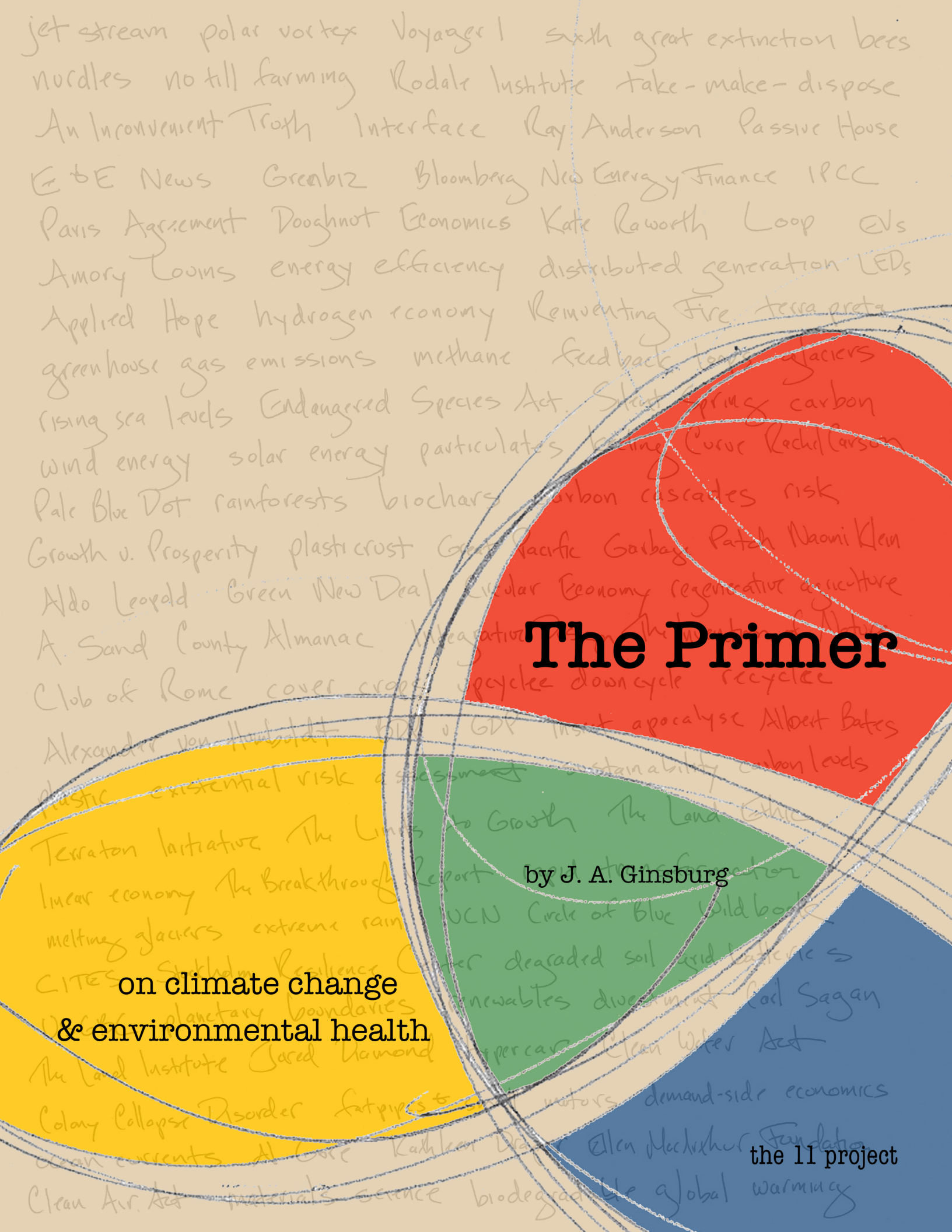

The Primer

by J. A. Ginsburg

on climate change
& environmental health

the 11 project

How to Read
The Primer

The Primer covers a lot of ground.

Scan, skim & explore.

Start in the middle. Or the end.

Or with a side bar.

The Primer is a reference,

a starting point,

a portal.

The **Table of Contents** page includes links to individual sections and sidebars.

Each section and sidebar is filled with links.

The (not a typical) Bibliography has even more links.

A link that will take you back to the **T**able **o**f **C**ontents is in the lower left corner of each page.

ToC

Follow the links!

LINKED TABLE OF CONTENTS

*on laptops, links work most reliably using the Firefox browser

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INTRODUCTION

The van sped down an Arizona highway, heading east toward the Blue Mountains. In it a film crew—of which I was a part—preparing to record the release of the first Mexican gray wolves into the wild since the species had been "extirpated" from the region decades earlier. As we drove past the Apache National Forest, Steve, a National Wildlife Federation senior scientist and our designated expert for the documentary, began reciting an essay by Aldo Leopold, a conservationist and writer who began his career in this area in 1909 working for the US Forest Service. Part of the job was killing wolves:

> *...I was young then and full of trigger-itch; I thought that because fewer wolves meant more deer, that no wolves would mean a hunter's paradise. But after seeing that fierce green fire die, I sensed that neither the wolf nor the mountain agreed...*

We stopped for gas in a small town with a tiny bookstore and a single, used copy of a collection of Leopold's essays: *A Sand County Almanac*. It felt like fate. This book was waiting for *me*.

The epiphany in the essay that Steve quoted—*Thinking Like a Mountain*—was about the importance of stepping back in order to better understand Nature's big picture. Without wolves, there are too many deer whose voracious grazing can destroy a forest and decimate a mountain.

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LEOPOLD'S LEGACY

Aldo Leopold began writing the essays in *A Sand County Almanac* during the late 1930s. He had written extensively for professional journals but wanted to reach a broader audience about the importance of conservation. This was the Dust Bowl era when enormous dust storms turned an entire region from Texas to Nebraska into a wasteland—the result of extended drought, catastrophic farming practices and federal land policies dating back to the Civil War. By the time it was all over, 35 million acres of farmland had to be abandoned, while another 125 million acres had lost significant amounts of topsoil. In 1934, a single, massive dust storm two miles high traveled 2,000 miles across the country. The dust was so thick on the East Coast that people couldn't see the Statue of Liberty or the U.S. Capitol.

In 1935, Leopold bought a small, worn-out farm about 50 miles from Madison, Wisconsin, where he was a professor at the university and the research director of the new Arboretum. On weekends the Leopold family would drive out to farm, camp out in "The Shack" (a former chicken coop) and set to work restoring the land. Through the Arboretum,

> *...The cowman who cleans his range of wolves does not realize he is taking over the wolf's job of trimming the herd to fit the range. He has not learned to think like a mountain. Hence we have dustbowls, and rivers washing the future into the sea...*

While putting together *The Primer*, I have thought a lot about that day twenty years ago, and about that essay. We *still* haven't learned to think like a mountain, only now it is so much more than a mountain in peril.

It is everything: Climate change. Deforestation. Degraded soil. Marine dead zones. A million species on the brink of extinction (a *million*!). Melting glaciers. Rising seas. Plastic everywhere. We have gotten ourselves into a toxic tangle of crises, all human-caused, and all coming to a head at the same time.

It is unbelievable. And tragic. And awful. And something needs to be done about it *right away*!

Faced with the enormity of all that has gone wrong, it is easy to become paralyzed by hopelessness. Yet there is still much that can be done to nudge the trajectory away from the cliff's edge and there may be just enough time to do it. This is an all-hands-on-deck moment where everyone—architects, engineers, designers, urban planners, manufacturers, farmers, scientists, economists, students, investors, consumers—has a vital role to play.

Leopold was able to get tree seedlings, mostly pine, which the family planted by the thousands. During the drought years almost all the trees died. But they kept planting and eventually a forest grew.

The visitor center at The Aldo Leopold Foundation was built using timber from a selective harvest of those very trees.

Several publishers passed on Leopold's manuscript, unconvinced that there was an audience for a book about nature, conservation and land ethics. Eventually Oxford University Press said yes, but the book still almost didn't make it into print. A week after the Oxford news, Leopold died of a heart attack while helping a neighbor put out a grass fire. His family rallied to work on the final edit. (The Leopold children grew up to be notable scientists in their own right).

A Sand County Almanac is a masterclass in what it truly means to be a scientist: to observe, question, research, reflect, test, write, share and observe more.

Meticulous record-keeping—phenology—was both central to his work and a way of life for

There are two parts to *The Primer*. The first—*How It Came to This*—is a backgrounder, a combination of science and history. The second—*How We Get to Next*—is a survey of technologies, methodologies, economic models and paradigms that are already setting us on a better course.

The Primer covers considerable ground, but is by no means definitive. If this is mostly new to you—especially if you are a student in college—I hope *The Primer* provides perspective and inspiration. Yours is the future that hangs in the balance.

According to the latest count, there are now 64 Mexican gray wolves living in Arizona, and another 67 across the border in New Mexico. That is a small fraction of the population that once roamed these lands, and their continued existence depends on the good grace of cattle ranchers and conservationists. Nonetheless it is a win for the mountains and a move in the right direction. It is proof of what is possible.

The fierce green fire may be a flicker of what it once was, but it still burns.

— J. A. Ginsburg

Founding Editor, The 11 Project

the Leopold family (as Nina Leopold Bradley, who lived near The Shack well into her 90s, explains is this wonderful video).

Although Leopold never saw his book in print, his essays have been read by millions around the world, translated into more than a dozen languages.

Long before the term "circular economy" became popular or anyone thought about "planetary boundaries," Leopold provided the ecological and philosophical underpinnings for both:

> *…That land is a community is the basic concept of ecology, but that land is to be loved and respected in an extension of ethics. That land yields a cultural harvest is a fact long known, but latterly forgotten…*

> *…[T]his much is crystal clear: our bigger and better society is now like a hypochondriac, so obsessed with its own economic health as have lost the capacity to remain healthy…*

Seventy years on, Leopold's words are more relevant than ever.

Part 1:
How It Came to This

SECTIONS

SIDEBARS

ToC

DIFFERENT WORLDS

On May 11, 2019, for the first time in roughly three million years, the level of carbon dioxide (CO2) in the Earth's atmosphere topped 415 parts per million (ppm). The last time levels were this high there were giant ground sloths and four-tusked, elephant-like gomphotheres on the planet. The first appearance of our ancestors, the first in the genus *homo,* was still hundreds of thousands of years in the future. Even the continents weren't quite where they are today. It was a different world.

It was a different world, too, a little more than 200 years ago when naturalist Alexander von Humboldt set out on his global travels. In 1800 the human population had just reached one billion—13% of today's tally—and atmospheric CO2 measured 290 ppm. Over the next several decades von Humboldt would discover and catalogue many species, including many that have since gone extinct due to hunting, loss of habitat, pollution and, of course, climate change.

The Industrial Revolution was ramping up, yet even back then many, including von Humboldt, raised concerns about the pollution generated by large-scale manufacturing. It occurred to no one that a steady stream of carbon molecules floating up into the atmosphere from the burning of coal and oil (and measured in a per *million* molecule mix!) could have such a profound effect on climate. Of course back then no one knew what a molecule was.

CARBON TRACKING

National Oceanic and Atmospheric Administration (NOAA), Earth System Research Laboratory (ESRL) (website)

CO2.Earth: tracks daily, monthly, yearly data from the Mauna Loa Observatory (website)

• *Scientists discover evidence for past high-level sea rise*, phys.org (article)

• *The forgotten woman who discovered the greenhouse effect,* The Next Web (article)

Nor did they know much about plastic* or imagine that one day oceans would be filled with so much of it that whales would wash ashore dead from eating the stuff.

It would be a different story 150 years later.

.....

To focus only on climate change misses the point. If water is undrinkable, soil poisoned, air barely breathable and the legacy of the "sixth great extinction" leaves the Earth a bio-depleted, semi-dead planet, it doesn't really matter if the climate is back to pre-industrial perfection.

To focus only on carbon also misses the point. Water, in one form or another, governs 95% of the Earth's heat dynamics notes soil biologist Water Jehne. By comparison, only about 4% is driven by carbon. Although hydrology, especially on a global scale, is quite complex, this opens up a significant second front in the fight to slow, and possibly reverse, climate change.

Hydrology is intimately tied to land use: to the living skin of our planet, the soil's microbiome. "That's our point of agency," says Jenhe. To pave or not to pave. To till or not to till. To clear cut or to plant. "It's not (only) how many raindrops we get...but just as important what happens to every raindrop."

***** Ironically the first polymer, which was developed in 1869, ten years after von Humboldt's death, was created for conservation: an alternative to the ivory used to make billiard balls. Save the elephants! Use plastic!

