Dynamic analysis of platinum material flows and stocks with hybrid MFA method aiming to carbon neutral targets of automotive industry in China

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ABSTRACT
Platinum is a key material in the automotive industry. In this study, we first quantitatively analyzed the platinum cycle from 2009 to 2019 in the automotive industry in China. The stocks of platinum to 2050 were then evaluated under different scenario in the automotive industry. The total amount of platinum entered into the automotive industry was 145.77 t from 2009 to 2019. Among them, the in-use stocks of platinum in vehicles increased from 37.07 t to 133.78 t. Platinum stocks in the automotive industry under 2°C scenario for high- and baseline- and low-demand in 2050 are 712.97 t, 529.32 t, and 345.67 t, respectively, while under carbon-neutral scenario, it is 440.55 t, 327.42 t, and 214.30 t, respectively. Under the carbon-neutral scenario, the platinum stocks in gasoline and diesel vehicles in 2035 and 2050 will decrease, which can provide 61.41% and 49.92% of the platinum stocks for fuel cell and hybrid vehicles in 2035 and 2050, respectively.

1. Introduction
Platinum group metals (PGMs) are widely used in various fields such as automobile manufacturing, and electronics and chemical functions. The gap between supply and demand of PGMs in China is huge due to its scarcity and the largest consumption in the world [1,2]. The global reserves of PGMs were 69,000 t in 2018, mainly in South Africa (63,000 t), Russia (3,900 t), Zimbabwe (1,200 t), and the United States (900 t), while the reserves of PGMs in China were only about 400 t [3]. Since 2009, the platinum demand of China has exceeded 60 t/yr, but the production of mines is only about 3 t/yr [4], so most platinum in China is mainly dependent on imports. Growth in platinum demand in the automotive industry is the main reason for the increase in platinum use. In 2016, the global use of PGMs in automotive industry had reached 0.4 kt, accounting for 63.4% of the total consumption, and the use of auto-catalysts is the largest field of primary platinum consumption (103.6 t) [5,6]. Over the past 30 years, global platinum usage has grown at an average annual rate of 2.73%/yr, while platinum usage in automotive has grown at an average annual rate of 5.73%/yr [7]. The platinum usage of automotive industry has increased with the growth of vehicle ownership in China. As the largest vehicle ownership country in the world, it is of great significance to study the metabolic evolution of platinum in the automotive industry in China to improve the efficiency of platinum utilization and to reduce external dependence.

Material flow analysis (MFA) is an analytical method to evaluate material stocks and flows within a certain time and space boundary, which is based on conservation of mass to track the input, output and storage of specific materials along its life cycle in the economic and environment system to analyze the relationship among materials [8,9]. The dynamic MFA is based on MFA considering both present material flow and past and future material flow that has been used in constructions, energy consumption, packaging industry, etc. [10]. There are a few studies on platinum flows in the automotive industry. At the global level, Rasmussen et al. applied dynamic MFA to analyze and predict the global PGMs flows and stocks from 1975 to 2050, concluding that the automotive and jewelry used the most of primary platinum from 1975 to 2016, and the stocks of electrolysis and fuel cell will increase in 2050 [5]. Alonso et al. forecasted that the future growth of FCVs is an important factor for platinum growth in the automotive industry [7]. At the regional level, Saidani et. al. proposed that 65% of platinum loss for catalytic converters in Europe was due to insufficient collections and unregulated exports, while 25% of platinum loss was from in-use dissipation [11]. Saurat et al. developed an MFA model of PGMs in Europe to quantify the flows of PGMs in 2004, and the results showed that the automotive...
industry was the single largest user of primary PGMs, and catalytic converters represented the major PGMs end use [12]. At the national level, Zhang et al. concluded that the demand for PGMs in China peaked at 4.75 t in 2019 with time-series MFA model and Gompertz model [13]. Li et al. forecasted that the PGMs demand will increase until 2030 in China, but the resources will be in short supply due to the restrictions on the PGMs [4].

