

Technological Revolutions through the Ages:  
Lessons for Leading the Cleantech Revolution

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In 2012, the global economy is on the verge of a great technological revolution. Historian Carlota Perez describes it as “a powerful and highly visible cluster of new and dynamic technologies, products and industries, capable of bringing about an upheaval in the whole fabric of the economy and of propelling a long-term upsurge of development.”<sup>1</sup> Global technological upheavals are not new. During the past two centuries, five technological revolutions have occurred. The Industrial Revolution (1770-1830) was followed by the Age of Steam and Railways (1830-1870), then the Age of Steel, Electricity, and Heavy Engineering (1875-1920), then the Age of Oil, Automobiles, and Mass Production (1908-1975), and most recently, the Age of Information and Telecommunications (1971-present).<sup>2</sup> In the twenty-first century, the Fifth Technological Revolution, which has brought products such as the Walkman, Macbook, and Blackberry, is giving way to the Sixth Technological Revolution, or Cleantech Revolution. This new era is defined by a paradigm shift and advancements in how people use, store, and generate energy with cleantech being any product, service, or process that delivers value using limited or zero non-renewable resources and/or creates significantly less waste than conventional offerings.<sup>3</sup> According to renowned venture capitalist John Doerr of Kleiner Perkins Caufield & Byers (KPCB), cleantech “promises to be the greatest wealth creation engine in the history of mankind.”<sup>4</sup>

History provides valuable insight on how the Cleantech Revolution may unfold. For this reason, it is imperative that contemporary leaders—engineers, entrepreneurs, investment bankers, lobbyists, policy-makers, researchers, and venture capitalists—have an informed understanding of the preceding five technological revolutions and the lessons they offer.

Cleantech experts Ron Pernick and Clint Wilder believe that:

The clean tech revolution, like other tech revolutions that preceded it, will require leaders who can shepherd us through new territory and overcome inevitable resistance from many quarters; clarion voices who can communicate mission and vision; and an army of dedicated soldiers work to make clean energy, transportation, water, and materials the norm, not the exception.<sup>5</sup>

Ultimately, the conditions that ushered in the Age of Oil will usher in the Age of Cleantech, and only when contemporary leaders have an informed understanding of the past can they best address the future challenges and lay a coherent framework for the Cleantech Revolution.

The purpose of this paper is to inform leaders on the structure and timing of technological revolutions as well as the influence of capital and government. It argues that there is an identifiable structure and timing to technological revolutions and a significant role for capital as well as government. The paper is organized into five sections. The first surveys a collection of academic and non-academic literature on the five preceding technological revolutions and the emerging Cleantech Revolution. The second highlights the structure and timing of technological revolutions, while the third and fourth analyze the role of capital and government. The paper concludes with an examination of historical trends and parallels and offers a set of recommendations to contemporary leaders.

### **Literature Review**

The literature on technological revolutions is extensive. For this paper, eight key works have been surveyed. In chronological order they are: (1) *The Industrial Revolution in World History* authored by Peter N. Stearns in 1998, (2) *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages* authored by Carlota Perez in 2002, (3) *Financing Innovation In the United States 1870 to the Present* co-edited by Naomi R. Lamoreaux and Kenneth L. Sokoloff in 2007, (4) *The Clean Tech Revolution: Discover the Top*

*Trends, Technologies, and Companies to Watch* co-authored by Ron Pernick and Clint Wilder in 2007, (5) *Hot, Flat, and Crowded: Why We Need A Green Revolution—And How It Can Renew America* authored by Thomas L. Friedman in 2008, (6) Merrill Lynch’s Industry Overview *The Sixth Revolution: The Coming of Cleantech* co-authored by Steve Milunovich and Jose Rasco in 2008, (7) *The Industrial Revolutionaries: The Making of The Modern World 1776-1914* authored by Gavin Weightman in 2009, and (8) *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and The World* authored by Jeremy Rifkin in 2011. Additional research includes a series of interviews with widely recognized cleantech thought leaders.

