China Automotive Energy Research
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Sustainable Automotive Energy System in China

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of Tsinghua University
Beijing, People's Republic of China

ISBN 978-3-642-36846-2 ISBN 978-3-642-36847-9 (eBook)
DOI 10.1007/978-3-642-36847-9
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013935950

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

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Preface

Energy safety and climate change have become topics of prime interest in current debates about international politics, economy, and the environment. In the ongoing process of modernization, China will continue to face challenges in providing a secure energy supply and in mitigating climate change over the long term. The development of future energy supply and usage in China will have a substantial impact on global energy markets and the local environment as well as implications for global climate change. China is currently one of the fastest growing regions in the global automotive market, and it has become one of the world's largest nations for automobile consumption and production. Automotive energy has therefore become a core energy and environmental issue in the country.

Commissioned by the National Energy Administration, the Ministry of Industry and Information Technology, the Ministry of Science and Technology, and other government departments, Tsinghua University's China Automotive Energy Research Center (CAERC) has studied the sustainable development of the country's automotive energy system. After examining such influences as energy, economy, environment, technology, society, industry leadership, and policy in addition to the life cycle of automotive energy in several technology strategies, CAERC has presented five scenarios for automotive energy development in China. These are the Reference Scenario (RS), the Electric Vehicles Development Scenario (EVDS), the Fuel Cell Vehicles Development Scenario (FCVDS), the Biofuels Development Scenario (BDS), and the Integrated Policy Scenario (IPS). In scenario analyses, CAERC assessed automotive energy demand management, improvement of vehicle fuel economy, and technical specifications of electric vehicles, fuel-cell vehicles, and vehicles powered by second-generation biofuels. CAERC has made policy recommendations and institutional arrangements for promoting sustainable transformation of China's automotive energy system. The aforementioned research efforts and CAERC's results are summarized in this present 13-chapter book.

This research was supported by the National Energy Administration, the Ministry of Industry and Information Technology, the Ministry of Science and Technology, General Motors (China) Company, and Shanghai Automotive Industry Company. Related supporting funds include National Key Basic Research and Development

Program (973) project 2010CB955600, National Science and Technology Support project 2007BAC03A04, a major project of the National Social Science Foundation of China (09&ZD029), projects of the National Natural Science Foundation of China (71041003, 71041028, and 71103109), a major project of the Humanities and Social Science Research Base of the Ministry of Education (2009JJD790029), the International Science and Technology Cooperation Program of the Ministry of Science and Technology (2010DFA72760), and Beijing Excellent Doctoral Dissertation Instructor project (20111000301). Thanks are also given to the Advisory Board of CAERC, especially to Dr. Michael Wang and Prof. Feng Fei.

Steering Committee Chairman Prof. He Jiankun
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Contents

Chapter 1
Introduction

Zhang Xiliang

Abstract In the process of modernization, China will have to face the challenges of ensuring energy security and of mitigating climate change over the long term. China is currently one of the fastest growing regions in the global automotive market and has become the world's largest nation of automobile consumers and producers. Automotive energy has therefore become a core energy and environmental issue for the country. China intends to establish a sustainable automotive energy system. However, there is as of yet no currently recognized standard definition of such a system anywhere in the world. The resource endowment, population and geography, economic and social development levels, infrastructure characteristics of energy and transportation, and technological innovation capability of energy and transportation vary by country. We believe there are six basic standards for estimating the sustainability of China's automotive energy system: the transportation economy, energy efficiency, greenhouse gas emissions, security of energy supply, supply and demand matching of fuel types, and automotive industry leadership.

Keywords Automotive energy • System analysis • China

Energy security and climate change have become major issues for current international economy and environment policy. In the process of modernization, China will have to face the challenges of ensuring energy security and of mitigating climate change over the long term. Future energy development will have a significant effect on global energy markets and on addressing climate change. China is currently one of the fastest growing regions in the global automotive market and

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CAERC, Tsinghua University, *Sustainable Automotive Energy System in China*,
DOI 10.1007/978-3-642-36847-9_1, © Springer-Verlag Berlin Heidelberg 2013

has become the world's largest nation of automobile consumers and producers. Automotive energy has therefore become a core energy and environmental issue for the country.