Although some studies have analyzed the platinum material flows in China’s automotive industry [4,13], the platinum content of different fuel vehicle types was missing, resulting in the uncertainty of outcomes. However, with the policies for promoting electric vehicles and achieving carbon neutrality, the supply and demand for platinum will change significantly with the change in the structure of vehicles ownership; therefore, considering vehicle ownership of different fuel types is an important factor in analyzing platinum material cycle and forecasting future platinum demand in the automotive industry.

This study uses dynamic MFA method to analyze the flows and stocks of platinum for automobile industry in China from 2009 to 2019, considering the vehicle ownership of different fuel types, and predicts the platinum demand under carbon-neutral scenario and 2°C scenario from 2020 to 2050. Then, policy suggestions for highly efficient management of platinum are provided.

2. Methodologies

2.1. The stocks and flows of platinum from 2009 to 2019

2.1.1. System definition

Presently, the platinum consumption of China’s automobile industry is mainly in the catalytic converters of gasoline vehicles (GVs) and diesel vehicles (DVs). The temporal boundary in this study is defined within the period from 2009 to 2019, and the spatial boundary is the mainland of China, excluding Macau, Taiwan and Hong Kong.

The platinum material flow model of automotive industry is shown in Figure 1. From the life cycle perspective, the life cycle of the automobile system is divided into three phases, namely manufacturing, use and waste management phases, including catalytic converter production and manufacturing, vehicle use, waste catalytic converter collection and disposal processes.

![Figure 1. System boundary of material flow analysis of automobile industry.](image-url)
and \( \text{H}_i(t) \) is the platinum content of catalytic converter in vehicle \( i \) in the year \( t \).

The formula for calculating platinum stocks is
\[
P(t) = \sum_j C_i(t) \times \text{H}_i(t)
\]  
(2)

where \( P(t) \) is the in-use stocks of platinum in vehicles in the year \( t \) and \( C_i(t) \) is the ownership of vehicle \( i \) - in year \( t \).

The formula for calculating the platinum dissipative loss is as follows:
\[
L_j(t) = \sum_i N_j(t) \times u_j(t)
\]  
(3)

where \( L_j(t) \) is the platinum loss rate for process \( j \) in year \( t \), \( N_j(t) \) is the platinum inflow in process \( j \) for catalytic converter and \( u_j(t) \) is the platinum rate in process \( j \) for catalytic converter in vehicle \( i \) in year \( t \). The platinum rate loss is assumed as 10\% in the recovery process [14], 1\% of collection process [15] and 0.06\% as platinum depletion of the EOL catalytic converter [11,16].

In addition to dissipative losses, the losses also include inventory losses during the production and use phase of catalytic converters. The formula for calculating inventory losses is as follows:
\[
L''_j(t) = L'_j(t) - L_j(t)
\]  
(4)

where \( L''_j(t) \) represents the inventory loss of process \( j \) in year \( t \), \( L'_j(t) \) represents the total loss in year \( t \), and \( L_j(t) \) represents the dissipative loss in year \( t \).

### 2.2. Scenarios setting

Future platinum stocks for the automotive industry depend on vehicle ownership and platinum content of the vehicle, with the details as follows.

#### 2.2.1. Vehicle ownership prediction

Ownership of different fuel vehicles is key to platinum stocks for the automobile industry in the future. The parameters of the set carbon-neutral scenario and the 2°C scenario were set according to the results of the *Annual Report on Automotive Industry in China* [2020] [17] and *A Study on China’s Timetable for Phasing-out Traditional Ice-vehicles* [18], respectively. Platinum is used in automotive catalytic converters, and in the future, fuel cell vehicles (FCVs) and hybrid electric vehicles (HEVs) are expected to rely upon it. Thus, we mainly focus on the ownership of DVs, GVs, FCVs and HEVs.

