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Why Understanding Limits Is the Key to Humanity's Future

Recent news articles about a breakthrough in nuclear fusion research heralded the potential for "limitless" energy. Whenever I read that word *limitless* I wince, because I've learned to view it as a subtle instruction to readers to "please stop thinking now." After decades of false promises to deliver limitless energy, we need to *start thinking* instead, and search for limits both obvious and hidden. Doing so usually leads to a better understanding of how things really work.

Fortunately, several other writers have successfully refuted "limitless energy" claims regarding fusion, so it's not necessary for me to do that here. However, it may be useful to explain more generally why the promise of limitlessness is misleading and sometimes deadly—and why limits are lovable after all.

Limits exist everywhere in nature. Physics, chemistry, biology, geology, astronomy—pick your field, dig into the literature, and you'll soon be struck by how everything in the universe is defined by limits of temperature, weight, volume, density, number, power, frequency, speed, and more. Limits enable the functioning of systems at scales from the subatomic realm all the way up to galaxy clusters. If there is any physical thing that could credibly be claimed to be infinite, it is the universe itself. But not all cosmologists believe the universe is infinite, and proving whether it is or not may be impossible in principle. Leaving the totality of the cosmos to one side (an action possible only within the human brain—which does, most assuredly, have its own limits), everything else we encounter in life has boundaries.

So, why have many people become obsessed with either denying or overcoming limits, to the point where they appear to feel that life can have meaning only if it's tied to some limitless thing, quality, or substance? Humanity's obsession with limitlessness probably began with the origin of language, which enables the asking of questions. People tens of thousands of years ago began to ask, "What happens to our essential sense of self when we die?" Their efforts to manage existential terror likely led them to tell stories about a boundless otherworld in which the dead live forever. Looking up at the night sky, they saw a realm of blackness punctuated by moving points of light; upon this screen they projected their wants, needs, and fears. Our lives and those of all the creatures around us may be brief, these early people must have thought, but there is another dimension that lies beyond—a dimension without endings. We've been searching for a path to infinity ever since.

Limits and Indigenous Wisdom

In practical terms, ancient peoples confronted limits every day. In addition to personal limits on muscular strength and endurance, there were also limits to environmental capacity that constrained whole groups. Overhunt game or overharvest wild plants this season, and starvation could follow in the next.

One solution to scarcity was to move to new habitats, a strategy greatly facilitated by the adoption of fire and clothing. By migrating, people escaped the confines of familiar places, but the benefit was temporary. For example, migrations from Asia to the Americas ten or twenty thousand years ago opened vast new human habitats; but, certainly by 500 years ago and likely much earlier, North and South America were fully peopled.

Migrants to previously human-free places seemed to believe that these environments possessed endless opportunity. The first migrants to Australia hunted megafauna like the giant kangaroo to extinction; ditto the first Pacific Islanders, who killed the very last members of about 1,000 different bird species. Altogether, human migration altered environments and reduced biodiversity across the planet.

However, people who stayed in one place long enough learned the limits to their bioregion's capacity for regeneration. Through a long series of tough lessons, people discovered how many plants of each kind they could harvest, and how many of each kind of animal they could hunt, and when. In doing this, they were emulating other predatory animals, which typically evolve to avoid extinguishing all their prey. In short, even if they sometimes thought about infinity, Indigenous peoples who stayed put for many generations adopted a worldview and a variety of behaviors that were overwhelmingly oriented toward successful adaptation to the finite.

The Restless, Voracious Modern Mind

That changed for some people, starting just a few thousand years ago. These were people with agriculture, writing, and metal weapons.

If language cracked open the door to thoughts about the infinite, writing kicked it wide. Writing enabled the development of mathematics, which led to geometry (invented for surveying land), which in turn paved the way to the discovery of irrational numbers, the relevance of which will be clear in a moment.

Imagine a square with each side one unit in length. How long is that square's diagonal? Answer: the square root of two. But what, exactly is the square root of two? Well, it's 1.41421356…, those final three dots indicating an infinite series of numerals. That's right, *infinite.* As an irrational number, the square root of two cannot be expressed precisely as the ratio of any two whole numbers. Irrational numbers are implicit in nature, but they endlessly resist efforts—even using modern supercomputers—to express them fully with decimals.

Mathematicians like to think of their field of study as an ethereal, universal realm containing infinity. Indeed, pure mathematics (i.e., study of mathematical concepts independent of any real-world application) may be as close to infinity as humans can get, and many mathematicians throughout history have thought of it in those exact terms. But that's not the same as

limitlessness in a practical sense. In theory there may be an infinite number of integers, prime numbers, irrational numbers, and imaginary numbers, but we never encounter infinity in physical life. Even if essential mathematical truths live forever in principle, mathematicians die just like the rest of us, and math textbooks eventually turn to dust.