In *The Industrial Revolution in World History*, historian Peter N. Stearns examines the international factors that initiated industrialization and its global spread and impact. Stearns defines the essence of industrialization in terms of technology and economic organization. He delineates three phases: the first phase (1760-1880) in Great Britain, France, Germany, and the United States, the second phase (1880-1950) in Russia and Japan, and the third phase (1950s-1990s) in Israel, the Pacific Rim, Brazil, Mexico and China. While the Industrial Revolution may have begun 250 years ago in Great Britain, it is still spreading from west to east—something that will undoubtedly have significant ramifications for the global economy.

Stearns provides a valuable historical overview of industrialization. He highlights the symbiotic relationship and implications of technological advancement and development, as technological advances such as the railroad or semiconductors led to industrialization. Industrialization occurs in waves. It originates in a single nation or region and is often initiated by government interest or policy, such as rising military spending in the United States and Soviet Union.<sup>6</sup> This is relevant to understanding the previous five technological revolutions as

well as the current Cleantech Revolution. For example, the Age of Information and Telecommunications (1971-present) originated in the United States, or more specifically Silicon Valley, and then spread throughout the global economy.

While published four years after in the wake of the dot-com bubble of 1995-2000, *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages* analyzes the five preceding technological revolutions. In the work, author Carlota Perez, a leading expert on technology and socio-economic development, presents the concept of Techno-Economic Paradigm Shift and a theory of great surges. She describes how the Industrial Revolution (1770-1830), the Age of Steam and Railways (1830-1870), the Age of Steel, Electricity and Heavy Engineering (1875-1920), the Age of Oil, the Automobile, and Mass Production (1908-1975), and the Age of Information and Telecommunications (1971-present) were massively disruptive, displacing old industries with new ones.<sup>7</sup> According to Perez, this process, which occurs about every half century, is driven by the underlying fundamentals of capitalism.

Perez's work serves as a useful framework for explaining the structure and timing of technological revolutions, as well as the role of capital and government. Particular to timing and structure, she highlights "...the interlinking of some of the new and some of the old that generates revolutionary potential"<sup>8</sup> and that the favorable conditions for the next wave of innovation are created when the potential of the previous one approaches exhaustion.<sup>9</sup>

Technological revolutions often feature synergy between old and new industries, such as the merging of mass production with microelectronics, and tend to follow a "*technological revolution-financial bubble-collapse-golden age-political unrest*" sequence.<sup>10</sup> It is on the tail end of this cycle when "creative destruction" cultivates innovation and the foundation for the

next technological revolution is laid.<sup>11</sup> Perez also emphasizes the importance of capital and government policy, which have been critical sources of support to all five technological revolutions.

*Financing Innovation In the United States 1870 to the Present*, co-edited by Naomi R. Lamoreaux and Kenneth L. Sokoloff, analyzes the interaction of financial capital and technological innovation, focusing on the past 140 years. Lamoreaux and Sokoloff argue that financial capital has evolved with each of the five technological revolutions and that this is one of the great strengths of the U.S. system.<sup>12</sup> In the book, leading economists and economic historians profile how American inventors and entrepreneurs have raised funds, whether from securities market, the government, or venture capitalists. They offer numerous case studies such as the automobile, telecommunication, and information technology industries.

