THE 100 MOST SUBSTANTIVE SOLUTIONS TO REVERSE GLOBAL WARMING, BASED ON METICULOUS RESEARCH BY LEADING SCIENTISTS AND POLICYMAKERS AROUND THE WORLD

In the face of widespread fear and apathy, an international coalition of researchers, professionals, and scientists have come together to offer a set of realistic and bold solutions to climate change. One hundred techniques and practices are described here—some are well known; some you may have never heard of. They range from clean energy to educating girls in lower-income countries to land use practices that pull carbon out of the air. The solutions exist, are economically viable, and communities throughout the world are currently enacting them with skill and determination. If deployed collectively on a global scale over the next thirty years, they represent a credible path forward, not just to slow the earth's warming but to reach drawdown, that point in time when greenhouse gases in the atmosphere peak and begin to decline. These measures promise cascading benefits to human health, security, prosperity, and well-being—giving us every reason to see this planetary crisis as an opportunity to create a just and livable world.

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THE MOST COMPREHENSIVE PLAN EVER PROPOSED TO REVERSE GLOBAL WARMING

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COMING ATTRACTIONS
MARINE PERMACULTURE

"The number of living creatures of all Orders, whose existence intimately depends on kelp, is wonderful. A great volume might be written, describing the inhabitants of one of these beds of seaweed . . . I can only compare these great aquatic forests . . . with terrestrial ones in the intertropical regions. Yet if in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here, from the destruction of the kelp." — Charles Darwin, from Voyages of the Adventure and Beagle

In his 1989 book, *The End of Nature*, Bill McKibben describes how nature is no longer a force independent of human activity but a process subordinate to human alteration, most of which is destructive to life. Recently, scientists have announced that civilization has entered a new epoch, the Anthropocene, a period defined by human domination of earth's physical environment. It marks the end of the Holocene, an 11,700-year "Goldilocks" era of benign and stable climate—not too cold and not too hot—just right for the birth of human civilization.

The usual assumption about human activity is that it makes nature worse, however well intentioned. But that has not always been the case. The productivity of the tallgrass prairies of the Great Plains region can be attributed to the fire ecology practiced by Native Americans. In Norman Myers's book *The Primary Source*, he describes going into a forty-thousand-year-old "untouched" primary forest in Borneo with an ethnobotanist. Both stayed in one spot for the day while the ethnobotanist identified the towering dipterocarps and other flora for Myers. It turns out the entire forest had been placed and planted by human beings before the last ice age. The Swiss agroecologist Ernst Gotsch works with deforested and desertified lands in Brazil and restores them in a matter of years to lush forest farms bountiful with food. In a video segment in which he describes his work, Gotsch picks up dark, moist soil and proclaims, "We are growing water."

In other words, human intervention can increase wildlife, fertility, carbon storage, diversity, fresh water, and rainfall. This entire book asks whether, as a species, we can reverse global warming. To do that, the demise of living ecosystems needs to be reversed. Marine permaculture may be one of the most extraordinary ways to answer that question affirmatively.

We usually do not speak of oceans and forests in the same sentence, but what if you could reforest the ocean? Dr. Brian Von Herzen devotes his life to this proposition. With a physics degree from Princeton University and a Ph.D. from California Institute of Technology, he had a fruitful career as a consultant specializing in electronic design and systems engineering. He created solutions for Intel, Disney, Pixar, Microsoft, HP, and Dolby. For adventure, he would pilot his twin-engine Cessna 337 Skymaster across the Atlantic.

The 337s are used extensively by firefighters as spotter aircraft. At the request of friends who were glaciologists, Von Herzen looked for melt ponds as he flew over the Greenland ice sheet in 2001. He spotted a few small ones. Two years later when he flew over again, there were hundreds. In 2005, there were thousands. By the next year, there were lakes exceeding six miles long and a hundred feet deep. By 2012, 97 percent of the ice sheet surface had melted. This led Von Herzen to focus on reversing global warming using the only means possible: increasing the primary production of living systems, specifically the oceans. Primary production is the creation of organic compounds from aqueous or airborne carbon dioxide through photosynthesis. This is accomplished by kelp and phytoplankton, the microscopic wandering plants that thrive in the oceans—a quarter billion of which fit nicely into a cup of seawater.

