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The TESLA Revolution

WHY BIG OIL IS LOSING THE ENERGY WAR

Table of Contents

Prologue

Nearly 10 years ago, I started investigating the history of oil and how its depletion could impact our postindustrial society. The situation concerned me after I learned about it firsthand from the experienced geologist Colin Campbell (PhD, formerly at BP) who had studied the issue for decades. Would there be enough oil around to fuel society in the centuries or even decades to come?

The book Willem and I coauthored in 2008, *The Permanent Oil Crisis*, emerged from this concern. Our aim was to raise awareness of the issue of peak oil and the need to transition to alternative forms of energy. Its basic premise was that a structural undersupply of cheap oil would disrupt the world economy, because the peak in conventional oil production was at hand. Oil supplies had been flat for several years, and oil prices were on the rise, with limited new sources of supply in sight. The situation was urgent given the lack of alternatives at the time, and we needed to transition to clean sources of energy.

In this new book, *The Tesla Revolution*, we examine what has happened in oil markets since then, with almost 10 years of learning added to the mix. Thanks to large-scale shifts towards alternatives over the last decade, our view is more positive now.

The world of clean energy is advancing rapidly thanks to the efforts of countless people who, like us, are concerned about the end of cheap oil, about how fossil fuel-based carbon emissions are linked to climate change, or both. Just as Nikola Tesla, together with Thomas Edison, revolutionized the world 120 years ago by sparking the electrical age, we are now entering a revolution in clean transport, electricity, and heating.

This new 'Tesla Revolution' in clean energy is driven primarily by the urgency to scale alternatives to oil in transportation, as signaled by high oil prices.

We know that oil is and will continue to be more expensive than in the early 2000s and prior, since we now need to extract either lesser-quality oil, or at more remote locations, or at far greater depths. The recent rise of shale oil in the United States is not changing this situation, since most of it is also costly to extract, as we explore in Chapter 4. Shale oil took the world by storm, and just like the oil industry, we did not see it coming early enough.

The shale oil boom is drying up, however, since the Middle East started pumping flat out in 2014, and oil prices have recently dropped even lower, to $40-$50 per barrel (still three times higher than in the early 2000s and prior). Since March 2015, shale oil production has fallen by 15%–in just 16 months. Since the costs of extraction are high—shale oil is not the cheap oil we're used to—major investments have been scrapped, well drilling has halted, and company bankruptcies are growing.

This situation is not unique to shale oil; if we look at oil production globally, we now need hundreds of billion-dollar investments every year in deep-water fields and oil sands to increase oil production, and many projects have recently been postponed.

Our key message is still valid. We cannot rely on continued smooth growth in (cheap) oil production. There is a large downside risk that oil supply will slump within the next 10 years, bringing substantial economic repercussions as almost all transportation today depends on oil. Not to mention the risk of severe geopolitical instability, since history teaches us that Western countries secure oil supplies via covert operations or military means, which we elaborate on in Chapter 3.

In this post cheap-oil era, we believe we need to work on reducing oil dependency and risk. In a figurative sense, sourcing transportation energy from clean sources where possible is an economic 'pension policy' that anyone who cares about their future should buy into. The faster we can scale alternative energy sources for transportation, the more likely it is that sufficient energy will be available.

The second driver of the Tesla Revolution is the urgency to scale alternatives for all fossil fuels—especially coal—to dramatically reduce carbon emissions. Carbon reductions are needed to halt the chemical alteration of the earth's atmosphere and thereby minimize the disruptive risks of climate change.

Reducing carbon pollution is currently a big driver of many government energy policies and a factor in the investment strategies of many companies and financial institutions. In our view, climate change is just as big a risk as cheap oil depletion in the next decades, and much greater for 2050 and beyond, since increasing climate disruptions will affect the world's economies. We just don't know what the effects will be in our lifetimes, let alone closer to the year 2100 and beyond.

Many people working to transform our fossil fuel-based economy, including the CEOs of Tesla Motors and Toyota, share our concerns. In our view, any book on energy published today needs to look at the extent to which carbon emission reductions are driving the world away from fossil fuels, as we discuss in Chapter 5. We will also update you on last year's Paris Agreement on Climate Change, carbon reduction policies, and Big Oil's underground carbon stock and the investment implications of it.

