# PREFACE

*"The greatest threat to our planet is the belief that someone else will save it."*

ROBERT SWAN

## BUILDING A BETTER FUTURE FOR HUMANITY

What does it take to build companies that fundamentally change the world? And of the companies that attempt to create this transformative change, what separates those who succeed from those who fall short?

This is a book about how we can solve humanity's most challenging problems with Transformative Technology entrepreneurship. This book explores the nature of these Intractable Problems and their shared characteristics. It delves into the characteristics of the kinds of Transformative Technologies that will likely form the basis of the best solutions to these problems. And it illuminates a set of principles, drawn from the successes of prior transformative solutions, that can maximize the chances of success for entrepreneurs who incorporate them into their strategy for building and scaling their solutions.

Though the book explores these problems, technologies, and principles for success in the context of several critical industries, the primary lens is of the agricultural system. This is due in part to the importance of our current moment in the history of our food system: we appear poised to undergo the biggest revolution in agricultural production since the domestication of plants and animals over ten thousand years ago. It is also because food is something anyone can understand. Whether through our fond memories of childhood foods or our experiences buying food at the grocery store each week and cooking for loved ones, we all experience our food at a deeply personal level.

In this way, the personal and emotional connections we have to food are unique, given its place as one of our oldest technologies. We don't feel that same connection to electricity or the Internet. This makes food a unique vehicle for discussing global challenges that would otherwise be impersonal and technology solutions that would appear disconcerting.

My journey into learning about the power of Transformative Technologies began in college, born from my deep interest in human health. When my exploration began, I was primarily interested in learning about the technologies and avenues through which I could have an impact on improving healthcare for people around the world. At the time, I was narrowly focused on the healthcare system itself—on the treatments, pharmaceuticals, and medical devices doctors could apply to treat people who were sick or injured. The more I learned, the more I began to realize my myopic view of human health was blinding me to the potential for Transformative Technologies to improve the human condition more broadly.

For me, the key moment of understanding came in the form of a scientific review article. It detailed the ways in which changing a cancer patient's diet could improve their strength during chemotherapy, reduce their symptoms, and even treat conditions that could not be targeted with medications.[1] After I read this article, my eyes were opened to the vast opportunity we have to solve our most pressing problems if we can understand them in their broader contexts. In this case, food could be medicine and could outperform our most advanced medical treatments in addressing burdensome ailments. What other problems could we solve if we understood them more deeply and applied the right Transformative Technologies to them in the right ways?

Using the agricultural sector as a primary example, this book demonstrates how the very technologies and systems that helped us build our modern society are now creating intractable problems that we must overcome to build a sustainable future. Through the emergence of cellular agriculture, the book describes the ways in which technologies can both produce transformative solutions and fizzle out without leaving a lasting impact. And through an assessment of animal agriculture, the book posits a vision for an abundant future for humanity and what it will take to achieve that vision.

1 Laura Soldati et. al, "The influence of diet on anti-cancer immune responsiveness," *Journal of Translational Medicine* 16, no. 1 (2018): 75.

These ideas and principles transcend the field of agriculture. Anyone who aspires to build a better future for humanity and solve the greatest challenges that stand between our present and that future can use these principles to do so. Overcoming intractable problems requires leverage, and the principles and frameworks presented in this book can help to increase the leverage of those who implement them. I hope this book captures the imagination of others who see the opportunity to positively impact billions of people by tackling these problems, in agriculture or other sectors, and inspires them to build the solutions that we need.

## AN UNEXPECTED DISCOVERY

In writing this book, I interviewed many of the thought leaders and pioneers in the cellular agriculture industry, including nonprofit advocacy groups, researchers, startup entrepreneurs, investors, and science communicators. I also had conversations with agriculture industry experts, scientists who study climate change, and scientists who investigate the environmental and social impacts of our food system. With their knowledge, I intend to provide a more comprehensive context around the broader impacts of the cellular agriculture movement and its importance to building a sustainable and resilient agricultural system. In addition to these interviews, I sought out the best available research on industrial agriculture—covering everything from costs to externalities and important process innovations to key challenges. My goal is to provide you with sufficient data from independent sources to draw your own conclusions about the future of food beyond the hypotheses I present in this book.