We are talking kelp forests, hundreds of thousands of acres of underwater plantations situated offshore, floating forests in the middle of the ocean. Today, kelp forests cover nineteen million acres. Ultimately, floating kelp forests could provide food, feed, fertilizer, fiber, and biofuels to most of the world. They grow many times faster than trees or bamboo. Von Herzen wants to restore the subtropical ocean desert and its fish productivity with thousands of new kelp forests. He calls this *marine permaculture*.

The situation in the oceans is dire. Half of the carbon dioxide that is recaptured from the atmosphere goes into oceans, causing surface acidification. And over 90 percent of the heat caused by global warming is absorbed into the surface waters, a trend that is steadily erasing the marine food chain. What makes oceans productive are upwellings of cold, nutrient-rich water from deep in the sea. Natural upwellings occur around the world, such as in the Grand Banks of Newfoundland—the richest fishing ground in the world—where the icy Labrador Current meets the warm Gulf Stream. This phenomenon is known as *overturning circulation*.

As waters have heated up, ocean deserts have expanded. Ninety-nine percent of the subtropical and tropical oceans are largely devoid of marine life. The oceans' wind- and current-driven pumps are being turned off one by one. In the Atlantic, satellite imagery is detecting a 4 to 8 percent per annum decline in biological activity, a number that exceeds predictions in global warming models.

Warm water reduces overturning circulation across thermoclines, the temperature gradients in the ocean. As heating of surface water increases, currents slow or are thwarted, and upwelling of nutrients decreases or stops altogether. Phytoplankton and seaweed production drops; subsequently, the aquatic food chain declines. Phytoplankton are minute, but the 1 percent

The number of creatures in a kelp ecosystem is extraordinary. Corallines, a branching coral like seaweed, may incrust every frond and leaf; cuttlefish dart in and out; multicolored ascidia, tiny invertebrate filter feeders, dot and cling to the waving leaves. On flat surfaces you find sea snails, limpets, mollusks, and bivalves. Permeating this undulating landscape, attached or unattached, you may find krill, shrimp, barnacles, woodlice, cuttlefish, and crabs. Sea urchins will be gnawing away at the stems, and wolf eels, starfish, and triggerfish will feed on them. Among them all will be tiny forage fish, the smelt, halfbeaks, and silversides. And circling the waters around the dense kelp growth, shimmering game fish will feed on the prey fish. (Inspired by Darwin)

annual decline in the oceans' plankton and kelp is massively significant: They comprise half of the organic matter on earth and produce at least half of the earth's oxygen.

What Von Herzen proposes would restore overturning circulation in the subtropics. Employing marine permaculture arrays (MPAs) .4 square mile in size—situated offshore and far from land—would re-create entire marine ecosystems. It would be like reforesting a desert—in this case, the ocean desert. Imagine a lightweight latticed structure made of interconnecting tubing, submerged 82 feet below sea level, to which kelp can attach. MPAs can be tethered near land, or self-guiding on the open sea. They are far enough below the surface that the largest cargo ships and oil tankers can pass right over them with no damage save some shredded kelp.

Buoys attached to the MPAs rise and fall with the waves, powering pumps that bring up colder waters from hundreds or thousands of feet below sea level. As the nutrient-laden waters come to the sunlit surface, seaweed and kelp soak up the nutrients and grow. What soon follows is what is called a *trophic pyramid*. With phytoplankton come algae, more kelp, and sea grass. These feed populations of herbivorous forage fish, filter feeders, crustaceans, and sea urchins. Carnivorous fish feast on the smaller herbivores, and seals and sea lions and sea otters feed on them. On top of this are seabirds, sharks . . . and fisher folk. The phytoplankton and kelp that is not consumed dies off and the majority drops into the deep sea, sequestering carbon for centuries in the form of dissolved carbon and carbonates.

Often the ocean is thought of as a single fluid entity, but nothing could be further from the truth. Most of the carbon emitted by human activity is contained within the top five hundred feet of the ocean known as the photic zone. It is accumulating carbon significantly faster than the rest of the ocean. In its entirety, the ocean stores fifty-five times as much carbon as is contained in the entire atmosphere. Looked at another way, if all the carbon in the atmosphere were removed and stored uniformly throughout the ocean, the increase in ocean carbon would be less than 2 percent. Thus, it is mostly an issue of moving carbon from the near-surface photic zone into the middle and deep ocean. Oceans naturally do an exquisite job of sending carbon from surface water into the depths, a process known as the biological pump. Marine permaculture supports the functioning of the biological pump so that oceans can do the job they always have.