The key questions we explore are at the heart of coal and natural gas: Has coal begun its long-term demise, as carbon

reductions require? Will natural gas play a major role in the future as a bridge to a clean energy world?

That brings me to the impact that the two drivers—expensive oil and climate change—is having on the global energy picture.

In 2008, when writing our previous book, Tesla Motors was a small player with its Roadster electric sports car, and its Chinese counterpart Build Your Dreams (BYD) only sold mini electric city cars. Now, thanks to many innovations, especially in lithium-ion batteries, the entire car world is changing rapidly.

In the wake of Tesla Motors' rise, major car companies around the world, from the United States to Germany to Japan, are aggressively pursuing electric cars, hybrid cars, or fuel-cell car models. Soon, they may follow further in the footsteps of Tesla and BYD which, at the time of publication, are the first two fully integrated electric car—battery—solar-energy companies, bringing renewable driving to your garage or front door.

Thanks to their efforts, it is likely that, not too long from now, car companies will take away transportation market share from Big Oil as electric cars in all segments become both desired and cost competitive. That will not put oil companies out of business (at least not for the foreseeable future), but it will push them to provide oil increasingly for trucking, shipping, flight, and chemicals, which are still more challenging uses to tackle. We examine this and a lot more in Chapters 1 and 6, not just for batteries and electric cars, but also for fuel cells, solar photovoltaic cells, wind power, electricity grids, and other technologies.

So much is happening around the world daily that the news is difficult to keep up with. Did you know that over 40,000 German households have battery systems connected

to their solar panels? Or that more than 200 million electric bikes, scooters, and motorcycles are being driven on China's streets already? Or that solar panels power at least 40 million households in regions without electricity grids?

The lack of good information has led to a lot of confusion when it comes to how fast renewables are entering the world's energy system. In our experience, many opinions and so-called facts are vented on the Internet and in newspapers based on outdated information and data, usually limited to experience within the country in which people live, or are ridden with bias. Part of this confusion comes from a lack of up-to-date information on the scale of renewables in the world's energy system as a whole.

To reduce some of this confusion, we paint a picture of the pace of change of the clean energy transition relative to the world's energy system in Chapter 1. Based on the most up-to-date data, up to the end of 2016, we explain how much fossil fuel and clean energy is used, for different energy uses, and the differences across continents and climates.

This provides a bird's-eye view of the current situation seen from the perspective of where we are headed and the scaling that is needed to accelerate the Tesla Revolution—a key part of the book—as we need to know whether the world is moving fast enough and how it could move faster to accelerate the rise of clean energy in the world's energy mix.

We hope that if you aren't already enthusiastic about clean energy, our book will inspire you to join and accelerate the Tesla Revolution. We all have a role to play in bringing the earth closer to a clean energy world. Without people buying electric cars or solar panels, building great tech innovations, shaping energy policies, or financing large-scale clean energy infrastructure, not much will change. We also hope that you find the content useful and that its clarity

contributes to your thinking on energy, to help you make better energy decisions in your daily life. We have more decision power than we think.

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London, November 2016

Special Introduction[1]

This book is about the energy revolution in which Tesla Motors plays a significant role. The name of the company honors Nikola Tesla, one of the greatest engineers and inventors ever.

Who was Nikola Tesla?

Nikola Tesla, born in 1856, was a Serbian-American inventor, electrical engineer, mechanical engineer, physicist, and futurist best known for his contributions to the design of the modern alternating current (AC) electricity supply system.[1]

In 1875, Tesla started at Austrian Polytechnic in Graz, Austria, on a Military Frontier scholarship. Tesla claimed that he worked from 3 a.m. to 11 p.m., including Sundays and holidays. After his father's death in 1879, Tesla found a package of letters from his professors to his father, warning that unless he was removed from the school, Tesla would die from overwork. During his second year, Tesla came into conflict with Professor Poeschl over the Gramme dynamo, when Tesla suggested that commutators were not necessary. At the end of his second year, Tesla lost his scholarship and became addicted to gambling.[2] He never graduated from the university and did not receive grades for the last semester. In December 1878, Tesla left Graz and severed all relations with his family to hide the fact that he had dropped out of school.[3]

