How the World Really Works

Smil, Vaclav

Extract

Understanding Our Material World

The Four Pillars of Modern Civilization

Where it matters, ranking is impossible—or, at least, inadvisable. The heart is not more important than the brain; vitamin C is no less indispensable for human health than vitamin D. Food and energy supply, the two existential necessities covered in the preceding chapters, would be impossible without mass-scale mobilization of many man-made materials— metals, alloys, non-metallic and synthetic compounds—and the same is true about all our buildings and infrastructures and about all modes of transportation and communication. Of course, you would not know this if you were to judge the importance of these materials by the attention they get (or rather do not get), not only from mass media "news" but also from supposedly much more exalted economic analyses or forecasts of notable developments. All of this coverage deals overwhelmingly with such immaterial, intangible phenomena as the annual percentage growth of GDP (how Western economists used to swoon over China's double-digit rates!), rising national debt ratios (unimportant in the world of Modern Monetary Theory, with money supply seen as unlimited), record sums poured into new initial public offerings (for such existentially critical inventions as gaming apps), the benefits of unprecedented mobile connectivity (awaiting 5G networks as something close to the second coming), or promises of artificial intelligence imminently transforming our lives (the pandemic was an excellent demonstration of the complete emptiness of such claims). First things first. We could have an accomplished and reasonably affluent civilization that provides plenty of food, material comforts, and access to education and health care, without any semiconductors, microchips, or personal computers: we had one until, respectively, the mid-1950s (first commercial applications of transistors), the early 1970s (Intel's first microprocessors), and the early 1980s (first larger-scale ownership of PCs).

And we managed, until the 1990s, to integrate economies, mobilize necessary investments, build requisite infrastructures, and connect the world by wide-body jetliners without any smartphones, social media, and puerile apps. But none of these advances in electronics and telecommunications could have taken place without the assured provision of energies and materials required to embody the inventions in myriads of electricity-consuming components, devices, assemblies, and systems ranging from tiny microprocessors to massive data centers. Silicon (Si) made into thin wafers (the basic substrate of microchips) is the signature material of the electronic age, but billions of people could live prosperously without it; it is not an existential constraint on modern civilization. Producing large, high-purity (99.999999999 percent pure) silicon crystals that are cut into wafers is a complex, multi-step, and highly energy-intensive process: it costs two orders of magnitude more primary energy than making aluminum from bauxite, and three orders of magnitude more than smelting iron and making steel.

But the raw material is super-abundant (Si is the second-most common element in the Earth's crust—nearly 28 percent, compared to 49 percent for oxygen) and the annual output of electronic-grade silicon Penguin Books Ltd. Kindle-Version. is very small compared to other indispensable materials, recently on the order of 10,000 tons of wafers.

Of course, annual consumption of a material is not the best indicator of its indispensability, but in this case the verdict is clear: as useful and as transformative as post-1950 electronic advances have been, they do not constitute the indispensable material foundations of modern civilization. And while there can be no indisputable ordering of our material needs based on claims of their importance, I can offer a defensible ranking that considers their indispensability, ubiquity, and the demand size.

Four materials rank highest on this combined scale, and they form what I have called the **four pillars of modern civilization: cement, steel, plastics, and ammonia**.

Physically and chemically, these four materials are distinguished by an enormous diversity of properties and functions. But despite these differences in attributes and specific uses, they share more than their indispensability for the functioning of modern societies. They are needed in larger (and still increasing) quantities than are other essential inputs. In 2019, the world consumed about 4.5 billion tons of cement, 1.8 billion tons of steel, 370 million tons of plastics, and 150 million tons of ammonia, and they are not readily replaceable by other materials—certainly not in the near future or on a global scale.