As I conducted research for this book, however, I began to recognize there was a larger story to be told. Much of my exposure to these global, pressing challenges, and transformative technologies came through working with professors to commercialize their biotechnology and medical technology research and from my experience as a serial entrepreneur in the healthcare and agri-food sectors. As a result, my initial research was limited by the scope of my own personal experience. Only during the process of writing this book did I begin to appreciate that many of the questions I was asking of these industries were also applicable more broadly.

In defining a set of principles for succeeding in food and agriculture innovation, I noticed that our agricultural industry is not unique in the challenges it faces or in its importance to our collective human future. Indeed, a number of industries are essential for our individual survival and the continued existence of our civilization. Most of these essential industries face large-scale intractable problems that will require transformative solutions in the coming years.

Could the same principles that have enabled entrepreneurs to solve challenging agricultural problems also pave the way for successful solutions to emerge in energy, transportation, and other critical sectors? If these principles *could* be applied more broadly to facilitate solutions to our most pressing, intransigent problems, how could I attract more entrepreneurs to work on these problems? These were key questions that stuck with me as I began writing this book and shaped my thinking in it.

### HISTORY IS DEFINED BY MOMENTS

The birth or death of a great leader. The rise and fall of a civilization. The invention of a Transformative Technology. History is defined by pivotal moments.

By my reckoning, we are currently witnessing the beginning of the greatest change in agricultural technology in ten thousand years. We are also facing a number of challenges unprecedented in the history of our species. In this moment, at the confluence of a rising global population, a changing climate, and dwindling resource availability, the decisions we make will determine the future of our species. Under this perfect storm of conditions that conspire to make our current systems and practices obsolete, we must develop technologies that will enable our civilization to endure sustainably if our civilization is to thrive in the twenty-first century and beyond.

A more abundant future for mankind is in our grasp. Will we seize it or let it go by?

# PART I

# POWER WITHOUT WISDOM: THE HUMAN STORY OF ABUNDANCE AND SCARCITY

## CHAPTER 1

# HOW WE GOT HERE

*"In the end, for the long term to prevail over the short term, we must want what the long term promises. Where there is no vision, there you find short-termism, for there is, then, no reason for compromise today for an unknown tomorrow."*

CHARLES B. HANDY

Modern humans have walked the Earth for around two hundred thousand years. In that time, humanity has undoubtedly solved some big problems that may have seemed intractable at the time. To survive that long, we would have had to use our unique brand of intelligence to outcompete other animals, developing better solutions to our common problems. Achieving the scale that our species has on Earth has required overcoming incredible obstacles to finding sufficient food, creating suitable shelter from the elements, and improving our health to dramatically increase our average longevity. All our technological, economic, and social innovations were built on this base of stable access to our basic needs.

As useful as our intelligence and ingenuity have been for our survival, it may be failing us at one of the most critical times in our history.

How can this be? How could the single feature that most differentiates us from other animals—the very sapience after which our species is named—now become a hindrance to solving the most important problems we face as a species?

The issue is two-fold: 1) the greatest problems we face are evolving more rapidly than ever before and at an accelerating pace, and 2) the scale of our ability to impact the world has grown by orders of magnitude, but our ability to conceptualize larger scales of time and impact has not.

One of the biggest challenges humanity has faced throughout our history has been securing a stable supply of sustenance for our population. Given that it is one of our basic needs, it makes sense that food would be a driving influence on our history. But few would probably recognize just how profound an effect on our nutrition has had in shaping our development path and our modern society. Indeed, our early civilizations were formed around agricultural production; social structures developed in which some people specialized in farming, others diversified to provide supporting services and necessities, and a governance structure emerged to manage the infrastructure for irrigation and grain storage.

As Tom Standage, author of *An Edible History of Humanity*, notes, "Food's influence on history can similarly be likened to an invisible fork that has, at several crucial points in history, prodded humanity and altered its destiny, even though people were generally unaware of its influence at the time."[2] Understanding how we navigated the ever-present and evolving challenge of feeding humanity throughout our history can provide a useful lens through which we can more clearly understand the advantages and shortcomings of our evolved mental toolkit for facing the challenges in our present and near future.