1 Based on public (Wikipedia) sources.

In 1881, Tesla moved to Budapest to work under Ferenc Puskás at a telegraph company, the Budapest Telephone Exchange. Within a few months Tesla was elevated to the chief electrician position. During his employment, Tesla made many improvements to the central station equipment and claimed to have perfected a telephone repeater or amplifier, which was never patented nor publicly described.[2]

In 1882, Tesla moved to France where he began working for the Continental Edison Company, designing and making improvements to electrical equipment. In June 1884, he emigrated to New York City in the United States.[4] He was hired by Thomas Edison to work at his Edison Machine Works on Manhattan's Lower East Side. Tesla's work for Edison began with simple electrical engineering and quickly progressed to solving more difficult problems.[5]

Tesla was offered the task of completely redesigning the Edison Company's direct current generators. In 1885, he said that he could redesign Edison's inefficient motors and generators, making an improvement in both service and economy. According to Tesla, Edison remarked: 'There's $50,000 in it for you—if you can do it.'[6],[7]

After months of work, Tesla fulfilled the task and inquired about payment. Edison, saying that he had only been joking, replied, 'Tesla, you don't understand our American humor.' Instead, Edison offered a $10 a week raise over Tesla's $18 per week salary. Tesla refused the offer and immediately resigned.[7]

After leaving Edison's company, Tesla partnered with two businessmen in 1886, Robert Lane and Benjamin Vail, who agreed to finance an electric lighting company in Tesla's name, Tesla Electric Light & Manufacturing. The company installed electrical arc light-based illumination systems designed by Tesla. It also designed dynamo electric machine

commutators, the first patents issued to Tesla in the United States.[3],[8]

The investors showed little interest in Tesla's ideas for new types of motors and electrical transmission equipment. They were more interested in developing an electrical utility than inventing new systems. They eventually forced Tesla out, leaving him penniless. He even lost control of the patents he had generated, since he had assigned them to the company in lieu of stock. He had to work at various electrical repair jobs and as a ditch digger for $2 a day.[9],[10]

In late 1886, Tesla met Alfred S. Brown, a Western Union superintendent, and New York attorney Charles F. Peck. The two men were experienced in setting up companies and promoting inventions and patents for financial gain. Based on Tesla's patents and other ideas, they agreed to back him financially and handle his patents. Together they formed the Tesla Electric Company in April 1887. They set up a laboratory for Tesla at 89 Liberty Street in Manhattan, where he worked on improving and developing new types of electric motors, generators, and other devices.[9]

In 1887, Tesla developed an induction motor that ran on alternating current, a power system format that was starting to be built in Europe and the United States because of its advantages in long-distance, high-voltage transmission.[11]

In 1888, *Electrical World* magazine editor Thomas Commerford Martin (a friend and publicist) arranged for Tesla to demonstrate his alternating current system, including his induction motor, at the American Institute of Electrical Engineers (now IEEE). Engineers working for the Westinghouse Electric & Manufacturing Company reported to George Westinghouse that Tesla had a viable AC motor and related power system—something for which Westinghouse had been trying to secure patents.[8],[9],[12]

Tesla's demonstration of his induction motor and Westinghouse's subsequent licensing of the patent, both in 1888, put Tesla firmly on the AC side of the War of Currents, an electrical distribution battle being waged between Thomas Edison and George Westinghouse that had been simmering since Westinghouse's first AC system in 1886.[3]

This started out as a competition between rival lighting systems, with Edison holding all the patents for DC and the incandescent light, and Westinghouse using his own patented AC system to power arc lights, as well as incandescent lamps of a slightly different design, to get around the Edison patent.[13]

The acquisition of a feasible AC motor gave Westinghouse a key patent in building a completely integrated AC system, but the financial strain of buying up patents and hiring the engineers needed to build it meant development of Tesla's motor had to be put on hold for a while. The competition resulted in Edison Machine Works pursuing AC development in 1890. By 1892, Thomas Edison was no longer in control of his own company, which was consolidated into the conglomerate General Electric and converting to an AC delivery system at that point.[14]