*Financing Innovation In the United States 1870 to the Present* highlights how financing has frequently been obtained from both public as well as private sources. Often government provides the initial infusion of capital to create a research and development infrastructure. When this occurs and the technology has reached its commercialization phase, the private sector intervenes.<sup>13</sup> This has been true of information technology and biotechnology and will likely be true of clean technology. Additionally, the authors demonstrate the importance of financial markets and intermediaries such as investment bankers, who fund new companies and facilitate industry consolidation. For example, in the 1920s the stock market helped to channel money into the nascent aviation and radio industries, while in the Age of Information and Telecommunications (1971-present) venture capitalists channeled money into semiconductors and the Internet.<sup>14</sup>

A more contemporary perspective on cleantech is presented in Ron Pernick and Clint Wilder's *The Clean Tech Revolution: Discover the Top Trends, Technologies, and Companies to Watch*. Pernick and Wilder identify the major forces that have pushed cleantech from a utopian ideal to a tangible technological revolution. They believe that as the world economy faces energy price spikes, resource shortages, global environmental problems, and security threats, clean technologies will be the next engine of economic growth. By highlighting eight major sectors—solar energy, wind power, biofuels and biomaterials, green buildings, personal transportation, the smart grid, mobile applications, and water filtration—they illustrate how investors, entrepreneurs, large corporations, and individuals can profit from this next wave of innovation. The authors believe that six major forces are pushing the widespread adoption of clean technology: costs, capital, competition, China, consumers, and climate.

Pernick and Wilder draw direct parallels between the Information Technology Revolution and the Cleantech Revolution. According to the authors, the same entrepreneurs and investors who led the Age of Information and Telecommunications (1971-present) are now leading the Age of Cleantech. To them, cleantech is built on many of the same concepts that influenced the growth of computers and the Internet.<sup>15</sup> Both revolutions witnessed and are currently witnessing a huge influx of capital from a wide range of sources. Furthermore, the U.S. federal government—mainly the Department of Defense and National Aeronautics and Space Administration (NASA)—is at the forefront of funding and innovation in both sectors. The same institutions and laboratories that commercialized computer chips and radar are advancing solar cells and battery technology. Pernick and Wilder also highlight how the two revolutions have merged to create new, disruptive technologies. For example, Silicon Valley companies are now applying semiconductor technology to solar panels and light-emitting

diodes (LEDs).<sup>16</sup> Yet, Pernick and Wilder also draw some distinctions between the Age of Information and Telecommunications (1971-present) and Age of Cleantech. They suggest that the latter will be lengthier and more capital intensive.<sup>17</sup>

In *Hot, Flat, and Crowded: Why We Need A Green Revolution—And How It Can Renew America*, renowned *New York Times* Foreign Affairs columnist Thomas L. Friedman offers a more geopolitical argument than Pernick and Wilder. Friedman addresses America's loss of national purpose since 9/11 and the global environmental crisis. He advocates that global warming, rapidly growing populations, and the expansion of the global middle class is leading to a convergence of 'hot, flat, and crowded.' Friedman believes that the Green Revolution, or the Cleantech Revolution, is the best way for America to solve this grave environmental threat and renew its political and economic stature in the world. In the twenty-first century, economic opportunities have shifted from information technology to clean technology as the global economy enters what Friedman describes as the "Energy Climate Era." This era will be marked by five major problems: (1) growing demand for scarcer supplies, (2) massive transfers of wealth to petrodictators, (3) disruptive climate change, (4) poor have-nots falling behind, and (5) an accelerating loss of biodiversity.

Throughout the work, Friedman calls for leaders who not only understand the importance of addressing this problem in a systematic manner, but who can generate the vision and authority to launch the Cleantech Revolution.<sup>18</sup> Similar to the other authors reviewed in this paper, he addresses the structure and timing of technological revolutions as well as the role of capital and government. He highlights how the Information Technology Revolution is currently merging with the Cleantech Revolution to unleash a wave of innovation, for example, smart grid and metering technologies.<sup>19</sup> Friedman also addresses the need for a cleantech asset



bubble like the dot-com bubble of 1995-2000.<sup>20</sup> In previous asset bubbles, such as the telegraph and railroad bubbles, bullish investors flooded the market with capital, which in turn funded infrastructure and drove further innovation. Friedman is also cautious of an overly active role of government in technological revolutions. He does not want the government picking winners, but instead funding research and setting the right tax, regulatory, and education policies that will prepare the market for the vetting process of venture capital.<sup>21</sup>