## FROM APE TO MAN

Modern humans, *homo sapiens*, are descended from a long line of ancestor species going back millions of years. Before we became who we are today, our ancestors were once foragers. In this discussion, we will venture back as far as *homo habilis* which walked the Earth about 2.5 million years ago.[3] They ate berries, leaves, fruits, and other plant matter—much like most monkey species—to get the nutrition they needed to survive. These plants were not very nutritionally dense, particularly in critical minerals and calories, so our ancestors spent quite a lot of their day foraging.[4] Much of this plant matter was quite fibrous, requiring a longer digestive tract and more energy to digest it and extract its nutritional value.[5] This wasn't anything new to the *homo* genus, and our

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2 Tom Standage, *An Edible History of Humanity (*London: Atlantic Books Ltd, 2012), Introduction.

3 Phillip V. Tobias, "Homo Habilis and Homo Erectus: From the Oldowan Men to the Acheulian Practitioners" *Anthropologie (1962-)* 18, no. 2/3 (1980): 115-19.

4 Ibid.

5 Leslie C. Aiello and Peter Wheeler, "The Expensive-Tissue Hypothesis: The Brain and the Digestive System in Human and Primate Evolution," *Current Anthropology* 36, no. 2 (1995): 199-221.

ancestors were quite adept at feeding themselves by these foraging methods.

But around two million years ago, something shifted quite dramatically, and a new species emerged: *homo erectus*. *Homo erectus* had a brain that was 50 percent larger than *homo habilis*. Our modern brains consume 25 percent of our daily energy needs and 20 percent of the oxygen we breathe while composing only 2 percent of our body weight. With their larger, more complex brains, *homo erectus* would have needed significantly more calories than *homo habilis*.[6] But where would this extra energy come from? It would have been nearly impossible to consume enough plant matter to provide the necessary energy surplus for the development of this more complex brain.

The evidence points to one transformation in the diets of our ancestors that made this larger brain possible: they started eating meat.

### THE GIFTS OF FIRE

*Homo erectus* appeared to have led the hunter-gatherer revolution, introducing meat into their diet in an effort to get a greater density of nutrients and increased calories for less effort. The evidence we have supports this theory. Compared to their ancestors, *homo erectus* had smaller teeth, indicating they spent less time chewing bulky and raw plant matter. They also had shorter digestive tracts, suggesting they

6 M.E. Raichle and D. A. Gusnard, "Appraising the Brain's Energy Budget," *Proceedings of the National Academy of Sciences* 99, no. 16 (2002): 10237–39.

ate fewer fibrous plants that would require a longer gut for proper digestion.[7] Together, these changes suggest that *homo erectus* began eating meat, which would have provided a dense source of nutrients that would otherwise be scarce in their foraging diet. But eating meat, especially when raw, created a whole separate set of potential risks related to food-borne illnesses.

Interestingly, *homo erectus* also appear to have lost their climbing adaptations, which would have been incredibly dangerous without a way to see at night and tools to keep predators at bay. According to Richard Wrangham, primatologist and author of *Catching Fire: How Cooking Made Us Human*, this evidence suggests that *homo erectus* also learned to use fire as a tool for protection and for making their meat safer to eat. Now armed with a source of dense nutrients in meat and a way to make those nutrients safer to consume and easier to digest through cooking, *homo erectus* suddenly had an energy surplus. It is this energy surplus that likely enabled the great leap forward in brain development.

Up to this point, a more complex brain could easily have been evolutionarily disadvantageous. The extra energy required to support such a brain would have made it more difficult for those individuals to find enough nutrients to survive, creating a selective pressure against larger brains. But with the energy surplus provided by meat consumption, a larger brain suddenly became an evolutionary advantage. Why? It enabled *homo erectus* to solve hard problems more

7 Tobias, "Homo Habilis and Homo Erectus: From the Oldowan Men to the Acheulian Practitioners."

inventively and quickly than others with smaller brain capacity. This hypothesis, first proposed by paleoanthropologists Leslie Aiello and Peter Wheeler, provides an explanation for how some of our oldest ancestors were able to overcome a major hurdle in their development.[8]

So, this one accident of evolution—consuming meat and learning to cook it to make it safer and more nutritious—enabled humans to develop the large, energy-hogging brains that provide the basis for our sapience. This one, unplanned event helped early humans make an evolutionary leap that, as far as we know, had not occurred before in our planet's history and has not been repeated on Earth since.