Kelp harvests can produce food, fish feed, fertilizer (including nitrate, phosphate, and potash), and biofuels. Each dry ton of kelp sequesters a ton of carbon dioxide. Fish populations will soar; these will be the ultimate fish farms (free-range aquaculture), except the fish will be diverse, wild, untainted, and full of omega-3 fatty acids. MPAs in larger groups may seasonally protect coastlines from the worst effects of hurricanes by lowering the surface water temperature and the energy upon which hurricanes depend. It is possible to seasonally protect reefs from thermally induced bleaching. Given that Hurricane Katrina alone cost $105.7 billion, and that 2015 saw twenty-two Category 5 hurricanes, this may be a cost-effective solution. The material costs are estimated at $2.6 million per square mile. With a million MPAs active for thirty years, the carbon dioxide reduction would equal 12.1 parts per million, or 102 billion tons. The economic return would exceed $10 trillion. On paper, the protein from restored fisheries could supply the protein needs of most of the earth's people. Perhaps with the implementation of MPAs, human beings can be agents of restoration and increased productivity of fish and kelp forests.

COMING ATTRACTIONS
INTENSIVE SILVOPASTURE

Silvopasture is the most commonly practiced form of agroforestry today, covering 1.1 billion acres worldwide. The theory is simple: Combine trees or woody shrubs and pasture grasses to foster greater yields. Cattle fatten faster and provide better-tasting meat than in any other system. Rarely are livestock and climate mitigation used in the same sentence; silvopasture, however, sequesters up to three times more carbon per acre than grazing alone—ranging from one to four tons per acre in the tropics and averaging 2.4 tons in temperate regions.

What happens if you intensify the silvopasture process? Add more cattle, plant different types of trees, and rotate the herd more quickly? It seems counterintuitive that it could have a beneficial effect on land and climate, as well as human health, but it does. There are reams of data showing how conventional cattle-raising systems, involving feedlots and accelerated fattening procedures, are among the more significant contributors to climate change, if not the most. Implausibly, ranchers have developed an intensive silvopasture system that is one of the most effective means known to sequester carbon. First developed in Australia in the 1970s before spreading to the tropics, it looks like chaos to the untrained eye. To someone accustomed to fields neat as a pin, with laser-guided row crops, intensive silvopasture would appear to be an unkempt jungle. In areas where ranching and farming are stressed by volatile and uncertain patterns of rainfall and heat, intensive silvopasture systems teem with life. Extremes in climatic variation make livestock farming riskier, if not ruinous, because grasslands are completely dependent on available natural resources, including rainfall. In contrast, intensive silvopasture creates resilience by increasing the density of flora and fauna.

Most intensive silvopasture systems revolve around a quickly growing, edible, leguminous woody shrub. *Leucaena leucocephala*, planted four thousand per acre, is intercropped with grasses and native trees. These intensive systems require rapid rotational-grazing regimes. They employ electric fences that allow for one- to two-day paddock visits, with forty-day rest periods between. Trees keep the wind in check and improve water retention, which causes increases in biomass. The combination of flora can reduce ambient temperatures in the tropics by fourteen to twenty-three degrees Fahrenheit, which enhances both humidity and plant growth. Species biodiversity doubles in intensive silvopasture systems. Stocking rates nearly triple. Meat production in pounds per acre per year is four to ten times higher than in conventional systems. The tannin content in *Leucaena leucocephala* seems to protect protein degradation in the rumen of cattle, reducing methane emissions, which partially explains the significant weight gain of animals raised via intensive silvopasture. And during the dry season, *Leucaena leucocephala* seeds can be harvested—netting another $1,800 per acre in income. *Leucaena leucocephala* is an invasive in Florida and many other places, and is toxic to animals with a single stomach, like people and horses. In the United States and in tropical highlands around the world, other species are being trialed. The key to intensive silvopasture is a fast-growing, high-protein woody plant that can handle heavy browsing and re-sprout quickly. In tropical Australia and Latin America, Leucaena is one that has passed the test so far.

Today, intensive silvopasture is practiced on more than five hundred thousand acres in Australia, Colombia, and Mexico. In Colombia and Mexico, producers are cultivating fruit, palm, and timber trees to further boost income. It may sound too good to be true, but there is one more piece of data: In a five-year study of intensive silvopasture in which trees were incorporated with grasses and *Leucaena leucocephala*, the rate of carbon sequestration exceeded an extraordinary ten tons per acre.

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