Economic analysis and business model exploration of hydrogen transport – Case study of heavy-duty FCV demonstration in China

Lu Xing
Strategic Business Unit of Capital Management & Financial Service, Sinopec Group, Beijing, 100728, China
e-mail: xinglu@sinopec.com

Abstract. Hydrogen is considered an important future energy to achieve a carbon neutral energy system, and transport is the most mature area to start a hydrogen economy. China proposed new policies in 2020 to encourage the development of FCV especially in heavy-duty transport, however little research can provide appropriate framework and practical data for the economic analysis of such demonstration, to provide important and rational support for the decision making of local government. This paper introduces a planned heavy-duty FCV demonstration project in city A, provides a framework for its economic analysis as well as practical data from FCV manufacturers, hydrogen producers and suppliers. Results show comprehensive investment required for such demonstration project, cash flow for the planning period and key impacting factors considering the whole circle of hydrogen production-transmission-refilling-utility. Findings show that FCV application shows better profitability than the hydrogen supply business, and long-term FCV planning targets are crucial to all practical business models; Capex reduction is the common and crucial element to realize commercial application of hydrogen transport, and hydrogen supply chain should be integrated to reduce the overall hydrogen cost.

1. Introduction
Hydrogen attracts increasing attention in recent years as a future energy in the global energy transition. More and more agencies believe that hydrogen, especially blue and green hydrogen will play an important role to meet the 2°C even 1.5 °C climate goal. International Energy Agency predicts that hydrogen will account in 2070 for 13% of all final energy needs, with 70% being used in transport and demand growth almost completely met by low carbon hydrogen [1]; and identifies opportunities in the next 10 years to boost hydrogen to achieve the necessary scale to bring down costs and reduce industry risks [2]. In the roadmap to a zero-carbon-emissions economy proposed by Energy Transition Council, all feasible scenarios involve a massively expanded role for clean electricity use and a very significant expansion of the role of low-carbon hydrogen, which will account for 15%-20% of final energy demand by 2050 [3]. International Renewable Energy Agency forecasts that green hydrogen will be cheaper than blue hydrogen in many regions in next 5-15 years [4], in consistent with a prediction that green hydrogen cost will be cut to 2 dollars per kg by 2030 [5].

Today, more than 130 countries have net zero carbon ambitions [6] and over 30 have hydrogen-specific strategies [7], transport is the priority sector for hydrogen application to achieve deep decarbonisation. More than 20 EU countries have announced sales bans on internal combustion engine (ICE) vehicles before 2035; while in the US, state-level initiatives in California and 15 other states have set ambitious targets to transition not only passenger cars but also trucks to zero-emission status by 2035.
In China, a 2021-2024 national program is proposed to award fuel cell vehicle (FCV) especially heavy-duty FCV deployment in pilot city clusters, covering both hydrogen and FCV supply chains; and the latest Development Plan of New Energy Vehicle Industry forecasts China’s FCVs ownership will reach 1 million by 2035.

Since China committed the carbon neutrality goal in 2020, industrial players and local governments have accelerated the demonstration of hydrogen transport, considering hydrogen to be a practical low-carbon alternative as well as emerging industry. However, there are few research focus on the economic analysis of such demonstration to illustration continuous investment and business model required for its sustainable development. Existing researches pay most attention to the technology competitiveness trajectory in the long-term and in a general way, lacking of practical feedback [8-10]. Several latest researches investigate FCV demonstration operation in Foshan and Beijing-Tianjin-Hebei region by collecting operation date without economy data, and all these date are based on FC buses [11-12]. This paper will focus on a pilot project of heavy-duty FCV which is the breakthrough of hydrogen transport application, based on the investigation with main FCV manufacturers and hydrogen suppliers for practical data, and also joint planning with local government. It will show the comprehensive investment required and cash flow for the planning year, and discuss key factors for a practical business model.

2. FCV demonstration project and methodology

2.1. Demonstration project

City A plans to deploy 210 FC trucks to replace traditional heavy-duty trucks for transporting aggregates in the city construction. They are 6 meter*4 meter trucks of 49 deadweight ton, with average hydrogen consumption about 0.13 kg per km considering both full-load and no-load hydrogen consumption. The length of the transportation route is 150 km. Suppose every truck travels 300 km per day, then daily hydrogen consumption for one truck is about 40 kg, which matches the on-board hydrogen storage capacity and means it needs to be refuelled once a day. According to the FCV deploy planning, hydrogen demand in 2025 will grow to 8.2 tons per day. Considering the planned hydrogen refuelling capacity of a single station is 1000kg/d, 9 hydrogen refuelling stations need to be built in City A by 2025.