Mathematics provided a logical basis for the belief in infinity. But it did far more than that. People in early civilizations used math mostly to keep track of livestock, land, money, and debt. Countable money then facilitated the expansion of trade and civilization itself. Math also helped in the invention and refinement of technologies via, for example, metallurgy, ballistics, and navigation. Technological developments in these fields subsequently assisted in the conquest of Indigenous peoples throughout the world. The conquerors felt superior in that they had developed a way of living that could overleap previous constraints on the scale and wealth of human societies. While they often attributed this assumed superiority to their religion (*our god is more infinite than yours!*), it was guns, germs, and steel that made the crucial difference.

Still, there were practical bounds to the energy sources then available—which consisted primarily of food crops and firewood. Agriculture enabled population growth and social complexity, but it gradually robbed soils of nutrients. Sailing ships guided with clocks and navigational charts could increase the scope of trade, but building wooden ships (and making charcoal for forging steel) was leading to the deforestation of whole continents. A reckoning with limits seemed to be in store.

Then a miracle happened. People who lived in some key centers of global trade started using fossil fuels—energy sources capable of delivering power in previously unimaginable and seemingly endless quantities. Coal, oil, and natural gas enabled the development of transport technologies (steamships, railroads, cars, trucks, and airplanes) that overcame prior limits to the speed of travel and trade, so that products and resources that were abundant in one place could be transported to places where they were scarce. Fossil fuels could be used to increase the rates of resource extraction via powered mining machinery, and to process lower grades of ores as more concentrated ores were depleted. They could be fashioned into plastics and chemicals to substitute for some natural materials that were getting scarce, such as hardwoods and whale oil. And they could be made into artificial fertilizers, which could replace soil nutrients lost due to unsustainable agricultural practices.

All these developments together enabled population growth at rates that far outstripped historic trends: human numbers expanded from one billion to eight billion in a mere two centuries. We were, in effect, stretching existing constraints on population and consumption to the point that it was difficult for many people to see that boundaries still existed at all.

A relatively new field of study, economics, saw the expansion of production, trade, and population as inherently beneficial, attributed it to human ingenuity (rather than to fossil fuels), and declared that it could and should go on forever. After all, the economists gushed, there are no limits to human ingenuity! (Actually, there are).

Eventually, math was accelerated to warp speed by the development of electricity systems (generators, transformers, motors, etc.) and computers—which enabled space exploration. Today, we take for granted the ability to bounce radio signals between thousands of satellites in orbit and billions of computers back on *terra firma*, thereby making trillions of items of information available in the palms of our hands.

It's understandable that many people think we humans are just getting started, and that in few more centuries we'll be able to know everything, control everything, and move at infinite speed. This "Star Trek" mentality consists of a widely held conviction that it is our duty and destiny as humans to take over not just the entire Earth, but increasing swathes of cosmic habitat—even if we have to subdue some unruly Klingons along the way.

Limits Snap Back

Meanwhile, here on planet Earth problems are brewing.

It turns out that fossil fuels suffer from a couple of serious drawbacks: depletion and pollution. Coal, oil, and natural gas are finite substances we extract from the Earth's crust using the low-hanging fruit principle. While we're not about to run out of these fuels in an absolute sense, the effort required to get them is increasing. We've already extracted all the easy stuff, and beyond a certain point it will take more energy to obtain the remaining fuels than they will yield when burned. We haven't arrived at that point yet, but years before we get to fossil-fuel energy break-even the global industrial system will begin to shudder and shake. And, yes, we may already be at that stage according to some analysts.

Pollution, the other drawback to fossil fuels, was recognized as a problem many decades ago when coal smoke began to cloud industrial cities like London and Pittsburgh. But it turns out that an invisible and odorless pollutant, carbon dioxide, will have much greater long-term impact than smoke. By burning tens of millions of years' worth of ancient plant matter in just a couple of centuries, we are releasing hundreds of billions of tons of CO_2, changing the chemical composition of the planet's atmosphere and oceans, causing climate patterns to become more chaotic, and thereby threatening not just global agriculture but the ecological cycles that support myriads of other creatures in addition to ourselves.

If the energy-climate conundrum were all we had to worry about, the obvious answer would be to transition industrial society to operate on other, less problematic energy sources. Unfortunately, it turns out that a full energy transition to renewable alternatives like solar and wind power won't be easy (for reasons I've discussed here, here, and here). But there's even worse news: the energy-climate problem isn't our only survival-level ecological dilemma.

As we've grown our population and our per capita consumption rates, we've been taking habitat away from other organisms. As a result, nature is in full retreat. Vertebrate and invertebrate animal species have suffered average population declines of 70 percent in the past 50 years, and thousands of plant species are endangered as well.

Not only are most people apparently willing to ignore the loss of Earth's

biodiversity as long as the industrial economy can continue to keep them fed, clothed, housed, and entertained, but they are also largely unaware of the exhaustion of the materials that feed the industrial machine. As high-grade ores deplete, miners are forced to dig deeper and process more ore in order to produce the same amounts of copper, iron, aluminum, and dozens of other critical materials. Yet merely the same amounts won't do: we need to double these amounts every 25 years to enable economic growth at recent rates—and we need loads more materials to build vast numbers of solar panels, wind turbines, and batteries that will be needed to substitute for fossil fuels.

