# Chapter 2

# Hydrogen Energy Demand and Supply Potential in China

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December 2021

**This chapter should be cited as**

Kutani, I. and M. Motokura (2021), 'Hydrogen Energy Demand and Supply Potential in China', in Li, Y., H. Phoumin, and S. Kimura (eds.), *Hydrogen Sourced from Renewables and Clean Energy: A Feasibility Study of Achieving Large-scale Demonstration.* ERIA Research Project Report FY2021 No. 19, Jakarta: ERIA, pp.7-25.

# Chapter 2

# Hydrogen Energy Demand and Supply Potential in China

Ichiro Kutani[3] and Mitsuru Motokura[4]

## 1. Hydrogen Demand Potential

Future hydrogen demand potential is difficult to estimate due to many uncertainties, including promotion policies. In addition, the absence of transparent and comprehensive statistics for hydrogen energy disables us from adopting econometric modeling approaches to estimate future hydrogen demand. Therefore, the study creates assumptions and scenarios to estimate China's hydrogen demand potential in 2040.

### 1.1. Basic assumptions for hydrogen demand estimation

The study assumes the following:

- No nation-wide hydrogen pipeline will be developed before 2040.
  - A stational fuel cell that consumes natural gas as a source of hydrogen is not counted as a demand.
- Focus on the transport sector and power generation
  - Fuel-cell vehicles
  - Fuel-cell power generation
  - Hydrogen-fuelled combined cycle gas turbine (CCGT)
- The following technologies are excluded from the analysis:
  - Fuel-cell ships, trains
  - Synthetic fuels produced from hydrogen, e.g. ammonia and methanol

### 1.2. Target sector and assumed fuel switch

The study considers the sustainable development scenario (SDS) in the World Energy Outlook (WEO) 2020 of the International Energy Agency (IEA) as a reflection of China's recently announced ambition to become carbon neutral by 2060, since the scenario assumes the world will become net zero by 2070.

The estimation time is set at 2030 and 2040 considering the availability of data, i.e. the WEO 2020 shows their outlook data only until 2040.

Fuel-cell electric vehicles (FCEVs) can substitute passenger vehicles and diesel-run heavy-duty vehicles, such as buses and trucks, in the transport sector.

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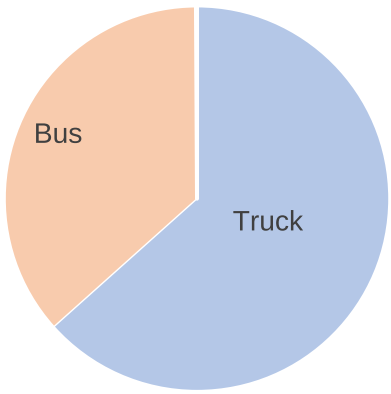
In the power generation sector, the study assumes two types of power generation: (i) fuel-cell power generation using 'otherwise curtailed' electricity from variable renewable electricity (VRE) and (ii) combined-cycle gas turbine power generation, which runs with pure hydrogen fuel or natural gas–mixed fuel.

### 1.3. Hydrogen demand potential in transport

As of September 2019, China's stocks totalled 3,518 FCEVs, of which trucks and buses share 2,230 (64%) and 1,285 (36%), respectively. Passenger vehicles numbered only three.

**Figure 2.1: Fuel-Cell Electric Vehicles, as of September 2019**




Source: NEDO (2020).

