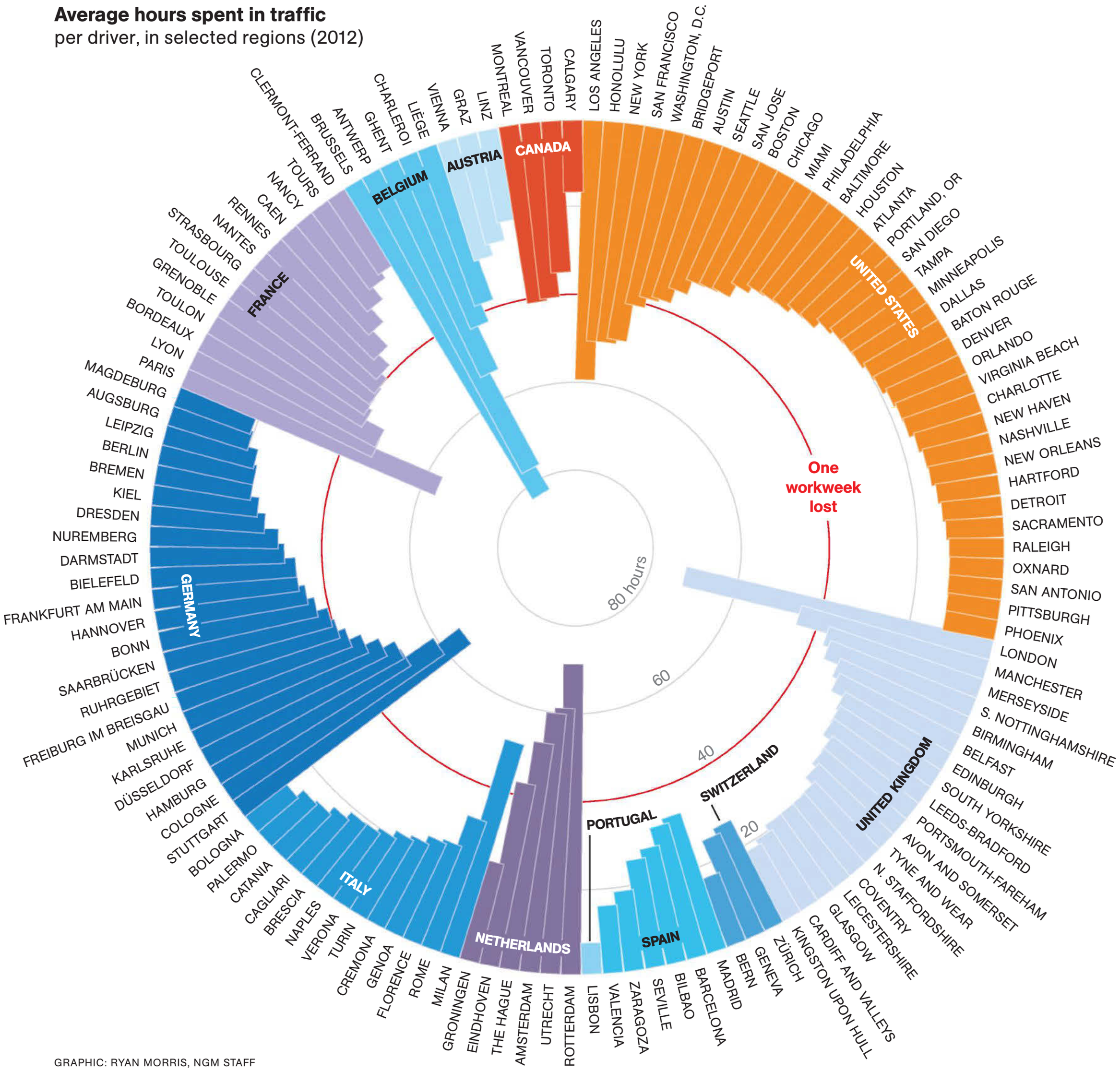
PHOTO: WEBB CHAPPELL

Commuter Science

By 8 a.m., rush hour is at full throttle in most cities. Accidents, the cost of fuel, and the quality of public transportation aren't the only factors that can make the drive to work range from ho-hum to hellish. According to traffic analyst Jim Bak, there's another thing that can cause commuting lengths to fluctuate: the state of the economy.

"When the recession hit in 2008, congestion across the U.S. dropped 30 percent," he says. Four years later, in 2012, drivers in Italy, France, and Spain also spent less time on the road as unemployment, especially among youth, skyrocketed in the wake of Europe's debt crisis. That same year, European Union officials tasked with managing the problem flocked to Brussels, Belgium—causing traffic and commute times in that city to soar. *—Catherine Zuckerman*

Average hours spent in traffic
per driver, in selected regions (2012)



GRAPHIC: RYAN MORRIS, NGM STAFF
SOURCE: INRIX

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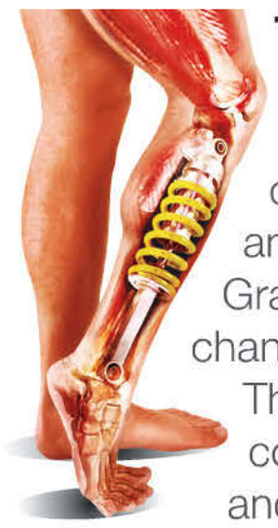

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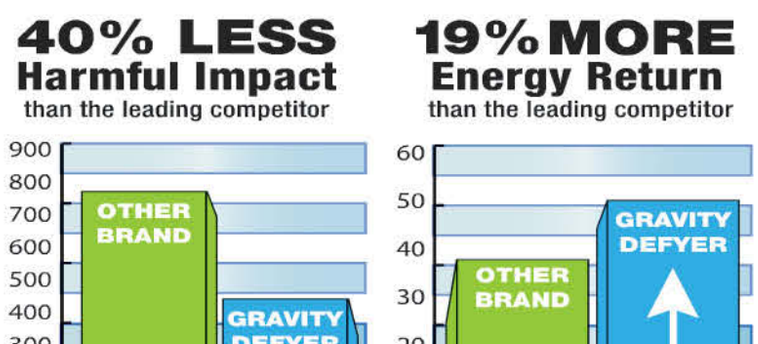

SHOCK ABSORPTION STUDY HPW Biomechanics, 2012

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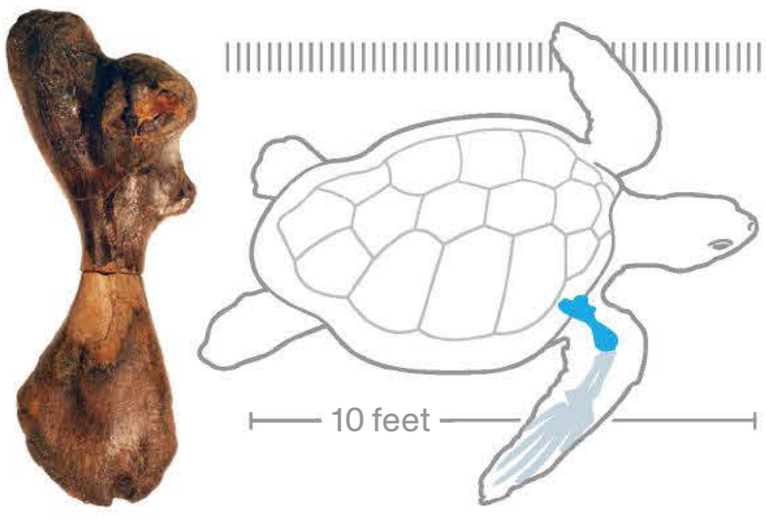
Growth Period

Artist Fritz Haeg's work is taking root. Over the past decade he's helped 15 families around the world turn their grass-only lawns into lush, organic gardens that he calls edible estates. Planted in front yards from Tel Aviv, Israel, to the Twin Cities in Minnesota, the plots give nourishment and pleasure. More important, says Haeg, they provide a sharp contrast to surrounding properties—which typically lack biodiversity.

Confronting the issue of land use is an idea that resonates with environmental geographer Paul Robbins. Turfgrass lawns are ecologically problematic because they keep other species from thriving. "Nature abhors a monoculture," says Robbins. "Lawn maintenance is a desperate struggle against nature." *—Catherine Zuckerman*

Siblings Andrea and Aaron Schoenherr tend their Woodbury, Minnesota, garden—part of a global art project.



A Humerus Tale

Call it the luckiest break. In 2012 an amateur paleontologist found half a turtle bone in New Jersey's Monmouth County. When David Parris of the state museum saw it, he was reminded of a leg-bone fragment he'd seen at Philadelphia's Academy of Natural Sciences, where it was studied back in 1849. The two parts fit together perfectly. Now a complete 21-inch humerus (far left) from a 2,000-plus-pound Cretaceous sea turtle exists—after more than 160 years. ***—Jeremy Berlin***

PHOTOS: CARLOS GONZALEZ; TED DAESCHLER, ACADEMY OF NATURAL SCIENCES, DREXEL UNIVERSITY (BONE). ART: ÁLVARO VALIÑO (TOP). SOURCE: EARTH POLICY INSTITUTE. NGM ART

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We asked Terry to tell us about his experience with Lyrica. To hear Terry's story visit Lyrica.com.

Prescription Lyrica is not for everyone. Tell your doctor right away about any serious allergic reaction that causes swelling of the face, mouth, lips, gums, tongue, throat, or neck or any trouble breathing, rash, hives or blisters. Lyrica may cause suicidal thoughts or actions in a very small number of people. Patients, family members or caregivers should call the doctor right away if they notice suicidal thoughts or actions, thoughts of self harm, or any unusual changes in mood or behavior. These changes may include new or worsening depression, anxiety, restlessness, trouble sleeping, panic attacks, anger, irritability, agitation, aggression, dangerous impulses or violence, or extreme increases in activity or talking. If you have suicidal thoughts or actions, do not stop Lyrica without first talking to your doctor. Lyrica may cause swelling of your hands, legs and feet. Some of the most common side effects of Lyrica are dizziness and sleepiness. Do not drive or work with machines until you know how Lyrica affects you. Other common side effects are blurry vision, weight gain, trouble concentrating, dry mouth, and feeling "high." Also, tell your doctor right away about muscle pain along with feeling sick and feverish, or any changes in your eyesight including blurry vision or any skin sores if you have diabetes. You may have a higher chance of swelling, hives or gaining weight if you are also taking certain diabetes or high blood pressure medicines. Do not drink alcohol while taking Lyrica. You may have more dizziness and sleepiness if you take Lyrica with alcohol, narcotic pain medicines, or medicines for anxiety. If you have had a drug or alcohol problem, you may be more likely to misuse Lyrica. Tell your doctor if you are planning to father a child. Talk with your doctor before you stop taking Lyrica or any other prescription medication.

Please see Important Risk Information for Lyrica on the following page.

To learn more visit www.lyrica.com or call toll-free 1-888-9-LYRICA (1-888-959-7422).

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IMPORTANT FACTS

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IMPORTANT SAFETY INFORMATION ABOUT LYRICA

LYRICA may cause serious, even life threatening, allergic reactions.
Stop taking LYRICA and call your doctor right away if you have any signs of a serious allergic reaction:
- Swelling of your face, mouth, lips, gums, tongue, throat or neck
- Have any trouble breathing
- Rash, hives (raised bumps) or blisters

Like other antiepileptic drugs, LYRICA may cause suicidal thoughts or actions in a very small number of people, about 1 in 500.
Call your doctor right away if you have any symptoms, especially if they are new, worse or worry you, including:
- suicidal thoughts or actions
- new or worse depression
- new or worse anxiety
- feeling agitated or restless
- panic attacks
- trouble sleeping
- new or worse irritability
- acting aggressive, being angry, or violent
- acting on dangerous impulses
- an extreme increase in activity and talking
- other unusual changes in behavior or mood

If you have suicidal thoughts or actions, do not stop LYRICA without first talking to your doctor.

LYRICA may cause swelling of your hands, legs and feet.
This swelling can be a serious problem with people with heart problems.

LYRICA may cause dizziness or sleepiness.
Do not drive a car, work with machines, or do other dangerous things until you know how LYRICA affects you. Ask your doctor when it is okay to do these things.

ABOUT LYRICA

LYRICA is a prescription medicine used in adults 18 years and older to treat:
- Pain from damaged nerves that happens with diabetes or that follows healing of shingles, or spinal cord injury
- Partial seizures when taken together with other seizure medicines
- Fibromyalgia (pain all over your body)

Who should NOT take LYRICA:
- Anyone who is allergic to anything in LYRICA

BEFORE STARTING LYRICA

Tell your doctor about all your medical conditions, including if you:
- Have had depression, mood problems or suicidal thoughts or behavior
- Have or had kidney problems or dialysis
- Have heart problems, including heart failure
- Have a bleeding problem or a low blood platelet count
- Have abused prescription medicines, street drugs or alcohol in the past
- Have ever had swelling of your face, mouth, tongue, lips, gums, neck, or throat (angioedema)
- Plan to father a child. It is not known if problems seen in animal studies can happen in humans.
- Are pregnant, plan to become pregnant or are breastfeeding. It is not known if LYRICA will harm your unborn baby. You and your doctor should decide whether you should take LYRICA or breast-feed, but you should not do both.

Tell your doctor about all your medicines. Include over-the-counter medicines, vitamins, and herbal supplements. LYRICA and other medicines may affect each other causing side effects. Especially tell your doctor if you take:

BEFORE STARTING LYRICA, continued

- Angiotensin converting enzyme (ACE) inhibitors. You may have a higher chance for swelling and hives.
- Avandia® (rosiglitazone)*, Avandamet® (rosiglitazone and metformin)* or Actos® (pioglitazone)** for diabetes. You may have a higher chance of weight gain or swelling of your hands or feet.
- Narcotic pain medicines (such as oxycodone), tranquilizers or medicines for anxiety (such as lorazepam). You may have a higher chance for dizziness and sleepiness.
- Any medicines that make you sleepy.

POSSIBLE SIDE EFFECTS OF LYRICA

LYRICA may cause serious side effects, including:
- See "Important Safety Information About LYRICA."
- Muscle problems, pain, soreness or weakness along with feeling sick and fever
- Eyesight problems including blurry vision
- Weight gain. Weight gain may affect control of diabetes and can be serious for people with heart problems.
- Feeling "high"

If you have any of these symptoms, tell your doctor right away.

The most common side effects of LYRICA are:
- Dizziness
- Blurry vision
- Weight gain
- Sleepiness
- Trouble concentrating
- Swelling of hands and feet
- Dry mouth

If you have diabetes, you should pay extra attention to your skin while taking LYRICA.

HOW TO TAKE LYRICA

Do:
- Take LYRICA exactly as your doctor tells you. Your doctor will tell you how much to take and when to take it. Take LYRICA at the same times each day.
- Take LYRICA with or without food.

Don't:
- Drive a car or use machines if you feel dizzy or sleepy while taking LYRICA.
- Drink alcohol or use other medicines that make you sleepy while taking LYRICA.
- Change the dose or stop LYRICA suddenly. If you stop taking LYRICA suddenly, you may have headaches, nausea, diarrhea, trouble sleeping, increased sweating, or you may feel anxious. If you have epilepsy, you may have seizures more often.
- Start any new medicines without first talking to your doctor.

NEED MORE INFORMATION?

- Ask your doctor or pharmacist. This is only a brief summary of important information.
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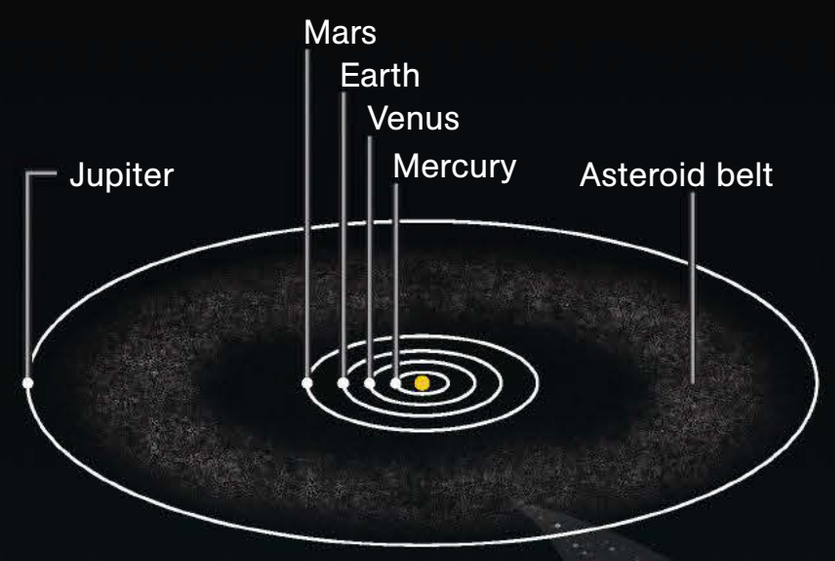
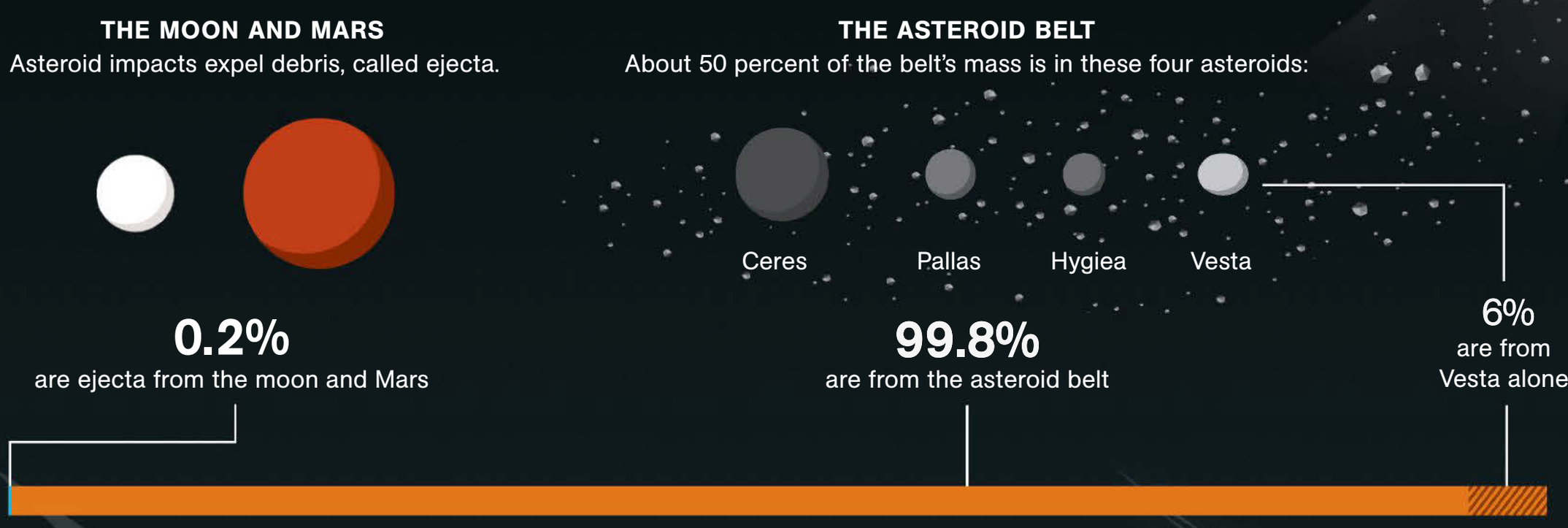
NEXT

On Deflection

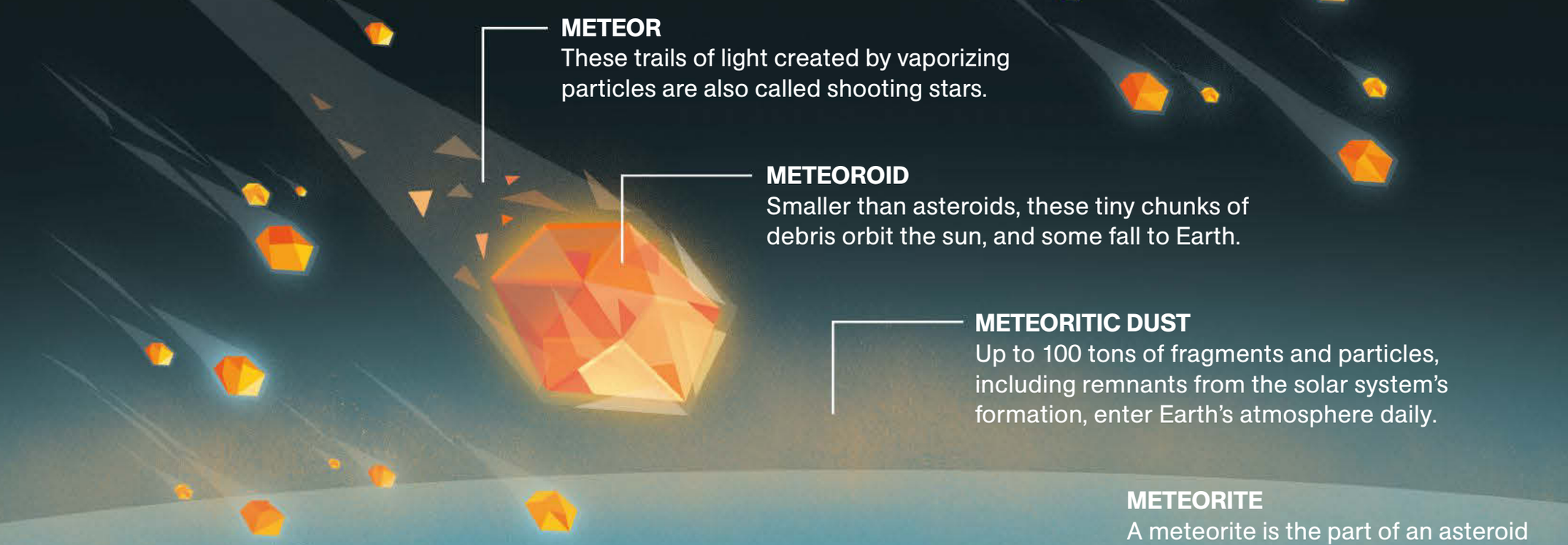
Asteroids of the size that caused the meteor explosion over Russia in 2013 may plunge into the atmosphere every 30 years—ten times more often than once thought. Veteran astronaut Tom Jones says that early warning could stop them. Robotic missions could ram an asteroid or hover to exert a gravitational tug. This might shift an asteroid's velocity enough, he says, "to make it miss its appointment with Earth." *—Eve Conant*



Where meteorites originate



Falling objects



Meteorites on Earth

The largest surviving meteorite on Earth is in Namibia. It weighs about 60 tons.

