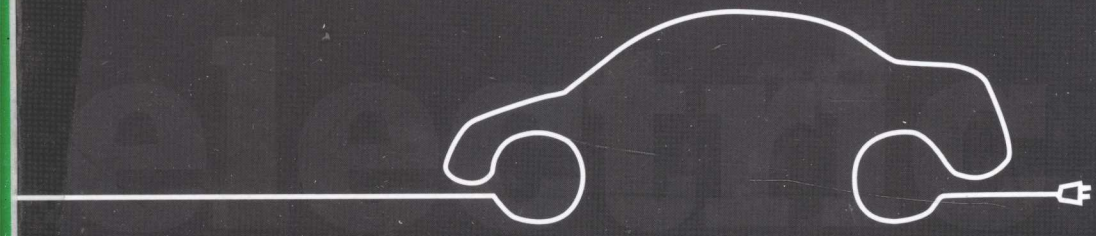
João Vitor Fernandes Serra

electric vehicles

technology, policy and commercial development



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João Vitor Fernandes Serra

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Electric Vehicles

Foreword

The world is searching for alternatives to the internal combustion engine, and the electric vehicle option is gathering momentum as we move into the early decades of this century. If electric vehicles do in fact achieve a perch in the commercial market, the story will be one of the most interesting written in the post-industrial revolution. This book is a unique contribution to that unfolding narrative.

Aimed at a broad, educated and increasingly eco-friendly audience—students, academics, business analysts, and investors, not to mention specialists in the EV industry—Electric Vehicles offers unusually comprehensive and readable coverage of issues surrounding the shift in transportation technology towards a more sustainable solution. The book is especially effective in covering technical areas—vehicle design, battery requirements, and support infrastructure, to name the most important. However, the book stands out from the growing body of literature on the topic in its review of commercialization and related policy measures—including those in the developing world, such as retrofits—that could either threaten to block or promise to facilitate the technological transition to a more environmentally friendly future.

To those probably already suspicious or anxious about oil dependence, like members of Gen X and Millennials, ready as consumers to enter the car market and voting booths with energy on their mind, the author offers a comprehensive and up-to-date perspective on important global and local issues such as climate change and energy efficiency. The book tackles these issues with creativity and analytical rigor in a manner that is accessible to those without a technical background.

While industry leaders like General Motors, Ford, and Toyota are probing the market with new ideas about fleets and automated guidance and safety electronics inside electric cars, this book sticks to the fundamental questions surrounding the personal transportation transition.

We are a turning point in history marked by several distinctly urban features. For one, as we have been reminded many times, the urban transition has been completed. For the first time in history, more people are now living in cities than in the countryside. Not so frequently mentioned is that nearly a thousand cities around the globe are deeply dependent on transportation and increasingly engaged in a search for new ideas and new solutions to transport. Adoption

of electric vehicles could dramatically shift the stakes in the coming decades for nations struggling to supply fossil fuels for automobiles, for cities grappling with congestion and pollution, and for billions of people looking for a better way to get around town. *Electric Vehicles* is a timely, balanced, and effective guide to help readers understand the place and prospects of a coming new wave.

Dr Tim Campbell

Introduction

A Contemporary Crisis

It always seems impossible, until it is done.

Nelson Mandela

At the start of the new millennium, society is faced with one of the most pressing crises in human history. As though the 2008 financial crisis were not enough to dampen growth prospects around most of the globe, the combination of energy security and environmental concern have cast a shadow on the way we live our lives. Since the 1990s, the world has gradually become increasingly aware of these challenges to sustainable growth. The 1992 Rio Earth Summit and the 1997 Kyoto Protocol took important first steps towards holding industries accountable for their carbon dioxide emissions. And while coal may still dominate global power markets, renewable sources – such as wind and solar technologies – have finally achieved a competitive position in some market segments. Not that any single solution will ever become a silver bullet, but together they will contribute to diversify power generation and reduce dependence on dirty hydrocarbons.

The shift towards a sustainable lifestyle has hardly managed to scratch one of society's core addictions: personal mobility and its dependence on gas-guzzling automobiles. While coal may be the world's dominant electrical energy source, petroleum is, hands down, the world's dominant primary energy source due to its prevalence in transportation. What is more, a full 67 per cent of petroleum consumption in the transportation sector results from private road transport, or so-called light duty vehicles (LDVs). We might say that petroleum dependence and carbon emissions lie right at our front doors – if not in our back yards – whether we like it or not.