As noted in chapter 2, only an impossibly complete recycling of all wastes voided by grazing animals could, together with near-perfect recycling of all other sources of organic nitrogen, provide the amount of nitrogen annually applied to crops in ammonia-based fertilizers. Meanwhile, there are no other materials that can rival the combination of malleability, durability, and light weight offered by many kinds of plastics. Similarly, even if we were able to produce identical masses of construction lumber or quarried stone, they could not equal the strength, versatility, and durability of reinforced concrete. We would be able to build pyramids and cathedrals but not elegant long spans of arched bridges, giant hydroelectric dams, multilane roads, or long airport runways. And steel has become so ubiquitous that its irreplaceable deployment determines our ability to extract energies, produce food, and shelter populations, as well as ensuring the extent and quality of all essential infrastructures: no metal could, even remotely, become its substitute. Another key commonality between these four materials is particularly noteworthy as we contemplate the future without fossil carbon: the mass-scale production of all of them depends heavily on the combustion of fossil fuels, and some of these fuels also supply feedstocks for the synthesis of ammonia and for the production of plastics.

Iron ore smelting in blast furnaces requires coke made from coal (and also natural gas); energy for cement production comes mostly from coal dust, petroleum coke, and heavy fuel oil. The vast majority of simple molecules that are bonded in long chains or branches to make plastics are derived from crude oils and natural gases. And in the modern synthesis of ammonia, natural gas is both the source of hydrogen and processing energy. As a result, global production of these four indispensable materials claims about 17 percent of the world's primary energy supply, and 25 percent of all CO2 emissions originating in the combustion of fossil fuels—and currently there are no commercially available and readily deployable mass-scale alternatives to displace these established processes.

Understanding the Future: Between Apocalypse and Singularity

Unprecedented commitments, delayed rewards

Dealing with this challenge will, for the first time in history, require a truly global, as well as a very substantial and prolonged, commitment. To conclude that we will be able to achieve decarbonization anytime soon, effectively and on the required scales, runs against all past evidence. The UN's first climate conference took place in 1992, and in the intervening decades we have had a series of global meetings and countless assessments and studies — but nearly three decades later there is still no binding international agreement to moderate the annual emissions of greenhouse gases and no prospect for its early adoption. In order to be effective, this would have to entail nothing less than a global accord. This does not mean that 200 nations must sign on dotted lines:

the combined emissions of about 50 small nations add up to less than the likely error in quantifying the emissions of just the top five greenhouse gas producers. No real progress can be achieved until at least these top five countries, now responsible for 80 percent of all emissions, agree to clear and binding commitments. But we are nowhere close to embarking on such a concerted global action.[1] Recall that the

[1] In 2018, the shares of global CO2 emissions were as follows : the top emitter (China) very close to 30 percent ; the top two (China and the US) a bit over 43 percent ; the top five (China , USA , India , Russia , Japan) 51 percent ; top 10 (add Germany , Iran , South Korea , Saudi Arabia , and Canada) almost exactly two - thirds : Olivier and Peters , Global CO2 emissions from fossil fuel use and cement production per country , 1970 – 2018