The meteor that exploded over Chelyabinsk, Russia, is the largest known object to enter Earth's atmosphere since 1908. Of its 13,200 tons, 76 percent vaporized above Earth.

GRAPHIC: PERISCOPIC. SOURCES: JEFFREY N. GROSSMAN AND MICHAEL E. ZOLENSKY, NASA

If You Bought Computers, Printers, Video Game Consoles,

or Other Devices with Memory

Get Money from $310 million Settlement

Simple Online Claim Form Takes 3-5 Minutes

State Attorneys General are Participating

There are class action Settlements involving DRAM, a memory part that is sold by itself or as part of electronic devices such as computers, printers, and video game consoles.

The lawsuits claim that the Defendants fixed the price of DRAM causing individuals and businesses to pay more for DRAM and DRAM-containing devices. The Defendants deny that they did anything wrong.

Who is included in the Settlements?

Individuals and businesses that:

- Purchased DRAM or a device containing DRAM anywhere in the U.S. between 1998 and 2002,
- For their own use or for resale.

Purchases made directly from a DRAM manufacturer are not included (see the list of manufacturers at www.DRAMclaims.com or by calling 1-800-589-1425).

What do the Settlements provide?

The combined Settlements total $310 million. The amount of money you will receive depends on the type and quantity of electronic devices you purchased and the total number of claims made.

Eligible individuals and businesses are expected to get a minimum $10 payment and perhaps much more. Large purchasers could recover many thousands of dollars.

How can I get a payment?

Claim online or by mail by **August 1, 2014**. The simple online Claim Form only takes 3-5 minutes for most individuals.

What are my rights?

Even if you do nothing you will be bound by the Court's decisions. If you want to keep your right to sue the Defendants yourself, you must exclude yourself from the Settlement Class by **May 5, 2014**. If you stay in the Settlement Class, you may object to the Settlements by **May 5, 2014**.

The Court will hold a hearing on **June 25, 2014** at **9:00 a.m.** to consider whether to approve the Settlements and a request for attorneys' fees up to 25% of the Settlement Fund, plus reimbursement of costs and expenses. You or your own lawyer may appear and speak at the hearing at your own expense.

For More Information:

1-800-589-1425 www.DRAMclaims.com

Text: "DRAM" to 96000

(You may receive notifications via text. Message & Data rates may apply.)

Chemistry Casanova Reinvents the Emerald

San Fransisco CA…It is 1937. You never saw a genius more in love. She loved him back, but how could he surprise her and stun her without breaking the bank? He knew she loved that glittering green necklace in the jewelry store window. But he also knew that he could never afford a natural emerald on a chemist's salary. So he made his own.

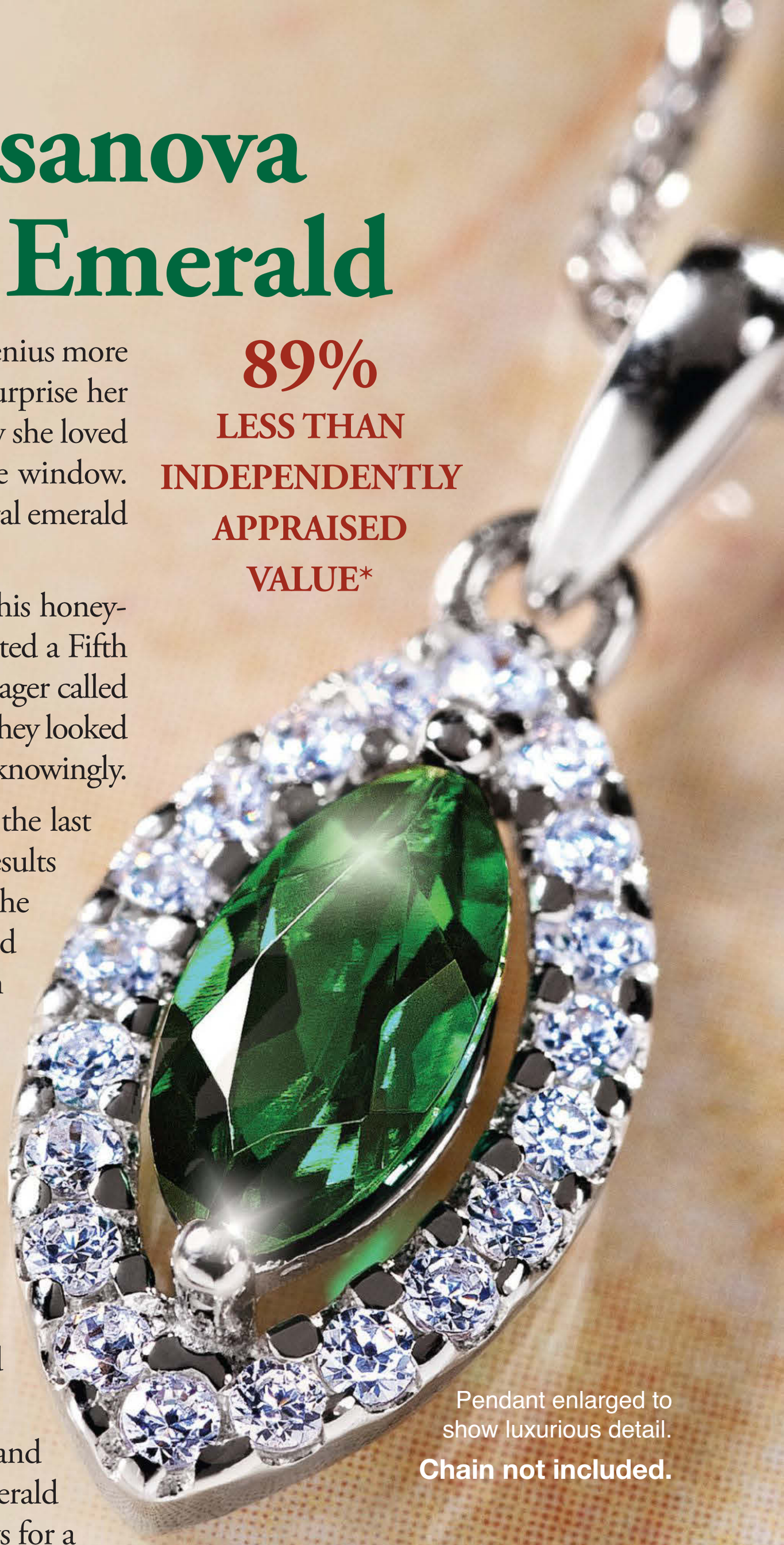
A few years later, he brought 100 carats along on his honeymoon in New York City. But when the couple visited a Fifth Avenue jeweler for a professional opinion, the manager called the cops. He assumed the gems were stolen because they looked too good to be true. His beautiful wife just smiled knowingly.

Own a piece of emerald history. We have spent the last few years refining this complex process and the results are stunning. The spectacular lab-created stone at the heart of our Scienza® ***Marquesa Pendant*** is a vivid ¾ carat marquise-cut green beauty cradled in gleaming .925 sterling silver and surrounded by the fire of our exclusive Diamond*Aura*® rounds.

Perfect from the start. The process begins with the seed of a natural emerald. In strictly controlled conditions, using intense heat of over 1800 degrees celsius, that seed takes over seven months to grow into a larger rough emerald. Chemically, the scientific stones grown in a lab are identical to mined emerald. They are just as hard and an incredibly rich, intense green.

Your satisfaction is guaranteed. Bring it home and see for yourself. If the brilliance of our Scienza Emerald fails to impress, simply send it back within 30 days for a full refund of your purchase price. But after wearing the world's smartest gem, you will see first-hand how beauty and brains come together.

89%
LESS THAN INDEPENDENTLY APPRAISED VALUE*



Pendant enlarged to show luxurious detail.
Chain not included.

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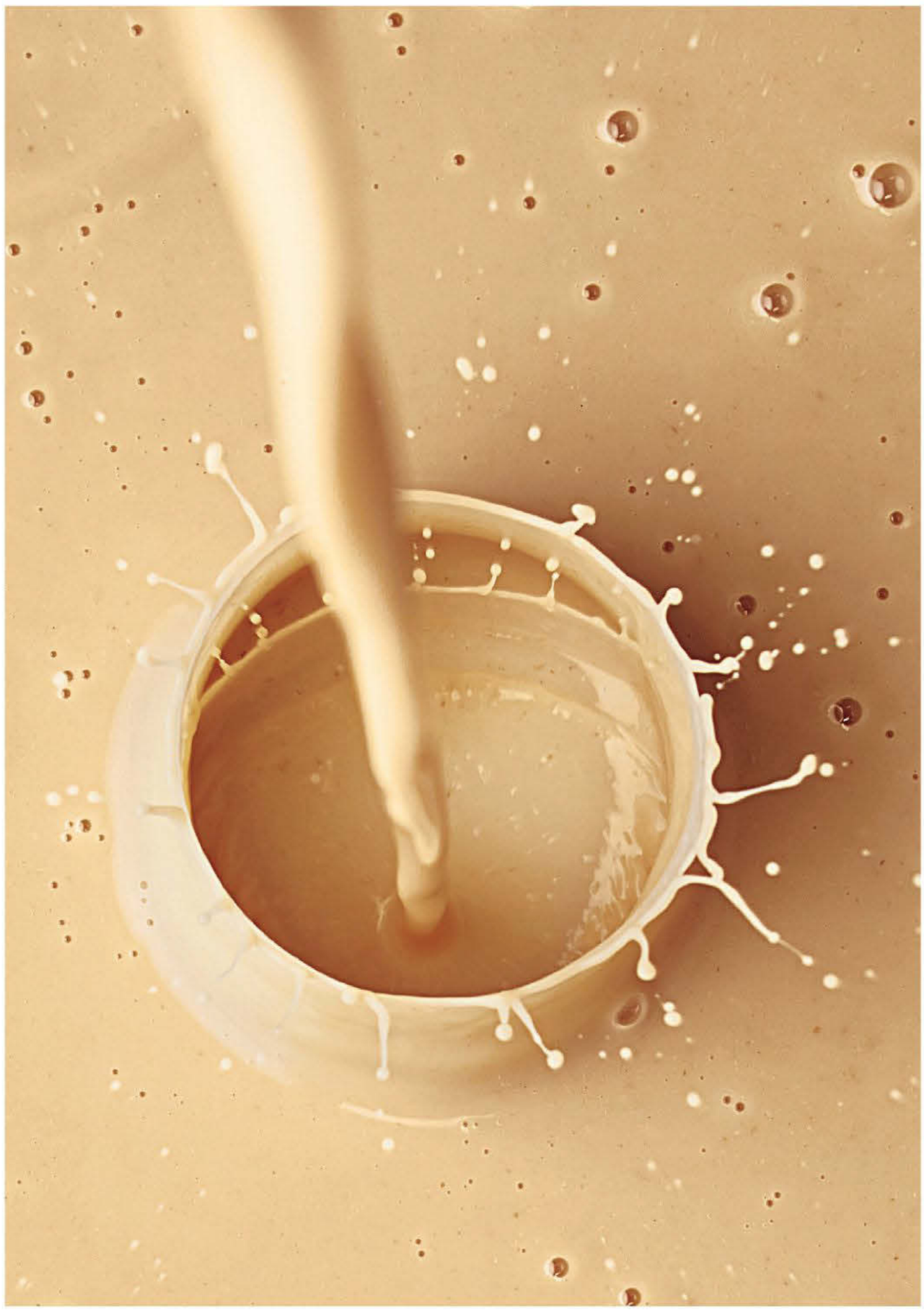
NEXT

A hummingbird's brain makes up 4.2 percent of its body weight, the highest proportion of any bird. A human brain makes up roughly 2 percent of an average person's body weight.



Liquid Asset

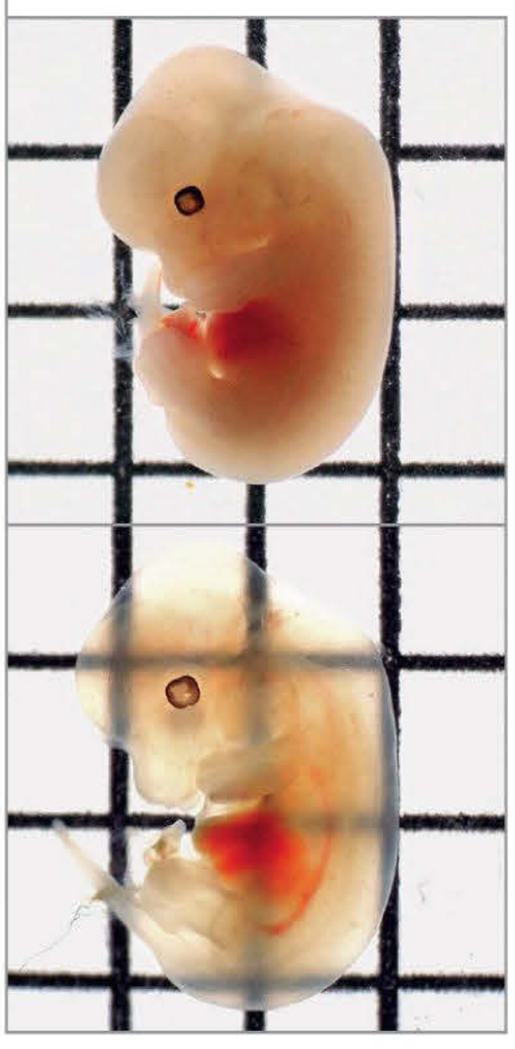
Rob Rhinehart thinks the future of food isn't in farms and animal husbandry. When the computer programmer didn't want to spend the time or money on traditional meals anymore, he created another option "by breaking food down to a molecular level." After several months of research into what human cells are made of and what they produce, Rhinehart ended up with a thick, bland liquid with a slightly chemical aftertaste he calls "soylent" (above). It has more than 30 ingredients, including calcium carbonate, copper, and selenium.

Cost and efficiency aren't Rhinehart's only drivers. He hopes soylent might bolster nutrition in food-scarce areas. "Food produced independently of agriculture could be a lot more sustainable," he says. "And there'd be plenty to go around." *—Johnna Rizzo*

In the Clear

Researchers study the internal structures of bodily organs to understand disease and function. The surrounding tissue can get in the way, though. Biologist Takeshi Imai's team has a fix: Bathe the tissues in a solution of fructose and water, and they turn clear (see mouse embryo, below).

Previously scientists used chemicals to achieve transparency, but those work slowly and can sometimes be toxic. They can also change structures and degrade dyes meant to trace nervous systems. Imai's sugar solution is the first to leave the object of study intact—bringing a more accurate picture into view. ***—JR***



PHOTOS: MARK THIESSEN, NGM STAFF (LEFT); MENG-TSEN KE AND TAKESHI IMAI, RIKEN. ART: ÁLVARO VALIÑO

JULIETTE, GEORGIA
Steam and smoke rise from the cooling towers and chimneys of the Robert W. Scherer power plant, the largest emitter of greenhouse gases in the U.S. It burns 12 million tons of coal a year.

ROBB KENDRICK

Coal provides
40 percent of the
world's electricity.

It produces
39 percent of global
CO_2 emissions.

It kills thousands a
year in mines, many
more with polluted air.

It's the dirtiest
of fossil fuels.
We burn eight billion
tons of it a year,
with growing
consequences.
The world must face
the question:

CAN COAL EVER BE CLEAN?

POCA, WEST VIRGINIA
The Poca High School "Dots" practice near an American Electric Power coal-fired plant that powers nearly two million homes. Scrubbers clean some of the sulfur and mercury—but not the carbon—from the smoke.

ROBB KENDRICK

Environmentalists say that clean coal is

By Michelle Nijhuis

Just look at West Virginia, where whole Appalachian peaks have been knocked into valleys to get at the coal underneath and streams run orange with acidic water. Or look at downtown Beijing, where the air these days is often thicker than in an airport smoking lounge. Air pollution in China, much of it from burning coal, is blamed for more than a million premature deaths a year. That's on top of the thousands who die in mining accidents, in China and elsewhere.

These problems aren't new. In the late 17th century, when coal from Wales and Northumberland was lighting the first fires of the industrial revolution in Britain, the English writer John Evelyn was already complaining about the "stink and darknesse" of the smoke that wreathed London. Three centuries later, in December 1952, a thick layer of coal-laden smog descended on London and lingered for a long weekend, provoking an epidemic of respiratory ailments that killed as many as 12,000 people in the ensuing months. American cities endured their own traumas. On an October weekend in 1948, in the small Pennsylvania town of Donora, spectators at a high school football game realized they could see neither players nor ball: Smog from a nearby coal-fired zinc smelter was obscuring the field. In

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Michelle Nijhuis has won multiple awards for her writing about the environment. Robb Kendrick's last piece, in April 2013, was on reviving extinct species.

COAL

a myth. Of course it is:

the days that followed, 20 people died, and 6,000 people—nearly half the town—were sickened.

Coal, to use the economists' euphemism, is fraught with "externalities"—the heavy costs it imposes on society. It's the dirtiest, most lethal energy source we have. But by most measures it's also the cheapest, and we depend on it. So the big question today isn't whether coal can ever be "clean." It can't. It's whether coal can ever be clean enough—to prevent not only local disasters but also a radical change in global climate.

Last June, on a hot and muggy day in Washington, D.C., President Barack Obama gave the climate speech that the American coal and electric power industries had dreaded—and environmentalists had hoped for—since his first inauguration, in 2009. Speaking in his shirtsleeves and pausing occasionally to mop his brow, Obama announced that by June 2014 the Environmental Protection Agency (EPA) would draft new rules that would "put an end to the limitless dumping of carbon pollution from our power plants." The rules would be issued under the Clean Air Act, a law inspired in part by the disaster in Donora. That law has already been used to dramatically reduce the emission of sulfur dioxide, nitrogen oxides, and soot particles from American power plants. But carbon dioxide, the main cause of global warming, is a problem on an entirely different scale.

In 2012 the world emitted a record 34.5 billion metric tons of carbon dioxide from fossil fuels. Coal was the largest contributor. Cheap natural gas has lately reduced the demand for coal in the U.S., but everywhere else, especially in China, demand is surging. During the next two decades several hundred million people worldwide will get electricity for the first time, and if current trends continue, most will use power produced by coal. Even the most aggressive push for alternative energy sources and conservation could not replace coal—at least not right away.

How fast the Arctic melts, how high the seas rise, how hot the heat waves get—all these elements of our uncertain future depend on what the world does with its coal, and in particular on what the U.S. and China do. Will we continue to burn it and dump the carbon into the air unabated? Or will we find a way to capture carbon, as we do sulfur and nitrogen from fossil fuels, and store it underground?

