Asia Society

AN ASIA SOCIETY SPECIAL REPORT

COORDINATED STRATEGIES

How the U.S. & China Can Work Together to Tackle Air Pollution & Climate Change

AN ASIA SOCIETY SPECIAL REPORT

COORDINATED STRATEGIES

How the U.S. & China Can Work Together to Tackle Air Pollution & Climate Change

SEPTEMBER 2018

REPORT AUTHORS

Fredrich Kahrl, Juan Wei, Samuel Corwin, Eli Wallach

CONTRIBUTING RESEARCHERS

Xinyue Ma, Nathan Park, Jiacheng Shao, Salmana Shah, Yue Zhao

REVIEWERS

Jim Williams, Fan Dai, Ben Guggenheim

© 2018 Asia Society. All Rights Reserved

Asia Society Northern California
500 Washington Street, Suite 350
San Francisco, CA 94111

Asia Society New York
725 Park Avenue
New York, NY 10021

PRODUCED BY

Asia Society

Asia Society is the leading educational organization dedicated to promoting mutual understanding and strengthening partnerships among peoples, leaders, and institutions of Asia and the United States in a global context. Across the fields of arts, business, culture, education, and policy, the Society provides insight, generates ideas, and promotes collaboration to address present challenges and create a shared future.

Founded in 1956 by John D. Rockefeller 3rd, Asia Society is a nonpartisan, nonprofit institution with major centers and public buildings in New York, Hong Kong, and Houston, and offices in Los Angeles, Manila, Mumbai, San Francisco, Seoul, Shanghai, Sydney, Tokyo, Washington, D.C., and Zurich.

SUPPORTED BY

ENERGY FOUNDATION
能源基金会

Energy Foundation China, established in Beijing in 1999, is a grantmaking charity organization dedicated to China's sustainable energy development. It is registered under the Ministry of Civil Affairs as Energy Foundation Beijing Representative office and supervised by the National Development and Reform Commission of China. It is a part of the Energy Foundation, which is based in San Francisco, California, U.S.A.

IN COLLABORATION WITH

Energy+Environmental Economics

With offices in the U.S. and Canada, E3 specializes in North American electricity markets. Founded in 1989, the firm advises utilities, regulators, government agencies, power producers, energy technology companies, and investors on a wide range of critical issues in the electricity and natural gas industries. This broad range of clients across all sectors of the industry is unique among consulting firms of E3's size and speaks to the fact that E3 has earned the respect and trust of clients and stakeholders for the objectivity of the firm's work and its grounding in the realities of the electricity marketplace.

CONTENTS

FOREWORD

COORDINATED STRATEGIES: HOW THE U.S. AND CHINA CAN WORK TOGETHER TO TACKLE AIR POLLUTION AND CLIMATE CHANGE is the third report by Asia Society in a series about U.S.-China Collaboration on clean technology and the issue of climate change. China has the world's largest population, second largest economy, and is the world's leading exporter. Consequently, China, like the United States, is one of the world's largest emitters of greenhouse gases. Poor air quality is a public health issue across both nations. Not only do these shared conditions create a large market for the development of clean technologies, but they also encourage U.S.-China collaboration. The natural synergy between the U.S. and China and the shared responsibility to lead sustainable innovation will push this partnership further toward realization.

As the effects of pollution continue to negatively impact people and the environment, this report seeks to build upon previous undertakings by the Asia Society to promote an increase in U.S.-China cooperation in dealing with this matter. This report aims to locate areas in which the two countries can collaborate, specifically looking at the automobile market and the building heating market. US-China collaboration could solve issues of high relative heating and vehicle costs, inadequate charging infrastructure and electric grids, and overly rigid tariff designs, improving the overall accessibility to clean technologies. Making the application of low-emission technology more convenient would increase its consumption rate, and thereby promote clean technology as the new global norm in transportation and housing. Despite being at different stages of this energy transition, the U.S. and China face similar environmental challenges where, in some cases, the solutions may be the same. Shared policy, technology research, and development efforts, as well as open markets, could allow both countries to better confront the problems at hand.

In both China and the U.S., considerable efforts are being made to reduce environmental pollution and counter climate change. In China, the majority of research, development, and promotion of clean technologies that address air quality is headed by the central government, whereas in the U.S., many of these responsibilities have recently fallen to the states, of which California has been the most outspoken. Efforts to revamp the current energy system include finding new, cleaner ways to obtain, store and use energy.

Additionally, after the technology has been developed, there is still the task of getting the product to market. Even in the looming shadow of a trade war, it remains important for companies from both countries to continue to compete and work in each respective market. The presence of competition between companies from both countries and the accessibility of their products from both sides of the globe will help expedite progress toward a cleaner future. This report demonstrates ways in which U.S. companies have successfully entered the Chinese marketplace and vice versa. Drawing upon the lessons learned from the successes and failures of various companies, we believe that more companies can reach a similar level of international prominence.

Zero-emission technologies, which are sustainable and have the potential to be very inexpensive, are the inevitable future. We hope that this report will provide some new ideas and suggest new opportunities for greater cooperation between the U.S. and China in this field.

Juan Wei
Senior Program Manager, Sustainability
Asia Society Northern California

LIST OF FIGURES AND TABLES

LIST OF FIGURES AND TABLES FOR CASE STUDIES (APPENDIX)

LIST OF ABBREVIATIONS

ARB Air Resources Board

ARFVTP Alternative and Renewable Fuel and Vehicle Technology Program

BEV Battery Electric Vehicles

CARB California Air Resource Board

CATARC China Automotive Technology and Research Center

CEC California Energy Commission

CERC Clean Energy Research Center

CSD California Department of Community Services and Development

CMP Carl Moyer Program

CO Carbon Monoxide

CO_2 Carbon Dioxide

CPUC California Public Utilities Commission

CVRP Clean Vehicle Rebate Program

DHS District Heating Systems

DRPP Diesel Risk Reduction Plan

EPA Environmental Protection Agency

EV Electric Vehicle

FCEV Hydrogen Fuel Cell Vehicle

FCV Fuel Cell Electric Vehicle

GHG Greenhouse Gas

GW Gigawatts

HC Hydrocarbon

HDV Heavy Duty Vehicles

HERS Home Energy Rating System Program

IARC International Agency for Research on Cancer

ICE Internal Combustion Engine

INDC Intended Nationally Determined Contribution

JV Joint Venture

kWh kilowatt/hour

LA DOT Los Angeles Department of Transportation

LCTP The Low Carbon Transportation Program

LNG Liquified Natural Gas

MEE Ministry of Ecology and Environment

MEP Ministry of Environmental Protection

MIIT Ministry of Industry and Information

MMT Million Metric Tons

MoF Ministry of Finance

MoHURD Ministry of Housing and Urban-Rural Development

MOST Ministry of Science and Technology

MY Model Year

NEB National Energy Bureau

NEV New Energy Vehicle Program

NRDC National Development and Reform Commission

NO_X Oxides of Nitrogen

NZEV Natural Gas near-zero-emission vehicle

OBD on-board diagnostic

PHEV Plug-in Hybrid Vehicle

PM Particulate Matter

$PM_{2.5}$ particulate matter of diameter 2.5 millimeters or smaller

SCAB South Coast Air Basin

SO_2 Sulfur Dioxide

TOU Time-Of-Use

TZEV Transitional Zero Emission Vehicle

UCCTC US-China Cleantech Center

VC Venture Capital

VOCs Volatile Organic Chemicals

WHO World Health Organization

WRI World Resources Institute

YLV Yellow Label Vehicle

ZEV Zero Emission Vehicle Program

ZNE Zero Net Energy

EXECUTIVE SUMMARY

REDUCING THE RISKS OF CLIMATE CHANGE WILL REQUIRE TRANSFORMING how human societies obtain, store, and use energy. The U.S. and China have a critical role to play in leading this transformation, as the world's largest energy users and emitters of greenhouse gases (GHGs).[1]

The transition to cleaner energy systems in the U.S. and China can be enhanced and accelerated through cooperation and coordination between the two countries. By coordinating policy direction and opening markets, the U.S. and China can lower the costs and advance the deployment of next-generation, zero-emission energy technologies faster than either country could on its own. Together, the U.S. and China account for nearly 40% of total global energy use, have nearly $10 trillion of annual investment capital, and spend tens of billions of dollars on energy-related research and development.[2]

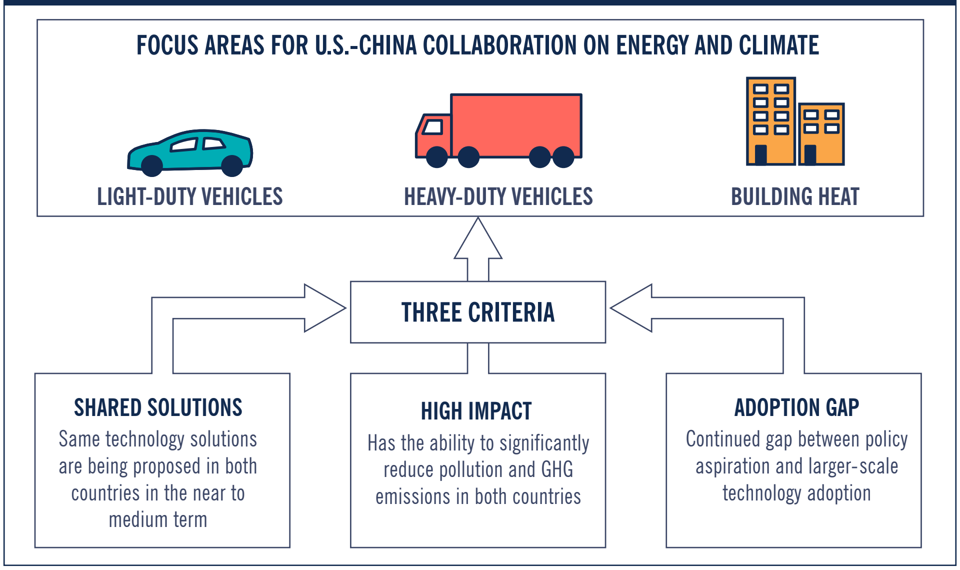
Zero-emission energy technologies will also enable significant reductions in air pollution and improvements in public health across both the U.S. and China, in cities like Beijing, Los Angeles, Houston, Pittsburgh, Tianjin, and Wuhan. In some regions, such as Northern China's Jing-Jin-Ji region and the Los Angeles Basin, meeting stringent air quality standards will likely not be feasible without large-scale adoption of zero-emission vehicles and buildings.

Effective cooperation and coordination require a common, focused vision. To contribute toward that vision, this report identifies three technology areas where near-term collaboration could have a transformative long-term impact: light-duty vehicles, heavy-duty vehicles, and space and water heating in buildings (Figure 1). Each area meets three criteria: (1) proposed solutions in the U.S. and China have focused on the same or similar technologies (shared solutions); (2) technological change in that area is pivotal to meeting climate goals and air quality standards in both the U.S. and China (high impact); and (3) there is a continued gap between policy vision and the pace of technology adoption (adoption gap).

[1] For energy use estimates, see IEA (2017a); for GHG emissions estimates, see the Climate Watch website, available at www.climatewatchdata.org/.

[2] For final energy consumption estimates, see IEA (2017a). Annual investment capital is based on annual investment in reported national income accounts, from the Bureau of Economic Analysis (U.S.) and National Bureau of Statistics (China). Energy-related R&D spending is a conservative estimate, based on IEA (2017b) and PwC (2018).

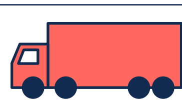
FIGURE 1. FOCUS AREAS FOR U.S.-CHINA ENERGY AND CLIMATE COLLABORATION, BASED ON THREE CRITERIA



Although government policies have already begun to drive adoption of zero-emission vehicles and buildings, there is still a large gap between current levels of adoption and the levels needed to make meaningful reductions in GHG emissions and improvements in air quality over the next decade. For instance, together the U.S. and China now have more than 1 million electric cars on the road, but electric cars still account for less than 2% of car sales in both countries.[3]

Long-term plans and goals in both countries imply a significant scale-up of zero-emission vehicles and buildings by 2030 (Figure 2). However, scaling-up adoption to these levels will require addressing a chicken-and-egg problem: higher costs and lower convenience of new technologies limit demand for them, but higher costs and lower convenience are partly the result of small manufacturing scale, underdeveloped supply chains, and lack of supporting infrastructure, which in turn are limited by a lack of demand.

FIGURE 2. FOCUS AREAS FOR U.S.-CHINA ENERGY AND CLIMATE COLLABORATION, BASED ON THREE CRITERIA

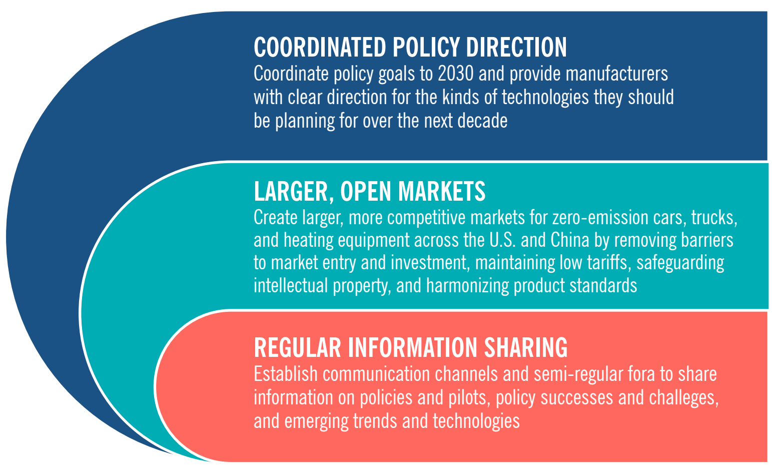
	**LIGHT-DUTY VEHICLES** existing goals imply more than one hundred million zero-emission vehicles on the road in the U.S. and China by 2030
	**HEAVY-DUTY VEHICLES** long-term plans imply hundreds of thousands of fuel cell and electric trucks on the road in the U.S. and China by 2030
	**BUILDING HEATING** exisiting goals and long-term plans imply hundreds of thousands of new all-electric buildings in the U.S. and China by 2030

[3] IEA (2017c).

National and local policy will be critical for bridging these adoption gaps. However, focused collaboration between the U.S. and China could also play a pivotal role in accelerating adoption of zero-emission vehicle and building technologies.

This collaboration would include three components: (1) *coordinated policy direction*, whereby governments in both countries jointly commit to medium- to long-term goals for zero-emission vehicle and building technologies, to provide clear signals to manufacturers and financial institutions; (2) *larger, open markets*, where the U.S. and China seek to create a large, common market for zero-emission vehicle and building technologies and their supply chains, through reciprocal efforts on trade tariffs, standards harmonization, protection of intellectual property rights, and regulations governing investment and market entry; (3) *regular information sharing*, whereby government agencies establish semi-regular fora for exchanging information on supporting policies and pilots, policy successes and challenges, and emerging trends and technologies (Figure 3).

FIGURE 3. THREE COMPONENTS OF MORE FOCUSED U.S.-CHINA COLLABORATION



This approach to collaboration would mark important shifts in U.S.-China cooperation on energy and climate. It would focus on a core set of technologies that have significant environmental leverage, rather than a more comprehensive strategy that results in significant breadth but little depth. It would shift cooperative activities from a focus on investments in joint research and innovation centers to negotiated, reciprocal activities around trade and commerce.

U.S.-China collaboration focused on vehicles and buildings could be globally transformative, enabling cleaner air and lower GHG emissions in both countries but also buying down the cost of zero-emissions technologies for lower-income countries. For industry, the scale of markets for zero-emission passenger cars, heavy-duty vehicles, and building heating technologies in the U.S. and China could be on the order of trillions of dollars by 2030.

INTRODUCTION

THIS REPORT IDENTIFIES AND EXPLORES THREE AREAS — light-duty vehicles, heavy-duty vehicles, and space and water heating in buildings — where U.S.-China collaboration on developing and commercializing new technologies could substantially accelerate progress in reducing GHG emissions and improving air quality in both countries over the next decade.

Through U.S. and China case studies, the report examines why these three areas are important leverage points for addressing environmental challenges, what nearer- to medium-term visions exist for the adoption of low- and zero-emission technologies in each area, what policy measures are currently in place to support adoption, and what barriers are currently impeding adoption.

The report argues that larger, more open markets and expanded investment and research and development (R&D) activities between the U.S. and China can spur commercialization of new vehicle and building technologies. To better understand the opportunities and challenges for deepening commercial collaboration, a second set of case studies examines experiences with market access, cross-border finance and investment, and existing joint R&D activities between the two countries.

The main body of the report is organized around three sections:

- **Background** provides overall context for the report;
- **Case Study Synthesis** provides a synthesis of themes from the case studies, organized around the three technology areas with a separate discussion of issues related to commercial collaboration;
- **Conclusions** distill themes from the case study synthesis into key conclusions.

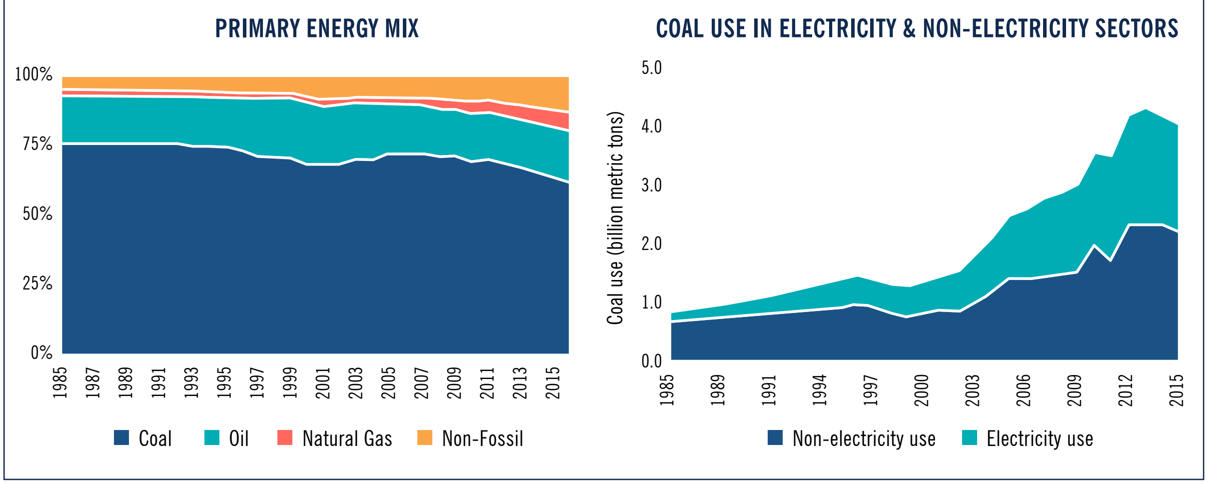
The following case studies are provided in an appendix to the report:

- **U.S. Case Studies**, which examine California's zero-emission vehicle program, initiatives to promote alternative fuel heavy-duty vehicles in California, and efforts to support low-carbon building technologies in California;
- **China Case Studies**, which examine China's new energy vehicle policies, policy efforts to encourage low-emission heavy-duty vehicles, and policy support for lower emissions buildings;
- **Cooperation Case Studies**, which explore cases where U.S. and Chinese companies have entered into one another's markets, cases of cross-border investment and finance, and existing joint R&D activities.

BACKGROUND

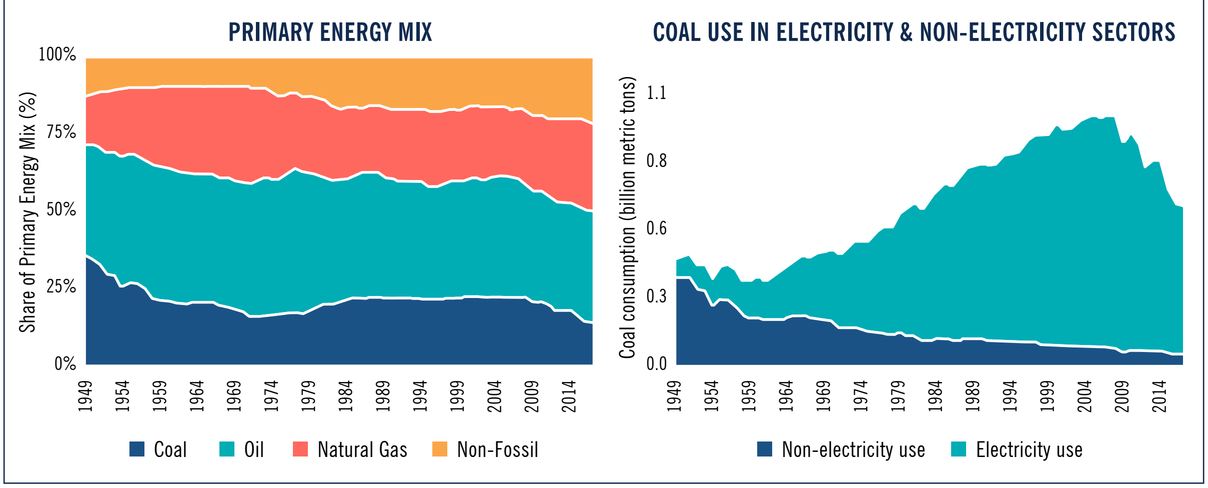
The U.S. and China are at different stages of a long-term transition to cleaner energy systems. In China, solid fuels — primarily coal — continue to be a large share of the country's primary energy mix. In addition to its use as a source of electricity, coal is widely used in industry and as a source of heating for residential and commercial buildings (Figure 4). By contrast, in the U.S. coal had become a smaller part of the U.S. energy mix by the early 1960s, and its use became increasingly concentrated in the electricity sector over the latter part of the twentieth century; by the 2000s more than 90% of coal consumed in the U.S. was used to generate electricity (Figure 5).

FIGURE 4. CHINA'S PRIMARY ENERGY MIX AND COAL USE IN THE ELECTRICITY & NON-ELECTRICITY SECTORS, 1985–2016



Source: Data are from China's National Bureau of Statistics (NBS), available at http://data.stats.gov.cn. Energy data before 1990 and coal use data before 1995 were interpolated based on annual average growth rates.

FIGURE 5. U.S. PRIMARY ENERGY MIX AND COAL USE IN THE ELECTRICITY & NON-ELECTRICITY SECTORS, 1949–2016



Source: Data are from the U.S. Energy Information Administration's (EIA's) *Monthly Energy Review*, www.eia.gov/totalenergy/data/monthly/. U.S. and China primary energy mixes may not be strictly comparable due to methodological differences.

Despite being at different stages of this energy transition, the U.S. and China face common environmental challenges where, in some cases, the solutions may be shared. For instance, in both countries the transportation sector is a leading contributor to poor air quality and a major source of GHG emissions. Both countries currently have similar proposed solutions to reducing transportation sector emissions — electrifying cars, tightening emissions standards for heavy-duty vehicles, and increasing the share of alternative fuel heavy-duty vehicles.[4]

In the near term, there are three main areas where

- These shared solutions exist;
- Larger-scale technology adoption could have a transformative impact on air quality and GHG emissions in both countries;
- Progress in transitioning to low- to zero-emission technologies has lagged potential; and
- Coordinating policy direction and creating larger markets between the U.S. and China could enable manufacturing scale to drive down costs and promote larger-scale technology adoption.

These three areas include light-duty vehicles, heavy-duty vehicles, and space and water heating in buildings. All three involve "end-use" technologies that consume rather than supply energy.

Long-term deep decarbonization studies have identified technology options for each area that are consistent with deep reductions in GHG and air pollution emissions (Table 1).[5] For many of these technologies — from electric vehicles (EVs) to electric heat pumps — these technology options are powered by electricity.

TABLE 1. KEY ZERO-EMISSION TECHNOLOGIES FOR PASSENGER CARS, HEAVY-DUTY VEHICLES, AND BUILDING HEATING

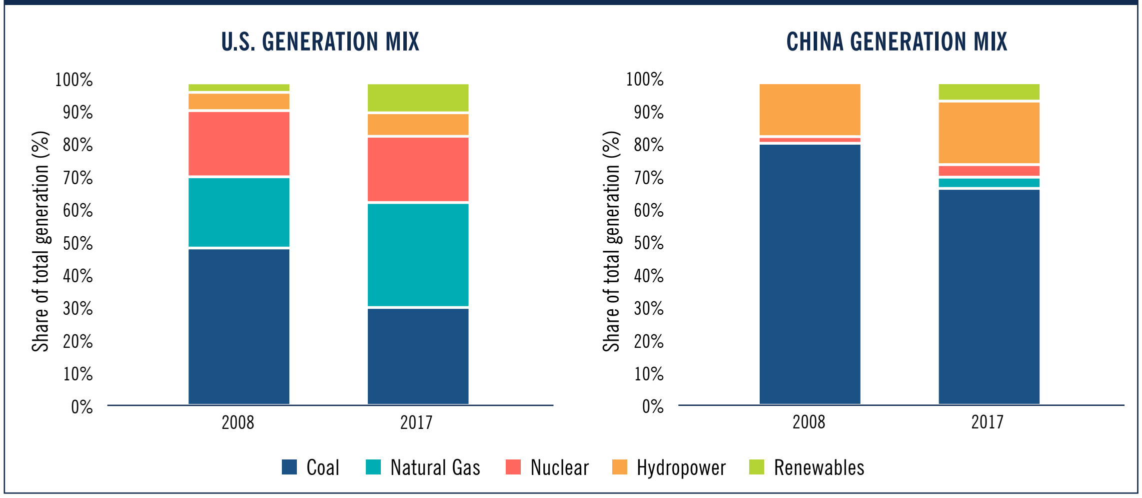
AREA	KEY TECHNOLOGIES
Light-duty vehicles	Electric vehicles, fuel cell vehicles
Heavy-duty vehicles	Fuel cell vehicles, electric vehicles
Building heating	Electric heat pumps

If powering zero-emissions vehicles and buildings with electricity is to reduce overall GHG emissions and air pollution, electricity must itself be generated from zero- or low-emission sources of energy. In both the U.S. and China, this transition to cleaner electricity has already begun. The share of renewable energy, large-scale hydropower, and nuclear power in the generation mix of both countries increased by nearly 10 percentage points over the past decade (Figure 6).

[4] See the U.S. and China Case Study sections for further detail on transportation sector emissions and proposed solutions.

[5] See, for instance, the results of the Deep Decarbonization Pathways Project, http://deepdecarbonization.org/.

FIGURE 6. U.S. AND CHINA ELECTRICITY GENERATION MIXES, 2008 AND 2017



Source: U.S. data are from the Energy Information Administration (EIA). China data are from the China Electricity Council.

A key driver of this change has been significant declines in the cost of solar and wind energy. In the U.S., the cost of solar photovoltaics (PV) fell by more than fourfold over the late 2000s and early 2010s, and new solar PV generation is increasingly cost-competitive with new natural gas-fired generation.[6] Wind energy is often now the cheapest source of electricity in the Midwestern U.S.[7] These cost declines were facilitated by the emergence of a mature, competitive, renewable energy industry, with sophisticated global supply chains and R&D capabilities, which could produce on a larger scale. Deepening business ties between the U.S. and China has been instrumental in the evolution of this industry.