In order to meet local needs with clean hydrogen, City A plans to use by-product hydrogen provided by a surrounding company, or use renewable energy to generate green hydrogen. Therefore, three hydrogen supply programmes are considerable as follow: i) A petro-chemical company could provide purified by-product hydrogen by tube trailers under pressure of 20 MPa, and the distance is 120 km; ii) Use local grid power to produce green hydrogen on-site at hydrogen refuelling stations, and it is known that a newly constructed power transmission line could send renewable energy far away to fully meet the demand for hydrogen production; iii) Use the newly built PV plant nearby to produce green hydrogen, and then transport it by tube trailers under pressure of 20 MPa, the distance is 150 km.

Details of demonstration project regarding FCV application and the three hydrogen supply programmes are shown as follows (Table 1).

| Heavy-duty FCVs (unit) | 2021 | 2022 | 2023 | 2024 | 2025 | Total |
|------------------------|------|------|------|------|------|-------|
| Hydrogen supply programmes | Hydrogen Production | Hydrogen Transportation | Hydrogen refuelling station |
| 1 | by-product hydrogen | PSA purification | 120 km | 20 MPa | 9*1000kg/d |
| 2 | green hydrogen /grid power | PEM electrolyser | 0 | - | |
| 3 | green hydrogen /PV plant | PEM electrolyser | 150 km | 20 MPa | |
2.2. Methodology of the economic analysis
Since the transportation industry and the energy industry are very different in characteristics, management models, and operating entities, economic analysis is carried out separately according to FCV application scenario and hydrogen supply scenario. In actual operation, energy companies are trying to explore the new energy transportation industry through joint ventures and other tactics. The prevailing model is to set up a heavy-duty FCV operation and management company for the procurement, operation or leasing.

This article will concentrate on the quantitative analysis of investment and production of the hydrogen demonstration project of City A only for the 14th five-year period, due to the following two facts: first, the planning objectives of hydrogen transport and infrastructure in City A cover only the 14th five-year period so far, with following plans still unclear. Second, the massive application of heavy-duty FCV is still on the demonstration stage, relevant functional and economic circumstances are still faced with uncertainties.

2.3. Key parameters
The depreciation and amortization periods of different assets are hypothesized as follows:
- **8 years** for the heavy-duty FCV;
- **10 years** for the hydrogen purification facilities in the petro-chemical company;
- **15 years** for the operation facilities, such as electrolysers, pumps, trailers, and station facilities;
- **50 years** for the land of the hydrogen refuelling stations.

The relevant financing hypotheses are set as follows:
- **Fixed Assets investments**: 30% financed with owned capital, 70% financed with 5-year loan with annual rate of 5%;
- **Working capital**: 30% financed with owned capital, 70% financed with 1-year loan with annual rate of 4%;
- **Cost of equity**: 5.5%, a capital cost implemented by SASAC (State-owned Assets Supervision and Administration Commission of the State Council) and adopted by state-owned oil companies.

3. Results and discussion
Due to the significant differences of operation entities and business models between application of FCV and supply of hydrogen, the quantitative analysis will be separately conducted base on two scenarios: i) Heavy-duty FCV scenario, which contains only one programme; ii) Hydrogen supply scenario, which contains three programmes, all organized with three parts: investment scale, cash flow and sensitivity.

3.1. Scenario 1: Heavy-duty FCV scenario
By the end of 2025, 210 heavy-duty FCVs will occupy approximately 7% of the total heavy trucks in City A, and transport about 10% of the aggregates used for the construction. In order to realize the goal above, RMB 1.13 billion is estimated to be spent during the 14th five-year, which constitutes: i) RMB 630 million for the purchase of vehicles; ii) RMB 220 million for the hydrogen; iii) RMB 160 million for labour costs, insurances, maintenance expenses, tolls, etc.; iv) RMB 80 million for costs of operation.

When it comes to the income, an accumulative revenue of RMB 710 million generated by providing transportation service is expected, assuming the charge is RMB 1/km·ton. Besides the transportation service revenues, central and local government vehicle subsidies will also be an important income for the project. If fully acquired, the overall government subsidies are expected to generate an income of RMB 130 million, for the period from 2021 to 2024, assuming central government and local government subsidize on a 1-1 basis.