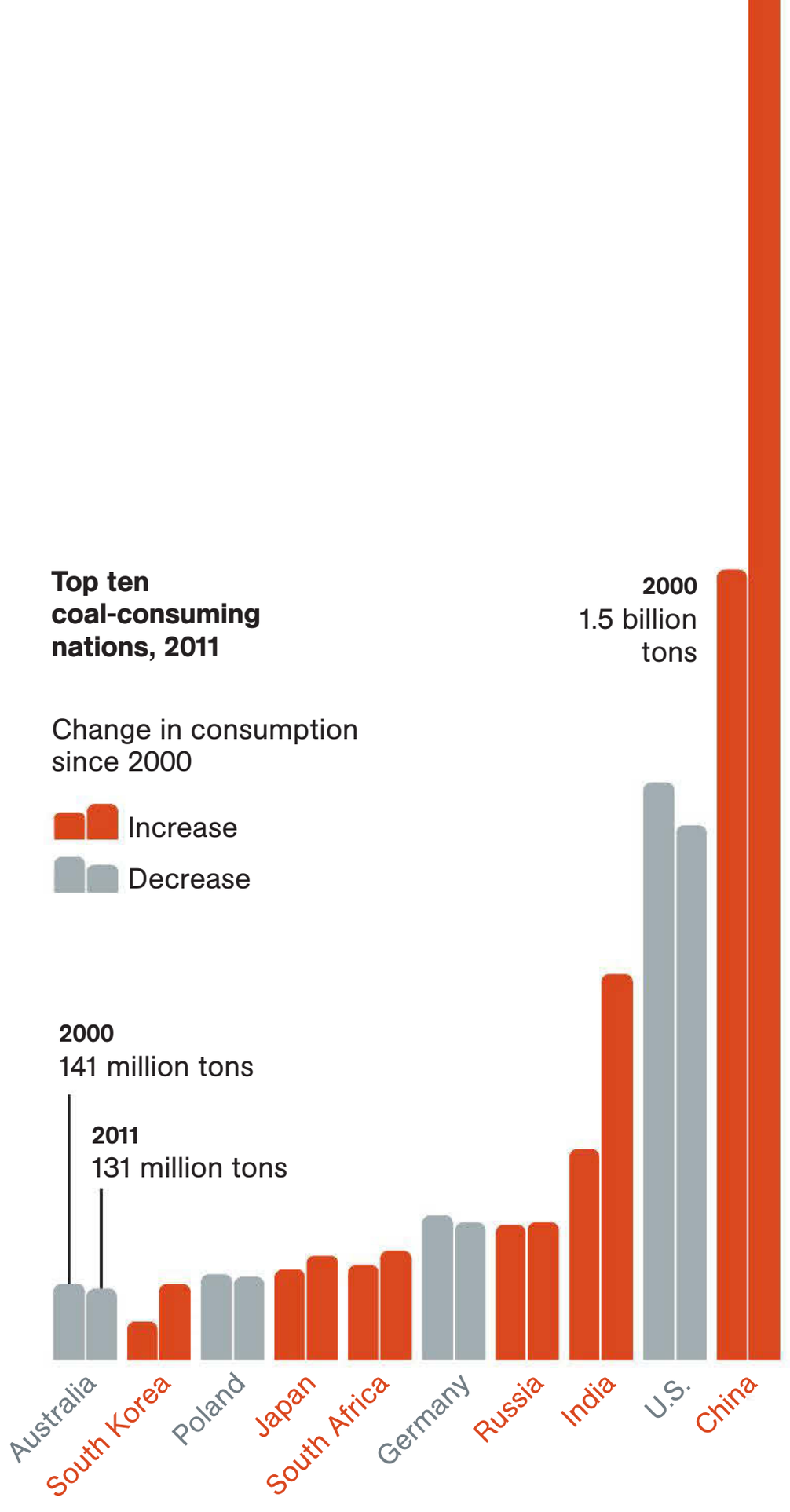
"We need to push as hard as we can for renewable energy and energy efficiency, *and* on reducing carbon emissions from coal," says Stanford University researcher Sally Benson, who specializes in carbon storage. "We're going to need lots of 'ands'—this isn't a time to be focusing on 'ors.'" The carbon problem is just too big.

AMERICAN ELECTRIC POWER'S Mountaineer Plant, on the Ohio River in New Haven, West Virginia, inhales a million pounds of Appalachian

World Coal Consumption

AN APPETITE FOR ENERGY

Though coal burning has plateaued in countries like the U.S., it has soared in rapidly industrializing countries like China and India, which manufacture many of the West's consumer products. World coal consumption rose by 54 percent from 2000 to 2011.



ALL CHARTS: JOHN TOMANIO AND ALEXANDER STEGMAIER, NGM STAFF
SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION

coal every hour. The coal arrives fresh from the ground, on barges or on a conveyor belt from a mine across the road. Once inside the plant, the golf-ball-size lumps are ground into dust as fine as face powder, then blown into the firebox of one of the largest boilers in the world—a steel box that could easily swallow the Statue of Liberty. The plant's three steam-powered turbines, painted blue with white stars, supply electricity round the clock to 1.3 million customers in seven states. Those customers pay about a dime per kilowatt-hour, or roughly $113 a month, to power the refrigerators, washers, dryers, flat screens, and smartphones, to say nothing of the lights, of an average household. And as Charlie Powell, Mountaineer's plant manager, often said, even environmentalists like to keep the lights on.

The customers pay not a cent, however, nor does American Electric Power (AEP), for the privilege of spewing six to seven million metric tons of carbon dioxide into the atmosphere every year from Mountaineer's thousand-foot-high stack. And that's the problem. Carbon is dumped without limit because in most places it costs nothing to do so and because there is, as yet, no law against it in the U.S. But in 2009 it looked as if there might soon be a law; the House of Representatives had already passed a bill that summer. AEP, to its credit, decided to get ahead of it.

That October, Mountaineer began a pioneering experiment in carbon capture. Powell oversaw it. His father had worked for three decades at a coal-fired power plant in Virginia; Powell himself had spent his career at Mountaineer. The job was simple, he said: "We burn coal, make steam, and run turbines." During the experiment, though, it got a bit more complicated. AEP attached a chemical plant to the back of its power plant. It chilled about 1.5 percent of Mountaineer's smoke and diverted it through

Coal use per capita, 2011

6.4 lbs

Average daily consumption of coal per person worldwide

a solution of ammonium carbonate, which absorbed the CO_2. The CO_2 was then drastically compressed and injected into a porous sandstone formation more than a mile below the banks of the Ohio.

The system worked. Over the next two years AEP captured and stored more than 37,000 metric tons of pure carbon dioxide. The CO_2 is still underground, not in the atmosphere. It was only a quarter of one percent of the gas coming out the stack, but that was supposed to be just the beginning. AEP planned to scale up the project to capture a quarter of the plant's emissions, or 1.5 million tons of CO_2 a year. The company had agreed to invest $334 million, and the U.S. Department of Energy (DOE) had agreed to match that. But the deal depended on AEP being able to recoup its investment. And after climate change legislation collapsed in the Senate, state utility regulators told the company that it could not charge its customers for a technology not yet required by law.

In the spring of 2011 AEP ended the project. The maze of pipes and pumps and tanks was dismantled. Though small, the Mountaineer system had been the world's first to capture and store carbon dioxide directly from a coal-fired electric plant, and it had attracted hundreds of curious visitors from around the world, including China and India. "The process did work, and we educated a lot of people," said Powell. "But geez-oh-whiz—it's going to take another breakthrough to make it worth our while." A regulatory breakthrough above all—such as the one Obama promised last summer—but technical ones would help too.

CAPTURING CARBON DIOXIDE and storing or "sequestering" it underground in porous rock formations sounds to its critics like a techno-fix fantasy. But DOE has spent some $6.5 billion over the past three decades researching and testing the technology. And for more than four decades the oil industry has been injecting compressed carbon dioxide into depleted oil fields, using it to coax trapped oil to the surface. On the Canadian Great Plains this practice has been turned into one of the world's largest underground carbon-storage operations.

Since 2000 more than 20 million metric tons of carbon dioxide have been captured from a North Dakota plant that turns coal into synthetic natural gas, then piped 200 miles north into Saskatchewan. There the Canadian petroleum company Cenovus Energy pushes the CO_2 deep into the Weyburn and Midale fields, a sprawling oil patch that had its heyday in the 1960s. Two to three barrels of oil are dissolved out of the reservoir rock by each ton of CO_2, which is then reinjected into the reservoir for storage. There it sits, nearly a mile underground, trapped under impermeable layers of shale and salt.

Capturing CO_2 sounds to its critics like a techno-fix fantasy.

For how long? Some natural deposits of carbon dioxide have been in place for millions of years—in fact the CO_2 in some has been mined and sold to oil companies. But large and sudden releases of CO_2 can be lethal to people and animals, particularly when the gas collects and concentrates in a confined space. So far no major leaks have been documented at Weyburn, which is being monitored by the International Energy Agency,

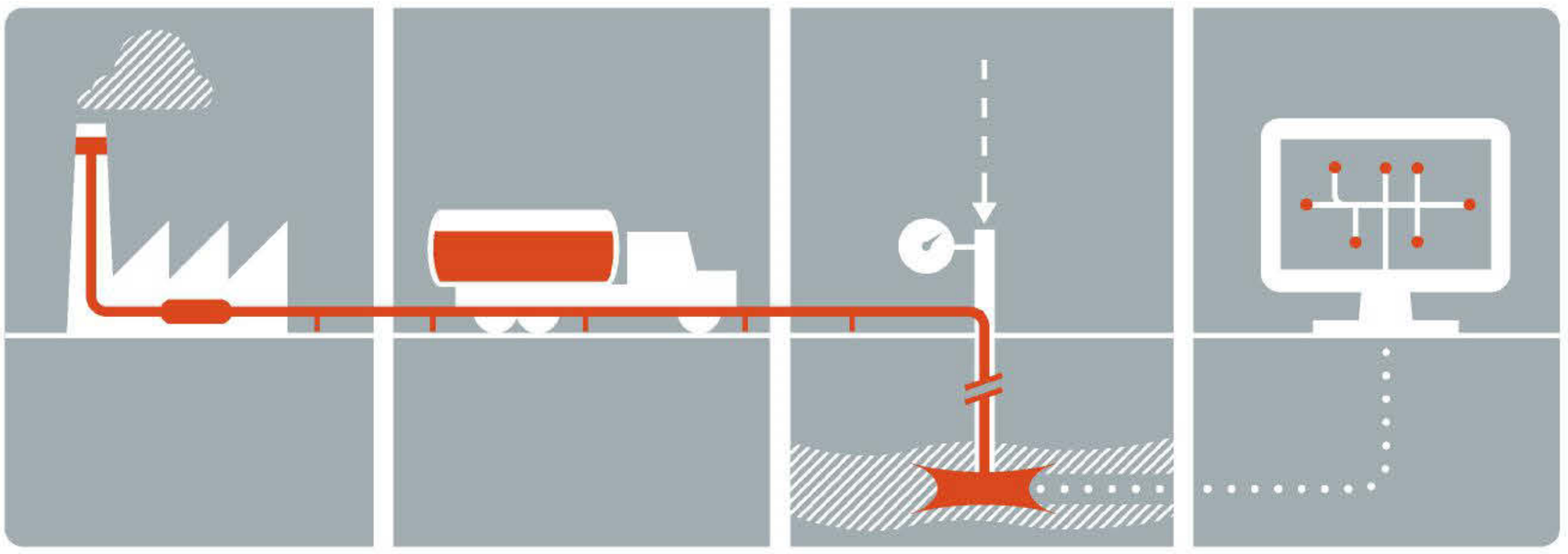
18 lbs | Average daily consumption of coal per person in the U.S.

33 lbs | Average daily consumption of coal per person in Australia—one of the world's highest figures

Carbon Capture and Storage (CCS)

DISPOSING OF WASTE CO_2

Venting CO_2 from a smokestack is usually free, like littering. Capturing and storing CO_2 underground would cost up to a quarter of a power plant's energy—and a lot of money. It won't become the norm unless governments make it happen.



The four steps of capturing and storing carbon dioxide

Capture
CO_2 is separated from other stack gases and compressed into a liquid-like state. This is the most costly step in CCS.

Transport
Fluid CO_2 is moved to a storage reservoir. Pipelines are the most efficient carrier, but trucks, trains, and ships can do the job.

Injection
CO_2 is injected deep underground into a porous formation—an old oil field, say, or a saline aquifer—under a cap rock that deters leaks.

Monitoring
The reservoir must be watched in perpetuity for leaks. Even slow ones could defeat the purpose of preventing climate change.

Underground formations could hold 1,000 years' worth of emissions.

or at any of the handful of other large storage sites around the world. Scientists consider the risk of a catastrophic leak to be extremely low.

They worry more about smaller, chronic leaks that would defeat the purpose of the enterprise. Geophysicists Mark Zoback and Steven Gorelick of Stanford University argue that at sites where the rock is brittle and faulted—most sites, in their view—the injection of carbon dioxide might trigger small earthquakes that, even if otherwise harmless, might crack the overlying shale and allow CO_2 to leak. Zoback and Gorelick consider carbon storage "an extremely expensive and risky strategy." But even they agree that carbon can be stored effectively at some sites—such as the Sleipner gas field in the North Sea, where for the past 17 years the Norwegian oil company Statoil has been injecting about a million tons of CO_2 a year into a brine-saturated sandstone layer half a mile below the seabed. That formation has so much room that all that

ART: ÁLVARO VALIÑO

SOURCES: HOWARD HERZOG, MIT; U.S. ENERGY INFORMATION ADMINISTRATION

CO_2 emitted by fossil fuels, 2011

21% of global fossil fuel CO_2 comes from burning natural gas, mostly for heat and electricity.

3.5 million metric tons
Annual CO_2 capture planned at first U.S. power plant equipped for CCS

1.5 billion metric tons
Annual CO_2 output of all U.S. coal-fired power plants

A small beginning for CCS

One U.S. power plant, in Mississippi, is now being equipped for CCS. It would take a whole new industry to make a dent in U.S. emissions.

CO_2 hasn't increased its internal pressure, and there's been no sign of quakes or leaks.

European researchers estimate that a century's worth of European power plant emissions could be stored under the North Sea. According to the DOE, similar "deep saline aquifers" under the U.S. could hold more than a thousand years' worth of emissions from American power plants. Other types of rock also have potential as carbon lockers. In experiments now under way in Iceland and in the Columbia River Basin of Washington State, for example, small amounts of carbon dioxide are being injected into volcanic basalt. There the gas is expected to react with calcium and magnesium to form a carbonate rock—thus eliminating the risk of gas escaping.

The CO_2 that Statoil is injecting at Sleipner doesn't come from burning; it's an impurity in the natural gas the company pumps from the seabed. Before it can deliver gas to its customers, Statoil has to separate out the CO_2, and it used to just vent the stuff into the atmosphere. But in 1991 Norway instituted a carbon tax, which now stands at around $65 a metric ton. It costs Statoil only $17 a ton to reinject the CO_2 below the seafloor. So at Sleipner, carbon storage is much cheaper than carbon dumping, which is why Statoil has invested in the technology. Its natural gas operation remains very profitable.

AT A COAL-FIRED POWER PLANT the situation is different. The CO_2 is part of a complex swirl of stack gases, and the power company has no financial incentive to capture it. As the engineers at Mountaineer learned, capture is the most expensive part of any capture-and-storage project. At Mountaineer the CO_2 absorption system was the size of a ten-story apartment building and occupied 14 acres—and that was just to capture a tiny fraction of the plant's carbon emissions. The absorbent had to be heated to release the CO_2, which then had to be highly compressed for storage. These energy-intensive steps create what engineers call a "parasitic load," one that could eat up as much as 30 percent of the total energy output of a coal plant that was capturing all its carbon.

One way to reduce that costly loss is to gasify the coal before burning it. Gasification can make power generation more efficient and allows the carbon dioxide to be separated more easily and cheaply. A new power plant being built in Kemper County, Mississippi, which was designed with carbon capture in mind, will gasify its coal.

Existing plants, which are generally designed to burn pulverized coal, require a different approach. One idea is to burn the coal in pure oxygen instead of air. That produces a simpler flue gas from which it's easier to pull the CO_2. At the DOE's National Energy Technology Laboratory in Morgantown, West Virginia, researcher Geo Richards is working on an advanced version of this scheme.

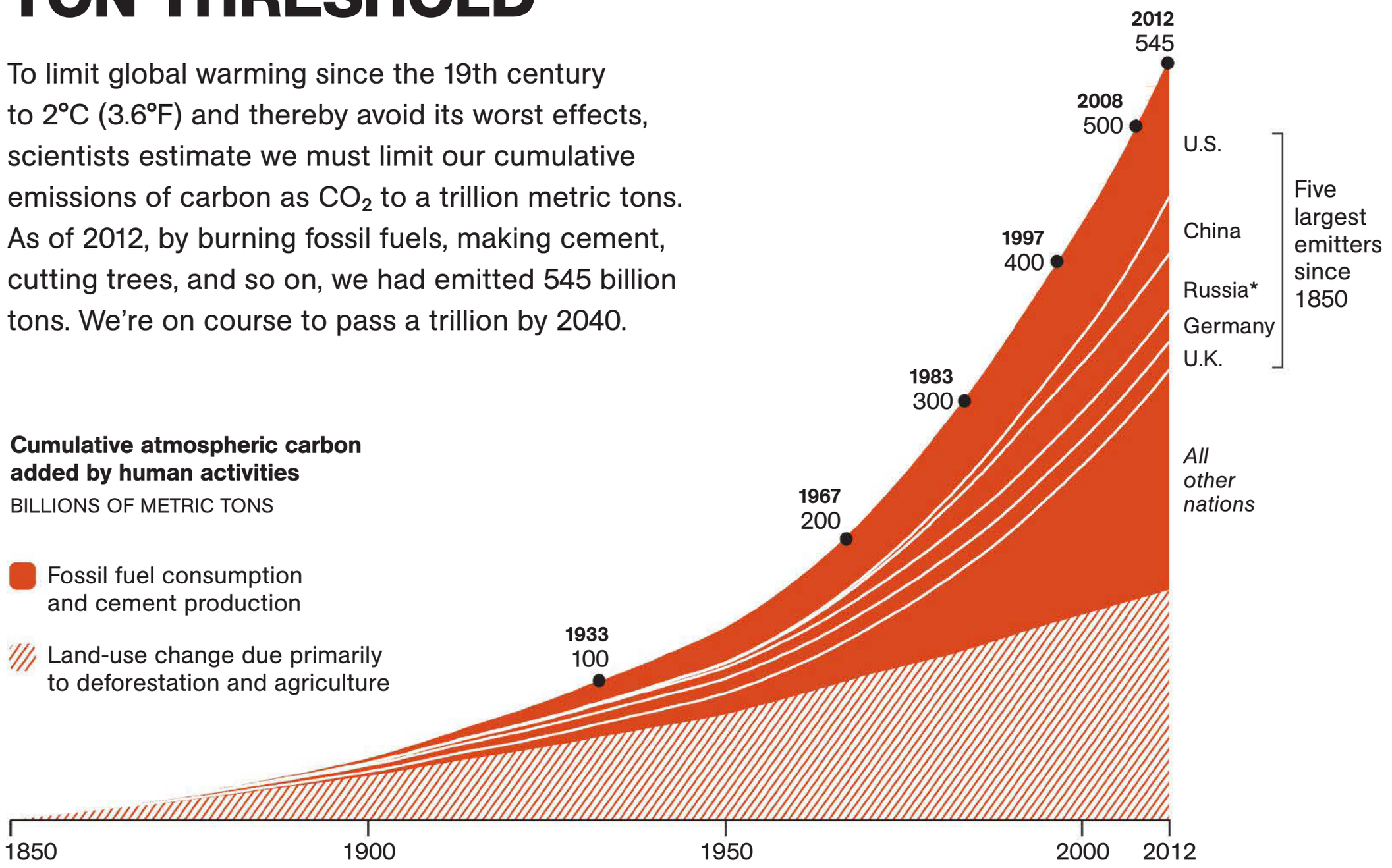
35% comes from oil, which is used primarily to make various transportation fuels.

44% comes from burning coal—the cheapest and dirtiest fossil fuel, used primarily for electricity.

CO_2 and Climate Change

THE TRILLION-TON THRESHOLD

To limit global warming since the 19th century to 2°C (3.6°F) and thereby avoid its worst effects, scientists estimate we must limit our cumulative emissions of carbon as CO_2 to a trillion metric tons. As of 2012, by burning fossil fuels, making cement, cutting trees, and so on, we had emitted 545 billion tons. We're on course to pass a trillion by 2040.



"Come and see our new toy," he says, hunching his shoulders against a bitter Appalachian winter day and walking briskly toward a large white warehouse. Inside, workers are assembling a five-story scaffold for an experiment in "chemical looping." Making pure oxygen from air, Richards explains, is costly in itself—so his process uses a metal such as iron to grab oxygen out of the air and deliver it to the coal fire. In principle, chemical looping could radically cut the cost of capturing carbon.

Richards has dedicated more than 25 years of his career to making carbon capture more efficient, and for him the work is largely its own reward. "I'm one of those geeky people who just like seeing basic physics turned into technology," he says. But after decades of watching politicians and the public tussle over whether climate change is even a problem, he does sometimes wonder if the solution he's been working on will ever be put to practical use. His experimental carbon-capture system is a tiny fraction of the size that would be required at a real power plant. "In this business," Richards says, "you have to be an optimist."

IN WEST VIRGINIA THESE DAYS, century-old coal mines are closing as American power plants convert to natural gas. With gas prices in the U.S. near record lows, coal can look like yesterday's fuel, and investing in advanced coal technology can look misguided at best. The view from Yulin, China, is different.

Yulin sits on the eastern edge of Inner Mongolia's Ordos Basin, 500 dusty miles inland from Beijing. Rust-orange sand dunes surround forests of new, unoccupied apartment buildings, spill over highway retaining walls, and send clouds of grit through the streets. Yulin and its three million residents are short on rain and shade, hot in summer and very cold in winter. But the region is blessed with mineral resources,

*U.S.S.R. DATA PRIOR TO 1992

SOURCES: THOMAS BODEN, CARBON DIOXIDE INFORMATION ANALYSIS CENTER/OAK RIDGE NATIONAL LABORATORY, U.S. DEPARTMENT OF ENERGY; R. A. HOUGHTON, WOODS HOLE RESEARCH CENTER; EPA

The rising CO_2 threat

84% Portion of U.S. greenhouse gases emitted by human activity that is CO_2

including some of the country's richest deposits of coal. "God is fair," says Yulin deputy mayor Gao Zhongyin. From here coal looks like the fuel of progress.