In Merrill Lynch's Industry Overview *The Sixth Revolution: The Coming of Cleantech*, research analyst Steve Milunovich and investment strategist Jose Rasco use Perez's work to argue that we are approaching the Age of Cleantech. They believe that "the current IT age should give way to the leadership of cleantech as the energy infrastructure moves back to renewables" and the current state of cleantech parallels where the Age of Information and Telecommunications (1971-present) was in the 1970s.<sup>22</sup> Similar to previous technological revolutions, Milunovich and Rasco foresee capital and government playing a pivotal role in cleantech, and they highlight how the fusion of venture capital and government research unleashed a wave of innovation in the Age of Information and Telecommunications (1971-present).<sup>23</sup> They also believe that cleantech is becoming the third focal point of venture capital after information technology and life sciences.<sup>24</sup>

Milunovich and Rasco apply Perez's model and concepts to the Cleantech Revolution. Their work draws valuable connections between the role of capital and government in previous technological revolutions and suggests what this role may look like in the Sixth Revolution. Given the massive economies of scale, the Cleantech Revolution will be highly capital intensive from an investor standpoint and require an unprecedented amount of government support.<sup>25</sup> As Friedman argues, the federal government has frequently played an active role in

developing and commercializing new technologies. For example, the Internet originated from work at the Defense Advanced Research Projects Agency (DARPA) during the Cold War.<sup>26</sup>

Gavin Weightman's *The Industrial Revolutionaries: The Making of The Modern World 1776-1914* provides a more historical perspective. In his work, Weightman profiles how innovative individuals such as Thomas Edison, James Watt, Josiah Wedgwood, Gottlieb Daimler, and others led what are commonly referred to as the First and Second Industrial Revolution. Beginning with innovators of iron smelting and ending with the founders of the chemical industry, Weightman profiles these individuals and their contributions to technological revolutions and the global economy.

Throughout the work, Weightman emphasizes the importance of leadership and individual contributions to industrial revolutions. He describes Robert Fulton's development of steamboat technology and how governments subsidized the infrastructure that made the mass adoption of steamboats possible. Following this invention, the governments of New York, Massachusetts, and Pennsylvania developed numerous canal projects.<sup>27</sup> Weightman also describes how individuals, such as Alfred du Pont, helped to disseminate technology, in this case chemical production, from one country to another.<sup>28</sup>

*The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World* is the most current work reviewed. In the book, economist, political advisor, and activist Jeremy Rifkin delineates three macro and three micro industrial revolutions. He then explores how Internet communication technology and renewable energy are merging to create the next industrial revolution. Rifkin believes that industrial civilization is nearing the end of the so-called "Carboniferous Period."<sup>29</sup> He argues that only "The Third Industrial Revolution offers the hope that we can arrive at a sustainable post carbon-era by mid-

century and avert catastrophic climate change.”<sup>30</sup> According to Rifkin, industrial revolutions occur when new communication technologies—print material and electrical communication—converge with new energy systems—steam-powered technology and oil-powered internal combustion engines. Rifkin denotes five pillars to the Third Industrial Revolution: (1) shifting to renewable energy; (2) using buildings as power plants; (3) deploying hydrogen and other storage technologies; (4) using Internet technology to transform the power grid; and (5) transitioning the transport fleet to electricity plug-in and fuel cell vehicles.<sup>31</sup> Rifkin points to the historic transformation of the European and American economies from wood-based fuels to coal-powered steam technologies and more recently, a shift to an oil, electricity, and auto economy—each of which took place over a half-century.<sup>32</sup>

Unlike other researchers, Rifkin refers to the Cleantech Revolution as the Third Industrial Revolution and views the preceding five technological revolutions as larger components of the First and Second Industrial Revolution. This paper considers Rifkin’s Third Industrial Revolution as the equivalent to the Sixth Industrial Revolution. Rifkin emphasizes the importance of an active government role in the Age of Cleantech. As in both the First and Second Industrial Revolution, large-scale government commitments and expansive policies were required to build the necessary infrastructure, such as the railroad. By comparison, Rifkin downplays the significance of capital to the Cleantech Revolution. Since hydrocarbons are so rare and the extraction, processing, and distribution of these resources so costly, capital has become concentrated in select individuals and institutions during the previous two industrial revolutions. On the contrary, in his view, the Third Industrial Revolution and the widely accessible nature of renewables will require a more distributed system of capitalism.

