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Fuel-efficiency technology trend assessment for LDVs in China: Summary of working paper series

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1 Background

Fuel-consumption standards drive down China's use of fuel by the on-road sector and encourage the uptake of advanced vehicle-efficiency technologies. Understanding the need for a policy roadmap and long-term strategies to provide certainty for long-term fuel consumption, technology advancement, and potential compliance costs for manufacturers, China is looking ahead to advance post-2020 standards for light-duty vehicles.

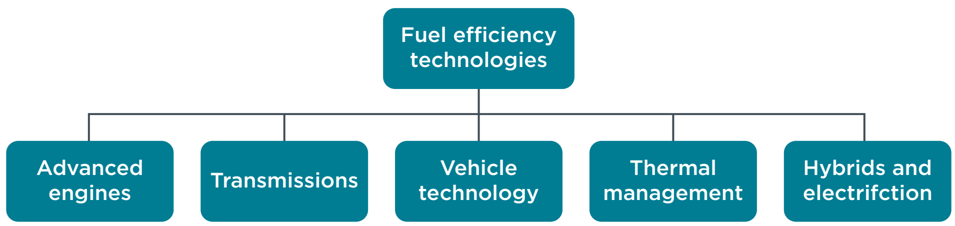

Figure 1 Categorization of fuel efficiency technologies in the working paper

In its "Made in China 2025" strategic initiative (MIIT, 2015), China set a 2025 fleet efficiency target of 4 L/100 km for passenger cars, a 20% decrease from the 2020 target of 5 L/100 km. In the Technology Roadmap for Energy Saving and New Energy Vehicles published by the Society of Automotive Engineers of China (SAE China, 2016), a 2030 fleet efficiency target of 3.2 L/100 km was set. To evaluate whether and how these targets can be met, it is essential to understand what technologies will be available within the 2020-2030 timeframe and what the costs of applying those technologies in the Chinese market will be.

This series of technical working papers aims to provide a comprehensive understanding of the current availability, effectiveness, and future market penetration of key fuel-efficiency technologies that manufacturers are likely to use in China by 2030. This information enables a more accurate, China-specific understanding of future technology pathways.

We group technologies into several categories: advanced engine, transmission, vehicle technologies, thermal management, and hybrids and electrification (Figure 1). The specific technologies we considered include those that are available today and others that are under development and expected to be in production in the next 5-10 years.

This research relies on information from publicly available sources, third-party databases, and information from the participating partners. Our approach includes:

- A detailed literature survey, including both Chinese and global regulatory documents, official announcements, and industry and academic reports.

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- Analysis of databases from Polk and Segment Y.
- Conversations with manufacturers, tier one suppliers, research entities, and domestic and international experts.

For each key technology, we discuss how it reduces passenger-car fuel consumption, its effectiveness in reducing fuel consumption, and its current level of application or potential application in the China market. Wherever applicable, we compare technology trends in China with those in the United States and the European Union to reflect potential technology pathways in the long term.

This working paper recaps the five detailed discussions in this series and summarizes the overall status of technology adoption in China. We evaluate the potential for reducing fuel consumption under different development scenarios. This is followed by a discussion of the next step of the research project

2 Summary of individual efficiency technology potential and market penetration

An overview of the efficiency technologies shows that the potential for reducing vehicle fuel consumption by adopting advanced technologies is great. Most efficiency technologies that are available on cars in other markets have already been introduced in China. Based on application status in China, we group the technologies into three categories:

Commercialized technologies. Technologies that have already been adopted on at least several production models in China and could be applied widely through the fleet. Production technologies include technologies that are already accepted by the Chinese market and could become more mature in the longer term.

Emerging technologies. Technologies that are available on passenger cars sold in the Chinese market but only on a couple of models, such as variants of flagship or luxury cars. These technologies, either introduced by joint ventures or developed by independent automakers, are still in the early stages of marketing and can be considered pilot products to test the Chinese market. Emerging technologies are the most advanced technologies in the Chinese market that we have identified and have the potential to provide additional fuel-efficiency benefits in the medium term.