Some scientists use math to determine how close we are to planetary limits. One such effort goes by the name "planetary boundaries"; its main proponents, scientists at the Stockholm Resilience Centre, calculate that, of nine critical global ecological thresholds that might lead to collapse, humanity has already crossed six. A related effort is being undertaken by the Global Footprint Network, which tracks our "ecological footprint"—how much of Earth's biological regenerative capacity is being used by human society. Our footprint scorecard currently shows humanity using resources as if we lived on 1.75 Earths—which it is only possible to do temporarily by, in effect, robbing future generations.

Altogether, civilization's survival dilemma in the 21st century is best described by a concept from population ecology—*overshoot*. This refers to the situation where a crucial resource temporarily becomes more abundant, thereby enabling a group of organisms to grow its population beyond levels that can be sustained over the long run. For a population of field mice in overshoot, the critical resource might consist of small plants whose unusually robust growth has been triggered by high levels of rainfall. For humanity currently, the critical resource is fossil energy. Temporary energy abundance has led to many good things (for some of us, anyway): more food, more people, more commercial products, more knowledge, more comfort, and more convenience. But we are about to become victims of our own success.

Indeed, humanity's confrontation with limits will make this century pivotal. Whether it's the rate of emission of greenhouse gases, the proliferation of "forever chemicals," the depletion of soils and minerals, or the destruction of habitat for other species, in each case we see industrial society plunging headlong over the guardrails. Our collective survival will depend on whether we can restrain population growth, resource extraction, and waste dumping so that we can get onto a path that can be sustained for centuries or millennia. That means de-growing economies, starting with the wealthiest ones like that of the United States.

But culturally we are ill-equipped for this necessary re-adaptation process. Indigenous wisdom, which should be our guide, persists in traditional societies fighting for cultural survival. Everywhere else, the dominant industrial worldview holds that talk of limits is dreary, scary, unimaginative, and uninspiring. Where limits are undeniable, as with carbon emissions and climate change, we try to finesse them with clever math (carbon credits, anyone?) and sophisticated technology.

Further, worsening economic inequality is undermining the social cohesion needed for a cooperative human about-face. Indeed, the people who are empowered to decide what direction society takes are in almost all cases ones

who tend to benefit most from overexploitation of resources. They're the very people least likely to propose measures that would pull us back from the precipice.

The Pleasure and Solace of Loving Limits

We have flown so far from safe boundaries that our only possible landing path entails a crash: the policies required to fully align our industrial system with nature's sustainable productive capacity would themselves trigger enormous economic and political problems. Imagine the response of American citizens if new regulations required them to cut back on energy and material usage by, say, 50 percent. What would happen to the economy in that scenario? There's no easy answer to overshoot, when it's gone to such lengths. This is not to say that activists should stop protesting new fossil fuel production projects, or that planning agencies should stop advocating more energy efficiency and solar panels, or that conservationists should stop protecting creatures and ecosystems. We must do what we can, even if it's not enough to avert *all* the environmental, social, and economic crises that we've been fomenting with decades of over-consumption.

However, in addition to such worthy efforts, at least some of us can adopt an attitude fundamentally different from the dominant "Star Trek" mindset—an attitude geared to help us find an equitable way through the Great Unraveling that's already begun, while laying the conceptual and cultural foundation for a truly sustainable society. The key will be a new(ish) attitude toward limits—a willingness to view them not as restrictions always to be fought against, but as boundaries that enable systems to work.

Sure, limits can sometimes be a straitjacket. Few of us like arbitrary strictures of outmoded custom. But far too little is said about the benefits of nature's limits—including the starkest limit of all, mortality. It's sad when loved ones die, and few of us look forward to our own demise; hence the perennial quest for an elixir of eternal life, or at least a cure for cancer. But if nobody died, the planet would quickly fill with humans and empty of all the things that feed and provision us. Death clears space for new life; it is the non-negotiable price of admission to the great banquet of existence.

Denying and fighting limits is hard work. We can afford to relax a bit and learn to better appreciate the immense beauty of the masterpiece that nature creates out of finite resources and lifespans.

In addition to Indigenous thinkers, some ancient Greek and Chinese philosophers understood the value of limits. Stoics like Seneca and Epictetus taught that we should view apparent obstacles as opportunities. They said things like, "You have power over your mind—not outside events. Realize this, and you will find strength." In China, at roughly the same time, Taoist sages proclaimed, "Life is a series of natural and spontaneous changes. Don't resist them; that only creates sorrow. Let reality be reality. Let things flow naturally forward in whatever way they like." Don't just respect limits; celebrate them and work in harmony with them.

This is a philosophy grounded in nature's way. Mortality, loss, beauty, and wisdom all arrive in the same package; sadly, many of us stop unwrapping it before we get to the wisdom at the center. Wisdom says: embrace limits even as they snap back, knowing that, in the long run, everything moves toward

balance.

It's a philosophy that's especially relevant in difficult times, such as ones we are entering, when it may be helpful to remember: *this too shall pass*. Even the craze for limitlessness has its limits.