**2.2.1.1. 2°C scenario.** The 2°C scenario is based on *A Study on China’s Timetable for Phasing-out Traditional Ice-vehicles* [18]. In the report, the vehicles ownership from 2020 to 2030 is based on national targets. For the ownership from 2030 to 2050, based on policy inertia, relevant research, etc., 2°C temperature control scenario for oil consumption is fitted, and a 55\% and 80\% reduction in fuel consumption in 2040 and 2050, respectively, compared to the peak for the automotive industry, is set as a basis for scenario setting. According to the report, we obtain the ownership of different fuel vehicles from 2020 to 2050, including internal combustion engine vehicles (ICEVs), new energy vehicles (NEVs), HEVs, FEVs, etc. However, the model only predicts the ownership of ICEV, without calculating the amount of DVs and GVs, respectively. The number of passenger vehicles dominated by GVs will increase, while the number of commercial vehicles and trucks dominated by DVs will remain basically unchanged from 2020 to 2050. In 2018, GVs and DVs accounted for 90.69\% and 9.3\% of fuel vehicle ownership, respectively. Therefore, the GVs and DVs are assumed to represent 92\% and 8\% of fuel vehicle ownership, respectively, in 2030, and 93.5\% and 6.5\% in 2040. The ownership of DVs, GVs, FCVs, and HEVs is as shown in Figure 2.

#### 2.2.1.2. Carbon neutral scenario.

Carbon emissions in the automotive industry mainly come from energy consumption during use phase [19], which can be reduced by developing new energy vehicles [20], promoting vehicle lightweighting [21], improving energy use efficiency, and promoting energy cleanliness [22].

Based on the plan for the automotive industry to reach carbon neutrality by 2060 in *Annual Report on Automotive Industry in China (2020)* [17], the quantity of vehicles in 2050 will increase to 5.62 billion from 2.81 billion in 2020. Mathematical models for predicting vehicle ownership include logistic models [23,24], time-series models [25], Gompertz models [26,27], neural network models [28], etc. The quantity of vehicles from 2009 to 2050 is shown in Figure 3. Assuming that the growth of vehicle ownership in 2020–2050 follows the logistic curve, a good fit is made based on the vehicle ownership data from 2009 to 2020 with \( R^2 \) of 0.999.

The proportion of vehicles for different fuel types is shown in Table 1. According to the carbon-neutral plan in *Annual Report on Automotive Industry in China (2020)*, the ownership of new energy vehicles will exceed 17\% in 2028, and the ratio of fuel vehicles to new energy vehicles will be approximately 10:90 in 2050. Therefore, this study assumes that fuel vehicles and new energy vehicles will account for 81.5\%, 17\% in 2028, 42.39\% and 55.8\% in 2040, 8.9\% and 89.1\% in 2050. Based on the lifetime of passenger vehicles and commercial vehicles, the lifetime of commercial vehicles dominated by DVs is shorter compared to passenger vehicles dominated by GVs. Therefore, we assume that the proportion of GVs in fuel vehicles will increase and DVs will decrease. According to China’s New
Figure 2. Vehicle ownership under the 2°C scenario from 2020 to 2050.

Figure 3. Vehicle ownership from 2009 to 2050 in China.

Table 1. Proportion of vehicles with different fuel types.

| Year | Percentage of GVs | Percentage of DVs | Percentage of HEVs | Percentage of FCVs |
|------|-------------------|-------------------|-------------------|--------------------|
| 2018 | 90.69%            | 9.31%             | 2.44%             | 0.45%              |
| 2028 | 72.75%            | 6.3%              | 19.07%            | 2.32%              |
| 2050 | 1.69%             | 0.09%             | 7.12%             | 4%                 |