Underdeveloped technologies. Technologies that have been adopted in other markets but currently are not available on cars produced in China, or technologies that have been announced by manufacturers or suppliers and are likely to be adopted on production cars in the near future. Underdeveloped technologies reflect the future trend of advanced technology development and have potential to further reduce vehicle fuel consumption in the long term.

Table 1 Efficiency technologies at different development stages in China

Type	Commercialized technologies	Emerging technologies	Underdeveloped technologies
Advance engine	• GDI • Cooled EGR for (NA engine) • Turbocharger (waste gate) • VVT • VVL • Atkinson cycle (hybrid) • Reinforced starter • Friction reduction	• Conventional cylinder deactivation • High compression ratio • Atkinson cycle (NA engine) • Direct starter	• Cooled EGR (Turbo) • Miller cycle • E-boost • Dynamic cylinder deactivation • HCCI/SPCCI • Variable compression ratio
Transmission	• 5/6MT • 5/6AT • 6/7DCT • CVT • Single reducer (EV)	• 8/9AT • AMT • DHT	• 8DCT* • eDCT, eCVT • multi-gear transmission (EV)
Vehicle technology	• Lightweighting 10% weight reduction • Low rolling resistance (5%)	• Lightweighting 20% weight reduction • Low rolling resistance (10%) • Active aerodynamic	• Lightweighting 30% weight reduction • Low rolling resistance (20%)
Thermal management	• Off-cycle credit for thermal management technologies accounts for 3% of fleet average fuel consumption	• Off-cycle credit for thermal management technologies accounts for 6% of fleet average fuel consumption	• Off-cycle credit for thermal management technologies accounts for 9% of fleet average fuel consumption

*8DCT is categorized as underdeveloped because it has been applied on only one luxury version of the Honda Spirior.