Assuming the WACC is 4.05%, the NPV of the project by the end of 2020 will be RMB -260 million, with a 2025-year-end book value of RMB 450 million of the fixed assets. Following is the detailed cash flow figures (table 2):
Table 2. Input-output of heavy-duty FCV scenario. in millions, ¥

| Scenario                      | Total | 2021 | 2022 | 2023 | 2024 | 2025 |
|-------------------------------|-------|------|------|------|------|------|
| Heavy-duty FCVs (unit)        | 210   | 0    | 30   | 60   | 60   | 60   |
| Hydrogen demand per day (kg)  | -     | 0    | 1,170| 3,510| 5,850| 8,190|
| Vol of Trans per year (thousand tons) | 4,750 | 0    | 300  | 890  | 1,490| 2,080|
| Aggregate Input               | 1,126.30 | 0    | 138.21| 280.36| 329.36| 378.37|
| Aggregate Output              | 712.80 | 0    | 44.55| 133.65| 222.75| 311.85|

Cash Flows

| Capex Cash Flow               | 0    | -90.00| -180.00| -180.00| -180.00| -180.00|
| Operating Cash Flow           | 0    | 26.03 | 81.64  | 110.76 | 113.44 | -66.56|
| Net Cash Flow                 | 0    | -63.97| -98.36 | -69.24 | -66.56 | -66.56|

By analysing the parameters related to NPV, one can find that the main affecting parameters are procurement costs of vehicles (negative related) and charge of transportation service (positive related). Under the same condition of price fluctuation, government subsidies and hydrogen price cast relatively insignificant impact on the NPV. Also, the per vehicle procurement cost is assumed to be RMB 3 million, significantly higher than the current price offered by automobile manufacturers, which ranges from RMB 1.5 million to RMB 1.8 million, leaving an optimization space for the cash flow.

If the City A government raises the service procurement price for heavy-duty FCV transportation to RMB 1.6/km·ton or above, the NPV of the project will improve significantly, and generate a positive value for the 14th five-year period. The sensitivity analysis is showed below (table 3):

| Range | FCV Service Charge | Hydrogen Price | Vehicle Price | Subsidies |
|-------|--------------------|----------------|--------------|-----------|
| -30%  | -396.25            | -218.70        | -108.29      | -286.09    |
| 0     | -260.02            | -260.02        | -260.02      | -260.02    |
| 30%   | -123.80            | -301.35        | -411.76      | -233.96    |

3.2. Scenario 2: Hydrogen supply scenario
To meet the local hydrogen demand, City A is expected to construct 9 hydrogen refuelling stations during the 14th five year, each with a capacity of 1000 kg per day. Based on variable hydrogen sources and transportation solutions, three programmes can be adopted for the supply of hydrogen, which will be demonstrated in detail in the following part. With different inputs, the previously mentioned 3 programmes will generate the same revenue, an accumulative revenue of RMB 220 million from hydrogen sale. Same as the heavy-duty FCV scenario, central and local government subsidies will also be an important income for the hydrogen supply. If fully acquired, the overall government subsidies for hydrogen supply are expected to generate an income of RMB 60 million for the period from 2021 to 2024, assuming central government and local government subsidize on a 1-1 basis.

From the perspective of financial feasibility and superiority, programme 1 is more preferable, compared to programme 2 and programme 3. Detailed analysis is demonstrated below.

3.2.1. Programme 1: purified by-product hydrogen from a petro-chemical company. A petro-chemical company 120km away has already realized the massive production of hydrogen with high-purity and adaptable for vehicles. Its production capacity of pure hydrogen is capable of meeting the daily demand of City A in the entire 14th five-year period.
The gross cost estimation for programme 1 within the period is RMB 680 million, including: i) for hydrogen production, RMB 50 million for PSA facilities to purify impure hydrogen; ii) for hydrogen transmission, RMB 180 million for the procurement of stations and trailers; iii) for hydrogen refuelling, RMB 15 million for constructing one refuelling station, 15 million for the land and 1.5 million for the annual operation expenditure for each station. Besides, the gross cost also includes the operation costs, such as the labour costs of trailer drivers, insurances, tolls, maintenance expenses, etc.