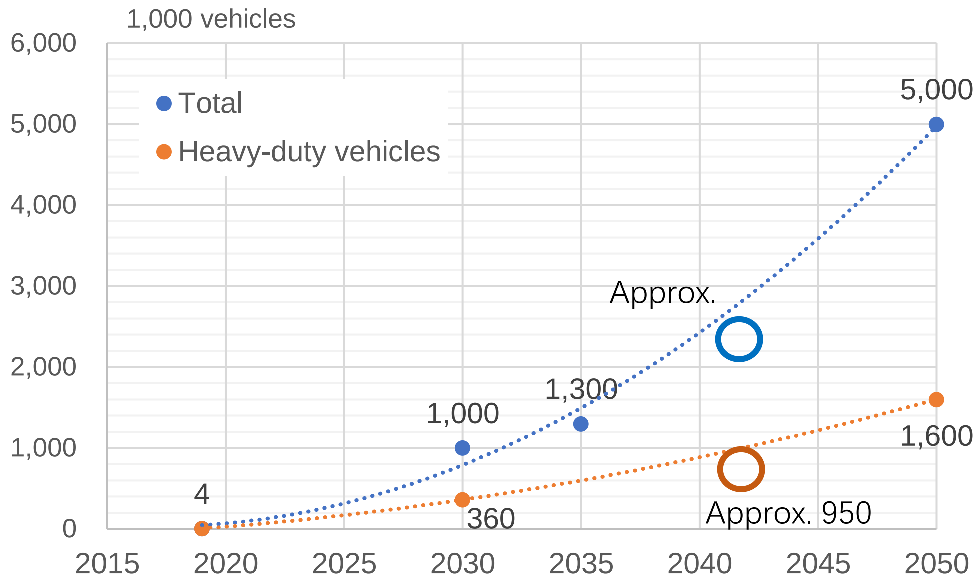
The study assumed FCEV stock, average fuel economy, and average driving distance to estimate hydrogen demand.

$$\begin{aligned} &Hydrogen\ demand \\ &\qquad = Vehicle\ stock \\ &\qquad \div Average\ fuel\ economy\ [km/L] \\ &\qquad \times Annual\ average\ driving\ distance\ [km] \end{aligned}$$

1) Vehicle stock

Total FCEV stocks are targeted to reach 1.0 million in 2030, 1.3 million in 2035, and 5.0 million in 2050 (China Hydrogen Alliance, 2018). Heavy-duty vehicles (HDVs) will be 0.36 million in 2030 and 1.6 million in 2050. From this date, the study assumes a total FCEV stock in 2040 of 2.4 million and heavy-duty FECV stock of 0.95 million.

**Figure 2.2: Target of FCEV Stock**




FCEV = fuel-cell electric vehicle.
Source: China Hydrogen Alliance (2018).

From the data, we could estimate vehicle stocks in 2030 and 2040. We assumed the HDV stock consists of 35% buses and 65% trucks (Table 2.1).

**Table 2.1: Assumed FCEV Stock**

| | | 2030 | 2040 |
|---|---|---|---|
| Passenger vehicles | thousand | 640 | 1,450 |
| Hevy-duty vehicles | thousand | 360 | 950 |
| of which buses | thousand | 126 | 333 |
| of which trucks | thousand | 234 | 618 |
| Total | thousand | 1,000 | 2,400 |

Source: Created from China Hydrogen Alliance (2018).

2) Fuel economy

We assumed a difference in fuel economy between internal combustion engine (ICE) vehicles and FCEVs to calculate hydrogen demand.

For passenger vehicles, we selected Toyota Crown as ICE vehicle and Toyota Mirai as FCEV as these are similar in body size and weight. Table 2.2 compares the two vehicles; the estimate shows that the fuel economy of FCEVs is 1.8 times better than ICE vehicles.

**Table 2.2: Fuel Economy of a Passenger Vehicle**

| | | Toyota Crown | Toyota Mirai |
|---|---|---|---|
| | |  |  |
| Dimension (cm) | L | 4,910 | 4,890 |
| | W | 1,800 | 1,815 |
| | H | 1,455 | 1,535 |
| Weight (kg) | | 1,590–1,650 | 1,850 |
| Displacement | | 2,000 cc | - |
| Driving mile/full load | | - | 650 km |
| Full load | | - | 85.68 m3 |
| Fuel economy | | 12.8 km/L | 7.59 km/m3 |
| | | 16,853 km/toe | 29,645 km/toe |

Note: MIRAI's fuel tank capacity is 122.4 L at a pressure of 70 MPa >> 85.68 m3-H2/full load
Source: Toyota Motor Corporation (2007).

For the HDVs, we first surveyed the fuel economy of major vehicles sold in Japan. Though the manufacturer differs, the average fuel economy is concentrated in a narrow range. Therefore, we assumed 4 kilometre (km)/L for ICE trucks and 5 km/L for ICE buses.