Energy Vehicle Industry Development Plan (2021–2035) [29], in 2035, battery electric vehicles will become the mainstream of new energy vehicles in the market, and FCVs will fulfill the commercialization of characteristic scenario. Based on above, we assume that in 2028, the proportion of GVs, DVs, HEVs and FCVs will be 72.75%, 6.3%, 2.44% and 0.45%, respectively. With reference to the ratio of GVs and DVs in recent years, we assumed that the ratio of hybrid gasoline electric vehicles (HGEVs) and hybrid diesel-electric vehicles (HDEVs) will be 10:1. In 2050, we assume that GVs, DVs, HEVs and FCVs will be 1.69%, 0.09%, 7.12% and 4.4%, respectively, of which the ratio of HGEVs and HDEVs remains unchanged. Vehicle ownership under carbon-neutral scenario is shown in Figure 4.

2.2.2. Automotive platinum content
From 2009 to 2019, the amount of platinum per DVs increased from 2 g to 3 g, while the amount of platinum in GVs was 0.3 g consistently [7,10].

The future platinum intensity in vehicles relies on future emission regulations, the price of PGMs and the price ratio of platinum to rhodium. Three scenarios for platinum content per vehicle by 2050 based on future automotive technology development are considered [5,30,31].

(1) Baseline-demand scenario: the future platinum demand of per vehicle is assumed to remain stable from 2020 to 2050, as 3 g for per DV, 0.3 g for per GV and 15 g for per FCV. It is assumed that the platinum content of each HGEVs and HDEVs is one-third of GVs and DVs, respectively, 0.1 g and 1 g.
(2) Low-demand scenario: the future platinum demand of per vehicle is assumed to reduce with the future automotive technology development. From 2020 to 2050, the intensity of platinum will vary from 1 to 3 g per DV, 0.1 to 0.3 g per GV and 10 g to 15 g per FCV, and the platinum content of per HGEV and HDEV will vary from 0.03 g to 0.1 g and from 0.33 g to 1 g, respectively.

(3) High-demand scenario: the future platinum demand of per vehicle is assumed to increase as future emission regulations become particularly stringent. From 2020 to 2050, the intensity of platinum will vary from 3 to 5 g per DVs, 0.3 to 0.5 g per GVs and 15 g to 20 g per FCVs, and the platinum content of per HGEVs and HDEVs will vary from 0.1 g to 0.16 g and from 1 g to 1.66 g, respectively.

3. Results and discussion

3.1. Platinum flows and stocks in automotive industry from 2009 to 2019

3.1.1. Consumption of platinum in automotive industry

From 2009 to 2019, the platinum required for the production of fuel vehicles increased from 8.99 t/yr to 15.23 t/yr, with an average annual growth rate of 6.9% as shown in Figure 5. The platinum required for GVs production increased from 3.28 t/yr to a peak of 7.35 t/yr in 2017, with an average annual growth rate of 15.51%, followed by a decline owing to the progress of new vehicles that gradually replaced the fuel vehicles. Platinum demand for DVs production was generally on the rise, but with high volatility. From 2009 to 2017, platinum demand for DVs increased from 5.71 t/yr to 8.89 t/yr, with fluctuating growth or decline in the cycle of one or two years, due to fluctuating changes in DVs production as a result of economic development and emission regulations. From 2017 to 2019, the platinum demand remained stable.

3.1.2. In-use stocks of platinum in automotive industry

As shown in Figure 6, China has experienced steady growth in in-use stocks of platinum for vehicles due to the growth in vehicle ownership and the increased platinum content of per DVs with pollutant emission
control being more stringent. From 2009 to 2019, in-use stocks of platinum for fuel vehicles increased from 37.7 t to 133.79 t, with an average annual growth rate of 25.49%. The in-use stocks of platinum in GVs and DVs increased from 15.15 t to 67.17 t and 21.92 t to 66.61 t with an average annual growth rate of 34.33% and 20.38%, respectively.