The sandy plateaus around Yulin are punctuated with the tall smokestacks of coal power plants, and enormous coal-processing plants, with dormitories for live-in workforces, sprawl for miles across the desert. New coal plants, their grids of dirt roads decorated with optimistic red-bannered gateways, bustle with young men and women in coveralls. Coal provides about 80 percent of China's electric power, but it isn't just for making electricity. Since coal is such a plentiful domestic fuel, it's also used for making dozens of industrial chemicals and liquid fuels, a role played by petroleum in most other countries. Here coal is a key ingredient in products ranging from plastic to rayon.

Coal has also made China first among nations in total carbon dioxide emissions, though the U.S. remains far ahead in emissions per capita. China is not retreating from coal, but it's more than ever aware of the high costs. "In the past ten years," says Deborah Seligsohn, an environmental policy researcher at the University of California, San Diego, with nearly two decades' experience in China, "the environment has gone from not on the agenda to near the top of the agenda." Thanks to public complaints about air quality, official awareness of the risks of climate change, and a desire for energy security and technological advantage, China has invested hundreds of billions of dollars in renewable energy. It's now a top manufacturer of wind turbines and solar panels; enormous solar farms are scattered among the smokestacks around Yulin. But the country is also pushing ultraefficient coal power and simpler, cheaper carbon capture.

These efforts are attracting both investment and immigrants from abroad. At state-owned Shenhua Group, the largest coal company in the world, its National Institute of Clean-and-Low-Carbon Energy was until recently headed by J. Michael Davis, an American who served as assistant U.S. secretary for conservation and renewable energy under the first President Bush and is a past president of the U.S. Solar Energy Industries Association. Davis says he was drawn to China by the government's "durable commitment" to improving air quality and reducing carbon dioxide emissions: "If you want to make the greatest impact on emissions, you go where the greatest source of those emissions happens to be."

Yesterday's fuel? In China coal looks like the fuel of progress.

Will Latta, founder of the environmental engineering company LP Amina, is an American expat in Beijing who works closely with Chinese power utilities. "China is openly saying, Hey, coal is cheap, we have lots of it, and alternatives will take decades to scale up," he says. "At the same time they realize it's not environmentally sustainable. So they're making large investments to clean it up." In Tianjin, about 85 miles from Beijing, China's first power plant designed from scratch to capture carbon is scheduled to open in 2016. Called GreenGen, it's eventually supposed to capture 80 percent of its emissions.

LAST FALL, AS WORLD COAL CONSUMPTION and world carbon emissions were headed for new

800,000 yrs | Minimum time since the CO_2 level was as high as it is today

108% | Increase in global per capita emissions between 1950 and 2010

records, the Intergovernmental Panel on Climate Change (IPCC) issued its latest report. For the first time it estimated an emissions budget for the planet—the total amount of carbon we can release if we don't want the temperature rise to exceed 2 degrees Celsius (3.6 degrees Fahrenheit), a level many scientists consider a threshold of serious harm. The count started in the 19th century, when the industrial revolution spread. The IPCC concluded that we've already emitted more than half our carbon budget. On our current path, we'll emit the rest in less than 30 years.

Changing that course with carbon capture would take a massive effort. To capture and store just a tenth of the world's current emissions would require pumping about the same volume of CO_2 underground as the volume of oil we're now extracting. It would take a lot of pipelines and injection wells. But achieving the same result by replacing coal with zero-emission solar panels would require covering an area almost as big as New Jersey (nearly 8,000 square miles). The solutions are huge because the problem is—and we need them all.

"If we were talking about a problem that could be solved by a 5 or 10 percent reduction in greenhouse gas emissions, we wouldn't be talking about carbon capture and storage," says Edward Rubin of Carnegie Mellon University. "But what we're talking about is reducing global emissions by roughly 80 percent in the next 30 or 40 years." Carbon capture has the potential to deliver big emissions cuts quickly: Capturing the CO_2 from a single thousand-megawatt coal plant, for example, would be equivalent to 2.8 million people trading in pickups for Priuses.

The first U.S. power plant that will capture most of its CO_2 is under construction.

The first American power plant designed to capture carbon is scheduled to open at the end of this year. The Kemper County coal-gasification plant in eastern Mississippi will capture more than half its CO_2 emissions and pipe them to nearby oil fields. The project, which is supported in part by a DOE grant, has been plagued with cost overruns and opposition from both environmentalists and government-spending hawks. But Mississippi Power, a division of Southern Company, has pledged to persist. Company leaders say the plant's use of lignite, a low-grade coal that's plentiful in Mississippi, along with a ready market for its CO_2, will help offset the heavy cost of pioneering new technology.

The technology won't spread, however, until governments require it, either by imposing a price on carbon or by regulating emissions directly. "Regulation is what carbon capture needs to get going," says James Dooley, a researcher at DOE's Pacific Northwest National Laboratory. If the EPA delivers this year on President Obama's promise to regulate carbon emissions from both existing and new power plants—and if those rules survive court challenges—then carbon capture will get that long-awaited boost.

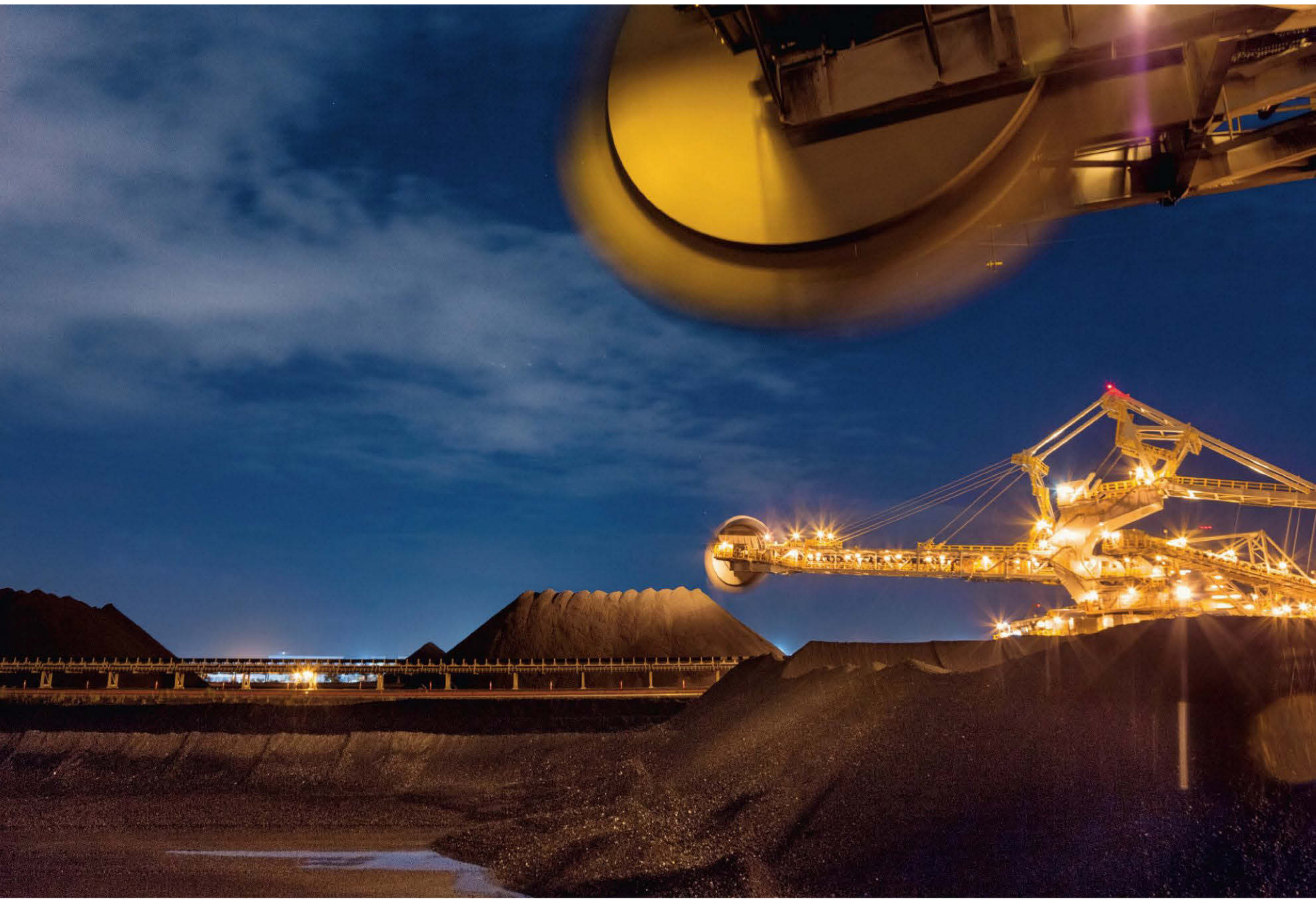
China, meanwhile, has begun regional experiments with a more market-friendly approach—one that was pioneered in the U.S. In the 1990s the EPA used the Clean Air Act to impose a cap on total emissions of sulfur dioxide from power plants, allocating tradable pollution permits to individual polluters. At the time, the power industry predicted disastrous economic consequences. Instead the scheme produced innovative, progressively cheaper technologies and significantly cleaner air. Rubin says that carbon-capture systems are at much the same stage that sulfur dioxide systems were in the 1980s. Once emissions limits create a market for them, their cost too could fall dramatically.

If that happens, coal still wouldn't be clean—but it would be much cleaner than it is today. And the planet would be cooler than it will be if we keep burning coal the dirty old way. ▯

COAL

Part two | ## The visible impacts

The world gets huge amounts of energy from coal—and puts huge energy into extracting it from the ground. The carbon that ends up in the atmosphere is just a ghostly echo of an industry of monumental scale and impact.



Photographs by Robb Kendrick

QUEENSLAND, AUSTRALIA
An automated bucket-wheel excavator loads coal into ships bound for China and India. Australia is second only to Indonesia in coal exports.

CHINA

It burns nearly half the world's coal, mostly to support a 13-fold increase in electricity generation since 1980. Demand is still growing. So is public outrage over the filthy air in Chinese cities, which has been linked to 1.2 million deaths a year.

SHUOZHOU, CHINA
Amid the withered stalks of last year's corn, a farmer prepares for spring near a power plant in Shanxi Province. The facility, which supplies electricity to Beijing, 200 miles away, covers local fields, crops, and people with soot.

DATONG, CHINA
At a coal terminal in Shanxi Province workers pick rocks from low-priced coal as it moves past on a conveyor belt. Often working without masks that would protect them from coal dust, they earn three dollars for an 11-hour shift.

U.S.

The U.S. mines more than a billion tons of coal a year. Once it came mostly from underground mines in the East; now strip mines in the West dominate. Domestic demand has fallen lately, but exports to Europe and Asia have increased.

MADISON, WEST VIRGINIA
They call it mountaintop removal. For each ton of coal taken from the Hobet 21 mine, 20 cubic yards of mountain are blasted away, then dumped in valleys. Hundreds of square miles of Appalachian ridges have been dismantled that way.

PANORAMA COMPOSED OF TWO IMAGES.

NORFOLK, VIRGINIA
At the Lamberts Point Coal Terminal, railcars loaded with coal line up to fill waiting ships. Some 20 million tons of coal—about 2 percent of U.S. production—move through this terminal each year, most of it from Appalachia.

WRIGHT, WYOMING
The Black Thunder mine, one of the world's largest, covers 75 square miles of public and private land. Trucks the size of houses haul more than 90 million tons of coal a year to trains, which carry most of it to eastern power plants.

INDIA

It has 300 million people without electricity and the fifth largest coal reserves in the world. The pressure to produce coal is taking its toll on miners, many of whom work in illegal and enormously dangerous mines.

JHARKHAND, INDIA
A young boy carries a chunk of coal into the mining camp where he lives. His family will burn the coal to make coke—a cleaner and hotter-burning fuel—which they'll either sell or use themselves for heating and cooking.

JHARKHAND, INDIA
Northeastern India has a long history of coal mining, and fires ignited by mining accidents almost a century ago still smolder in deeply buried coal deposits. In this mining camp the air is thick day and night with smoke from coal fires.

MEGHALAYA, INDIA
A miner (left) works in one of hundreds of coal mines in eastern India that are neither sanctioned nor regulated by government. He lies on his back in low-ceilinged, unsupported passageways, without protective clothing, using a pick and shovel to load his cart. Coal is lifted out of the mine shaft two tons at a time (top) and trucked to a depot (above), where it is sorted by size and quality.

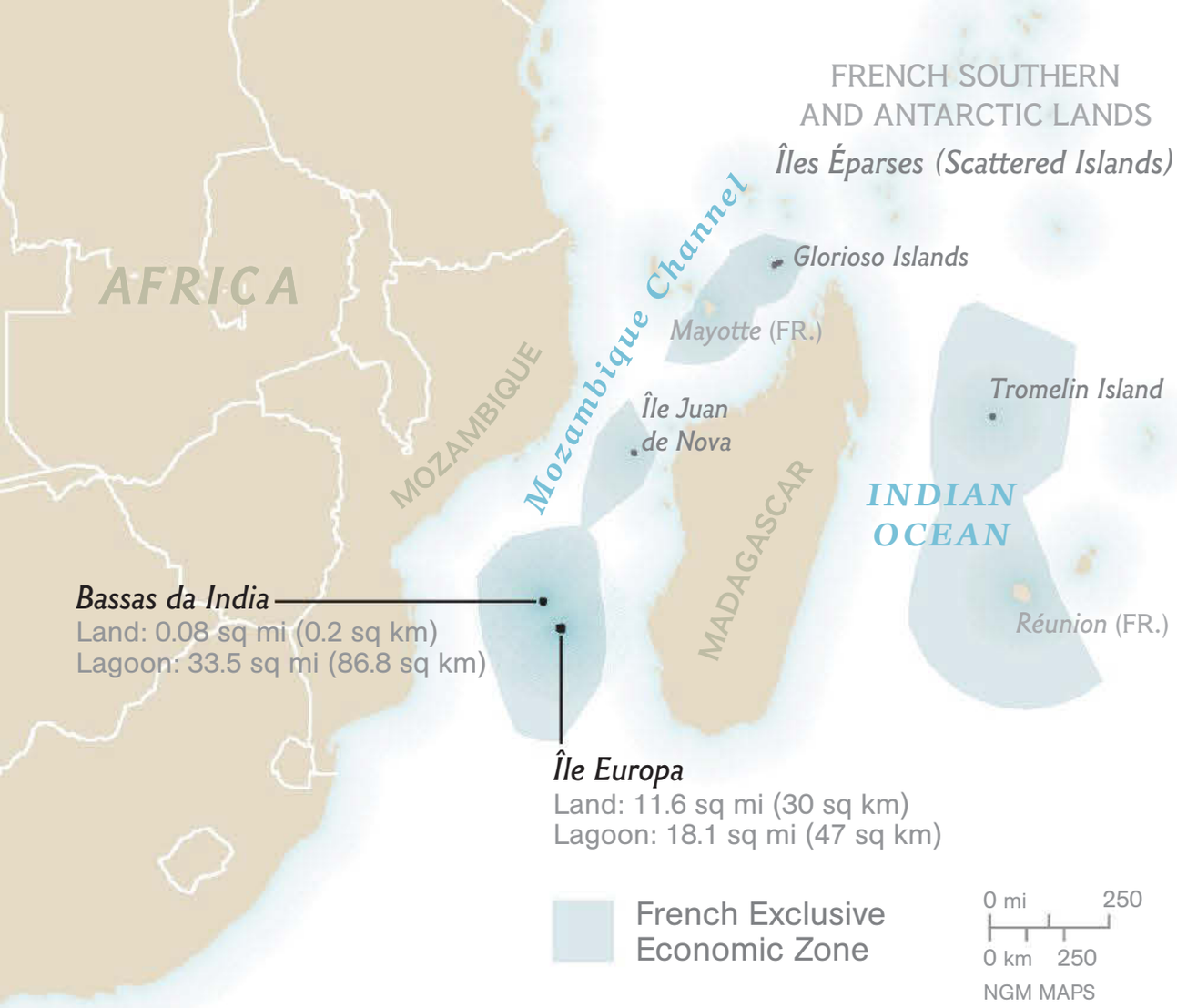
MEGHALAYA, INDIA
A coal miner climbs a shaky ladder to daylight. A 19th-century mine in the U.S. or Europe might have looked just as hellish; mines there are safer now. But coal's environmental costs have grown—and become global.

A Tale of Two Atolls

One of a pair of tiny French territories tucked between Madagascar and southern Africa provides a mating area for green turtles. The other is home to Galápagos sharks.

EUROPA Clutched in the embrace of her partner, a female green turtle glides through indigo seas at Europa atoll, a vital breeding area for this endangered species.

BASSAS Galápagos sharks, though named for the islands that furnished Darwin with insights into evolution, are found around tropical oceanic reefs worldwide. Almost all the sharks in the protected lagoon at Bassas da India are Galápagos sharks; the lagoon is thought to be a nursery for the species.



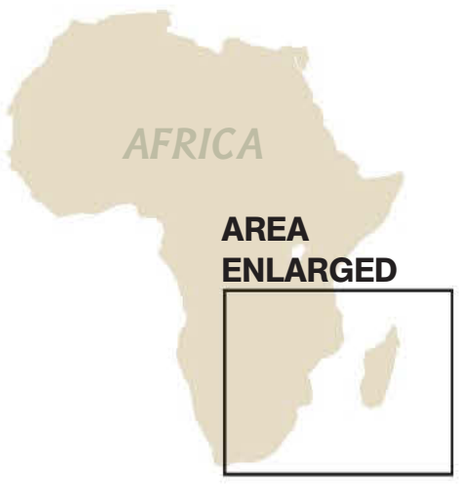
By Kennedy Warne

Photographs by Thomas P. Peschak

PICTURE TWO BOULDERS DANCING. That's an approximation of green turtle sex: two sumo-size behemoths clipped to each other's shells, finning languidly through the crystal waters of a coral reef. A reef such as the one that encircles Île Europa, off the southwestern coast of Madagascar, where on average more than 10,000 female green turtles congregate each year to mate, later going ashore to lay their eggs.

Green turtles have a reproductive strategy known as "scramble polygamy." Rather than expend energy defending a territory or engaging in combat, males focus their elephantine effort on finding an unattached female—or attempting to cut in on a mating in progress. Males have large claws on their flippers and tail, and use these to attach themselves to the shell of the female. Other males attempt to knock a successful paramour off his perch, jousting and biting and often wounding both members of the pair.

Occasionally a hormone-addled rival will clip on to the shell of the mounted male. "This is going absolutely nowhere for male number two," notes marine biologist Wallace J. Nichols. Nichols has seen stacks of up to four males, each clinging to the turtle in front. "When this sort of thing happens with earthworms in the garden, it's merely curious," he observes. "With 400-pound sea turtles, it's a circus."

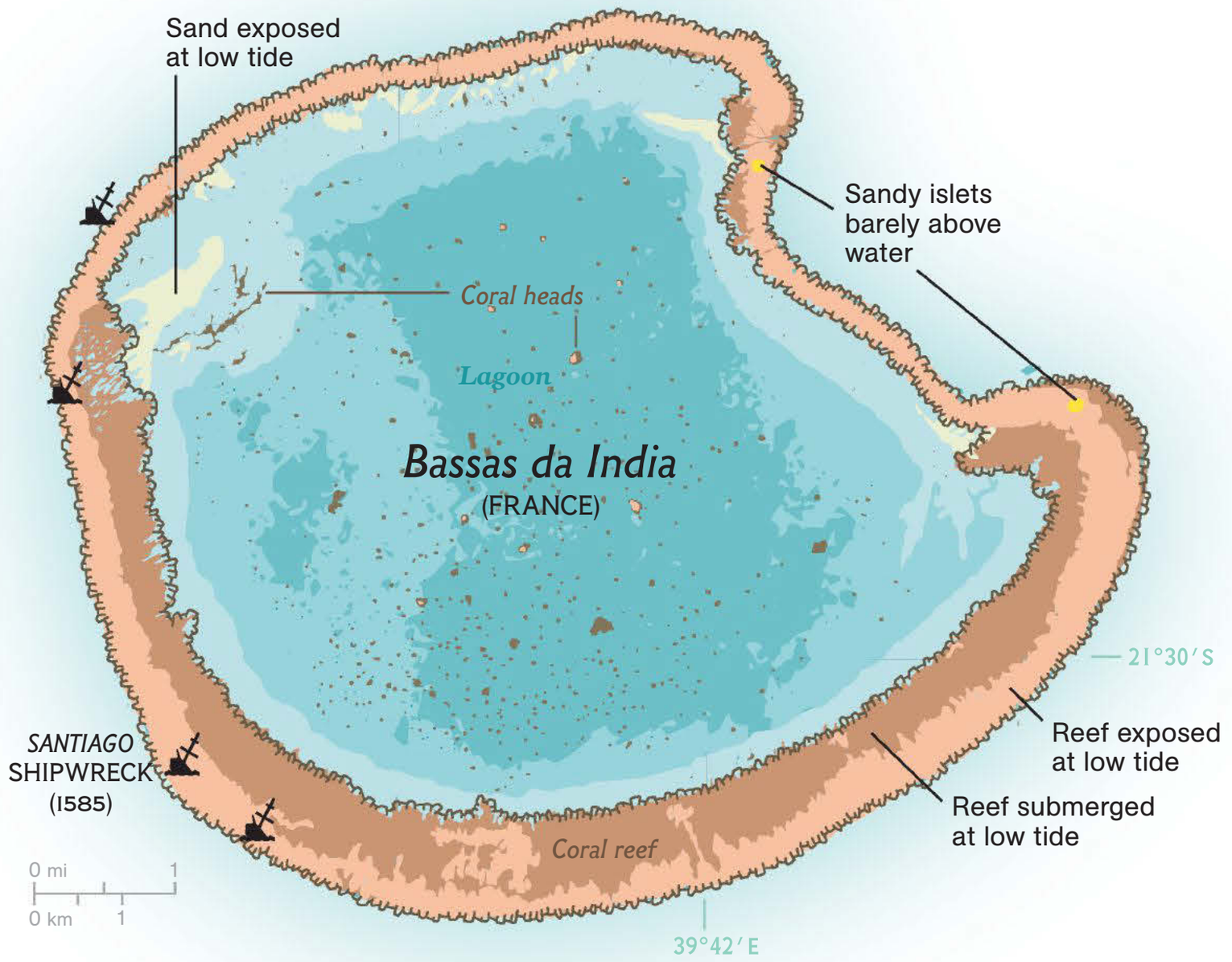


EUROPA'S TURTLE CIRCUS is rarely seen by human eyes. The island is a nature reserve, and its waters are protected. Like its neighbor, Bassas da India, 70-odd miles to the northwest, it is part of the Scattered Islands, five specks of land that ring Madagascar like moons. Remnants of the once mighty French colonial empire, they fly the Tricolor as part of the French Southern and Antarctic Lands.