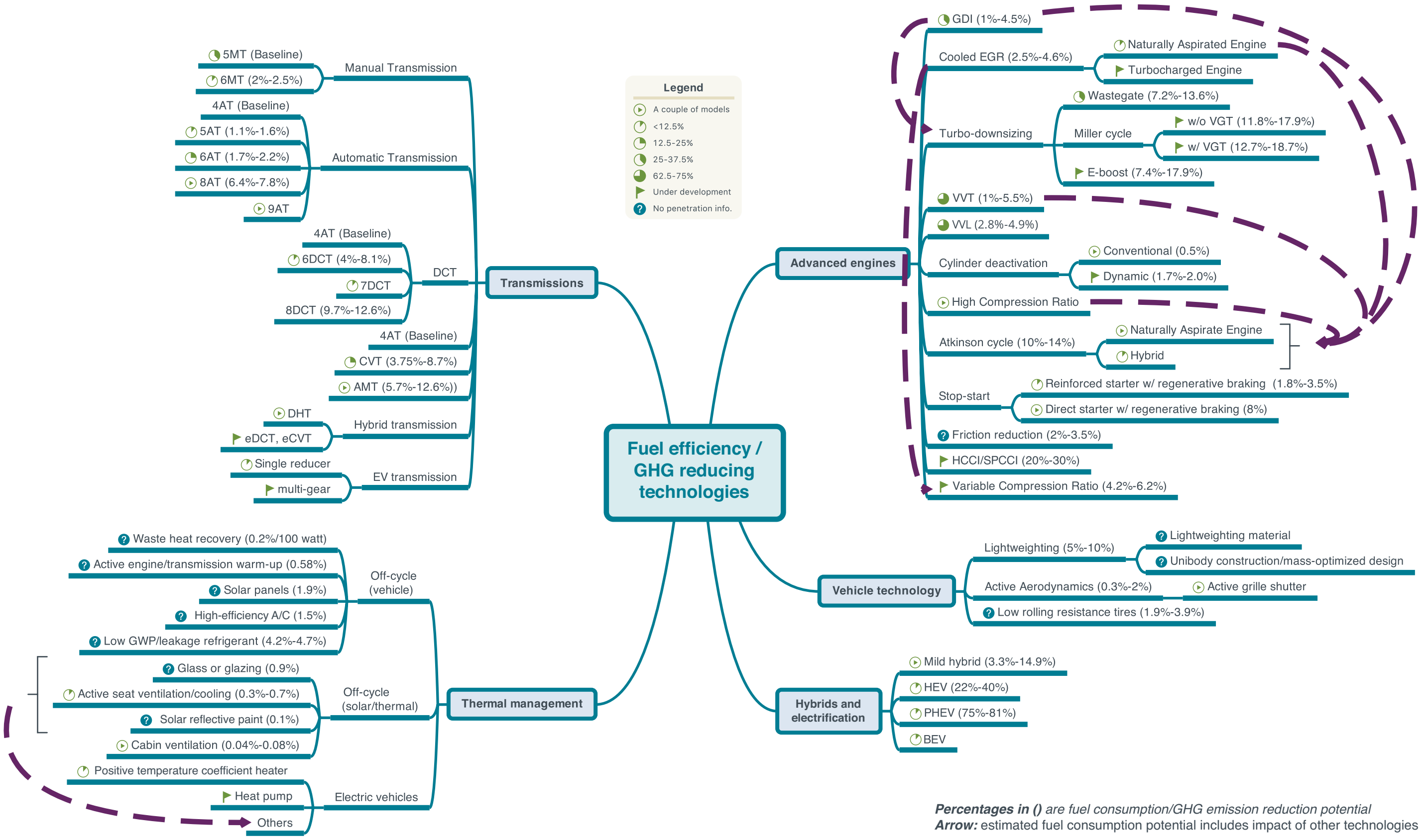

Figure 2 Fuel efficiency technology map for passenger cars in China

Table 1 summarizes the categorization of each technology type. Detailed methodology for the categorization can be found in the working papers for each technology group.

Figure 2 summarizes the key information discussed in the working paper series. The figure includes three sets of information:

- Existing, emerging, and underdeveloped technologies in each of the five categories. Some technologies are broken down into different types to reflect technical details.
- The adoption status of each technology in the China market. A pie chart indicates market penetration level of commercialized technologies; the start symbol, emerging technologies; and a green flag, underdeveloped technologies. In addition, a blue question mark designates technologies without market penetration information or technologies that cannot be simply summarized as a percentage of penetration, such as lightweighting. Although there is some lack of information, we have collected market penetration information of most critical technologies.
- A summary of each technology's potential impact in reducing fuel consumption as percentages in parentheses. For some technologies, the impact on fuel consumption is provided in combination with other technologies that are difficult to isolate. In those cases, we use arrows to indicate which technologies are included in the estimates for lowering fuel consumption.

3 Cumulative efficiency potential for internal combustion engine vehicles

Modern vehicles are usually equipped with multiple advanced efficiency technologies to reduce fuel consumption while maintaining, if not improving, their performance.

For conventional vehicles, we estimate the cumulative impact on fuel saving using different technology routes (Figure 3). The colors of the columns differentiate technology categories. The estimates under Technology Route 1 in Figure 3 illustrate the potential fuel savings from applying the most efficient technologies already commercialized compared with baseline vehicle technologies and without any other advanced technologies. Technology Route 2 additionally takes into account emerging technologies. Technology Route 3 widens the technology range to include all underdeveloped technologies.

When defining each technology route, if there are technologies that do not work with each other (mainly advanced engine technologies), we choose the technology combination that has highest fuel-saving potential. For vehicle technologies such as lightweighting that involve a combination of technologies, we reflect the technology development stage by differentiating the percentages of mass reduction achieved under each technology route. The same method is used for evaluating off-cycle cabin thermal management technologies.

This comparison aims to measure the overall fuel-saving potential for passenger cars in China with technologies at different stages of maturity. We find that adoption of the most efficient commercialized technologies can reduce vehicle fuel consumption by 31%. The potential reduction for vehicles that additionally apply emerging technologies is 51%, and further application of underdeveloped technologies can bring cumulative savings to 73%.