3.1.3. Platinum recycling in automotive industry
As shown in Figure 7, from 2009 to 2019, as the attention to the automotive recycling industry, the platinum recycled from vehicles increased from 0.62 t/yr to 1.01 t/yr, with an average annual growth rate of 6.29%. From 2014 to 2015, as the China’s state council and local governments continued to promote the obsolescence and elimination of old vehicles including yellow label vehicles, the platinum recycling volume of scrapped vehicles grew rapidly reaching a peak of 1.55 t/yr in 2015, and then declined to 1.01 t/yr. From 2009 to 2019, the amount of platinum recycled from GVs and DVs increased from 0.25 t/yr to 0.5 t/yr and 0.37 t/yr to 0.51 t/yr with an average annual growth rate of 10% and 3.7%, respectively.

3.1.4. Results of platinum MFA
Figure 8 shows the flows and stocks of platinum within the automobile industry from 2009 to 2019. The total amount of platinum that entered the
The total amount of platinum that entered use phase was 139.85 t, and among them, 133.79 t of platinum was still in use, and 9.49 t of platinum entered vehicle recycling. The total loss of platinum was 4.975 t, that is, 0.69 t from production stage, 3.29 t from use stage and 0.995 t from recovery stage. The loss in use phase was the largest which accounted for 66.13% due to the high vehicle ownership and the loss of scrapped vehicles that do
not enter the recycling stage, while the next is the loss in production process which accounted for 13.87%. Although the losses in platinum recovery process were not significant, the loss in recovery process accounts for 10% of the input used for recovery.

3.2. Platinum stocks from 2020 to 2050 under two scenarios

3.2.1. 2°C scenario

Figures 9–11 show the platinum stocks of GVs, DVs, FCVs and HEVs under the high-, medium- and low-demand from 2020 to 2050 in 2°C scenario. In these scenarios, the total stocks for platinum from 2019 to 2050 are increasing. In 2050, under high-, medium- and low-demand, the platinum stocks will be 712.97 t, 529.32 t and 345.67 t, respectively. Among them, the platinum demand for FCVs will be 676.92 t, 507.69 t and 338.46 t, respectively, accounting for 94.94%, 95.51% and 97.91% of the total stocks, respectively, which are the main reasons for the increase in platinum stocks.

From 2020 to 2030, the growth of platinum stocks in high-demand scenario will be slowly increasing from 139.61 t to 208.85 t due to the continuous decline of GVs and DVs and the slow increase of FCVs, while in medium- and slow-demand scenarios, it will begin to grow and then decrease from 139.63 t to 176.95 t and 139.63 t to 142.12 t, respectively. From 2035 to 2050, the platinum stocks of three scenarios will experience a rapid growth due to the increasing number of FCVs. According to vehicle type, under high-, medium- and low-demand scenarios, the platinum stocks of GVs and DVs will increase from 2020 to a peak in 2025 of 86.56 t, 78.69 t, 70.04 t and 88.76 t, respectively.
80.69 t, 71.81 t, respectively. From 2025 to 2050, the platinum stocks of GVs and DVs will decrease as their ownership declines. The platinum stocks of FCVs will increase rapidly with the rapid increase of its possession. Due to its increased ownership, under high-, medium-, and low-demand scenarios, the platinum stocks of HEVs will reach peaks of 341.21 t, 27.47 t and 12.36 t in 2045.

The vehicle ownership of different fuel types has a significant effect on platinum stocks in the future, while the platinum content of per vehicle is also a critical factor. The platinum stocks in 2050 under the high-demand scenario is 106.25% higher compared to the low-demand scenario.