The First Plastic Billiard Balls Routinely Exploded, Mental Floss (article)

There are a series of interconnected, existential crises all coming to a head at the same time:

- climate change (carbon pollution)
- ocean acidification (carbon pollution)
- air pollution (chemical, particulates)
- water pollution (plastic, chemical and biological)
- soil degradation (chemical-dependent farming)
- systems collapse (pathogens; biodiversity and habitat loss)

How did this happen?

STORMY WEATHER

After months of heavy, gray skies and cold, slushy storms, it looked like the summer side of spring had finally come to Chicago in late May. Sunlight pierced through clouds. Buds burst into leaves. Birds sang. And with a single, mind-altering, lilac-and-lily-of-the-valley-scented breeze, I was ready to forget winter ever happened. If not for all the coats, hats, gloves, scarves and boots stuffed into my front closet and a bumper crop of pot-holes that threatened my car literally at every turn, I would have chalked it up to a bad dream. I bought a beach token and stocked up on sunscreen.

WARMER WORLD, BIGGER HAIL

Imagine an ice-ball bigger than a baseball hurtling to Earth at the speed of a fastball. Now imagine clouds full of them. You actually wouldn't have to imagine if you were in Cullman, Alabama, on March 19, 2018. Giant hail strafed the town of 15,000 people located between Birmingham and Huntsville. Car windshields were smashed with blitzkrieg abandon.

Wind and rain dominate the wild weather headlines of summer, but hail can be just as damaging. According to a 2017 report by insurance industry analyst Verisk, 10.7 million properties in the US were damaged that year by hail, for a collective tally of $22 billion. That's on par with a hurricane.

Thanks to global warming, hailstones are getting bigger, too. For every 1°C (1.8 °F) rise in temperature, the atmosphere can hold about 7% more moisture. Given the right conditions in a thunderstorm or tornado, a rain droplet forms, then freezes into a hail pellet. Additional layers of water freeze onto the pellet until the hail stone is so heavy, it falls to the ground. The fiercer the storm, the bigger the hail.

But the dreary weather dragged on for weeks, locked in place by a confluence of meteorological events that also brought record warmth to the Arctic. In a trade that made no one happy, sunshine that was supposed to be in Chicago was stuck in Greenland, while the cold needed to keep ice sheets and permafrost roads properly chilled drifted south.

To the west and south, the Great Plains and the Midwest were caught in the cross-hairs of a perfect storm of storms. Spring kicked off in March with a rare "bomb" cyclone: a massive blizzard that shredded much of Nebraska and Iowa. Weeks of heavy rain followed. In May an outbreak of hundreds of tornados pirouetted across a dozen states. Twisters packing winds well in excess of 100 mph kicked up debris fields visible from space.

Levees breached, rivers jumped banks, farm fields and cities flooded. Buildings blew apart, cars floated away, roads washed out, dams cracked and bridges weakened. Freight trains were stopped in their tracks by high water, while dangerous river currents shut down barge traffic. A US military base was trashed.

If it looked like a war zone, it's because it *was*.

We are under siege from weaponized weather. Climate change is no longer an abstraction with far off, not-in-our-lifetime consequences. It is happening right now, to us, and pretty much as predicted by decades of meticulous scientific research.

In June 2019, a storm with updraft winds at least 110 mph produced hail the size of grapefruits about 55 miles northeast of Cullman, breaking windows and killing a calf.

The average number of "billion dollar disasters" in the US (mostly hurricanes and fires) stayed steady at about a half dozen per year from 1980 to the early 2010s. The number has since doubled with climate change viewed as a contributing factor. It isn't only a matter of extreme weather driving up the costs, though. There are more people and property in harm's way—more windshields for giant hail stones to smash.

• *Montana hailstorm slaughters 11,000 birds,* Washington Post (article)

It is hard to find a spot anywhere on Earth that isn't reeling from extreme weather linked to climate change. In Europe, Alaska and the Arctic, it's heat. In Mozambique, Paraguay, South Africa, China, the US, England and Afghanistan, it's floods. In Australia it's fire. In North Korea and Thailand, it's drought. In India, it's heat, floods *and* drought. Russian winters are getting colder, even by Russian standards. Glaciers are in retreat from the Himalayas to the poles. Ice sheets disintegrate into the sea.

By the time you read this there will no doubt be new round of gobsmacking disasters vying for space in the record books.

We were warned.

We are still being warned. The forecast from the National Oceanic and Atmospheric Administration (NOAA) for spring 2019 called for "...a potentially unprecedented flood season, with more than 200 million people at risk for flooding in their communities." When two-thirds of the population is in the cross-hairs, there is nowhere to hide.

Agriculture took a series of direct hits. Silos full of grain from last year's harvest flooded. Then planting was delayed, and in some cases prevented, because the ground was saturated. Tens of thousands of acres were under water and littered with all kinds of storm debris, including river sand several feet deep.

Meanwhile, countless tons of fertilizer-laced topsoil from thousands of farms in the Mississippi watershed was stripped from the land, filling streams and rivers with potassium and nitrogen-rich run-off. Hundreds of miles downstream in the Gulf of Mexico, fishermen prepared for a record "dead zone." Instead of corn and soy, the fertilizer-enhanced water would nourish a bumper crop of pond scum: an epic algal bloom that would keep sunlight from reaching marine plants and soak up all the oxygen in the water. Fish, shrimp and other marine life would either have to swim away or die.*

This happens every year—and not just in the Gulf of Mexico. Any source of fertilizer run-off, including suburban lawns and sewage, can play havoc with watershed ecosystems. This year's nearly 7,000 square mile swath of destruction along the coasts of Louisiana and Texas is catastrophic, but it is the cumulative effect of repeated environmental assaults that makes it difficult, if not impossible, for the ecosystem to fully recover.

Scientists can now calculate the role climate change plays in specific weather events—and there is plenty of evidence that a warming world was a factor in the massive floods of 2019. That level of granular analysis is useful, yet all anyone really needs to know is that warm air holds more moisture than cold air. As a direct result of global warming caused by the burning of fossil fuels, the Earth's atmosphere contains at least 7% more water vapor than it did at the start of the Industrial Revolution 250 years ago. That means there is

* *Everything connects. Hurricane Barry limited the size of the 2019 dead zone by stirring up the waters in the Gulf, which added more oxygen to the mix. The dead zone was still big: about 7,000 square miles, well beyond government targets. Barry also caused significant, widespread flooding.*

- *Lake Erie algal blooms are costing tax payers millions, could stretch into billions* (video & article)
- *Two-Mile Dead Zone Confirmed in Chesapeake Bay Due to Warm, Wet Weather* (video & article)
- *Mississippi River Flooding's Impact On Commercial Fishing* (podcast & article)

more moisture that can condense into more rain, or snow, slush or hail. It's just a matter of figuring how much will fall where and when.

HOW WEATHER SHAPES CLIMATE & CLIMATE SHAPES WEATHER

Weather patterns emerge from the constant interplay between hot air and cold. Jet streams—high-altitude, fast-moving ribbons of air—mark the boundaries. The greater the temperature difference between hot and cold, the straighter and more predictable the jet stream.

The jet stream for the Northern Hemisphere is now at a tipping point, literally buckling from climate change. Since temperatures rise faster at the poles, the temperature differential is decreasing. This allows bulges (also known as dips) to form in the jet stream. Just like bends in a river slow down water currents, these bulges slow the winds, making it more difficult for the jet stream to straighten out again. The result: weather patterns that get stuck, leading to floods, heat waves, droughts and cold spells.

Land use impacts the jet stream. For example, deserts (or large, paved urban areas) can radiate vast amounts of heat that generate high pressure "heat domes." These behave like invisible mountains that make it harder for moisture-laden low pressure systems to break through,

DUST UP

Could dust from Africa lead to flooded farm fields in Iowa?

According to chaos theory, the flap of a butterfly's wings can be enough to set off a chain of events that eventually leads to the formation of a tornado.

Everything on Earth is part of a greater, dynamic whole. No matter how seemingly inconsequential, everything has consequences. Even dust.

The impacts of dust are complex and varied. Dust that blows onto the Rocky Mountains from the desert Southwest can accelerate spring snow melt, jumpstarting the growing season. Plants soak up water before it can flow into mountain streams, which means less water for the Colorado River.

Meanwhile in the Arctic scientists are puzzling over whether dust from ground that's has been newly exposed beneath melted glaciers will lead to increased cloud formation—and whether that will accelerate or slow polar warming. The feedback loops are subtle yet significant.

Massive changes in land use globally, particularly over the last couple of centuries (forests to farms, farms to cities, etc.) has had a profound impact on climate. Among other things, it affects hydrology and since water vapor is the most abundant greenhouse gas, this is critical. Although water vapor cycles more quickly in the atmosphere than other greenhouse gases (about 10 days), it can function as an amplifier.

Likewise changes in ocean water temperature— for example, "The Blob" that in recent years has occasionally formed near Alaska—can shape weather patterns all along the West Coast of North America. Since everything connects, the knock on effects can be global.

Fifteen years ago bulges in the jet stream were an anomaly. Now they're beginning to look like the "new normal."

A LEGACY OF WARNINGS

By 1962 (317 ppm CO2) the impacts of industrial pollution were abundantly clear. That was the year biologist Rachel Carson's book *Silent Spring* was published (after first being serialized as a three-part article in *The New Yorker* magazine).

Carson's excoriating take-down of the chemical industry began with "*A Fable for Tomorrow"* about the poisoning of "a town in the heart of America where all life seemed to live in harmony with its surroundings." Everything was great until "a strange blight crept over the area," which sickened and killed poultry, livestock, wildlife and bees.

So *can* dust from Africa trigger floods halfway around the world?

Each year 100 million tons of African dust blows west over the Atlantic. Not only does all this dust play a vital role replenishing North American soils, but it can also act as a buffer against tropical storms off the coast of Florida. The dust dries out the air, making it more difficult for storms to form. But beneath the haze, the ocean heats up. Once the dust blows inland, the warm surface water turns the dry air humid creating a mass of hot, moist air that expands upward and outward. Perhaps it pushes north where it could cause, or reinforce, a buckle in the jet stream. If the buckle were then to cause a rainy weather pattern to stall over the Midwest, it could rain for days on end.

There are too many variables to draw a direct link between African dust and Midwestern floods, but like the butterfly's wings, each perturbation leads to the next. Scientists have only begun to tease apart and understand the complex relationships that shape weather and climate.

Indeed, only recently have scientists connected the dots between global warming, shifting wind patterns and ocean currents, and the thinning of Western

> *...There was a strange stillness. The birds, for example—where had they gone? Many spoke of them, puzzled and disturbed. The feeding stations in the backyards were deserted. The few birds seen anywhere were moribund; they trembled violently and could not fly. It was a spring without voices...*
>
> *...The apple trees were coming into bloom, but no bees droned among the blossoms, so there would be no pollination and there would be no fruit...*

The people in this once idyllic town got sick, too, but had yet to connect the dots to the powdery residues left behind by pesticide sprays.

Carson's clarion call catalyzed an environmental movement and led to the founding of the Environmental Protection Agency (EPA) and laws regulating pollution.

Yet nearly 60 years later, we are in the midst of an "insect apocalypse," with an estimated 40% of insect species threatened with extinction. A bee plague called Colony Collapse Disorder (CCD), which has been linked at least in part to the use of neonicotinoid pesticides, has decimated commercial hives and also likely those of wild bees. But instead of increasing efforts to support the insects that pollinate about one third of the crops we eat, the USDA, citing budget concerns, has suspended the annual Honey Bee Colony Survey, while the EPA reversed course on a ban

Antarctica's ice, which will have a profound impact on sea level rise.

The more we know, the better prepared we can be. This is the moment to invest in more —much more—research, *not less*.

- *Missing: Nearly 3 billion birds that used to live in North America* (article)
- *Action on the Bee Crisis: Paul Stamets*, Science & Nonduality (video)
- *Groundbreaking Research Gives Hope to Bees*, Fungi Perfecti (with

for sulfoxaflor, a pesticide considered highly toxic to bees and other pollinators.

According to the UN's latest Global Assessment Report on Biodiversity and Ecosystem Services, the insect apocalypse is part of a much larger story: a million species are now on the brink of extinction and entire ecosystems in imminent danger of collapse.

> *In parts of the ocean, little life remains but green slime. Some remote tropical forests are nearly silent as insects have vanished, and grasslands are increasingly becoming deserts. Human activity has resulted in the severe alteration of more than 75 percent of Earth's land areas, the Global Assessment found. And 66 percent of the oceans, which cover most of our blue planet, have suffered significant human impacts. This includes more than 400 dead zones—where scant life can survive—that collectively would cover the state of Oregon or Wyoming.*
> *— Stephen Leahy, National Geographic*

More than a decade before *Silent Spring,* Aldo Leopold's pioneering work on ecosystem dynamics laid the foundation for the modern conservation movement. In his essay *The Land Ethic*, he writes about the need for a moral code to guide and define humanity's relationship with the natural world in a way that transcends the narrow definition of property.