By contrast, manufacturing scale for electric and fuel cell vehicles and heat pumps remains limited, due to relatively low levels of demand. Lower demand is the result of high relative costs and lack of supporting infrastructure. For instance, key barriers to EVs have been high battery and vehicle costs, overly rigid tariff designs for EV charging, and lack of adequate charging infrastructure.

By creating a larger source of demand through coordinated policy direction and a common market, the U.S. and China can drive reductions in costs and large-scale adoption of these next-generation, zero-emitting technologies. Doing so will entail more focused collaboration oriented around policy, trade, and commerce.

The remainder of this report explores opportunities for U.S.-China collaboration in each of the three areas, and more broadly how U.S.-China commercial collaboration around clean energy technologies can continue to evolve in an era of turbulent diplomatic relations.

[6] Bolinger et al. (2017).

[7] Wiser and Bolinger (2017).

CASE STUDY SYNTHESIS

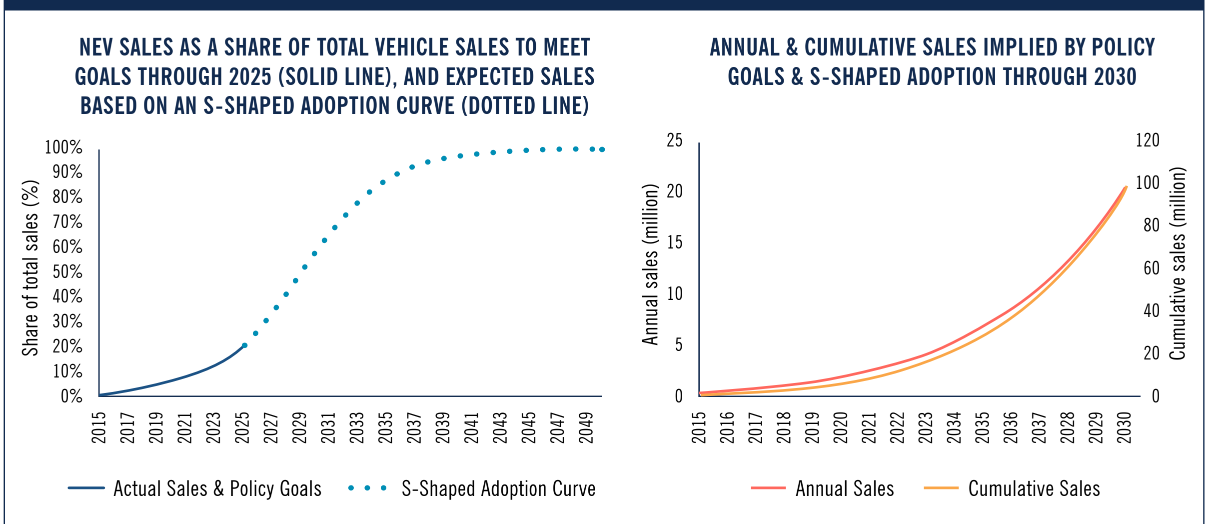
Light-Duty Vehicles

Stricter emission and fuel efficiency standards have significantly reduced the air quality impacts and GHG emissions of light-duty vehicles in both the U.S. and China. However, light-duty vehicles remain a key contributor to poor air quality in cities like Los Angeles and Beijing, as well as a major source of GHG emissions in both countries. In California, for instance, cars are the largest source of GHG emissions.

Motivated by air quality and climate change concerns, governments in the U.S. and China have articulated a long-term vision for transitioning to zero-emission passenger cars and light-duty trucks by mid-century.

In China, this is a national vision: China's Ministry of Industry and Information Technology (MIIT) is studying a ban on new fossil fuel vehicle sales for the entire country sometime before mid-century. MIIT has set annual sales targets of 2 million new energy vehicles (NEVs) — mainly EVs — by 2020 and 7 million by 2025, translating into roughly 30 million in cumulative EV sales by 2025.[8] Following an s-shaped adoption curve where NEV sales reach 100% of total light-duty vehicle sales by the early 2040s, this trajectory implies that annual NEVs will account for 50% of total vehicle sales, or around 20 million NEVs annually, in the early 2030s (Figure 7).[9] Annual sales of 20 million NEVs by 2030 imply nearly 100 million in cumulative NEV sales by 2030.

FIGURE 7. ACTUAL AND PROJECTED NEV SALES TO 2040 AND IMPLIED ANNUAL AND CUMULATIVE SALES TO 2030



[8] China's targets for NEVs are in terms of annual sales shares (a flow) rather than number of vehicles on the road (a stock). The stock of total vehicles is the sum of annual sales, adjusted for retirements. Assuming linear growth rates between 2017–2020 and 2020–2025 and that all sales targets are met, China will have reached 28.6 million in cumulative NEV sales by 2025. MIIT's target for 2025 includes exports and thus some of these vehicles will be "on the road" in other countries.

[9] This estimate assumes, conservatively, that the total annual vehicle sales in China remain flat (constant) at 35 million per year between 2025 and 2030.

In the U.S., the vision for a transition to zero-emission vehicles is driven by states. For instance, meeting California's 2050 GHG emission reduction goals will require that between 2040 and 2050, zero-emission vehicle (ZEV) sales account for all new car sales.[10] California's memorandum of understanding (MOU) with nine other U.S. states targets a total of 3.3 million ZEVs on the road by 2025,[11] and California has set a goal of 5 million ZEVs on the road by 2030. If the nine MOU partner states follow California's lead, at least 11 million ZEVs would be on the road in the U.S. by 2030.[12]

Between the U.S. and China, existing goals imply that cumulative sales of low-emission and zero-emission light-duty vehicles[13] could be on the order of 30 million total vehicles (7 million in annual sales) by 2025 and 110 million by 2030 (25 million in annual sales), with China driving most of the growth in vehicle sales. The total value of this market would be on the order of $500 billion ($100 billion annually) by 2025 and $1.5 trillion ($400 billion annually) by 2030.[14]

The large gap in policy ambition between the U.S. and China is an artifact of the difference between state and national goals. Spread across its 33 provincial-level regions, the level of ambition in China's national NEV goals is consistent with that in California.[15] In California, ZEVs are also anticipated to reach more than 50% of total vehicle sales by 2030 to meet state policy goals.[16]

Neither China's NEV nor California's ZEV policy targets are guaranteed. Both face similar obstacles: high relative vehicle costs, inadequate charging infrastructure, and overly rigid electricity tariff designs. Charging infrastructure and tariff solutions will vary between countries, due to different driving and parking patterns and differences in electricity sectors. The main area for U.S.-China collaboration is in reducing vehicle costs.

China's and California's zero-emission vehicle goals are supported by similar programs — in China NEV mandates and in California the ZEV program. In both, the challenge is how to bridge the near-term adoption gap, where manufacturers are reluctant to make significant investments in new vehicle lines for fear that demand may not materialize due to high costs. If demand does not materialize, auto manufacturers face losses both on vehicles they cannot sell and on their sunk investments in manufacturing facilities and R&D. In the context of an individual state or province, such as California, zero-emission vehicle policies create significant risks for auto manufacturers.

The certainty of larger markets, however, can dilute that risk. The U.S. and China can help support larger markets for zero-emission light-duty vehicles through coordinated actions, including the following (Figure 8):

---

[10] California lawmakers have also introduced a bill (AB 1745) that would require all vehicles sold as of January 1, 2018, to be ZEVs.

[11] For more detail, see Multi-State ZEV Task Force website, available at www.zevstates.us/.

[12] This estimate assumes that California's share of the 2025 ZEV MOU goal (45%) remains the same in 2030.

[13] China's goals for "new energy vehicles" include low-emission plug-in hybrid electric vehicles. However, policies and incentives are driving the market to zero-emission vehicles and this report assumes that by 2030 all new energy vehicles are zero-emission vehicles.

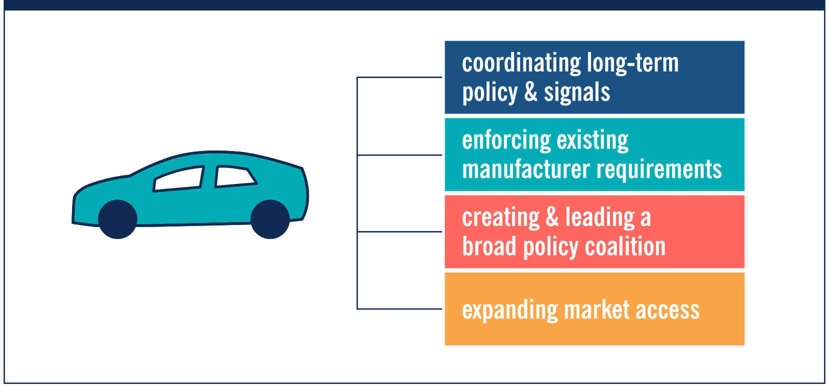
[14] This estimate conservatively assumes an average cost of USD 15,000 per vehicle, in line with an average between potential costs in the U.S. and China.

[15] China's targets equate to roughly 1 million NEVs per province, whereas California is targeting 1.5 million vehicles, by 2025. California has a smaller population but higher car ownership than most Chinese provinces.

[16] See, for instance, E3 (2015).

- Coordinated signaling to manufacturers, distributors, ride-sharing companies, and consumers that zero-emission vehicles are the future of passenger car travel. Both China and California have longer-term goals for zero-emission vehicles supported by nearer-term regulations, but a joint policy statement between China and key U.S. states with loosely coordinated timelines would provide an important sense of direction for both the auto and mobility industries.
- Enforcing existing rules for zero-emission vehicle programs and ensuring mandates become increasing stringent over time. In the U.S., these programs will likely continue to be driven by states, whereas in China they will be national.
- Expanding the scope of partnerships for zero-emission vehicles. In the U.S., this implies leadership by California and other states that have signed the ZEV MOU to engage additional states to join the MOU and create ZEV programs, as well as leadership by California to extend the ZEV MOU targets to 2030. For China, and perhaps later the U.S., this implies creating a coalition of countries that are pursuing long-term goals for zero-emission vehicles, such as India, France, Norway, and the United Kingdom.
- Expanding market access in both countries, as discussed in *Commercial Collaboration* later in this section.

FIGURE 8. COORDINATED ACTIONS THE U.S. AND CHINA CAN TAKE TO SUPPORT LARGER AND MORE STABLE MARKETS FOR ZERO-EMISSION LIGHT-DUTY VEHICLES



Together, these four actions provide a supporting policy edifice that can encourage manufacturer innovation and investment by creating long-term business models, reducing costs and expanding choice through competition, and ultimately increasing adoption.

Heavy-Duty Vehicles

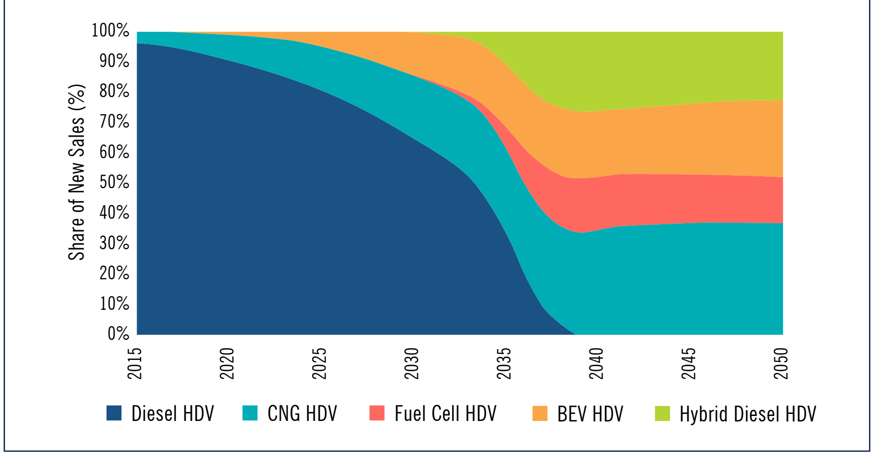
With other pollution sources subject to stricter emission limits, heavy-duty vehicles — and freight trucks in particular — have emerged as a key contributor to $PM_{2.5}$ and ozone pollution in both the U.S. and China. Heavy-duty vehicles are a smaller source of GHG emissions, but one that is critical to address to meet long-term goals for GHG emission reductions.

In both countries, most of the emphasis on controlling pollution from heavy-duty vehicles has been on reducing tailpipe emissions from diesel trucks rather than encouraging a shift from diesel to alternative energy sources. As the California case study describes, however, alternative energy sources and new vehicle technologies will be necessary to meet increasingly strict nitrogen oxide (NO_X) and particulate matter (PM) emission standards and GHG goals.

Next-generation zero-emission vehicle technologies and infrastructure for heavy-duty vehicles are generally at an earlier stage of development and deployment than for light-duty vehicles. Thus far, adoption of zero-emission trucks has largely been limited to short-haul applications in areas with poor local air quality, such as around ports.

Neither China's national government nor U.S. states have set targets for zero-emission heavy-duty vehicles, as they have for light-duty vehicles. For California, studies of pathways to meet the state's 2030 and 2050 GHG reduction goals suggest that some adoption of alternative fuel heavy-duty vehicles by 2030 is consistent with long-term goals. For instance, Figure 9 shows projected new heavy-duty vehicle sales in a "base case" scenario that achieves the state's long-term climate goals, based on a 2018 study for the California Energy Commission. In this scenario, electric trucks account for around 15% of total heavy-duty vehicle sales, with tens of thousands of electric trucks on the road by 2030.

FIGURE 9. SCENARIOS FOR LOW- AND ZERO-EMISSION HEAVY-DUTY VEHICLES ON THE ROAD IN CALIFORNIA BY 2025 AND 2030



Source: E3 (2018)

Analysts project that the global market for electric drive trucks could rise to several hundred thousand by the mid- to late 2020s.[17] A reasonable estimate of the potential number of zero-emission heavy-duty vehicles on the road in the U.S. and China by 2030 might be in the hundreds of thousands, with a total market value in the tens of billions of dollars.[18]

[17] For instance, Navigant projects that the global market for electric drive trucks will reach 332,000 by 2026. See Navigant. 2017. "Global Annual Sales of Electric Trucks Are Expected to Reach 332,000 by 2026." Available at www.navigantresearch.com/newsroom/global-annual-sales-of-electric-trucks-are-expected-to-reach-332000-by-2026. McKinsey & Company (2017) projects that battery electric medium-duty and heavy-duty trucks could reach around 20% and 2%, respectively, of total vehicle stocks by 2030, equating to hundreds of thousands of vehicles in both countries. See McKinsey & Company. 2017. "What's Sparking Electric-Vehicle Adoption in the Truck Industry?" Available at www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry.

[18] This estimate assumes an average cost per heavy-duty vehicle of USD 100,000 per vehicle.

High costs relative to traditional diesel vehicles and lack of supporting infrastructure suggest that the market for zero-emission heavy-duty vehicles is likely to continue to be segmented by application over the next decade, with adoption focused on shorter-distance vehicles in environmentally sensitive areas, such as short-haul trucks near ports and buses and municipal fleets in cities, and then more gradually expanding to long-distance trucking and construction vehicles. Reductions in battery and fuel cell costs and more rapid deployment of electric charging and hydrogen infrastructure could accelerate adoption.

Zero-emission heavy-duty vehicles face many of the same barriers as zero-emission light-duty vehicles,[19] but the policy strategies for addressing these barriers are likely to be different. Whereas strategies to encourage zero-emission light-duty vehicles will likely continue to focus on fleet-wide requirements on manufacturers at the national or state level, nearer-term strategies to encourage zero-emission heavy-duty vehicles will likely be targeted more by location and function.

For shorter-distance vehicles, these strategies could include municipal procurement of buses, waste management trucks, street sweepers, sewer-cleaning trucks, maintenance trucks, and other municipally owned vehicles, or contracts with service providers that require the use of zero-emission vehicles; as well as efforts by port operators, cities, and state regulators to reduce emissions around ports. For longer-distance freight trucks and construction vehicles, strategies could include voluntary corporate procurement and financial incentives for manufacturers and fleet owners.

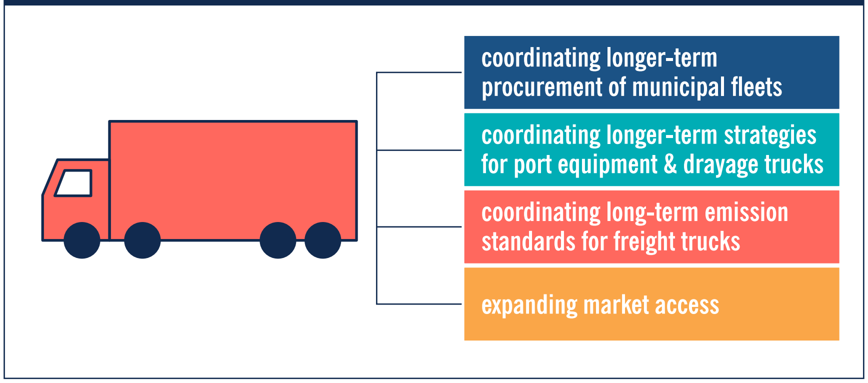
If concentrated in a few cities or states and provinces, markets for zero-emission heavy-duty vehicles are likely to remain relatively small and costs are likely to remain high. Manufacturers face significant risks to scaling production. Cities and fleet owners are likely concerned about the cost of zero-emission vehicles.

As with light-duty vehicles, coordination among cities, states, and provinces in the U.S. and China can create larger markets for zero-emission heavy-duty vehicles and drive down costs through coordinated action, including the following (Figure 10):

- Among cities, coordinating long-term targets and procurement plans for municipal trucks. An example of this kind of coordination might include joint statements and targets for zero-emission municipal trucks among groups of cities, based on long-term procurement plans.
- Among port operators and states and provinces, coordinating long-term plans for procuring port equipment and setting emissions regulations for drayage (short-haul) trucks.
- Among governments, coordinating longer-term emission standards and policies for long-distance freight trucks and construction equipment. Coordination could include harmonizing standards over time and regularly sharing information on incentive programs and pilots.
- Among governments and port operators, expanding access to markets for zero-emission heavy-duty vehicles. For municipal procurement, market access can be expanded through open, competitive procurement processes that allow participation and encourage partnerships by U.S. and Chinese companies. For private fleet operators and infrastructure investment, market access is governed by national trade and investment policy, discussed in *Commercial Collaboration* later in this section.

[19] For a more detailed discussion of adoption barriers for zero-emission heavy-duty vehicles, see ICCT (2018).

FIGURE 10. COORDINATED ACTIONS THE U.S. AND CHINA CAN TAKE TO SUPPORT LARGER AND MORE STABLE MARKETS FOR ZERO-EMISSION HEAVY-DUTY VEHICLES



Building Heating

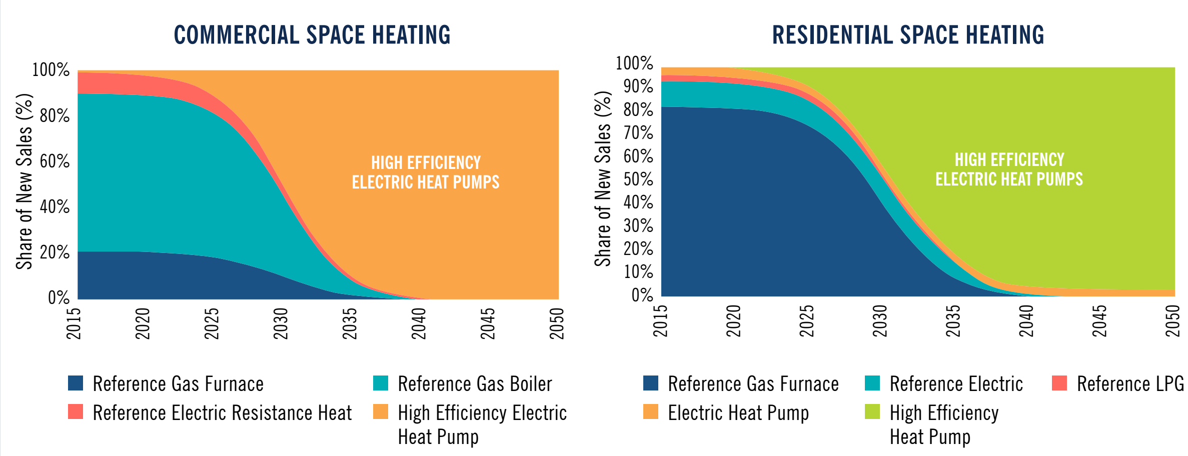
The U.S. and China face different environmental concerns related to space and water heating in buildings. Space heating in Northern China is mostly coal based and is a significant contributor to poor local air quality in the winter. To address air quality concerns, China's central government mandated a rapid, large-scale shift to greater use of natural gas for heating in late 2017, which had the unanticipated effect of leaving some residences and schools without heat and driving up regional natural gas prices in Asia. In response to concerns over natural gas supplies, China's central government and provincial governments are exploring alternatives, including electric heating.

In the U.S., most space and water heating in buildings has been fueled by natural gas since the 1950s, with smaller amounts of electric heating in areas with rich and inexpensive hydropower resources and oil heating in parts of the Northeast. As a result, heating in buildings is generally less of an air quality concern in most of the U.S. However, in states like California and New York, reducing natural gas use in buildings is a critical part of plans to meet 2030 and 2050 GHG reduction goals. Building electrification is currently anticipated to be the main strategy for doing so.

Current plans in China and California suggest a dramatic increase in electrified buildings over the next decade. In China, current plans aim for 5% of all heated floor area to be provided with electricity by the early 2020s. In California, current GHG targets imply that high-efficiency electric heat pumps would account for more than 50% of all commercial and residential space heating equipment sold in the state by 2030 (Figure 11). These goals are consistent with a future in which the U.S. and China have tens to hundreds of thousands of new all-electric buildings and a market for electric heating equipment in the hundreds of millions of dollars annually by 2030.[20]

[20] Finding common metrics for housing between the U.S. and China is difficult, because of differences in floor area units (square meters [m^2] versus square feet) and buildings (apartments versus houses). This estimate assumes that China adds 250 million square meters of electrified floor area annually in 2030, with an average building area of 15,000 m^2 per building, and California adds 100 million square feet (~9 m^2) of electrified floor area annually in 2030, with an average building area of 2,500 square feet per building. It assumes a cost for electric heating of $1 per square foot ($10.76/m^2).

FIGURE 11. SALES OF COMMERCIAL AND RESIDENTIAL SPACE-HEATING TECHNOLOGIES IN CALIFORNIA TO MEET THE STATE'S 2030 AND 2050 GHG TARGETS



Source: E3 (2018).

Despite different starting points, China and the U.S. are beginning to converge on building electrification as a shared solution for addressing emissions from heating in residential and commercial buildings. The most promising technology for electrifying buildings is high-efficiency heat pumps. Heat pumps are not a new technology, but their use has historically been limited to areas without access to natural gas or where electricity is inexpensive.

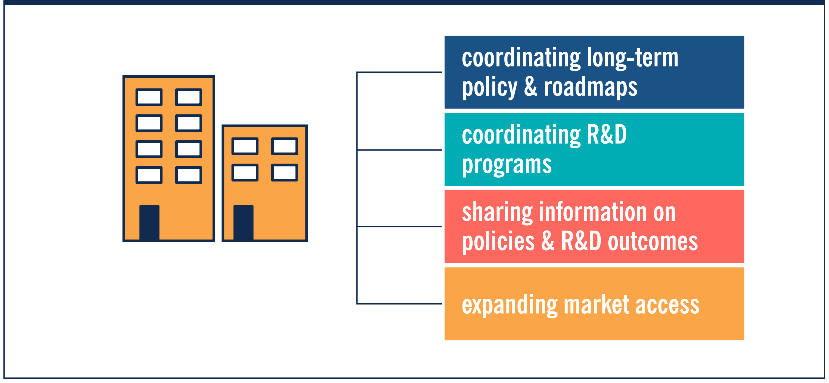
In competing with natural gas and coal-based heating, electric heat pumps face the dual challenges of often being more expensive to buy and to operate. There are generally five potential solutions to this problem: (1) reducing the cost of heat pumps, (2) increasing heat pump efficiency, (3) reducing the cost of electricity, (4) increasing the cost of natural gas and coal, and (5) implementing building standards that mandate zero-emission technologies.

U.S.-China collaboration is most likely to be effective in reducing heat pump costs and improving their efficiency. Coordination actions to improve heat pump technologies might include the following (Figure 12):

- Coordinating longer-term policy on zero-emission buildings to give manufacturers and installers a strong sense of direction for the market for building heating technologies that support investments in innovation and new business models. Neither China nor U.S. states have yet to develop long-term roadmaps for heating technologies. As with vehicles, joint policy statements could have a powerful influence on the direction of the building industry.
- Coordinating R&D programs focused on heat pump technologies. Although such programs already exist, coordination could improve their scale and focus. For instance, government agencies could set targets for heat pump efficiency and cost, similar to what the U.S. Department of Energy did for solar energy through its SunShot Initiative.[21]
- Sharing information on policies and R&D outcomes, as a means to accelerate the innovation process.
- Expanding market access across the heat pump supply chain to drive down heat pump costs.

[21] For more on the SunShot Initiative, see www.energy.gov/eere/solar/sunshot-initiative.

FIGURE 12. COORDINATED ACTIONS THE U.S. AND CHINA CAN TAKE TO SUPPORT LARGER AND MORE INNOVATIVE MARKETS FOR ZERO-EMISSION BUILDINGS



Commercial Collaboration

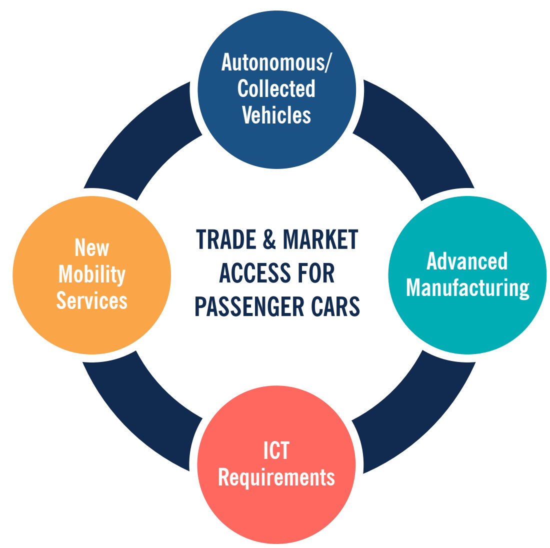
More open markets between the U.S. and China could accelerate adoption of emerging zero-emission vehicle and building heating technologies by encouraging competition and innovation, expanding choice, and reducing costs. Larger, more competitive, and more innovative markets for these technologies are predicated on more open access to markets for producers and investors, greater harmonization of national regulations, enhanced protection of intellectual property, and conditions that enable R&D and commercialization of new technologies. The case studies in this report focus on market access for suppliers and investors and joint R&D and commercialization.