Assuming the WACC is 4.05%, the NPV of the project by the end of 2020 will be RMB -350 million, with a 2025-year-end book value of RMB 410 million of the fixed assets. The main factors that affect the NPV of programme 1 are (sorted by the influence) the hydrogen sale price, fixed asset investment of hydrogen transportation, fixed asset investment of hydrogen refuelling (excluding land costs), subsidies. Since the government requires a hydrogen sale price under RMB 35 per kg in order for the hydrogen operators to get subsidies, increasing the sale price of hydrogen proves to be an infeasible way to improve the cash flow situation of the project. By introducing the domestication of equipment and intensified procurement, the fixed asset investment can be optimized. Along with the improvement of local governments’ subsidies, the cash flow of the project can be largely optimized. The sensitivity analysis is showed below (table 4):

| Range | Hydrogen Price | Power Price | Fixed Assets Investment |
|-------|----------------|-------------|-------------------------|
|       | production     | transportation | refueling | production |
| -30%  | -308.08        | -337.54     | -361.91    | -394.33    | -383.92 |
| 0     | -353.93        | -353.93     | -353.93    | -353.93    | -353.93 |
| 30%   | -390.73        | -361.26     | -336.89    | -304.47    | -314.89 |

Taking all the relevant parameters into estimation, the average cost of hydrogen supply for programme 1 is RMB 40.6 per kg, and can be separated into 3 parts: i) RMB 19.3 per kg for hydrogen production; ii) RMB 10.8 per kg for hydrogen transportation and iii) RMB 10.4 per kg for hydrogen refuelling.

3.2.2. Programme 2: Station on-site green hydrogen. City A clearly puts forward the goal of increasing the proportion of regional green power consumption through hydrogen production. On-site hydrogen production in pilot hydrogen refuelling stations can be considered for to avoid high hydrogen transportation cost and greatly reduce hydrogen supply cost. A 20MW electrolyser can meet the needs of a single hydrogen refuelling station, and the initial facility investment is about RMB 20 million. Operating costs mainly include labour cost, water and electricity cost. Calculated based on the general industrial and commercial electricity price of RMB 0.6 per kWh in City A, the total investment will be RMB 720 million. If City A can provide policy and electricity price support for on-site hydrogen production, for example, if the hydrogen production electricity price drops to RMB 0.4 per kWh, the total investment in programme 2 can be reduced to RMB 650 million, which is lower than programme 1.

Assuming the WACC is 4.05%, the NPV of the project by the end of 2020 will be RMB -370 million, with a 2025-year-end book value of RMB 370 million of the fixed assets. The factors that have the greatest impact on the NPV of programme 2 are the fixed investment in hydrogen production and the hydrogen production electricity price. Speeding up the localization of electrolyser and striving for preferential policies for hydrogen production electricity prices are the key to improving the cash flow of programme 2. The sensitivity analysis for programme 2 is showed below (table 5):
Table 5. Sensitivity analysis of NPV- Programme 2. in millions, ¥

| Range | Hydrogen Price | Subsidies | Power Price | Fixed Asset Investment |
|-------|----------------|-----------|-------------|------------------------|
|       |                |           |             | Production | Refueling |
| -30%  | -415.48        | -386.02   | -331.65     | -328.14     | -339.64   |
| 0     | -374.16        | -374.16   | -374.16     | -374.16     | -374.16   |
| 30%   | -332.83        | -362.30   | -416.66     | -420.18     | -408.67   |

Taking all the relevant parameters into estimation, the average cost of hydrogen supply for programme 2 is RMB 54.3 per kg, and can be separated into 2 parts: i) RMB 43.9 per kg for hydrogen production; ii) RMB 10.4 per kg for hydrogen refuelling. If the electricity price is reduced to RMB 0.49 per kWh, the average hydrogen supply cost will be RMB 47.7 per kg, which is consistent with the cost of programme 3.

3.2.3. Programme 3: green hydrogen from surrounding PV plant. For this programme, a newly built large scale PV plant 150km away would be used to produce green hydrogen and then make it transported to City A. Compared to programme 1, this programme will be conducted with higher costs in both hydrogen production and transportation. While compared to programme 2, this programme shows lower cost in hydrogen production, but with higher cost in hydrogen transportation. Besides, this programme requires the largest fixed assets investment scale within the 3 programmes.