On 30 July 1891, at the age of 35, Tesla became a naturalized citizen of the United States.[15] He established his South Fifth Avenue laboratory in New York City, and later another at 46 E. Houston Street. He lit electric lamps wirelessly at both locations, demonstrating the potential of wireless power transmission.[2],[3]

Tesla served as a vice president of the American Institute of Electrical Engineers from 1892 to 1894, the forerunner of the modern-day IEEE (along with the Institute of Radio Engineers).[2] Starting in 1894, Tesla began investigating what he referred to as radiant energy of 'invisible' kinds

(X-rays) after he had noticed damaged film in his laboratory in previous experiments.[16]

Much of Tesla's early research—hundreds of invention models, plans, notes, laboratory data, tools, photographs—was lost in the Fifth Avenue laboratory fire of March 1895.[17]

Tesla's theories on the possibility of transmission by radio waves go back as far as lectures and demonstrations in 1893 in St. Louis, Missouri, the Franklin Institute in Philadelphia, Pennsylvania, and the National Electric Light Association.[18]

In 1898, Tesla demonstrated a radio-controlled boat—which he dubbed 'teleautomaton'—to the public during an electrical exhibition at Madison Square Garden. Tesla tried to sell his idea to the US military as a type of radio-controlled torpedo, but they showed little interest.[8],[19]

In 1900, Tesla was granted patents for a 'system of transmitting electrical energy' and 'an electrical transmitter'.

On 6 November 1915, a Reuters news agency report from London erroneously stated that the 1915 Nobel Prize in Physics had been awarded to Thomas Edison and Nikola Tesla. There have been subsequent claims by Tesla biographers that Edison and Tesla were the original recipients and that neither was given the award because of their animosity toward each other; that each sought to minimize the other's achievements and right to win the award; that both refused ever to accept the award if the other received it first; that both rejected any possibility of sharing it; and even that a wealthy Edison refused it to keep Tesla from getting the $20,000 prize money.[7]

In 1928, Tesla received his last patent, US Patent 1,655,114, for a biplane capable of taking off vertically (VTOL aircraft) and then of being 'gradually tilted through manipulation of the elevator devices' in flight until it was flying like a

conventional plane. Until his death, he kept working on energy-related inventions including a secret weapon that could send out beams of energy ('death rays'). There are at least 278 patents issued to Tesla in 26 countries that have been accounted for. Many inventions developed by Tesla were not put under patent protection.[7],[20],[21]

Tesla worked every day from 9:00 a.m. until 6:00 p.m. or later, with dinner from exactly 8:10 p.m. in a hotel restaurant. He dined alone, except on the rare occasions when he would give a dinner party to a group to meet his social obligations. Tesla would then resume work, often until 3:00 a.m.[6] He said that he believed that all fundamental laws could be reduced to one. In his article 'A Machine to End War' published in 1937, Tesla stated, 'To me, the universe is simply a great machine, which never came into being and never will end.'[22]

Tesla read and wrote many works, memorized complete books, and supposedly possessed a photographic memory. He was a polyglot, speaking eight languages: Serbo-Croatian, Czech, English, French, German, Hungarian, Italian, and Latin.[6],[7]

Tesla was asocial and prone to isolate himself with his work. However, when he did engage in a social life, many people spoke very positively and admiringly of Tesla. In middle age, Tesla became close friends with Mark Twain; they spent a lot of time together in his lab and elsewhere. Twain notably described Tesla's induction motor invention as 'the most valuable patent since the telephone.'[23],[24]

On 7 January 1943, at the age of 86, Tesla died alone in room 3327 of the New Yorker Hotel, where he had lived for years. Two days later, the FBI ordered the Alien Property Custodian to seize Tesla's belongings, even though Tesla was an American citizen.[17] On 10 January 1943, New York

City mayor Fiorello La Guardia read a eulogy written by Slovene-American author Louis Adamic live over WNYC radio while violin pieces 'Ave Maria' and 'Tamo daleko' were played, while 2,000 people attended the state funeral for Tesla. Despite having sold his AC electricity patents, Tesla was impoverished and in debt when he died.[2],[17]

Tesla Motors' CEO is Elon Musk. Just like Nikola Tesla 100 years earlier, Musk is a remarkable engineer and inventor who will be remembered, just like Tesla, as a man whose ideas have changed the world.