As the case studies suggest, commercial collaboration between the U.S. and China on an array of clean energy technologies has continued to grow, despite a recent worsening of trade relations and efforts by the U.S. federal government to roll back some federal emission standards. This apparent discrepancy is due, in part, to the role of U.S. states in driving environmental and economic policy. The case studies illustrate how businesses have been able to adapt to changes in national trade and industrial policies, deepening interdependence between the U.S. and Chinese economies.

Greater restrictions on market access between the U.S. and China for vehicles or building energy technologies would run upstream of current trends. In the vehicle industry, for instance, U.S. companies are already heavily reliant on the Chinese market and Chinese companies are beginning to make inroads into the U.S. market. Both countries have room to further open markets, particularly for automobiles. For instance, despite having low tariffs on cars, the U.S. has a 25% import tariff on light-duty trucks that dates to the early 1960s. China recently eliminated its joint venture requirement for foreign car manufacturers and reduced import tariffs, but tariffs remain at 15%.

Negotiations between the U.S. and China on market access in the vehicle and building energy sectors should be forward-looking. Over the next two decades, both industries are likely to be reshaped by changes in the nature of services and production (Figure 13). These changes include connected and autonomous vehicles, new mobility services and changes in vehicle ownership, changes in building design, advanced and more automated manufacturing, digitalization, and increasing requirements that electric vehicles and space and water heating technologies be able to communicate and interact with the electricity system. As these changes gather momentum, openness will be more strategic than protectionism and incrementalism.

FIGURE 13. TRADE AND MARKET ACCESS FOR PASSENGER CARS IN THE CONTEXT OF CHANGES IN THE AUTOMOBILE INDUSTRY AND IN MOBILITY



More focused collaboration between the U.S. and China to increase adoption of zero-emission vehicle and building technologies implies shifting U.S. collaboration on energy and climate from memoranda of understanding, joint R&D centers, and innovation centers to efforts to spur commercialization of and cost reductions for emerging technologies through policy, trade, and commerce. Ongoing information sharing on policies and policy successes and challenges plays a critical role in this kind of collaboration.

In the U.S., policy efforts to accelerate deployment of zero-emission vehicle and building technologies will continue to be the domain of states, led by California. California, however, is limited in what it can do without the support of other states. The ZEV MOU among the governors of California and nine other states provides a foundation for this kind of cooperation, but California needs to expand the number of states involved and ensure that they are willing to make real commitments. Ironically, China could be an effective partner for doing so because of its national and local commitments and their implications for global markets.

CONCLUSIONS

The U.S. and China have both an opportunity and a responsibility to lead the world in improving air quality and reducing GHG emissions by transforming their energy systems. The U.S. and China are at different stages in this transformation, but in several areas they will likely share common technology solutions that do not directly contribute to air pollution or climate change — zero-emission technologies. Coordinated strategy and action by both countries in developing and commercializing key zero-emission technologies could accelerate the transition to cleaner energy systems.

This report identifies three areas where greater coordination between the U.S. and China could be transformative: light-duty vehicles, heavy-duty vehicles, and building heating. These three areas meet three criteria: (1) they have *shared solutions*, meaning that the technologies to address air quality and GHG emission concerns in the U.S. and China are likely to be the same; (2) they are *high impact*, meaning that greater adoption of zero-emission technologies in each area would lead to significant reductions in air pollution and GHG emissions in both countries; and (3) there is an *adoption gap*, meaning that, despite policy efforts to encourage zero-emission technologies, they remain a small share of the market.

- **Light-duty vehicles** are a major source of air pollution and GHG emissions in both the U.S. and China. China's national government and nine U.S. states and have set aggressive goals for zero-emission vehicles that would transform the global automobile market by 2030, with tens of millions of electric vehicles sold each year and a market worth nearly half a trillion U.S. dollars per year across both countries. Both China and California have used similar policy strategies to encourage zero-emission vehicles, but vehicle costs remain high. To meet longer-term goals, vehicle costs will need to continue to decline.
- **Heavy-duty vehicles** are a dominant source of air pollution and an important source of GHG emissions in both the U.S. and China. Longer-term targets for zero-emission heavy-duty vehicles have been mainly set by municipal governments and ports to address local air quality concerns. Increasing the scale of these local efforts and creating a market for zero-emission long-haul trucks would accelerate progress toward air quality goals and is critical to meeting 2030 climate goals in several U.S. states. Between the U.S. and China, doing so would imply total sales of zero-emission heavy-duty vehicles numbering in the tens to hundreds of thousands per year, and a total market value in billions of dollars per year by 2030. Expanding the market for zero-emission heavy-duty vehicles requires lowering vehicle costs, creating new business and service models, and providing incentives for early adoption.
- **Space and water heating in residential and commercial buildings** is a larger air quality issue in China than in the U.S., but zero-emission buildings are a key component of plans to achieve 2030 and 2050 GHG emission reduction targets in California and New York. Despite these different driving concerns, both countries have converged on building electrification as a strategy for reducing emissions from buildings. By 2030, the U.S. and China could be adding tens to hundreds of thousands of new all-electric buildings each year, with a market for heating equipment in the hundreds of millions of dollars annually. In most of the U.S. and China, electric heating is not yet cost-effective. Improving its cost-effectiveness requires innovations in technology and building designs and reductions in the cost of electricity relative to the cost of natural gas and coal.

Electricity is anticipated to play a central role in the transition to zero-emission vehicles and buildings. For electric vehicles, electric trucks, fuel cell trucks, and electric heat pumps to be truly zero-emission, they must be powered by zero-emission sources of electricity: renewable, nuclear, and hydroelectric energy. In both the U.S. and China, this shift to zero-emission electricity sources is underway and will likely continue to gather momentum over the next decade. For renewable energy, stronger trade and commercial links between the U.S. and China have been instrumental in the evolution of the industry thus far and will likely continue to be so in the future.

Across these three areas, the transition to zero-emission technologies shares a common and familiar chicken-and-egg challenge. Zero-emission technologies are more expensive than fossil fuel–based alternatives, but increases in production scale, innovation, and competition can significantly bring down their costs. Businesses are reluctant to invest in new production facilities, R&D, and relationships without greater certainty of demand or regulatory requirements. As in the case of California's ZEV program, governments must often balance the level of policy ambitions and the costs they impose on consumers, particularly in smaller markets.

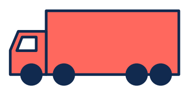
The solar PV industry illustrates that larger policy-driven markets — covering multiple countries, states, provinces, or cities — can provide manufacturers with the confidence needed for longer-term investments. As described in the *Case Study Synthesis* section, coordinated actions that the U.S. and China can take to create these larger markets differ across each of the three areas (Figure 14).

FIGURE 14. COORDINATED ACTIONS THE U.S. AND CHINA CAN TAKE TO SUPPORT LARGER MARKETS

LIGHT-DUTY VEHICLES

Coordinated Actions:

- Coordinating long-term policy & policy signals
- Enforcing existing manufacturer requirements
- Creating & leading a broad coalition
- Expanding market access



HEAVY-DUTY VEHICLES

Coordinated Actions:

- Coordinating long-term procurement of municipal fleets
- Coordinating longer-term strategies for port equipment v& drayage trucks
- Coordinating long-term emission standards for freight trucks
- Expanding market access

BUILDING HEATING

Coordinated Actions:

- Coordinating long-term policy & road maps
- Coordinating R&D programs
- Sharing information on policies & R&D outcomes
- Expanding market access

Despite differences, several themes emerge across the actions in Figure 14. First, providing industry — manufacturers, installers, distributors, banks, and others — with a common vision of where both countries are going through coordinated policy direction can provide a powerful signal for long-term investment decisions, given the joint size of the U.S. and Chinese markets for vehicles and building technologies. Second, more open markets can complement coordinated policy direction by encouraging competition and innovation. Lastly, regular information sharing between the U.S. and China is not only an essential foundation for coordination but also allows greater convergence in policy and regulation over time.

REFERENCES

Bolinger, Mark, Joachim Seel, and Kristina Hamachi LaCommare. 2017. *Utility-Scale Solar: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States.* Berkeley: Lawrence Berkeley National Laboratory (LBNL). Available at https://emp.lbl.gov/sites/default/files/utility-scale-solar-2016-report.pdf.

Energy and Environmental Economics (E3). 2015. *California PATHWAYS: GHG Scenario Results.* Available at www.ethree.com/wp-content/uploads/2017/02/E3_PATHWAYS_GHG_Scenarios_Updated_April2015.pdf.

E3. 2018. *Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model.* Sacramento: California Energy Commission. Available at www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf.

International Council on Clean Transportation (ICCT). 2017. *Transition to Zero-Emission Heavy-Duty Freight Vehicles.* San Francisco: ICCT. Available at www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf.

International Energy Agency (IEA). 2017a. *World Energy Outlook 2016.* Paris: OECD/IEA.

IEA. 2017b. *Energy Technology RD&D Budgets: Overview. Paris: OECD/IEA.* Available at www.iea.org/publications/freepublications/publication/EnergyTechnologyRDD2017Overview.pdf.

IEA. 2017c. *Global EV Outlook 2017.* Paris: OECD/IEA. Available at www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf.

PwC. 2018. *The 2017 Global Innovation 1000 Study.* Available at www.strategyand.pwc.com/innovation1000.

Wiser, Ryan and Mark Bolinger. 2017. *2016 Wind Technologies Market Report.* Washington, DC: Department of Energy. Available at https://emp.lbl.gov/sites/default/files/2016_wind_technologies_market_report_-_corrected_back_cover.pdf.

APPENDIX: U.S. CASE STUDIES

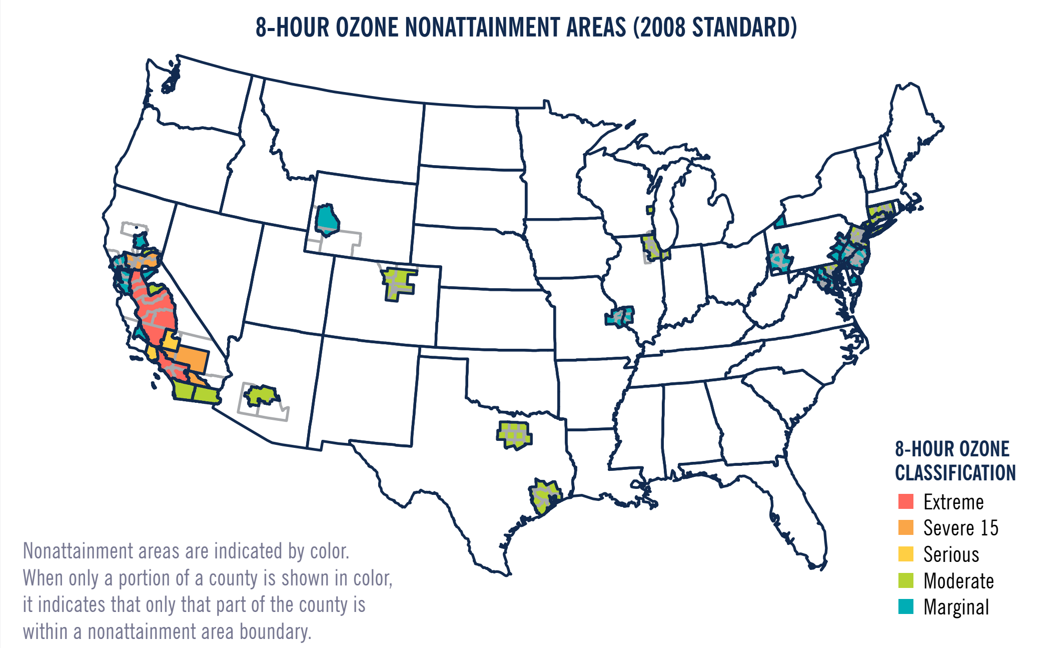
PASSENGER CARS: CALIFORNIA ZERO-EMISSION VEHICLE (ZEV) PROGRAM

California has set an aggressive goal of having 5 million zero-emission vehicles (ZEVs) on the road by 2030, but the state still faces an uphill climb to meet this goal.

Environmental Challenges

California is the largest market for passenger vehicles and light-duty trucks in the U.S. With an estimated 25 million registered autos, Californians drive 800 million miles each day.[1] This car dependency has significant environmental impacts. For instance, passenger vehicles and light-duty trucks are important contributors to nitrogen oxide (NO_X) emissions within the state, leading to high ozone concentrations.[2] A large portion of California does not meet federal emission standards for ozone (Figure 1).

FIGURE 1. AREAS IN THE U.S. THAT ARE OUT OF COMPLIANCE WITH FEDERAL OZONE STANDARDS



Source: U.S. EPA. Available at www3.epa.gov/airquality/greenbook/map8hr_2008.html.

[1] See ARB. 2016. "Zero Emissions Vehicles Program." Available at www.arb.ca.gov/msprog/zevprog/zevprog_template_draft_mm2.htm.

[2] ARB's 2012 emissions inventory estimates that light-duty passenger vehicles and trucks accounted for 11% of statewide NOX emissions, though their contribution to urban ozone concentrations is likely higher. See ARB. "2012 Estimated Annual Average Emissions." Available at www.arb.ca.gov/app/emsinv/2017/emssumcat_query.php?F_YR=2012&F_DIV=-4&F_SEASON=A&SP=SIP105ADJ&F_AREA=CA#0.

Passenger vehicles are also the largest source of GHG emissions in California. According to the California Air Resources Board (ARB), passenger vehicles contribute more than one-quarter of California's total GHG emissions, more than any other sector.[3]

To reduce pollution and GHG emissions from passenger vehicles, California's policymakers and state agencies have developed ambitious goals and policies to transition the state toward ZEVs.

Technology Goals

California has led the U.S. in its ZEV goals. As established by Governor Jerry Brown's executive order in 2012, California aims to have 1.5 million ZEVs on the road by 2025. In 2018, Governor Brown released another executive order setting a target of 5 million ZEVs by 2030. In the statement, the governor also proposed to direct $2.5 billion in funds to build 250,000 electric vehicle (EV) charging stations and 200 hydrogen fueling stations by 2025.[4]

California's ZEV Action Plan, a product of the governor's Interagency Working Group on Zero-Emission Vehicles, describes specific milestones for the auto industry to meet the state's long-term climate goals.[5] The plan notes that to reach the state's long-term GHG reduction goals, between 2040 and 2050 nearly 100% of new passenger vehicles sold in California must be ZEVs.[6]

In line with these goals, ZEV sales have been increasing rapidly. Californians drive 47% of all ZEVs in the U.S.[7] In 2017, California ZEV sales increased by 29.1% year-over-year, expanding the number of ZEVs on the road by 53% compared to 2013.[8]

Policy and Regulatory Strategies

California's main regulatory tool for increasing ZEV adoption is its ZEV program, which requires auto manufacturers to sell a minimum number of ZEVs each year, with compliance maintained through a crediting system. The ZEV program is complemented by federal, state, and electric utility incentives for ZEV owners.

The definition of "ZEVs" in California has historically been broad but, as described later, is narrowing over time. Table 1 describes key ZEV categories under California's ZEV program.

---

[3] See ARB. 2017. *California Greenhouse Gas Emissions for 2000 to 2015 – Trends of Emissions and Other Indicators*.

[4] See Office of Governor. 2018. "Governor Brown Takes Action to Increase Zero-Emission Vehicles, Fund New Climate Investments." Available at www.gov.ca.gov/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/.

[5] Governor's Interagency Working Group on Zero-Emission Vehicles. 2016. *2016 ZEV Action Plan.*

[6] ARB. 2014. *California Greenhouse Gas Emissions for 2000 to 2015 – Trends of Emissions and Other Indicators.*

[7] Governor's Interagency Working Group on Zero-Emission Vehicles. 2016. *2016 ZEV Action Plan.*

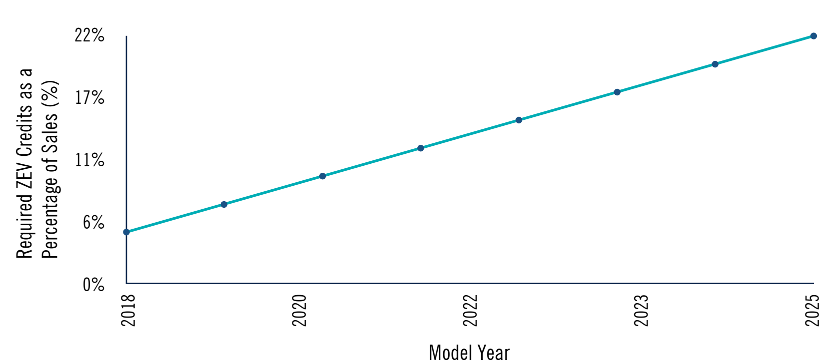
[8] "New Analysis of California ZEV Market Finds State Will Meet or Exceed 1.5 Million by 2025 Goal," *BusinessWire*. January 2018. Available at www.businesswire.com/news/home/20180130005410/en/New-Analysis-California-ZEV-Market-Finds-State.

TABLE 1. VEHICLE TYPES AND DESCRIPTIONS UNDER CALIFORNIA'S ZEV PROGRAM	
VEHICLE TYPE	**VEHICLE DESCRIPTION**
Transitional zero-emission vehicle (TZEV)	TZEVs are ZEVs that still have an internal combustion engine and offer dual use to consumers
Plug-in hybrid vehicles (PHEVs)	PHEVs are the primary subset of TZEVs. They combine a gasoline-powered engine with an electric battery
Battery electric vehicles (BEVs)	BEVs use only electricity and have batteries that can be recharged from the grid
Hydrogen fuel cell vehicles (FCEVs)	FCEVs operate on electricity produced from a fuel cell that uses hydrogen gas

Source: UCS (2016).

The ZEV program was created in 1990. The program is based on a system of credits and credit requirements, whereby automakers earn credits based on the number and type of ZEVs they can sell. Manufacturers that do not meet their credit requirement must pay a $5,000 fine for each credit they are short. Figure 2 displays California's ZEV credit requirements from 2009 to 2026.

FIGURE 2. CALIFORNIA'S ZEV REQUIREMENTS (CREDITS AS A PERCENTAGE OF SALES), 2008–2026



Source: ARB. 2018. *Zero Emission Vehicle Standards for 2018 and Subsequent Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles*.

Credits vary by drive type and electric range. For example, whereas TZEVs are eligible to receive between 0.4 and 1.3 credits per vehicle sold, BEVs and FCEVs receive between 1 and 4 credits depending on range. Because credits do not accumulate at a 1:1 ratio with vehicles sold, the ZEV requirements do not reflect the share of ZEV sales in a manufacturer's fleet. For example, ARB estimates that the 2025 ZEV credit requirement of 22% can be achieved through ZEV sales that are 8% of total auto sales.[9]

[9] UCS (2016).

In 2018, ARB tightened its ZEV program rules, creating a minimum ZEV floor requirement. This minimum floor requires manufacturers to meet a minimum share of their ZEV credit requirement with fully electric (BEV) and fuel cell (FCEV) vehicles reaching 16% in model-year 2025. Although manufacturers can still use TZEV credits to meet a portion of their ZEV requirements, the share of allowed TZEV credits in total ZEV credits will decrease over time.

The ZEV program also takes into account the size of the automaker. Generally, the ZEV program's requirements apply to large-volume manufacturers, which sell more than 20,000 vehicles. Intermediate-volume manufacturers, which sell between 4,500 and 20,000 vehicles per annum, are able to meet all of their ZEV requirements with TZEV sales. Small-volume manufacturers, which sell on average fewer than 4,500 vehicles per year, are exempt from the ZEV requirements.

The ZEV program allows automakers to trade and bank credits. Trading enables automakers that are short credits to buy from those that have excess credits. Some auto manufacturers have chosen to buy credits rather than develop new vehicles, and Tesla has been a major supplier of credits. Banking enables companies to carry over credits from one year to another. Auto manufacturers had already banked a significant number of credits by 2018, potentially enough to comply beyond 2020.[10]

Beyond California, nine states have adopted California's ZEV program. The program contains a "travel" provision, which allows auto manufacturers to apply credits earned in California to comply with ZEV programs in other states. This provision, which expired in 2018, has been a boon for California's ZEV sales at the expense of ZEV sales in other states. With the provision no longer in effect, however, ZEV sales in other states are expected to pick up pace.

Key Challenges

While ZEV sales in California have risen rapidly in recent years, the state faces several challenges to meeting its 2030 ZEV goals. Key challenges include affordability, industry scale, charging and fueling infrastructure, electricity cost, and grid impact.

In California, ZEVs remain significantly more expensive than equivalent internal combustion engine (ICE) vehicles. For EVs, cost differences are largely driven by battery costs, which have declined significantly over the past decade; some auto manufacturers are predicting that EVs will be cost-competitive with ICE vehicles by the early to mid-2020s.[11] However, in the nearer term the ZEV industry has been slow to expand and scale up, in part due to the flexibility given to manufacturers through trading and banking credits.

To make ZEVs more affordable, California offers ZEV rebates through the Clean Vehicle Rebate Program (CVRP). The program offers incentives for the purchase or long-term lease of ZEVs. Drivers can earn $5,000 for FCEVs, $2,500 for BEVs, and $1,500 for PHEVs, with added assistance for low-income consumers.[12] The U.S. government also provides tax incentives for EVs and fuel cell vehicles. However, these incentives are not yet large enough to cover the higher incremental cost of ZEVs.

---

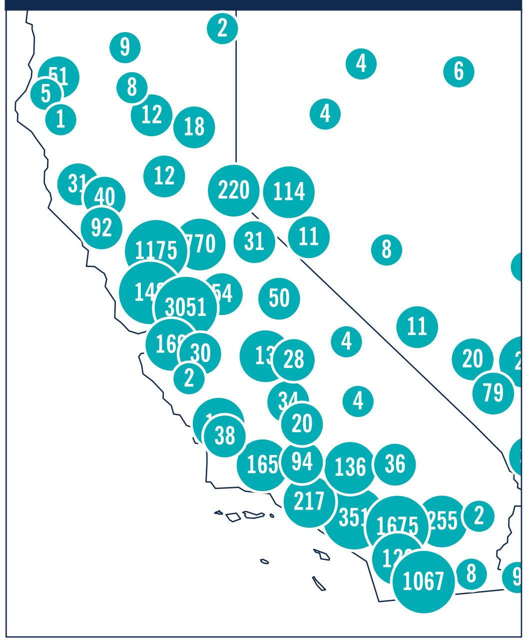
[10] UCS (2016).

[11] See, for instance, Campbell, Peter. "Nissan Sees 2025 as Turning Point for Electric Cars." *The Financial Times.* February 2018. Available at www.ft.com/content/7bbd9a9a-1326-11e8-940e-08320fc2a277.

[12] In 2017–2018, these funds primarily came from California's cap and trade auction proceeds, the Air Quality Improvement Program (AQIP), the Volkswagen settlement funds for ZEVs, and a new Zero-Emission Warehouse Program.

Inadequate charging and fueling infrastructure is also a barrier to ZEV adoption. California has taken multiple steps to address this challenge. For instance, Assembly Bill 118 (2017) established the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). As of January 2018, ARFVTP had funded 39% of total public charging sites and 38% of charging outlets in California.[13] As of May 2018, California had 4,913 charging stations and 18,213 charging outlets, as displayed in Figure 3.

FIGURE 3. CHARGING STATIONS IN CALIFORNIA AND NEVADA



Source: ChargePoint Inc. Available at https://na.chargepoint.com/charge_point.

By state law, California permits electric utility ownership of EV charging stations on a case-by-case basis. Utilities have announced plans to build more than 10,000 utility-owned stations across the state.[14] Regulated utility ownership of charging stations has raised concerns over the potential to crowd out investment from the private sector.[15] Roles, regulations, and business models for charging infrastructure in California are still evolving.

Electricity costs and potential grid impacts are a final set of challenges for scaling up ZEV adoption in California. The cost of electricity varies significantly over time. Charging customers lower prices for EV charging when the cost of producing electricity is low can reduce the cost of driving an EV, encouraging adoption. In addition, aligning electricity costs and prices can reduce potential impacts of electricity on the electric grid, encouraging EV owners to charge when the grid has spare capacity.

---

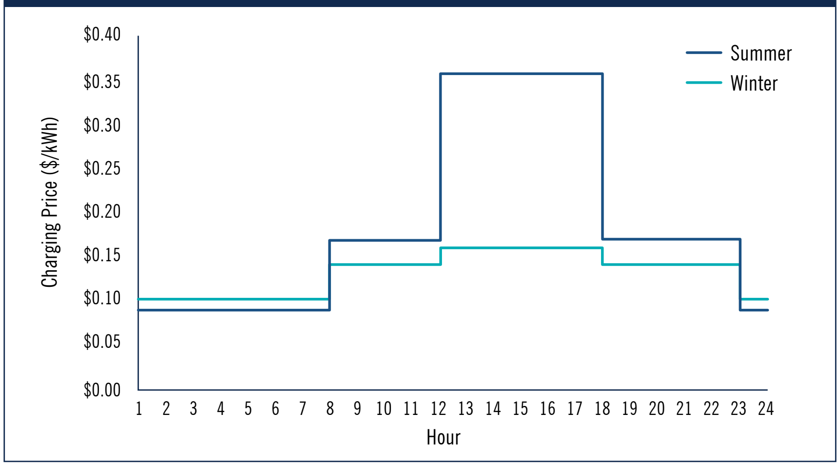
[13] California Clean Energy Commission. 2017. *Tracking Progress.*

[14] California Clean Energy Commission. 2017. *Tracking Progress.*

[15] Ryan and McKenzie (2016).

California's three main investor-owned utilities have all begun to offer time-of-use (TOU) pricing for EV charging that varies over the course of a day and by season. Figure 4 shows one example EV TOU rate from Southern California Edison. Utilities, regulators, and researchers are still exploring how to make pricing for EV charging cost less and be better aligned with electricity system needs, particularly as the level of intermittent wind and solar generation increases over the next decade to meet the state's 50% renewable portfolio standard in 2030.

FIGURE 4. SOUTHERN CALIFORNIA EDISON'S TOU-EV-3-A RATE FOR EV CHARGING



Source: Prices are from the Southern California Edison website. Available at www.sce.com.

CALIFORNIA BUILDING ENERGY: PATHWAYS TO ZERO EMISSIONS

California aims to significantly reduce greenhouse gas emissions from buildings over the next two decades, but how best to do so remains controversial.