- *The New West: A Sand County Almanac Turns 70 - Todd Wilkinson interviews Curt Meine*, Buckrail (article)

…In all of these cleavages, we see repeated the same basic paradoxes: man the conquerer versus man the biotic citizen; science the sharpener of his sword versus science as the searchlight on his universe; land the slave and servant versus land the collective organism…

…[Q]uit thinking about decent land-use as solely an economic problem. Examine each question in terms of what is ethically and aesthetically right, as well as what is economically expedient. A thing is right when it tends to preserve integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.

LIMITS

Both Carson and Leopold described a nature profoundly out of balance as a consequence of human action. It wasn't until the early 1970s, though, that a team of data scientists at MIT set out to model environmental feedback loops on a planet-wide scale. Their work, published as a book called *The Limits to Growth* by the Club of Rome in 1972 (327 ppm CO2), was the first to make the link between long-term environmental and economic health.

The data were clear: If Earth's resources continued to be used at a rate faster than they could be replenished (if they *could* be replenished), economic growth would eventually grind to a halt. The researchers developed a model for evaluating global systems dynamics called World3 (W3), which they used to study the impacts of population growth,

THE IPCC & THE PARIS AGREEMENT

1988 was the last year atmospheric CO2 levels saw monthly averages below 350 ppm (September and October), the amount considered safe in terms of climate change. It was also the year the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) founded the Intergovernmental Panel on Climate Change (IPCC), tasking it with evaluating the science, assessing social and economic impacts, and recommending response strategies to global warming.

Over the years the IPCC has produced a series of reports synthesizing the latest research of top scientists from around the world. The Fourth Assessment in 2007 (383 ppm CO2) was the first to state unequivocally that the planet was warming and seas were rising due to climate change "very likely due to observed increase in anthropogenic GHG concentrations." In other words, we unwittingly created a planetary-scale greenhouse of our own making by the mass burning of fossil fuels.

food production, non-renewable resource depletion and industrial output and pollution. According to W3's analysis, by the year 2100—barring significant changes—everything would begin to unravel. The promise of a better future would quickly devolve into a dystopia defined by hunger, illness and death.

Many heard the urgent call for action: The book sold 30 million copies worldwide. It was also political poison.

"There are no limits to growth and human progress when men and women are free to follow their dreams," declared President Ronald Reagan in his second inaugural address in 1984 (344 ppm CO2). The future would take care of itself with a little good old American know-how and unfettered capitalism.

Reagan wasn't entirely wrong. Innovation, including digital technologies and materials that didn't even exist back then, has vastly improved resource use and agricultural productivity. But there are now 3 billion more people on the planet—a population increase of 40%—who need food, clothing, shelter, water, electricity and now a good internet connection, too.

Despite Reagan's wishful optimism, *The Limits to Growth* has proved unnervingly accurate. If anything W3 was overly rosy. A full third of all the world's farmland is already classified as degraded, with topsoil losses estimated at 24

The IPCC received the 2007 Nobel Prize for its work, which it shared with Al Gore, former vice president and author of *An Inconvenient Truth*.

The IPCC Assessments led to the Paris Agreement, which was adopted by consensus in December 2015 (402 ppm CO2). By 2019, 195 countries had signed on, agreeing to limit greenhouse gas emissions in an effort to keep global temperature rise below 1.5 °C (2.7 °F), considered the least catastrophic climate change scenario. The Agreement went into effect four days before President Trump took office. The US is now in the process of withdrawing from its commitment.

• *COP25: Key outcomes agreed at the UN climate talks in Madrid*, Carbon Brief (article)

• *E.P.A. to Roll Back Regulations on Methane, a Potent Greenhouse Gas*, New York Times (article)

• *The 'lungs of the planet' are on fire*, World Economic Forum (article)

• *The Arctic Is on Fire, and It Might Be Creating a Vicious Climate 'Feedback Loop',* Vice (article)

billion tons each year. According to a recent UN report, 75% of all land is in some way degraded, a figure that could rise to 95% by 2050. Rivers and lakes have become stews of industrial chemicals, complete with gender-bending synthetic estrogens and drug residues. Aquifers have dried up. Deforestation has destroyed unimaginably vast swaths of habitat. Oceans have become more acidic. And an estimated two-thirds of the world's fish stocks have been fished to their limits, or beyond.

Those are just a sampling of the disasters you can see.

What you can't see is the one trillion metric tons of CO2 that has spewed skyward since the beginning of the Industrial Revolution, creating an invisible, heat-trapping greenhouse around our planet. Just over 37 gigatons were emitted by the burning of coal, gas and oil in 2018, up slightly from the year before. It's getting hotter under the dome.

And that, in turn, has set in motion all sorts of changes just beyond view. For the first time in 10,000 years earthworms are thriving in the warming boreal forests that ring the Arctic, dining on thawed leaf litter and releasing long-sequestered carbon into the atmosphere in the process.

Dig a little deeper and hungry methane-generating microbes are stirring to life as permafrost melts, emitting a greenhouse gas 30x as potent as carbon. Scientists are now

worried that a region long considered one of the world's great carbon sinks could soon become a carbon "spout."

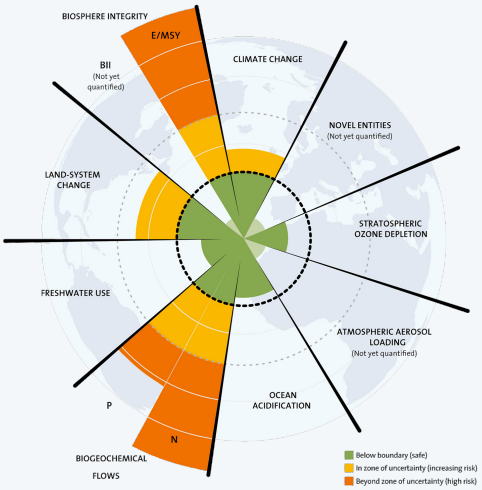
The fuse has been lit. Global warming tied to human activity has sparked natural feedback loops with the potential to heat up the planet even faster. Worms and microbes (like a handful of climate-denying politicians) simply don't do emissions targets, and the challenge of slowing climate change becomes that much more daunting.

CONSEQUENCES

In 2009 (386 ppm CO2), nearly forty years after *The Limits to Growth* was published, a team of scientists at the Stockholm Resilience Center at Stockholm University identified a series of nine "planetary boundaries" beyond which life as we like it is no longer possible. Should the ozone layer be compromised, cancer-causing UV levels will spike. If "biosphere integrity" is lost, a cascade of extinction will follow. If water resources are squandered, then a half billion people will be desperately thirsty by 2050 (a preview of which is unfolding right now in India, where major cities have recently gone dry).

There is considerable overlap between the different kinds of threats, so as each approaches its planetary boundary, there are implications for the others.

THE NINE PLANETARY BOUNDARIES



A new report from the Australia-based National Centre for Climate Restoration (aka Breakthrough)—*Existential climate-related security risk*—looks at what happens on the ground when those planetary boundaries are breached. Climate change is viewed as a "threat multiplier and an accelerant to instability," with the fate of civilization itself hanging in the balance.

This work builds on years of similar assessments, including several reports from the US military. What's new is the call for an "existential risk management" framework that takes into account the irreversible consequences of climate change outcomes:

> *Traditionally, risk is assessed as the product of probability and damage. But when the damage is beyond quantification, this process breaks down. With existential risks, learning from mistakes is not an option.*

In other words, it isn't the range of estimates for sea-level rise that matters, or even the probability for the worst case. What matters is the *possibility* that it could be the worst case because the damage would last centuries. There are also "unknown unknowns," non-linear, wildcard factors that are difficult to model or quantify in probabilistic terms. The higher the stakes, the more they matter, too.

LESSONS FROM THE PAST

History is full of cautionary tales about civilizations whose demise was hastened by a changing local climate and/or the loss of natural resources.

• Cambodia's remarkable Angkor Wat civilization collapsed in the 15th century after more than five hundred years. It literally crumbled from a one-two punch of epic droughts and fierce monsoons that destroyed an elegant and complex water infrastructure designed to support agriculture.

• At its zenith 1,400 years ago, as many as 15 million people lived in Mesoamerica's Mayan Empire. Many factors led to its decline, but evidence of a series of mega-droughts suggest that a changing local climate served as a threat-multiplier.

• Degraded soil helped seal Rome's fate. Wheat for bread to feed Roman citizens and soldiers had to be imported from Egypt, diverting significant military resources.

None of scenarios outlined in the Breakthrough report, which focuses on the next thirty years, are terribly encouraging. If the Paris Agreement fails and emissions continue to rise over the next decade, the authors predict global temperatures will climb at least 3 °C (5.4 °F). Depending on how much methane is released from melting permafrost and through other natural feedback loops, it could get considerably warmer than that.

In this "hothouse Earth" scenario:

• More than half the population experiences at least three weeks of lethal heat each year. West Africa, the Middle East, Southeast Asia and tropical South America can expect at least three months of extreme hot weather.

• Sea level rise reaches about a foot and half by 2050, then increases rapidly as polar ice melt accelerates. The last time there was this much CO2 in the Earth's atmosphere, sea levels were more than 80 feet higher than they are today.

• Jet streams destabilize and buckle, making a mess of global weather. Monsoons become less predictable in Asia and Africa. North America bounces from extreme drought to floods. Agriculturally-important river deltas are submerged. Crop yields fall by least 20% and food prices skyrocket.

Given recent floods in the American farm belt and a buckled jet stream blamed for record heatwaves in Europe and Alaska, those predictions seem alarmingly plausible. The implications are grim:

> *This scenario provides a glimpse into a world of 'outright chaos' on a path to the end of civilisation and modern society as we have known it, in which the challenges to global security are simply overwhelming and political panic becomes the norm…*

To avoid this hellscape, the Breakthrough report recommends a military-style mobilization to build a "zero-emissions industrial system," though no details are given for what a "Marshall Plan" to save the climate might look like, or even how such an effort would ramp up.

Put another way, in the vernacular of the Marvel Cinematic Universe, we are Thanos, only worse. The comic book super-villain set out to extinguish only half of all life in the universe (for the noble, if twisted, reason of sparking regeneration). But humanity is on track to trash almost all life, at least on here on Earth.

Like *The Avengers*, we have exactly one chance to avoid complete catastrophe and it requires turning back time. Amazingly, we can still do that—at least enough to give the next few generations a fighting chance.

Part 2:
How We Get to Next

SECTIONS

SIDEBARS

APPLIED HOPE

> *Applied hope is not about some vague, far-off future but is expressed and created moment by moment through our choices... Applied hope requires fearlessness.*
>
> *— Amory Lovins, co-founder and chief scientist, Rocky Mountain Institute (RMI)*

- *Applied Hope: Commencement remarks to the Natural Science School, University of California at Berkeley, 15 May 2011*
  by Amory Lovins (article)

We are not starting from scratch, nor are things as bad as they might be. Consider: Over the last forty years, gains in energy efficiency have kept at least 100 ppm of CO2 out of the atmosphere. We could easily be well in the thick of worst-case climate change right now. We're not. The game *isn't* over.

In 2011 (391 ppm CO2), Lovins published *Reinventing Fire*, a book that mapped out in detail how the US could transition to a clean energy economy by 2050 using only existing technologies. In just a few decades we could be completely free of fossil fuels and nuclear energy, and in so doing more than double size of the economy. So far, we are hitting all the benchmarks Lovins outlined.

A few years later, the Chinese government hired RMI as part of a research consortium to draw up a similar plan for China. This is a trillion dollar opportunity that embeds resilience while delivering competitive advantage. By every definition fossil fuels are a thing of the past and a drag on the future.

The key is integrative design, a methodology that optimizes for the functionality of entire systems.

• *Integrative Design: Amory Lovins at Autodesk University* (video)

"Failures inevitable by design become impossible by design," says Lovins.

The Upside of Knotty Problems

Nature is an integrative design master, which is why all the environmental crises now coming to head are knotted so tightly together. One way or another everything connects, from tiny microbiomes to vast rainforests. Collectively all the ecosystems on Earth operate as a single, synergistic, self-regulating, complex system: Gaia.

It is remarkable that a change of just a few degrees in the surface temperature of stretch of Pacific Ocean off the western coast of South America can determine how much rain will fall in Indonesia, half a world away. In fact ENSO—the El Niño Southern Oscillation—is considered to be the "most influential natural climate pattern on Earth."

• *Global warming could make El Niño events less predictable*, phys.org (article)

Likewise, all it takes to overheat the planet is the addition of few dozen extra parts per million of CO2 in the atmosphere.

With connections this subtle, far-reaching and powerful, the first challenge is to understand how various systems function in combination: How is the knot knotted?