## FOOD SHAPED OUR CIVILIZATION

With this stroke of evolutionary luck, humanity took the first steps toward modern civilization. Our ancestors, now *homo sapiens*, began farming rather than hunting around 13,000 BCE. The first farmed crop, likely rice, was followed by an explosion of crop domestication over the next fourteen thousand years, encompassing grains, nuts, beans, and fruits. As early as 7,000 BCE, our ancestors also realized that they could farm their meat and began domesticating sheep, followed by cows, pigs, goats, and poultry. We now had a consistent source of both calories and nutrition without having to travel as the seasons changed to get it.

8 Aiello and Wheeler, "The Expensive-Tissue Hypothesis: The Brain and the Digestive System in Human and Primate Evolution."

But this reliable supply of food did not only come from wild-growing plants and animals that we discovered and grew exactly as they existed in nature. No, these crops and domesticated animals emerged through a process of coevolution with humans, deliberately cultivated and propagated solely due to human farming.

Our ancestors cultivated these plants and animals, and through continuous selection refined the genetic composition of the population to reflect those traits they valued most. For plants, this included larger grains and fruiting bodies, smaller inedible parts, and faster growth rates. For animals, we selected for more docile individuals, those that grew faster, and those that produced more offspring. In many ways, these cultivated plants and animals were some of our first technological inventions, after stone tools and fire. Agriculture became an incredible instrument that made civilization possible, and even as we transformed plants, the plants transformed us.

Throughout our history, food has done far more than provide the energy we needed to live. As Tom Standage said, "[Food] has acted as a catalyst of social transformation, societal organization, geopolitical competition, industrial development, military conflict and economic expansion."[9]

Initially, settling in one place and developing a reliable source of nutrition through farmed plants and domesticated animals enabled our ancestors to think beyond food production. It enabled different groups of people to specialize, completing

9 Standage, *An Edible History of Humanity*, Introduction.

different tasks that benefitted the collective whole of their group while others did the same for them. This lifestyle laid the foundation for civilizations to emerge, particularly as centralized social structures formed around food production, distribution, and storage. These centralized structures eventually led to the development of the first governments, where food was used as a currency for payments and taxation—long before the concept of central, state-backed currency, food was wealth and control of food was power.

Again, we see that some of the most important turning points in human history were driven by innovations in our food system. In this case, cultivation and refinement of crops for desired traits enabled us to produce enough to sustain a growing fixed population, something that would not have been possible if we had only farmed the wild varieties of grains and animals. These innovations were not deliberate or methodically implemented, but they altered the trajectory of our history nonetheless.

But as with most technologies, where they alleviated scarcity in one area, they created it in another.

## THE POPULATION BOMB

Our agricultural prowess created a calorie glut. Perhaps inevitably, the availability of food caused the average time between pregnancies to fall and our population to boom. In just a few centuries, the human population on Earth blew past one billion and kept growing. By the seventeenth century, the rapid growth of our population nearly made us victims of our own success. We were nearing a point at which we would not be able to feed the global population with the then-current methods. Just as it happens to other animals that outgrow the resources available in their ecosystems, our population would have collapsed back below the carrying capacity.

The Second Agricultural Revolution provided the solution. By applying newly developed tools and methods—like crop rotation, selective breeding, and a better plow—to agriculture, we were able to make our current land far more productive and to expand the number of hectares that an individual could farm. These new farming methods helped us to overcome the challenge of food scarcity yet again, staving off this recurring challenge for a while longer.

Increased agricultural efficiency meant that fewer farmers were needed. Suddenly, a large portion of society had time available to apply their labor to making other goods and providing services to others. This created the urban labor force required to enable the Industrial Revolution and a shift to a far more diverse economy in which individuals specialized further than ever before.

Inevitably, the growing population caused the challenge of food production to rise to prominence once again in the twentieth century. Though the Second Agricultural Revolution introduced mechanized tools to farms and further increased their productivity, exponential population growth had put these systems under enormous pressure.

Prior agricultural solutions had bought humanity thousands of years before food production became a major hurdle again.

The fruits of the Second Agricultural Revolution only lasted about two hundred years.