Environmental Challenges

Buildings are a major source of GHG emissions in the U.S., accounting for approximately 40% of total U.S. CO2 emissions in 2012.[16] The largest source of energy demand in buildings comes from space heating and water heating, which are responsible for 25% and 13%, respectively, of household energy use in the U.S.[17] In California, space and water heating contributes more than 66% of all GHG emissions from residential and commercial buildings.[18] Natural gas use is the largest contributor to these emissions, due to the state's high reliance on natural gas for space and water heating. Nearly 90% of the homes in the state, or 13 million homes, use gas appliances.[19]

---

[16] DOE. 2015. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities.*

[17] See Delforge, Pierre. "Cutting Emissions in Buildings Is Critical to Climate Fight." *NDRC Expert Blog.* September 2017. Available at www.nrdc.org/experts/pierre-delforge/cutting-emissions-buildings-critical-climate-fight.

[18] Southern California Edison. 2017. *The Clean Power and Electrification Pathway.*

[19] See Golden, Rachel. "Gas Heaters: The Skeleton in California's Closets." *Sierra Club.* July 2017. Available at www.sierraclub.org/compass/2017/07/gas-heaters-skeleton-californias-closets.

Natural gas also contributes to GHG emissions through leakage of natural gas, which is predominantly methane, through production and distribution. Methane is a very potent GHG, with each gram of methane contributing the same impact to the atmosphere as 25 grams of CO2. Methane leakage contributes to 9% of California's GHG emissions measured in CO2 equivalent units.[20] Moreover, several studies have shown methane leakage to be significantly underreported.[21]

Technology Goals

To meet its GHG emission reduction goals, California has set up targets and standards for the building sector. These include targets for zero net energy (ZNE) buildings, building energy efficiency, and implied targets for switching from natural gas to electric appliances or zero-emitting sources of pipeline gas.

ZNE targets are a key part of the transition to zero-emission buildings in California. ZNE refers to buildings that consume no net energy in a typical year. Based on current plans, all new residential and commercial buildings would be required to be ZNE by 2020 and 2030, respectively, and 50% of existing buildings would meet a ZNE standard by 2030 (Table 2).

TABLE 2: CALIFORNIA'S ZNE TARGETS

TARGET	YEAR
All new residential construction in California is ZNE	2020
All new commercial construction in California is ZNE	2030
50% of existing buildings are ZNE	2030

Improving end-use energy efficiency in new and existing buildings is a key part of the state's plan to reduce GHG emissions from buildings. The California Public Utilities Commission (CPUC) aims to achieve a 40% reduction in energy demand through implementing energy efficiency improvements while retrofitting the residential building sector.[22]

California has also set benchmarks focused on reducing building emissions. Chapter 11 of California's Building Energy Efficiency Standards, the Green Building Standards (CALGreen code), sets a mandatory baseline for energy efficiency in buildings specifically tailored to allow the state to reach its GHG emission reduction goals set by AB 32. Every three years, state agencies collaborate with industry stakeholders to update the standards according to technological advancements.[23] The California Energy Commission (CEC) developed the CALGreen code, which first appeared in the 2013 iteration of the Building Energy Efficiency

[20] ARB. 2017. "Methane (CH4)." Available at www.arb.ca.gov/cc/inventory/background/ch4.htm.

[21] See Page, Samantha. "California Just Put Serious Limits on Methane Leaks." *ThinkProgress.* March 2017. Available at https://thinkprogress.org/california-just-put-serious-limits-on-methane-leaks-6392ea30289/.

[22] ARB. 2013. "Existing Building Retrofits." Available at www.arb.ca.gov/cc/greenbuildings/retrofits.htm.

[23] California Energy Commission. 2018. *Achieving Energy Efficiency.*

Standards. In addition to the CALGreen code, the CEC created more ambitious voluntary standards, called the Beyond Code, which local governments can choose to opt into.

Regular increases in building efficiency standards have led to continuous reductions in estimated energy use, limiting increases in building sector emissions. With the introduction of the CALGreen code, for instance, the 2013 building standards reduced energy consumption for lighting, heating, cooling, ventilation, and water heating by 25% compared to the 2008 standards.[24] Moreover, updates to the standards in 2016 aim to reduce energy consumption for new single-family homes by 28%.[25]

As shown in Table 3, ARB has designated that implementation of standards and retrofit programs should contribute 26 million metric tons (MMT) of CO_2 emission reductions, making up 15% of California's overall 2020 GHG emission reduction target set by AB 32.[26] Moreover, ARB's 2017 scoping plan calls for doubling energy efficiency of all buildings by 2030.[27]

TABLE 3: ARB'S BUILDING SECTOR GHG EMISSION REDUCTION TARGETS

MEASURE	DESCRIPTION	2020 REDUCTIONS*
CALGreen Code	Consistent mandatory provisions for all building types	2.9
Beyond Code	Encourage voluntary efforts to go beyond mandatory code requirements	3.6
Existing Building Retrofits	Retrofit existing state, school, residential, and commercial buildings	20
Total		26

* Units of million metric tons of carbon dioxide equivalents (MMTCO2e)

Although ZNE and improvements in building efficiency can lower energy use, they do not necessarily address GHG emissions from natural gas use in buildings. ARB's 2017 Scoping Plan highlights two strategies for reducing GHG emissions from natural gas use in buildings: (1) electrification of space and water heating through high-efficiency heat pumps and (2) production of low-carbon gas, using a blend of biofuels and hydrogen and synthetic natural gas produced from renewable electricity.

Although both options remain on the table, electrification has gained greater currency because it is more "technology ready." To meet the state's long-term GHG reduction goals, a significant portion of new space- and water-heating appliance sales would need to be zero-emissions by 2030. A study for California state agencies estimated that to meet the state's longer-term GHG goals, high-efficiency heat pumps would need to account for roughly 50% of new heating equipment sales in residential and commercial buildings by 2030.

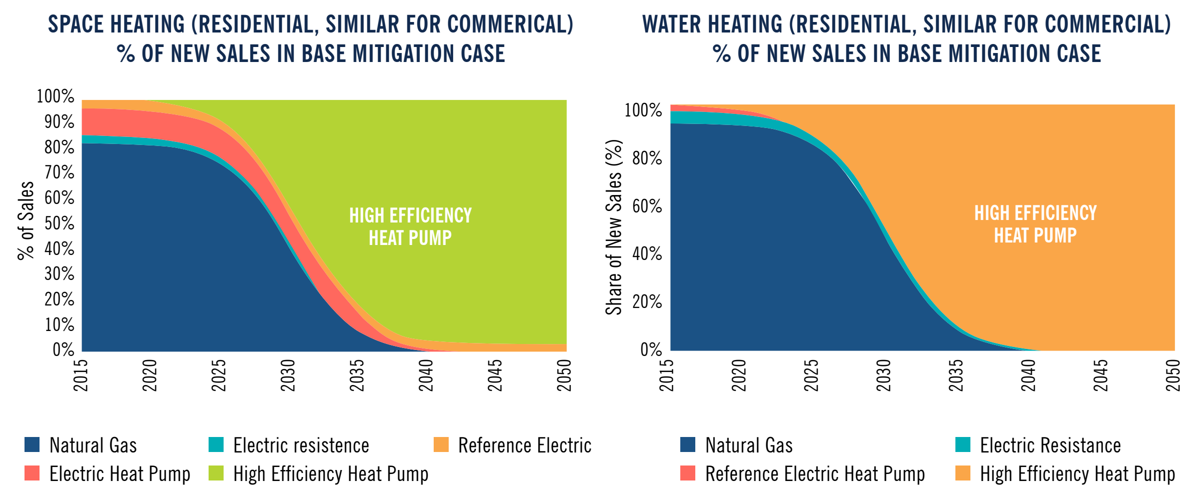
[24] California Energy Commission. 2012. *Building Energy Efficiency Standards: Frequently Asked Questions.*

[25] California Energy Commission. 2016. *Building Energy Efficiency Standards: Frequently Asked Questions.*

[26] AB 32 requires that California reduce its GHG emissions to 1990 levels by 2020. See ARB. 2014. "California Green Building Strategy." Available at www.arb.ca.gov/cc/greenbuildings/greenbuildings.htm.

[27] ARB. 2017. *California's 2017 Climate Change Scoping Plan.*

FIGURE 5. SALES OF SPACE- AND WATER-HEATING TECHNOLOGIES IN CALIFORNIA TO MEET STATE GHG TARGETS



Source: E3. 2017. *Long-Term Energy Scenarios in California: Updated Results from the California PATHWAYS Model.*

Policies and Strategies

California employs a diverse mix of mandates and incentives to achieve its GHG emission reduction targets. Incentives range from rebates for new products to direct incentives to building and appliance owners. Table 4 describes the financial incentive programs that support homeowners' and public institutions' investment in energy efficiency retrofits.

TABLE 4. FINANCIAL INCENTIVES FOR RETROFITTING BUILDINGS IN CALIFORNIA

AGENCY	DESCRIPTION
CPUC	CPUC funds the Energy Upgrade California rebate program. Through the program, homeowners who retrofit their houses are eligible for a rebate of up to $3,000 for building shell improvements and up to $5,500 for advanced upgrades of home appliances.
CSD	The California Department of Community Services and Development (CSD) administers the Low-Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP), which provide energy efficiency services to low-income households. Every year, the CSD services about 50,000 home energy retrofits throughout California through these programs.
CEC	The CEC oversees the Energy Efficiency Financing Program, which provides zero- and low-interest rate loans to local governments, schools, hospitals, and public institutions specifically to install energy efficiency upgrades and clean energy projects. The CEC also manages the implementation of Proposition 39: The Clean Energy Jobs Act program for schools (K-12), which services local education boards with grant funding for energy efficiency upgrades and clean energy projects.

To enforce the green standards in existing single-family homes, it is critical that building managers have access to information about the energy efficiency of their building. To achieve this in the residential sector, the CEC created and oversees the Home Energy Rating System (HERS) program. The program provides home-owners with trained professional home energy auditors, called HERS raters. HERS raters are tasked with energy auditing services for single-family homes as well as compliance testing for new residential buildings. For buildings housing public institutions and schools, the CEC provides energy audits and other technical assistance directly through the Commission Bright Schools Program and Energy Partnership Program.

Key Challenges

Although energy efficiency will continue to be a cornerstone of California's efforts to reduce GHG emissions in buildings, ultimately the state will need to reduce the building sector's reliance on natural gas for space and water heating. At present, however, both of the means to do so — electrification through heat pumps and production of low-carbon gas — are expensive, raising questions of affordability.[28,29]

For heat pumps, higher costs include both the higher upfront cost of the equipment, relative to natural gas furnaces and water heaters, and the higher cost of electricity relative to natural gas. Low-carbon gas is in the early stages of development. Some combination of lower equipment costs, lower electricity costs, and higher natural gas prices are necessary to increase the cost-effectiveness of electric heating and low-carbon gas.

An important obstacle to reducing the cost of heat pumps in California is that standing policy restricts utilities from providing incentives for appliances, such as heat pumps, that will lead customers to switch fuel sources. To address this issue, the National Resource Defense Fund, the Sierra Club, the California Energy Efficiency Industry Council, and 24 other organizations petitioned CPUC to modify this rule to allow for fuel switching.[30] The authors of the report cite that amending incentives is critical to the state reaching its GHG reduction goals.[31]

California's ZNE mandate is also the subject of considerable debate and uncertainty. Critics of the ZNE mandate argue that the rule may crowd out lower-cost, more efficient renewable energy sources, such as utility-scale solar facilities, and that it may push higher costs onto California residents.[32] Proponents argue that the ZNE mandate internalizes costs that are often ignored in benefit-cost analysis. Irrespective of the merits of these arguments, it remains unclear how the ZNE mandate will be implemented and the extent to which it will address GHG emissions in new and existing buildings.

---

[28] Rocky Mountain Institute. 2018. *The Economics of Electrifying Buildings.*

[29] See, for instance, Merchant, Emma Foehringer. "Electric Heating Accelerates the Push for Deep Decarbonization, but Cost Remains an Issue." *GreenTechMedia*. June 2018. Available at www.greentechmedia.com/articles/read/electric-heating-deep-decarbonization-cost#gs.0FV6TPc.

[30] Borgeson et al. (2017).

[31] See Borgeson, Merrian. "Commission Should Enable Switching to Clean Energy for Heat." *NDRC Expert Blog.* June 2017. Available at www.nrdc.org/experts/commission-should-enable-switching-clean-energy-heat.

[32] See, for instance, Nikolewski, Rob. "California's New Solar Mandate: A Leap Forward or a Step Back?" *The San Diego Union-Tribune.* May 2018. Available at www.sandiegouniontribune.com/business/energy-green/sd-fi-solarmandate-critique-20180528-story.html.

HEAVY-DUTY VEHICLES: ALTERNATIVE FUELS FOR CALIFORNIA'S HEAVY-DUTY FLEET

Emission standards for heavy-duty vehicles in California are becoming increasingly strict and cleaner vehicle options are rapidly coming to market, but significant obstacles to achieving substantial emission reductions from heavy-duty vehicles remain.

Environmental challenges

With about 12 million registered heavy-duty trucks, heavy-duty vehicles (HDVs) represent 7% of all vehicles in America. However, HDVs are responsible for about 50% of smog-precursor emissions[33] and 20% of the transportation sector's greenhouse gas emissions. In California specifically, diesel HDVs account for 2% of vehicles on the road, but 53% of NO_x emissions.[34] Additionally, HDVs also emit particulate matter (PM) and a mixture of other harmful toxic air contaminants.

Most HDVs are powered by diesel engines. In 2012, the International Agency for Research on Cancer (IARC) designated diesel exhaust as a known carcinogen to humans.[35] Diesel PM makes up 60% of the inhalation cancer risk in background ambient air.[36] Due to their disproportionately high emission levels and subsequent impact on the environment, HDVs have become a key area of focus for environmental regulators.

Technology goals

California's HDV emission regulations follow targets set by state-level plans. For example, in 2000, the California Air Resource Board (CARB) published the Diesel Risk Reduction Plan (DRPP), which details how the state will reduce risks associated with PM emissions from diesel fuels. The DRPP targets 75% PM reduction by 2010 and 85% by 2020.[37] To achieve this, the DRPP proposed regulatory standards for diesel engines and fuels as well as retrofit requirements.[38]

Additionally, CARB's Mobile Source Strategy, released every five years, details CARB's comprehensive plan to address emissions from mobile sources, including passenger cars and HDVs. As a key part of the 2016 strategy, CARB announced plans to implement HDV low-NO_x standards for 2019 implementation based on CARB's optional heavy-duty low-NO_x standard released in 2013. The new standards represent a 90% reduction in NO_x emissions compared to the previous national standard.[39] Specifically, in high-polluting areas, such as California's Southern Coast, CARB projects that successful implementation of HDV regulations in conjunction with the Mobile Sources will reduce HDV NO_x emissions by nearly 70% between 2015 and 2031.[40]

---

[33] Smog-precursor emissions include volatile organic compounds (VOC) and NO_x.

[34] See Uranga, Rachel. "Why California's Most Polluting Vehicles Aren't Required to Get Smog Checks," *The Mercury News.* July 2014. Available at www.mercurynews.com/2017/07/24/why-californias-most-polluting-vehicles-arent-required-to-get-smog-checks-9/.

[35] International Agency for Research on Cancer. 2012. *Diesel Engine Exhaust Carcinogenic.*

[36] ARB and California Air Pollution Control Officers Association. 2015. *Risk Management Guidance for Stationary Sources of Air Toxics.*

[37] ARB. 2000. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.*

[38] See "California: Diesel Risk Reduction Plan." *TransportPolicy.net.* Available at www.transportpolicy.net/standard/california-diesel-risk-reduction-plan/.

[39] See ARB. 2018. *Heavy Duty Low-NO_x.* Available at www.arb.ca.gov/msprog/hdlownox/hdlownox.htm.

[40] Carter, Michael. 2017. *Heavy-Duty Low-NO_x and Phase 2 GHG Plans.*

Another key plan driving adoption of cleaner HDVs is California's Innovative Clean Transit measure. According to the plan, alternative fuel HDVs should represent 20% of new urban bus purchases by 2018 and 100% by 2030. Additionally, the measure requires that all new natural gas buses and diesel buses meet the optional heavy-duty low-NO_x standard by 2018 and 2020, respectively.

Policy and regulatory strategies

For California to reach its goals in reducing HDV emissions, the state has undertaken a multifaceted approach, including requiring manufacturers to produce cleaner technologies, providing financial incentives for companies to adopt cleaner vehicles, requiring fleet owners to upgrade emission controls in in-use vehicles, and applying public sector procurement standards.[41]

In addition to increasingly stringent emission standards, California's On-Road Heavy-Duty Diesel Vehicles (In-Use) Regulation, first passed in 2008 and expanded in 2010 and 2014, mandates all diesel HDVs that operate in California be upgraded to reduce emissions, requiring all in-use HDVs to meet model-year (MY) 2010 emission standards by 2023. Table 5 illustrates the timeline ARB designated for HDV upgrades based on the MY of the original engine.[42]

TABLE 5. HDV ENGINE REQUIREMENTS SCHEDULE

ENGINE YEAR	LEVEL-3 PM FILTER	2010 MY ENGINE
Pre-1994	Not required	January 1, 2015
1994–1995	Not required	January 1, 2016
1996–1999	January 1, 2012	January 1, 2020
2000–2004	January 1, 2013	January 1, 2021
2005 or newer	January 1, 2014	January 1, 2022
2007–2009	If already equipped	January 1, 2023

CARB's emissions standards for new and in-use HDVs are supported by a system of financial support programs. Table 6 provides an overview of California's programs that facilitate HDV emission reductions.

[41] ARB. 2016. *Mobile Source Strategy.*

[42] ARB. 2016. *A Guide to ARB's Heavy-Duty Diesel Vehicles Regulations.*

TABLE 6. OVERVIEW OF CALIFORNIA'S FINANCIAL PROGRAMS RELATED TO HDV EMISSIONS CONTROLS		
PROGRAM	**DESCRIPTION**	**FUNDS ALLOTTED**
Carl Moyer Program (CMP) (1998–current)	CMP funds many programs through local air districts to supply cleaner engines. CMP's On-Road Heavy Duty Vehicles Voucher Incentive Program (VIP) provides financial incentives to replace high-polluting HDVs with lower-emission HDVs. The VIP funds help offset the costs of the replacement vehicles and parts.	The CMP provides approximately $60 million in grant funding every year. Between 1998 and 2017, the CMP provided $467 million in funding.
The Low Carbon Transportation Program (LCTP) (2008–current)	Through LCTP, CARB invests proceeds from California's cap and trade program into clean transportation and new technologies that reduce emissions from mobile sources.	Each year, California's legislature decides the funding amount allotted to CARB for LCTP. The 2015–2016 State Budget allotted $350 million for LCTP.
The Loan Incentives Program: Heavy-Duty Loan Program (2008–2009)	The Heavy-Duty Loan Program was implemented to reduce the impact of fleet transitions required by the On-Road Heavy-Duty Diesel Vehicles (In-Use) Regulation.	The program disbursed approximately $35 million in related loans.
Proposition 1B (2013–2014)	Prop 1B provides incentives to freight vehicles to upgrade to cleaner technologies on an accelerated timeline.	The program allots $1 billion in funding specifically focused on air quality of freight vehicles.
AB 134 (2017)	AB 134 targets emissions reductions in disadvantaged and low-income communities.	AB 134 allots $250 million to air districts for implementation of projects in conjunction with CMP.

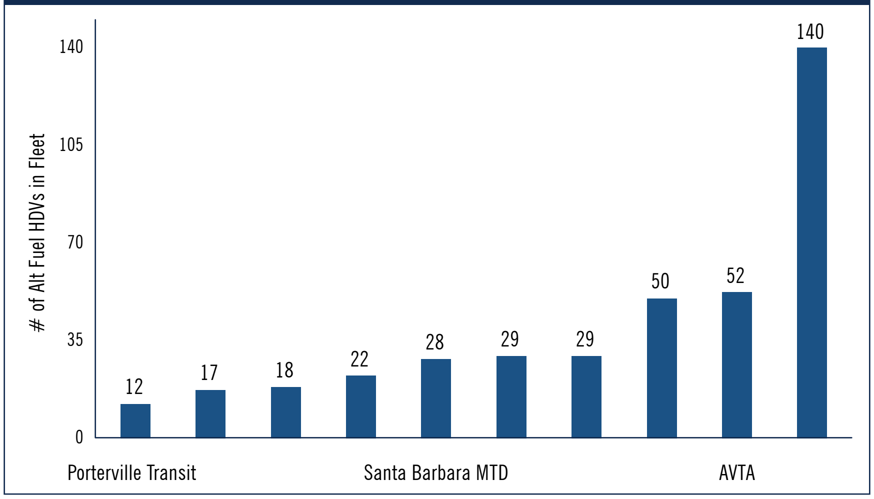
Beyond emission controls from diesel-engine vehicles, battery electric vehicles (BEVs) and fuel cell vehicles (FCVs) are emerging in the HDV market and are expected to bring about significant HDV emission reductions in the medium to long term. A 2015 white paper estimates that heavy-duty ZEVs have the potential to reduce the NOx and GHG inventories in the South Coast Air Basin (SCAB) by 18% and 19%, respectively.[43]

Due to California's Innovative Clean Transit measure, public transit fleets are among the earliest adopters of heavy-duty ZEVs in California. The Los Angeles County Metropolitan Transportation Authority (LA Metro), Foothill Transit, and the City of Los Angeles Department of Transportation (LA DOT) have already committed to zero-emissions from their bus fleets by 2030, and the San Joaquin Regional Transit District (San Joaquin RTD) by 2025. Figure 6 shows the status of ZEV adoption by local public transit authorities in California.[44]

[43] Gladstein, Neandross & Associates. 2016. *Gamechanger Technical White Paper: Next Generation Heavy-Duty Natural Gas Engines Fueled by Renewable Natural Gas.*

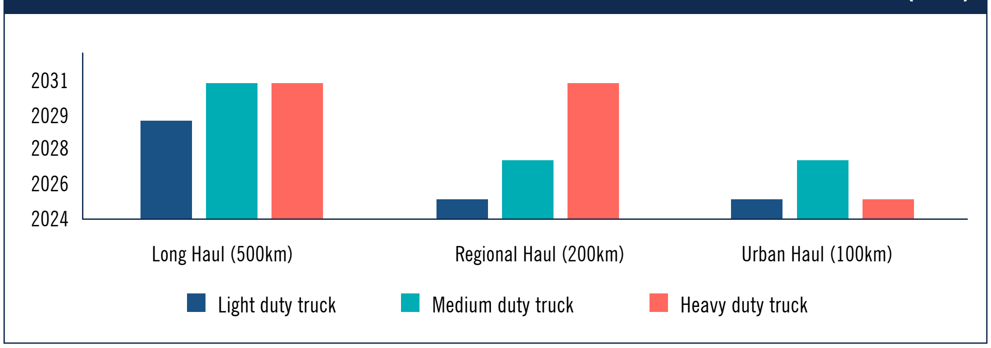
[44] See ARB. 2018. *Battery and Fuel Cell Electric Buses at California Transit Agencies with Over 100 Buses.* Available at https://arb.ca.gov/msprog/ict/faqs/toptransitzebs.pdf.

FIGURE 6. CALIFORNIA TRANSIT AUTHORITIES WITH THE MOST ALTERNATIVE FUEL HDVS



While the benefits of heavy-duty ZEVs is clear, many analysts postulate that heavy-duty ZEVs will not dominate the market immediately upon commercial introduction. In 2015, CARB released a statement that combustion technology will likely dominate California's roads for the next 15 years.[45] Alternative fuel HDV adoption is expected to occur when there is price parity between alternative fuel HDVs and diesel HDVs. According to McKinsey's estimates, this will occur between 2025 and 2031, as seen in Figure 7.[46]

FIGURE 7. PRICE PARITY PROJECTIONS BETWEEN ALTERNATIVE FUEL HDV AND DIESEL HDV (YEAR)



Natural gas near-zero-emission vehicles (NZEVs) are another option for fleet owners aiming to comply with tightening standards. Currently, natural gas NZEVs with engines 90% cleaner than the federal standard are commercially available, with early adopters including UPS and Waste Management, and a $21 million

[45] ARB estimates that combustion technology will dominate California's roads for the next 15 years.

[46] See Bernd, Heid. "What's Sparking Electric-Vehicle Adoption in the Truck Industry?" *McKinsey & Company.* September 2017. Available at www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry.

effort carried out by the South Coast Air Quality Management District is helping replace more than 400 diesel trucks to these more environmentally friendly alternatives.[47,48]

Key challenges

California's pursuit of lower emissions from HDVs faces significant obstacles. While the state has implemented rigorous standards for HDV engines, regulators are limited in their ability to ensure compliance. While HDVs are required to have on-board diagnostic (OBD) systems that are regularly inspected during required smog checks, California does not mandate that HDV operators make these data readily available to third parties in between regular examinations. Remote OBD technology offers an opportunity to make emission control data available to operators and regulators via cellular networks. California has undertaken a pilot program for testing remote OBD systems, which remains voluntary.[49]

Another major challenge in reducing HDV emissions stems from the fact that on any given day, a large portion of HDVs on the road are from out of state. As California's low-NOx emission standards for HDVs exceeds those of federal standards, ARB has designated the inconsistency between state and federal standards as a key challenge for the state to reach its NOx emission reduction targets. The EPA officially stated that it would consider developing low-NOx emission standards for HDVs, and ARB has announced its intent to coordinate standards development set for 2019 release.[50]

Lastly, the lack of necessary infrastructure presents a major obstacle in transitioning to alternative energy HDVs. Natural gas trucks, fuel cell trucks, and heavy-duty ZEVs require refueling stations that can provide natural gas, hydrogen, and electricity. Thus, significant infrastructure investment costs are needed to enable heavy-duty ZEVs and natural gas NZEVs to replace diesel HDVs. On the other hand, the predictable nature of truck routes may allow for cost-effective construction of needed infrastructure along heavily traveled delivery routes. Given the chicken-and-egg problems around fueling infrastructure, a key question will be who pays for it.

Cost and technology limitations — in particular, driving range for trucks — also present obstacles for alternative fuel HDVs. HDV manufacturers are beginning to roll out new zero-emission electric and fuel cell trucks with longer driving ranges, as seen in Table 7, which indicates that these new vehicles are at various stages of commercialization, illustrating both the potential and remaining challenges to transitioning to zero-emission HDVs.

---

[47] See, for instance, Lawson, Thomas. "How Corporate Fleets Can Go Carbon-Negative Now." *Sustainable Brands.* April 2018. Available at www.sustainablebrands.com/news_and_views/cleantech/thomas_lawson/how_corporate_fleets_can_go_carbon-negative_now.

[48] See, for instance, Lillian, Betsy. "Hundreds of SoCal Fleets Make Moves Toward Natural Gas." *NGT News.* March 2018. Available at https://ngtnews.com/hundreds-of-socal-fleets-make-moves-toward-natural-gas.

[49] See ARB. 2015. "On-Board Diagnostic II (OBD II) Systems – Fact Sheet / FAQs." Available at www.arb.ca.gov/msprog/obdprog/obdfaq.htm.