French sovereignty, though contested by Madagascar and other states, is strategic. The total land area of the Scattered Islands is a mere 16 square miles, but their collective exclusive economic zone is 15,000 times greater—an expanse of ocean almost the size of Texas. Crucially for the islands'

BASSAS The lagoon is likely a haven for Galápagos sharks in their early years, protecting them from predation by adults of their species before they face the challenges of the open sea.

BASSAS
At high tide only a few rocks show above the waterline at Bassas da India. When the tide ebbs, it exposes a ring of coral 300 feet wide and six miles in diameter. This atoll is the summit of an undersea volcano that rises from the seabed 10,000 feet below the surface.



biodiversity, France curbs illegal fishing and turtle poaching. Military garrisons and a gendarmerie maintain a presence on several of the islands—Europa included—and naval ships patrol their waters.

ALTHOUGH EUROPA and Bassas da India lie close together in the middle of the Mozambique Channel, they are very different places. Europa is a scrub-covered island that is home not only to nesting turtles but also to a million breeding pairs of seabirds. Bassas is an atoll that barely shows above the waterline and has a shark-filled lagoon the size of Manhattan. Both are among the last vestiges of healthy marine ecosystems in the western Indian Ocean—sanctuaries for wild nature in depleted seas. "On the surface these places look like nothing—like insignificant dots," says marine biologist Thomas Peschak, who photographed this article. "But once you've dived here, you're spoiled for the rest of your life."

The two islands occupy an expanse of ocean whose vexing currents and eddies have challenged mariners for centuries. Today's marine scientists have found a way to study this environment without even going to sea. Because of the close ecological connection between seabirds and marine life, they can use birds as proxies for open-water species such as tuna. Many seabirds rely on these ocean-roaming hunters to drive prey to the surface, within reach of their bills and talons.

Boobies and terns form low-flying flocks that track marine life from just above the surface. These network foragers fan out from their roosts on land, keeping each other in sight, ever alert in case one should encounter prey. Other species track the trackers, soaring to high altitudes to survey the panorama. Frigatebirds are supreme among the high fliers. These exceptional

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Frequent contributor Kennedy Warne specializes in stories about nature and the environment. Thomas P. Peschak is director of conservation for the Save Our Seas Foundation, which facilitated his photographic coverage of the atolls.

EUROPA

A million pairs of seabirds, including sooty terns, red-footed boobies, and two species of frigatebird, breed on Europa, and several thousand green turtles nest on its beaches. Unlike Bassas da India, which is uninhabitable, Europa hosts French troops.

aerialists soar on thermals, rising up to a mile high to scan not just the sea but also the low-flying birds. When they spot a foraging flock, they swoop down on their jet-black, angular wings—seven feet from tip to tip—to snatch squid from the waves or take flying fish in midair.

At Bassas da India there are no trees for seabirds to roost in and no beaches where turtles can lay their eggs. Bassas is a young atoll, still forming on its parent volcano, a seamount that erupted from the seabed almost two miles below the surface. From the air it looks like a blue plate with a bite-size chunk missing from its northeast rim.

Where Europa has mangroves and a shallow lagoon that drains almost dry at low tide, Bassas has not a sprig of vegetation and a lagoon that's up to 45 feet deep—a giant tropical aquarium full of young sharks. Nearly all are Galápagos sharks, a species often found around tropical islands but rarely in the concentrations seen here. Biologists, puzzled as to why Galápagos sharks should be so predominant at Bassas, have suggested that the limited range of habitats available in the comparatively barren Bassas lagoon favors these sharks, whereas in Europa's lagoon the presence of mangroves and sea grasses offers habitat or refuge for other species. Bassas may offer a unique snapshot in a shark's life history—and an all-too-uncommon example of a healthy juvenile population of a heavily exploited species.

The ebbing tide at Bassas da India reveals the anchors of ships that have been wrecked on the reef over the centuries. In 1585 the *Santiago,* a 900-ton Portuguese vessel, split in two when it plowed into the reef in darkness. Imagine the horror as dawn revealed the passengers' plight—a disintegrating ship, an intimidating expanse of reef, the lifeboats washed away or broken. More than 400 perished, and a trove of bullion spilled from the ship's belly into the depths.

In the 1970s divers recovered some of this treasure: silver coins, bronze cannon, jewels, an astrolabe. But these are mere baubles compared with the real wealth of Bassas da India and Europa—not the bullion of ancient ships but the biodiversity that flourishes in these tiny islands. ◻

VIRGINIA W. MASON, NGM STAFF

SOURCES: TERRES AUSTRALES ET ANTARCTIQUES FRANÇAISES; DIRECTION RÉGIONALE DE L'ENVIRONNEMENT, RÉUNION; CIA; DIGITALGLOBE

BASSAS Young Galápagos sharks nose the camera in the lagoon. The relatively undisturbed reefs of the two atolls are marine baselines, says Thomas Peschak. “Other places in the Indian Ocean, all I see is what’s missing.”

EUROPA Few divers ever explore the reefs around Europa, which lies in a stretch of the Mozambique Channel known for its massive eddies, productive nutrient upwellings, meandering currents—and spectacular surf.

EUROPA The bumps and bites of turtle courtship (left) precede a mating that may last several hours, the male clinging to the shell of the female with his flippers and tail. Promiscuity is rampant, and hormone-juiced males will attempt to dislodge rival males from their partners.

Witnessing the birth of stars would require a telescope larger in diameter than many cities. Say hello to ALMA.

COSMIC DAWN

LIGHT FROM THE SETTING SUN DANCES ON ANTENNAS FORMING PART OF THE ATACAMA LARGE MILLIMETER/SUBMILLIMETER ARRAY (ALMA), HIGH IN CHILE'S ATACAMA DESERT.

A view of the colliding Antennae galaxies, 70 million light-years from Earth, combines visible light (blue) captured by the Hubble Space Telescope with never before seen swirls of interstellar gas revealed in a test image from the ALMA telescope.

By Yudhijit Bhattacharjee Photographs by Dave Yoder

ON A MAY MORNING TWO PICKUP TRUCKS PASSED THROUGH THE QUIET TOWN OF SAN PEDRO IN CHILE'S ATACAMA DESERT AND HEADED UP A MOUNTAINSIDE ON A DIRT ROAD. IT WAS 1994, AND THE FIVE MEN INSIDE THE TRUCKS WERE ON A PECULIAR QUEST: TO FIND THE HIGHEST, DRIEST, FLATTEST PLACE ON THE PLANET.

They had already spent a week and a half scouting other locations in the Atacama, one on the Argentine side of the desert. Now, guided by a map obtained from the Chilean military by one of the men, a Chilean astronomer named Hernán Quintana, they were searching for a route up to the Chajnantor plateau—at 16,400 feet, almost as high as the two base camps serving climbers on Mount Everest.

With the Andes Mountains forming a barrier to clouds gathering above the Amazon to the east, and the winds from the Pacific to the west picking up little moisture as they pass over the cold Peru Current (formerly called the Humboldt Current), the Atacama Desert is known to be among the driest places on Earth, with less than a half inch of rain a year on average. The desert's remoteness and inhospitably thin, dry air—ideal for observing the night sky—had already lured several large, multinational telescope projects. For the most part, these were designed to view the fraction of the cosmos visible at optical wavelengths—the portion of the light spectrum that the human eye can see. Quintana and his companions were scouting a location for a different kind of telescope, one designed to penetrate the curtains of dust and gas that shroud galaxies, swirl around stars, and stretch through the expanses of interstellar space. The project would require some 20 years and more than a billion dollars to design and build.

First, however, they had to find the right spot.

OBJECTS IN THE UNIVERSE radiate energy in various wavelengths, depending on how hot or cold they are. Exploding supernovae, for instance, are extremely hot; in addition to emitting visible light equal to that of billions of suns, they release shortwave, high-energy x-rays and gamma rays, detectable by specialized telescopes such as NASA's space-based Chandra X-ray Observatory. Toward the opposite, colder end of the spectrum are comets and asteroids, which shed infrared wavelengths longer than what our eyes and our optical telescopes can see.

Much of the universe is colder still. The clouds of dust and gas from which stars are made are only slightly warmer than absolute zero—the temperature at which atoms come to a standstill. The birth of planets occurs in similar settings, seeded by fragments of dust and gas that clump together within the swirling fog that rotates around newly born stars.

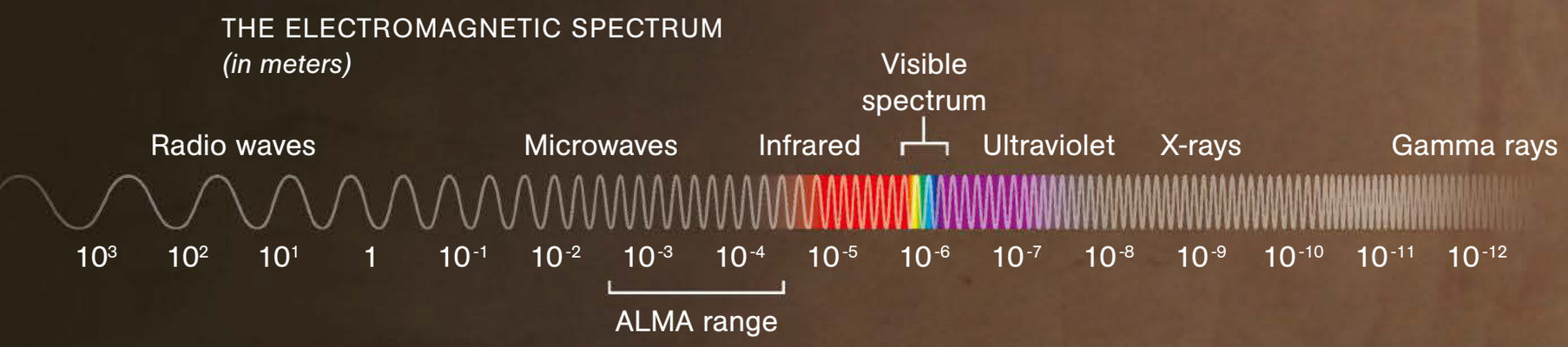
In the 1960s astronomers attempting to penetrate this "cold universe" quickly realized how challenging it was to use ground-based antennas to detect wavelengths in the millimeter and submillimeter range, even longer than infrared. Their first problem was how to cope with a gigantic amount of static. Unlike visible light, which travels through the planet's atmosphere without much interference, millimeter and submillimeter waves are absorbed and distorted by water vapor, which emits radiation in the same band of the spectrum, adding earthly noise to waves arriving from the heavens. Millimeter and submillimeter waves also carry far less energy than visible light does, producing a weak signal even in a radio dish with an enormous collecting area.

The solution scientists came up with was to arrange several antennas in an array on a site with very dry air, combining their signals so that they functioned together as a single

COLORIZED COMPOSITE IMAGE: ALMA (ESO/NAOJ/NRAO) AND NASA/ESA HUBBLE SPACE TELESCOPE. SOURCE: ESO

AN EYE ON THE HEAVENS

Like our own eyes, optical telescopes are tuned to see visible light. ALMA is designed to sense longer waves of electromagnetic radiation, roughly where the microwave and infrared bands meet. By operating at these millimeter and submillimeter wavelengths, the telescope can observe deep-space gas clouds and other dark, cold areas veiled to optical instruments. The most distant galaxies from Earth, whose light is stretched into longer wavelengths because the universe is expanding, are also within ALMA's sight.

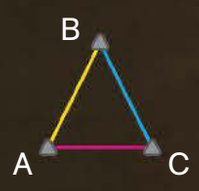


THE POWER OF TWO

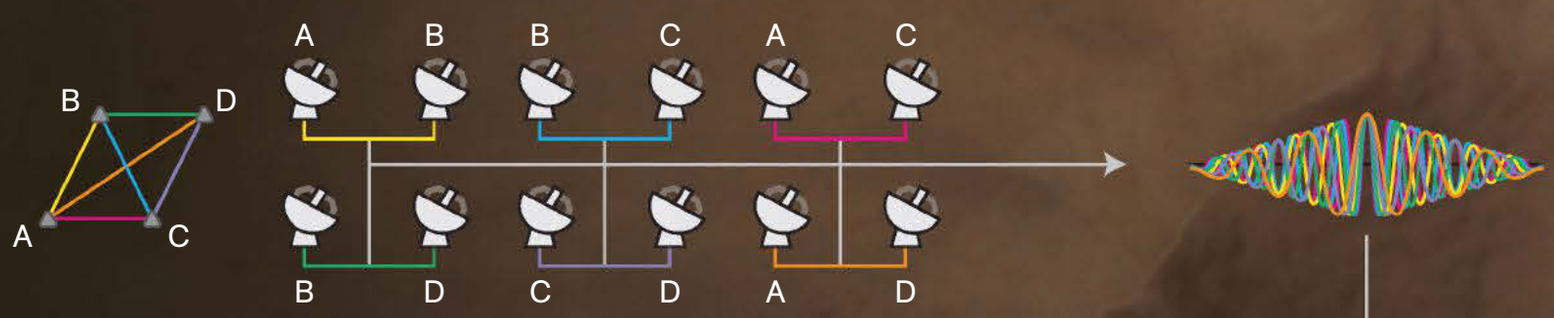
A single-dish telescope can detect faint signals, but its images are blurry. Interferometry, which combines signals from two dishes spaced a distance apart, produces higher resolution. The longer the distance, or baseline, the finer the details that can be resolved.

THE MORE THE BETTER

One long baseline can detect fine details; additional baselines reduce interference.



Expanding from two to three antennas creates three baselines.



Adding one more antenna doubles the baselines to six. Adding even more antennas further sharpens the signal and reduces the noise.

ALMA's 66 antennas can create 1,291 separate baselines, giving the telescope superb sensitivity and the ability to capture very fine details.

JASON TREAT AND VIRGINIA MASON, NGM STAFF; KIRSTEN HUNTLEY
SOURCES: CHARLES BLUE, JAMES J. CONDON, AND BILL COTTON, NRAO

SOUTH AMERICA

ALMA

CHILE

ALMA'S TEN-MILE-WIDE ZOOM

Elevation: 16,400 feet

Rearranging antennas on the wide plateau is like adjusting a camera's zoom. At maximum spread, shown here, the telescope focuses in on tight sections of sky and fine details. Clustering the antennas closer together is like using a wide-angle lens to take in broader swaths of sky.

Mt. Everest

Atacama Plateau (ALMA location)

Machu Picchu

12-meter antenna

Antenna pad

Baseline

Service roads

ALMA consists of two telescope arrays working together. Two massive transporters relocate antennas in the main array with submillimeter precision. The Morita Array (above), a separate group of 16 antennas built by Japan, targets large-scale structures in the universe.

Ten-mile diameter

As the last of 25 North American antennas rolls toward a docking pad (at lower right), the world's largest—and at $1.3 billion, costliest—ground-based telescope nears readiness. The joint American, European, and Japanese project will map unseen cosmic regions with unprecedented clarity.


DV-24
SCHEUERLE
BSXH 49

telescope. By the 1980s several small arrays were operating in Japan, France, and in the United States, in Hawaii and California. Soon technological advances made it possible to contemplate a far larger radio array, an enormous lens with vastly more resolving power—provided a site could be found that was high and flat enough to expand the distance between antennas to whole miles. And if the dishes were portable, the distance between them could be adjusted to change the sensitivity of the telescope to reveal fine detail. Placed far apart, they could zoom in to focus on a small target such as a disk of dust around a star. Bunching the antennas together would have the effect of zooming out, which would be useful for imaging large objects such as a galaxy.

Searching for an ideal setting for such a telescope, research groups from Europe, Japan, and the U.S. converged on the Atacama Desert.

HERNÁN QUINTANA, who had pored over the military maps of the desert for weeks before the expedition in the spring of 1994, suspected that only the high ground above San Pedro de Atacama would satisfy all the requirements. But it wasn't easy to get to.

"The trip was slow and painful, because the tires kept getting stuck in sand," remembers Riccardo Giovanelli of Cornell University, who accompanied Quintana, along with Angel Otárola from the European Southern Observatory (ESO) and Paul Vanden Bout and Robert Brown from the National Radio Astronomy Observatory (NRAO). Halfway up the road from San Pedro, Vanden Bout and Otárola's truck broke down. The others made it to the top of the Jama Pass.

"The sky was beautiful—it was the deepest blue one can expect to see," Giovanelli says. One of the astronomers had brought along an instrument to measure water vapor. The volume of vapor in the air was lower than the group had ever encountered anywhere. "There was no doubt in anybody's mind that somewhere nearby was the place," Giovanelli says. A short time later, on a second scouting trip, Brown found the actual site, a wide, expansive plateau at the bottom of Cerro Chajnantor, a nearby peak.

It was soon clear to all three international parties that by joining forces they could build a single array far more powerful than any one of them could alone. In 1999 the National Science Foundation and the ESO signed an agreement to work together. They settled on a plan to contribute 32 antennas apiece, each 12 meters in diameter, or about 40 feet. The Japanese agreed to provide 16 more antennas in a complementary array.

Thus began an almost two-decade effort to transform one of the world's loneliest spots into a bustling modern observatory. Land mines planted decades before by the Chilean military to deter incursions from Bolivia to the north had to be located and removed. Protracted negotiations were needed to persuade an oil company that was planning to run a pipeline through the site to reroute it. Prototype antennas were redesigned after testing in New Mexico. Costs mounted. Quarrels were joined and resolved. The NRAO and ESO couldn't agree on a single antenna design, in part because each side wanted to support manufacturers on its own shores; in the end they chose two designs and two suppliers for their share of the antennas, reduced to 25 from each of the agencies. Then there was the little town of San Pedro, which had just two telephone lines and a single gas station. "We had to assemble a little city on the mountainside in the middle of nowhere," says the NRAO's Al Wootten, the lead North American scientist on the project.

The first of the antennas—weighing more than a hundred tons—arrived from the U.S. at the Chilean port of Antofagasta in April 2007. Escorted by a convoy of police cars, a truck hauled the gigantic dish up the mountain, its progress occasionally interrupted by herds of llamas being shepherded across the road.

Over the next five years the dishes continued

This is Yudhijit Bhattacharjee's first story for National Geographic. *Dave Yoder photographed Florence's Duomo for the February issue.*

ALMA IS DESIGNED TO PENETRATE THE CURTAINS OF DUST AND GAS THAT SHROUD GALAXIES, SWIRL AROUND STARS, AND STRETCH THROUGH THE EXPANSES OF INTERSTELLAR SPACE.

to arrive. Setting them up to work collectively as a single telescope required astonishing precision. They would need to swivel together on command and point at the same target in the sky within a second and a half of one another. To merge their signals coherently, a massive supercomputer had to be installed on-site that was capable of adjusting, to within the width of a human hair, the distance the signals traveled through a cable from the antennas to the processing center—while compensating for the expansion and contraction of the cable due to temperature fluctuations.

ON A BRIGHT APRIL MORNING a panoramic view of the plateau offers a striking juxtaposition of the ancient and the modern. The brown expanse is studded with white dishes that look tiny against the sky's limitless azure backdrop. Up close, each of the 12-meter antennas towers above the ground, the dish's surface glinting in the sun. Operated remotely from a base camp, they swivel gracefully in unison at the click of a button, belying their massive weight. Two custom-made 28-wheel transporters, nicknamed Otto and Lore, stand ready to move them to new locations on the plateau as needed.