After World War II, the world was facing what began to be known as *The Population Bomb.* In an eponymous book published in 1968, Stanford University Professor Paul R. Ehrlich noted that the rate of population growth would outpace agricultural production and lead to widespread famine and subsequent suffering in the 1970s and 1980s.[10]

A global famine that would have threatened the lives of more than one billion people was prevented in large part by the work of one man who never intended to take up that work in the first place. In spite of his monumental impact on the lives of billions of people, few enough know his name even today. That man was Norman Borlaug.

## WORLD PEACE WILL NOT BE BUILT ON EMPTY STOMACHS

Norm, as Borlaug was known to all who worked with him, grew up on a farm in Northeastern Iowa. Growing up in the midst of the Great Depression, Norm experienced firsthand the effects of the existing agricultural practices and how the resulting Dust Bowl devastated crop yields, soil quality, and the lives of farmers. These experiences impressed upon him that there had to be better ways to farm while preserving the land.

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10 Paul R. Ehrlich, *The Population Bomb* (New York, NY: Ballantine Books, 1971).

While in college, Norm attended a lecture that would shape the rest of his life. Dr. Elvin Stakman, the head of the plant pathology department, gave the lecture on the topic of rust, a fungal disease that significantly reduces yields of wheat and a number of other cereal crops. At the end of that lecture, Dr. Stakman made a statement that would have strained credulity at the time, but which Borlaug's work proved to be true. The science of rust resistance, Dr. Stakman said, would "go further than has ever been possible to eradicate the miseries of hunger and starvation from this earth."[11]

After that lecture, Borlaug's life took a different path. Norm went on to work for DuPont Corporation, where he was approached by the Rockefeller Foundation to join a new project to develop a rust-resistant wheat that would alleviate the food insecurity that plagued many Mexican communities. "In 1944, when Borlaug arrived in Mexico, its farmers raised less than half of the wheat necessary to meet the demands of the population. Rust perennially ruined or diminished the harvest," Professor R. Douglas Hurt, of the Department of History at Purdue University, observed.[12]

Initially, things were tough for Borlaug. The local farmers had little reason to trust a young American who did not speak their language and were hesitant to adopt new farming

11 Kenneth M. Quinn, "Chapter 1: Dr. Norman E. Borlaug: Twentieth Century Lessons for the Twenty-First Century World," in *ADVANCES IN AGRONOMY*, ed. Donald L. Sparks (San Diego: Academic Press, 2008), 100:13–27.

12 Kenneth M. Quinn, "Norman Borlaug—Extended Biography," The World Food Prize Foundation, 2009.

techniques they thought may leave them in an even more precarious situation.

But Norm, famous now for his work ethic, persevered, learning the local Spanish dialect and working long days in the fields breeding new strains of wheat. "Borlaug labored for thirteen years before he and his team of agricultural scientists developed a disease resistant wheat," Professor Hurt states, "[But] still problems remained."[13] The primary problem was that the new rust-resistant wheat did not have stems strong enough to hold the now heavy heads of grain. As a result, the plants would blow over under heavy wind and rain, a process known as "lodging."

To solve this new problem that stood between Borlaug and his goal of a self-sufficient Mexico, he looked to a dwarf strain of wheat from Japan. He sought to breed this dwarf strain with his rust-resistant strain, producing a wheat variety that could tolerate the hot, dry climate of Northern Mexico without lodging during storms. But time was short. Without this new semi-dwarf wheat strain, Borlaug's rust-resistant wheat was of limited use due to its vulnerability to storms.

To accelerate his breeding efforts, Borlaug developed a new method known as "shuttle breeding." He grew two separate crops of wheat, one in the semi-arid, irrigated plains of Ciudad Obregón in Sonora and the other in the high-altitude, wetter region of Toluca.[14] He would harvest the crop from

13 Rolf H. J. Schlegel, *History of Plant Breeding (*Boca Raton, FL: CRC Press, 2018).

14 Quinn, "Norman Borlaug—Extended Biography."

one region and shuttle the seeds to the other for planting, enabling Borlaug to double his output per year compared to his peers.