[50] See ARB. 2018. *Heavy Duty Low-NO$_x$.* Available at www.arb.ca.gov/msprog/hdlownox/hdlownox.htm.

TABLE 7. REPORTED DRIVING RANGE FOR NEW ZERO-EMISSION HDVS					
	TESLA SEMI	VOLVO FL ELECTRIC	CUMMINS WESTPORT AEOS	NIKOLA TRUCK	TOYOTA PROJECT PORTAL
TYPE	Electric	Electric	Electric	Electric	Fuel cell
EXPECTED RELEASE	2019	In operation	2019	2019	In operation
RANGE	500 miles	186 miles	100 miles	1,000 miles	200 miles

APPENDIX: CHINA CASE STUDIES

PASSENGER CARS: CHINA'S NEW ENERGY VEHICLE (NEV) PROGRAM

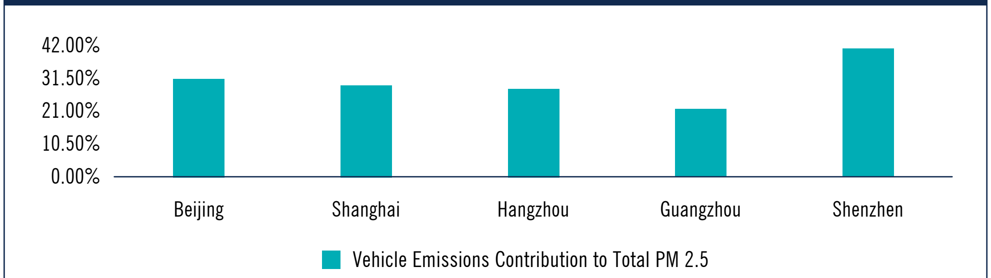
With ambitions for new energy vehicle (NEV) sales to reach 7 million by 2025, China is making a concerted policy effort to become a leader in the electric vehicle industry.

Environmental Challenges

China has more than 242 million registered passenger cars, making it the largest car market in the world.[51] As China continues to urbanize and develop, car ownership is expected to grow. Analysts expect that urban private car ownership will reach 356 million vehicles by 2050.[52]

Vehicle use in China has led to significant environmental problems. In 2015, passenger cars accounted for more than 9% of China's overall NO_x emissions.[53] In tandem with rising emissions of volatile organic chemicals (VOCs), increases in NO_x emissions have led to higher ozone concentrations in major urban areas, such as Beijing and the Pearl River Delta cities. Vehicle exhaust has also become the primary source of $PM_{2.5}$ emissions in many congested urban areas as seen in Figure 1.

FIGURE 1. VEHICLE CONTRIBUTION TO TOTAL $PM_{2.5}$ POLLUTION



Source: MEP. 2017. *China Vehicle Environmental Management Report 2017.*

Technology Goals

In an effort to reduce air pollution from passenger vehicles, the Chinese government has undertaken ambitious efforts to promote NEV adoption. China considers NEVs to include vehicles completely or primarily fueled by new energy sources, such as plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCVs).[54] Table 1 outlines the major targets set by China.

---

[51] MEP. 2017. *China Vehicle Environmental Management Report 2017.*

[52] Zhou, Nan et al. 2013. "China's Energy and Emissions Outlook to 2050: Perspectives from Bottom-up Energy End-use Model." *Energy Policy.* Available at http://eaei.lbl.gov/sites/all/files/lbnl-6179e.pdf.

[53] Figure calculated using aggregate numbers from International Council on Clean Transport (ICCT). Available at www.theicct.org/blogs/staff/latest-step-forward-on-china-vehicle-emissions-regulation. Emissions by type proportions from MEP's 2017 *China Vehicle Environmental Management Annual Report.* Available at www.mep.gov.cn/gkml/hbb/qt/201706/t20170603_415265.htm?COLLCC=2084844201&

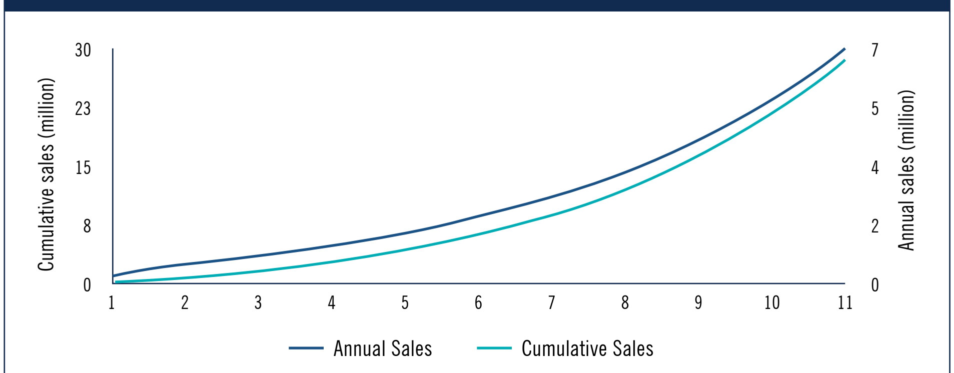
[54] ICCT. 2018. *China's New Energy Vehicle Mandate Policy.*

TABLE 1. REVIEW OF NEV TARGETS 2012–2018

YEAR	AGENCY	DOCUMENT	TARGET
2012	The State Council	Energy Saving and New Energy Vehicles Industry Development Planning (2012–2020)	0.5 million NEVs on the road by 2015 5 million NEVs on the road by 2020 2 million domestic NEV production capacity by 2020
2015	MIIT	Made in China 2025	1 million China-branded domestic NEV sales, accounting for more than 70% of the domestic market by 2020 3 million China-branded domestic NEV sales, accounting for more than 80% of the domestic market by 2025
2015	The State Council	Guiding Opinions on Accelerating the Electric Vehicle Charging Infrastructure Construction	At least one in ten public car park facilities equipped with electric car charging capabilities by 2020 All newly built residential communities equipped with charging stations by 2020 At least one charging station for every 2,000 electric cars by 2020
2017	MIIT, NDRC, and the MST	Guidelines for China's Medium- and Long-Term Car Industry Development	NEV sales represent one-fifth of total vehicle sales, an estimated 7 million vehicles by volume, by 2025

China's ambitious NEV targets have proven challenging to achieve. In December 2015, Chinese automakers recorded 423,000 cumulative NEV sales, falling just shy of the 500,000-unit target. However, this target was quickly eclipsed in 2016 when China experienced NEV sales of 507,000 units in the span of 12 months.[55] By the end of 2017, total NEV ownership in China reached 1.8 million units. Figure 2 illustrates China's NEV annual sales trajectory in conjunction with the resulting cumulative sales trend.

FIGURE 2. CHINA NEV SALES TARGETS VS. ACTUAL SALES



Note: Figure assumes annualized growth rates between 2017–2020 and 2020–2025.

[55] See "China's New NEV Rules." *The Economist Intelligence Unit.* May 2017. Available at www.eiu.com/industry/article/1185390902/chinas-new-nev-rules/2017-05-03.

Policy and Regulatory Strategies

China's NEV promotion policies vary by region. At the national level, however, Beijing has put in place a system of consumer subsidies and pressure on producers. In 2011, the Ministry of Finance committed 100 billion yuan (USD 15.6 billion) to support the development of the NEV industry from 2011 to 2020. Specifically, China set out 50 billion yuan (USD 7.8 billion) for the purpose of investing in the research and production of key technologies for NEVs. Much of these funds manifest operationally in the form of concessional loans from state-owned banks to NEV production lines.[56]

In 2012, the central government announced its intent to invest 15 billion yuan (USD 2.3 billion) to stimulate NEV consumption over the next 10 years.[57] Using subsidies from the Ministry of Finance, consumers in China are able to reduce costs when buying NEVs. The Chinese central government generally subsidizes NEV purchases by up to 50,000 yuan (USD 7,800) for PHEVs and 60,000 yuan (USD 9,375) for BEVs.[58] Consumers are also exempt from acquisition and excise taxes ranging in worth from 35,000 yuan to 60,000 yuan (USD 5,470 to USD 9,375).[59]

The government has begun to phase out consumer subsidies. In the NEV Subsidy 2016–2020 Plan, jointly issued by a number of Chinese ministries, the government announced that it will gradually phase out NEV subsidies by 2020, with 20% reductions each year leading up to the final cut.[60] Moreover, at the end of 2017, the Chinese government released updated subsidy allocation plans to encourage more efficient NEVs. The updated rules exclude NEVs whose driving range falls below 150km. NEVs that have a range of at least 300km remain viable for subsidies and with ranges of more than 400km are eligible for higher subsidies.[61]

Additionally, in 2017, MIIT published China's NEV Mandate policy, set to take hold in 2019. The policy, which uses elements from California's ZEV program, requires that auto companies with annual production or import volume of at least 30,000 conventional passenger cars meet credit requirements correlated to the number of NEVs produced.[62] Failure to meet NEV credit targets after adopting all possible compliance pathways will lead to MIIT denial of type approval for new models that cannot meet their specific fuel consumption standards until those deficits are fully offset. While NEV credits can be traded across companies, they do not roll over to the following year.[63] Credits appropriation varies by NEV type and range, as shown in Figure 3.

---

[56] Ou, Shiqi et al. (2017).

[57] See Zaretskaya, Victoria. "China Promotes Both Fuel Efficiency and Alternative-Fuel Vehicles to Curb Growing Oil Use." *U.S. Energy Information Agency.* May 2014. Available at www.eia.gov/todayinenergy/detail.php?id=16251#.

[58] APEC. 2017. *The Impact of Government Policy on Promoting New Energy Vehicles (NEVs).*

[59] IEA. 2017. *Global EV Outlook 2017.*

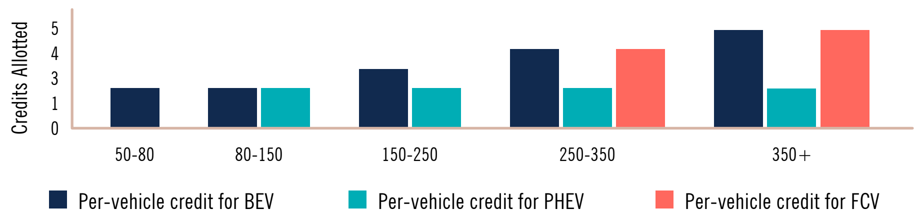
[60] MOF. 2018. *Notice on the Adjustment and Improvement of the New Energy Automobile Promotion and Application of Fiscal Subsidy Policy.*

[61] See Dixon, Tim. "Chinese Electric Vehicle Subsidy Changes in 2018 – The Details." *CleanTechnica.* January 2018. Available at https://cleantechnica.com/2018/01/06/chinese-electric-vehicle-subsidy-changes-2018-details/.

[62] See, for instance, Perkowski, Jack. "How China Is Raising the Bar with Aggressive New Electric Vehicle Rules." *Forbes.* October 2017. Available at www.forbes.com/sites/jackperkowski/2017/10/10/china-raises-the-bar-with-new-electric-vehicle-rules/#708e38ca77ac.

[63] With the exception of 2019–2020. ICCT. 2018. *China's New Energy Vehicle Mandate Policy.*

FIGURE 3. NEV CREDIT ALLOTMENT BY TYPE AND RANGE (KM)



Source: ICCT. 2018. *China's New Energy Vehicle Mandate Policy.*

At the local level, policymakers have deployed many strong pull incentives to accelerate EV adoption. For example, NEV consumers are often exempt from license plate fees and restrictions, which are commonplace in many first-tier cities. In Beijing, where more than 2.72 million people compete in a lottery for 90,000 licenses, EV owners are exempt from the license plate lottery. In Shanghai, where license plate fees can cost up to 80,000 yuan (USD 12,500), NEV consumers are exempt from paying the fee. In cities such as Beijing and Wuhan, NEVs are also exempted from road space rationing and lane restrictions originally intended for traffic mitigation. Due to these pull factors set in place by local governments, 70% of NEV sales in China occur in just six cities, which all happen to restrict license plates.[64]

Key Challenges

As EV sales have rapidly accelerated over the past half-decade, the demand for residential charging has increased tremendously. In China, where most people live in apartments, the availability of electricity charging is a primary concern for prospective NEV buyers. In a survey of China's NEV market conducted by University of California–Davis, only 45% of Beijing respondents indicated that they had access to a private charger. Another 13% resorted to using an unsafe "fly-line" from their home wall outlets, usually through windows. Only 42% of the respondents agreed that "it is convenient to find a charger near residential community."[65]

To address this bottleneck, China plans to deploy 4.3 million private electric vehicle service equipment outlets, 0.5 million public chargers for cars, and 850 intercity quick-charge stations by 2020.[66] Local governments are eligible to receive 90 million yuan (USD 14 million) to build charging stations depending on their ability to reach EV purchase benchmarks.[67]

Another obstacle to China's EV transition is cost. Currently, NEV sales are supported by consumer subsidies to mitigate any price disadvantage for NEVs. As the government phases out consumer subsidies, there is concern that demand for NEVs will cool. In effect, however, NEV sales figures have continued to accelerate year-over-year even as subsidies recede. On the other hand, NEV manufacturers have reported significant declines in

[64] See, for instance, Clover, Charles. "Subsidies Help China Sell the Most Electric Cars." *Financial Times.* October 2017. Available at www.ft.com/content/18afe28e-a1d2-11e7-8d56-98a09be71849.

[65] Xing et al. (2016).

[66] IEA. 2017. Global EV Outlook 2017.

[67] See Lu, Jieyi. "Comparing U.S. and Chinese Electric Vehicle Policies." *Environmental and Energy Study Institute.* February 2018. Available at www.eesi.org/articles/view/comparing-u.s.-and-chinese-electric-vehicle-policies.

profitability following the retrenchment of subsidies, indicating their vulnerability to policy shifts.[68] Automakers may have relief in the near future, though. Due to advances in battery technology, UBS forecasts that EVs will reach lifetime price parity with internal combustion engine (ICE) vehicles by 2023 in China.[69]

BUILDING ENERGY: CHINA'S TRANSITION AWAY FROM COAL-BASED HEATING

China has targeted heating as a key sector for reform in its efforts to achieve clean air. But its rapid rate of policy implementation has led to unforeseen side effects.

Environmental Challenges

Coal-based heating is a principal contributor to air pollution in China. Reliance on coal-based heating correlates to smog-level variance across seasons and geographies. A study of 14 Chinese cities shows that $PM_{2.5}$ concentrations in winter are three times higher than in summer.[70] Moreover, a 2013 joint study by Tsinghua University, the Massachusetts Institute of Technology, and Hebrew University of Jerusalem found that Northern China, which employs central heating systems primarily fueled by coal[71,72] had a level of particulate matter that was 55% higher than in the south.[73] Thus, as Beijing strives to limit air pollution, reducing use and intensity of coal-based heating is imperative.

In 2016, Northern China's urban heated floor area spanned 14.1 billion square meters and rural heated floor area was 6.5 billion square meters. Urban areas are mainly serviced through centralized district heating systems (DHS), which have higher energy efficiency than decentralized boilers common in rural areas. As a result, the average rural house consumes 40% more energy for heating per square meter than its urban counterpart.[74] Currently, coal is the primary source of energy for floor heating, accounting for about 83% of the total heated floor area, while natural gas, renewables, and industrial waste heat jointly contribute around 17%.[75]

Technology Goals

In recent years, China has adopted a series of policy and regulatory strategies to combat air pollution. These include large-scale national policies, such as the 2013 Air Pollution Prevention and Control Action Plan ("the Action Plan") and ambitious air quality goals in recent five-year plans, among others. According to the

---

[68] See, for instance, "China's New Energy Automakers Dealing with Subsidy Cut." *Xinhua.* May 2018. Available at www.xinhuanet.com/english/2018-05/18/c_137188711.htm.

[69] See, for instance, Campbell, Peter. "Electric Car Costs Forecast to Hit Parity with Petrol Vehicles." *Financial Times.* May 2017. Available at www.ft.com/content/6e475f18-3c85-11e7-ac89-b01cc67cfeec.

[70] Cao, Junji et al. (2012).

[71] Huai River and Qinling Mountains divide north and south for the access to central heating in their homes six decades ago.

[72] Northern China includes the 14 provinces of Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Shaanxi, Gansu, Ningxia, Xinjiang and Qinghai, as well as some parts of Henan Province.

[73] Chen, Yuyu et al. (2013).

[74] See Myllyvirta, Lauri and Anders Hoves. "Analysis: How to Fix China's Botched Heating Policy." *The China Dialogue.* December 2017. Available at www.chinadialogue.net/article/show/single/en/10308-Analysis-How-to-fix-China-s-botched-heating-policy.

[75] NDRC. 2017). *Clean Winter Heating Plan for Northern China (2017-2021).*

Action Plan, small coal-fired boilers will be required to reduce particulate matter, NO_X, and sulfur dioxide (SO_2) emissions.[76] The plan also designates China's intent to accelerate the process of converting coal to natural gas or to electricity in the heating sector.

In December 2017, the National Development and Reform Commission (NDRC), the National Energy Administration, and eight other agencies jointly released *Clean Winter Heating Plan for Northern China (2017–2021)* ("the Plan"), in which the government set out its goals for transitioning to cleaner heating practices. The Plan calls for clean heating energy to replace bulk coal heating at a rapid pace, with clean heating making up 50% of heated floor area by 2019 and 70% by 2021. According to the Plan, these clean fuels will replace 150 million tons of China's scattered coal used for heating by 2021. As seen in Table 2, natural gas, clean coal, and renewables are set to play a major role in China's shift away from coal-based heating.[77]

TABLE 2. CHINA'S HEATING GOALS BY ENERGY TYPE

HEATING SOURCE	2016 FLOOR AREA COVERED (MILLION SQUARE METERS)	PERCENTAGE OF TOTAL HEATING	2021 FLOOR AREA COVERED (MILLION SQUARE METERS)	PERCENTAGE OF TOTAL HEATING	FLOOR AREA GROWTH
Clean Coal-Fired Centralized Heating	3,500	17%	11,000	34%	214%
Natural Gas	2,200	11%	6,800	21%	209%
Electric Heating	400	2%	1,500	5%	275%
Biomass	200	1%	2,100	6%	950%
Geothermal	500	2.50%	1,000	3%	100%
Solar	N/A	0%	50	0.2%	N/A
Industrial Waste	100	>1%	200	1%	100%

Energy demand efficiency has also been a central goal of the Chinese government. China's 12th Five-Year Plan outlined Beijing's intention to bolster standards for new buildings and expand energy efficiency programs. In the 13th Five-Year Plan, the NDRC called for further heightened stringency and compliance with building energy codes.[78] Moreover, China's intended nationally determined contribution (INDC) to the Paris climate accords addresses the need to create energy efficient buildings and sets a target for green buildings to comprise half of newly built buildings in cities and towns by 2020.[79]

---

[76] MEP. 2013. *The State Council Issues Action Plan on Prevention and Control of Air Pollution Introducing Ten Measures to Improve Air Quality.*

[77] NDRC. 2017. *Clean Winter Heating Plan for Northern China (2017–2021).*

[78] NDRC. 2016. *The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China.*

[79] Yu, Sha (2016).

Policy and Regulatory Strategies

China's heating policy can be traced back to the Mao era. During that central planning period, the Chinese government established free winter heating[80] of homes and offices as a basic right via the provision of free coal fuel for boilers. Due to budgetary limitations, however, this right was extended only to areas located in Northern China above the Huai River line.

More recently, to accelerate the adoption of natural gas in heating, the government has made significant investments in regasification terminals at Tangshan and Tianjin as well as gas pipelines through its western provinces. Additionally, in March 2017, the then China's Ministry of Environmental Protection (MEP),[81] with support from the NDRC, the Ministry of Finance (MoF), the National Energy Bureau (NEB), and several municipal governments, issued a 2017 Work Plan on Atmospheric Air Pollution Prevention and Control for Beijing-Tianjin-Hebei (Jing-Jin-Ji) and Its Neighboring Areas. In the document, the MEP required 50,000 to 100,000 households in each of the 28 cities to replace coal heating systems by the end of October 2017.[82] Accordingly, during 2017 more than 1 million users in the Beijing-Tianjin-Hebei area converted from traditional coal to gas.[83]

In May 2017, the MEP, in conjunction with the MoF, Ministry of Housing and Urban Rural Development (MoHURD), and the NEB, chose 12 cities to take part in clean heating pilot work. The selected cities include Tianjin, Taiyuan, and Zhengzhou, among the most polluted cities in the country. Selected cities are tasked with finding innovative ways to use clean energy sources for heating that suit local conditions. According to this trial plan, these 12 cities will receive a total of 21.9 billion yuan (USD 3.4 billion) in the next 3 years to support their transition to clean heating. Additionally, local finance agencies will invest around 69.7 billion yuan (USD 10.9 billion) to support the implementation of the plan.[84]

Local governments have also developed their own clean heating strategies. In March 2017, several ministries and provincial governments jointly issued a document calling for each city in the 26+2 region to set a target to replace coal stoves with gas boilers or electric heaters in 50,000 to 100,000 homes by the end of October.[85] In Beijing alone, the municipal government has ordered the installation of electric heating in millions of village homes near Beijing to cut winter coal burning.[86]

Provincial governments have also heavily subsidized the transition from coal to electric power. For example, Shanxi Province reimburses two-thirds of the cost of heating for those who switch to electric heating. Residents of Hebei Province who switch to electric heating save 0.2 yuan per kilowatt/hour (kWh), and those in Gansu province save an average of 0.2 yuan per kWh, as well as enjoy a two-hour extension period of minimum rates.[87]

---

[80] Winter refers to the period between November 15 and March 15.

[81] The name was recently changed to Ministry of Environment and Ecology.

[82] MEP. 2017. *The 2017 Air Pollution Prevention and Control Work Plan for Beijing, Tianjin, Hebei and Surrounding Areas Is Released and Focuses on Controlling of Pollution from Diesel Trucks in the 26+2 Cities.*

[83] See, for instance, "'Coal to Electricity' Gains Momentum, Heat Pumps Make Entrance into Thousands of Homes gradually." *Sina.* March 2018. Available in Mandarin at http://k.sina.com.cn/article_6438154626_17fbe71820010056kz.html.

[84] See, for instance, "A Total of 21.9 Billion Yuan Was Awarded to 12 Cities to Trial of Clean Winter Heating." *China News.* September 2017. Available in Mandarin at www.chinanews.com/gn/2017/09-19/8335086.shtml.

[85] See Li, Jing. "What Caused China's Squeeze on Natural Gas?" *The China Dialogue.* December 2017. Available at www.chinadialogue.net/article/show/single/en/10322-What-caused-China-s-squeeze-on-natural-gas.

[86] The Beijing Municipal Government. 2017. *Notice on the 2017 Village Winter Clean Heating Work Plan.*

[87] See, for instance, "'Coal to Electricity' Gains Momentum, Heat Pumps Make Entrance into Thousands of Homes Gradually." *Sina.* March 2018. Available in Mandarin at http://k.sina.com.cn/article_6438154626_17fbe71820010056kz.html.

The reform efforts have been particularly ambitious in the heart of China's coal economy. In October 2017, officials of Taiyuan, the capital of China's coal hub Shanxi Province, banned the sale, transport, and burning of coal by individuals, companies, and most power plants excluding several major steel and power plants. According to the city's environmental protection bureau, the ban is expected to reduce coal use by 2 million metric tons (2.2 million tons), or about 90% of the total coal consumption in the city of more than 3 million. Alternatively, during the 2017–2018 winter the city planned to heat some 134,000 households with renewable energy or natural gas.[88]

These and other efforts to control pollution have borne fruit. In the last quarter of 2017, according to data from Greenpeace, the concentrations of PM2.5 plunged by 33% in Beijing, Tianjin, and 26 surrounding cities compared with the last three months of 2016.[89] Beijing authorities also noted that by the end of 2017, the city had achieved its air pollution reduction targets set out under the city's 2013–2017 pollution prevention action plan.[90]

Key Challenges

The implementation of China's clean heating initiative faces several key challenges, including a lack of clear substitutes for coal, higher costs for consumers, and unclear environmental benefits with electricity unless electricity gets cleaner.

In the heating sector, transitions from coal to gas are limited by significant supply constraints, such as insufficient infrastructure and domestic production. These constraints were made notably visible during the winter of 2017, when many northern cities faced natural gas shortages. In the periods leading to the winter of 2017, many local governments in Beijing and the surrounding region invested in equipping households with gas boilers or electric heaters. Of the retrofits, natural gas boilers made up 84% of the replacements and electric heating just 16%, likely due to perceived affordability of gas and the worry that electric heating might pose further strains to the power sector.[91,92]

While the MEP's initiative was largely successful, achieving an estimated 1 million retrofits above the 3 million target, the mass transition of fuel source led to unforeseen problems. The meteoric rise in natural gas heating appliances boosted the price of gas to a three-year high when temperatures dipped below freezing in the first week of December.[93] This surge in price proved especially challenging for rural populations that lack central heating systems and aimed to transition away from coal. Additionally, many families with new gas and electric appliances expressed that the new appliances did not produce as much heat as their coal-based counterparts.[94] Reports emerged of schools conducting classes outside to gain heat from the sunlight and

---

[88] See Feng, Coco. "China's Coal Hub Bans Coal." *Caixin.* October 2017. Available at www.caixinglobal.com/2017-10-03/101153185.html.

[89] Greenpeace. 2018. *Analysis of Air Quality Trends in 2017.*

[90] Zhang, Hang. "Beijing Completes the National 10 Air Task Targets, Achieves More and More Blue Skies." *Beijing Evening News.* January 2018. Available in Mandarin at www.bjd.com.cn/jx/toutiao/201801/03/t20180103_11077920.html.

[91] Hove, Andrew (2017).

[92] See Li, Jing. "What Caused China's Squeeze on Natural Gas?" *The China Dialogue.* December 2017. Available at www.chinadialogue.net/article/show/single/en/10322-What-caused-China-s-squeeze-on-natural-gas.

[93] The price of LNG in the first 10 days of December hit 6,967 yuan per ton (USD 1,053), which represented a 23.6% increase compared with the previous 10 days. He, Huifeng. "Why Winter Heating Crisis Will Not Stop China's Dash for Gas." *South China Morning Post.* December 2017. Available at www.scmp.com/news/china/economy/article/2124590/why-winter-heating-crisis-will-not-stop-chinas-dash-gas.