much - praised Paris accord had no specific emission - reduction targets for the world’s largest emitters, and that its non - binding pledges would not mitigate anything — they would result in 50 percent higher emissions by 2050! Moreover, any effective commitments will be expensive , they will have to last for at least two generations in order to bring the desired outcome (of much reduced , if not totally eliminated , greenhouse gas emissions), and even drastic reductions going well beyond anything that could be realistically envisaged will not show any convincing benefits for decades .[2] This raises the extraordinarily difficult problem of intergenerational justice — that is , our never - failing propensity to discount the future .[3] We value now more than later , and we price it accordingly . An avid 30 - year - old mountaineer is willing to pay some $ 60,000 for permits, gear, Sherpas, oxygen, and other expenses to climb Mount Everest next year. But he would demand a steep discount — reflecting such obvious intervening uncertainties as his health, the stability of future Nepali governments, the probability of major Himalayan earthquakes preventing any expeditions, and the likelihood of shutting down the access — for buying a promise to scale the mountain in 2050. This universal inclination to discount the future matters greatly when contemplating such complex and costly undertakings as pricing carbon in order to mitigate global climate change, because there would no discernible economic benefits for the generation of people that would launch the expensive quest. Because greenhouse gases remain in the atmosphere for long periods of time after they have been emitted (for CO2 , up to 200 years), even very strong mitigation efforts would not give a clear signal of success — the first significant decline of global mean surface temperature — for several decades .[4] Obviously , a temperature rise that would continue for 25 – 35 years after the launching of a massive global decarbonization effort would present a major challenge for enacting and pursuing such drastic measures . But because there are currently no globally binding commitments that could see any widespread adoption of such steps within a few years, both the break - even point and the onset of measurable temperature declines advance even further into the future. A commonly used climate - economy model indicates the break - even year (when the optimal policy would begin to produce net economic benefit) for mitigation efforts launched in the early 2020s would be only around 2080. Should average global life expectancy (about 72 years in 2020) remain the same, then the generation born near the middle of the 21st century would be the first to experience cumulative economic net benefit from climate - change mitigation policy.[5] Are the young citizens of affluent countries ready to put these distant benefits ahead of their more immediate gains? Are they willing to sustain this course for more than half a century even as the low - income countries with growing populations continue, as a matter of basic survival, to expand their reliance on fossil carbon? And are the people now in their 40s and 50s ready to join them in order to bring about rewards they will never see? The latest pandemic has served as yet another reminder that one of the best ways to minimize the impact of increasingly global challenges is to have a set of priorities and basic measures for how to deal with them — but the pandemic, with its incoherent and non - uniform inter - and intranational measures, has also shown how difficult it would be to codify such principles and to follow such guidelines. Failures revealed during crises offer costly and convincing illustrations of our recurrent inability to get the basics right, to take care of the fundamentals. By now, readers of this book will appreciate that this (short) list must include the security of basic food, energy, and material supply, all provided with the least possible impact on the environment, and all done while realistically appraising the steps that we can take to minimize the extent of future global warming. That is a daunting prospect, and nobody can be sure that we will succeed — or that we will fail. Being agnostic about the distant future means being honest : we have to admit the limits of our understanding , approach all planetary challenges with humility , and recognize that advances , setbacks , and failures will all continue to be a part of our evolution and that there can be no assurance of (however defined) ultimate success , no arrival at any singularity — but , as long as we use our accumulated understanding with determination and perseverance , there will also not be an early end of days . The future will emerge from our accomplishments and failures, and while we might be clever (and lucky) enough to foresee some of its forms and features, the whole remains elusive even when looking just a generation ahead. The first draft of this closing chapter was written on May 8, 2020, the 75th anniversary of the end of the Second World War in Europe. Let’s imagine a scenario in which on that spring day in the mid - 20th century a small group of people embodying all extant knowledge of the time sat down to discuss and predict the state of the world in 2020. Being aware of the latest breakthroughs in areas ranging from engineering (gas turbines, nuclear reactors, electronic computers, rockets) to life sciences (antibiotics, pesticides, herbicides, vaccines), they could correctly foresee many rising trajectories, ranging from mass automobilization and affordable intercontinental flight to electronic computing, and from rising crop yields to significant gains in life expectancy. But they would not be able to describe the advances, complexities, and nuances of the world that we have created by our accomplishments and failures during the intervening 75 years. To stress this impossibility, just think in national terms. In 1945 Japan’s wooden cities were (save for Kyoto) essentially leveled. Europe was in postwar disarray, shortly to be split by the Cold War. The USSR was victorious but at an enormous cost, and it remained under Stalin’s ruthless rule. The US emerged as an unprecedented superpower, generating about half of the world’s economic product. China was desperately poor and, again, on the brink of civil war. Who could have traced their specific trajectories of rise and fall (Japan), of new prosperity, new problems, new unity, and new disunity (Europe), of aggressive confidence (“We will bury you !”) and demise (USSR), of blunders , defeats , wasted accomplishments, and unrealized possibilities (USA), and of suffering , the world’s worst famine , slow recovery , and steep ascent to questionable heights (China)? Nobody in 1945 could have predicted a world with more than 5 billion additional people that is also better fed than at any time in history — even as it keeps wasting an indefensibly high share of all the food it grows. Nor did anybody foresee a world that relegated a number of infectious diseases (most notably polio everywhere , and tuberculosis in affluent nations) to historical footnotes , but that cannot keep economic inequality from widening even in the richest countries ; a world that is at once much cleaner and much healthier yet also more polluted in new ways (from plastic in the ocean to heavy metals in soils) and, due to the ongoing biospheric degradation , also more precarious ; or a world suffused in instant and essentially free information that comes at the price of massively disseminated misinformation , lies and reprehensible claims . A lifetime later, there is no reason to believe that we are in a better position to foresee the extent of coming technical innovations (unless, of course, you are a believer in near - imminent Singularity), the events that will shape the fortunes of nations, and the decisions (or their regrettable absence) that will determine the fate of our civilization during the next 75 years. Despite the recent preoccupation with the eventual impacts of global warming and with the need for rapid decarbonization, few uncertain outcomes will be as important in determining our future as the trajectory of the global population during the remainder of the 21st century. Extreme forecasts offer very different futures: will the global population surpass 15 billion by 2100 (nearly twice as many as in 2020), or will it shrink to 4.8 billion, losing more than half of today’s total, with China shrinking by 48 percent?[6] As expected, the medium variants of these forecasts are not that far apart (8.8 and 10.9 billion). Still, being 2 billion people apart is not an inconsequential gap, and these comparisons show how even basic population forecasts veer apart after just a single generation. All too obviously, even when forecasts go only as far as today’s life expectancy in affluent countries, the implications of their extreme values shape two very different economic, social, and environmental trajectories. And as the first and second drafts of this book were written during the first and second waves of COVID - 19, it is quite realistic to ask if the new pandemics we will face throughout the remainder of the 21st century (given their post - 1900