**Table 2.3: Fuel Economy of ICE Heavy-Duty Vehicles**

| Type of Vehicle | | | Manufacturer | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Isuzu | | Hino | | Fuso | |
| Truck | 10 tonne class | km/L | 6.50 | 6.70 | 5.70 | 6.30 | 5.00 | 6.00 |
| | 20 tonne class | km/L | 4.15 | 4.45 | 3.80 | 4.40 | 3.75 | 4.40 |
| | 25 tonne class | km/L | 4.05 | 4.25 | 4.05 | 4.45 | 3.75 | 4.25 |
| | 35 tonne class | km/L | 3.15 | 3.30 | | 3.25 | 3.15 | 3.40 |
| | 60 tonne class | km/L | 1.92 | 1.98 | 1.92 | 1.98 | 1.86 | 1.94 |
| | Average | km/L | 4.05 | | 3.98 | | 3.75 | |
| Bus | 10 tonne or more | km/L | 3.95 | 6.00 | 3.95 | 6.00 | 3.95 | 5.90 |
| | Average | km/L | 4.98 | | 4.98 | | 4.93 | |

Note: A value indicates the minimum and maximum ranges.
Source: MILT (2020).

Toyota conducted a long-term FECV bus pilot project in Tokyo and Chubu airport in 2007 (Toyota, 2007). The result showed that fuel economy of the FCEV bus is 1.6 times to 2.0 times better than the ICE bus. Therefore, we assumed that the fuel economy of the FCEV HDV is 1.8 times better than the ICE HDV, which is coincidentally the same as that of passenger vehicles.

3) Driving distance

According to MILT (2004), in Japan, the average annual driving distance is 10,000 km for passenger vehicles; 55,000 km for buses; and 68,000 km for trucks. Meanwhile, in China, passenger vehicles' average monthly driving distance is 1,272 km (Sun et al., 2011), i.e. approximately 15,000 km per annum, 1.5 times longer than in Japan. From this, we assume 1.5 times longer driving distance for buses and trucks as well.

**Table 2.4: Annual Average Driving Distance**

| | China | Japan |
|---|---|---|
| Passenger vehicle | 15,000 km | 10,000 km |
| Bus | 80,000 km | 55,000 km |
| Truck | 100,000 km | 68,000 km |

Source: MILT (2004), Sun et al. (2011).

4) Estimated hydrogen demand

Table 2.5 shows the estimated hydrogen demand of 4.1 Mtoe in 2030 and 10.6 Mtoe in 2040 in the road transport sector.

**Table 2.5: Estimated Hydrogen Demand for Transport**

| | | 2030 | | | 2040 | | |
|---|---|---|---|---|---|---|---|
| | | Passenger Vehicle | Bus | Truck | Passenger Vehicle | Bus | Truck |
| Fuel economy of ICE vehicle | km/L | 12.8 | 5.0 | 4.0 | 12.8 | 5.0 | 4.0 |
| Fuel economy of FCEV (oil equivalent) | km/L | 23.0 | 9.0 | 7.2 | 23.0 | 9.0 | 7.2 |
| Annual average driving distance | km | 15,000 | 80,000 | 100,000 | 15,000 | 80,000 | 100,000 |
| Annual average fuel consumption per vehicle | toe | 0.5 | 7.6 | 11.9 | 0.5 | 7.6 | 11.9 |
| FCEV stock | | 640,000 | 126,000 | 234,000 | 1,450,000 | 332,500 | 617,500 |
| Hydrogen demand | Mtoe | 0.3 | 1.0 | 2.8 | 0.7 | 2.5 | 7.4 |
| Total hydrogen demand | Mtoe | 4.1 | | | 10.6 | | |

FCEV = fuel-cell electric vehicle.
Source: Author.

### 1.4. Hydrogen demand potential for fuel cell sourced from curtailed electricity

When the VRE capacity substantially increases in a power generation mix, curtailment of excess electricity will become necessary to maintain the frequency and voltage of the power grid. The curtailment rate would reach as high as 20% to 30% (Chang and Han, 2021). This ‘otherwise curtailed’ electricity can be stored or converted into other types of energy to be used when necessary. One option of such an application is to convert curtailed electricity into hydrogen by water electrolysis. Produced hydrogen can be supplied to a fuel cell as a distributer electricity and heat generator.

1) Assumptions

The study assumes the following:

- 25% curtailment rate, by referring to Chang and Han (2021)
- 50% of curtailed electricity will be converted into hydrogen (the remaining 50% goes to a storage battery)
- Apply 5 kWh/Nm3-H2 of production efficiency by referring to some catalogue data of alkaline water electrolysers.