While wind farm and solar panel projects might now be called commonplace, sustainable transport remains an alien concept. However, contrary to

common perception, LDV technology is a prime candidate for a shift towards sustainability. This book makes the case for an energy-efficient and low-carbon transportation future based on electric propulsion. Granted, many aspects of an electric vehicle (EV) solution still require fine-tuning, but this is to be expected in the initial stage of any major technological innovation. No matter, the EV is the most cost-effective, and perhaps the only, acceptable technological solution to sustainable transportation in sight.

The book hopes to appeal to a wide range of readers – from a technologically inclined audience new to the subject, to those interested in the broader policy aspects of clean transportation, to the petrol-heads afraid that EVs will put an end to their fun. Its goal is to provide an introduction to the complex array of issues surrounding EVs – a coherent foundation for what has tended to be an overwhelmingly confusing discussion.

The book cannot forgo some technical discussions. However, because the intended audience is assumed to be of varied background and interest, the book adopts a fluid conversational tone and provides abundant illustrations to support technical discussions. Wherever technical details are not absolutely crucial to the core discussion, complementary boxes have been included for the slightly more curious. This should help readers to keep track of the basic storyline even if they make brief detours into more detailed specific areas along the way. The reader should also be warned that, although predominantly based on scientific evidence and scholarly material, the discussion must at time draw on current news and material published on the internet as this is a fast-paced topic.

Part I of the book provides a contextual background for the discussion. Chapter 1 offers a historical overview of the development of the automobile – from the first steam-powered vehicle to the 2008 meltdown of what became a mammoth enterprise over little more than one hundred years. This is meant to help the reader understand what has led us to our current technological scenario. Chapter 2 turns the spotlight on some of the historical and still powerful influences on the industry today, but is concerned in this discussion with identifying what is different from the context that prevailed up to the end of the millennium. It highlights factors that are likely to transform the automotive industry in the decades to come.

Throughout Part I, the reader will perhaps be reminded of the Chinese word for crisis – *weiji* – which emphasizes both a sense of imminent threat and a call for change or transformation. By the end of Part I, the reader should have a sense of the urgent need to shift away from internal combustion engine vehicle (ICV) technology, but also an initial understanding of why present conditions finally favour the EV.

Part II of the book dives into an evaluation of the EV solution. Chapters 3 and 4 provide an overview and comparative analysis of the technology behind the ICV and EV – notably their vehicle propulsion and energy storage systems. Chapter 5 shifts attention to one of the most pressing issues in EV development – the recharge infrastructure and associated energy services.

Indeed, this is the heart of the book. By the end of Part II, the reader should have a well-rounded understanding of the EV solution – from its internal workings and performance, to its interface and impact on the electrical grid, to the business challenges and opportunities that can make or break this solution. This discussion assesses how well the EV solution works, according to the criteria that a prospective consumer/driver or vehicle/service provider would take into account: What are the key emerging vehicle options? What mileage can the consumer get from each? How far can the consumer go before 'recharging'? How is the recharge infrastructure likely to evolve? What are the risks that the consumer or the producer will get stranded with a rapidly obsolete option?

The third and final part of the book shifts the focus back to the initial concern and aims to assess, in Chapter 6, whether, all things considered, the EV is indeed a cost-efficient low-carbon transportation solution. Chapter 7 discusses what an EV implementation strategy might look like by, initially, examining various recently published market forecasts and, ultimately, developing an independent market penetration outlook. It is worth noting that technological transformations are neither linear nor continuous. Rather, historical evidence suggests sudden irreversible bursts. Finally, Chapter 8 evaluates the scope for policy intervention as a way to accelerate and smooth the transition away from ICVs – particularly motivated by potential economic and environmental benefits.

Before diving into the main discussion, it is worth making two points that might be seen as the underlying assumptions for the analysis developed in this book.

As indicated at the start, society is faced with a crisis of paramount proportions for which conventional solutions are inadequate. While the book presents seemingly insurmountable obstacles – most of all, perhaps, when evaluating EV infrastructure deployment – the reader should realize that our situation today is in many ways not unprecedented. Throughout history, society has overcome far more complex problems with only a fraction of the resources that may be needed to shift away from petroleum-dependent private transportation.