Only then is it possible to identify which strings to pull first to leverage the most collateral good.

The following sections describe several of the most promising strings. Some are driven by technology, some by biology, while others focus on economics and business models.

ENERGY EFFICIENCY

There are two ways to cut into the profits of fossil fuel companies. Divestment is a strategy designed to starve them of capital, which increases the cost of production.
This approach has gained a lot of traction over the last few years with sovereign funds, universities, pension funds and philanthropies, which collectively have moved trillions of dollars out the sector.

The second strategy isn't limited to those with deep pockets: Cut demand. The fastest, most effective way to do that is through efficiency, which works at every scale: an individual switching to LED light bulbs; a manufacturer redesigning industrial processes; a nation setting standards. The benefits compound over time, delivering savings year after year.

“The cheapest barrel of oil is the one you don’t need,” notes Amory Lovins. The same goes for the cheapest train car full of coal, the cheapest power plant and the cheapest pipeline.

FROM THE ARCHIVES

- *Energy Strategy: The Road Not Taken?* by Amory B. Lovins, reprinted by Friends of Earth via Foreign Affairs, 1977 (pdf)

It is easy to overlook efficiency because there's not much to see. There are no photo-friendly solar arrays and giant wind turbines. Most of the magic is hidden in walls, buried in basements or covered by lamp shapes. To all but the wonkiest, an energy smart window looks just like a regular window. Yet efficiency technologies have had more than 30x the impact of renewables in terms of "keeping it in the ground."

It can also be hard to see savings. A utility bill tells us how much we owe, not how much more we would have owed if not for efficiency. And while efficiency products are often marketed in terms of "payback," even that can seem a little abstract. LED lightbulbs are as much as 80% more efficient than incandescent bulbs and last several times as long. They can save x amount of energy over y number years, and pay for themselves several times over. But what does that look like on a monthly bill?

Yet it adds up. Over the last few decades efficiency has pumped trillions of dollars into the US economy through lower utility bills. This demand-driven "efficiency dividend" has freed up capital that businesses have used to invest in growth and consumers have used to buy more of whatever they want. It has played a pivotal role in the economy's impressive three-fold expansion since the 1980s.

On the flip side, policies that thwart efficiency function as a hidden tax that weakens an economy. Higher costs make businesses less competitive, while at the same time shrinking consumer spending power.

The numbers are not trivial. For nearly 30 years, the EPA's Energy Star program has tested and ranked consumer goods for efficiency, saving Americans more than third of a trillion dollars in energy costs — as much as $30 billion in a single year. The program operates on an annual budget of roughly $60 million, delivering an astonishing return on investment.

In large part thanks to efficiency, primary energy use in the US today is about half of what the experts in 1980 predicted it would be. As a result, fewer power plants needed to be built, which meant less coal needed to be burned and less CO2, SOx, NOx, mercury, particulates and other pollutants poured out of smokestacks. There was still way too much carbon pollution, but without efficiency there would have been considerably more.

INTEGRATIVE DESIGN

Despite its self-effacing nature, efficiency is actually the biggest global provider of energy services, notes Lovins. Viewed as a resource, the world's "efficiency reserves" dwarf those for oil. And the best way to "drill" for it is integrative design.

- *NOx: Nitrogen Oxides*, Wikipedia (article)
- *Sulfur Dioxide (SO2) Pollution*, EPA (article)
- *Common air pollutants: ground-level ozone*, Government of Canada (article)
- *Basic Information about Mercury,* EPA (article)
- *Mercury Exposure and Children's Health,* NCBI / NIH (research paper)
- *Trump EPA Says Mercury Limits On Coal Plants Too Costly, Not 'Necessary',* NPR (article)
- *How big is the energy efficiency resource?* | Amory Lovins, Environmental Research Letters, IOPScience (website with link to pdf)

Exhibit A: Lovins' 4,000 square foot home in the Colorado Rockies, which lacks a furnace, but boasts a mini-jungle atrium with a stream and waterfall and small grove of wildly prolific banana trees. More to the point, it doesn't need a furnace because it *has* that mini-jungle: The atrium generates most of the heat the house needs for the year, with the summer's warmth stored in thick walls, floors and a massive concrete beam that also holds up the building. In fact, the beam has a dozen functions, including blocking sunlight from reaching too far into the building during the summer, overheating the space. The winter sun, which is lower in the sky, can sneak in beneath the beam to deliver warmth and—just as important during the cold dark months—light.

This speaks to a core principal of integrative design:
One cost. Multiple benefits.

Leveraging the economics of a project in terms of the whole is key—calculating both capital costs (capex) and operating cost (opex). The cost of building extra thick walls if considered separately seems like an extravagance. But within the context of the entire project, it is a bargain. Being able to design out the need for a furnace (and all the ductwork and maintenance that goes with it) more than made up for the extra cost of the walls, the beam, lots of smart windows and, of course, the mini-jungle. With integrative design, the whole is often cheaper—and is always better—than the sum of its parts.

BUILT TO BE BETTER

- Passive House Institute US (PHIUS) (website)
- US Greenbuilding Council (USGBC) | LEED (website)
- International WELL Building Institute (website)
- Architecture 2030 (website)

Lovins' home was marginally more expensive to build than comparable homes in the area in early 1980s (~342 ppm CO2), and cost almost nothing to run. With some recent upgrades it now generates more energy that it uses. Over the last 35 years "The Banana Farm," as the house is known, has more than paid for itself in saved operational costs. The bananas—more than 70 harvests so far—are a tasty bonus.

Many of the design principles and strategies first demonstrated in Lovins' home have since become standard practice. Although most buildings don't have mini-jungles, using the methodology of integrative design opens the door to innovation in a field often constrained by convention. It challenges assumptions, changing the narrative from "Who builds a house without a furnace?" to "How can we engineer a building to optimize for natural light, heat and cooling, while minimizing its footprint for energy and water, and reducing overall costs?"

Since buildings account for almost 75% of electricity use in the US, the potential savings are significant. A retrofit of New York City's Empire State Building reduced energy use nearly 40%, with a three-year payback for the upgrades.

The savings have proportionally more significance for the nearly one third of US households that struggle to pay utility bills. According to a recent report from the US Energy Information Administration, millions of Americans are forced

KEEPING OUR COOL

Air conditioning, named one of "the top 10 greatest mechanical engineering achievements of the 20th century," together with the incandescent light bulb, played a pivotal role in creating the modern world. These two inventions changed everything, including the very nature of time. Days no longer ended at sunset. And indoors at least, June now stretched well into September.

Air conditioning dramatically boosted labor productivity. It also tamed the tropics, making cities from Miami to Rio, and from Delhi to Dubai, bearable, It made the manufacture of microchips—and the digital revolution—possible.

Yet while energy efficiency for lighting has dramatically improved with LEDs, there has been no comparable advance for air conditioning. Even worse, the chemical refrigerants used for cooling—chlorofluorocarbons (CFCs) and the hydrofluorocarbons (HFCs) that replaced them—proved to be environmental disasters.

In the 1980s, scientists discovered that CFCs were punching a great big hole in the planet's critical, UV-filtering ozone layer.

to make trade-offs, cutting back on food, medicine and other household necessities in order to keep the lights on and their homes comfortable. Energy efficiency, then, is also about social equity.

A handful of pilot projects for low income housing have now been built to "passive house" standards inspired by Lovins' work. These buildings are comfortable by design (passive), which means they don't require much additional heating or cooling (active). It is an encouraging start, but imagine the collective impact if every building were as well-designed. No one should have to pay for energy they don't need.

Integrative design is about "assemblages of ideas," explains Lovins, a methodology that can be easily scaled up, but also customized to fit anything that requires design, whether it's a building, a product or a process.

A systems approach—and understanding that systems nest within systems—makes it easier to identify solutions that aren't simply better, but also generate cascades of collateral good. For example:

- A Plumbing Fix: Switching from the traditional long, skinny pipes with 90° elbow joints to shorter, fatter pipes connected at shallower angles (30° to 45°) reduces the friction that pumps must overcome to move liquid through pipes by at least 80%. This means much smaller motors could do the job. Since roughly a sixth of the world's

In a remarkable show of unity and common sense, the nations of the world agreed on the Montreal Protocol, which called for the scaling back of their use. But CFCs and HFCs are also "super greenhouse gases," with more than 12,000 times the potency of CO2.

Those emissions, combined with the electricity needed to run billions of air conditioners (the tally for room units is expected to triple to 4.5 billion by 2100) could ratchet up the global thermostat .5°C by the end of the century. It is a given that renewable energy must replace fossil fuels, but finding climate-friendly cooling alternatives is also essential.

In late 2019 ten finalists were named for $1 million Global Cooling Prize, a competition organized by the Government of India and Rocky Mountain Institute to develop and commercialize environmentally-compatible cooling solutions . These technologies will be tested first in the lab and then in apartment buildings.

- *Revolutionizing the Air Conditioner Industry to Solve the Cooling Challenge*, RMI (article with link to report)

- *There's been a huge spike in one of the world's most potent greenhouse gases*, MIT Technology Review (article)

electricity is used to power motors to run pumps, this would dramatically slash demand. By Lovins' back-of-napkin calculations, if all the world's pipes were immediately reconfigured, then half the world's coal plants could be shut down, and so could the coal mines that supply them.

- An Auto Fix: Twenty years ago RMI began working on a prototype for a super fuel-efficient automobile called the Hypercar. In order to keep it light enough to run on a hydrogen fuel cell, the body was made of carbon fiber, a pioneering move at the time. In addition to lightweighting, the choice of carbon fiber simplified the manufacturing process. For example, adding color to carbon fiber eliminated the need for the paint shop, and paint.

- A Grid Fix: Banks of supermarket freezers in England may soon do double duty as a "virtual battery" for the national grid, freeing up as much 50MW of power for other uses. An algorithm coordinates brief power cuts to the freezers—too short for anything to melt—so that electricity can be redirected elsewhere on the grid, avoiding power outages during periods of high demand. By analyzing the grid as an integrated system, it was possible to flip the paradigm and see a major power consumer (supermarket freezers) as a power storage system: a battery. Notably there is no new physical technology in the mix. The new configuration could save ratepayers millions of dollars because the utility won't need to purchase banks of pricey grid-level batteries.

ON THE ROAD: MOBILITY

The story about fuel efficiency is essentially the same as electricity, but with one notable twist: For every coal plant smokestack there are hundreds of millions of tailpipes.

The emissions are distributed, going wherever fossil fuel-burning cars, trucks, motorcycles, boats, ships, trains and planes travel.

While CO2 floats skyward, at ground level we are steeped in carcinogenic, asthma-inducing particulates. Meanwhile, Nitrogen Oxide (NOx) reacts to sunlight, creating smog.

Fuel efficiency standards not only reduce carbon emissions and improve air quality (with a direct impact on public health), but also save drivers money. Over the average 11-year lifespan of an American car, those savings amount to thousands of dollars.

The Trump administration's efforts to freeze fuel efficiency standards for cars and light trucks at 2021 levels would be costly by every measure. Emissions would increase from what they would have been under the Obama rules, adding the polluting equivalent of several million cars to America's roads by 2025. Drivers would also spend thousands of dollars more on gas. Compared to the proposed Trump

• *Access denied: 2 climate change pages removed from DOT's website,* CNN (article)

standards, cars and trucks under the Obama regulations would perform 6 to 8 mpg better by 2025 (fleetwide averages).

Yet fuel efficiency numbers could still improve despite the rollbacks. Electric vehicles (EVs) already exceed the Obama standards, with some models surpassing 100 miles per gallon equivalent.

EVs are cheaper to run, too. It costs between $13 and $15 to charge up a Tesla for a 300 mile trip, depending on local electric rates. By comparison, at $3 per gallon it costs twice as much in gas—$30—for a conventional car averaging 30 mpg to go the same distance.

- *Trump is trying to kill electric cars but will kill jobs and the climate instead*, ThinkProgress (article)

There has been enormous technological progress over the last half century. A 2019 Tesla Model X averages 102 mpg (e), while a gas-guzzling sedan circa 1973 averaged about 12 mpg. That was the year of the Arab oil embargo which saw prices at the pump soar and motivated Congress to pass the first legislation mandating fuel efficiency standards.

At 12 mpg, a 15-gallon fill-up gets the 1973 car 180 miles.
At 102 mpg(e), the energy equivalent of a 15-gallon fill-up gets Tesla 1,530 miles: 8.5 times the distance.

And when electricity for EVs is sourced from solar or wind, there are *no* emissions.

EVs can be cheaper to maintain, too. Typically, over the life of a gas-powered car or light truck as much is spent on maintenance as the vehicle initially cost. With EV prices steadily falling—there are now hundreds of models worldwide—competition is heating up. When the initial investment is comparable, but operational costs are significantly lower, it is not a hard choice. It's the "Banana Farm" story on wheels.

