subjects include such things as the nanotechnology facilities of the above-mentioned Bilkent University in Turkey, the nanotechnology virtues and vices of titanium dioxide and carbon, and nanotechnology in K-12 and higher education.

Is *Nanotechnology: Social and Ethical Implications* worth the price? It depends on what you want to do with it. It would be worthwhile to put it on the reserve-book list of a course on either the technical or the social and ethical aspects of nanotechnology. Individual chapters could be excerpted for various special purposes in teaching, or conceivably as references for research in a graduate course. But the book falls a long way short of being the definitive word on the social and ethical implications of nanotechnology. Despite all the funds expended on these topics, such a definitive book remains to be written, and perhaps cannot be written until the word "nanotechnology" ceases to excite the attention of anyone except historians. And thanks to the U.S. government, that will not happen for a while yet.

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Tesla: Inventor of the Electrical Age

by W. Bernard Carlson, Princeton University Press, 2013, 520 pages. Reviewed by Eric P. Wenaas.

W. Bernard Carlson points out in his new book, *Tesla: Inventor of the Electrical Age*, that Nikola Tesla's counterculture status has attracted a number of authors to write books about his life and inventions, most of which are celebratory in nature and often make assertions about his theories and inventions that have no basis in fact. Carlson's book is refreshing not only for its candor in describing how and why Tesla succeeded in the technologies he brought to fruition, but also why he failed in the technologies he did not reduce to practice. He states quite correctly that as an historian, he has to tell Tesla's story based on the documents, and quite mercifully he avoids the unsubstantiated stories about Tesla that swirl about on the Internet, in books, and elsewhere.

This book is truly the first scholarly study of Tesla that is not only objective but also provides extensive references and endnotes to support and document the narrative. There are a whopping forty-nine pages of references and endnotes, a rich list of archival collections, and a list of major sources of information — not the least of which is *The Tesla Collection*, originally a 23-volume collection of full-text articles by and about Tesla appearing in periodicals and newspapers between 1896 and 1920. These difficult-to-find articles are catalogued by publication, author, year subject and title — and the best part is they can be accessed from the Internet at www.teslacollection.com/.

Carlson notes that while other biographies have focused largely on Tesla's personality, his book "seeks

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to take measure of both the man and his creative work." The book is actually written on two different levels that are integrated into a cohesive and compelling story. First, there is the main narrative addressing Tesla's visions and how he developed them, and then there are the pauses in the narrative where Carlson, using Tesla as an example of an inventor extraordinaire, comments on the inventive process, the role of illusion in the process, and the social implications of inventions as they are introduced. Throughout the book, he seeks to answer these three questions: "How did Tesla invent? How did his inventions work? And what happened as he introduced his inventions?"

Carlson answers the first question at the outset by quoting Tesla on his approach to invention:

> "I have unconsciously evolved what I consider to be a new method of materializing inventive concepts and ideas… When I get an idea, I start right away to build it up in my mind. I change the structure, I make improvements, I experiment, I run the device in my mind. In this way, you see, I can rapidly develop and perfect an invention, without touching anything. …I then construct this final product in my brain. Every time my device works as I conceive it should and my experiment comes out exactly as I plan it."

According to Carlson, Tesla's method of inventing was both his strength and his weakness. Apparently Tesla was a visionary not only in the conceptual phase but also in the design phase — not the best time to be a visionary. Indeed, Carlson says the actual experiment did not always come out as he envisioned in his mind, and later in his career it rarely did. The other two questions are answered in the remainder of the book consisting of sixteen chapters, which are arranged chronologically and cover the specific time periods identified in each chapter title.

Carlson focuses on Tesla's major technology thrusts that he characterizes as "disruptive," which means that they disrupt or reorder the pattern of established industries and alter the everyday life of consumers, presumably for the better. He says that Tesla introduced two disruptive technologies in the late 1880s that made him rich and famous — the AC motor and polyphase power, the combination of which allowed for the efficient transfer and utilization of power over long distances. Carlson describes a "Eureka" moment experienced by Tesla in 1882 while walking in Szigeti Park, Budapest, where he claims to have visualized the fully developed design of the AC motor that he would later patent and develop. Carlson pauses the narrative to point out that this watershed moment is an example of "subjective rationality" whereby the idea or invention comes from within — as opposed to "objective rationality" whereby it comes as a response to an outside stimulus such as a market need or technical requirement. He also points out that the AC motor was not adopted just because it was technologically superior, but because Tesla and his backers "created the right sort of illusions about it." He concludes from this, "we need to develop more sophisticated ways to think about business decisions and technological choices."