.

[2] This necessity for very long - term commitment further diminishes the likelihood that such disparate actors as China and the US or India and Saudi Arabia will agree on a generally acceptable and durable way to proceed.

[3] Ramsey’s classic appraisal is unequivocal: “It is assumed that we do not discount later enjoyments in comparison with earlier ones, a practice which is ethically indefensible and arises merely from the weakness of imagination. ”F. P. Ramsey, “A mathematical theory of saving,” The Economic Journal 38 (1928), p. 543. Of course, such an unyielding position is quite impractical.

[4] C. Tebaldi and P. Friedlingstein, “Delayed detection of climate mitigation benefits due to climate inertia and variability, ”Proceedings of the National Academy of Sciences 110 (2013) , pp . 17229 – 17234; J. Marotzke , “ Quantifying the irreducible uncertainty in near - term climate projections , ” Wiley Interdisciplinary Review : Climate Change 10 (2018) , pp . 1 – 12; B. H. Samset et al., “Delayed emergence of a global temperature response after emission mitigation, ”Nature Communications 11 (2020) , article 3261 .

[5] P. T. Brown et al., “Break - even year: a concept for understanding intergenerational trade - offs in climate change mitigation policy, ”Environmental Research Communications 2 (2020) , 095002 . Using the same model, Ken Caldeira calculated the internal rate of return on the abatement investment ramping (as stated by many recent national goals) to zero carbon by 2050 and the starting date of the positive return (when avoided climate damage exceeds abatement expense) : the rate is about 2.7 percent and the positive return does not come until early next century .

[6] High forecast : United Nations , World Population Prospects 2019 . Low forecast: S. E. Vollset et al., “Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study, ”The Lancet (July 14 , 2020) .

frequency — 1918 , 1957 , 1968 , 2009 , 2020 — we can expect at least two or three such events before 2100) will be similar , much weaker , or far more virulent than the 2020 event . Living with these fundamental uncertainties remains the essence of the human condition — and it limits our ability to act with foresight. As I noted in the opening chapter, I am not a pessimist or an optimist, I am a scientist. There is no agenda in understanding how the world really works. A realistic grasp of our past, present, and uncertain future is the best foundation for approaching the unknowable expanse of time before us. While we cannot be specific, we know that the most likely prospect is a mixture of progress and setbacks, of seemingly insurmountable difficulties and near - miraculous advances. The future, as ever, is not predetermined. Its outcome depends on our actions.