

## HOW THE WORLD REALLY WORKS: THE SCIENCE BEHIND HOW WE GOT HERE AND WHERE WE'RE GOING

by Vaclav Smil

Reviewed by Mosby G Perrow IV\*

At the end of this summer, speaking to a room full of energy executives, their employees, and their service providers, a CEO of a Fortune 500 energy company declared that in the wake of the Inflation Reduction Act, the laws of economics have been suspended. But, he added, the laws of physics cannot be. Such is the thrust of Vaclav Smil's latest book, *How the World Really Works: The Science Behind How We Got Here and Where We're Going*.<sup>1</sup>

A Distinguished Professor Emeritus at the University of Manitoba in Winnipeg, Canada, Smil is a favorite of C-suite officers at energy companies. His many volumes of books are filled with exquisite details that unpack the realities of energy infrastructure; he takes a scientific and methodical approach to civilization's building blocks, reveling in detail, layer-by-layer, down to the atoms and millijoules of life and its surroundings.

For example, in one of Smil's earlier books, *Energy and Civilization: A History*, he begins with the provocative yet unimpeachable statement that "Energy is the only universal currency: one of its many forms must be transformed to get anything done." That book forges a dense narrative from the energy packed in prehistoric diets (wooly mammoths offered 10-12 MJ/kg while large monkeys a mere 5-6 MJ/kg) through the "great transition" to fossil fuels with England the first to shift from plants (16-19 MJ/kg for hard woods) to coal (31-33 MJ/kg for anthracites), setting the stage for industrialization. *Energy and Civilization* includes approximately 70 pages of source references and a timeline for energy-related developments starting around 1,700,000 with the Oldowan stone tools and ending with the average concentration of atmospheric CO<sub>2</sub> reaching 400 ppm in 2015.

Smil has written a half dozen or so books on energy alone. They are dense, but not dry. David Keith, a climate scientist at Harvard University, reportedly called Smil "a slayer of bullshit."<sup>2</sup> In an age where facts and opinions often seem to be treated interchangeably, especially when it comes to our energy policies and efforts to address anthropomorphic climate change, we would do well for Smil to have a wider audience.

Enter Smil's *How the World Really Works*.

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1. Vaclav Smil, *How the World Really Works: The Science Behind How We Got Here and Where We're Going* (2022) (ebook) ("*How the World Really Works*").

2. Paul Voosen, *The Realist*, 359 SCIENCE 1320 (2018).

Intentionally less dense than his academic work, Smil's latest book draws on decades of research—his own and others—and presents essential topics in compelling terms accessible to any curious reader. The book is structured around six topics underpinning life for modern humans: Energy, Food Production, Our Material World, Globalization, Risk, and the Environment. The book ends with a chapter on “The Future” and begins with an introduction: “Why Do We Need This Book?”

According to Smil, the gap between “wishful thinking” and reality is vast, but the contest of ideas can only proceed in a rational way if all sides share “at least a modicum of relevant information about the real world, rather than trotting out their biases and advancing claims disconnected from physical possibilities.”<sup>3</sup>

How did we get here? Smil suggests that urbanization and mechanization are two culprits. But he also points to what is perhaps the more structurally engrained and less visible reason: “the poor, and declining, understanding of those fundamental processes that deliver energy (as food or as fuels) and durable materials (whether metals, non-metallic minerals, or concrete) is that they have come to be seen as old fashioned.”<sup>4</sup>

And so it is that the “best minds” do not go into “soil science,” but instead lawyers, economists, code writers, and money managers earn high rewards for work “completely removed from the material realities of life.”<sup>5</sup> Thus, *How the World Really Works* is effectively a crash course for lawyers, guns, and money.

Beginning with “the only universal currency,” Smil invites the reader to imagine a probe approaching Earth every 100 years that is programed to make a second pass for a closer inspection if it detects a previously unobserved kind of energy conversion. For billions of years, the probe passes without a second pass over volcanic eruptions, earthquakes, and storms. The probe makes very few “second passes” over the course of hundreds of millions of years: it investigates the first, single-celled photosynthetic microbes in shallow seas 3.5 billion years ago; it looks at cyanobacteria converting CO<sub>2</sub> and water into new organic compounds and releasing oxygen hundreds of millions of years later; it witnesses the Cambrian explosion 541 million years ago and the rise of organisms. Things get more interesting for the probe. The stage is set for humans.