1.1 Influences of Automotive Energy

There are four categories affecting development of the automotive industry: economic growth, population and geography, technological progress, and public policy.

1.1.1 Economic Growth

The demand for automotive transportation services determines car ownership and consumption of automotive energy in a country. Demand is also determined by macroeconomic characteristics such as total economic scale, economic structure, and industrial structure of the country. Over a certain period, economic scale, automotive transportation service demand, and consumption of automotive energy generally have strong positive correlations. One important example of this strong positive correlation is related to China's reform and opening up. By the middle of this century, China will achieve basic modernization and become a middle-income, developed country. In the future, the economy will remain in a growth stage, and the GDP growth rate will be a major driver of the country's automobile transportation services demand.

1.1.2 Population and Geography

In addition to economic scale and developmental level, the population and geography of a country are key influences on automobile transportation service demand and consumption of automotive energy. Characteristics of said population and geography include its size, demographic composition, land area, urbanization rate, urbanization patterns, and transportation infrastructure. In the United States, there are vast land areas, decentralized urban agglomerations, a highly developed highway network, and a high rate of car ownership at 785 cars per 1,000 people. In Japan, there is a small land area, high population density, dense urbanization, and a car ownership rate of 450 cars per 1,000 people less than America. The rate of car ownership in other countries such as Canada, the United Kingdom, Germany, and France lies between those of the aforementioned two countries. Therefore, population growth rate, population density, urbanization rate, urbanization patterns, and transportation infrastructure will be major drivers of China's demand for automobile transportation services and consumption of automotive energy.

1.1.3 Technological Progress

Future progress of automotive and energy technologies will significantly affect the development of automotive energy. Innovation and promotion of energy-saving technologies will continually improve automotive fuel economy and reduce emission levels of pollutants, including carbon dioxide. Advancement of new vehicle energy technology such as pure battery electric vehicles (BEVs) and fuel cell vehicles (FCVs) will significantly enhance automotive fuel economy and lower pollutant emissions. This will also bring new innovations such as automotive energy conversion and storage technologies, automotive energy infrastructures, and profound changes in the automotive industry itself. In addition, advances in bio-based alternative energy technologies will modify China's automotive energy supply structure. However, future automotive energy technology progress and market penetration rates are very uncertain.

1.1.4 Public Policy

The goal of China's automotive energy development is to establish a sustainable automotive energy system. Because of certain inconsistencies between the country's overall interests and individual interests, the market mechanism fails to internalize externalities and information supply. Establishment of a national sustainable automotive energy system should be supported by public policy. Policy orientation largely determines technical automotive progress. Under the same circumstances and with consideration for macroeconomic, population, and geography factors, different policy orientations will play distinct roles in technological innovation and selection of the technological direction for future automotive energy.

1.2 Sustainable Automotive Energy System

As stated above, China intends to establish a sustainable automotive energy system. However, there is as of yet no currently recognized standard definition of such a system anywhere in the world. The resource endowment, population and geography, economic and social development levels, infrastructure characteristics of energy and transportation, and technological innovation capability of energy and transportation vary by country. Therefore, the explanation, definition, and requirements of a sustainable automotive energy system also vary. China is a vast, developing country with a large population, relative lack of resources, and rapid economic development. Thus, the country's sustainable automotive energy system will have certain characteristics as follows:

1. Automotive traffic economy: social and economic development and the individual demands for automotive transport services should be satisfied by affordable (or as low as possible) cost. The sustainable automotive energy system will help reduce oil imports, which expend substantial foreign exchange reserves and economic resources. Consequently, the transition to a sustainable automotive energy system will significantly benefit the automotive traffic economy.
2. Efficiency of energy system: the future automotive energy system will expend minimum energy resources to satisfy social and economic development and individual demand for automotive transport services. The ideal sustainable automotive energy system should be one that achieves minimum or reduced energy consumption in the well-to-wheel (WTW) life cycle, under the same conditions as the automotive transport services demand.
3. Greenhouse gas emissions: carbon dioxide is the main greenhouse gas (GHG). According to the global CO_2 emission control target scenario, global average CO_2 emissions per capita in 2050 will be just greater than 1 t as presented by the fourth-version IPCC report. Controlling CO_2 emission has been a major impetus within automotive energy technology innovation. Automotive vehicles have become some of the most serious pollution contributors to air deterioration in cities. The ideal sustainable automotive energy system should be one in which CO_2 emissions of the WTW life cycle and motor vehicle pollutants are minimized or reduced, under similar conditions of automotive transport services demand satisfaction.
4. Security of energy supply: China's oil resources are relatively scarce. Its dependence on oil imports reached nearly 55 % in 2010 and will increase in the future. Because more than 95 % of automotive energy comes from petroleum-based fuels, an increase in the need for automotive energy is the main reason for the recent rise in dependence on oil imports. The sustainable automotive energy system should have the ability to respond to the risks of the international energy markets. From this standpoint, the automotive energy supply should be diversified and should reduce dependence on energy imports under feasible economic conditions.
5. Supply and demand matching of fuel type: the sustainable automotive energy system should not only ensure a supply and demand balance of automotive energy in quantity but also reasonably match automotive energy types. This is an attempt to avoid a surplus or deficiency of automotive energy types and ensure scientific use of automotive energy infrastructure in the processes of energy production, transport, and filling.
6. Competitiveness of automotive industry: although China's automotive industry began late and lacked competitiveness in traditional automotive and energy technologies, it has a greater possibility to excel in the area of new energy

vehicles. The country's new energy automotive market will provide the impetus for upgrading and introducing competition into the automotive industry once it reaches a certain scale.

The sustainable automotive energy system is an ideal policy target scenario. We believe there are six basic standards for estimating the sustainability of China's automotive energy system: the transportation economy, energy efficiency, greenhouse gas emissions, security of energy supply, supply and demand matching of fuel types, and automotive industry leadership.

1.3 Contents of This Book

China's automotive energy situations are very complex. They are related to energy, economy, environment, technology, society, industry leadership, and public policy. Systematic, in-depth multidisciplinary and comprehensive studies will provide a solution for the country's automotive energy challenges. Commissioned by the National Energy Administration, Ministry of Industry and Information Technology, Ministry of Science and Technology, and other government departments, Tsinghua University's China Automotive Energy Research Center (CAERC) has studied the sustainable development of the country's automotive energy industry. After studying influences such as energy, economy, environment, technology, society, industry leadership, and policy, plus the life cycle of automotive energy in several technology roadmaps, CAERC put forward five scenarios of automotive energy development in China. These are the Reference Scenario (RS), Electric Vehicles Development Scenario (EVDS), Fuel Cell Vehicles Development Scenario (FCVDS), Biofuels Development Scenario (BDS), and Integrated Policy Scenario (IPS). In scenario analyses, CAERC assessed automotive energy demand management, improvement of vehicle fuel economy, and technical specifications of BEVs, FCVs, and second-generation biofuels. CAERC made policy recommendations and institutional arrangements for promoting sustainable transformation of the national automotive energy system. The aforementioned research works and CAERC achievements are summarized in this 13-chapter book. Chapters 2 through 13 are described as follows.

Chapter **2** Motor Vehicle Development and Air Pollution Control illustrates environmental problems caused by the development of motor vehicles in China, focuses on the relationship between urban motor vehicles and air pollution, analyzes pollution control measures of motor vehicles, and summarizes relevant challenges and future prospects.

Chapter **3** Scenario Analyses of China's Vehicle Ownership and Vehicle Traffic Services focuses on future projections of vehicle ownership and vehicle traffic services; forecast of ownership of private passenger vehicles, public transport vehicles, and other vehicles, through creating predictive models related to population density, household income, and other factors; and also forecast of passenger and freight vehicle traffic services, combined with future projections of annual vehicle mileage and passenger/cargo rates.

Chapter 4 Vehicle Powertrain Technology: systematic assessment of the development status of China's motor vehicle power systems, which includes technologies of high-efficiency and clean vehicle power, hybrid and pure electric drive. Also, there is an introduction to RD&D of these technologies in the country.

Chapter 5 Petroleum-Derived Liquid Fuels: analysis of the country's oil supply chain around petroleum-based vehicle issues, as well as examination of oil production, imports, refining, and consumption. Strategic recommendations are provided for future development.

Chapter 6 Natural Gas: discussion of the future of China's natural gas supply and demand and technology development of natural gas vehicles. Also, there is the discussion of the potential for using natural gas in automotive energy.