Now, constructing a photovoltaic power station with capacity of 500 MWp costs RMB 250 million. Since the cost can be covered by the sale of electricity, rather than hydrogen production, this programme will not take the cost of photovoltaic power station into consideration. Supposing the photovoltaic power station provides electricity to hydrogen production with a price of RMB 0.3 per kWh, the gross cost of the entire programme 3 will be RMB 850 million.

Assuming the WACC is 4.05%, the NPV of the project by the end of 2020 will be RMB -480 million, with a 2025-year-end book value of RMB 520 million of the fixed assets. The main factor that affects the NPV of programme 3 is the investment scale of fixed assets for hydrogen production and transportation (as showed in table 6).

Table 6. Sensitivity analysis of NPV- Programme 3. in millions, ¥

| Range | Hydrogen Price | Power Price | Fixed Asset Investment Scale |
|-------|----------------|-------------|-------------------------------|
|       |                |             | production | transportation | refueling a |
| -30%  | -521.73        | -459.15     | -431.78   | -435.47       | -445.88    |
| 0     | -480.40        | -480.40     | -480.40   | -480.40       | -480.40    |
| 30%   | -439.08        | -501.65     | -529.02   | -525.33       | -514.92    |

a Here he cost of refuelling doesn’t include the cost of land.

Taking all the relevant parameters into estimation, the average cost of hydrogen supply for programme 3 is RMB 47.7 per kg, and can be separated into 3 part3: i) RMB 25.9 per kg for hydrogen production; ii) RMB 11.4 per kg for hydrogen transportation and iii) RMB 10.4 per kg for hydrogen refuelling.

3.2.4. Comparison amongst three programmes. Results in table 7 show that, for investment scale, programme 3 > programme 2 > programme 1; for NPV, programme 1 > programme 2 > programme 3, all programmes have realized negative NPV for the 14th five-year period; while for overall cost of hydrogen supplied, programme 2 > programme 3 > programme 1.
Table 7. Overview of the hydrogen demonstration project. in millions, ¥

| Investment Scale | Total   | 2021    | 2022    | 2023    | 2024    | 2025    |
|------------------|---------|---------|---------|---------|---------|---------|
| Programme 1      | 677.96  | 98.33   | 101.00  | 157.14  | 174.04  | 147.46  |
| Production       | 146.09  | 20.70   | 5.53    | 47.95   | 30.02   | 41.90   |
| Transportation   | 226.51  | 15.53   | 30.90   | 42.16   | 43.47   | 94.46   |
| Refuelling       | 305.36  | 62.10   | 64.57   | 67.03   | 100.55  | 11.10   |
| Programme 2      | 724.51  | 103.50  | 121.11  | 152.22  | 235.08  | 112.59  |
| Production       | 419.15  | 41.40   | 56.54   | 85.19   | 134.53  | 101.49  |
| Refuelling       | 305.36  | 62.10   | 64.57   | 67.03   | 100.55  | 11.10   |
| Programme 3      | 853.22  | 122.31  | 147.58  | 176.15  | 246.47  | 160.71  |
| Production       | 317.59  | 44.69   | 51.87   | 66.22   | 101.28  | 53.53   |
| Transportation   | 230.27  | 15.53   | 31.14   | 42.89   | 44.64   | 96.08   |
| Refuelling       | 305.36  | 62.10   | 64.57   | 67.03   | 100.55  | 11.10   |

Cash Flow

| Programme 1       |         |         |         |         |         |         |
|-------------------|---------|---------|---------|---------|---------|---------|
| Capex Cash Flow   | -95.00  | -87.00  | -123.00 | -120.00 | -75.00  |         |
| Operating Cash Flow| 1.33    | 10.56   | 27.22   | 41.32   | 24.78   |         |
| Net Cash Flow     | -93.68  | -76.44  | -95.78  | -78.68  | -50.22  |         |

Programme 2

| Capex Cash Flow   | -100.00 | -100.00 | -100.00 | -150.00 | 0       |         |
| Operating Cash Flow| 1.32    | 6.29    | 13.87   | 20.38   | -7.01   |         |
| Net Cash Flow     | -98.68  | -93.71  | -86.13  | -129.62 | -7.01   |         |

Programme 3

| Capex Cash Flow   | -115.00 | -127.00 | -133.00 | -180.00 | -75.00  |         |
| Operating Cash Flow| 1.57    | 9.87    | 24.38   | 38.28   | 19.02   |         |
| Net Cash Flow     | -113.43 | -117.13 | -108.62 | -141.72 | -55.98  |         |