Not long afterwards, the probes nearly miss the significance of a mechanical shift with enormous energetic implications: many four-legged animals briefly stand or awkwardly walk on two legs, and more than 4 million years ago this form of locomotion becomes the norm for small ape-like creatures that begin spending more time on land than in trees.<sup>6</sup>

From two legs, over several hundred thousand years, develops the first external energy conversion, or as Smil puts it, “extrasomatic use of energy—external to one's body; that is, any energy conversion besides digesting food.”<sup>7</sup> This changes everything for the apes – their diet expands because they can now eat food

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3. *How the World Really Works*, *supra* note 1, at loc. 129.

4. *Id.* at loc. 92.

5. *Id.*

6. *Id.* at loc. 244.

7. *How the World Really Works*, *supra* note 1, at loc. 253.

that was previously hard to digest. They can live in colder climates, warming their bones by the fire. They can keep away dangerous animals and forge tools for hunting.

By beginning in this way – and each chapter follows a unique and creative entry point for these “soil science” topics – Smil manages to highlight how truly extraordinary, revolutionary, and expedited our world has become with each advance in energy conversion from plant and animal energy to exploiting fossilized plants and animals. In 1800, plant fuels supplied more than 98 percent of our heat and light and 90 percent of all mechanical energy needed for farming, construction, and manufacturing was supplied by human or animal muscle. “The world of 1850 is much more akin to the world of 1700 or even of 1600 than that of the year 2000.”<sup>8</sup> By 1950, fossil fuels supply nearly three-quarters of primary energy and more than 80 percent of all mechanical energy.

Smil helps the reader observe this change from a variety of angles. “An average inhabitant of the Earth nowadays has at their disposal nearly 700 times more useful energy than their ancestors had at the beginning of the 19<sup>th</sup> century.”<sup>9</sup> Or in terms of gain, “the 20<sup>th</sup> century saw a nearly 40-fold gain in useful energy; since 1800 the gain was about 3,500-fold.”<sup>10</sup> Or in terms of physical labor, “it is as if 60 adults would be working non-stop, day and night, for each average person; and for the inhabitants of affluent countries this equivalent of steadily laboring adults would be, depending on the specific country, mostly between 200 and 240.”<sup>11</sup>

Smil explains this dramatic increase in access to energy through the eyes of physicists and economists, quoting Erwin Schrodinger “what an organism feeds upon is negative entropy” and referencing Alfred Lotka’s idea that “those organisms that best capture the available energy hold the evolutionary advantage.”<sup>12</sup> In economic terms, we have built “a system for extracting, processing and transforming energy as resources into energy embodied in products and services.”<sup>13</sup> Smil’s point is that no one can understand the world without “at least a modicum of energy literacy.”

The chapter then goes on to explain the difference between energy and power, how different forms of energy have certain advantages and drawbacks, why energy density matters, and what all of this means for the energy transition. What is so fascinating about Smil’s exploration of these topics is that they do not read like textbook or encyclopedic entries. Smil is telling a story made powerful through his years of research and writing on the subjects he unpacks. And unlike what the title might suggest, Smil does not patronize the reader, and his style is far from smug or condescending. Rather, his prose reads like a stimulating conversation with a friendly professor talking to another professor who happens to be in a different field.

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8. *Id.* at loc. 302.

9. *Id.* at loc. 339.

10. *Id.* at loc. 335.

11. *How the World Really Works*, *supra* note 1, at loc. 343.

12. *Id.* at loc. 357.

13. *Id.* at loc. 367.