Who is Elon Musk?

Elon Reeve Musk (1971) is a South African-born Canadian-American engineer and inventor. He is the founder and CEO of SpaceX; cofounder and CEO of Tesla Motors; cofounder and chairman of SolarCity; and cofounder of PayPal. Currently (in 2016) he is one of the 100 wealthiest people in the world.

Musk has stated that the goals of SolarCity, Tesla Motors, and SpaceX revolve around his vision to change the world and humanity. His goals include reducing global warming through sustainable energy production and consumption, and reducing the 'risk of human extinction' by 'making life multiplanetary' by setting up a human colony on Mars.[25]–[27] He also has envisioned a high-speed transportation system known as the Hyperloop and has proposed a VTOL supersonic jet aircraft with electric fan propulsion known as the Musk electric jet.[28]

At age 10, he developed an interest in computing with the Commodore VIC-20. He taught himself computer programming and at age 12, sold the code for a BASIC-based video game he created called Blastar to a magazine called *PC and Office Technology* for approximately $500.[29],[30]

Musk was severely bullied throughout his childhood, and he was once hospitalized when a group of boys threw him down a flight of stairs and then beat him until he blacked out. He was initially educated at private schools and moved to Canada in June 1989, just before his 18th birthday, after obtaining Canadian citizenship through his Canadian-born mother.[30]

In 1992, after spending two years at Queen's University, Musk transferred to the University of Pennsylvania, where, at the age of 24, he received a Bachelor of Science degree

in physics from its College of Arts and Sciences, and a Bachelor of Science degree in economics from its Wharton School of Business.[31] In 1995, at age 24, Musk moved to California to begin a PhD in applied physics and materials science at Stanford University, but left the program after two days to pursue his entrepreneurial aspirations in the areas of the Internet, renewable energy, and outer space. In 2002, he became a US citizen.[30]

In 1995, Musk and his brother, Kimbal, started Zip2, a web software company, with $28,000 of their father's (Errol Musk) money.[30] The company developed and marketed an Internet 'city guide' for the newspaper publishing industry. Musk obtained contracts with *New York Times* and the *Chicago Tribune*. While at Zip2, Musk wanted to be CEO, but none of the board members would allow it. Compaq acquired Zip2 for $307 million in cash and $34 million in stock options in February 1999. Musk, aged 28, received $22 million from the sale.[32]–[34]

In March 1999, Musk cofounded X.com, an online financial services and e-mail payment company, with $10 million from the sale of Zip2. One year later, the company merged with Confinity, which had a money transfer service called PayPal. The merged company focused on the PayPal service and was renamed PayPal in 2001. PayPal's early growth was driven mainly by a viral marketing campaign where new customers were recruited when they received money through the service.[35] In October 2002, PayPal was acquired by eBay for $1.5 billion in stock, of which Musk received $165 million. Before its sale, Musk, who was the company's largest shareholder, owned 11.7 % of PayPal's shares.[36]–[38]

In 2001, Musk conceptualized 'Mars Oasis', a project to land a miniature experimental greenhouse on Mars

containing food crops growing on Martian regolith, in an attempt to rekindle public interest in space exploration.[39],[40] In October 2001, Musk travelled to Moscow to buy refurbished ICBMs that could send the envisioned payloads into space but returned to the United States empty-handed. In February 2002, he was offered a Russian rocket for $8 million. On the flight back from Moscow, Musk realized that he could start a company that could build the affordable rockets he needed.[41] According to early Tesla and SpaceX investor Steve Jurvetson, Musk calculated that the raw materials for a rocket were actually only 3% of the sales price of a rocket at the time. By applying vertical integration and the modular approach from software engineering, SpaceX could cut launch price by a factor of 10 and still enjoy a 70% gross margin. Ultimately, Musk ended up founding SpaceX with the long-term goal of creating a 'true spacefaring civilization.'[42],[43]