Hydrogen may end up as the fuel of choice altogether, especially now that China has joined Japan in the effort to build a "hydrogen society." Meanwhile in Canada, long-haul electric truck manufacturer Nikola has attracted considerable interest from fleet operators for a hydrogen model currently in development. In Europe testing has begun on hydrogen-powered commuter trains. And the US military has been prototyping hydrogen-powered trucks.

Soon the only thing coming out of those billions of tail pipes worldwide could be water.

- *Loonshots* by Safi Bahcall (book)
- *Safi Bahcall: How to Nurture the Crazy Ideas that Transform Industries*, SxSW (video)

THE SPEED OF CHANGE

In 2007 (382 ppm CO2) Apple launched the iPhone. Less than a decade later more than a billion iPhones had been sold. Today more than a billion smartphones are sold around the world each year.

It is an impressive story of rapid transformation, but one that illustrates a rule rather than an exception: Compelling tech spreads fast.

When Henry Ford figured out how to make a "horseless carriage" that most people could afford in 1908 (229 ppm CO2), it took only a few years before Model T's outnumbered horse-drawn buggies and wagons on the streets of New York and other American cities. An elaborate array of supporting infrastructure popped up just as quickly: garages, gas pumps, refineries, traffic signs, lights and better roads.

Incandescent light bulbs replaced candles. Cable lost out to streaming. And everything that was made of anything else is now made of plastic.

Some changes are foundational. "Moore's Law," the prediction made in 1965 (320 ppm CO2) that the number of transistors in integrated circuits would double every couple of years, has transformed almost everything we see and use. You can't build a desktop computer—or a laptop, tablet or smartphone—with vacuum tubes. The integrated circuit was a better answer.

Rapid technological change follows predictable patterns that are reinforced by the market. Financial analyst Kingsmill Bond of CarbonTracker points out that investors are far more interested in a company's potential for growth rather than its size for the simple motivating reason that there is

- *New Report Suggests the Speed of the Energy Transition Is Rapid* (overview), Jules Kortenhorst, RMI
- *The Speed of the Energy Transition Gradual or Rapid Change?* (report), World Economic Forum (pdf)

more opportunity to make money. Once a startup company in a slow-growth sector secures a market share of just 3%, it is positioned steal the game from the incumbents. Writes Bond: “US horse numbers peaked when cars were 3% of their size. UK steam demand peaked when electricity was 3% of power supply. UK gas-lighting demand peaked when electricity was 2% of lighting.”

The promise of better returns starts a feedback loop of investment. Startups use the first round of investment to grow market share and lower operational costs, which attracts the next round of investment. Before you know it, boxes of incandescent bulbs are gathering dust on the shelf next to boxes of candles, while LEDs shine bright in every lamp.

Even without market support, good ideas have a way of catching on quickly. Somebody at some point invented the wheel. In a blink they were everywhere.

The market is tipping toward renewables. Solar has about 2% of global market share, while wind is closing in on 6% of total electricity generation. Combined with batteries (or banks of freezers turned into virtual batteries), the transition to clean energy is accelerating. According to Bloomberg analysts, by 2050 renewables could account for as much as half of all energy generation.

RETHINKING ECONOMICS

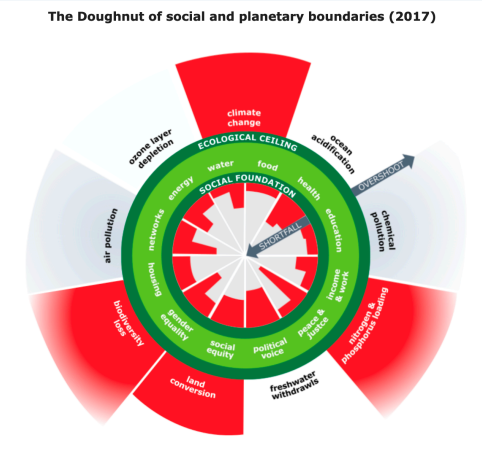
Economics is the study of how goods and services are produced, distributed and consumed. Although it defines every aspect of our lives, for many of us, our understanding of economics begins and ends with the law of supply of demand. While that certainly plays a core role, economics is really about setting the rules of the game. Over time economic models and systems have changed and they will need to change again to support efforts to slow climate change and restore environmental health.

How an economy operates is essentially a design problem—one particularly well-suited for an integrated, whole systems approach.

"I wouldn't begin Economics Education with supply and demand, which suddenly talks about the Market as if it were in equilibrium," says Oxford economist Kate Raworth. "I would start by drawing the economy within the living world. This is a radical act, recognizing the 'environmental externalities': The economy as a subset of the living world, ultimately dependent on it. ...If we start there, it's an utterly different mindset."

To help economists—and everyone else—better understand the challenge, Raworth developed "a compass for the 21st century." First she drew a circle representing the nine planetary boundaries described by the Stockholm Resilience

DOUGHNUT ECONOMICS



A THOUGHT EXPERIMENT: MEASURING BDP INSTEAD OF GDP

With prosperity tied to ecological restoration as the goal, could environmental health be used as a metric for progress? When air is clean, soil healthy, and water drinkable, businesses and communities are better able to thrive. Could biodiversity as a proxy of a healthy ecosystem be used as an economic yardstick? Instead of GDP, we could measure BDP: Biodiversity Domestic Product. BDP would be the tally of the variety of species, their populations, and the value of ecosystem services in an area over a given

Center. Next she drew a smaller circle inside the first, divided into sections listing a dozen essential requirements for a healthy and equitable society. The area between the two, which looks like a doughnut, is the sweet spot.

If the planetary boundaries are overshot, or basic human needs are unmet (clean water, food, shelter, sanitation, healthcare, etc.), civilization disintegrates along the lines detailed in the Breakthrough report. The economist's job, then, is to design an economy optimized to fit within the doughnut, making such an outcome impossible rather than inevitable.

Growth Versus Prosperity

Growth and prosperity are not the same thing, though there can be overlap. Growth is about "more": an increase over what one had before. But too much "more" isn't always a good thing. Unchecked growth, notes Raworth, is the actual definition of cancer. Prosperity, other the hand, is about thriving. Growth is a metric. Prosperity is systemic.

A jungle, for example, cannot expand (grow) beyond its ecological boundaries, yet within those limits it prospers. Prosperity—true wealth—is both regenerative and expansive.

The global economy is optimized for growth measured in the narrow terms of Gross Domestic Product. GDP is a tally of the market value of all the goods and services produced

period of time. These numbers would be weighted to reflect an ideal baseline, while algorithms would factor in migratory species and other variables. Instead of growth, the goal would be to achieve a high number—the highest possible—and maintain it. Bonus points for protecting endangered species.

Right now global BDP is scraping bottom with an estimated one million species on the brink of extinction. One third of agricultural land is classified as degraded, while a staggering 19 million acres of forest are lost every year (27 soccer fields-worth per minute). Oceans, lakes and rivers are turning acidic from carbon pollution and warmer from climate change, while fertilizer-enhanced run-off creates dead zones and industrial-scale trawling decimates fish stocks.

Fortunately, nature is remarkably—miraculously—resilient. Fifty years ago Ohio's Cuyahoga River was so polluted it routinely caught fire, but thanks to massive clean up efforts, it's now a tourist attraction. Prairies have been restored, coral reefs built on artificial substrates, forests replanted and depleted fisheries

within a given period of time. Although that sounds like it covers everything, there are significant gaps.

GDP does *not* factor in:

• Non-compensated Labor: A nanny's services are included, but childcare services provided by a stay-at-home relative aren't, even if those unpaid services are essential for other family members to hold paying jobs.

• Infrastructure: The cost of building and maintaining roads, bridges and other infrastructure is included, but between repairs infrastructure disappears from the tally, despite the fact that it is absolutely essential to conducting business. Workers can't get to work, customers can't get to stores, and products can't be shipped without infrastructure.

• Nature's Services: Until there is a carbon tax on CO2 emissions, there is no direct way to factor in the cost of climate change. Instead the price is paid in property damage and crop losses by those in the path of extreme-weather-linked global warming. There are all sorts of indirect costs that affect GDP, such as disrupted supply chains and reduced labor productivity from extreme heat. Meanwhile, the cost of keeping air, water and soil free of industrial pollutants has been framed by some as a "regulatory burden" that cuts into to corporate profits. Yet there is "deregulatory burden" as well, whose costs—measured in

revived. Even California condors, nearly killed off by lead poisoning, have made a comeback. It is, of course, much more of a challenge to un-melt a glacier or bring an extinct species back to life. But it is possible to slow the damage and in some cases reverse it.

When BDP improves, so do the prospects for GDP.

"Externalities"—the costs of clean water, air, soil and a stable climate—cannot be kept off the accounting books forever. According to the Fourth National Climate Assessment published in 2018 (a report mandated by Congress that compiles research from 13 federal agencies): "With continued growth in emissions at historic rates, annual losses in some economic sectors are projected to reach hundreds of billions of dollars by the end of the century —more than the current gross domestic product (GDP) of many U.S. states."

According to a new report from Moody's Analytics, that's sugar-coating it. Even if the emissions targets set by Paris Accord are met and global temperatures increase no more than the 1.5 °C (2.7 °F) considered safe, climate change will still cost the global economy $54 trillion by

illness, death, degraded ecosystems and even extinction—are difficult to calculate with the narrow parameters of GDP.

GDP also focuses on aggregate wealth, rather than the distribution of wealth. A nation with an impressive GDP might have only a handful of very rich citizens, while most of the population barely scrapes by.

Economist Simon Kuznets, whose work helped popularize GDP, was well aware of its limitations: "...The welfare of a nation can scarcely be inferred from a measure of national income." And yet that is exactly what is popularly inferred.

The distortions of GDP are exacerbated by the emphasis on shareholder value as the entire raison d'être for business. This puts pressure on companies to show growth on quarterly earnings reports, which make it more difficult to develop long-term strategies.

But what would an economy designed for prosperity look like? How would progress and success be measured?

"Humanity's journey through the 21st century will be led by policy-makers, entrepreneurs, teachers, journalists, community organizers, activists and voters who are being educated today," says Raworth. "But these citizens of 2050

the end of the century. If temperatures rise 2 °C (3.6 °F), the cost increases to $69 trillion. Any hotter than that and all bets are off.

Yet as gobsmacking as those calculations are, the Moody's numbers are probably low. The report doesn't factor in plant and animal diseases that would severely impact agriculture and further degrade wild ecosystems.

In a trashed world, GDP, the brass ring of modern economics, becomes a measure of loss.

• *'Silent death': Australia's bushfires push countless species to extinction* The Guardian (article)

• *Business Roundtable Redefines the Purpose of a Corporation to Promote 'An Economy That Serves All Americans'* (statement)

are being taught an economic mindset that is rooted in the textbooks of 1950, which in turn are rooted in the theories of 1850."

In short, we are hurtling toward a fraught and fragile future crippled by an economic model long past its sell-by date. The realities of today—more to the point, those of tomorrow—are completely different than those of the past. The population has grown six-fold since 1850, with an additional 125 ppm CO2 floating in the atmosphere creating a planet-size greenhouse of our own making.

Raworth suggests that we start by shifting the goal of business from maximizing financial value for shareholders to maximizing benefits for everyone, including shareholders. This requires new business models. For example a B Corp is designed to track social and environmental metrics as well as financial performance. Setting up a company as an employee-owned cooperative puts stakeholders front and center.

Next, addressing pollution (waste) needs to be reframed as a business opportunity rather than a burden, a source of profit rather than an expense. For example, instead of selling products that eventually end up as garbage, lease the *functionality* of the products. Lighting manufacturer Philips has switched to offering "outcome based performance": leasing lumens (lighting) as a package of managed services.

PROOF OF THE PROFITABLE POSSIBLE

Twenty-five years ago Ray Anderson, founder and CEO of Interface, a Georgia-based carpet manufacturer, read Paul Hawken's book, *The Ecology of Commerce*, and completely changed the way his company did business. The company's signature product—carpet tiles—was made from fossil fuel feedstocks. Every part of the business was drenched in oil or covered in coal. Anderson was determined to change that and also prove to the world that such radical transformation was possible.

During the first dozen years scaling "Mount Sustainability," Interface slashed its greenhouse gas emissions by more than 80%. This was done through combination of efficiency, renewable energy and also experimenting with alternative materials. Sales increased an impressive 60%, while profits, even more impressively, doubled. The savings—$400 million in avoided costs—not only more than covered the costs of the transition, but boosted the bottom line.

Customers get exactly the kind of lighting they want, while Philips is incentivized to design more efficient systems to increase its profits.

This could also mean upcycling, which draws inspiration from nature: designing products so they can be remade and reused. Within a natural ecosystem, nutrients are constantly cycling through various life forms. There is no top-of-the-food-chain because even the fiercest predators ultimately cycle through microbes. Nothing is thrown away. There is no garbage. There is no waste.