Whichever technology route is chosen, upgrading engine technologies contributes the most to fuel saving. Vehicle technologies—mainly lightweighting—make the second-biggest contribution. Efficient transmissions will play a bigger role if the emerging technologies and underdeveloped technologies are adopted.

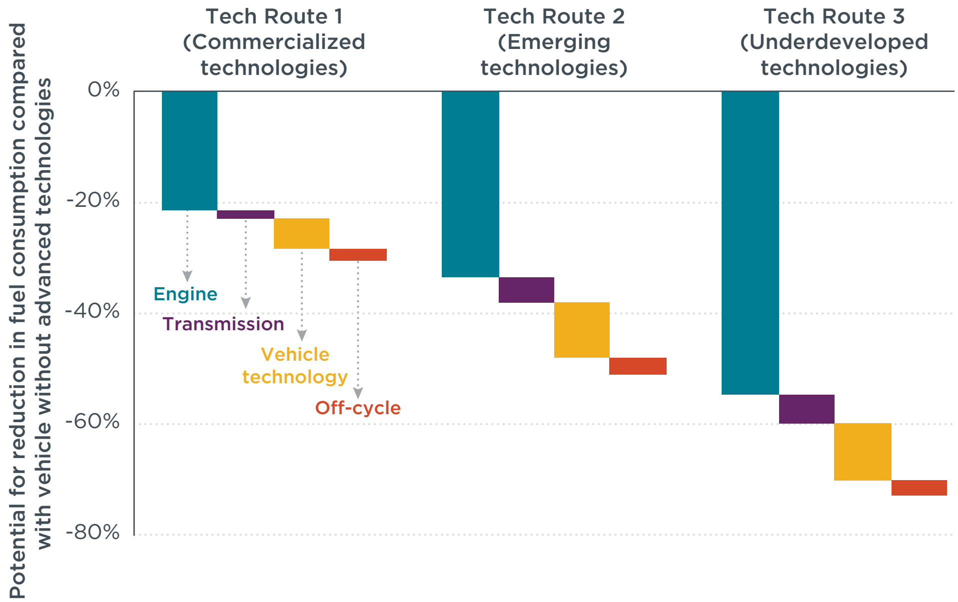

Figure 3 Estimates of average fuel-saving potential of three technology routes for conventional passenger cars in China by technology type

The impact of each technology on fuel saving is usually recorded as a range. Our cumulative estimates simplify this by using the average impact on fuel saving. In addition, the estimates of the fuel-efficiency benefits from adding multiple technologies to a vehicle generally do not fully account for synergies between technologies.

Although these caveats reduce the accuracy of the estimates, they don't change the general observations and conclusions. This working paper provides rough estimates to illustrate the current status and future trend. We will deal with these issues in the next phase of research to make the estimates more accurate, including the use of simulation models to account for synergies and estimate fuel-saving impact by vehicle segment.

4 Cumulative efficiency potential for hybrid and electrified vehicles

For electrified vehicles, we assess market penetration in China and fuel saving potential. As Figure 4 shows, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs) are still at an early stage in the Chinese market. Although the uptake rate of BEVs grew faster from 2016 to 2017, BEVs accounted for less than 2% of new sales in 2017. Sales of PHEVs amounted to 0.45% of the market, and HEVs, 0.71%. Even though HEVs do not receive the same government incentives as BEVs and PHEVs, the market share of HEVs exceeded that of subsidized PHEVs. This suggests that HEVs could be more competitive than PHEVs in China's existing policy environment.

To evaluate the fuel-saving potential of electrified vehicles, we analyze a range of technologies using electricity to assist the powertrain or propel a vehicle. The estimates shown in Figure 5 are based on popular models available in China, representing the fuel savings of existing technologies.[1] Average mild HEVs reduce fuel consumption by 12%, and full HEVs, 30%. In a mild HEV, the electric motor can assist the ICE to power the drivetrain but is not used to drive the wheels on its own. A full HEV can be driven by only the ICE, only the electric motor, or a combination of the two. The fuel-saving findings are similar to those for HEVs in the Unites States and the European Union, where all full HEV and most mild HEV models available in China are also available.