This method effectively bred a rust-resistant strain of wheat that could grow in most warm climates. The result, a rust-resistant, semi-dwarf wheat, was broadly considered an agricultural miracle. Further, Norm's unconventional shuttle breeding also led his wheat to be photoperiod insensitive, meaning that two crops could be cultivated per year, massively increasing the calories that could be produced per acre. Aided by irrigation and fertilizers, Borlaug's wheat enabled Mexico to achieve self-sufficiency in wheat in 1956, something many others thought would be impossible for many more years.

But Norm did not consider this a victory. Rather, he considered it "a temporary success in man's war against hunger and deprivation."[15] He recognized that the "population bomb" was still looming large in Asia, Africa, and the Middle East, and further work was needed to ensure food security and stability in those regions. Norm was known to say that "world peace will not be built on empty stomachs."[16] Indeed, that statement would describe his lifelong mission.

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15 Don Paarlberg, "Norman Borlaug: Hunger Fighter," Foreign Economic Development Service, US Department of Agriculture, cooperating with the US Agency for International Development (PA 969), (Washington, D. C.: US Government Printing Office, 1970).

16 Sanjaya Rajaram, "Norman Borlaug: The Man I Worked With and Knew," *Annual Review of Phytopathology* 49, no. 1 (2011): 17–30.

His project in Mexico well in hand, Norm and the Rockefeller Foundation turned their attention to India and Pakistan. These two countries, having just recently won independence from Great Britain and split in the 1947 Partition, were in a precarious food situation. Subsistence agricultural practices were still quite common, but the rapid population growth meant the specter of famine loomed large if conditions reduced agricultural output in a given year. Indeed, 2.5 million people are thought to have starved to death in Bengal in the 1943 famine alone.[17]

Borlaug's initial work involved the introduction of his "miracle" rust-resistant, semi-dwarf wheat to India and Pakistan. But what followed may have had an even greater impact. M.S. Swaminathan in India and Robert Chandler, Henry Beachell, and Gurdev Khush in the Philippines replicated Borlaug's work in rice. Their work yielded IR8, a new high-yield, semi-dwarf strain of rice that was dubbed "Miracle Rice."[18] This rice was introduced in 1966 and, along with Borlaug's wheat, saved India, Pakistan, and the Philippines from massive famine. Miracle Rice spread rapidly across Asia, as it increased individual crop yields and enabled farmers to cultivate two crops per year.

The impact of this work cannot be overstated. The World Food Prize website notes, "This in turn led to tangible improvements in the quality of life: child mortality dropped; malnutrition abated; and children, especially girls, stayed in

17 Debora Mackenzie, "Norm Borlaug: the Man Who Fed the World," *New Scientist*, September 14, 2009.

18 Quinn, "Norman Borlaug—Extended Biography."

school longer." Further, tensions were high between India and Pakistan in the 1960s. Both countries fought regular skirmishes and had heated disputes over land and water resources. If persistent famine had raised the stakes even higher, it is not hard to believe that full-scale war may have broken out, killing millions even as millions more starved.[19]

Beyond the India-Pakistan region, the Green Revolution that Borlaug championed and realized led to "a corresponding decrease in the level of armed conflict and military hostilities. It was as though the combination of new roads and new rice seed caused the roots of violent extremism to wither and disappear in a way that military action alone could not."[20]

On October 20, 1970, Norm received a phone call to inform him that he was being awarded the Nobel Peace Prize that year. Well, he would have received the call, but he was out working in a wheat field in rural Mexico. His wife, Margaret, took the call in his stead and then drove an hour out to the farm where Norm was working to give him the news. When she asked him to come back to the house to respond to the many dignitaries and press who wanted to speak with him, he simply stated that he had far too much work to do to leave the fields early. A few hours later, the reporters would arrive at the field to find Norm tending to his wheat.

Norman Borlaug remains the only agricultural scientist to have ever been honored with the Nobel Peace Prize. He is

19 David Gale Johnson, *The Struggle against World Hunger,* (New York, NY: Foreign Policy Association, 1967).

20 Quinn, "Norman Borlaug—Extended Biography."

also one of its least known recipients. His work is perhaps the single most important reason that calorie production expanded faster than the human population everywhere in the world outside sub-Saharan Africa. His miracle wheat and rice ended cycles of famine in many countries and prevented mass starvations that would have numbered in the hundreds of millions in the following years. Ironically, his name is largely unrecognized compared to his peer Nobel Laureates, given that he had "probably saved more lives than all of them put together."[21] Indeed, Borlaug is today frequently dubbed "the man who saved a billion lives."