In 1858, after the better half of a century living with open sewage and cholera epidemics, the British Parliament commissioned the development of what was to be the first modern sewer system in London. The 22,000km of underground sewer channels, which eliminated London's cholera epidemics, were built in merely two decades and established the basic parameters by which every sewer system would be designed to this day.

London's sewer system is by no means a unique case of large-scale infrastructural or technological development in a short period of time or of one that transformed the lives of its customers. The industrialized world has many other such examples – Germany's Autobahn highway network development during the 1930s; the reconstruction of Europe following the Second World War through the Marshall Plan; NASA's Apollo programme which landed the first man on the moon; the development of the mobile phone industry and infra-

structure, to name but a few. Furthermore, emerging markets have proven equally capable of such achievements. Beyond the obvious present-day case of Chinese development, Brazil's 1956 Plano de Metas aimed to promote '50 years-worth of growth in five years', having established a nationwide highway network, thriving automotive and oil industries, and various other manufacturing and basic industries.

The first point is that society has repeatedly demonstrated its capacity to overcome major technological and infrastructural obstacles in very short periods of time. Indeed, the current EV recharging infrastructure and energy technology obstacles, which will be discussed at length throughout the book, seem to be dwarfed next to previous accomplishments.

This introduction has emphasized the concern over sustainability – on energy security and environmental grounds – as one of the guiding principles to future transportation solutions. Granted, any book on EVs will be motivated to some extent by contemporary concerns over sustainability and how such concerns provide the conditions for an emerging EV market. However, constraining the scope of the discussion to sustainability would be ignoring an important if, for many, superfluous aspect of what drives the automotive market.

For a machine whose sole purpose is transport, the automobile has a mystique like no other product. How cool would James Bond or even Danny Zucco (remember John Travolta in *Grease*?) be if it were not for their rides. Indeed, the automobile is, to a large extent, as much a medium for expressing one's identity as it is a mode of transportation. Or yet, for expressing social status and economic achievement on an individual or family basis.

As such, the second point is that this story is often as much a tale of passion or image as it is a discussion of a sustainability crisis and the potential for transformation. Indeed, the book will pay particular attention to how the driving experience may be affected and how different consumers may react as a result. The author believes the EV provides a solution to modern sustainability concerns in the realm of personal mobility which will not come at the expense of the driving experience. Rather, while they may not know it yet, the EV will soon become a dream come true for current petrol-heads.

Contents

PART III — ELECTRIC VEHICLE ROADMAP

Part I

Private Transport: Seizing the Initiative

1

How Combustion Beat Electric

Many of life's failures are people who did not realize how close they were to success when they gave up.

Thomas Edison

Why is it that internal combustion engine vehicles (ICVs) became such a dominant technology while battery electric vehicles (BEVs), which were invented half a century before, failed to enjoy similar market success? Some of the most valuable lessons that history has to offer may often go unnoticed for some time due to the narrow interpretation of the constraints and opportunities we face at any given point. Perhaps our evaluation of ICVs and BEVs over the past half-century has been skewed, for instance, by a lack of understanding of the impact – on energy resources and the environment – that the 'Western' way of life and patterns of consumption have led to, as well as by an inability to imagine (and pursue) a future outside of prevailing standards.

Despite being an engineer, the author has a soft spot for history and believes that understanding why and how we arrived where we are provides an important basis to understanding what lies ahead. In this context, this book begins with a historical look at personal mobility, exploring how and why the ICV became the cornerstone of a mammoth automobile[1] industry and for the last century has held an impermeable position as the dominant technology in that market. What dimensions were missed and left by the roadside during its impressive expansion? This chapter hopes to show that the changes that started to manifest themselves, in some cases, nearly 50 years ago have gradually accelerated and gained public visibility over recent decades, creating the conditions at the start of the new millennium for a paradigm shift – towards the era of the electric vehicle[2] (EV).

The Rise of the Automobile

Urbanization, economic growth and the automobile

Since the Industrial Revolution, the world has experienced a dramatic change in the way human beings go about their daily lives. From jet planes and subways, to personal computers, cell phones and the internet, to refrigerators and espresso machines, mankind has witnessed a massive wave of technological advance and a corresponding increase in the rate of energy consumption over this period. In particular, the increased level of mobility offered by motorized transportation has revolutionized the spatial demographics of the industrialized world.