Calculating fuel consumption for PHEVs is controversial among regulators and academics. The issue is that while the vehicle is operating within its battery-only range, direct fuel consumption is zero. Once the vehicle exceeds the battery's range, the ICE operates and burns fuel to sustain the battery's charge. This combination of battery-only and charge-sustaining modes can reduce fuel consumption by as much as 80% from that of a comparable ICE vehicle, we found.

To compare the efficiency technologies of PHEVs, we broke out the fuel savings in charge-sustaining mode only and found a reduction of about 25% from benchmark ICE autos. This was about 5 percentage points lower than savings recorded by full HEVs. The benefit gap between full HEVs and PHEVs running in charge-sustaining mode is partly because of the additional weight from an expanded battery pack in PHEVs.

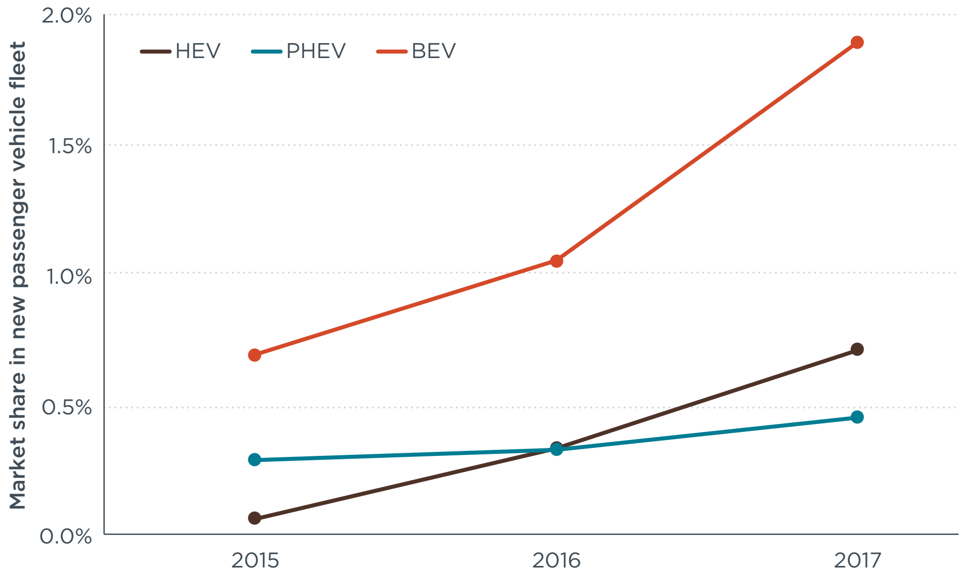

Figure 4 2015-2017 Market penetration of full hybrid vehicles, plug-in electric vehicles, and battery electric vehicles in China