3.2.2. Carbon-neutral scenario

Figures 12–14 represent the platinum stocks of GVs, DVs, FCV, and HEVs under the high-, medium- and low-demand from 2020 to 2050 in carbon-neutral scenario. In these scenarios, the total stocks for platinum from 2019 to 2050 is increasing. In 2050, the total platinum stocks in the automotive industry of high-, medium- and low- demand will be 440.55 t, 327.42 t and 214.30, respectively. Among them, the platinum demand for FCVs will be 420.62 t, 315.46 t and 210.31 t, respectively, accounting for 98.13%, 96.34% and 95.47% of the total stocks, which are the main reasons for the increase in platinum stocks. From 2020 to 2040, the growth of platinum stocks in high- and medium-
demand scenarios will be slowly increasing from 150.60 t to 289.89 t and 150.60 t to 226.77 t due to the continuous decline of GVs and DVs and the slow increase of FCVs, and in the slow-demand scenario will be growing and then decreasing, from 150.60 to 159.30 t, respectively. From 2040 to 2050, the platinum stocks of three scenarios will experience rapid growth due to the increasing number of FCVs. According to vehicle types, from 2020 to 2028, under high- and medium-demand, the platinum stocks of GVs and DVs will increase to a peak of 118.14 t, 98.45 t and 102.31 t, 85.26 t in 2028, respectively, with the growth of its ownership. From 2028 to 2050, the platinum stocks of GVs and DVs will decrease as their ownership will decline. Due to the increase in FCVs ownership, under high-, medium- and low-demand scenarios, the platinum stock of HEVs will reach peaks of 341.21 t, 27.47 t, and 12.36 t in 2045.

The same as 2°C scenario, expect for the vehicle ownership of different fuel types, the platinum content of per vehicle is also a critical factor. The platinum stocks under the high-demand scenario compared in 2050 are 105.57% higher than the low-demand scenario.

### 3.3. The difference of platinum stocks in automotive industry between two scenarios

According to the forecast results, the platinum stocks of automotive industry in 2050 increase significantly. Under the platinum baseline-demand, in 2050, the platinum stocks of vehicles will increase by 263.60% and 117.41%, respectively, for 2°C scenario and carbon-neutral scenario compared to 2020. A rapid increase in the platinum demand is mainly due to the growth of FCVs and the high platinum content of FCVs. Based on the policy background of phasing out fuel vehicles and promoting new energy vehicles in the future, the demand for platinum will shift from GVs and DVs to FCVs. At the same time, the large difference in platinum stocks in 2050 between the carbon-neutral scenario and the 2°C scenario is also due to the difference in the number of FCVs. Under carbon neutrality for platinum baseline demand, as vehicle ownership reaches its peak in 2028 and then declines, the platinum stocks for GVs and DVs in 2035 and 2050 will decrease to 68.98 t and 179.36 t compared to 2028. Based on a 0.06% platinum loss during the use phase and 90% platinum recovery rate, 62.05 t and 161.32 t of platinum can be recovered from scrapped DVs and GVs, which can provide 61.41% and 49.92% of the platinum stocks for fuel cell and hybrid vehicles in 2035 and 2050, respectively. Under the policy platinum baseline demand scenario, as vehicle ownership reaches its peak in 2025 and then declines, the platinum stock of GVs and DVs in 2035 and 2050 will be reduced by 80.00 t and 159.69 t compared with 2025. Based on a 0.06% platinum loss and 90% platinum recovery rate during vehicle use, 71.95 t and 143.63 t of platinum can be recovered from scrapped diesel and gasoline vehicles, which can provide 62.51% and 27.08% of the platinum stocks of fuel vehicles and hybrid vehicles in 2035 and 2050, respectively.

### 3.4. Platinum resource management in automotive industry

In this study, the flows and stocks of platinum in Chinese automobile industry were analyzed using dynamic MFA method, and the stocks of platinum for automobile industry from 2020 to 2050 were predicted. The results of this study can provide...
development directions and recommendations for the sustainable development of China’s automotive industry and the management of platinum resources.