2) Estimated demand

Since demand depends on the amount of curtailed electricity, the study firstly calculated the amount of curtailed electricity. The amount of VRE power generation is referred to as SDS of IEA’s WEO 2020.

The estimated hydrogen demand is 18.1 Mtoe in 2030 and 33.5 Mtoe in 2040.

**Table 2.6: Estimated Hydrogen Demand for Fuel Cell**

| | | 2030 | 2040 |
|---|---|---|---|
| VRE power generation | TWh | 2,827 | 5,230 |
| Curtailment rate | | 25% | 25% |
| Hydrogen storage rate | | 50% | 50% |
| VRE power for hydrogen production | TWh | 353 | 654 |
| Hydrogen production efficiency | kWh/Nm3-H2 | 5 | 5 |
| Hydrogen production (= consumption) | Bcm | 70.7 | 130.7 |
| | Mtoe | 18.1 | 33.5 |

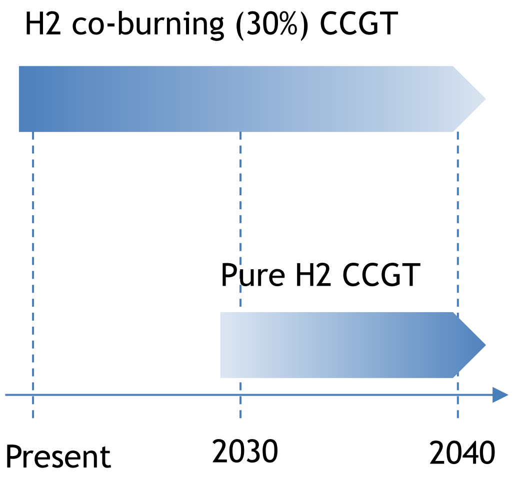
VRE = variable renewable energy.
Source: Author.

### 1.5. Hydrogen demand potential in CCGT

1) Available technology

Currently, technology is already commercially available to burn a 30% hydrogen-mixed fuel in a natural gas CCGT.5 The technology can also retrofit to existing CCGT by replacing a burner. While utility-scale pure hydrogen CCGT is being developed, the study assumes the technology will become available after 2030 (Figure 2.3).

**Figure 2.3: Assumed Technology**



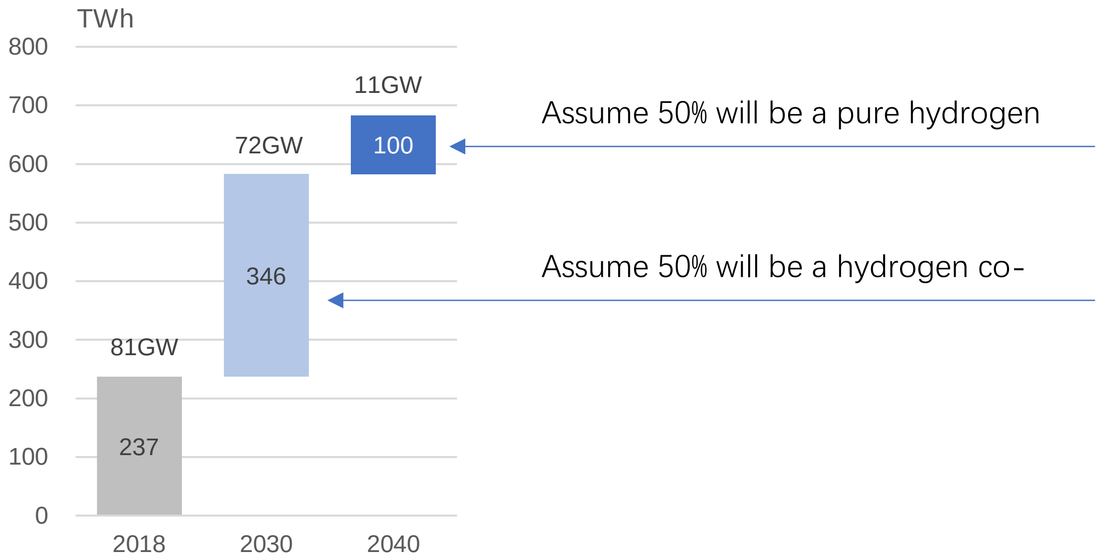

CCGT = combined cycle gas turbine.
Source: Author.