By the time it was officially inaugurated in March 2013, the Atacama Large Millimeter/submillimeter Array—ALMA—had already begun to deliver on expectations. The year before, with only 16 antennas in operation, researchers led by Caltech's Joaquin Vieira had peered through ALMA at 26 distant galaxies showing bursts of star formation. They were surprised to find that the galaxies were on average as far as 11.7 billion light-years away, meaning that their star production had been under way when the universe was barely two billion years old. Such frenetic star birth had previously been thought to have begun at least a billion years later.

Since ALMA's inauguration, there has been a steady stream of other discoveries. In July 2013 astronomers reported that the telescope's observations had helped solve a long-standing puzzle: why massive galaxies are so rare in the universe. ALMA's high-resolution images of the nearby Sculptor galaxy showed cold, dense gas billowing out from the center of the galactic disk. Astronomers concluded that the gas was being blasted out by winds from newly formed stars, a huge loss of starmaking material that could stymie the galaxy's future growth. If confirmed in other galaxies, the phenomenon could solve the mystery.

True to its promise, ALMA is also helping researchers understand how planets are born. Last year they reported on ALMA's images of a disk of dust circling a young star—a nursery of planets. The images revealed what appeared to be a dust trap within the disk: a sheltered region where little grains of dust could stick to one another and, grain by grain, grow large enough to seed a planet. This was the first ever glimpse into the start of the planet-forming process.

These observations are just the beginning. When all of the antennas come on line later this year, ALMA will conjure even finer details of galaxies and star systems. On an arid plateau a few miles from where shepherds once slept, our eyes will open upon an unseen universe. □

Tune in to *Cosmos: A SpaceTime Odyssey*, a new series on the National Geographic Channel on Monday evenings.

Legacy in Lace

The isolated villages of Brittany, in the northwest corner of France, were once known for their distinctive headdresses and costumes. Now a younger generation is continuing the tradition.

Plouguenast, Côtes-d'Armor

Each Breton ensemble is specific to a place: an individual village and sometimes the surrounding area, known as a *pays*. In these photos, taken in Brittany with a translucent backdrop, each outfit is identified by village and *département,* an administrative unit of modern France.

Photographs by CHARLES FRÉGER

CLIMBING OUT OF A TINY EUROPEAN CAR IS challenging enough; it's nearly impossible in a hat 13 inches tall. Yet Alexia Caoudal, 87, and Marie-Louise Lopéré, 90, manage to cantilever out of the backseat of a friend's silver Citroën with remarkable dignity, if not grace. Their host hurries to greet them with such smiling deference that they might be royalty.

Princesses they are not—the two women spent decades toiling in fish canneries. But Caoudal and Lopéré have achieved a certain celebrity in this bit of northwest France known as Bigouden country, in the Finistère region at the western edge of Brittany. They are the only women known to routinely wear the towering headdress, or *coiffe,* that was once a part of daily life here.

Age has bent their bodies, but the stiff lace stands tall atop their waves of white hair, like a lighthouse signaling: Here is a Bigouden woman.

Rostrenen, Côtes-d'Armor

This funeral garb has velvet and embroidery on the skirt, lace and ribbons on the sleeve ends.

There are dozens of Breton costumes, varying by village, occasion, and time period. The once simple caps used by peasant women for modesty and protection from the elements evolved into fantastic shapes and sizes in the 19th and 20th centuries, inspiring artists like Paul Gauguin. In those times the coiffe "was like an identity card," says Solenn Boennec, an assistant curator at the Musée Bigouden in Pont-l'Abbé. "It can reveal who you are, where you're from, and if you're in mourning for someone."

By the 1950s, however, most young women had abandoned the old style. Today it lives on in Breton rituals and in social groups called Celtic circles, where young people like the ones in these portraits train year-round to compete in full costume at summer dance festivals. They also sometimes participate in weddings and a traditional religious pilgrimage, called a *pardon,* during the feast of a local patron saint.

"It's seen as less old-fashioned now than when we were younger," says 20-year-old Apolline Kersaudy, who joined a Celtic group when she was six. "Other friends don't understand why we can't go on summer holidays with them. But the circle is more important."

Caoudal and Lopéré pull, comb, and pin their plaits up under a special black bonnet every morning, adding the lace top on Sundays and special occasions. Donning the full coiffe takes nearly half an hour and seems wildly impractical on this wet and windy edge of the North Atlantic. Is it comfortable? "We're used to it," says Caoudal, shrugging. Like others of their generation, the women speak a mixture of French and Breton, the regional language. Full of colliding consonants, it's similar to Welsh, a reminder of Brittany's Celtic heritage.

Today's youth guard that heritage with a fierce pride. "I am Breton, and I am French," says Malwenn Mariel, 17, a member of the Pont-l'Abbé Celtic circle. "But I am Bigouden first."

A Bigouden woman is frank and unafraid, the girls in the circle say. She doesn't let anyone walk all over her. Like her headdress, she is a tower of strength. *—Amanda Fiegl*

Pont-l'Abbé, Finistère

The high point of Breton fashion is the *coiffe,* or headdress—and the most striking coiffe is that of the area around Pont-l'Abbé.

Guéméné-sur-Scorff, Morbihan

Châteaulin, Finistère

Cesson-Sévigné, Ille-et-Vilaine

Batz-sur-Mer, Loire-Atlantique

St.-Nicolas-du-Pélem, Côtes-d'Armor

Pride and Prejudice

Though covering only about 10,500 square miles, Brittany is the kind of place where local pride runs so deep that villagers will tell you a town ten miles away is "nowhere nearby." In earlier times residents of different Breton communities could be identified by their distinctive costumes—and also mocked for them. People in neighboring villages gave teasing nicknames to one another's headdresses, says Jean-Pierre Gonidec, collections manager at the Breton Museum in Quimper. The towering Bigouden coiffe, for instance, is still called *le pain de sucre*—the sugarloaf. Other coiffe nicknames: wheelbarrow and sardine head.

St.-Évarzec, Finistère

The wings of this coiffe are delicately pinned down and heavily starched to hold their shape. Even light mist will deform them.

Fouesnant, Finistère

The forerunner of this coiffe was famous in the late 1800s due to the attention of the Pont-Aven school of artists, Paul Gauguin in particular.

Pontivy, Morbihan

The fashion in Pontivy was sober. Decorations were confined to embroidery on the apron and sometimes on the coiffe.

Île de Bréhat, Côtes-d'Armor

The embroidery on this shawl is too fancy for a funeral, although it could have been worn at the end of a prolonged period of mourning.

Le Croisty, Morbihan

The dress at right reflects the fashion of 1900. As in other parts of Brittany, the apron, of silk or satin, is colored if worn by a young woman.

Wild Obsession

The perilous attraction of owning exotic pets

John Matus bought Boo Boo impulsively as a cub. Last summer the Ohio man gave her to a wildlife sanctuary. “She needs to be with her own kind,” he says. “It’s a lonely life.”

By Lauren Slater
Photographs by Vincent J. Musi

All across the nation, in Americans' backyards and garages and living rooms, in their beds and basements and bathrooms, wild animals kept as pets live side by side with their human owners. It's believed that more exotic animals live in American homes than are cared for in American zoos. The exotic-pet business is a lucrative industry, one that's drawn criticism from animal welfare advocates and wildlife conservationists alike. These people say it's not only dangerous to bring captive-bred wildlife into the suburbs, but it's cruel and it ought to be criminal too. Yet the issue is far from black or white.

At least not to Leslie-Ann Rush, a horse trainer who lives on a seven-acre farm outside Orlando, Florida, a place where the wind makes a rustling sound when it whips through the palms. Rush, 57, who has a kind face and hair the color of corn, breeds and trains gypsy horses she houses in a barn behind her small petting zoo, a wire enclosure where three male kangaroos, four lemurs, a muntjac deer (originally from Asia), a potbellied pig, a raccoon-like kinkajou called Kiwi, and a dog named Dozer all live—the lemurs leaping freely, the kangaroos sleeping on their sides, the petite pig rooting in the ground, the Asian deer balancing its rack of antlers on its delicate head.

Rush weaves in and around her exotic pets with ease and cheerfulness and Cheerios, doling them out to the lemurs. They thrust their humanlike hands into the open boxes and draw out fistfuls of O's, which they eat almost politely, one by one, dining daintily while the drool gathers in the corners of their mouths.

Rush has a ring-tailed lemur, Liam; two ruffed lemurs, Lolli and Poppi; and a common brown lemur named Charlie. While many lemurs are threatened, the ruffed lemurs are considered critically endangered in the wild. Rush believes that by caring for these captive-bred creatures she is doing her part to help keep lemurs alive on Earth, and she cares for her animals with a profound commitment that consumes her days and even her nights. As darkness falls, she moves from the small enclosure into her home and takes her favorite lemur with her; he shares her bed, coiled up on a pillow by her head.

Because kangaroos are active typically at dawn and dusk, the animals look lazy in the daylight, dun-colored beasts lying on their sides in cylinders of sun, their thick tails trailing in the dry dirt. But come evening they hop up on their hind legs and press their faces against the large glass window, looking in on Rush in her home:

In 2011 Terry Thompson released 50 of his exotic pets from their cages and then killed himself. Deputies outside Zanesville, Ohio, shot the animals dead. At the time Ohio did not require a license or permit for exotic-pet ownership.

AP IMAGES

In response to Ohio's strict new law, Mike Stapleton is building a larger enclosure for his five tigers. He doesn't get into the cage with them: "You never know when that instinct they have is going to kick in."


“Nobody can tell me that their cat is 100 percent safe.”
—Mike Stapleton

Sasha, a cougar, is “the love of my life,” says Mario Infanti, who underwent more than a thousand hours of training before he acquired his first wild cats. The Florida musician had Sasha declawed when she was a month old, but “she can still bite.”

“I’ve been bitten
a lot. After 60,
I stopped counting.”

—Albert Killian

A Burmese python entwines Albert Killian in the Florida home he shares with 60 snakes. Tags noting the proper antivenom—and the nearest hospital that carries it—are posted next to venomous pets.

Let me come in, they seem to say. Rush does not let them in, although she did when they were babies. "I have all of these amazing animals of different species, from different continents, and the thing is, they play together," she says, and she sweeps her hand through the air, gesturing to her multicolored menagerie sunning, sleeping, snacking. She has filmed and posted videos of them playing on YouTube, the lemurs leaping over the kangaroos, which hop and twirl and chase the primates around the yard.

Despite occasional reports of wild kangaroos attacking humans in Australia, Rush's pets display not a hint of aggression. This may have something to do with the fact that kangaroos are naturally somnolent during daytime hours, and it may also have something to do with the fact that Rush's kangaroos are no longer truly wild: They were bred in captivity; two of them have been neutered; they are used to human contact. Rush raised each kangaroo in diapers, bottle-fed it, and, touching the sleek suede fur continually, accustomed each animal to human hands.

They take the uncivilized into society and in doing so assert their power.

The $35 that Rush charges to visit what she calls her Exotic Animal Experience helps defray the costs involved in keeping her pets. Some exotic-animal owners spend thousands a year on fresh meat, for carnivores that dine daily on raw steak, for primates—omnivores with complex dietary needs—for snakes, which eat rat after rat after rat. In Rush's case her kangaroos consume huge quantities of grain, while the lemurs eat mounds of fruits and vegetables.

Rush herself lives a lean life, much of her own money poured into feeding her herd. And then there's her time. She puts abundant hours into caring for her exotics. "They're 24/7," she says, and then goes on to add, "but they're my family. They need me. I can't explain to you what that feels like. I wake up every morning and come out here, and all my animals come rushing up to greet me. I feel loved, and that feels great.

"My family," she repeats, and a shadow sweeps across her face. "All my life," she says, "people have let me down. My animals never have."

PRIVATELY OWNING exotic animals is currently permitted in a handful of states with essentially no restrictions: You must have a license to own a dog, but you are free to purchase a lion or baboon and keep it as a pet. Even in the states where exotic-pet ownership is banned, "people break the law," says Adam Roberts of Born Free USA, who keeps a running database of deaths and injuries attributed to exotic-pet ownership: In Texas a four-year-old mauled by a mountain lion his aunt kept as a pet, in Connecticut a 55-year-old woman's face permanently disfigured by her friend's lifelong pet chimpanzee, in Ohio an 80-year-old man attacked by a 200-pound kangaroo, in Nebraska a 34-year-old man strangled to death by his pet snake. And that list does not capture the number of people who become sick from coming into contact with zoonotic diseases.

The term exotic pet has no firm definition; it can refer to any wildlife kept in human households—or simply to a pet that's more unusual than the standard dog or cat. Lack of oversight and regulation makes it difficult to pin down just how many exotics are out there. "The short answer is, too many," says Patty Finch of the Global Federation of Animal Sanctuaries. It's estimated that the number of captive tigers alone is at least 5,000—most kept not by accredited zoos but by private owners. And while many owners tend to their exotic pets with great care and at no small expense, some keep their pets in cramped cages and poor conditions.

Commercially importing endangered species

Lauren Slater is the author of The $60,000 Dog: My Life With Animals. *Vince Musi often photographs animals, domesticated and otherwise.*

into the United States has been restricted since the early 1970s. Many of the large exotic animals that end up in backyard menageries—lions and tigers, monkeys and bears—are bred in captivity. Today on the Internet you can find zebras and camels and cougars and capuchins for sale, their adorable faces staring out from your screen; the monkeys with their intelligent eyes; the big cats with their tawny coats. And though such animals are no longer completely wild, neither are they domesticated—they exist in a netherworld that prompts intriguing questions and dilemmas.

From his experience in providing sanctuary for exotic animals in need of new homes, often desperately, Roberts says that exotic-pet owners tend to fall into multiple overlapping categories. Some people treat their animals, especially primates, as surrogate children, dressing them up in baby clothes, diapering them, and training them to use the toilet. Some own exotics as symbols of status and power, the exotic animal the next step up from a Doberman or pitbull. There are impulse buyers who simply could not resist purchasing a cute baby exotic. Still others are collectors, like Brandon Terry, who lives in Wake County, North Carolina, in a one-bedroom apartment with 15 snakes, three of them venomous. And then there are wild animal lovers who may start out as volunteers at a wildlife sanctuary and end up adopting a rescued animal in need of a home.

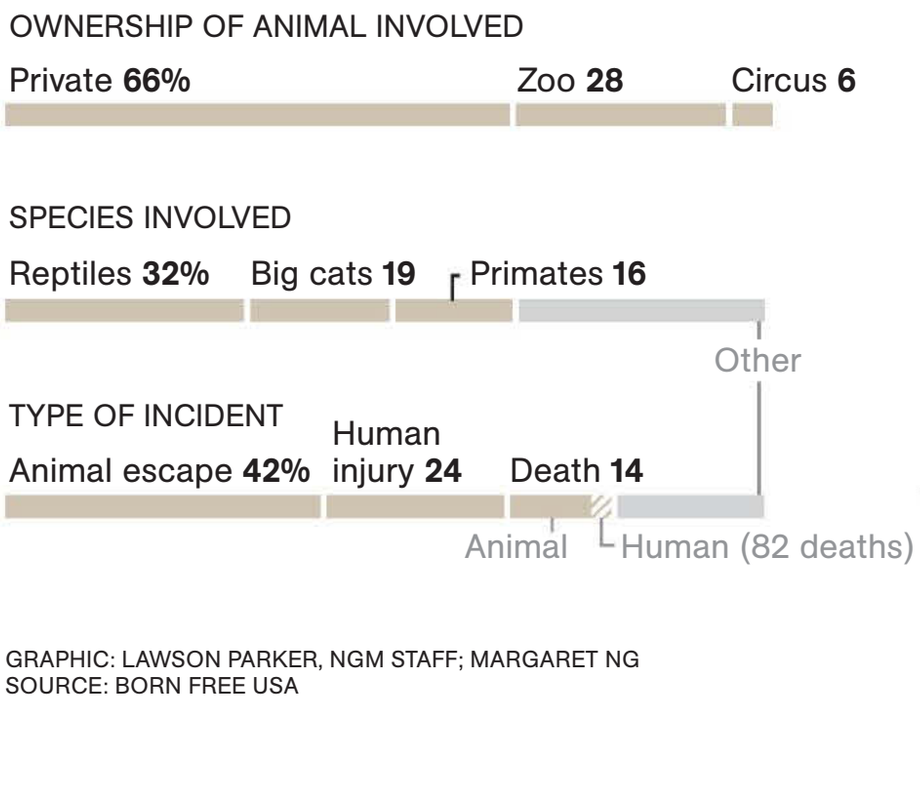
Denise Flores of Ohio explains how she acquired her first tiger. "I went to a wild animal park one day, and someone put a baby tiger in my lap. My heart melted; it just melted. I was hooked," says Flores, who ended up caring for eight rescued big cats, including two white tigers so beautiful they looked like fluid ivory.

Some people seek wild animals as pets as a way to reconnect with the natural world. They believe their exotics set them apart, the relationship made all the more intense by the unintended social isolation that is often the result of having an unpredictable beast as a companion. "Yes, of course my exotics make me feel unique," Rush says. Though anyone can own a cat or dog, exotic-pet owners take pleasure in possessing an animal that has, for hundreds of thousands of years, refused the saddle of domestication: They take the uncivilized into society and in doing so assert their power.

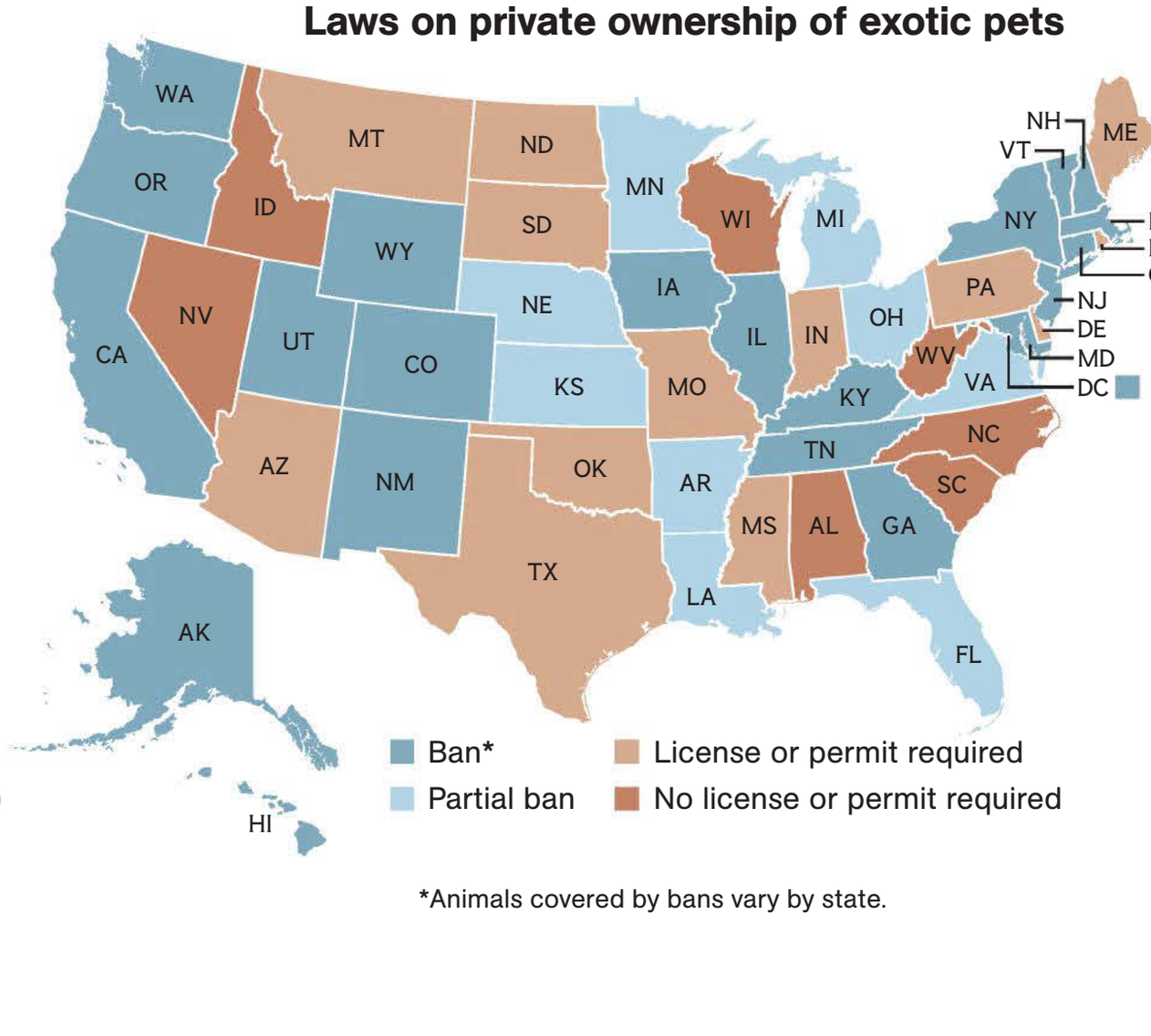
"I wanted something different, something unusual," says Michelle Berk, formerly of Palisades, Florida, who bought her kinkajou, Winnie, on craigslist. "She was there for me to make my own. We didn't get a dog because there's nothing cool or outstanding about owning a dog. A

Exotic-pet incidents 1990-2013

Born Free USA has tracked 2,000 incidents involving wild animals held in captivity. Due to incomplete reporting, the database is limited.