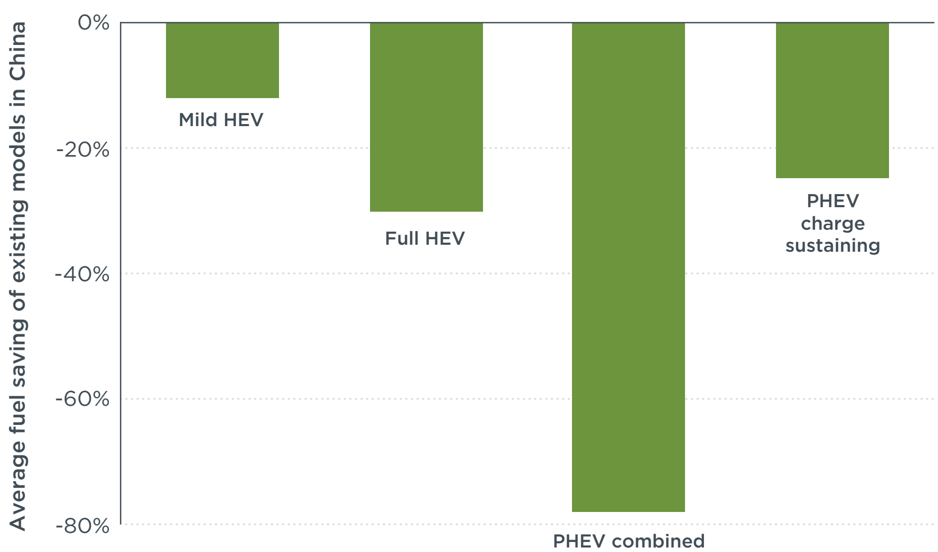

Figure 5 Estimated fuel saving potential of electrified vehicles in China

More importantly, it reflects differences in PHEV technologies between China and the American and European markets. Many PHEVs sold in those markets are built on mature HEV systems, so these PHEVs can be as efficient as counterpart HEV models when running in charge-sustaining mode. For example, a 2017 Toyota Prius Prime PHEV is rated at 54 mile per gallon (mpg) in charge-sustaining mode, even more efficient than the 52 mpg for the counterpart Toyota Prius HEV (DOE, 2018).[2] However, most PHEVs sold in China are manufactured

1 For detailed methodologies, please refer to (Cui & Xiao, 2018)

2 Data retrieved from fueleconomy.gov.

by independent domestic automakers and are mostly built directly on conventional gasoline models. They tend to be equipped with less-efficient hybrid technologies than are used in the more-advanced markets. The difference in fuel efficiency of PHEVs in charge-sustaining mode could be a concern if users drive PHEVs more with gasoline rather than electricity. BEVs could realize 100% fuel saving without considering upstream energy consumption.

Full HEVs are competitive on fuel-saving potential with ICE vehicles using commercialized technologies. HEVs also have the potential to compete with ICE vehicles with emerging technologies because HEV fuel-saving potential as summarized in Figure 5 is compared with baseline ICE models that have already adopted some commercialized technologies. Moving forward, BEVs and PHEVs are revolutionary technologies that significantly reduce fuel consumption, even though the fuel-saving potential of PHEVs in the real world would largely depend on the ratio of driving on electricity and gasoline.

5 Passenger-car efficiency-technology penetration

This series of working papers allows us to update the market penetration comparison of key efficiency technologies among China, the European Union, and the United States published in a previous ICCT report (Zhou & Yang, 2018)

As shown in Figure 6, it is clear that the application of key advanced efficiency technologies is accelerating in the Chinese passenger car fleet. Most of these technologies are available in China and even have a comparable market penetration as in the United States and European Union. As these commercialized technologies become more mature and as emerging and underdeveloped technologies are introduced, the ICE vehicle fleets have great potential to further reduce fuel consumption. The accelerated uptake of electrified vehicles is likely to speed the reduction of fuel consumption at the fleet level.

We found that much of the application of advanced efficiency technologies is by joint ventures. This means many key technologies are patented by international automakers. Independent automakers are stepping up efforts to develop domestic-brand technologies, which would be critical for China to keep up with advances in other vehicle markets.