#### FOOD *IS* TECHNOLOGY

In the years after Borlaug became a Nobel Laureate, a backlash against his methods and the Green Revolution he championed around the world has grown. To many modern environmentalists, these methods are "unnatural" and "extractive" compared to their preferred agricultural practices. Even groups like the World Bank and the Rockefeller and Ford Foundations, who were funders of Borlaug's work, are now separating themselves from it. The mounting pressure from activists who consider themselves environmentalists has largely driven this shift. Notably, these voices rarely offer an alternative solution that would have avoided the cost in human lives had these technologies not been implemented.

Borlaug himself has presented data suggesting that 40 percent of the world's more than six billion people (as of 2003) were alive because of the Haber-Bosch process that enables

21 Ibid.

industrial production of eighty million tons of Nitrogen each year.[22] And though the overuse of fertilizers in the wake of the Green Revolution has rightly drawn criticism, claims that organic production methods could feed the world have been broadly exaggerated. The evidence demonstrates that organic fertilization alone could only support a fraction of the current global population.[23]

Though many of Borlaug's supporters bowed to pressure from activists, Borlaug continued to be a strong advocate for Green Revolution-style farming, particularly in areas still plagued by food insecurity and famines. In Borlaug's view, the population was growing exponentially, and the options available were to feed them with the best available tools or to leave them to starve. Ethically, that was no choice at all. As an article about Norm in *The Atlantic* noted, "In this debate the moral imperative of food for the world's malnourished—whether they 'should' have been born or not, they must eat—stands in danger of being forgotten."[24]

From Norman Borlaug's perspective, the choice we face is obvious: either we significantly increase the yields of existing farmland or we destroy the last remaining rainforests and condemn untold species to death to give ourselves the necessary land to farm. Using biotechnology to increase farm yields and productivity would help to preserve wild

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22 Norman E Borlaug, "Feeding a world of 10 billion people," (The TVA/IFDC Legacy Travis P. Hignett Memorial Lecture, International Fertilizer Development Center, Muscle Shoals, AL, 2003).

23 Rajaram, "Norman Borlaug: The Man I Worked With and Knew," 17–30.

24 Gregg Easterbrook, "Forgotten Benefactor of Humanity," *The Atlantic*, March 26, 2019.

ecosystems that are being destroyed by slash-and-burn agriculture while also reducing malnutrition and hunger.

Despite what his advocacy for biotechnology and intensive farming practices may imply, Borlaug did not think the fight to eradicate hunger would be won so easily. He recognized that intensive farming had its challenges and that it would only buy humanity a reprieve, perhaps thirty to fifty years, to develop more sustainable, improved methods. One of Borlaug's greatest laments was that his work appeared to encourage governments to reduce their investment in agriculture innovation, thinking that the problem had been solved.

For this reason, and because he was unable to affect the creation of a Nobel Prize for Agriculture, Borlaug established the World Food Prize to recognize outstanding contributions to improving agriculture and to efforts to counter poverty and hunger. He hoped the spotlight the World Food Prize created would draw attention to the important work that still needed to be done in agriculture. As Borlaug foresaw and many others would not recognize until much later, "the Green Revolution wasn't the final answer to our problems, but it was the start of the answer."[25]

Many people will look at this story and state that it demonstrates that we have always been able to develop the technology we needed to save us from an emerging threat just in time. They will point to it as evidence that we should not worry about seemingly intractable problems because things have worked out in the past without a coordinated effort

25 Mackenzie, "Norm Borlaug: the Man Who Fed the World."

to develop a solution. This view can be best described as **techno-optimism**, the belief that technology can provide solutions to all of our problems and that such technology will emerge when it is needed because necessity is the mother of invention. Such claims can appear harmless enough. Why does it matter if people think technology will save us from the problems we face? The answer is that this line of thinking obscures a more insidious underlying thought process.