Laws on private ownership of exotic pets



GRAPHIC: LAWSON PARKER, NGM STAFF; MARGARET NG
SOURCE: BORN FREE USA

*Animals covered by bans vary by state.

Ohio veterinarian Melanie Butera took in Dillie after the blind farm deer's mother rejected her. Dillie used to sleep with Butera but now has her own room. "She's treated like a princess," says Butera.

Watch a video of Dillie's story on our digital editions.

After her first capybara died of liver failure, Melanie Typaldos bought Garibaldi Rous. The Texan was attracted to the giant rodents, which tend to die in captivity, after seeing wild ones in Venezuela.


“You earn the love of an animal like this. Not like a dog, with its thousands of years of programming.”
—Melanie Typaldos
NO DIVING
NO DIVING

kinkajou—now that seems untouchable. And who doesn't want the untouchable? They say don't touch it, so you want to touch it."

TIM HARRISON UNDERSTANDS the allure of owning exotic pets. Thirty-two years ago he worked as a public safety officer in the city of Oakwood, Ohio, and kept a menagerie in his house. He had snakes wrapped around lamp poles. He had rhesus monkeys leaping from counter to couch. He had lions sunning themselves on his gravel driveway. He had capuchins and bears and wolves, which were his favorites.

The delusion, rooted in a desire to commune with wild animals, lingered long after the beasts were gone.

After a hard day of chasing criminals or a boring day of ticketing cars, Harrison would change out of his uniform and drive home to his animals. He always went to the wolves first. His body aching, his mind numbed, he'd let the canines come to him, weaving around his legs. He'd drop down on his knees and then lie flat on his back, the wolves clambering over him. "I would just lie there and let them lick me," Harrison says, "and it was one of the best feelings in the world."

Now the animals are gone. Harrison will never again own anything wild or exotic. He believes ownership of all potentially dangerous exotic animals should be banned and is working to make that happen. He underwent a profound transformation, his entire outlook shattered and put back together again in a new way.

What happened is this: After decades of being an exotic-pet owner, Harrison went to Africa. He drove over the open plains and grasslands, and he can remember, all these years later, the giraffes' long lope, the lions' hypnotic canter, the elephants sucking water up their trunks and spraying themselves so their hides glistened. Harrison gazed upon these wild animals, and he says it was as if his eyes had been blistered shut and were suddenly opened as he witnessed these mammals moving in such profound harmony with their environment that you could hear it: a rhythm, a pulse, a roar. This, Harrison suddenly realized, was how wild animals are supposed to live. They are not supposed to live in Dayton or any other suburb or city; they are creatures in and of the land, and to give them anything less suddenly seemed wrong.

Harrison says he understood then that he didn't really own wild animals. What he had back in Dayton was a mixed-up menagerie of inbreeding and crossbreeding that resulted in animals that had almost nothing to do with the creatures before him now. He felt that he'd been no better than a warden and that he needed to change his ways. When he returned to Ohio, one by one he gave up his beloved wolves and primates and cats and handed them over to sanctuaries where they'd at least have safety and space. It hurt him to do this. He knew his wolves so well he could howl a hello, and a goodbye.

Today Harrison is retired from the police force. He puts as many hours as he can into Outreach for Animals, an organization he helped found to rescue exotic pets and place them in one of the sanctuaries he trusts. Many of the so-called wildlife sanctuaries in this country are actually using their animals to make a profit, commercially breeding them or allowing public contact. The few that operate solely for the benefit of the animals are already overloaded, says Vernon Weir of the American Sanctuary Association, an accrediting organization. "I have trouble finding space for wolf-dog mixes, potbellied pigs, some species of monkeys—many retired from use in research—and all the big cats and bears," Weir says. "A good sanctuary will take in only what they can afford to care for."

Harrison's agency fields hundreds of calls a month from law enforcement officials dealing with an escaped animal or owners overwhelmed by the cost and responsibility of an animal's care.

He has been on more than a hundred big cat rescues in the past year and over his lifetime has rescued close to a thousand exotic felines. He was there when a man in Pike County, Ohio, named Terry Brumfield finally agreed to give up his beloved but ill-kept lions. He is currently working with a man who owns a bear that bit off his finger. The owner can't yet bring himself to let the bear go.

"I meet people where they're at," says Harrison. "If an owner isn't ready to give their exotic up, I help them care for the animal in the best way possible. I help them build a better enclosure or get the best kind of feed. I don't judge. My hope is that, with the right kind of support, the person will eventually see that owning this animal is a dangerous drain and will voluntarily choose to give it up."

Harrison feels empathy for wild animal owners, whose affection he so well understands. He loved his animals. He believed, as most owners do, that his animals loved him. He believed that having a thriving menagerie made him special. "But I was deluded," he says. "I used to believe there was no animal I could not tame, no animal I was unable to train, and that any animal living under my roof was receiving the best of care." The delusion, rooted in a deep desire to commune with wild animals, has lingered long after the beasts were gone. Every time he participates in a rescue he has to stop himself from taking the animal home. "I try to keep my contact with the animals I rescue to a minimum," Harrison explains, "because my addiction can come back at a moment's notice."

THE STATE OF OHIO HAS become ground zero for the debate over exotic-animal ownership, and here's why: In October 2011, outside the city of Zanesville, in Muskingum County, a man named Terry Thompson let 50 of his wild animals, including lions and tigers, out of their cages and enclosures before killing himself. The local sheriff's department had little choice but to shoot most of the animals, which were dodging cars, loping across backyards, and posing a threat to public safety. Prior to the Zanesville incident, Ohio was one of a handful of states that required no license or permit to keep an exotic or wild animal as a pet.

The Zanesville tragedy woke Ohio up. In response to the outcry over the sight of exotic carcasses lined up near Thompson's property, the governor of Ohio signed an executive order cracking down on unlicensed animal auctions. The state now requires owners of "dangerous exotic animals" to have a permit, to microchip their pets, to establish a relationship with a veterinarian, and to buy insurance.

"I couldn't afford the insurance," Flores says, and so she sent her big cats to live in accredited sanctuaries, which is exactly what state officials hoped would happen. "These are beautiful animals, yes, but let me tell you," says Flores, "I had the common sense to know to never get in the cage with them. I'd pet them through the bars, if that. That was all."

Sheriff Matthew Lutz was the one who gave the order to shoot the animals after Thompson released them from their cages. The incident continues to haunt him. He has joined forces with animal rights activists who have lobbied for years, to no effect so far, for a federal law that would prohibit the private possession and breeding of large cats except by zoos and other registered facilities.

Like Rush, many exotic-pet owners and private breeders say they are motivated by a desire to preserve and protect threatened species. "Climate change and human population growth could wipe out a species in record time, so having a backup population is a good idea," says Lynn Culver, a private breeder of felines and executive director of the Feline Conservation Federation who believes that "those who do it right should have the right to do it."

But advocacy groups like Born Free USA and the World Wildlife Fund say that captive breeding of endangered species by private owners—whether for commercial, conservation, or educational reasons—serves only to perpetuate a thriving market for exotic animals. That, in turn, results in a greater risk to animals still living in their natural habitat. Conservation efforts

“My life is completely about the animals,” says Leslie-Ann Rush, a Florida horse trainer. “I rarely leave them overnight or take a vacation.” She raised her kangaroos and lemurs from infancy.


LEMURS

“I wouldn’t advise anyone to get a chimp. Exotic animals shouldn’t be part of the pet trade.”

—Pamela Rosaire Zoppe

Florida animal trainer Pamela Rosaire Zoppe bought Chance from pet owners who could no longer keep him. He now appears in Hollywood films. “Chimps are so intelligent that they get bored,” she says.

should focus on protecting animals in the wild, they assert, not on preserving what are often inbred animals in private zoos.

If a federal law ever passes, violators could face a fine and time in jail, as well as have their animal confiscated. That prospect enrages some exotic-animal owners, who argue that the number of incidents involving injuries from exotic pets pales in comparison to the number of people who visit the emergency room for dog bites each year.

"Placing bans on wild animal ownership will only increase the population of illegal exotics

When we keep wild animals as pets, we turn them into something for which nature has no place.

out there," says Zuzana Kukol, who co-founded REXANO (Responsible Exotic Animal Ownership) to oppose bans on the private ownership or use of animals. "Bans do not work. We've seen this with alcohol and prostitution."

Kukol and co-founder Scott Shoemaker live on ten acres of land an hour's drive from Death Valley, in the state of Nevada. They own two bobcats, two African lions, two cougars, four tigers, one serval, and one ocelot. They point out that wild animal ownership has existed throughout history and in all cultures—"by monarchs, kings, monks, nomads, and peasants"—and insist that most owners today treat their animals well and keep them from harming people. When it comes to risk and its management, she is very clear: "I'd rather die by a lion than by some stupid drunk driver."

Local people, including farmers, give the couple their ailing cows and horses, which Shoemaker kills with a simple gunshot to the head, then butchers into small pieces and feeds to the menagerie, including Kukol's favorite pet, a male African lion named Bam Bam. She has always gravitated more toward animals than people. "Ever since I was a little girl, I wanted to surround myself with animals," she says. "I never wanted children."

It's true that even in states where wild animal ownership is explicitly banned, existing laws are not well enforced. The market for exotics is so alive and thriving that to call it underground is a bit misleading. "The worst offenders are the tiger petting zoos that churn out 200 cubs a year so people can have their picture taken with them," says Carole Baskin of Big Cat Rescue, an accredited sanctuary.

At the raucous auctions held in muddy fields or paved parking lots, auctioneers hold out adorable tiger cubs with scrumptious soft scruffs or display tiny chimps in baseball hats and T-shirts that say, "I (heart) you." But people don't realize that all too soon that adorable tiger will outgrow its role as family pet and end up confined in a chain link enclosure.

It's backyard breeders that Tim Harrison believes are to blame for most wild animal abuse. He's been to auctions where cages are stacked one on top of the other, cramped with cougars and other big cats, mostly cubs; the tents awhirl with people whose pockets bulge with cash; snakes and primates being sold for thousands of dollars. The parking lots are filled with everything from shining Cadillacs to rusted trucks, the public pouring in to see and touch.

The breeders stand to make hundreds of thousands of dollars during an auction. They coach their auctioneers—the middlemen—to tell prospective buyers that their animals, usually babies, are harmless, and they are correct. "The problem comes," says Harrison, "when the animal reaches sexual maturity and its natural predator instinct kicks in."

Remember Michelle Berk and her kinkajou? Like so many other wild animal stories, Winnie's came to a sad end. For years Berk kept the kinkajou in peace, but when the animal went into her first heat, her behavior changed. She tried to eat her own tail as Berk and her family tried to protect themselves while stopping the kinkajou

from tearing herself to pieces. After that Berk turned Winnie over to a sanctuary. "It's like we lost a child. She'll always be our baby. Now she has gone to a place where she'll finally get to be a kinkajou," says Berk, who seems at peace with the decision. "I've learned that Winnie never really needed us. She didn't need to be our pet. She didn't need to be locked up. We got her because we needed her."

So yes, the infant animals are docile, but docile is different from domesticated. Of all the large land mammals that populate the planet, just over a dozen have been successfully domesticated. No matter how tamed or accustomed to humans an undomesticated animal becomes, its wild nature is still intact.

When making the case against exotic-pet ownership, animal rights advocates tend to highlight the dangers these formerly wild creatures pose to humans; wild animal owners underscore the inherent rights of humans to own exotics. Back and forth the argument goes, but what can get lost is what's best for the animals. If only it were possible to look at the issue from the animal's point of view.

YET PERHAPS WE NEED only look more closely, with our own human eyes, at even a model example of responsible wild animal ownership. Here we are, back at the ranch owned by Leslie-Ann Rush, the marsupials still snoozing in the sun, the pig still rooting in the earth, the fruit trees heavy with papayas.

In all ways Rush has done a fantastic job. The enclosure where she keeps her animals is clean. Despite the financial pressures, they are well fed and content. She is 100 percent committed and, on top of that, has managed to carve out for herself a life that suits her, a sustaining interdependent community of breathing beings, and this is no small thing.

Like most exotic owners I spoke with, Rush does not believe her animals pose a danger to herself or anyone else. "I don't have predators," she says. "I'm not *that* kind of wild animal owner." But perhaps danger to humans is not really the point.

A rabbit runs through the yard, a newcomer, or simply suddenly visible. The potbellied pig sniffs and snorts. One kangaroo lifts a lazy eyelid and then lowers it and starts to slumber again. Only the youngest kangaroo is awake, and now, suddenly, he perks up. His ears fork forward and his eyes take on a sheen.

Hauling himself up on his hind legs, he sniffs the pig's mottled hide as it trots by, then starts to hop behind the animal, lowering his pointed nose to get a whiff of the pig's rear. The pig turns around and snarls. The kangaroo, the youngest one, which hasn't been neutered, doesn't seem to understand the meaning of the snarl—why would he, since he's been raised to comprehend not animal but human language—and continues to pursue the pig, which picks up speed. The kangaroo is now in hot pursuit, trying to mount the pig.

"Look!" Rush says. "They're playing!" But the animals do not seem to be playing. The pig's snarl grows more threatening. There is, all of a sudden, in what was a peaceful enclosure, a series of misunderstandings. Although it seems evident to me that the kangaroo is trying to mate with the pig, Rush later tells me it was grooming. Whatever is happening, the pig is having no part of it and trots away as fast as his little legs will go. Of course, a kangaroo cannot successfully mate with a Vietnamese potbellied pig. Yet here, in this wired enclosure, the natural order has been altered.

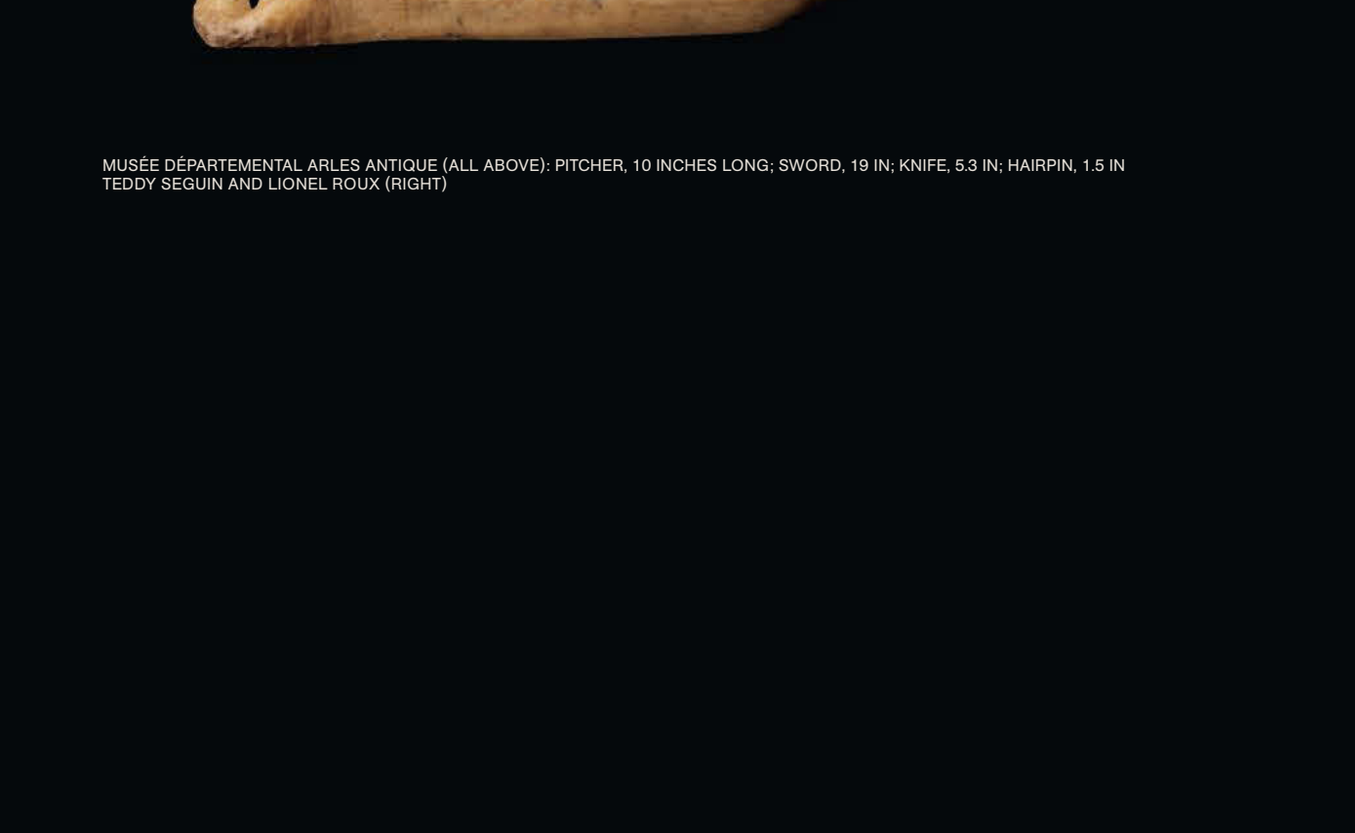
Adam Roberts of Born Free USA says his organization's mission is to keep wildlife in the wild, where it belongs. When humans choose to keep what are supposed to be wild animals as pets, we turn them into something outside of wild, something for which nature has no place. In the famous children's book *Where the Wild Things Are,* a boy sails on a boat to an island where he dances with beasts born from his own imagination. In the end what we learn from exotic-pet ownership is that when you take the wild out of the wild, you eradicate its true nature and replace it with fantasy—the fantasy being ours, we humans, the animals at once the most and the least tamed of all. □

An ancient wreck tells the tale of

Romans in France

Built for river commerce in the first century A.D., a 102-foot-long Roman barge was lifted in 2011 from the Rhône River in Arles, France. Virtually intact after two millennia in the mud, the boat went on display last fall in the local antiquities museum. A marble Neptune, also found in the river, watches over it.

COMPOSITE IMAGE; MUSÉE DÉPARTEMENTAL ARLES ANTIQUE



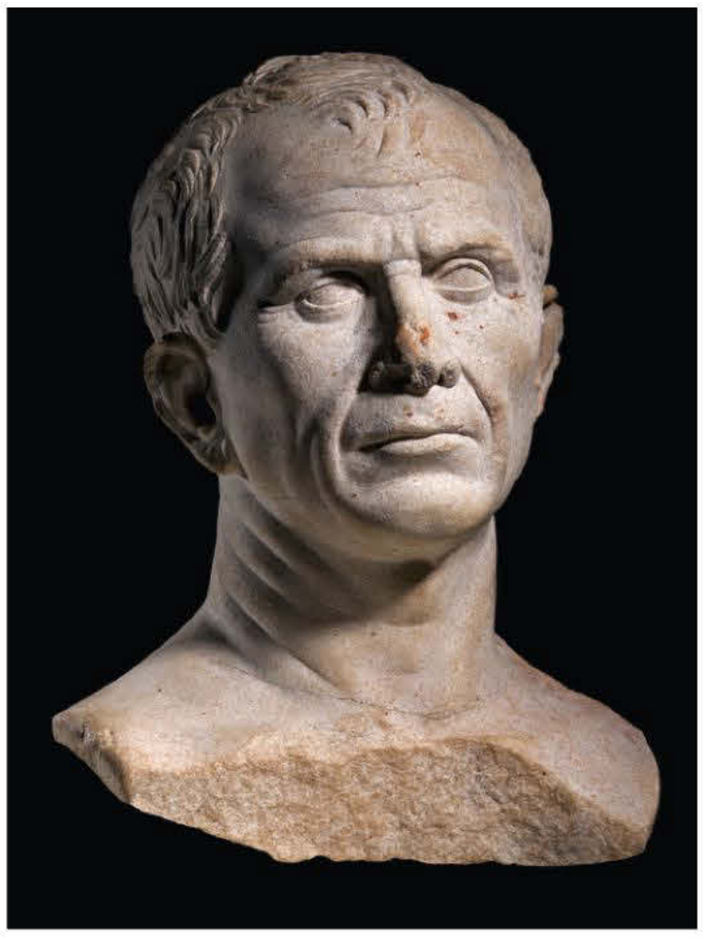
To uncover the barge, which they named *Arles-Rhône 3,* archaeologists had to excavate a Roman trash dump that was itself a rich trove. Amphorae (right) made up the bulk of it, but there were other relics of daily life: a ceramic pitcher in the shape of a dog; an iron sword; a bone-handled knife; and the decorative tip of a hairpin, also carved from bone.

MUSÉE DÉPARTEMENTAL ARLES ANTIQUE (ALL ABOVE): PITCHER, 10 INCHES LONG; SWORD, 19 IN; KNIFE, 5.3 IN; HAIRPIN, 1.5 IN
TEDDY SEGUIN AND LIONEL ROUX (RIGHT)

Working in water rarely this clear—"we were groping around in a labyrinth," says archaeologist Sabrina Marlier—divers brought up thousands of clay jars known as amphorae. This Spanish one carried fish sauce.