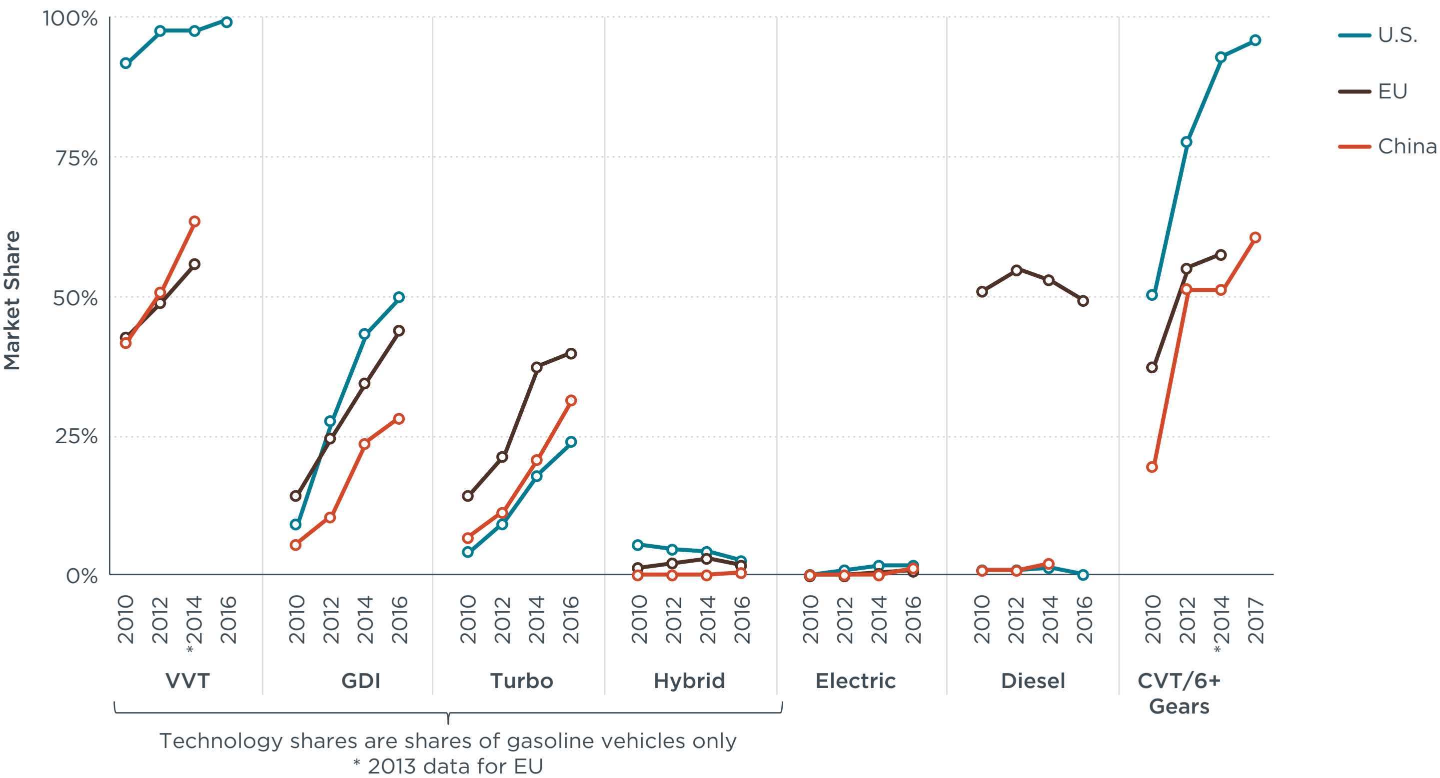

Figure 6 Power train technology adoption rates of China, U.S. and EU passenger cars from 2010 to 2016/2017

6 Next steps

This series of working papers provides a thorough review of existing and emerging vehicle-efficiency technologies, their potential to reduce fuel consumption in China, and how technology trends compare with those in the United States and the European Union. This contributes to a more accurate, China-specific understanding of future technology development and deployment.

At the same time, because of the relatively long time frame of this analysis out to 2030, it is likely that unanticipated new, innovative technologies will make their way into the fleet, very possibly in significant numbers.

The next step will be to develop fuel-consumption cost curves for the Chinese passenger vehicle fleet in the 2021–2030 time frame, assessing various near- to long-term efficiency and CO_2 reduction technologies based on cost-effectiveness. This will be useful in informing policy-making on future phases of standards and targets. The ICCT has already developed cost curves for Europe (Meszler, German, Mock, & Bandivadekar, 2017) and the United States (Lutsey, Isenstadt, German, & Miller, 2017), which will be used to inform the process of establishing cost curves for China.

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