3.4.1. To improve new energy vehicles technology and develop multiple types of new energy vehicles

Compared with DVs and GV, FCVs require more platinum, which is the main reason for the growth of platinum demand in the future. To alleviate the shortage of platinum. On the one hand, the development and innovation of new energy vehicle technology should be encouraged to continuously improve the durability and service life of fuel cells and to reduce the platinum content of fuel cells. On the other hand, considering the limitations of platinum resources, we propose to develop on a broader new energy vehicle technology, such as battery electric vehicles and hybrid electric vehicles.

3.4.2. To increase the recovery rate of platinum and strengthen the closed-loop management of platinum

With the gradual replacement of fuel vehicles by new energy vehicles, and the rapid increase in the number of EOL vehicles, the future of EOL vehicles recycling will face tremendous pressure. Recycling platinum from the EOL catalytic converter will relieve pressure on platinum resources and reduce dependence on imported resources. Therefore, a complete platinum recycling system is important. China has not yet issued the relevant laws and regulations for platinum recycling, so most platinum recovery in China is mainly based on workshops. Therefore, we should formulate corresponding policy and regulations, and fully implement ‘extended producer responsibility’ to complete closed-loop management system [35]. Metal prices also affect recovery activities, so the price mechanisms for platinum should attract attention [36].

In addition, the relevant technologies should be improved to recover the available components of platinum tailings and smelting slag in production process and reduce the loss of platinum during use phase.

3.4.3. To establish a national precious metal reserve mechanism

Platinum is highly dependent on China's imports. Political factors and price fluctuations are likely to affect the future supply of platinum. The platinum supply risk in South Africa is considered to be very high, with more than 90% of the known reserves. For example, a strike by 70,000 workers in South Africa in 2014 led to a 40% reduction in global platinum production [5]. It is recommended to establish a national reserve mechanism, implement a combination of national reserves and private reserves and use policy subsidies and other means to encourage enterprises to reserve during low-price period of platinum.

4. Conclusion

In this study, we first developed a dynamic platinum MFA model in automotive industry, quantitatively analyzing the platinum cycle from 2009 to 2019 in China. Then, the future stocks of platinum to 2050 were evaluated under the carbon-neutral scenarios and 2°C scenario in automotive industry. With the growth of vehicle ownership, the total amount of platinum entered into automotive industry was 145.77 t from 2009 to 2019. Among them, the in-use stocks of platinum in gasoline vehicles increased from 15.15 t to 67.17 t, and it increased from 21.92 t to 66.61 t in diesel vehicles. The recycled platinum from vehicles increased from 0.62 t/yr to 1.11 t/yr. The future platinum stocks of automotive industry under 2°C scenario for high, baseline and low demand in 2050 are 712.97 t, 529.32 t, and 345.67 t, while under carbon-neutral scenario are 440.55 t, 327.42 t and 214.30 t, respectively. Compared to 2020, because of the great growth of fuel cell vehicles, the platinum stocks in 2050 under 2°C scenario and carbon-neutral scenario of high-, baseline- and low-demand will increase as 573.36 t, 389.71 t, 207.06 t and 289.95 t, 176.82 t, 63.7 t, respectively. Under platinum-baseline demand scenario in the carbon-neutral scenario, the platinum stocks in gasoline and diesel vehicles in 2035 and 2050 will decrease by 68.98 t and 179.36 t compared to 2028, which can provide 61.41% and 49.92% of the platinum stock for fuel cell and hybrid vehicles in 2035 and 2050, respectively. Under the policy platinum baseline-demand scenario, as vehicle ownership reaches its peak in 2025 and then declines, the platinum stock of gasoline and diesel vehicles in 2035 and 2050 will be reduced by 80.00 t and 159.69 t compared with 2025, which can provide 62.51% and 27.08% of the platinum stocks of fuel vehicles and hybrid vehicles in 2035 and 2050, respectively. To better manage and utilize platinum resources, China should improve new energy vehicle technology and develop multiple types of new energy vehicles, strengthen the closed-loop management of platinum metal and establish a national precious metal reserve mechanism.

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