By Robert Kunzig

Photographs by Rémi Bénali



The Romans had a serious trash problem, though by our standards it was good-looking trash. Their problem was amphorae. They needed millions of the curvy clay jars to ship wine, olive oil, and fish sauce around the empire, and often they didn't recycle their empties. Sometimes they didn't even bother to pop the cork—it was quicker to saber the neck or the pointy base, drain the thing, then chuck it. In Rome there's a five-acre, 160-foot-high hill, Monte Testaccio, that consists entirely of shattered amphorae, mostly 18-gallon

A second- or third-century bas-relief depicts how freight moved in Roman Gaul: on riverboats, hauled upstream by teams of men. A life-size bust thought to depict Julius Caesar (above) was found in the Rhône at Arles in 2007. Shipyards in the town built him a dozen warships in 49 B.C.

MUSÉE LAPIDAIRE D'AVIGNON, FONDATION CALVET (BAS-RELIEF); MUSÉE DÉPARTEMENTAL ARLES ANTIQUE (BUST)

olive oil jars from Spain. They were tossed out the back of warehouses along the Tiber River. Spanish archaeologists who've been digging into the dump believe its rise probably began in the first century A.D., as the empire itself was rising toward its greatest heights.

Around that time in Arles, on the Rhône River in what is now southern France, the stevedores did things a bit differently: They threw their empties into the river. Arles in the first century was the thriving gateway to Roman Gaul. Freight from all over the Mediterranean was transferred there to riverboats, then hauled up the Rhône by teams of men to supply the northern reaches of the empire, including the legions manning the German frontier. "It was a city at the intersection of all roads, which received products from everywhere," says David Djaoui, an archaeologist at the local antiquities museum. Julius Caesar himself had conferred Roman citizenship on the people of Arles as a reward for their military support. In the city center today, on the left bank of the Rhône, you can still see the amphitheater that seated 20,000 spectators for gladiator fights. But of the port that financed all this, and that stretched half a mile or more along the right bank, not much remains—only a shadow in the riverbed, in the form of a thick stripe of Roman trash.

Trash to them, not to us. In the summer of 2004 a diver surveying the dump for archaeological

riches noticed a mass of wood swelling from the mud at a depth of 13 feet. It turned out to be the aft port side of a 102-foot-long barge. The barge was almost intact; most of it was still buried under the layers of mud and amphorae that had sheltered it for nearly 2,000 years. It had held on to its last cargo and even to a few personal effects left behind by its crew. And through a further series of small miracles, including another intervention by Julius Caesar, it has emerged from the trash to resume its last voyage—safe this time in a brand-new wing of the Musée Départemental Arles Antique.

LAST JUNE, AS RESTORATION experts were rushing to ready the barge for its public debut, I spent a week in Arles in a small stone house overlooking the Rhône. The summer season was not yet in full swing, and away from the tourist hot spots the narrow streets of the town were lonesome. The mistral blew relentlessly. At night I awoke to rattling shutters and the hollow grind of a plastic bottle rolling down the stone quay.

From the roof terrace I could look across the river to the quay on the right bank, where on an earlier visit photographer Rémi Bénali and I had picked up two large, rusty, hand-forged nails—small spikes might be a better description. Then as now the quay was empty save for a large shipping container. But for seven months in 2011 that container had served as a hive for the divers and archaeologists who buzzed in and out of the river every day, vacuuming away the mud that covered the Roman barge, hand-sawing it into ten sections, and hoisting them one by one out of the water with a crane. The nails had fallen from one of the dripping timbers, which meant they were roughly contemporary with, and probably similar to, the ones that had attached Jesus to the Cross.

Gazing down at the Rhône, which was gray and ill-looking and stirred by shifting, rushing eddies—it's the most powerful river in France—I tried to imagine wanting to dive into it. I could not. Neither could Luc Long, at first. Long is the archaeologist whose team discovered the barge. He's been diving in the Rhône for decades, but the first time still haunts him.

Boyish at 61, with a Beatle-ish shock of brown hair, Long works for the DRASSM, a French government department tasked with protecting the nation's underwater patrimony. Long had worked on wrecks all over the Mediterranean when, in 1986, his friend, diver and wreck hunter Albert Illouze, guilt-tripped him into diving in his home river. The Arlésiens turned away from the Rhône centuries ago, Long explained, even before roads and the railway diminished its commercial import. They came to fear it as a source of floods and disease—and he was raised in that tradition. "I had no desire to dive in the Rhône," he said.

Long and Illouze entered the river on a Saturday morning in November, just across from where the antiquities museum is today. The water was around 48 degrees Fahrenheit, foamy and odoriferous—there were sewage outfalls nearby. Long could see no more than three feet in front of him, which for the Rhône was a clear day. Its strong current buffeted and scared him. Gooey streams of algae licked his face. At a depth of around 20 feet, he found himself clinging to a hubcap. It was attached to a truck. Slowly, apprehensively, Long felt his way around to the driver's side of the cabin. He found a Roman amphora in the driver's seat.

After that, he and Illouze swam over a vast field of amphorae. Long had never seen so many intact ones, and his future opened before him: He's been mapping the Roman dump ever since. But the Rhône never became pleasant to work in. Long and his divers had to get used to the gloom, the pollutants, and the pathogens. There were rare but unsettling encounters, among the shopping carts and wrecked cars, with giant catfish. As long as eight feet, the beasts would loom from the murk and grab a diver's swim fin. "When you find yourself being pulled by a flipper," Long said, "it's a moment of great solitude. It's a few seconds that you don't forget."

For the first 20 years or so, no one paid much attention to what he was doing. In 2004, when

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Photographer Bénali lives in Arles; this is his first piece for the magazine. Kunzig is a senior editor.

Luxury items in the mud above *Arles-Rhône 3* attest to the wealth of Roman Arles. This bronze vase, about a foot and a half high, had twin handles, each shaped like a sea monster with the head of a dog, the tail of a dolphin, webbed feet, and flashing silver eyes. The vase may have fallen overboard while being unloaded from a boat.

MUSÉE DÉPARTEMENTAL ARLES ANTIQUE

Arles-Rhône 3 arrives at the quay on its last voyage, laden with 33 tons of building stones from a quarry nearly ten miles north of town. In the first century A.D., Arles was a booming commercial crossroads. The road from Rome to Spain crossed the Rhône on a pontoon bridge. Goods hauled upriver from the Mediterranean were transferred at Arles to barges that carried them all over France (see map).

FERNANDO G. BAPTISTA, NGM STAFF; MESA SCHUMACHER. ART: JAIME JONES. MAP: RYAN MORRIS, NGM STAFF

SOURCE: SABRINA MARLIER, MUSÉE DÉPARTEMENTAL ARLES ANTIQUE

Arles-Rhône 3 traveled locally, but larger boats ranged beyond Lyon. Roads linked the Rhône to other rivers, extending commerce as far as Britain and Germany.

his team discovered the barge he named *Arles-Rhône 3*—he had found evidence of two other boats previously—he had no notion of there ever being enough money available to raise it. He and a colleague sawed a section out of the exposed part, which the colleague analyzed down to matchsticks. In 2007 three younger archaeologists, Sabrina Marlier, David Djaoui, and Sandra Greck, took over the study of *Arles-Rhône 3*.

As they began diving onto the wreck that year, just north of the highway bridge with its thundering current of long-haul trucks, Long proceeded with his survey of the rest of the dump, around 50 yards upstream. Opposite the center of Arles now, he started finding pieces of the town: monumental blocks of stone, including the capital of a Corinthian column, on which he could make out traces of weathering by the mistral. He also started finding statues—a Venus here, a captive Gaul there. Word began to leak out. The French customs police warned Long that antiquities thieves might be watching his operation. When his divers found a life-size statue of Neptune, god of the sea and sailors, they brought it up at night.

Before that diving season was out, the same diver who had found *Arles-Rhône 3,* Pierre Giustiniani, discovered the statue that set the boat on its present course: a marble bust that looked like Julius Caesar. Portraits of Caesar are surprisingly rare. This one might be the only one extant that was sculpted while he was alive—perhaps

Nero graced one coin found in the mud, but the barge was probably built before his reign, just after A.D. 50—by "C and L Postumius," judging from the brand on one timber (right). The boat's flat bottom was made of oak planks, its flanks from two halves of a fir trunk. Some 1,700 nails held it together. Only one aft section had been ripped away by the river. An oil lamp (lower left) belonged to the crew.

MUSÉE DÉPARTEMENTAL ARLES ANTIQUE (ALL): COIN, 1.4 INCHES; LAMP, 3 IN; BRAND ON TIMBER, 4.5 IN. BARGE: 125 IMAGES ASSEMBLED BY SYLVESTRE BÉNARD AND NICOLAS DE BONNI, SINTEGRA

right after he declared Arles a Roman colony, launching it into long centuries of prosperity.

YOU HAVE TO UNDERSTAND, said Claude Sintes, the director of the antiquities museum: Arles is a small town, even a poor town. The locomotive workshop closed in 1984, the rice mill and the paper mill within the past decade. What's left is mostly tourism. The tourists come in part for Van Gogh, who painted here for a time. But the town sits on minable deposits of the Roman past—you almost can't sink a shovel into your garden without hitting a Roman stone or tile. The exhibition that Sintes built around the bust of Caesar, after news of it spread around the world, showed that some of that stuff was commercial grade. "The exhibition's success was astonishing," Sintes said. "When a modest town like ours got 400,000 visitors, the politicians understood that the economic return was strong."

By the fall of 2010, as the Caesar exhibition was nearing the end of its run, those officials were looking for more culture to invest in: The European Union had designated Marseille and the whole Provence region a 2013 European Capital of Culture. Arles wanted in on that promotional action. Suddenly nine million euros became available to build a new wing on Sintes's museum and put a Roman barge into it. There was just one catch. The project would need to be completed by 2013.

That sounds like enough time unless you know about ancient wood and about the Rhône. Mud

had protected the wood of *Arles-Rhône 3* from microbial decay, but water had dissolved the cellulose and filled the wood's cells, leaving the whole boat soft and spongy. "The wood was held up only by water," said Francis Bertrand, director of ARC-Nucléart, a restoration and conservation workshop in Grenoble. "If the water were to evaporate, the whole thing would collapse." The solution was to bathe the wood for months in polyethylene glycol, then freeze-dry it—gradually infusing it with the polymer before removing the water. But the barge would have to be cut into sections small enough to fit into the freeze-dryers. And the process would take nearly two years.

That left only one field season, 2011, to extract the boat from the Rhône. "The project was doomed to fail," said Benoît Poinard, a professional diver and the site foreman. The gloomy premonition had come to him even before he got stuck briefly under the boat one day. Normally, Poinard explained, the Rhône is safe for diving only from late June to October; otherwise the current is too strong. Three or four months would not be enough to excavate *Arles-Rhône 3*.

Then 2011 arrived. It hardly snowed in the Alps that winter; that spring it barely rained. The Rhône's current was so gentle that Marlier's team got in the water by early May. The visibility that month reached an almost unheard of five feet. Marlier, who managed her anxiety about diving in the Rhône by never straying from the barge, saw for the first time that she'd been working for four years right next to an abandoned car. Her team worked straight into November, losing only a single week to bad weather—and completed the job. "Two hours after we finished," Poinard said, "the Rhône became undivable for the whole winter."

Late in the field season, as restorers from ARC-Nucléart were disassembling the bow of the boat on the quay, they found a silver denarius the size of a dime. The boat's builder had sealed the coin between two planks; it was meant to bring good luck. And it did—2,000 years later.

WHEN *ARLES-RHÔNE 3* SANK, it was carrying 33 tons of building stones. They were flat, irregular slabs of limestone, from three to six inches thick.

When the barge sank, it was probably tied to the quay. Among the things scattered on board was this 15-inch iron sickle, which the crew used to cut kindling. No human remains were found.

They had come from a quarry at St. Gabriel, less than ten miles north of Arles, and were probably headed toward a construction site on the right bank or in the Camargue, the marshy farmland south of Arles. The boat was pointed upstream, though, rather than downstream, indicating it had been tied up at the quay when it sank. A flash flood had probably swamped it.

As the flood subsided, the cloud of sediment it had kicked up settled out of the water again, draping the barge in a layer of fine clay no more than eight inches thick. In that clay, in contact with the boat, Marlier and her team found the crew's personal effects. A sickle they'd used to chop fuel for their cooking fire, with a few wood splinters next to the blade. A dolium, or large clay jar, cut in half to serve as a hibachi, with charcoal in the bottom. A plate and a gray pitcher that belonged to the same man—both bore the initials AT. "That's what's exceptional about this boat," said Marlier. "We're missing the captain at the helm. But otherwise we have everything." The mast, with its traces of wear from the towropes, is to her the most precious find.

To that snapshot of the boat, the nearly 1,200 cubic yards of mud and Roman trash that eventually buried it add a kind of time-lapse image of the commerce that was Arles. In the museum's dim basement, Djaoui and I walked down long aisles of amphorae, many with their necks sliced off. "All this will have to be studied," he said, with a trace of ambivalence. The dump is almost too rich; the archaeologists had already placed 130 tons of ceramic sherds back in the riverbed, in the hole left by the boat. I asked Djaoui about the building stones that had started the whole story. They were too heavy for the restored boat, he said; replicas were being used. Djaoui took me out behind the museum. The stones were there, next to a large trash bin, awaiting their own return to the river. ☐

MUSÉE DÉPARTEMENTAL ARLES ANTIQUE

NG CONNECT

Every month this page features our staff picks of National Geographic Society products and events. For more go to *nglive.org.*

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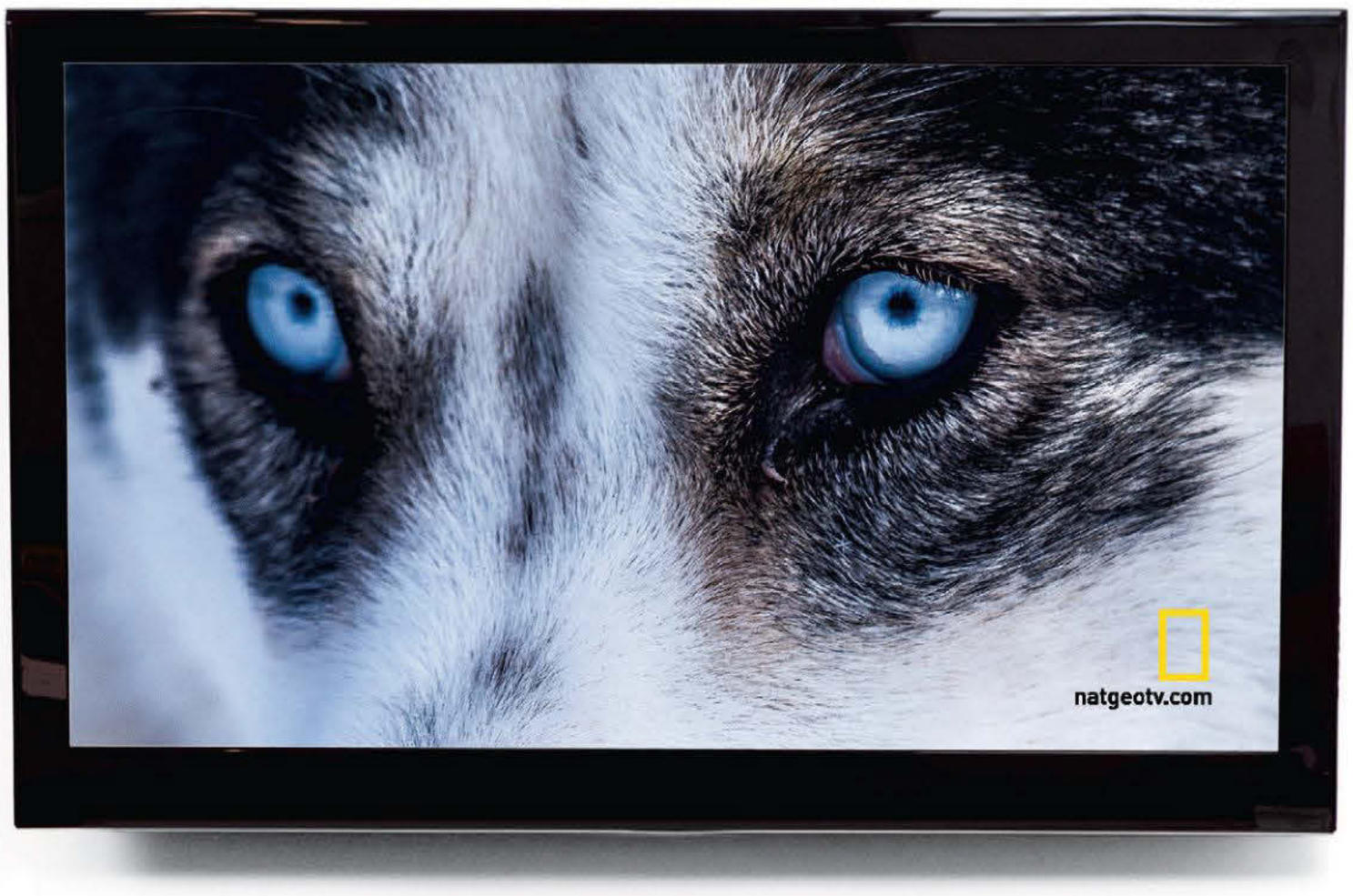

Life Below Zero

Imagine a place where the Arctic Circle is 200 miles to the south and the nearest neighbor is several hours away. This is remote Alaska, and its few human inhabitants are a rugged bunch. Find out how they manage day to day—from traveling by sled dog (left) to warding off hungry grizzly bears. It's all part of *Life Below Zero,* back for its second season this month on the National Geographic Channel.

LECTURE

LENS OF ADVENTURE Bryan Smith finds innovative ways to film in extreme locations. Join him for stories of what goes on behind the scenes during the making of a National Geographic film. Speaking dates in the United States and Canada are listed at *nglive.org.*

EXHIBIT

EARTH EXPLORERS This interactive exhibit introduces visitors to diverse environments, including rain forests, the Poles, and the African savanna—where Michael "Nick" Nichols (left) photographed lions. The exhibit runs through September 1 at the Museum of Science and Industry in Chicago. Visit *msichicago.org* for tickets.

BLOG

PHENOMENA *National Geographic*'s spirited science writers take on dinosaurs, genetics, new discoveries, quirky theories, and more on our Phenomena blog. Go to *phenomena .nationalgeographic.com* for fresh posts from Virginia Hughes, Brian Switek, Ed Yong, and Carl Zimmer.

TRIP

NATIONAL PARKS Explore Yellowstone, Denali, the Grand Canyon, and Zion (right) on naturalist-led expeditions, active adventures, and family trips. See all the itineraries at *ngexpeditions.com/nationalparks.*

Book of the Month

Mission: Animal Rescue

Packed with true stories, striking photography, and fun facts, this new series is for kids who love animals and are passionate about saving them. Read about a lioness raising her cubs. Get tips from explorers in the field. Try hands-on rescue activities. The lion and wolf editions are available April 8; look for more titles soon ($12.99).

PHOTOS (FROM TOP): DEREK WHIPPLE, BBC WORLDWIDE LTD; KEN GEIGER, NGM STAFF; JUSTIN REZNICK, GETTY IMAGES

Coal Tender

His ten-hour workday is finished. But now this miner burns coal from 4 p.m. to 10:30 p.m. After the flames die down, what's left are pieces of coke, a hot-burning fuel his family can use for cooking and for heating their home. His wife will sell any extra at the nearby market in Ranchi, in northern India. "I look at this man—he's got three kids, I've got two," says photographer Robb Kendrick. "The only difference between him and me is our circumstances."

The man's village is located inside a mining complex, where he works six days a week hauling 60-pound baskets of coal on his head, nearly five tons daily, for about four dollars a day. There is little relief from the smoky air. Coal fires, which have smoldered for decades because of accidents and poor management, release a constant haze of soot. This fire, ringed with children from the village, adds even more smoke and heat.

Kendrick spent a few days in the village building trust, then began taking pictures. "I was five or six feet away for this shot, and my hands were burning," he says, amazed at the man's fortitude. Before he left, Kendrick snapped a portrait of the man's family, located a print shop, and gave a copy to the "beaming" father. *—Eve Conant*

Listen to an interview with Robb Kendrick on our digital editions.

PHOTO: JEANNIE RALSTON (TOP)

FOUND

Tired Out "The biggest tire ever made will cruise a lifeless continent," boasted the caption for this photo—taken in Akron, Ohio, near Goodyear headquarters—in the February 1940 *Geographic.* Ten feet in diameter and weighing 700 pounds, the tire was made for a huge snow cruiser specially built for Admiral Richard Byrd's 1939-1941 Antarctic expedition. The cruiser never cruised much in Antarctica, though. It had trouble enough in the United States.

The plan was to drive the vehicle from Chicago to Boston's port, where it would be shipped south to Byrd. Among other mishaps along the way, it got stuck in a rural Ohio creek for three days and had two motors replaced in Erie, Pennsylvania.

In Antarctica things only got worse. First the cruiser crashed through the loading ramp. Then its great weight sank the giant spinning tires deep into the snow. Within months Byrd's men abandoned the vehicle. Eventually it disappeared beneath the snow. The cruiser was last glimpsed during a 1958 expedition but in the decades since has vanished again. *—Margaret G. Zackowitz*

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PHOTO: WILLARD R. CULVER, NATIONAL GEOGRAPHIC CREATIVE

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