Hydrogen cost ¥ per kg

| Programme 1       | 40.6    | 19.3    | 10.8    | 10.4    |         |         |
| Programme 2       | 54.3    | 43.9    | 0       | 10.4    |         |         |
| Programme 3       | 47.7    | 25.9    | 11.4    | 10.4    |         |         |

In general, programme 1 is the most economical among the three programmes. The economic improvement of programme 2 and programme 3 heavily depends on the decrease of the cost of electrolyser, while programme 2 is the least competitive programme under the current electricity price condition. In conclusion, taking all the predictable factors into consideration, programme 1 is the most preferable in the early stage of Hydrogen Demonstration Project of City A.
4. Conclusion and suggestions

Conclude analysis and results above, we can find several key implications for a practical business model for the demonstration operation in heavy-duty transportation, as well as suggestions for all stakeholders in this hydrogen transport ecosystem.

4.1. For business model

Long-term FCV planning targets is essential to all practical business model. Today, most regional or local governments published hydrogen transport planning only for the next 3-5 years. Whether there will be more FCVs deployed afterwards or whether the supporting policy environment will change is unclear. It brings very high risk to hydrogen suppliers whose assets depreciation and amortization period is much longer than the FCV owners. In actual practice, refueling station owner, who play the role as a node connecting hydrogen supply and hydrogen consumption, is usually a joint venture evolving local government, or extra subsidy for the station construction or operation is required to avoid uncertainties. Therefore, longer-term FCV deployment targets could help to settle down the hydrogen transport demonstration and reduce the subsidy requirement from the local government.

FCV application shows better profitability than the hydrogen supply business. Although NPVs of both heavy-duty FCV scenario and hydrogen supply scenario are negative, NPV of heavy-duty FCV scenario and period-end book value of the fixed assets shows better performance. And if we take the decreasing cost of FCV into account, which mainly benefit from scaling up application, heavy-duty FCV scenario could realize positive NPV since 2024. This can explain why hydrogen supply companies is exploring to expand their business to FCV application with capital cooperation. And operation optimization and precise management to raise transportation load and efficiency could also contribute to the business performance.

Hydrogen supply chain should be integrated to reduce the overall hydrogen cost, considering the local resources and requirement. Comprehensive energy companies rich in hydrogen resources, like by-product hydrogen and renewable energy for electrolysis as well as transmission and refuelling resources take advantages to unify the hydrogen supply chain. Besides, under a short-term FCV planning, outsourced service may significant lower the Capex required and improve the cash flow performance. For example, if we buy transmission service in programme 1, total investment required could be cut by RMB 160 million.

Capex reduction is the common and crucial element to realize commercial application of hydrogen transport. For current and planning hydrogen demonstration projects, most investment are going to Capex in electrolyser, storage, transmission, refuelling and fuel cell stacks. Considering technology development and scale up application, Capex reduction show great potential. Solutions with quick effect on Capex reduction, one is to accelerate localization of core equipment manufacture, the other is to unify standards of core equipment and apply centralized procurement in the specific demonstration project.

4.2. For stakeholders

Local government should take hydrogen transport demonstration as part of its transport and energy transition from a long-term consideration and systemic perspective. Except for strict safety regulation, flexible technology routes, price mechanism and business models, as well as multi participants should be encouraged to strengthen the ecosystem.

Industrial players in the FCV chain should insist market oriented principle, to provide tailor-made and competitive FCV with good quality, low price and high efficiency. To be specific about heavy-duty FCV mentioned in this case, output capacity of fuel cell stack need to be raised while the life time should be greatly extended, and hydrogen consumption per km is expected to be cut down significantly.

Players in the hydrogen supply chain should cooperate together to provide high-quality, cheaper and low carbon hydrogen to end users. Stable, safe and convenient supply is the goal at first stage, and now the economy goal shows increasing importance for expanding application. Companies in the core position of hydrogen supply chain face opportunity to unify all these resources.
Acknowledgments
Thank my colleagues L. L. Wang, L. Zhang, W. C. Zhang and C. L. Zhang for assistance and helpful conversations to this research. Thank Air Liquid China, Re-fire, SANY for industrial data. This work was also supported by Youth Program of National Natural Science Foundation of China (Grand No. 71804087).

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