Prior to the Industrial Revolution, the size of human settlements was largely restricted to walking and horse-driven distances. However, with the introduction of motorized transport – in particular steam and electric trains and trams – urban boundaries expanded far afield along the corridors formed by public transportation links. The subsequent development of private transportation went a step further, allowing greater flexibility, beyond public transport corridors, for individuals. Urban areas began to expand in all directions, creating urban sprawl – of which the Randstad, the Eastern Corridor linking Boston and Washington, DC, and the São Paulo Metropolitan Area are just three examples (Figure 1.1).

Throughout the 20th century, economic growth in industrialized nations led to an accentuation in private transportation and automobile ownership, greatly accelerating urban sprawl. In turn, sprawl created a demand for access to ever more distant locations, which, as will be discussed, favoured the range advantages of ICVs for private transport. The growth of cities benefited from the mass-market version of the automobile while the automobile industry boomed with the growth of urban peripheries.

In fact, industrial society has become so dependent on the automobile that public transportation, while critically important to the functioning of cities, could be seen perhaps as a niche transportation market. Even in the case of Europe, public transit deteriorated at alarming rates in the closing decades of the 20th century. In England and Wales, for instance, the share of public transit trips dropped from 33 per cent in 1971 to 14 per cent in 1991 (Cervero, 1998). A similar trend can also be observed in the megacities of developing countries such as Buenos Aires (Argentina), Bangkok (Thailand) and Manila (Philippines).

Private transportation, the automobile industry and urbanization became mutually reinforcing symbols of modernity and progress in the 20th century. Indeed, one can hardly imagine a world without ICVs and the gas stations which service them. So how did this particular technology become such an intrinsic component of the modern way of life? Let's look back at the origins of the automobile.

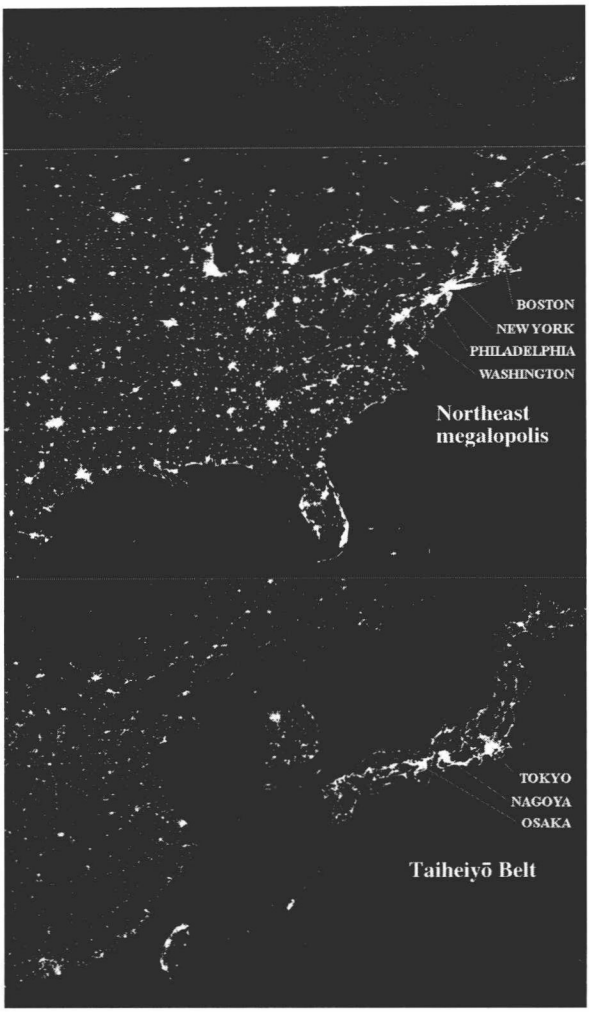

Figure 1.1 *Urban sprawl*

Source: Bill Rankin (2009)

Innovators and early vehicle development

In 1801, Richard Trevithick, a Cornish mine manager, built the first steam-powered carriage (Figure 1.2) – also considered to be the first automobile or motor vehicle – giving way to the era of horseless transport. However, automobiles were not an immediate success. The steam engines that powered them were noisy and dirty and did not offer a significant improvement in performance relative to horse-driven transport.

The next major breakthrough in motor vehicle technology came in 1834, when Thomas Davenport, an American blacksmith and inventor, developed the first direct-current electric motor and used it to power model locomo-