## Structure and Timing of Technological Revolutions

Over the last two centuries, technological revolutions have occurred approximately every fifty years. In general, each originates in a single nation or region and as Perez suggests, tends to follow a “*technological revolution-financial bubble-collapse-golden age-political unrest*” sequence.<sup>33</sup> At the end of this fifty-year cycle, old industries begin to merge with new ones to create a new technological revolution; as a result, the foundation for the next age is laid.<sup>34</sup> These may be products and industries that have existed for some time, in either relatively minor economic roles or as important complements for prevailing industries.<sup>35</sup> Currently, the global economy is in the midst of the Information Technology Revolution and is approaching the beginning of the Cleantech Revolution.

The Age of Information and Telecommunications (1971-present) supplanted the Age of Oil, the Automobile and Mass Production (1908-1975). Its catalyst was the announcement of Intel’s microprocessor in Santa Clara, California.<sup>36</sup> This unleashed a wave of innovation that included cheap microelectronics, computers, software, telecommunications, control instruments, computer-aided biotechnology, the Internet, and email—most of which originated in the United States and eventually spread to Europe and Asia.<sup>37</sup> As in all five technological revolutions, technologies and components of the prior age merged with the current one to create or define new technologies. For example, the assembly line—first developed by the Ford Motor Company in the Age of Oil, the Automobile and Mass Production (1908-1975)—was adopted by newly minted technology companies such as Apple, Intel, and Microsoft to cheaply mass produce microelectronics, computers, and software programs in the Age of Information and Telecommunications (1971-present). This flurry of innovation and capital market activity reached its peak in the dot-com bubble of 1995-2000 when bullish venture capitalists

overinvested and the NASDAQ stock exchange surpassed 5,000. The recent return of information technology in the form of social media and smartphones suggests that the global economy may currently be entering the golden age of Perez's model.

The Cleantech Revolution is currently nascent, similar to where the Information Technology Revolution was in the 1970s. The announcement of Germany's feed-in tariff policy in 2004 acted as the catalyst, or the Intel microprocessor moment, for the Cleantech Revolution and has helped to launch solar sales—a technology that was originally developed in the 1950s.<sup>38</sup> Already, the Age of Information and Telecommunications (1971-present) is merging with the Age of Cleantech to generate revolutionary potential.<sup>39</sup> For example, control instruments and the Internet, a product of the Age of Information and Telecommunications (1971-present), are being used to digitalize energy in the form of smart grid and metering technologies.

### **Role of Capital in Technological Revolutions**

The enabling role of financial capital is crucial and has historically evolved with each of the five technological revolutions. All major technological revolutions, from the Industrial Revolution (1770-1830) to the Age of Information and Telecommunications (1971-present), were dependent on an influx of capital from a range of sources—including the private and public sectors. Each technological revolution was initially capital intensive and required massive upfront investment in new or redefined industries. Traditionally, agents of financial capital (brokerages, banks, and other financial institutions) have filled this financial void to provide the necessary liquidity. At times, this has resulted in an explosion of capital market activity, which can lead to “irrational exuberance” and financial bubbles.