Perhaps the downside to this approach is that his conclusions tend to be somewhat blander than the stimulating history Smil weaves. According to the energy chapter in *How the World Really Works*, “our civilization is so deeply reliant on fossil fuels that the next transition will take much longer than most people think.”<sup>14</sup> Not quite the eureka moment one might expect from the buildup of four billion years of history. But this is by design. From the outset, Smil views his job as that of scientist, not advocate.

And so go similar deep dives focusing on food production, the material world, globalization, risk, and the environment. There is much wisdom in these chapters and fantastic juxtapositions of facts. For example, on food production, the rapid rise in the number of people we are able to feed – “1950 the world was able to supply adequate food to about 890 million people, but by 2019 that had risen to just over 7 billion: a nearly eight-fold increase in absolute terms!” – is explained through well-curated details – “In two centuries, the human labor to produce a kilogram of American wheat was reduced from 10 minutes to less than two seconds.”<sup>15</sup> As with many of the chapters, this rapid rise in our ability to feed the world depends, in large part, on our ability to exploit more efficient conversions of energy through fossil fuels.

The chapter on materials investigates the rise and uses of what Smil calls the four pillars of modern civilization: cement, steel, plastics, and ammonia. The chapter systematically explains why these materials are so ubiquitous, how we depend so heavily on them, and why these are so difficult to substitute with less carbon intensive materials. In keeping true to form, this is not a dry recitation of facts, but a presentation of “ah-ha” details that reveal old truths in illuminating context.

For example, there is a section that explains the billions and billions of tons of steel and cement we use by reviewing famous milestones in architecture and industrial design beginning with the sixteen-story Ingalls Building in Cincinnati which was the world’s first reinforced concrete skyscraper in 1903 to the 164.8 kilometer Danyang-Kunshan Grand Bridge in China completed in 2010. Smil notes that “in just two years—2018 and 2019—China produced nearly as much cement (about 4.4 billion tons) as did the United States during the entire 20th century (4.56 billion tons).”<sup>16</sup>

Perhaps the most intriguing chapter in the book is the one on risk. Smil attempts to unpack how we look at risk and how civilization is at its core an attempt to reduce risk. He explores risk perception versus risk tolerance and voluntary versus involuntary risk before providing thoughts on existential risks. There are lessons here, too. Smil calls them truisms: “most people and most governments find it difficult to deal properly with low-probability but high-impact (high-loss) events” and “we habitually under-estimate voluntary, familiar risks while we repeatedly exaggerate involuntary, unfamiliar exposure” and “the lessons we derive in the aftermath of major catastrophic events are decidedly not rational.”<sup>17</sup>

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14. *Id.* at loc. 385.

15. *How the World Really Works*, *supra* note 1, at loc. 845, 929.

16. *Id.* at loc. 1864.

17. *Id.* at loc. 3170.

This discussion of risk, and our ability and inability to properly account for and respond to risk, leads naturally to the chapter on the environment. Here, what is at stake is put simply: “Quests to avoid unnecessary energy use, to reduce air pollution and water, and to provide more comfortable living conditions should be perennial imperatives, not sudden desperate actions aimed at preventing a catastrophe.”<sup>18</sup> Through data and pithy explanation, Smil explores oxygen, water, food, and climate change.

Smil concludes this relatively concise, but incredibly detailed book with “The Future.” What should we expect? Noting a familiar clash between catastrophists and cornucopians, Smil suggests that “Apocalypse and singularity offer two absolutes: our future will have to lie somewhere within that all-encompassing range.”<sup>19</sup> *How the World Really Works* begins and ends with the similar refrain that “a realistic grasp of our past, present, and uncertain future is the best foundation for approaching the unknowable expanse of time before us.”<sup>20</sup>

In the end, there is no prescription, no prediction, and no revolutionary theory to launch a movement. Rather, *How the World Really Works* is a crash course on the basics of our modern world. It should be required reading for anyone embarking, advancing, or reflecting on a career in energy law or policy. We should teach the book in our schools and give copies to our leaders in need of tools for rational decisions and actions on our most pressing problems.

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18. *Id.* at loc. 3628.

19. *How the World Really Works*, *supra* note 1, at loc. 3925.

20. *Id.* at loc. 4359.