With $100 million of his early fortune, Musk founded Space Exploration Technologies, or SpaceX, in June 2002. It develops and manufactures space launch vehicles with a focus on advancing the state of rocket technology.[44] In seven years, SpaceX designed the family of Falcon launch vehicles and the Dragon multipurpose spacecraft. In September 2008, SpaceX's Falcon 1 rocket became the first privately funded kerosene fueled vehicle to put a satellite into Earth's orbit. In May 2012, the SpaceX Dragon vehicle berthed with the ISS, making history as the first commercial company to launch and berth a vehicle to the International Space Station.[45]

In 2006, SpaceX was awarded a contract from NASA to continue the development and testing of the SpaceX Falcon 9 launch vehicle and Dragon spacecraft in order to transport cargo to the International Space Station, followed by a $1.6

billion NASA Commercial Resupply Services program contract on December 23, 2008, for 12 flights of its Falcon 9 rocket and Dragon spacecraft to the Space Station, replacing the US Space Shuttle after it retired in 2011.[46]–[48] Astronaut transport to the ISS is currently handled solely by the Soyuz, but SpaceX is one of two companies awarded a contract by NASA as part of the Commercial Crew Development program, which is intended to develop a US astronaut transport capability by 2018.

In December 2015, SpaceX successfully landed the first stage of its Falcon rocket back at the launch pad. It was the first time in history such a feat had been achieved by an orbital rocket and is a significant step towards rocket reusability, lowering the costs of access to space. This first stage recovery was replicated several times in 2016 by landing on an autonomous spaceport drone ship, an ocean-based recovery platform.[49]–[51]

SpaceX is both the largest private producer of rocket engines in the world and holder of the record for highest thrust-to-weight ratio for any known rocket engine. SpaceX has produced more than 100 operational Merlin 1D engines, currently the world's most powerful for its weight.[52],[53]

His goal is to reduce the cost of human spaceflight by a factor of 10. In a 2011 interview, he said he hopes to send humans to Mars within 10–20 years. In Ashlee Vance's biography of Musk, the entrepreneur reportedly stated that he wants to establish a Mars colony by 2040.[30] SpaceX intends to launch a Dragon spacecraft on a Falcon Heavy in 2018 to soft-land on Mars; this is intended to be the first of a regular cargo mission supply run to Mars, building up to later crewed flights. Musk stated in June 2016 that the first unmanned flight of the larger Mars Colonial

Transporter (MCT) spacecraft is scheduled for departure to the red planet in 2022, to be followed by the first manned MCT Mars flight departing in 2024.[54],[55]

Tesla Motors was incorporated in July 2003 by Martin Eberhard and Marc Tarpenning who financed the company until the Series A round of funding. Both men played active roles in the company's early development prior to Elon Musk's involvement. Musk led the Series A round of investment in February 2004, joining Tesla's board of directors as its chairman. Musk took an active role within the company and oversaw product design at a detailed level but was not deeply involved in day-to-day business operations.[56]

Following the financial crisis in 2008, Musk assumed leadership of the company as CEO and product architect, positions he still holds today, and he owns 22% of the company.[57] In 2014, Musk announced that Tesla Motors will allow its technology patents to be used by anyone in good faith in a bid to entice automobile manufacturers to speed up development of electric cars.[58]

Musk provided the initial concept and financial capital for SolarCity, which was then cofounded in 2006 by his cousins Lyndon and Peter Rive.[59],[60] Musk remains the largest shareholder. SolarCity as of 2016 is the third-largest provider of solar power systems in the United States.[61]

The underlying motivation for funding both SolarCity and Tesla is to help combat global warming. In 2012, Musk announced that SolarCity and Tesla Motors are collaborating to use electric vehicle batteries to smooth the impact of rooftop solar on the power grid. At the moment of writing in 2016, Tesla Motors was in a process to acquire SolarCity,[62],[63] promoting an integrated future, with an electric car producer, a Powerwall-battery maker and a solar

roof producing company seamlessly integrated into a new Tesla corporation.

In 2013, Musk unveiled a concept called the Hyperloop: a high-speed transportation system incorporating reduced-pressure tubes in which pressurized capsules ride on an air cushion driven by linear induction motors and air compressors. The mechanism for releasing the concept was an alpha-design document that, in addition to scoping out the technology, outlined a notional route where such a transport system might be built: between the Greater Los Angeles Area and the San Francisco Bay Area.[64]