Carlson continues with the narrative by describing Tesla's next major technology thrust beginning in 1891 when he turned his attention to applications of high frequency and high voltage, with the first application being illumination by gas-filled light bulbs without interconnecting wires. By using the principle of resonance in the discharge of capacitors though induction coils, Tesla invented and patented his oscillating transformer, generally known today as a Tesla coil. By 1893 he envisioned launching a second electrical revolution by using the earth as a source of unlimited power, and by transmitting power and communicating intelligence through the earth without wires. He delivered a series of presentations between 1891 and 1893 with spectacular demonstrations complete with lightning bolts generated by his oscillating transformer that captured the imagination of his audiences.

Carlson observes that Tesla rejected the "Hertz theory of wireless transmission," which employs electromagnetic or Hertzian waves, and instead attempted to excite currents in the ground by generating currents in the atmosphere between two grounded antennas separated by great distances. His first attempt to generate large displacement currents in the atmosphere using electrostatic interactions between two antennas of large capacity was entirely unsuccessful. He then proposed to generate large conduction currents in the rarefied atmosphere at high altitudes between transmitting and receiving antennas held aloft by balloons. He theorized that the high voltages from his oscillation coil when applied to one antenna could be used to break down the air and form low-loss conducting plasma between the two antennas, an approach described in his two wireless patents filed in 1897. Carlson writes:

> "With wireless power, Tesla was especially driven to impose his vision on the material world. He truly believed that he had discovered the penultimate ideal, or as he once told J. P. Morgan, 'the philosopher's stone.' "

Indeed, if Tesla could have reduced his vision to practice he would have clearly created another disruptive technology. However, as Carlson notes, that did not happen because

> "Tesla stopped worrying about the validity of his ideal and instead focused on getting the

illusions right…illusions got ahead of the ideal, and Tesla suffered a nervous breakdown when he was unable to grasp the disjuncture between how he thought his system should work versus how the Earth actually responds."

Carlson says that following Tesla's breakdown in 1905, ideal and illusion continued to shape his creative approach to the very end, but added, "While he lived another thirty-eight years, his career as a bold innovator had come to an end."

Carlson uses an epilogue not only to reflect on Tesla as a cultural figure but also to reflect on what can be learned from him about the innovation process and the role innovation plays in the economy. He says Tesla became a figure in popular culture for the many colorful predictions he made about his inventions such as accessing unlimited energy from the earth by wireless, talking to Mars, a race of robots, abolishing war, and death rays. Tesla's concluding statement from an article he published in 1919 also assures him eternal counter-cultural status among mainstream scientists:

> "The Hertz wave theory of wireless transmission may be kept up for a while, but I do not hesitate to say that in a short time it will be recognized as one of the most remarkable and inexplicable aberrations of the scientific mind which has ever been recorded in history [1]."

"The Hertz wave theory of wireless transmission may be kept up for a while, but I do not hesitate to say that in a short time it will be recognized as one of the most remarkable and inexplicable aberrations of the scientific mind which has ever been recorded in history."
—Nikola Tesla, 1919

Carlson makes an inexplicable assertion that "Tesla never made it into the history books of the second half of the twentieth century." He follows up with several reasons that do not ring true: 1) "in part, because he never created a major eponymous corporation to manufacture his inventions," and 2) "…that in cold war America he was not a useful figure. Unlike Edison or the Wright brothers, Tesla was not born in America and could not represent 'Yankee Ingenuity...'" This would certainly be a snub if true, and would also constitute a conspiracy of epic proportion involving several generations of historians from different scientific disciplines. In fact, Carlson's assertion about Tesla's absence from history books appears to be untrue, which can be confirmed by Googling "Nikola Tesla" in "Google Advanced Book Search" for the period from 1950–2000. There are numerous books published during this period devoted entirely to Tesla, and a multitude of books with references to Tesla and his work on AC power, wireless, the Tesla oscillator, and other technologies.