THE CIRCULAR ECONOMY

The results of the Paris Climate Agreement so far have been mixed, with many countries nowhere near meeting their self-defined targets. Yet even if all the targets were met (and the US, Russia, Saudi Arabia and Kuwait weren't trying to spike the deal) a goal of "less bad" isn't the same as "good." Nature doesn't stop at "It'll do." Nor is carbon pollution the only kind of pollution.

The paradigm of the circular economy takes its cue from nature: to make pollution (waste) as impossible as possible. The more circular the economy, the less waste produced.

Circularity itself is a repurposing and rebundling of long-established practices: recycling, reusing, upcycling, downcycling, remanufacturing, cradle-to-cradle design,

By every measure doing better was better. The company was able to weather the 2002-2003 recession in such good shape it was able to gain market share from competitors who weren't so well-positioned.

Long before Raworth started thinking about Doughnuts or the scientists in Stockholm identified the nine planetary boundaries, Anderson understood the essential role business could play restoring environmental health.

Interface, now a global powerhouse with over $1 billion in annual sales, transformed an entire industry by example because business-as-usual couldn't compete against sustainability.

The new Interface goal is "Climate Take Back." The challenge is to design industrial processes that don't simply "do no harm," but that actually do some good. What would a factory that operated in balance with the ecosystem in which it is set look like? Could floor tiles be made of materials that absorb CO2? "Mount Sustainability," it turns out, was only a foothill.

• *Ray Anderson: The Business Logic of Sustainability*, TED (video)

biomimicry, efficiency. The difference is the lens through which all these efforts are analyzed: material flows.

Instead of the "take-make-dispose" model of a linear economy—a straight line material flow that turns non-renewable natural resources into garbage—the mantra of the circular economy is "make, use, return."

Since 2012 (392 ppm CO2), Dame Ellen MacArthur and her eponymous foundation have helped popularize and mainstream the idea of the circular economy. In collaboration with McKinsey, the World Economic Forum and dozens of corporate partners, the Foundation has published a series of reports analyzing the circular potential for plastics, fashion and textiles, food and agriculture, and urban planning.

For MacArthur, a former solo world sailing champion, the benefits of circularity are self-evident. When you are all alone in the middle of the ocean what you have is what you've got. Likewise for the nearly 8 billion people sailing on our blue dot planet through a cosmic ocean, the natural resources we have are all the natural resources we're going to get.

In nature, the rate of nutrient cycling is a proxy for ecosystem productivity. Man-made materials don't break down either easily or quickly, which leads to the circular economy's defining problem: What does a better, more eco-friendly cycling of man-made materials look like?

PLASTIC

Carbon pollution may be hard to see, but plastic is easy. It's everywhere you look. It's also inside us. According to a new study, humans ingest as many as 52,000 microplastic particles each year and breathe in another 22,000 particles. This makes the specter of dead seabirds and whales washing ashore with their guts filled with plastic not only disturbing and scary, but personal. Are we next?

Meanwhile, "plasticrust," an entirely new category of pollution, has glommed its way onto the tidal rocks of Madeira off the coast of Portugal, while plastic "nurdles" (pre-production polymer pellets) have become a plague along the Gulf Coast of Texas.

The plastic-lynchpin of our disposable culture has proved remarkably durable, assimilating, if not killing, everything it touches.

This challenge has inspired a range of innovative solutions:

• Natural Alternatives: In 2007 (383 pm CO2), Ecovative Design, a biomaterials startup, introduced biodegradable packaging grown from plant waste and mushroom mycelia as a replacement for non-biodegradable styrofoam made from petroleum feedstocks. The company has since branched out with mushroom-based building materials and textiles. The global market for biodegradable packaging is expected to exceed $20 billion over the next few years.

• Recommerce: This is a circular update on the thrift store model, where high profile brands such as Patagonia and Eileen Fisher incentivize customers to return used clothing they no longer want so it can be refurbished and resold. The brands develop a deeper relationship with customers and also benefit from direct, secondary markets. There are also take back programs sponsored by large retailers such as H&M, which oversee the conversion of unwearable clothing into cleaning cloths or even into fibers that can be used to make insulation.

• Reengineering: There are many examples, but perhaps the coffee cup best epitomizes the potential. An estimated 600 billion disposable coffee cups end up in landfills every year because the thin plastic coating that keeps them from leaking also keeps them from being recycled. Nearly 500 teams submitted ideas to the NextGen Cup Challenge, whose sponsors included McDonald's and Starbucks. Most

• *4 companies pioneering the clothing recommerce market,* Greenbiz (article)

• *TerraCycle*, Bloomberg (video)

• *Rethinking Packaging with TerraCycle CEO Tom Szaky*, Fortune CEO Initiative 2019 (video)

of the dozen finalists focused on alternative liquid barriers, while a few suggested take-back schemes (e.g., cups that can be dropped off for cleaning in designated bins at a network of locations).

• Refill: Perhaps the most ambitious circular business is Loop, a consumer goods platform where customers pay a one-time, refundable deposit for returnable packaging that is cleaned and processed by the company for reuse. Shifting the ownership of packaging to manufacturers (just as milk bottles were once owned by dairies), makes it an asset rather than an expense. When packaging is an expense, then lightweight, inexpensive, poly-laminate, throw-away materials make sense. These materials—though technically recyclable—end up in landfills because they are too expensive to recycle. When packaging is an asset, then the goal is to create customer value. Product designers are having a field day with Loop, rethinking everything from how much longer an ice-cream container can keep its contents cold to reimagining toothpaste as a tablet (which also saves water in manufacturing—the tablet foams up in your mouth). Although Loop sounds complicated, pilot tests are off to a good start with several high profile companies on board (Proctor & Gamble, Unilever, Clorox and Coca-Cola among others), and also retailers (Walgreens in the US, Carrefour in France and Tesco in the UK)

REGENERATIVE AGRICULTURE & THE CIRCLE OF (MICROBIAL) LIFE

Regenerative agriculture, which is sometimes called "carbon farming," brings circular thinking and integrative design to agriculture. Unlike conventional, petrochemical-dependent farming (fertilizers, pesticides, herbicides, fungicides), which depletes soil of nutrients, regenerative agriculture leverages biological systems to build up the health of the land.

Agriculture is responsible for as much as a third of greenhouse gas emissions (including methane-laced cow burps). Regenerative agriculture can turn that around, transforming farmland into carbon sinks able to sequester vast amounts of atmospheric CO2. Soils become more resilient to heat, drought and flooding, too.

Regenerative agriculture involves three core practices designed to minimize soil disturbance and maximize biodiversity.

It begins with no-till planting, which involves drilling tiny holes in the ground into which seeds are placed. This in a radical departure from plowing, which for millennia has defined agriculture. Tilling the land is actually quite destructive, releasing tons of carbon into the air while shredding the intricate, delicate microbiome of the soil. Plowing makes fields more vulnerable to run-off after rains and to dust storms when it's dry. By contrast, no-till leaves the soil's

3D OCEAN FARMING

Bren Smith, a life-long fisherman who got his start in the industry as a teenager shooting seagulls from a trawler in the Bering Sea (protecting the catch!), has had to improvise. When fisheries began failing, he found work on fish farms, but then those proved to be environmentally problematic. In 2003, he decided to try a radically different approach—one that at the time got him "laughed off the docks." Thimble Island Ocean Farm just off the coast of Connecticut, a short drive from New Haven, is a polyculture vertical farm that grows vast quantities of kelp, mussels, tinyscallops and oysters using a mix of scaffolds, nets and cages over a comparatively small area: 20 acres.

Like his landlubber, regenerative-farming counterparts, Smith minimizes inputs. In fact, he proudly notes that no inputs are required at all: no fresh water, no feed, no fertilizer. Regenerative farmers sequester carbon in the soil. Smith captures it in the kelp. And just as with regenerative farms, biodiversity flourishes. Everything from striped bass and blue crabs to seals, ducks and the occasional seahorse has been spotted swimming around the farm: a fabulous indicator of a healthy ecosystem, and also of nature's remarkable resilience. The trillions of oysters that used

microbial communities undisturbed, so earthworms, fungi, bacteria and other small creatures can go about their business creating soil fertility.

Next, instead of a typical two-crop rotation of conventual commodity farming (e.g., corn and soy), regenerative agriculture uses more complex crop rotations. This makes it easier to control plant diseases and insect pests without chemical sprays. In a two-crop rotation, insects and pathogens can survive an off year to return with a hungry vengeance when their target crop is planted the following year. Planting at least three different crops in rotation increases the time buffer, naturally crashing populations of crop-specific pests.

Finally, cover crops are used to protect the land—to keep it covered—between commercial plantings. When fields are prepared for the main crops, cover crop residues provide a "green manure." Cover crops also provide a more varied diet for pollinators, setting the stage for the anti-"Silent Spring": biodiverse fields filled with birdsong and butterflies.

With each crop, plants send carbon absorbed via photosynthesis down through their roots into the ground, where it builds up the soil's carbon content. In a virtuous circle of goodness, this helps the microbiome flourish, which allows soil to better absorb water, which allows roots to grow deeper and plants to flourish.

to form reefs along the Atlantic coast are long gone. Smith's farm is a tiny approximation of what once was, yet enough to show what is still possible.

Smith's success has sparked considerable interest from World Wildlife Fund and Bioneers to the World Economic Forum, who see in his work a replicable, scalable, economically viable solution for an environmentally-beneficial, nutritious food production system with the potential to create a significant number of jobs. Smith has been working with chefs to develop tasty dishes from his harvests. Kelp pasta anyone?

Meanwhile off the coast of California, Catalina Sea Ranch, which bills itself as "the first aquaculture facility in U.S. federal waters, plants to expand its 100-acre test farm to 1,000 acres in the near future. Currently the only crop is Mediterranean mussels, a non-native species brought to the US in the early 20th century, but plans are in the works to add kelp, oysters, abalone, sea urchins and spiny lobsters.

• Greenwave, Bren Smith's Ocean Farmers Training program (website)

Agroforestry and multi-paddock managed grazing also fall under the regenerative umbrella. The former incorporates trees and shrubs into the mix, which increases biodiversity and reduces erosion. The latter involves the constant movement of livestock between a series of enclosed fields to mimic the migrations of wild herbivores, whose wandering ways ensure the fertility of the grasslands upon which they depend. An area might be grazed to stubble, but generous contributions of cow patties (or those of bison, giraffe, elephant or zebra) naturally fertilize the range between visits.

HYDROLOGY & THE SOIL CARBON SPONGE

For each gram of carbon sequestered in soil, the ground can hold an additional eight grams of water. Since water vapor is also a greenhouse gas, the drawdown of atmospheric moisture into the soil is as critical for steadying the climate as the drawdown of CO2.

For each one degree C rise in temperature, the atmosphere can hold 7% more moisture, so charting the steady, annual rise in global temperature reveals only part the story. The combination of temperature and humidity can be calculated in terms of a heat index, which is why when it's 90°F (32°C) in the middle of August in Chicago and the humidity soars to 90%, it feels like 122°F (50°C). At that point, the human body has difficulty cooling itself down, so the only place to be is in an air-conditioned bubble, or better yet *in* Lake Michigan.

THE TERRATON INITIATIVE

During the three or more years it takes to transition from conventional to regenerative agriculture, crop yields suffer. It takes time for soil carbon levels build up and a damaged soil microbiome to recover. To help farmers navigate the lean period, Indigo, a Boston-based ag-tech company known for its microbe-enhanced seeds, launched the Terraton Initiative, which will pay farmers $15 per metric ton of sequestered carbon to switch to regenerative practices.

The idea is to develop a marketplace for soil carbon credits, providing farmers with a much-needed additional income stream while also addressing climate change.

According to Indigo's President and CEO David Perry, if the world's 3.6 billion acres of farmland were to transition to regenerative practices—and the average soil carbon level increased from today's 1% to 3% (the average prior to the Industrial Revolution), one trillion metric tons of CO2 would be sequestered. That amount—a "terraton"—is roughly the

Not only can cities expect to experience more extremely hot days due to climate change, but even days that are a normal level of hot will *feel* hotter.

Drawing down water vapor into the "soil carbon sponge" also brings much-needed water to the soil's microbiome, a vibrant mix of fungal mycelia, bacteria, viruses, plant roots, nematodes, earthworms and insect larvae that collectively help make essential nutrients bio-available to plants.

"80% of the fertility of soils isn't about how many nutrients are in that soil, but about the availability of nutrients," notes soil biologist Walter Jehne. "So the whole business about fertility is about the microbial ecology of the soils."