Chapter 7 Coal-Derived Liquid Fuels: analysis of the supply chain of coal-based liquid fuel technology; comprehensive and objective assessment of technological developments of coal-based liquid fuel. Basic developmental recommendations are provided.

Chapter 8 Liquid Biofuels: assessment and commentary on various resources and technologies that would affect China's future biofuels. There is multi-scenario analysis of future automotive biofuels (fuel ethanol and biodiesel), combined with future key technological breakthrough points and policies.

Chapter 9 Energy for Electric Vehicles: analysis of electrical system development status and future development scenarios, with respect to development issues of automotive electrical energy. There is the discussion of key effects on electrical system development and assessment of the possible use of electricity as an automotive fossil-fuel alternative. An outlook for feasible directions is also provided.

Chapter 10 Hydrogen and Fuel Cell Vehicle Technology: analysis of China's hydrogen production and utilization, with respect to development issues of hydrogen and fuel cell vehicles. Exploration of sources of future automotive hydrogen, together with technological development of fuel cell vehicles, is also presented.

Chapter 11 Life-Cycle Energy Consumption and Greenhouse Gas Emissions of Automotive Energy Pathways: after introducing models and related parameters of different fuel and power technologies, the life cycle of the multi-fuel/vehicle line is comprehensively compared, based on the same computing platform as China's automotive energy pathways. There is also the forecast of energy consumption and carbon emissions under the life cycle of the key technical path.

Chapter 12 Scenario Analyses of Automotive Energy: five future development scenarios of China's automotive energy are provided, with respect to its sustainable transformation—the Reference Scenario (RS), Electric Vehicles Development Scenario (EVDS), Fuel Cell Vehicles Development Scenario (FCVDS), Biofuels Development Scenario (BDS), and Integrated Policy Scenario (IPS). Analysis and assessment of these five scenarios within the scope of energy, economy, environment, and technology, and industry leadership are also presented.

Chapter 13 Policy Recommendations Regarding Sustainable Development of China's Automotive Energy: quantitative analysis of sustainable transformation of the country's automotive energy system with policy recommendations.

Chapter 2
Motor Vehicle Development and Air Pollution Control

Huo Hong, Yao Zhiliang, and He Kebin

Abstract This chapter first introduces the general ambient environmental issues caused by vehicles in China and then simulates CO, HC, NO_x, and particulate matter (PM) emissions from vehicles in 12 selected typical Chinese cities during 1990–2009. The results show a decreasing trend in CO and HC emissions but an increasing trend in NO_x and PM emissions in the examined cities. Megacities (e.g., Beijing and Shanghai) have stricter emission standards than the national level, so their vehicle emissions decrease faster than those of other cities. Also, the ambient SO_2, NO_2, and PM_{10} concentrations in Beijing, Shanghai, and Guangzhou show a decreasing trend during the past decade. However, in cities where the emission measures are relatively lenient (e.g., Jinan, Ningbo, and Chongqing), the NO_x and PM emissions increased significantly. Therefore, vehicle pollution is no longer a problem that exists only in large cities. Local governments need to pay great attention to the fact that vehicle pollution is rapidly rising in provincial capitals and prefecture-level cities. This chapter finally discusses the measures implemented during recent 10 years to control vehicle emissions in China.

The rapid vehicle growth in China has caused various environmental issues, especially urban air pollution. Fortunately, the national government and local governments have implemented many measures to control vehicle emissions. It is important to emphasize that vehicle emission-control measures must be in accord with vehicle development in order to protect the urban ambient environment.

Keywords Vehicle emissions • Air pollution • Emission standards

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CAERC, Tsinghua University, *Sustainable Automotive Energy System in China*,
DOI 10.1007/978-3-642-36847-9_2, © Springer-Verlag Berlin Heidelberg 2013

2.1 Environmental Problems Caused by Motor Vehicles

With the growth of China's economy and urbanization in addition to the continuous improvement in living standards in the country, the number of motor vehicles has rapidly risen over the past several decades. In 32 years from 1978 to 2010, China's vehicle population increased from 1.36 to 80 million (excluding motorcycles, low-speed trucks, and low-speed electric vehicles). The annual average growth rate was 14 %, though since 2000 this rate has reached 17 %. The rapid increase in the number of vehicles has brought greater convenience and a higher quality of life, but it has also resulted in serious environmental problems.