In the Age of Steel, Electricity, and Heavy Engineering (1875-1920), investment banker John Pierpont Morgan almost single-handedly acted as the agent of financial capital to the United States. The Third Technological Revolution brought new technologies and industries, which required massive infrastructure investments such as railways, bridges and tunnels, and electrical networks. In this critical time of expansion known as the Gilded Age, Pierpont provided the necessary capital and oversaw the financial consolidation of U.S. industry. He orchestrated mergers and restructurings of numerous American rail, steel, oil, iron, and electric companies. His financial prowess provided liquidity to American capital markets and ensured that emerging U.S. industries such as rail, steel, oil, iron, and electric had the necessary financing to expand.

The Sixth Technological Revolution is capital intensive. It requires huge upfront investments to commercialize clean technology and upgrade energy transmission capabilities, which were built to serve a hydrocarbon-based system. As in the Age of Information and Telecommunications (1971-present), the venture capitalists of Silicon Valley are providing pre-initial public offering (IPO) financing in the Age of Cleantech.<sup>40</sup> While counter-intuitive, the Age of Cleantech needs a significant asset bubble like the dot-com bubble of 1995-2000.<sup>41</sup> Historically, asset bubbles flood the market with capital; this in turn helps emerging technologies overcome economies of scale and drives further innovation in the long-term.<sup>42</sup> When Bill Gates was asked whether Internet stocks were an asset bubble at the Davos World Economic Forum in 1999, he replied saying: “Of course they’re a bubble. But you’re all missing the point. This bubble is going to attract so much new capital to this Internet industry that it is going to drive innovation faster and faster.”<sup>43</sup> Despite the short-term costs, an asset

bubble would radically transform the global economy for the better and leave behind a valuable infrastructure that would allow the Googles and Facebooks of cleantech to emerge.

### **Role of Government in Technological Revolutions**

Governments have always played an active role in technological revolutions. Government research and development, funding, and policy have been the central driving forces in bringing nascent, underutilized technologies to market. Without government support, none of the five technological revolutions would have been possible.<sup>44</sup> Historically, the government has catered to new, emerging industries—whether oil, automotive, or telecommunications—and given them special preferences. These special preferences include lobbying to ensure that every level of government would provide the necessary financial underwriting for infrastructure, as well as industry-friendly codes, regulations, and standards to ensure market success. Nowhere has this active role of government been more visible than in the Department of Defense.<sup>45</sup>

The Age of Oil, the Automobile, and Mass Production (1908-1975) is an instructive example. During this time, the United States saw the outbreak of two world wars, the Cold War, and as a result, an unprecedented expansion of government. The U.S. government scrambled and launched numerous infrastructure, research and development, as well as defense-related procurement programs, for example, the Manhattan Project of 1942-1946, the Federal-Aid Highway Act of 1956, and Defense Advanced Research Projects Agency (DARPA). In a similar manner, defense contractors like Lockheed Martin, Boeing, and Northrop Grumman have benefited from the Military-industrial complex and consequently made significant strides in aviation technology. Through these programs, the necessary infrastructure was laid and numerous technologies were commercialized such as civilian

nuclear power, radar, semi-conductors, the computer, the Internet, solar panels, and fuel cells. All of these technologies continue to have a substantial multiplier effect on the global economy and later played a role in the Age of Information and Telecommunications (1971-present). In fact, the government has seen its greatest successes in commercializing technologies when political and military—not economic—logic is applied. Compared to the private sector, the public sector, or specifically the Department of Defense, can more effectively open “...avenues of research, technology and production” and through procurement absorb the “extravagant costs that could not be normally recovered in the market.”<sup>46</sup> The public sector is more willing and able to pay a premium for new, underutilized technologies than the private sector.