## PROGRESS IS NOT INEVITABLE

Putting our full faith in the timely emergence of technology to save us from our problems is essentially betting many hundreds of millions of lives on the emergence of a hero who will solve the problem just as it begins to turn severe, saving us from those effects. Is it rational for us to bet one billion or more lives on the hope that a problem will be solved without a coordinated effort and allocation of resources? Can we rationally wait for another Borlaug to emerge to solve a problem like a global famine just a few years before hundreds of millions of lives would have been lost? What happens if these heroes arrive even two years too late? What if they never arrive at all?

To state that our problems will resolve themselves when this new technology emerges seems flippant. Doubly so given that most of our problems have not resolved themselves without the intervention of a few individuals with the foresight to see what was coming and develop solutions in advance.

This line of reasoning also assumes the past will be a good predictor of the future because the future will mirror the past. But we already have significant evidence that this is not the case. Humans took over one hundred thousand years to transition from hunting and gathering to agriculture as a primary source of calories. We took only two hundred years to develop intensive farming techniques. And in just thirty years, we moved from traditional agricultural methods to intensive agriculture spurred on by the Green Revolution. We now have the ability to genetically engineer crops to tune traits much more rapidly than could ever be achieved through breeding. This last leap occurred in only ten years.

## EXPONENTIALS CHANGE EVERYTHING

The rate of change is not linear, but exponential. The exponential rate of change means the past will not be a good predictor of the future, at least not for direct comparison. The slower rate of change in our past provided us far more time to adjust to changing circumstances and develop solutions than we will have today. And if the exponential trends continue, the time frame between the onset of a problem and the need for a solution will continue to shrink. Thus, our past ability to develop technological solutions to emerging problems before they became catastrophic may not tell us very much about our ability to address these problems as they emerge today and in the future.

Further, the scope of these obstacles and the scale of their impact is also growing exponentially. As the human population has grown exponentially, so too has the impact of our activities on the planet. Anthropologists have even classified the current era as a new geologic age, the Anthropocene, to reflect the fact that humans are now the single, most important driver of planetary change. That is why this era is somewhat different from the circumstances under which we dealt with prior grand challenges.

In prior instances, our resource constraints that drove change occurred at the micro-level. We did not have enough wild-caught meat, so we started to farm it. A country's population was growing faster than its agricultural system, so they invented better tools and fertilizers to increase yield. We have historically existed at a small enough scale that we could ignore planetary-level effects and constraints without causing catastrophic fallout. Only once before, with the emergence of the hole in the ozone layer, did we begin to recognize that we humans had begun to operate on a planetary scale.

With ten billion people expected to inhabit Earth by 2050, almost every decision we make now has planetary-scale repercussions. Our choice to ignore planetary-scale impacts of our past activities has created a number of pressing challenges—from climate change to biodiversity loss—that we must contend with when developing our next set of solutions and plans for the future. Now that we are consistently operating on a planetary scale, we must recognize that our constraints exist on a planetary scale as well.

Barring asteroid mining and other futuristic technologies, we will have to develop solutions to feed ourselves and survive that do not exhaust our resources on Earth. At a minimum, we must ensure that we keep the biosphere sufficiently in balance so it does not bring about our downfall. As the pace of change has continued to accelerate since humans' first technological inventions, we must also be able to address these problems in less time, while impacting a greater number of people than ever before.

One thing of which we can be sure is that this question of how we will feed the global population with existing resources will arise again. Several data points would indicate we are actually facing this challenge again now. We now know our current agricultural practices are a substantial contributor to anthropogenic climate change and the degradation of our environment. Now, we are faced with developing new technologies that will enable us to feed over two billion more people while dramatically reducing these effects. We need to develop and implement these solutions by 2050 if we are to deploy them in time to meet the demand.

Even with our prior history of overcoming this recurring problem of food production, that is a daunting challenge. What solutions will we develop? Will we do as some suggest and not worry about the problem because a solution will inevitably arise just in time to avoid a crisis as it has in the past? Or can we take a structured, forward-looking approach to develop and fund the most promising solutions?

Those solutions could come from emerging technologies like vertical farming, regenerative agriculture, cultured meat, and genetic modification technology. Or they could be something entirely new that we have not yet invented. One thing is for certain: solving these challenges will require us to develop the tools to understand exponentials and to think on longer time horizons than our evolutionary path has prepared us for.