While this book is thoroughly enjoyable and informative, it is not without problems. There are some factual errors and misstatements that may go unnoticed by the casual reader but will likely be troublesome to the wireless aficionado. For example, Carlson writes that there was a "1935 ruling by the United States Court of Claims that invalidated the fundamental Marconi patent because it was anticipated by Tesla and other early inventors." However, the patent to which this ruling refers — U.S. patent no. 763 772 for tuning — is not the fundamental Marconi patent, as Carlson asserts. The patent historically cited as the fundamental Marconi patent is U.S. patent no. 586 193 issued on July 13, 1897 — the U.S. version of the first-ever British patent for wireless transmission of intelligence by Hertzian waves, which also constitutes the first description of a complete system of practical Hertzian telegraphy (see for example, [2]–[4]). Further, it is the patent cited by many historians that accords Marconi precedence for creating the art of communicating intelligence by Hertzian waves. Perhaps Carlson was misled by the writings of Tesla supporters who in recent years have attempted to recharacterize the U.S. version of Marconi's 1904 tuning patent as the "fundamental Marconi patent" in order to support a claim of precedence for Tesla by asserting that the fundamental Marconi patent was invalidated, thereby attempting to deny him precedence. In fact, the U.S. version of the fundamental Marconi British patent has been challenged in court but never invalidated.

Perhaps the most significant examples of misstatements occur on p. 210 where Carlson attempts to explain the differences between Marconi's approach to communicating intelligence using Hertzian radiation and Tesla's approach using earth currents. Carlson starts out well enough by describing how most early "Hertzian" investigators thought the approach worked:

> "They assumed that the transmitter would generate electromagnetic waves that would be sent through the air to the receiver." He then states, "The circuit would be completed because both the receiver and transmitter were grounded, and a return current would travel from the receiver back to the transmitter."

However, there is no evidence that the early Hertzians thought that electromagnetic radiation caused or required a circuit between the transmitter and receiver to be completed by any means, whether grounded or not. Clearly, there are no return currents in the earth when terrestrial transmitters and receivers are ungrounded, nor when signals are radiated from earth to spacecraft, nor when radiated between two distant spacecraft. Ground currents are indeed produced if and when a source for electromagnetic radiation is connected between an antenna terminal and ground, but the ground currents are confined to the immediate vicinity of the antenna. They generally serve to increase the effective length of an electrically short antenna and thereby increase the radiated power, something Marconi first demonstrated in 1895. (See [5]. For a more basic explanation, see [6].)

Carlson then describes Tesla's initial vision for wireless transmission:

> "… the transmitter sent an oscillating current through the earth's crust to the receiver. The circuit was then completed by having electromagnetic waves flow through the atmosphere from the receiver back to the transmitter."

However, Tesla did not believe that electromagnetic radiation played a part in any of his approaches, and no one believed that that the *receiver* emitted electromagnetic radiation. Tesla actually believed that it was "practicable to disturb by large machines the electrostatic condition of the earth." He believed that ground currents could be generated by electrostatic (capacitive) interactions between the transmitter and receiver antennas and the "outer conducting air strata" [7]. As Carlson correctly points out at the end of his discussion, Tesla later believed that conduction currents in the plasma formed in the rarefied atmosphere at high altitudes by high voltages applied to his transmitter antenna would generate large earth currents.

The key distinction between the two approaches is that Tesla never believed that electromagnetic radiation played a role in transmitting power or intelligence to distant points, and the early Hertzian investigators never believed that ground currents flowed between the transmitter and receiver to complete a circuit. By claiming otherwise, Carlson has comingled the two approaches, which are actually quite disparate.

In the end, the positive aspects of this book far outweigh the occasional problems with factual errors and inaccurate assertions. It is a very readable work and presents the whole picture of Tesla both as an electrical wizard and as a human being with all the associated foibles. I particularly liked the way Carlson interspersed the narrative with commentary on the inventive process, the role of illusion, and the social implications of his technologies on bringing about positive changes in society as a whole. If you wish to read a factual book about Tesla, this is the one.

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