Because oil and gas industries have received nearly \$700 billion in U.S. federal energy incentives over the past fifty years, government support will be especially crucial in the Age of Cleantech.<sup>47</sup> If clean technologies are to reach the required economies of scale, the government must become a driving force behind development and mass commercialization. The government views cleantech as an opportunity for economic growth, technological leadership, and to alleviate security concerns related to energy and climate change. As the single largest buyer of energy in the world and a leading research institution, the U.S. Department of Defense is at the forefront of funding and innovation in this sector and has demonstrated a keen interest in high-efficiency solar cells, advanced batteries, fuel cells, as well as advanced-generation biofuels. In 2005 alone, the Pentagon’s Defense Advanced Research Projects Agency (DARPA) announced a \$30 million program to more than double the efficiency of solar cells.<sup>48</sup>

### **Conclusion: Lessons for Leading the Cleantech Revolution**

This paper aimed to inform contemporary leaders of the Cleantech Revolution on the structure and timing of technological revolutions as well as the role played by capital and



government. It argued that there is an identifiable structure and timing to technological revolutions and a significant role for capital as well as government. As the Age of Information and Telecommunications (1971-present) comes to a close, contemporary leaders are laying the framework to foster and expedite the Age of Cleantech. In the process, it is essential that they consider historical trends, parallels, and lessons of the preceding five technological revolutions. Contemporary leaders should critically examine the fifty-year life cycle of technological revolutions, vital role of capital, as well as the role of government in the realms of research and development. No one technological revolution has been realized without widely accessible sources of capital as well as favorable government policies. These lessons are closely interrelated, as structure and timing, or the stage of the technological revolution, often dictates capital and policy requirements. Early revolutions are not only capital intensive but also dependent on government support.

However, some are already beginning to doubt the early stages of the Cleantech Revolution. Recent events and trends such as the bankruptcy of California solar panel manufacturer Solyndra, eroding support for government policy, rising competition from China, as well as falling natural gas prices suggest that the Cleantech Revolution is merely a “green” fairy tale. Despite what critics may argue, it is important to remember that the Cleantech Revolution is still very nascent. The current trial and error process is not abnormal and is in fact an indication of future innovation.<sup>49</sup> According to Michael Butler, a widely regarded cleantech thought leader and local investment banker:

Innovation takes place when times look the most bleak. Winners emerge from creative destruction...If you go back and look at any of those revolutions, you see the exact the same trends. It is no different than what has transpired in previous technological revolutions.<sup>50</sup>

Going forward, as governments, investors, and entrepreneurs continue to pour resources into this sector, it will mature and experience impressive long-term growth across the globe. While parallels and trends do exist, history shows that no one technological revolution is guaranteed to be the exact same. Each technological revolution is unique with its own paradigm and mode of growth. Undoubtedly, the Cleantech Revolution will present new challenges and take a different shape and form than the previous five technological revolutions.

## Notes

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<sup>1</sup> Perez, Carlota. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham (UK): E. Elgar, 2002. 4. Print.

<sup>2</sup> Ibid., p.14.

<sup>3</sup> Anderson, Leonard. "For Investors, a Heads-up on Clean Tech." Rev. of *The Clean Tech Revolution: The Next Big Growth and Investment Opportunity*. *The Boston Globe* [Boston] 5 Aug. 2007. Web. <[http://www.boston.com/business/globe/articles/2007/08/05/for\\_investors\\_a\\_heads\\_up\\_on\\_clean\\_tech/](http://www.boston.com/business/globe/articles/2007/08/05/for_investors_a_heads_up_on_clean_tech/)>.

<sup>4</sup> Milunovich, Steven, and Jose Rasco. *The Sixth Revolution: The Coming of Cleantech*. Rep. New York: Merrill Lynch, 2008. Print.

<sup>5</sup> Wilder, Clint, and Ron Pernick. *The Clean Tech Revolution: The Next Big Growth and Investment Opportunity*. New York: Collins, 2007. 286. Print.

<sup>6</sup> Stearns, Peter N. *The Industrial Revolution in World History*. Boulder, Colo: Westview, 1998. 191. Print.

<sup>7</sup> Perez, Carlota. *Technological Revolutions and Financial Capital*. p.14.

<sup>8</sup> Ibid., p.13.

<sup>9</sup> Ibid., p.27.

<sup>10</sup> Ibid., p.5.