Owing to the relatively low levels of pollution control for motor vehicles as well as the slow development of infrastructure construction and transportation management in China, individual vehicle emission factors are generally higher than in developed countries. At the same time, because of the high density of urban traffic and population, vehicle emission density and pollutant concentrations are generally high, which are greatly injurious to health.

Toward controlling vehicle pollution, China is rapidly undertaking the production of unleaded gasoline, and it has implemented new vehicle emission standards. However, because China was late in starting vehicle pollution control, automobiles with relatively backward pollution-control mechanisms still account for a certain proportion of the vehicle population, and the average emission level is much higher than in the United States and European countries. Further, construction of the supporting infrastructure and transportation management has failed to keep pace with the rapid growth in the number of vehicles. Insufficient transport structure and composition have led to chronic traffic saturation on the major roads of many big cities. Low average running speeds and the high incidence of idling have aggravated the air pollution in China's cities (Sidebar 2.1).

Sidebar 2.1: Impact of Vehicle Pollutants on Health and the Environment

The main vehicle pollutants are carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$). These pollutants can cause serious harm to human health. CO and HCs result from incomplete combustion. CO can lead to a decrease in oxygen transmission function in the blood. Low concentrations of CO cause headaches, dizziness, and intoxication; high concentrations are lethal. Among HCs, benzene and polycyclic aromatic substances are proven carcinogens. Among NO_x, NO_2, in particular, is highly toxic. It is a red-brown gas with a pungent smell, and it can greatly damage the human respiratory and immune systems at a concentration of 5 ppm. Following inhalation, $PM_{2.5}$ can become deposited in lungs and lead to diseases in the respiratory system. In addition, it can be very harmful through its surface adsorption of many toxic substances. Furthermore, photochemical

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reactions occur between NO_x and HCs, generating low-altitude ozone and photochemical smog. NO_x are a major source of acid rain, which is also very harmful to human health. Black carbon (BC) in vehicle emissions not only causes decreased visibility but also impacts on the climate.

Table 2.1 Annual change of NO_2 concentration in Beijing (μg/m^3)

Year	2006	2007	2009
Central city	69.5	67.5	59.3
Outer city (central city excluded)	63.3	61.8	57
Suburbs	50.4	47	45.3

Note: The central city comprises Dongcheng, Xicheng, Xuanwu, and Chongwen; the outer city comprises Haidian, Chaoyang, Fengtai, and Shijingshan; and the suburbs comprise Fangshan, Daxing, Tongzhou, Mentougou, Changping, Shunyi, Pinggu, Yanqing, Huairou, and Miyun

Table 2.2 Contributions of pollution sources to total emissions in Beijing in 2008 (excluding fugitive emissions, %) (Wang et al. 2010)

Pollution source	NO_x	PM_{10}	HC
Power plants	8	2	5
Building materials	10	45	2
Chemical industry	1	4	1
Smelting	1	14	1
Industrial boilers	14	15	11
Mobile sources	66	20	79

Table 2.1 shows the annual change of NO_2 concentration in Beijing (Beijing Municipality's Bureau of Environmental Protection 2007, 2008, 2010). It is observed that the NO_2 concentrations in the central city were 31–44 % higher than in suburban areas. In the traffic-dense central city, the characteristics of vehicle pollution are very clear.

With increased auto emissions, the contribution of vehicle pollutants to air pollution is currently showing an upward trend in Chinese cities. The contributions of vehicles to total CO and HC emissions are more than 50 % in most cities, and it is even over 90 % in megacities. In population-dense city centers, the proportion of vehicle pollutants among both total emissions and emission concentrations is over 80 %, and this figure is continuously rising. Vehicle emissions have thus become a major source of air pollution in cities (Huo 2005; Guan et al. 2006; Guan and Yu 2007; Jin 2009; Li et al. 2010; Yang et al. 2009). In cities that have experienced a rapid growth in vehicle population, such as Beijing, Shanghai, and Guangzhou, automobiles have become the primary source of air pollution. Vehicle pollution has become the top priority in city air pollution control. Table 2.2 shows the contributions of major pollution sources to the total emissions in Beijing in 2008