The extra moisture also extends the length of time plants—including crops—can grow. "Instead of the soil drying up and we've got 10 days of growth, we've got 100 days of growth....There's a multiplier effect of longevity of green growth and extending drawdown (photosynthesis), extending productivity, extending resilience," explains Jehne.

Jehne began his career working on projects for the Green Revolution, which emphasized chemical inputs over biological systems. Although the extensive use of fertilizer was able to increase yields by as much as 40% (at least in the short term), it came the expense of the soil's microbiome, which was further compromised by repeated applications of pesticides, fungicides and weed-killers. Over

same amount that has been added to the atmosphere over the last couple centuries.

It is a remarkably ambitious goal, yet already some regenerative farmers in the US have seen carbon soil levels increase as much as 6%.

Several large food companies, including General Mills, Land O' Lakes and Danone, have also launched programs to support regenerative agriculture, framing the transition as vital to their companies' interests.

- *This is a $15 trillion opportunity for farmers to fight climate change*, CNBC (article)

- *Will Indigo Ag's New Private Carbon Market Pay Off for Farmers?* CivlEats (article)

- *Soil Wealth: Investing in Regenerative Agriculture Across Asset Classes, Delta Institute, Croatan Institute* (report)

- *David Montgomery On 'Growing A Revolution',* Worldview, WBEZ (podcast)

the last 150 years, half the planet's topsoil has been lost and much of what's left has been degraded to a large extent by misguided agricultural practices.

Greening a Planet

In the span of 100 million years, the Earth's barren, rocky surface was transformed into a riotously fertile, green Eden. Given the planet's age of roughly 4.5 billion years, that's fast. The process was kickstarted by the pioneering efforts of adventurous marine fungi later joined by an army of lichens. Bit by bit, molecule by molecule, they broke apart the rock and solubilized its minerals. Their bodies decomposed into the first humus. The cleared the way for plants to take root and access essential nutrients.

By the Carboniferous Period, more than 300 million years ago, nearly every inch of ice-free land was covered with green, photosynthesizing life. When fungi began their mycelial conquest, atmospheric CO2 levels measured at least 7,000 ppm. Photosynthesizing plants and lichens were able to draw down all but about 100 ppm. What had once been in the air was now buried in the ground.

Today we routinely burn that long sequestered carbon in the form of coal, oil and natural gas. And in the process send it skyward once again.

ToC

WILD AT HEART

"Rewilding is restoration by letting go, allowing nature to take the driving seat," explains Isabella Tree, who with her husband Charlie (Sir Charles Raymond Burrell, the 10th Baronet), transformed the ancestral family estate, Knepp Castle in Sussex, England, from an conventional, and notably unprofitable, farming operation to a natural landscape that has also proved to be more economically viable. Rewilding isn't quite the same as ecosystem restoration. Where the latter is focused more on preserving a specific moment and eco-balance in time, rewilding is about following nature's lead in the present. There is, however, considerable overlap.

Over the last twenty years, rewilding has changed landscapes all over the world, from the Scottish highlands and Australian bush to the heart of Texas. Lands that had literally lost their vitality—worn out soils, reduced wildlife populations and fewer species—have gotten their mojo back. In the process, not only are these lands more fertile and vibrant, but they also are able to sequester far more carbon than they used to.

• *A Trump Policy 'Clarification' All but Ends Punishment for Bird Deaths*, New York Times, (article)

SEQUESTRATION

Imagine all fossil fuel emissions coming to a full stop tomorrow, the targets of the Paris Accord not only met, but exceeded. But emissions continue to rise, the Keeling Curve continuing its stair-step climb to climate catastrophe. Why? Oceans are now so saturated with CO2 that they are becoming increasingly acidic. It will take decades, if not longer, for the oceans to re-equilibrate by releasing all that excess carbon back into the air. The only fix is to sequester as much carbon as possible as fast as possible in the only place where there is not enough of it: in the ground.

By far the most effective way to drawdown atmospheric carbon is through natural processes: preserving, restoring and planting ecologically diverse forests, grasslands, wetlands, parks and gardens. In an era characterized as a "climate emergency," every piece of land has the potential to make a difference for storing carbon.

Technological fixes don't come close. The vision of large machines sucking up vast amounts of carbon out of thin air, then storing the problematic gas deep underground in depleted oil and gas wells or saline aquifers (Carbon Capture & Storage - CCS) has generated significant interest among investors, including Bill Gates, but delivers a remarkably small bang for a very big buck.

THE TRUTH ABOUT COWS & METHANE

Grasslands first appeared roughly 50 million years ago, evolving in elegant tandem with grass-eating animals—herbivores. Ruminant herbivores, a group that includes cows, bison, sheep, goats, deer and giraffes, developed bacterially-enhanced digestive systems specifically designed to process plant cellulose, which their internal microbes handily break down.

The constant cycling of dung-enriched nutrients provided by the grazers builds up the carbon soil sponge. As much as 80% of a grassland's biomass is underground in the form of roots that extend several feet deep, surrounded by vast tangle of fungal mycelia, microbes, insects, worms and everything that burrows and eats them.

Above ground, transpiration (the process by which water moves from roots to shoots and eventually evaporates) and sunlight sets in motions a series of chemical processes, including one that breaks down methane—vast amounts of which are routinely emitted through the prodigious burping of ruminants. Although methane is 30 times as potent a greenhouse gas as CO2, for tens of millions of years atmospheric methane levels remained steady at roughly 700 parts per billion (ppb).

Carbon is *needed* in the soil, where it can improve fertility, water retention, and support biodiversity both below and above ground. More than 8% of the global carbon emissions track back to agricultural land use. Tillage and petrochemical fertilizers release CO2.

As the carbon soil sponge becomes ever spongier, plants become healthier, more resilient and able to sequester yet more carbon in a virtuous circle of positive impact. Plus there are all those fruit, nuts, vegetables, meat and dairy that can be harvested. In cities, plants filter out other, pesky fossil fuel pollutants such as particulates that can damage lungs. There is a cooling bonus, too, through shade and transpiration. This approach points us back toward Eden.

By contrast, spending a great deal of money only to entomb carbon may get some carbon out of the air, but it's doesn't address other greenhouse gases such as methane and water vapor. Indeed fossil energy companies are interested in injecting carbon deep underground as way to pump yet more oil and natural gas from wells that would otherwise be abandoned as unprofitable.

Promoters of CCS characterize these fuels as carbon neutral because carbon-sucking machines will eventually remove the CO2 they produce. But they won't be *climate* neutral because of all the other greenhouse gases and smog-generating particulates released through combustion. They will not—cannot—move the climate dial nearly as much as

Massive herds of herbivores—far more than there are cattle today—were in balance with their grasslands.

That is not the case with today's factory-farmed dairy cows and beef cattle, which has upended the natural balance. Although some begin their lives munching on pasture grass, tens of millions are "finished" each year in giant feedlots where they are given corn, a grain for which their digestive systems are ill-equipped. Whatever methane they burp simply floats into the air. On the other end of things, wastes are stored in holding tanks and open air ponds where yet more methane—one of a suite of noxious substances—is emitted.

Most of the corn fed to cattle is grown on large farms that use standard industrial agricultural practices that include tillage and the generous use of petrochemical fertilizers. This releases yet more carbon into the atmosphere.

Meanwhile, grasslands minus their herbivores become less fertile. Without a steady supply of cow pies, the soil loses carbon and with it the ability to hold as much water. Rain is more likely to run off rather than sink in. Grass, no longer kept in check by grazing, grows tall, dries out and becomes more vulnerable to fire. Instead of cycling through those exquisitely evolved biodigesters—the ruminants—grass oxidizes and burns. More carbon goes up in smoke.

hyped because carbon is only part of the problem. They will, however, take a toll on environmental and public health.

That said, technologies that capture CO2, ideally *before* it gets into the atmosphere, then use the gas to produce useful products, *can* play an important role in sequestration.

GAIA

The Gaia hypothesis, first proposed by chemist James Lovelock and microbiologist Lynn Margulis in the 1970s, suggests that the interplay between inorganic materials and living organisms generate a synergistic, self-regulating, complex system conducive for life. In other words, land use, life and climate are connected. In fact, without life, the Earth's average temperature would hover (and shiver) around -18°C (-1.4F). Instead, it is a comparatively comfortable 15°C (59°F).

First little by little, then more and faster, humans have refashioned much of the Earth's surface. Forests and grasslands were turned into farms and cattle ranches. Small farms gave way to large petrochemical-dependent agri-factories for corn and soy. Cities sprawled into metroplexes and mega-cities. Entire mountain tops were leveled into coal mines. Tens of millions of miles were paved for roads and expressways. Rivers were dammed for power and drained for irrigation. Giant ocean trawlers raked seabeds clean.

Over the last few hundred years, atmospheric methane levels have more than doubled to 1,850 ppb. Yet cows, even those now dining on corn, have played only a small role. Of far more significance has been "ghost" methane that escapes from oil and gas wells and coal mines. Yet even that prodigious source could be easily dwarfed by the release of truly massive amounts of methane from thawing permafrost soils and marine hydrates (ice-like solids of methane and water). This methane, which has been sequestered for millennia, could spark an unstoppable global warming feedback loop.

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On a more hopeful note, meat and dairy products sourced from grass-fed livestock can be good for the climate, if the livestock were raised using a multi-paddock system that mimics the movements of wild herbivores on natural grasslands. In a healthy pasture, bovine methane emissions should zero out. Adding small amounts of biochar to cattle feed can also help reduce methane burps. Within a ruminant's rumen—the digestive chamber where microbes break down plant cellulose— biochar, a stable form of carbon, serves as a kind coral-like

These changes have impacted how much heat is absorbed or deflected, and how much water soaks into the ground or runs off. The atmospheric dance of high and low pressure reflects these changes and long-stable weather patterns begin to shift. Growing seasons lengthen, or shorten. Monsoons become less predictable. Droughts become mega-droughts — "big dries" that can lead to the kind of incinerating fires seen in Australia.

Humans are also driving what has been called the Sixth Great Extinction. According to a UN report released in 2019, an estimated one million plant and animal species are on the brink of disappearing. And at least 40% of all insect species are under threat.

A lethal mix of habitat loss, the profligate use of agricultural chemicals (including neonicotinoids linked to mass bee die-offs), industrial pollution, disease, overfishing, overhunting and an increased number of extreme weather events associated with rapid climate change has proved too much.

Life in all its complex, micro to macro, interrelated, dizzying glory is the literal animating force of our planet. Which means that the blink-of-an-eye loss of biodiversity on a global scale, coupled with massive changes in land use, can dramatically alter—is dramatically altering—the dynamics of the entire biosphere.

structure. The biochar "reef" allows methane-eating microbes to flourish.

Meanwhile, a steady supply of cow pies (even better if they are biochar-enriched) builds up the carbon soil sponge, increasing CO2 sequestration and improving the underground ecosystem of microbial goodness. Grasses and other pasture plants have access to more micronutrients, which in turn makes for more nutritious meat and milk.

One good thing leads to another: A healthy, carbon-rich soil can support a diverse web of life above ground, ranging from native bees to migrating birds. And since everything connects, the benefits of a well-run farm can, eventually, span the planet.

• *Joel Salatin: Cows, Carbon & Climate* TEDxCharlottesville (video)

• *Cows, Compost & Carbon*, Northern California public media (video)

- *Stripped bare: Australia's hidden climate crisis,* The Guardian (article)

• *A Letter From Canberra: The apocalyptic fires in Australia signal another future*, Sierra Club

Blast from the Past

This has happened before. When dinosaurs ruled the Earth, the average temperature was 35°C (95°F), which was ideal for giant lizards and tropical forests that stretched pole to pole. But tens of millions of years of climate stability came to an abrupt end when a 6-mile wide asteroid slammed into the planet 66 million years ago, vaporizing rock, igniting globe-spanning fires, kickstarting enormous tsunamis and triggering giant earthquakes. An estimated 80% of all life on the planet died.

Yet somehow 20% managed to survive in what was now a dramatically altered landscape. Over eons a new ecological balance emerged from the interplay of organic and inorganic —one that created a climate better suited for the first modern humans who strolled onto the scene roughly 300,000 years ago.

According to chaos theory, the flap of butterfly's wings can set off a chain of events that could lead to a hurricane forming halfway around the world. The reverse could be just as dramatic: a flap never flapped because the butterfly went extinct because too many of it species died from extreme weather linked to climate change during migration, so the hurricane never happened. That might be good news for coastal property owners, but what if the hurricane was needed to rejuvenate fish stocks by stirring up the water and

• *Insect apocalypse: German bug watchers sound alarm*, PhysOrg (article)

• *Why insect populations are plummeting—and why it matters* National Geographic (article)

breaking up a marine dead zone? Could an extinct butterfly lead to dead fish?

The point is that what happens, or doesn't, sets the stage for what will happen next. Or won't. The system is dynamic.