[94] See Meng, Meng and Aizhu Chen. "China Villagers Hail First Gas-Fired Heat for Winter, but Balk at Higher Bills." Reuters. November 2017. Available at www.reuters.com/article/us-china-pollution-gas-heating/china-villagers-hail-first-gas-fired-heat-for-winter-but-balk-at-higher-bills-idUSKBN1DF1IY.

arrests over illicit use of coal heaters.[95] In light of this, MEE announced on December 7 that households in the region would not be penalized for using coal-based appliances, reversing previous policy directives.[96]

Beyond the soaring demand, the slow construction of pipelines to import more supply and the lack of gas storage facilities also significantly contributed to the gas shortage.[97] Moreover, the NDRC expects Chinese annual gas demand to reach to 450 billion cubic meters by 2030, nearly double China's 2017 consumption. To meet this demand, China must invest in enhanced production, transportation, and storage infrastructure or else risk future gaps between policy targets and operational capacity similar to that seen in winter 2017. In light of this, China has announced plans to have 104,000km of domestic pipelines by 2020, triple underground gas storage capacity, and raise domestic production to 207 billion cubic meters in 2020 from 135 billion cubic meters in 2015. Additionally, China is in the process of building three new international natural gas pipelines as shown in Table 3.[98]

TABLE 3. CHINA'S NATURAL GAS PIPELINE CAPACITY

PIPELINE	STATUS	CAPACITY (BILLION CUBIC METERS/YEAR)
Central Asia Pipeline	Existing	55
Myanmar Pipeline	Existing	12
4th Central Asian Line	Planned	30
Power of Siberia	Planned	38
West Siberia – Altai Project	Planned	30

Another bottleneck obstructing China's smooth transition to cleaner heating is the lack of competition in China's natural gas market. To incentivize more players to enter this field, China has focused on rolling out pricing mechanisms in the sector.[99] In 2015, China liberalized gas prices for nonresidential customers. And in 2016, China announced that it would grant a flat 8% return on investment for interprovincial pipeline projects. Moreover, natural gas markets popped up in Shanghai and Chongqing in 2016, with the purpose of assisting in boosting competition and revealing true prices.[100]

[95] See Li, Jing. "What Caused China's Squeeze on Natural Gas?" *The China Dialogue.* December 2017. Available at www.chinadialogue.net/article/show/single/en/10322-What-caused-China-s-squeeze-on-natural-gas.

[96] See Wyns, Arthur and Katharina Wecker. "China's U-turn on Rapid End to Coal Heating." *DW.* December 2017. Available at www.dw.com/en/chinas-u-turn-on-rapid-end-to-coal-heating/a-41816867.

[97] See Xin, Zhengg. "Suppliers Take Steps to Tackle Gas Shortage." *China Daily.* December 2017. Available at www.pressreader.com/china/china-daily-usa/20171220/281492161676952

[98] Abache, Abreu et al. (2018).

[99] Hove, Andrew (2017).

[100] As of 2017, these two markets facilitated too low trade volume for full-price discovery according to consultancy IHS CERA.

HEAVY-DUTY VEHICLES: POLLUTION CONTROL AND ALTERNATIVE FUELS FOR CHINA'S HEAVY-DUTY VEHICLE FLEET

China has taken aggressive steps to reduce pollution from heavy-duty vehicles, focusing on emissions and fuel efficiency standards for new vehicles; alternative fuel buses and trucks are beginning to make inroads.

Environmental Challenges

According to a 2014 World Health Organization (WHO) review of the sources of ambient PM around the world, traffic contributed 15% and 18% urban ambient $PM_{2.5}$ concentration in Northern and Southern China, respectively, and 25% and 17% to the PM_{10} concentration.[101] Large cities are especially at risk from air pollution. The former Ministry of Environmental Protection stated that in megacities such as Beijing, Shanghai, and other eastern cities with dense urban populations, mobile sources contributed to 20%–40% of total $PM_{2.5}$ concentration – up to 50% in extremely unfavorable circumstances.[102]

Among all types of vehicles, heavy-duty vehicles (HDVs) are the largest contributor to air pollution. As of 2016, there were 9.3 million HDVs in China, accounting for 5% of China's total vehicles. However, HDV contributions to $PM_{2.5}$ emissions were one to two orders of magnitude greater than those from their light-duty counterparts. Specifically, HDVs constituted 85% of all vehicle PM emissions as well as 84% of all vehicle NO_x emissions, 35% of all vehicle carbon monoxide (CO) emissions, and 43% of all vehicle hydrocarbon (HC) emissions in China.[103] In Beijing alone, while HDVs accounted for only 4% of vehicles in the city, their emissions of NOX and PM made up 50% and 90%, respectively, of total vehicle emissions.[104]

Technology Goals

To address air pollution from HDVs, China has set increasingly stringent emission and fuel standards for new HDVs. These standards regulate emissions from HDV engines and fall under the jurisdiction of the Ministry of Ecology and Environmental (MEE, previously Ministry of Environmental Protection, MEP). The standards, China I, II, III through VI, are largely based on those developed in Europe.[105] The most recent standard, China VI, was drafted in 2016 and is set for nationwide implementation in 2020.[106]

To enforce these standards, many cities have created a color-based labeling system to indicate compliance. Figure 4 demonstrates Beijing's color-labeling system for HDVs. In the 2013 Action Plan for Prevention and Control of Air Pollution, the State Council designated that by 2015, China will phase out all yellow-label vehicles (YLVs) registered before the end of 2005 and all other YLVs by 2017.[107]

---

[101] WHO (2014).

[102] MEP. 2017. *China Motor Vehicle Environmental Management 2017 Report.*

[103] MEP. 2017. China Motor Vehicle Environmental Management 2017 Report.

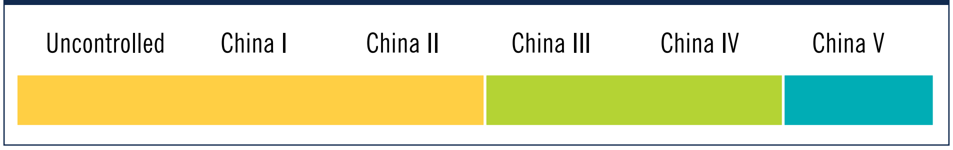
[104] See, for instance, You, Du. "Beijing Restricts Heavy-Duty Diesel Use to Reduce Vehicle Gas Emissions," *China Daily.* February 2013. Available at www.chinadaily.com.cn/cndy/2018-02/13/content_35694925.htm.

[105] See "China: Heavy-Duty: Emissions ." *TransportPolicy.net.* Available at www.transportpolicy.net/standard/china-heavy-duty-emissions/.

[106] MEP. 2016. *Request for Environmental Protection Standards on the 'Vehicle Compression Ignition Spark Engines, Gas, Fuel and Car Exhaust Pollutant Emission Limits and Measurement Methods (China phase 6) (draft)' Opinion Letter.*

[107] State Council. 2013. *The State Council Notice Regarding the Air Pollution Action Plan.*

FIGURE 4. BEIJING'S COLOR CLASSIFICATION FOR HDVS



Individual municipalities also set goals to reduce HDV emissions in their jurisdictions and can preemptively apply standards on the condition of State Council approval. Beijing, in particular, has consistently implemented engine standards ahead of national timelines since 1999.[108] In 2016, Beijing's Municipal Environmental Protection Bureau announced that it aims to eliminate heavy-duty diesel vehicles below China IV standard, and light-duty buses failing to meet China III standards by 2020.[109] In recent years, Beijing has also set targets for inspection quotas. For example, Beijing's Municipal Environmental Protection Bureau announced plans to inspect 840,000 HDVs in 2017, citing a 20% increase from the prior year.[110]

Fuel standards are another method through which Chinese authorities aim to limit HDV emissions. In China, while HDVs represent about 10% of the new vehicle market, they make up almost 50% of China's total on-road fuel use.[111] Thus, MIIT, through its subagency the China Automotive Technology and Research Center (CATARC), has developed fuel standards that regulate the maximum fuel levels that HDVs can consume.

In 2012, CATARC implemented its first phase of standards, known as the Industry Standard. Subsequently, CATARC updated the standard in 2015 to a more comprehensive National Standard, which narrowed fuel consumption limits for new HDVs by 10.5% to 14.5%.[112] Still, China's average HDV fuel consumption remains higher than those in the U.S. and Japan by around 10%–15%. To close this gap, CATARC released plans for Stage 3 HDV standards in 2016, which are set for 2019 implementation. The new standard aims to reduce HDV fuel consumption by 15% in 2020 based on 2015 levels.[113]

Chinese policymakers have also taken active measures to introduce alternative fuel HDVs, specifically fuel cell HDVs. In Shanghai's 2017 Fuel Cell Vehicle Development Plan, local officials announced targets to raise production of fuel cell vehicles to 3,000 units a year and install 10 hydrogen filling stations by 2020.[114] In 2018, Shanghai deployed 500 HDVs powered by fuel cell technology primary purposed for intra-city delivery of goods. The fleet was produced by automaker Dongfeng and uses Canadian fuel cell company Ballard's fuel cell stack technology.[115]

---

[108] See "China: Heavy-Duty: Fuel Consumption." *TransportPolicy.net.* Available at www.transportpolicy.net/standard/china-heavy-duty-fuel-consumption/.

[109] See, for instance. "Beijing to Eliminate Higher Emission Vehicles by 2020," *GBTimes.* May 2016. Available at https://gbtimes.com/beijing-eliminate-higher-emission-vehicles-2020.

[110] See, for instance, Luo, Qianwen. "Jing-Jin-Ji Inspection of Heavy Duty Diesel Emissions." *Beijing Evening News.* March 2017. Available in Mandarin at www.bjd.com.cn/jjj/yaowenzhanshi/201703/29/t20170329_11055908.html.

[111] Delgado, Oscar (2018).

[112] See "China: Heavy-Duty: Fuel Consumption." *TransportPolicy.net.* Available at www.transportpolicy.net/standard/china-heavy-duty-fuel-consumption/.

[113] Delgado, Oscar (2018).

[114] See, for instance, "Shanghai: Hydrogen Fuel-Cell Cars Will Be Put into Public Service in 2019." *Xinhua.* April 2018. Available at www.xinhuanet.com/power/2018-04/20/c_129854602.htm.

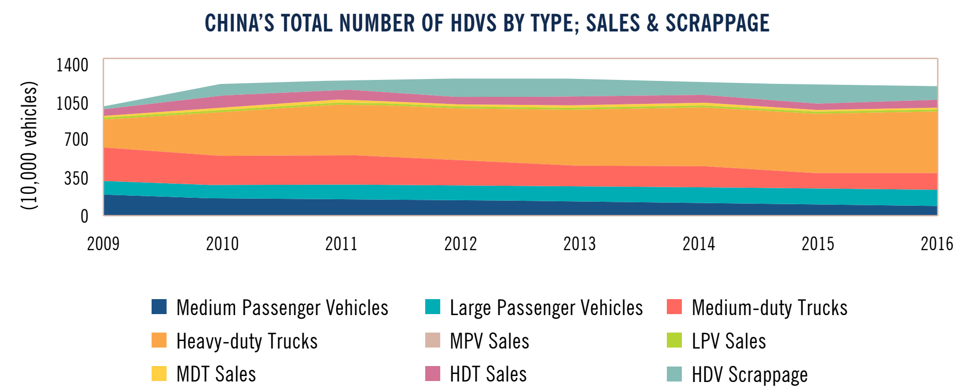
[115] See, for instance, Manthey, Nora. "500 H2 Trucks by Dongfeng Powered by Ballard Fuel Cells." *Electrive.* Febraury 2018. Available at www.electrive.com/2018/02/14/500-h2-trucks-dongfeng-powered-ballard-fuel-cells/.

Policy and Regulatory Strategies

National and local governments in China have developed a range of policy and regulatory tools to enforce emission and fuel standards. China uses similar inspection and monitoring (I/M) mechanisms as the U.S. to manage existing vehicles. Since 1999, China has implemented periodic environmental inspection and mandatory environmental labeling policies. However, in 2017, China canceled its environmental label-testing requirement and, for the sake of bureaucracy minimization, incorporated the test into the mandatory annual safety inspection.[116]

To incentivize owners of outdated vehicles to replace them, 10 ministries jointly issued the Vehicle Replacement Implementation Method in 2009, which established scrappage subsidy standards. According to the latest available data, new HDV sales each year that fall under the mandate of the latest emission standards account for around 12% of China's total HDVs, while the net growth rate of the number of HDVs is only around 2%, as demonstrated in Figure 5.[117] This means that China's HDV scrappage rate is catching up with the new vehicles growth rate, which allows the new vehicle emission standards to have a relatively high impact potential.

FIGURE 5. CHINA'S HDV SALES



In 2017, Beijing inspected more than 20 million in-use vehicles and found 58,000 HDVs that did not comply with minimum standards.[118] Beijing also prohibited HDVs that fail to meet China III emission standards from entering Beijing's urban core, designated as anywhere inside the 6th ring road. Additionally, in November 2017, Beijing, Tianjin, and the 26 other cities (known as the "2+26" cities) mandated the substitution of China VI–qualified vehicle fuel for any lower-standard fuel, including both gasoline and diesel, in advance of the national schedule.[119]

---

[116] This is also because all yellow-labeled vehicles should have been eliminated by 2017 according to the Air Pollution Prevention Action Plan issued in 2015.

[117] HDV sales by type each year are calculated with data from the China Association of Automobile Manufacturer's 2016 and 2015 annual China automobile industry reports. Total numbers of each type of HDV by year are taken from MEP's 2013–2017 annual motor vehicle environmental reports. Scrappage each year (year "n") is calculated by author using formula "scrappagen=salesn-net increasen= salesn-(total HDVn- total HDVn-1)".

[118] See You, Du. "Beijing Restricts Heavy-Duty Diesel Use to Reduce Vehicle Gas Emissions," *China Daily.* February 2013. Available at www.chinadaily.com.cn/cndy/2018-02/13/content_35694925.htm.

[119] SAIC. 2017. *Announcement of a Nationwide Supply of Diesel Fuel with Sulphur Content Less Than 10ppm.*

As a result of the high proportion of HDV traffic devoted to commercial freight, Chinese localities have also approached HDV emission reductions through regulating ports. In the MEP's 2017 Beijing-Tianjin-Hebei and Surrounding Areas Air Pollution Prevention and Control Work Plan, the agency mandated that ports along the Bohai rim discontinue accepting coal from diesel HDVs and instead amplify train freight of coal.[120] In the Tianjin port, officials have banned HDVs from entering altogether on high-pollution days and only permit standard-abiding HDVs on other days.[121] Officials expect that the policy will cut emissions from 4 million diesel HDVs annually.[122]

China also aims to reduce HDV emissions through incentivizing alternative fuels. Subsidy amounts are calculated by comparing the subsidy amount weighted for kilowatt hours (kWh) versus the subsidy upper limit. The kWh metric refers to the vehicle's battery capacity relative to the amount of energy needed to sustain one kW over the period of an hour. The lower figure of those is then multiplied by the adjustment coefficients, as illustrated in Table 4.[123]

<table>
<tr><th colspan="8">TABLE 4. SUMMARY OF HDV SUBSIDIES AS OF 2018</th></tr>
<tr><th rowspan="2">HDV TYPE</th><th rowspan="2">NATIONAL SUBSIDY (RMB/ KWH)</th><th rowspan="2" colspan="3">ADJUSTMENT COEFFICIENTS</th><th colspan="3">SUBSIDY UPPER LIMIT (RMB) (L = HDV LENGTH)</th></tr>
<tr><th>6<L≤8M</th><th>8<L≤10M</th><th>L>10M</th></tr>
<tr><td rowspan="3">Fast-Charging BEV Bus</td><td rowspan="3">2100</td><td colspan="3">Charging Speed of Batteries (CS)</td><td rowspan="3">40,000</td><td rowspan="3">80,000</td><td rowspan="3">130,000</td></tr>
<tr><td>3C–5C</td><td>5C–15C</td><td>15C+</td></tr>
<tr><td>0.8</td><td>1</td><td>1.1</td></tr>
<tr><td rowspan="3">Non-Fast-Charging BEV Bus</td><td rowspan="3">1200</td><td colspan="3">Battery Energy Density (BD, Wh/kg)</td><td rowspan="3">55,000</td><td rowspan="3">120,000</td><td rowspan="3">180,000</td></tr>
<tr><td colspan="2">115–135</td><td>135+</td></tr>
<tr><td colspan="2">1</td><td>1.1</td></tr>
<tr><td rowspan="3">PHEV Bus</td><td rowspan="3">1500</td><td colspan="3">Fuel Economy Rate</td><td rowspan="3">22,000</td><td rowspan="3">45,000</td><td rowspan="3">75,000</td></tr>
<tr><td>60%–65%</td><td>65%–70%</td><td>70%+</td></tr>
<tr><td>0.8</td><td>1</td><td>1.1</td></tr>
<tr><td>FCEVs</td><td colspan="4"></td><td colspan="3">500,000</td></tr>
</table>

[120] MEP. 2017. *Notice on the Issuance of the 2017 Air Pollution Prevention and Control Work Plan for Beijing, Tianjin and Hebei Areas.*

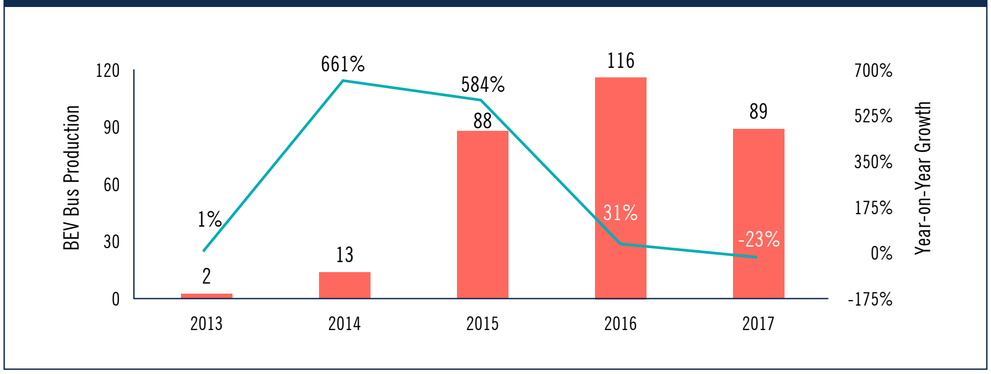
[121] See Needham, Kristy. "In China, the War on Coal Just Got Serious." October 2017. Available at www.smh.com.au/world/in-china-the-war-on-coal-just-got-serious-20171011-gyyvi6.html.

[122] See Zheng, Yiran. "NPC Deputies: Beijing-Tianjin-Hebei Cluster to Further Enhance Integrated Development." *China Daily.* March 2018. Available at www.chinadaily.com.cn/a/201803/09/WS5aa2471fa3106e7dcc140b26.html.

[123] MEP. 2018. *Notice on the Adjustment and Improvement of the New Energy Vehicle Promotion Subsidy Policy.* Available in Mandarin at http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/201802/t20180213_2815574.html.

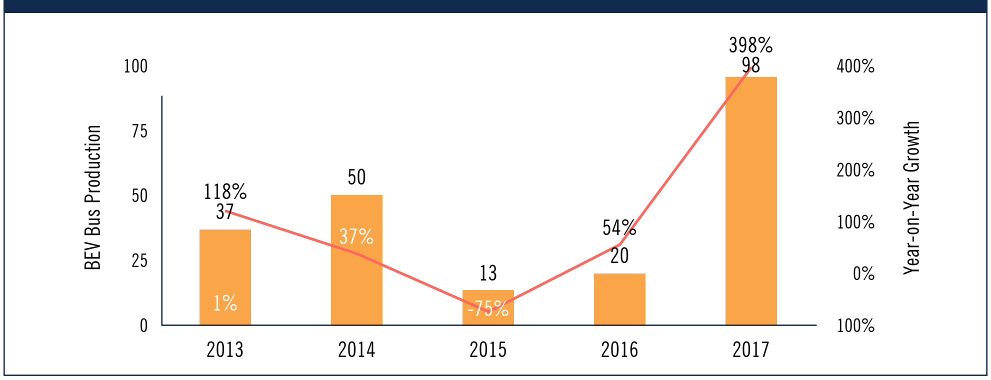
These incentives, in conjunction with advances in technology, have spurred robust growth in the sector, as exemplified by the BEV bus production trend shown in Figure 6.[124] Additionally, China's fuel cell bus production reached 173 in the first five months of 2018, vis-à-vis 10 during the same period last year.[125]

FIGURE 6. CHINA BEV BUS PRODUCTION



Moreover, China has also steadily promoted transition to natural gas–fired HDVs. Specifically, NDRC's 2017 "Opinion Document on Accelerating the Utilization of Natural Gas" emphasized the need to transition to natural gas–fired HDVs in the Beijing-Tianjin-Hebei region.[126] In the aftermath of this directive, China's natural gas truck production has skyrocketed since 2017, as seen in Figure 7.[127]

FIGURE 7. CHINA'S NATURAL GAS TRUCK PRODUCTION



[124] The year 2017 saw a slight decline in BEV sales due to China's rollback of its NEV subsidy, which takes place gradually between 2014 and 2020. For more information on China's subsidy rollback, see the ICCT's 2017 *Adjustments to Subsidies for New Energy Vehicles report.* Available at www.theicct.org/sites/default/files/publications/China-NEV_ICCT_policy-update_17052017_vF.pdf.

[125] See, for instance, Xie, Guangyao. "Electric Vehicles Sales Top 14,000, Surging 782%, with the Help of a Hundred Fuel Cell Vehicles." 第一商用车网. June 2018. Available in Mandarin at https://mp.weixin.qq.com/s?__biz=MjM5NDI0NTQyMA==&mid=2650967076&idx=1&sn=31e5d8c6c6dcfeb1c757d24db079f60d&chksm=bd7c92678a0b1b71a434a45c61a48223f9849238ae755975b522f539e7faa61fbc3047c7b93d&scene=0#rd.

[126] NDRC. 2017. *Suggestions on Accelerating the Use of Natural Gas.*

[127] See, for instance, Xie, Guang Yao. "The First Commercial Vehicle Network Hits Record High of 96,000 Units in 2017." *CVWorld.cn.* January 2018. Available at http://cvworld.cn/news/sycnews/guangyao/180118/141943.html.

Key Challenges

One of the largest obstacles to advanced emission control technologies for HDVs and alternative fuel HDVs is cost. According to preliminary estimates, at the initial stage of implementing the standard, the cost of the engine will increase from 20,000 to 30,000 yuan (USD 3,125 to 4,690) from China V to China VI. Similarly for alternative fuels, according to Sinopec, a heavy-duty Liquified Natural Gas (LNG) truck is about 30,000 to 50,000 yuan (USD 4,690 to 7,815) more expensive at purchase than a diesel truck. However, assuming a mileage per year of 150,000 kilometers and LNG/diesel relative price of 0.6 (as of mid-2017), an LNG truck of the same capacity can save nearly 140,000 yuan (USD 21,875) in fuel costs compared to heavy diesel trucks.[128]

Additionally, due to the pressure that new standards impose on producers, inability to turn over inventory of HDVs has caused friction in transitioning between standard phases. This has been exacerbated by fraudulent activity on the part of HDV operators and a lack of accountability among test sites. In January 2018, MEP issued fines worth more than 38 million yuan (USD 5.94 million) to Shandong-based Kama Automobile Manufacturing and Shandong Tangjun Ouling Automobile Company on the charge that the companies engaged in emissions fraud, specifically highlighting the companies' tampering of OBD systems to pass emission tests.[129] While this marked the first public case of applying fines to an automotive company for disobeying China's air pollution regulation, reports from industry insiders remark that such practices are not uncommon due to heavy economic competition and financial burden on the part of drivers.[130] Moreover, while coverage of testing facilities and the rate of compliance have significantly increased, local testing facilities are rarely held accountable for correctly implementing standards. It is reported that more than 98% of the "short transient loaded mode" testing equipment has no license, and that operators could easily bypass the actual test.[131]

Environmental protection bureaus also suffer from lack of coordination with other jurisdictions. According to road tests conducted by Beijing's Municipal Environmental Protection Bureau, more than 100,000 vehicles that enter the city daily are HDVs and half are YLVs.[132] To counter this, efforts are being made toward transparency and interconnectivity of test information to enhance accountability. Currently, the Beijing-Tianjin-Hebei region is operating pilots to jointly govern HDV checks and ensure compliance across jurisdictions.

[128] See Sinopec. "China's Heavy Natural Gas Trucks Face New Development Opportunities." *Economic Information Daily.* August 2017. Available in Mandarin atl www.sinopecgroup.com/group/xwzx/hgzc/20170821/news_20170821_406387552089.shtml.

[129] See, for instance, "Two Truck Makers Hit with 38m Yuan Fine." *South China Morning Post.* January 2018. Available at www.scmp.com/news/china/policies-politics/article/2127481/chinese-truck-makers-fined-us58m-emissions-fraud-and.

[130] See, for instance, Li, Xun. "The Diesel Car Pollution Battle." *Pengpai.* June 2018. Available in Mandarin at www.sohu.com/a/238080086_260616.

[131] See, for instance, Zhang, Ke. "Why Do Experts Say China's Automobile I/M System Has Failed?" *Yicai.* February 2017. Available in Mandarin at http://m.yicai.com/news/5234242.html.

[132] See, for instance, "More Than Half of the Heavy Vehicles Entering Beijing Are Yellow Standard Vehicles." *Legal Daily.* November 2016. Available in Mandarin at http://epaper.legaldaily.com.cn/fzrb/content/20161123/Articel06008GN.htm.

APPENDIX: COMMERCIAL COLLABORATION CASE STUDIES

These case studies explore three elements of commercial and research cooperation between the U.S. and China: (1) market access, (2) finance and investment, and (3) research and development.

MARKET ACCESS

Open markets for clean technologies and their component supply chains can accelerate deployment of these technologies by driving down their costs. Expanding market access enables increased competition, which will drive down the cost of recent technologies through efficiency, innovation, and economies of scale.

This market access case study explores the challenges and successes of four companies — BYD, JinkoSolar, GE Renewable Energy, and Tesla — entering and expanding into the U.S. and Chinese markets. Each company is actively developing clean technologies and has sought to expand into new markets. All four companies have encountered challenges in entering the U.S. or Chinese market and have developed strategies that have allowed them to gain a foothold and expand. The lessons from these four companies provide insights on common challenges of market access and strategies for overcoming them.

BYD

BYD, which stands for Build Your Dreams, was founded in 1995 and is globally headquartered in Shenzhen, China. The company's primary areas of expertise consist of information technology, automobiles, rail transit, and renewable energy. Some of its products include electric vehicles, energy storage stations, and electric forklifts, among others. With roughly 220,000 employees worldwide, BYD is valued at approximately $18.4 billion.[133]

U.S. Market Presence

In 1999, BYD Company established BYD America Corp to serve as a sales branch in Los Angeles, California.[134] In October 2011, the company also created a North America headquarters in Los Angeles, which is now home to over 25 R&D and sales personnel.[135] BYD now has branches in major cities across the U.S., including San Diego, Seattle, San Jose, San Cupertino, Chicago, Austin, and New York. As of 2017, BYD's American factories, all located in California, employed more than 700 people.

---

[133] Miranda Kennedy and Steve Inskeep, November 2017, "Chinese Electric Carmaker Aims To Become A Global Brand," *National Public Radio*, available at: https://www.npr.org/sections/parallels/2017/11/06/562270850/chinese-electric-carmaker-aims-to-become-a-global-brand.