<sup>11</sup> Ibid., p.22.

<sup>12</sup> Sullivan, Mary A. "Funding New Industries: A Historical Perspective on the Financing Role of the U.S. Stock Market in the Twentieth Century." *Financing Innovation in the United States, 1870 to the Present*. Ed. Naomi R. Lamoreaux and Kenneth Lee. Sokoloff. Cambridge, MA: MIT, 2007. 210. Print.

<sup>13</sup> Fabrizio, Kira R., and Mowery, David C. "Federal Role in Financing Major Innovations" *Financing Innovation in the United States, 1870 to the Present*. Ed. Naomi R. Lamoreaux and Kenneth Lee. Sokoloff. Cambridge, MA: MIT, 2007. 285. Print.

<sup>14</sup> Sullivan, Mary A. "Funding New Industries". p.197.

<sup>15</sup> Wilder, Clint, and Ron Pernick. *The Clean Tech Revolution*. p.9.

<sup>16</sup> Ibid., p.34

<sup>17</sup> Ibid., p.18

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<sup>18</sup> Friedman, Thomas L. *Hot, Flat, and Crowded: Why We Need a Green Revolution, and How It Can Renew America*. New York: Farrar, Straus and Giroux, 2008. 405. Print.

<sup>19</sup> Ibid., p.240

<sup>20</sup> Ibid., p.259

<sup>21</sup> Ibid., p.246

<sup>22</sup> Milunovich, Steven, and Jose Rasco. *The Sixth Revolution*.

<sup>23</sup> Ibid.

<sup>24</sup> Ibid.

<sup>25</sup> Ibid.

<sup>26</sup> Ibid.

<sup>27</sup> Weightman, Gavin. *The Industrial Revolutionaries: The Making of the Modern World, 1776-1914*. New York: Grove, 2009. 44-45. Print.

<sup>28</sup> Ibid., p.89.

<sup>29</sup> Rifkin, Jeremy. *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World*. New York: Palgrave Macmillan, 2011. p.12. Print.

<sup>30</sup> Ibid., p.5.

<sup>31</sup> Ibid., p.37.

<sup>32</sup> Ibid., p.38.

<sup>33</sup> Perez, Carlota. *Technological Revolutions and Financial Capital*. p.4.

<sup>34</sup> Ibid., p.22.

<sup>35</sup> Ibid., p.13.

<sup>36</sup> Ibid., p.11.

<sup>37</sup> Ibid., p.14.

<sup>38</sup> Milunovich, Steven, and Jose Rasco. *The Sixth Revolution*.

<sup>39</sup> Butler, Michael. "Technological Revolutions Through the Ages: Lessons for Leading the Cleantech Revolution." Telephone interview. 24 Apr. 2012.

<sup>40</sup> Ranken, Tom. "Technological Revolutions Through the Ages: Lessons for Leading the Cleantech Revolution." Telephone interview. 23 Apr. 2012.

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<sup>41</sup> Friedman, Thomas L. *Hot, Flat, and Crowded*. p. 259.

<sup>42</sup> *Ibid.*

<sup>43</sup> *Ibid.*, p. 258.

<sup>44</sup> *Ibid.*, p.93.

<sup>45</sup> Martin, John. “Technological Revolutions Through the Ages: Lessons for Leading the Cleantech Revolution.” Telephone interview. 25 Apr. 2012.

<sup>46</sup> *Ibid.*, p.28.

<sup>47</sup> Milunovich, Steven, and Jose Rasco. *The Sixth Revolution*.

<sup>48</sup> Wilder, Clint, and Ron Pernick. *The Clean Tech Revolution*. p. 45.

<sup>49</sup> Gerritson, Steve. “Technological Revolutions Through the Ages: Lessons for Leading the Cleantech Revolution.” Telephone interview. 24 Apr. 2012.

<sup>50</sup> Butler, Michael. “Technological Revolutions Through the Ages”.