Changes in landscape (which include changes in the water: an increasingly acidic ocean, the collapse of coral reefs) and the imminent mass loss of species may lack the apocalyptic drama of direct hit from an asteroid, but the implications are just as serious. If we are not careful, the next Gaian reset may once again pump up the Earth's thermostat to favor large lizards.

CARBON CASCADES

"Why would you have an agriculture that destroys soil, when you could just as easily have an agriculture that builds soil?" — Albert Bates, co-author, Burn: Using Fire to Cool the Earth

Carbon has been cast as a villain, but what if it's really a hero? What if the problem isn't carbon, but the balance of carbon between between earth, air and water? When there is too much carbon in the atmosphere, the planet heats up. Too much in the water and oceans, lakes and rivers become acidic. Too much locked in the ground can trigger an ice age.

Human civilization emerged in a planetary Goldilocks moment when the balance of carbon was just right for the development of large-scale agriculture. The climate warmed and weather patterns became predictable.

- *Biochar or Using Fire to Cool the Earth: An Interview with Albert Bates*, Nori: Reversing Climate Change (podcast)
- International Biochar Initiative (website)
- The Carbon X Prize: Transforming Carbon into Valuable Products (website)
- LanzaTech: Carbon recycling (website)
- *Through a new partnership and $72 million in funding, LanzaTech expands its carbon capture tech* TechCrunch (article)

Then in a blink of just 13 human generations (about 250 years) the mass burning of coal, gas and oil—fossil fuels that had been buried in the ground for millions of years—transferred a trillion metric tons of carbon from the earth to the sky.

So how do we bring it back?

We burn more carbon, says Albert Bates, a former environmental rights lawyer, scientist, permaculture pioneer and longtime biochar champion.

Biochars are an extremely stable form of carbon made by burning biomass (typically plant material) in a low-oxygen process called pyrolysis (gasification). Depending on the feedstock, the resulting "chars" can be used for everything from soil amendments to building materials. In circular-economy terms chars, according to Bates, are essential for designing out waste on a planetary scale.

Biochar as a soil amendment is actually a very old idea, used by civilizations throughout South America and West Africa for thousands of years. It was rediscovered by a Dutch soil scientist working in the Amazon Basin in the 1950s, but it took several decades before researchers realized that the *terra preta* (Portuguese for black earth) was actually a man-made soil, rich in carbon and spectacularly fertile.

TREES, WHALES & CARBON

According to a recent study, planting a trillion trees—most in just six countries—would be the cheapest, fastest way to counter climate change. Nothing sequesters carbon like a forest! Technically, there is enough land to do it, although logistics on the ground are complicated. About 15 billion trees are cut down each year of the three trillion total. To make up the difference and add another trillion requires afforestation—the mass planting of new forests.

It is not only the number of trees, but also where they are planted that matters. Planting a forest on what was a grassland, for example, can lead to disaster.

Another proposal getting a lot of attention focuses on whales. Nothing sequesters carbon like a whale! According to a team of economists at the International Monetary Fund (IMP) who crunched the numbers, a whale's individual lifetime value, including sequestrations services, is $2 million. Saving whales, along with

These soils, often meters deeps, were created over many years by mixing char into otherwise nutrient-poor tropical soils. The physical structure of the char was perfect for microbial colonization.

While early farmers in Europe and Asia depleted soils through tillage and irrigation, their counterparts in the Americas and West Africa were building up soils, creating regenerative fertility that improved over time.

For the last decade, biochar as a soil amendment has generated considerable interest. It is even included as an IPCC negative-emission strategy. As an exceptionally stable form of carbon, biochar keeps carbon in the ground far longer than decomposing plant waste. But Bates sees agricultural applications as only the beginning of char's potential to address climate change. (That said, adding a tiny bit of biochar to cattle feed could significantly reduce those bovine methane burps.)

Chars made from contaminated feedstocks, such as biosolids from sewage treatment plants, are unsuitable for agriculture, but can be used as binders to make cement and asphalt. It actually makes these materials more durable, while also sequestering carbon, says Bates.

This sets the stage for "carbon cascades" where waste streams such as biosolids become material feedstocks and

the massive number of CO2-metabolizing phytoplankton their poop supports, is a fine idea, but the proposal quickly devolves into a misleading spreadsheet comparison: "To put things in perspective, we calculate this [restoring whale populations] is the equivalent to the amount of CO2 captured by 170 trillion trees—four Amazon forests' worth—or 70 times the amount absorbed by all the trees in the US Redwood National and State Parks each year..."

Unlike dollars and nonsense, species and ecosystems aren't fungible. Nor do they operate in isolation. Lose the one Amazon forest we actually have—we are fast approaching the tipping point—and the climate would be so dramatically altered that everything, including whales and phytoplankton, would feel the effects. The Amazon also supports an invisible atmospheric river that thanks to the trees transports 5 times the water volume of the river itself each day—30 billion liters—across the basin. Lose the forest, lose the atmospheric river.

pollution is virtually eliminated: "With this new perspective, a world of opportunity opens up in terms of how and how much biochar can displace materials that either have a large carbon footprint, are non-renewable, are toxic or are simply too expensive."

According to Bates' calculations, used at scale across farm, industrial and public works sectors, biochars have the potential to sequester far more carbon in a year than is currently emitted. In other words, the balance could tip not at carbon neutral, but *carbon negative*.

NOT OVER

We live in a world significantly diminished from the one into which we were born. This is true even if you were born yesterday. There are fewer forests, less biodiversity, hotter temperatures, smaller glaciers, higher seas, more floods, weirder weather, more intense wildfires, more droughts, more ticks, more mosquitoes, bigger dead zones, more degraded land, more pollution, more suffering.

Yet it could be worse. Atmospheric CO2 levels could be soaring well past 500 ppm right now. They are not, largely due to efficiency gains. That remarkable track record is proof of what is possible.

The answer is not either / or, but rather an integrated, all-of-the above approach that leverages the inter-relatedness of ecosystems and uses biodiversity as a proxy for planetary health. (see sidebar on BDP versus GDP)

• *Can Planting Billions Of Trees Halt Climate Change?* CNBC (video)

• *The White House blocked my Report on Climate Change and National Security*, New York Times (article)

• *A Grave Climate Warning, Buried on Black Friday*, The Atlantic (article)

• *Government Scientists Are Censoring Themselves,* Scientific American (article)

• *'It feels like something out of a bad sci-fi movie': A top climate scientist quit USDA, following others who say Trump has politicized science,* Politico (article)

We are teetering on the edge of runaway climate change, but there is still much that can be done to avert catastrophe. Technological advances in renewable energy generation and battery storage are literally changing the power dynamic. The transition to a low-carbon economy is accelerating, despite the barrage of largely political obstacles. We have the tools to put the breaks on climate change and do it in a way that restores ecological health and shifts the economic paradigm from unsustainable growth to regenerative prosperity.

It is *still* possible to leave a world significantly better for the generations yet to be born.

The knee-capping of science (burying research papers, slashing budgets, cancelling conferences, barring expert testimony before Congress) will serve only to increase suffering, deepen economic loss and compromise national security. Manipulating data so that harmful exposure to air pollution can be reclassified as legal doesn't mean that it doesn't cause illness.

The facts on the ground—and in the ocean and in the air—can be papered over, but they don't change. Ignoring and distorting data can't un-melt a glacier, remove plastic from the belly of a dead whale, or revive bees killed off by pesticides.

• *The Energy 202: Trump's budget seeks cuts to climate research and renewable energy programs*, Washington Post (article)

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• *95 Environmental Rules Being Rolled Back Under Trump* New York Times (article)

• *Trump Administration Moves to Limit Climate Reviews for Federal Projects* Scientific American / E & E News (article)

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It is always better to have more data, yet we already know enough to take action. The link between burning fossil fuels and climate change has been clear for decades, ever since a scientist named Charles David Keeling (for whom the Keeling Curve is named) began measuring levels of atmospheric CO2 in the 1950s. We know that degraded soil, floods, droughts, and massive dead zones mean hunger. We know that business-as-usual cannot continue.

In *The Primer*, we have looked at some of the tools and strategies that are already making a significant difference. There is so much more: game-changing developments in every field, many with cross-sector implications.
These are the stories that will be covered in "11," a new "textzine" (magazine + website) designed to serve as a reference, resource and tip-sheet that promotes and supports the transition to a low / no carbon economy.

Knowing, or even simply imagining, that the impossible is possible provides the confidence to try again, try harder and try something new (see Ray Anderson's ascent up "Mount Sustainability," or anything on the long list of *Star Trek*-inspired inventions).

Curiosity is essential. Many of the most innovative ideas are hybrids that cross sectors, disciplines and technologies. Breakthroughs in one area can have profound implications for others.

• *Dr. Joseph DeSimone, CEO, Carbon,* mHub (video)

For example, on the surface, the "greenest" thing about 3D-printing startup Carbon would appear to be its polymer feedstocks, many of which are recyclable or biodegradable. But that literally only scratches the surface. The company uses a proprietary process that is a hundred times speedier than other 3D printers and is capable of producing high quality finished products. Banks of printers can be set up almost anywhere, making distributed manufacturing at scale practical. This means that products can be made closer to where they will be used, reducing transport costs and fuel emissions.

Several major companies have already begun using Carbon, including Ford, which is experimenting with auto parts, and Adidas, which is making soles for high-end running shoes. Carbon is also being used to make dental prosthetics.

Now let's mix things up a bit: What if Carbon's polymer waste —anything that wasn't readily recyclable or biodegradable— could be turned into "char" that could be upcycled, creating an additional revenue stream in the process?

This is speculative, of course, but by taking a systems approach and bringing a zen-like "beginner's mind" to the complex challenges we face, it is possible to come up with solutions that are better in every way.

It is also fun, which rarely gets mentioned given the seriousness of it all. Creativity and inventiveness bring out our best. The future is *still* ours to make. Despite—or perhaps

• *Designing Tomorrow Better: Brian Collins & Julia Marsh*, Aspen Ideas Festival (video)

(not a typical) BIBLIOGRAPHY

Inspired by a children's encyclopedia that was popular in the 1930s and '40s called The Book of Knowledge, *The Primer's* bibliography is a little unusual in its structure: organize topically rather than alphabetically. Links within categories are grouped by relational relevance.

Some references are listed under multiple headings. Some repeat links from the text. This is to improve discoverability. The three-column layout encourages serendipitous scanning. Dive in!

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A HANDFUL OF #HASHTAGS

;As full as The Primer may be, there is so much more! Research via social media hashtags is a great way to quickly survey the latest and pursue leads. Below are a few suggestions to get you started. Please note these are not links.

#Climate
#ClimateChange
#ClimateEmergency
#GreenFinance
#GreenEnergy
#GreenNewDeal
#CircularEconomy
#RegenerativeAgriculture
#Rewilding
#Drawdown
#Water

PERSPECTIVE

On Valentine's Day 1990 (355 ppm CO2), Voyager I, a small satellite then 13 years into a mission to explore the solar system and beyond (a mission that continues to this day), turned to face Earth for the last time. At the request of astronomer Carl Sagan, a series of photographs were taken of our planet, a barely visible "pale blue dot" 4 billion miles away, "a mote of dust suspended in a sunbeam."

> *From this distant vantage point, the Earth might not seem of any particular interest. But for us, it's different. Consider again that dot. That's here. That's home. That's us.*
>
> *On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives…*

• *Pale Blue Dot: A Vision of the Human Future in Space* by Carl Sagan (book)

"Saving the planet" is code for saving ourselves. Earth's future is assured, at least for the next several billion years until the sun expands into a red giant that envelopes and vaporizes it. Our future is less certain.

It is hard to believe that it took only a few hundred years of burning coal, oil and natural gas to put us on the brink of catastrophic climate change. And it is far too easy to believe that the extremes we are experiencing today—floods, droughts, heat, fire, cold, rising sea levels, mass extinctions—are only a prelude of what is to come.

There isn't much time left to turn things around: to slow global warming and bring a poisoned planet back to health. What happens over the next decade will determine what happens for thousands of years into the future.

The mission of The 11 Project is to serve as a resource and inspiration—to show what is possible—and to develop a network of people whose work is already making a difference.

With literally everything at stake, it is essential to expand our collective peripheral vision as we focus on the tasks at hand. It is going to take collaboration, cooperation and a belief that the greater good benefits us all. Knowledge really *is* power.

Wrote Sagan:

> *...There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known...*

• *Pale Blue Dot, narrated by Carl Sagan* (video)

Ok, then. We have our marching orders.

— J. A. Ginsburg

Founding Editor, The 11 Project

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The Primer is a publication of The 11 Project.

A special thanks
to Hilary Mac Austin
for her many deft insights
and to Coralie Ginsburg
for her uniquely cosmic inspiration.