[134] Kim Kyung Hoon, January 2017, "This Chinese Automaker Wants to Be the First to Sell Cars in America," *Fortune*, available at: http://fortune.com/2017/01/19/chinese-automaker-byd-america/.

[135] BYD, April 2014, "Press Release: California Governor Jerry Brown Helps BYD Showcase Its Breakthrough Battery Technology During Unveiling of State's First Ever Long-Range Electric Bus Factory In Lancaster, Calif.," available at: http://en.byd.com//usa/news-posts/california-governor-jerry-brown-helps-byd-showcase-its-breakthrough-battery-technology-during-unveiling-of-states-first-ever-long-range-electric-bus-factory-in-lancaster-calif/.

By the end of 2017, BYD had delivered 140 electric buses to customers in the United States, with an additional 300 ordered. BYD's North American operations, earning $150 to $200 million in revenue, constitute a relatively small portion of its overall revenue. According to BYD, however, North American revenue is expected to surpass $1 billion by 2022.[136] Among BYD's various U.S. customers are public transportation authorities in California, Indianapolis, Denver, Albuquerque, and Kansas City, plus educational institutions such as Stanford, UCLA, U.C. Irvine, and U.C. San Francisco.[137]

In addition to these sales, BYD forged a partnership with ride-hailing app Uber in 2015. Uber launched a program to aid its drivers in buying or leasing cars. Through a partnership with Green Wheels USA, a car dealership in Chicago, Uber drivers can drive the BYD e6. As of March 2015, Uber drivers in Chicago were driving 25 BYD vehicles, with the long-term goal of increasing this figure to a few hundred vehicles.[138]

Issues Encountered in the U.S. Market

Despite continued expansion into the U.S. market, BYD has faced numerous issues along the way, notably consumer and industry skepticism, delays, local production requirements, and allegations of labor law infringements.

Despite BYD cars being used by Uber drivers in Chicago and New York, the company is still only selling buses and taxis in the United States and is yet to break into the passenger car market. At the beginning of 2017, BYD announced its plans to begin selling electric cars in the U.S. market within two to three years. However, BYD's deputy general manager for branding and public relations, Li Yunfei, added a caveat, noting that the plans are not set in stone since breaking into the U.S. market has not been as seamless as once expected.[139] One of the various challenges is selecting an appropriate time to break into the market, especially in the presence of various other electric vehicles. While some prior Asian entries to the U.S. automobile market have aimed to appeal to consumers via lower prices, BYD executive Stella Li noted in a 2015 interview, "We don't want to compete on price anymore, but on quality and innovation."[140]

BYD is now hoping to enter the U.S. car market by the end of the decade. The company, however, originally planned to break into the market nearly ten years ago, in 2010. At the time, inadequate preparation for a foray into the U.S. market ran into an unexpected amount of scrutiny from media, political organizations, and competing businesses. Further delays were caused by an abundance of regulations, a dearth of electric vehicle charging stations, and low overall sales numbers for electric vehicles in the United States.[141] Upon encountering this web of issues, then-president of BYD America, Michael Austin, proclaimed that "BYD's

---

[136] Nick Cox, October 2017, "E-Buses Will Help Drive Further Growth For BYD," *Seeking Alpha,* available at: https://seekingalpha.com/article/4114053-e-buses-will-help-drive-growth-byd?page=3.

[137] Joshua Bateman, January 2018, "The Biggest Electric Vehicle Company You've Never Heard Of," Fast Company, available at: https://www.fastcompany.com/40517240/the-biggest-electric-vehicle-company-youve-never-heard-of.

[138] Nichola Groom, March 2017, "Exclusive: Uber in deal with China's BYD to test electric cars," *Reuters*, available at: https://www.reuters.com/article/us-uber-byd/exclusive-uber-in-deal-with-chinas-byd-to-test-electric-cars-idUSKBN0M92KU20150313.

[139] Reuters, January 2017, "This Chinese Automaker Wants to Be the First to Sell Cars in

America," *Fortune*, available at: http://fortune.com/2017/01/19/chinese-automaker-byd-america/.

[140] Paul A. Eisenstein, January 2017, "China's BYD Again Outlines Plans to Enter U.S. Market," *The Detroit Bureau*, available at: http://www.thedetroitbureau.com/2017/01/chinas-byd-again-outlines-plans-to-enter-u-s-market/.

[141] Paulson Institute (2015)

not in a rush to come to the U.S.…We want to get it right."[142] Nearly a decade later, the company thinks it is on the verge of getting it right.

BYD's delays in the U.S. were not only limited to the car market but extended to the establishment of its North American headquarters in Los Angeles. The original plan was to set up the headquarters in 2010 and staff it with about 150 employees by the end of 2011. The company, however, ran into issues related to permitting and building renovations. As a result, when the headquarters finally opened in October 2011, it was staffed with only 20 employees.[143]

Unfortunately for BYD, after establishing its American operations, the headache continued when it faced allegations of both safety and labor violations in California. After claims that BYD manufactured buses to inadequate safety standards, accusations also surfaced that the company was paying Chinese laborers $1.50 per hour to work in its Lancaster manufacturing facilities. Not only would this have constituted a violation of minimum wage laws, but the allegations drew the ire of a public expecting the Lancaster facility jobs to go to Californians. BYD proved the pay accusations to be false, and citations against the company were dropped when it demonstrated its workers were making $12-16 per hour, in compliance with state and federal laws.[144] Despite proving the claims to be false, the protests, public outcry, and negative press coverage brought about by the allegations tarnished the image of a company hoping to win over consumer and industry skeptics.

Keys to Success in the U.S.

Despite a bumpy foray into the U.S. market, BYD has not been without success. Long before establishing its North American headquarters in Los Angeles, BYD established a subsidiary there to work with partners in the U.S. and expand its market presence. Starting in California was a strategic decision for the company, given the state's push for zero-emission vehicles and its status as the country's leader in sustainability.

Beyond the hospitability of the California market, politicians in the state aggressively courted BYD. In the hope that BYD would provide the city with manufacturing jobs and foreign investment, Los Angeles initially granted BYD tax incentives totaling nearly $2 million and federal loan guarantees worth $2.4 million to establish facilities in the city's business district. Los Angeles also included BYD in the State Enterprise Zone, providing the company with additional tax credits and deductions on net interest.[145]

BYD also established manufacturing facilities in Lancaster, CA, in April 2013 to be able to bid on contracts with local production requirements.[146] For example, after setting up the Lancaster facilities, BYD went on to win an electric bus deal from the city of Long Beach, CA. Covering ten buses, charging equipment and relevant training, the deal was worth $11.5 million. Without the California manufacturing facilities, BYD would have been unable to secure the deal; because of receiving partial government funding, 60% of all parts

---

[142] Eisenstein, "China's BYD Again Outlines Plans to Enter U.S. Market."

[143] Paulson Institute (2015)

[144] Matt Sheehan, December 2017, "How China's Electric Car Dreams Became a PR Nightmare in America," *Huffington Post*, available at: https://www.huffingtonpost.com/2014/04/01/byd-china-electric-car_n_4964233.html.

[145] Paulson Institute (2015)

[146] Zach Shahan, May 2013, "Two BYD Manufacturing Facilities Launched In Lancaster," *EV Obsession*, available at: https://evobsession.com/two-byd-manufacturing-facilities-launched-in-lancaster/.

had to be manufactured domestically.[147] A year later, due to a technical error related to documents proving BYD's ability to bid on the initial contract, the Federal Transit Administration declared that BYD should not have been eligible to bid in the first place, leading to the termination of the contract.[148] The Lancaster facilities still, however, provide benefits to BYD in terms of a "local" image and its ability to bid on future government contracts in the U.S.

In addition to being able to compete for deals with local manufacturing requirements, BYD's California manufacturing plants bolstered the company's quality image. All electric buses manufacturing within the state must meet strict requirements set forth by both the Environmental Protection Agency (EPA) and the California Air Resources Board.[149] The move also enabled the company to be viewed more favorably by domestic clients aiming to support local manufacturing.

Due to aforementioned delays in entering the U.S. car market, public backlash, and consumer skepticism, BYD pivoted to a focus on fleet vehicles in the American market, namely buses and taxis. Rather than trying to convince skeptical consumers, they could appeal to fleet managers. The fleet managers buying vehicles in bulk for transit authorities or universities are more intent on recouping costs through fuel savings realized with electric vehicles, plus they tend to not be as susceptible to brand skepticism as consumers. Additionally, selling fleet vehicles circumvents the issue of limited electric vehicle charging infrastructure in the U.S., as there are centralized charging stations for fleet vehicles.[150] Shifting its focus from consumer vehicles to fleet sales, BYD has successfully increased brand awareness in the United States in recent years without having to deal directly with a skeptical consumer base on the heels of negative publicity.

JINKOSOLAR

JinkoSolar is a Shanghai-based solar firm with about 15,000 employees across the world. Founded in 2006, the company held its IPO in 2010. With production facilities in China, Malaysia, and South Africa, JinkoSolar has an annual production capacity of 5 gigawatts (GW) of silicon ingots and wafers, 4 GW of solar cells, and 6.5 GW of solar modules. In 2016, the company shipped 2.13 GW of modules, or 32% of its global shipments, to North America.[151]

U.S. Market Presence

In 2010, JinkoSolar established its first American office in San Francisco. Establishing an office in the U.S. was the primary mechanism used by JinkoSolar to break into the U.S. market. It enabled the company to adapt quickly to changing market forces and allowed for local personnel to develop a U.S. market presence. Prior to the establishment of the U.S. office in 2010, the company did not sell solar products in volume in

---

[147] Tim Dixon, April 2013, "Chinese EV Bus Company BYD Lands $11.5 Million Contract in California," *EV Obsession,* available at: https://evobsession.com/chinese-ev-company-muscles-into-us-market/.

[148] Sarah Bennett, Marcy 2014, "Long Beach Transit and BYD Motors Mutually Agree to Terminate Electric Bus Contract," *Long Beach Post*, available at: https://lbpost.com/news/long-beach-transit-and-byd-motors-mutually-agree-to-terminate-electric-bus-contract/#.UzSggl6T6Lk.

[149] Cox, "E-Buses Will Help Drive Further Growth For BYD."

[150] Paulson Institute (2015)

[151] JinkoSolar (2017)

the U.S.[152] In 2010, JinkoSolar sold 83,166 yuan of products to the U.S., which increased to over 118,000 yuan in 2011 and then close to 136,000 yuan in 2012.[153] Since then, the United States has become the company's largest market outside of China, with 2016 sales to the U.S. totaling 7.7 million yuan, or 36% of total sales.[154] Establishing the San Francisco office opened the door to this success.

JinkoSolar's projects in the United States include both commercial and residential projects across the country. In the last three years, due in part to the eleven executive personnel in the San Francisco office, the company has delivered 1.5 GW of solar products to the U.S.[155] The company's presence in the U.S. continues to expand rapidly. In the beginning of 2018, JinkoSolar inked a deal to supply NextEra Energy with 2.75 GW of solar panels, which is one of the largest solar panel supply deals ever made.[156]

Issues Encountered in the U.S. Market

Not long after JinkoSolar entered the U.S. solar market in 2010, the U.S. began levying import tariffs against Chinese-manufactured solar panels. Following an investigation by the International Trade Commission and U.S. Department of Commerce into allegations of imbalanced subsidies causing harm to U.S. manufacturers, duties on Chinese-manufactured solar products were set at 31 percent, on average. Another round of import tariffs was implemented in 2014 to close a loophole in the initial ruling that allowed Chinese companies to assemble solar cells manufactured in other countries as a means of avoiding tariff.[157] Without manufacturing facilities in the U.S., JinkoSolar products are further impacted by the most recent round of solar tariffs implemented by the United States. In January 2018, the Trump Administration announced a 30% tariff on all imported solar modules.[158] The intermittent tariffs have decreased cost competitiveness and increased instability for JinkoSolar's U.S. operations.

Keys to Success in the U.S.

JinkoSolar has expanded its brand recognition and positive media coverage within the U.S. through community engagement and local partnerships. For example, the company has donated solar panels to non-profit organizations such as GRID Alternatives and Everybody Solar.[159] In addition to philanthropy, the company has gained visibility through its high-level corporate partnerships, such as the one it has with the Golden State Warriors.[160]

To avoid tariffs on solar panels imported to the U.S., JinkoSolar announced in April 2018 that it will open a manufacturing facility in Jacksonville, Florida. Once production starts later in 2018, the manufacturing

---

[152] JinkoSolar (2011)

[153] JinkoSolar (2013)

[154] JinkoSolar (2017)

[155] JinkoSolar, n.d., "Our Team," *JinkoSolar,* available at: https://jinkosolar.com/us/about-jinko/our-team/.

[156] Joshua S. Hill, April 2018, "JinkoSolar To Open First US Solar Factory in Florida In Support Of 2,750 Megawatt NextEra Energy Deal," *CleanTechnica,* available at: https://cleantechnica.com/2018/04/03/jinkosolar-to-open-first-us-solar-factory-in-florida-in-support-of-2750-megawatt-nextera-energy-deal/.

[157] Julia Pyper, December 2014, "New Tariffs on Chinese Solar-Panel Makers Split the US Solar Industry," *Greentech Media*, available at: https://www.greentechmedia.com/articles/read/commerce-department-hits-chinese-panel-makers-with-higher-tariffs#gs.xqJ9zpc.

[158] Julia Pyper, January 2018, "JinkoSolar Set to Build a US Factory, the First Planned in Response to Tariffs," *Greentech Media*, available at: https://www.greentechmedia.com/articles/read/jinko-solar-first-us-manufacturing-trump-solar-tariff#gs.ZjlcxcU.

[159] JinkoSolar, 2015, "Jinko Cares," *JinkoSolar*, available at: https://jinkosolar.com/us/about-jinko/our-community/.

[160] JinkoSolar, n.d., "Golden State Warriors," *JinksoSolar*, available at: https://jinkosolar.com/us/about-jinko/golden-state-warriors/.

plant will have an annual production capacity of 400 MW, which translates to roughly one million solar panels. Establishment of the facility is set to generate over 200 new jobs.[161] The move comes after Jacksonville's City Council offered incentives totaling $24.2 million. Modules produced at the Jacksonville facility will reportedly be about 10% more expensive than those manufactured in Asia, giving them a net advantage over modules imported with the 30% tariff.[162] Establishing manufacturing operations in the U.S. will allow JinkoSolar to avoid import tariffs while simultaneously building its brand within the country.

TESLA

Founded in 2003, Tesla provides electric vehicles and energy storage systems.
The company has over 37,000 employees worldwide.[163]

Market Presence in China

Tesla's market presence in China has been rapidly increasing since it first delivered vehicles to China in the spring of 2014. The company quickly expanded upon early success, selling 10,400 vehicles in China during 2016, representing 13% of global sales and a threefold increase from the year prior. Sales figures in early 2017 put Tesla on track to then double its 2016 figures. Building on this success, in March 2017, Chinese conglomerate Tencent purchased $1.8 billion worth of Tesla stock. Due to recent success, Tesla now has over 600 staff in China.[164] In 2017, Tesla's revenue in China exceeded $2 billion.[165]

Issues Encountered in the Chinese Market

The primary issue encountered by Tesla in its efforts to enter the Chinese market has been high barriers to entry. Before 2018, foreign carmakers had to enter into joint ventures (JVs) with Chinese companies to operate in China, with the foreign company's ownership stake limited to 50%. This arrangement created profit sharing risks for foreign companies, and also made protection of intellectual property difficult since companies were forced to share IP with the local JV partners.

If a company opted to import its vehicles, rather than manufacture them in China with a JV partner, they faced steep import tariffs. Duties levied against vehicles imported to China stood at 25%, 10 times the rate of 2.5% on vehicles imported to the U.S.[166] Teslas sold in China are all imported from California, making them considerably more expensive than they are in the U.S. given the 25% import tariff and a 17% value-added tax.[167]

---

[161] Hill, "JinkoSolar To Open First US Solar Factory in Florida In Support Of 2,750 Megawatt NextEra Energy Deal."

[162] Pyper, "JinkoSolar Set to Build a US Factory, the First Planned in Response to Tariffs."

[163] Bloomberg, n.d., "Company Overview of Tesla, Inc.," *Bloomberg*, available at: https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=27444752.

[164] Scott Cendrowski, June 2017, "Tesla Takes Off in China," *Fortune*, available at: http://fortune.com/2017/06/07/fortune-500-tesla-china/.

[165] Fred Lambert, February 2018, "Tesla Made Over $2 Billion in China Last Year, Doubled Sales and Expanded Retail/Charging Presence," *electrek*, available at: https://electrek.co/2018/02/23/tesla-china-double-sales-expanded/.

[166] Reuters, March 2018, "Factbox: Barrier to Entry – China's Restrictions on U.S. Imports," *Reuters*, available at: https://www.reuters.com/article/us-usa-trump-china-factbox/factbox-barrier-to-entry-chinas-restrictions-on-u-s-imports-idUSKCN1GQ0PQ.

[167] Cendrowski, "Tesla Takes Off in China."

China's policy environment surrounding foreign carmakers is, however, beginning to change. In April 2018, China announced its plans to eliminate all ownership limits on foreign automakers by 2022. For auto companies manufacturing electric vehicles, foreign ownership limits are being removed in 2018.[168] These new rules will benefit Tesla, which has been keen to hold on to its IP and avoid a JV. On the downside, however, by going it alone, Tesla would be forced to cover all investment costs, which are usually shared with a JV partner. Additionally, local JV partners tend to be more experienced navigating the complex political and labor environment in China.[169]

Beyond fears of IP theft and issues navigating the policy environment in China, Tesla faced early issues in the Chinese marketplace related to delays, scalping, and media attention. Chinese customers who preordered Tesla automobiles prior to their release in 2014 encountered delays in receiving their vehicles plus mediocre service related to Tesla's lack of operations in China at the time.[170]

Another issue the company encountered came in the form of scalpers. Sensitive to providing a quality customer experience, Tesla initially required prospective customers to prove ownership of a charger, a parking spot, and proximity to a Tesla service center prior to purchasing a vehicle. These requirements limited customer options, considering that when Tesla first entered the Chinese market, only Beijing and Shanghai had Tesla service centers. As a result, resellers bought Tesla vehicles in bulk and resold them in China.[171]

Furthermore, Tesla encountered a learning curve in terms of educating customers about its vehicles. Initially, due to scant media coverage, many Chinese customers did not have a proper understanding of Tesla products and how they could be charged at home daily. On account of weak customer support upon entry to the market, Tesla had shipped 4,700 cars to China by the end of 2014, yet just over half of them sold.[172]

Keys to Success in China

One element of Tesla's success in China has been the way the company is viewed by the Chinese government. Tesla has received support due in part to marketing itself as a company on the forefront of combating climate change and air pollution, key issues in China in recent years. Tesla and its high-cost, high-performing vehicles are also viewed as a model for what the government thinks Chinese electric vehicle companies should aspire to be. Furthermore, over the last few years, Tesla has been increasingly sourcing parts for its vehicles from Chinese manufacturers, a move viewed positively by the government.[173]

In the second half of 2017, Tesla confirmed its plans to build a manufacturing facility in China, which would allow it to avoid the import tariffs imposed by the Chinese government. Production of vehicles at the facility could start within three years.[174]

---

[168] Norihiko Shirouzu and Adam Jourdan, April 2018, "China to Open Auto Market as Trade Tensions Simmer," *Reuters,* available at: https://www.reuters.com/article/us-china-autos-regulation/china-to-open-auto-market-as-trade-tensions-simmer-idUSKBN1HO0YA.

[169] Keith Bradsher, April 2018, "China Loosens Foreign Auto Rules, in Potential Peace Offering to Trump," *New York Times*, available at: https://www.nytimes.com/2018/04/17/business/china-auto-electric-cars-joint-venture.html?emc=edit_nn_20180417&nl=morning-briefing&nlid=7802238620180417&te=1.

[170] Cendrowski, "Tesla Takes Off in China."

[171] Ibid.

[172] Ibid.

[173] Ibid.

[174] Darrell Etherington, November 2017, "Elon Musk Says Tesla's China Factory Could Begin Production in Roughly Three Years," *TechCrunch,* available at: https://techcrunch.com/2017/11/01/elon-musk-says-teslas-china-factory-could-begin-production-in-roughly-three-years/.

GE RENEWABLE ENERGY

GE Renewable Energy, a multi-billion-dollar company created by GE, delivers wind, solar, and hydropower solutions across the world. With a presence in 55 countries, GE Renewable Energy has installed over 35,000 wind turbines around the world.[175]

Market Presence in China (Wind)

GE Renewable Energy entered the Chinese wind power market in 2004. Since its entry into the market well over a decade ago, the company has installed over 2 GW of wind energy in China.[176] Despite its early entry, GE Renewable Energy has struggled to accumulate a substantial portion of China's booming wind energy sector. In 2016, GE installed 205 MW of wind turbines in China, accounting for less than 1% of annual installations in the country.[177]

Along with installations, GE has been manufacturing and assembling wind turbines in China for over a decade. In June 2006, when it broke ground in Shenyang, GE opened its first wind turbine assembly plant in China.[178] GE now owns three additional wind turbine manufacturing facilities in China, located in Qinhuangdao, Tianjin, and Jiangyin.[179]

Issues Encountered in the Chinese Market

Upon entry to the Chinese market, GE faced prohibitive costs associated with shipping wind turbines from the U.S. to China. The hassle and price of this obstacle have subsequently been reduced with the opening and purchase of assembly and manufacturing facilities in China.

A current issue faced by GE Renewable Energy is the oversaturation of the Chinese wind energy market. The degree of oversaturation can best be viewed from data provided by CCM Consultancy: Between 2015 and 2020, the Chinese government plans for nationwide annual wind installations totaling 20 GW, yet the annual cumulative production capacity of wind manufacturers in China totals 40 GW.[180]

In addition to the oversaturation of the market, GE's attempts to expand its wind energy presence in China have been further stifled by the additional government support provided to local suppliers. Even though many Chinese-manufactured wind turbines do not meet the same quality standards as some foreign products, they adhere to Chinese standards and continue to receive added support from the government.[181] A 2012 study found that when compared to foreign-manufactured wind turbines, Chinese-manufactured counterparts produce 10-20% less energy, on average. Reliability issues were linked

---

[175] GE, 2018, "About GE Renewable Energy," *GE*, available at: https://www.gerenewableenergy.com/about-us.

[176] GE, 2016, "GE in China Fact Sheet," *GE*, available at: https://www.ge.com/cn/sites/www.ge.com.cn/files/GE_in_China_fact_sheet_EN_0811.pdf.

[177] David Weston, February 2017, "Importing OEMs Double China Market Share," *Wind Power Monthly,* available at: https://www.windpowermonthly.com/article/1424516/importing-oems-double-china-market-share.

[178] June 2006, "GE Energy Opens Wind Turbine Assembly Facility in China," *Renewable Energy World*, available at: https://www.renewableenergyworld.com/articles/2006/06/ge-energy-opens-wind-turbine-assembly-facility-in-china-45306.html.

[179] GE, n.d., "GE Renewable Energy Locations," *GE*, available at: https://www.gerenewableenergy.com/about-us/locations.

[180] Katherine Steiner-Dicks, May 2015, "China Fund to Boost Wind Turbine Trade as Exports Grow," *New Energy Update*, available at: http://newenergyupdate.com/wind-energy-update/china-fund-boost-wind-turbine-trade-exports-grow.

[181] Ibid.

to component defects such as broken gear teeth and leaky gearboxes.[182] These issues are not indicative of all Chinese-manufactured turbines, however, as many Chinese companies have garnered a reputation for quality products internationally.

Keys to Success in China

An early element to GE Renewable Energy's success in China's wind power sector was the decision to open a wind turbine assembly facility in Shenyang, China. The facility allowed for on-the-ground personnel to support GE's expansion into the sector. Additionally, it enabled the company to compete for wind power contracts with localization requirements.[183]

Another strategic move to facilitate GE's expansion into the Chinese wind sector came with the company's JV partnership with Harbin Power Equipment. The JV came to fruition in September 2010, with Harbin Power Equipment manufacturing and selling GE wind turbines to clients in China. Under the JV arrangement, Harbin Electric owned 51% of the company and GE owned 49%. The move was an effort to circumvent some of the local protectionism issues encountered by GE in the Chinese market.[184] In 2013, however, the JV partnership was canceled due to disagreements regarding business objectives and strategies.[185]

More recently, GE spent $1.65 billion to acquire LM Wind Power in 2017. The Danish firm LM Wind Power, with factories all over the world, supplies blades to about 20% of the world's wind turbines. With blade-production facilities in China and other countries, the move will help GE continue its expansion into the Chinese market. President and CEO of GE Renewable Energy, Jérôme Pécresse, noted at the time of the acquisition that it would enable the company to reduce costs and increase flexibility while expanding involvement in local markets.[186]

FINANCE AND INVESTMENT

Given the capital-intensive nature of clean technology manufacturing, financing can be a limiting factor in the expansion of these markets. Opening and expanding financial and investment partnerships between the U.S. and China can provide companies with increased funding, allowing them to make long-term investments and scale their operations.

Thus far, Chinese corporate investment in the clean technology industry in the U.S. has included acquisition, minority investment, and venture capital investments, whereas the majority of U.S. corporate investment in the Chinese clean technology industry has been through JVs.

---

[182] Zhao et al. (2012)

[183] "GE Energy Opens Wind Turbine Assembly Facility in China."

[184] Kirsten Korosec, September 2010, "Why GE's 'Made in China' Strategy Works," *CBS News*, available at: https://www.cbsnews.com/news/why-ges-made-in-china-strategy-works/.

[185] Qi Wu, July 2013, "GE and Harbin End Chinese Joint-Venture," *Wind Power Monthly*, available at: https://www.windpowermonthly.com/article/1188550/ge-harbin-end-chinese-joint-venture.

[186] Maggie Sieger, April 2017, "Catching More Wind: GE Acquires World's Largest Turbine Blade Maker," *GE*, available at: https://www.ge.com/reports/catching-wind-ge-acquires-worlds-largest-turbine-blade-maker/.

Equity Investment

Several Chinese firms have acquired U.S. clean technology companies in recent years. Examples include U.S.-based Cirrus Wind Energy, which was acquired by Jiangxi's A-Tech Wind Power in 2012.[187] China's Wanxiang Group, an automotive component manufacturing firm, purchased battery company A123 Systems in 2013 for $257 million and the EV company Fisker Automotive for $149 million in 2014. Hanergy, a Chinese renewable energy company, acquired the American solar power company MiaSole for $30 million in 2012.[188]

In addition to acquisition, Chinese firms have also bought minority shares of U.S. clean technology firms. For example, Chinese conglomerate Tencent bought a 5% stake in Tesla in 2017 for roughly $1.8 billion.[189] China Petrochemical has also been active in the U.S. conventional energy sector, purchasing various oil and gas assets and a 50% share in Mississippi Lime, a calcium product manufacturer, in 2013.[190]

CHINESE WIND FIRM SECURES TAX-EQUITY FINANCING IN THE U.S.

In May 2017, Goldwind Americas, a subsidiary of Xinjiang Goldwind Science & Technology Co., received $130 to $140 million in tax equity financing for a 160 MW wind power project in Texas. The McCulloch County, Texas, project received financing from MidAmerican Wind Tax Equity Holdings, a subsidiary of Berkshire Hathaway, and Citi.

Demonstrating a sign of market acceptance, this funding marked the first time a Chinese wind power company has obtained a tax-equity financed project in the United States. Financial institutions such as the ones that financed the Goldwind project are often a crucial source of funding for wind power projects in the U.S. because they can monetize the tax credits from the projects. The tax-equity funding opens a new door to financing projects in the United States for Goldwind, which has relied on the China Development Bank for funding past projects. Indeed, it paved the path for new opportunities. In August 2017, Goldwind signed a deal to provide Ohio-based One Energy with 60 MW of wind turbines. Prudential Capital Group provided the financing for the project.

U.S. companies have also taken equity positions in Chinese energy firms. For example, in an effort to power all of its global facilities with renewable energy, Apple purchased a 30% stake in various wind power companies operated by Chinese firm Goldwind in 2016.[191] In the conventional energy sector, U.S. oil company Schlumberger Ltd. purchased a 20.1% stake in China's Anton Oilfield Services Group for $80 million in 2011.[192]

---

[187] Tal Yellin, n.d., "Chinese Acquisitions of U.S. Companies," *CNN Money*, available at: http://money.cnn.com/interactive/economy/chinese-acquisitions-us-companies/.

[188] Jeffrey Ball, December 2015, "Silicon Valley's New Power Player: China," *Fortune,* available at: http://fortune.com/china-clean-tech-silicon-valley/.

[189] Nicholas Cheng, July 2017, "Tencent Invests Big Money in US Cleantech," *The Straights Times,* available at: https://www.straitstimes.com/world/united-states/tencent-invests-big-money-in-us-cleantech.

[190] Yellin, "Chinese Acquisitions of U.S. Companies."

[191] Ivan Shumkov, December 2016, "Apple to Take Part in Chinese Wind Power JVs with Goldwind," *Renewables Now*, available at: https://renewablesnow.com/news/apple-to-take-part-in-chinese-wind-power-jvs-with-goldwind-549656/.

[192] Swagato Chakravorty, July 2012, "U.S. Companies Invest in Chinese Shale Gas," *Energy & Capital,* available at: https://www.energyandcapital.com/articles/us-companies-invest-in-chinese-shale-gas/2351.

Venture Capital Investment

Clean technology venture capital (VC) investments are currently dominated by Chinese capital being invested in the United States, particularly in California. In the last few years, Silicon Valley has seen an expanding number of Chinese-backed technology incubators setting up shop. With funding provided by Chinese corporations, individual investors, and municipal and provincial governments, around 20 incubators had established operations in Silicon Valley by the end of 2015. One of the more successful of these incubators, InnoSpring, opened its doors in 2012.[193]

Chinese multinational firm Tencent also has a sizable presence in California, due in part to TenX, the company's VC branch established in Palo Alto, California. Among its recent ventures were investments totaling $1.9 billion into four U.S.-based sustainability start-ups. Tencent has also provided VC investments to Clarity, a company working to develop pollution monitoring devices. David Wallerstein, head of TenX, noted that the company's ability to spend extensively on unproven clean technologies stems from their substantial revenues.[194]

Outside of Silicon Valley, Chinese venture capital firm GSR Ventures has been active in the American clean technology sector. In 2015, with $1.9 billion in debt provided by the Bank of China, GSR Ventures acquired Philips' Lumileds LED Lighting unit for $3.3 billion. One strategy for Chinese firms investing in American companies has been to acquire U.S. firms and relocate them to China. This was the model GSR Ventures followed in 2011 when it moved battery company Boston Power to China following its $125 million acquisition.[195]

R&D

In the rapidly evolving clean technology space, R&D is essential to innovation and advancement. R&D, however, tends to be highly capital intensive with no guarantee of significant returns. Collaboration in R&D can thus be an effective way to reduce costs and increase the probability of success. Despite the potential benefits, individual firms may be hesitant to collaborate with other firms on R&D, hoping to retain ownership and the ensuing profits of any technological breakthroughs. Publicly-funded R&D programs can help to overcome these barriers.

There are several avenues through which the U.S. and China collaborate on R&D, including joint research centers, clean technology centers, and joint commercialization projects. The following examples highlight instances of each type of collaboration while showing some of the potential benefits and shortcomings.

Joint Research Centers

The U.S. and China have multiple joint research centers that aim to promote cross-border R&D through partnerships between public and private sector organizations. One example is the U.S. China Clean Energy Research Center (CERC). CERC aims to promote joint research about advanced coal combustion

---

[193] Ball, "Silicon Valley's New Power Player: China."

[194] Cheng, "Tencent Invests Big Money in US Cleantech."

[195] Ball, "Silicon Valley's New Power Player: China."

technology between organizations in the U.S. and China. Collaboration is oftentimes limited to sharing published articles and methodologies, however, since firms and research organizations are hesitant to share engineering information due to its commercial sensitivity. A WRI report on CERC found a lack of continuity with the private sector, identifying the need to strengthen joint R&D and private sector participation.[196]

Another example of a joint research center is the Innovation Center for Energy and Transportation, or iCET. Registered as a nonprofit organization in both Beijing and California, iCET works to develop public-private partnerships between the U.S. and China in the areas of clean transportation and clean technology innovation. Through tools regarding developments such as sustainable fuels, fuel consumption, and electric vehicle supply, iCET has partnered with automobile companies such as BYD, GM, and Tesla. Some of the research outcomes from iCET influenced biofuel standards and new-energy vehicle credits in China.[197]

Established in 2014, the China-U.S. ZEV Policy Lab also promotes collaboration in the development and promotion of clean vehicles. A partnership between UC Davis and the China Automotive Technology and Research Center (CATARC), the ZEV Policy Lab aims to share best practices for ZEV policy and examinations of market trends. Among the various collaboration projects taking place through the ZEV Policy Lab is new research on how Chinese consumers respond to new energy vehicles.[198]

Clean Technology Centers

Other efforts aimed at promoting R&D activities between the U.S. and China come in the form of clean technology centers. For example, iCET and the Department of Commerce partnered to form the U.S.-China Cleantech Center (UCCTC). The UCCTC aims to help U.S. clean energy companies expand their technologies into the Chinese market. One of its programs, the Tech Bank, promotes technical collaboration between U.S. companies and Chinese buyers and investors. UCCTC also offers a program called the GreenMakerSPACE, which provides education and relationship opportunities for American cleantech startups expanding into China, and vice versa.[199]

Joint Commercialization Projects

In addition to joint research centers and cleantech centers, some companies are collaborating between the U.S. and China to commercialize products. One such company is Lanzatech NZ Ltd., a firm founded in 2005 in New Zealand but based in Illinois. Lanzatech utilizes waste gases from industrial facilities to produce fuel ethanol.[200]

---

[196] Yang (2016)

[197] iCET, 2016, "Clean Transportation Transformation Program (CTTP)," *Innovation Center for Energy and Transportation,* available at: http://www.icet.org.cn/english/admin/upload/2017033139644101.pdf.

[198] "China-U.S. ZEV Policy Lab," *UC Davis China Center for Energy and Transportation,* available at: https://chinacenter.ucdavis.edu/initiatives/china-u-s-zev-policy-lab/.

[199] UCCTC, n.d., "UCCTC Organizational Brochure," *U.S. China Cleantech Center,* available at: http://uschinacleantech.org/wp-content/uploads/2016/05/UCCTCs-Organizational-Brochure.pdf

[200] Bloomberg, n.d., "Company Overview of Lanzatech NZ Ltd.," *Bloomberg,* available at: https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=34034878

SCALING INNOVATIVE TECHNOLOGY IN CHINA: LESSONS FROM LANZATECH

Over the course of the last decade, Lanzatech has partnered with two different Chinese companies, Shanghai Baosteel Group and Shougang Group, on pre-commercial demonstration plants. As per Lanzatech CEO Jennifer Holmgren, "Nobody in the world moves as quickly as China. So in my mind, if you have a new technology, a new idea, China can help get it into a point where it is truly commercially ready faster than anywhere else in the world." This may be true, but the commercialization of these projects did not happen quite as quickly as Holmgren expected; originally planning to open a commercial facility with Shanghai Baosteel in 2013, the joint demonstration project has since been shut down. Lanzatech is planning to start its commercial plant in conjunction with Shougang Group in 2018.

When it comes to joint commercialization across borders, many firms in the private sector worry about IP theft. In Lanzatech CEO Holmgren's view, "In every country, you can have your IP stolen, even in the U.S., too. China is a wilder world than the U.S. in the maturity of IP, but I think it is changing here, and the government is paying more attention. The best way to protect the IP is to develop trustworthy partners."[201] As Holmgren points out, the IP environment is changing quickly in China. China has been using legal changes and enhanced enforcement to improve IP protection in the country.[202] Regarding the remaining risks, Holmgren points out that China "helps us move the technology forward. You can own 100 percent of something and move it slowly, or you can deal with some risks and move it quickly. I'll gladly take that risk."[203]

[201] Liu, "More Western Clean-Tech Companies Take Off in China, but There are Gaps in the Runway."

[202] William Weightman, January 2018, "Chinia's Progress on Intellectual Property Rights (Yes, Really)," *The Diplomat,* available at: https://thediplomat.com/2018/01/chinas-progress-on-intellectual-property-rights-yes-really/.

[203] Liu, "More Western Clean-Tech Companies Take Off in China, but There are Gaps in the Runway."

REFERENCES

Abache, Abreu et al. 2018. "Opportunities and Challenges of China's LNG Expansion." *S&P Global Platts.* Available at www.platts.com/IM.Platts.Content/InsightAnalysis/IndustrySolutionPapers/sr-china-lng-expansion-032018.pdf.

APEC. 2017. "The Impact of Government Policy on Promoting New Energy Vehicles (NEVs)." Available at www.apec.org/Publications/2017/03/The-Impact-of-Government-Policy-on-Promoting-New-Energy-Vehicles-NEVs--The-Evidence-in-APEC-Economie.

ARB. 2000. "Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles." Available at www.arb.ca.gov/diesel/documents/rrpFinal.pdf.

ARB. 2014. "Proposed Amendments to the Zero Emission Vehicle Regulation." Available at www.arb.ca.gov/regact/2014/zev2014/zev14isor.pdf.

ARB. 2016. "A Guide to ARB's Heavy-Duty Diesel Vehicles Regulations." Available at www.arb.ca.gov/msprog/truckstop/pdfs/booklet_english_may2016.pdf.

ARB. 2016. "Mobile Source Strategy." Available at www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf.

ARB. 2017. "California Greenhouse Gas Emissions for 2000 to 2015 – Trends of Emissions and Other Indicators." Available at www.arb.ca.gov/cc/inventory/pubs/reports/2000_2015/ghg_inventory_trends_00-15.pdf.

ARB. 2017. "California's 2017 Climate Change Scoping Plan." Available at www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf.

ARB. 2017. "The Carl Moyer Program Guidelines: 2017 Revisions." Available at www.arb.ca.gov/msprog/moyer/guidelines/2017gl/2017cmpgl_20170527.pdf.

ARB. 2018."Zero-Emission Vehicle Standards for 2018 and Subsequent Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles." Available at hwww.arb.ca.gov/msprog/zevprog/zevregs/1962.2_Clean.pdf.

ARB and California Air Pollution Control Officers Association. 2015. "Risk Management Guidance for Stationary Sources of Air Toxics." Available at www.arb.ca.gov/toxics/rma/rmgssat.pdf.

Borgeson, Merrian et al. 2017. "Motion of the Natural Resource Defense Council (NDRC), Sierra Club, and the California Energy Efficiency Industry Council Seeking Review and Modification of the Three-Prong Fuel Substitution Test." Available at https://drive.google.com/file/d/0B2t1mDNwWpVKQ0VJWnlxVGQ3YVU/view.

California Energy Commission. 2012. "Building Energy Efficiency Standards: Frequently Asked Questions." Available at www.energy.ca.gov/title24/2013standards/rulemaking/documents/2013_Building_Energy_Efficiency_Standards_FAQ.pdf.

California Energy Commission. 2016. "Building Energy Efficiency Standards: Frequently Asked Questions." Available at www.energy.ca.gov/title24/2016standards/rulemaking/documents/2016_Building_Energy_Efficiency_Standards_FAQ.pdf.

California Energy Commission. 2017. "Tracking Progress." Available at www.energy.ca.gov/renewables/tracking_progress/documents/electric_vehicle.pdf.

California Energy Commission. 2018. "Achieving Energy Efficiency." Available at www.energy.ca.gov/commission/fact_sheets/core/ee/EE-AchievingEnergyEfficiency.pdf.

Cao, Junji et al. 2012. "Winter and Summer PM2.5 Chemical Compositions in Fourteen Chinese Cities." *Journal of the Air & Waste Management Association.* Available at www.tandfonline.com/doi/abs/10.1080/10962247.2012.701193.

Carter, Michael. 2017. "Heavy-Duty Low-NOx and Phase 2 GHG Plans." Available at www.4cleanair.org/sites/default/files/Documents/Fall_2017_Carter.pdf.

Chen, Yuyu, et al. (2013) "Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy." PNAS. Available at www.pnas.org/content/pnas/early/2013/07/03/1300018110.full.pdf.

Delgado, Oscar. "Stage 3 China Fuel Consumption Standard for Commercial Heavy-duty Vehicles." *The International Council on Clean Transportation.* July 2018. Available at www.theicct.org/publications/stage-3-china-fuel-consumption-standard-commercial-heavy-duty-vehicles.

E3. 2017. "Long-Term Energy Scenarios in California: Updated Results from the California PATHWAYS Model." Available at www.ethree.com/public_proceedings/summary-california-state-agencies-pathways-project-long-term-greenhouse-gas-reduction-scenarios/.

Gladstein, Neandross & Associates. 2016. "Gamechanger Technical White Paper: Next Generation Heavy-Duty Natural Gas Engines Fueled by Renewable Natural Gas." Available at http://ngvgamechanger.com/pdfs/GameChanger_FullReport.pdf.

Governor's Interagency Working Group on Zero-Emission Vehicles. 2016. "2016 ZEV Action Plan." Available at www.gov.ca.gov/wp-content/uploads/2018/01/2016_ZEV_Action_Plan-1.pdf.

Greenpeace. 2018. "Analysis of Air Quality Trends in 2017." Available at https://secured-static.greenpeace.org/eastasia/Global/eastasia/publications/campaigns/Climate%20and%20Energy/Analysis%20of%20air%20quality%20trends%20in%202017.pdf.

Hove, Andrew. 2017. "Natural Gas in China." *The Paulson Institute.* Available at www.paulsoninstitute.org/economics-environment/paulson-primers/natural-gas-in-china/.

ICCT. 2018. "China's New Energy Vehicle Mandate Policy." Available at www.theicct.org/sites/default/files/publications/ICCT_China-NEV-mandate_policy-update_20180111.pdf.

iCET. 2016. "Clean Transportation Transformation Program (CTTP)." Available at www.icet.org.cn/english/admin/upload/2017033139644101.pdf.

IEA. 2017. "Global EV Outlook 2017." Available at www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf.

International Agency for Research on Cancer. 2012. "Diesel Engine Exhaust Carcinogenic." *World Bank*. Available at www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf.

JinkoSolar. 2011. *JinkoSolar 2010 Annual Report* (Annual Report). Available at http://ir.jinkosolar.com/static-files/f2895df7-0eee-4704-b3cd-00b99d89130f.

JinkoSolar. 2013. *JinkoSolar 2012 Annual Report* (Annual Report). Available at http://ir.jinkosolar.com/static-files/9809ddd9-98dd-4b5a-a0c9-c8411a09f15f.

JinkoSolar. 2017. *JinkoSolar 2016 Annual Report* (Annual Report). Available at http://ir.jinkosolar.com/static-files/9f2fbe00-e3b2-4165-af7e-c1c9525dcc28.

MEP. 1999. “Technical Policy on Prevention and Control of Pollution by Motor Vehicles.” Available in Mandarin at http://kjs.mep.gov.cn/hjbhbz/bzwb/wrfzjszc/200607/t20060725_91277.shtml MEP.

MEP. 2013. “The State Council Issues Action Plan on Prevention and Control of Air Pollution Introducing Ten Measures to Improve Air Quality.” Available at http://english.mep.gov.cn/News_service/infocus/201309/t20130924_260707.htm.

MEP. 2016. “China Motor Vehicle Environmental Management 2016 Report.” Available in Mandarin at www.mep.gov.cn/home/jrtt_1/201606/W020160602535609145311.pdf.

P .a/ . . MEP. 2016. “Interim Assessment Report on the Implementation of the Air Pollution Action Plan.” Available at www.mep.gov.cn/xxgk/hjyw/201607/t20160706_357205.shtml.

MEP. 2016. “Request for Environmental Protection Standards on the ‘Vehicle Compression Ignition Spark Engines, Gas, Fuel and Car Exhaust Pollutant Emission Limits and Measurement Methods (China phase 6) (draft)’ Opinion Letter.” Available in Mandarin at www.mep.gov.cn/gkml/hbb/bgth/201610/t20161017_365634.htm.

MEP. 2017. “China Motor Vehicle Environmental Management 2017 Report.” Available in Mandarin at www.mep.gov.cn/gkml/sthjbgw/qt/201706/W020170605537942778925.pdf.

MEP. 2017. “China Vehicle Environmental Management Report 2017.” Available in Mandarin at www.mep.gov.cn/gkml/hbb/qt/201706/t20170603415265.htm?COLLCC=2084844201&.

MEP. 2017. “Notice on the Issuance of the 2017 Air Pollution Prevention and Control Work Plan for Beijing, Tianjin and Hebei Areas.” Available in Mandarin at http://dqhj.mep.gov.cn/dtxx/201703/t20170323_408663.shtml.

MEP. 2017. “The 2017 Air Pollution Prevention and Control Work Plan for Beijing, Tianjin, Hebei and Surrounding Areas Is Released and Focuses on Controlling of Pollution from Diesel Trucks in the 26+2 Cities.” Available in Mandarin at www.mep.gov.cn/xxgk/hjyw/201703/t20170330_409037.shtml.

MIIT. 2015. “Made in China 2025: Promoting the Development of Energy-Saving and New-energy Vehicles.” Available in Mandarin at www.gov.cn/zhuanti/2016-05/12/content_5072762.htm.

MIIT. 2017. “Guidelines for China’s Medium- and Long-Term Car Industry Development.” Available in Mandarin at www.xinhuanet.com/auto/2017-04/25/c_1120869697.htm.

MIIT. 2017. “Parallel Management Regulation for Corporate Average Fuel Consumption and New Energy Vehicle Credits for Passenger Cars.” Available in Mandarin at www.xinhuanet.com/auto/2017-06/13/c_1121134739.htm.

MOF. 2018. “Notice on the Adjustment and Improvement of the Fiscal Subsidy Policy for New Energy Automobile Promotion.” Available in Mandarin at http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/201802/t20180213_2815574.html.

MOF. 2018. “Notice on the Adjustment and Improvement of the New Energy Automobile Promotion and Application of Fiscal Subsidy Policy.” Available in Mandarin at http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/201802/t20180213_2815574.html.

NDRC. 2016. “The 13th Five-Year Plan for Economic and Social Development of the People’s Republic of China.” Available at http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf.

NDRC. 2017.“Clean Winter Heating Plan for Northern China (2017–2021).” Clean Energy Portal. Available at https://chinaenergyportal.org/en/clean-winter-heating-plan-for-northern-china-2017-2021/.

NDRC. 2017. "Suggestions on Accelerating the Use of Natural Gas." Available in Mandarin at www.ndrc.gov.cn/zcfb/zcfbtz/201707/W020170704620817903063.pdf.

Ou, Shiqi et al. 2017. "A Study of China's Explosive Growth in the Plug-in Electric Vehicle Market." *Oakridge National Laboratory.* Available at https://info.ornl.gov/sites/publications/files/Pub72210.pdf.

Paulson Institute. 2015. "California Dreaming: How a Chinese Battery Firm Began Making Electric Buses in America." Available at www.paulsoninstitute.org/wpcontent/uploads/2017/01/PPI_Case-Study-Series_BYD_English_R.pdf.

Rocky Mountain Institute. 2018. "The Economics of Electrifying Buildings." Available at www.rmi.org/insights/reports/economics-electrifying-buildings/.

Ryan, Nancy and Lucy McKenzie. 2016. "Utilities' Role in Transport Electrification: Promoting Competition, Balancing Risks." *Public Utilities Fortnightly.* Available at www.fortnightly.com/fortnightly/2016/03/utilities-role-transport-electrification-promoting-competition-balancing-risks.

South Coast Air Quality Management District. 2018. "Carl Moyer Program 2018." Available at www.aqmd.gov/docs/default-source/aqmd-forms/moyer/carl-moyer-brochure.pdf?sfvrsn=26.

Southern California Edison. 2017. "The Clean Power and Electrification Pathway." Available at www.edison.com/content/dam/eix/documents/our-perspective/g17-pathway-to-2030-white-paper.pdf.

The Beijing Municipal People's Government. 2017. "Notice on the 2017 Village Winter Clean Heating Work Plan." Available in Mandarin at http://zhengce.beijing.gov.cn/library/192/33/50/438650/157841/index.html.

The State Administration for Industry and Commerce (SAIC). 2017. "Announcement of a Nationwide Supply of Diesel Fuel with Sulphur Content Less than 10ppm." Available in Mandarin at http://home.saic.gov.cn/scs/gfjg/201711/t20171109_270238.html.

The State Council of the People's Republic of China. 2012. "Energy Saving and New Energy Vehicles Industry Development Planning (2012–2020)." Available in Mandarin at http://www.nea.gov.cn/2012-07/10/c_131705726.htm.

The State Council of the People's Republic of China. 2013. "The State Council Notice Regarding the Air Pollution Action Plan." Available in Mandarin at www.gov.cn/zwgk/2013-09/12/content_2486773.htm.

The State Council of the People's Republic of China. 2015. "Guiding Opinions on Accelerating the Electric Vehicle Charging Infrastructure Construction." Available in Mandarin at www.gov.cn/zhengce/content/2015-10/09/content_10214.htm.

The World Health Organization (WHO). 2014. "WHO's Ambient Air Pollution Database – Update 2014. Data Summary of the AAP Database." Available at www.who.int/phe/health_topics/outdoorair/databases/AAP_database_results_2014.pdf?ua=1.

Union of Concerned Scientists (UCS). 2016. "What Is ZEV?" Available at www.ucsusa.org/clean-vehicles/california-and-western-states/what-is-zev.

U.S. China Cleantech Center (UCCTC). 2016. "UCCTC Organizational Brochure." Available at http://uschinacleantech.org/wp-content/uploads/2016/05/UCCTCs-Organizational-Brochure.pdf.

United States Department of Energy (DOE). 2015. "Increasing Efficiency of Building Systems and Technologies."

Chapter 5 of the *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities.* Available at www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf.

The US-China Business Center (USCBC). 2012. "China's Ownership Restrictions on US and Other Foreign Investors." Available at www.uschina.org/sites/default/files/USCBC List of China Ownership Restrictions May 2012.pdf.

Xing, Yan et al. 2016. "A Comparison of Plug-in Electric Vehicle Markets Between China and the U.S. Based on Surveys." Chapter in *Blue Book of New Energy Vehicles 2016.* Available in Mandarin at https://its.ucdavis.edu/research/publications/?frame=https%3A%2F%2Fitspubs.ucdavis.edu%2Findex.php%2Fresearch%2Fpublications%2Fpublication-detail%2F%3Fpub_id%3D2680.

Yang, Xiaoliang. 2016. "U.S.-China Clean Energy Collaboration: Lessons from the Advanced Coal Technology Consortium." *World Resource Institute.* Available at www.wri.org/sites/default/files/US_China_Clean_Energy_Collaboration_lessons_from_the_Advanced_Coal_Technology_Consortium_1.pdf.

Yu, Sha. 2016. "Building Energy Efficiency in China: Policies and Markets." World Resources Institute. Available at www.chinafaqs.org/files/chinainfo/Building%20Energy%20Efficiency%20Fact%20Sheet_0.pdf.

Zhao, Z. et al. 2012. "Comparative Assessment of Performance of Foreign and Local Wind Turbine Manufacturers in China." *Renewable Energy.* Available at www.researchgate.net/publication/257414381_Comparative_assessment_of_performance_of_foreign_and_local_wind_turbine_manufacturers_in_China.

Zhou, Nan et al. 2013. "China's Energy and Emissions Outlook to 2050: Perspectives from Bottom-up Energy End-use Model." *Energy Policy.* Available at http://eaei.lbl.gov/sites/all/files/lbnl-6179e.pdf.

ACKNOWLEDGMENTS

This work would not have been possible without the financial support of the Energy Foundation. We would like to thank Lijian Zhao and Yuan Lin of Energy Foundation China for contributing their insights into the report.

We also want to thank Dr. Fredrich (Fritz) Kahrl at Energy + Environmental Economics (E3), who was instrumental in the drafting of this report. Samuel Corwin, Eli Wallach, Xinyue Ma, Nathan Park, Jiacheng Shao, Salmana Shah and Yue Zhao also helped drafted part of the case studies and provided critical research work for the report.

We are also grateful to Dr. Jim Williams at University of San Francisco to review the report and provide very insightful comments and suggestions.

A particular note of thanks is also due to all of our colleagues at the Asia Society Northern California and our interns, particularly Ben Guggenheim who provided project management and research support and Andrew Selvo who helped put all the pieces coherently together.

Juan Wei
Senior Program Manager, Sustainability
Asia Society Northern California

FOR MORE INFORMATION, PLEASE VISIT ASIASOCIETY.ORG/COORDINATEDSTRATEGIES

Other Asia Society Policy and Business Reports

A Clear Opportunity: U.S.-China Collaboration on Clean Air

Roadmap to a Northeast Asian Carbon Market

Breaking Ground: Chinese Investment in U.S. Real Estate

A Vital Partnership: California and China Collaborating on Clean Energy and Combating Climate Change

Asia Society

Asia Society is the leading educational organization dedicated to promoting mutual understanding and strengthening partnerships among peoples, leaders, and institutions of Asia and the United States in a global context. Across the fields of arts, business, culture, education, and policy, the Society provides insight, generates ideas, and promotes collaboration to address present challenges and create a shared future.

Founded in 1956 by John D. Rockefeller 3rd, Asia Society is a nonpartisan, nonprofit institution with major centers and public buildings in New York, Hong Kong, and Houston, and offices in Los Angeles, Manila, Mumbai, San Francisco, Seoul, Shanghai, Sydney, Tokyo, Washington, D.C., and Zurich.