2) Scenario

In 2018, an 81 GW gas power generator in China generated 237 TWh of electricity (Figure 2.4). WEO 2020 estimated that 583 TWh of electricity will be supplied by a 153 GW gas power plant in 2030 and 683 TWh of electricity by a 164 GW capacity in 2040. The study assumes half of added power generation capacity between 2018 and 2030 will become a hydrogen co-burning fleet in 2030. After 2030, the study assumes half of the added capacity will become pure hydrogen CCGT in 2040.

5 Interview of Mitsubishi Heavy Industries staff.

**Figure 2.4: Outlook of Natural Gas Power Generation and Assumption of Fuel Switch**




Source: Created from IEA (2020a).

3) Estimated hydrogen demand

Table 2.7 shows the estimated hydrogen demand of 7.1 Mtoe in 2030 and 13.9 Mtoe in 2040 in the power generation sector.

**Table 2.7: Estimated Hydrogen Demand for CCGT**

| | | 2030 | Change between 2030–2040 | 2040 |
|---|---|---|---|---|
| Additional natural gas power generation | TWh | 346 | 100 | - |
| Conversion ratio to H2 generation | | 50% | 50% | - |
| Converted generation | TWh | 173 | 50.2 | - |
| | Mtoe | 14.9 | 4.3 | - |
| Thermal efficiency | | 63% | 63% | - |
| Required energy input | Mtoe | 23.6 | 6.85 | - |
| Hydrogen content ratio in a fuel | | 30% | 100% | - |
| Hydrogen demand | Mtoe | 7.1 | 6.8 | 13.9 |

Source: Author.

### 1.5. Summary of hydrogen demand potential and avoided CO2 emission

The total estimated hydrogen demand is 29.2 Mtoe in 2030 and 58.0 Mtoe in 2040. They are equivalent to 1.4% in 2030 and 2.9% in 2040 of total final energy consumption (TFEC) in the respective years (Table 2.8). However, the share of hydrogen to the TFEC is small because the use of hydrogen energy has just started. Thus, even in 2040, it is too early to expect the total penetration of hydrogen technologies in society. Besides, the study does not count industry demand due to its complexity and the need for pipelines for supplying hydrogen.

**Table 2.8: Total Hydrogen Demand**

| | 2030 | | 2040 | |
|---|---|---|---|---|
| | Amount (Mtoe) | % of TFE | Amount (Mtoe) | % of TFE |
| Transport | 4.1 | 0.2% | 10.6 | 0.5% |
| Fuel cell | 18.1 | 0.8% | 33.5 | 1.7% |
| Power generation | 7.1 | 0.3% | 13.9 | 0.7% |
| **Total** | **29.2** | **1.4%** | **58.0** | **2.9%** |

TFEC = total final energy consumption from the SDS scenario in IEA (2020a).
Source: Created from IEA (2020a).

Fuel switch from fossil fuel to hydrogen can reduce CO2 emissions. Table 2.9 shows the avoided CO2 emission amount. But again, the share of reduced CO2 emission to total CO2 emission is small even in 2040.

**Table 2.9: Avoided CO2 Emission**

| | 2030 | | 2040 | |
|---|---|---|---|---|
| | Amount (mil. tonne-CO2) | % of total CO2 | Amount (mil. tonne-CO2) | % of total CO2 |
| Motor gasoline | 0.11 | 0.00% | 0.25 | 0.01% |
| Diesel oil | 1.21 | 0.02% | 3.20 | 0.10% |
| Natural gas | 10.71 | 0.16% | 20.17 | 0.66% |
| **Total** | **12.03** | **0.17%** | **23.62** | **0.77%** |

Note: Carbon content of fossil fuel: Motor gasoline = 18.9 kg-C/GJ, Diesel oil = 20.2 kg-C/GJ, Natural gas = 15.3 kg-C/GJ.
Source: Created from IEA (2020b).

## 2. Hydrogen Supply Potential

### 2.1. Hydrogen production technologies and their cost

The hydrogen production process has long been developed for synthetic or city gas. Industrial hydrogen production processes developed to date include steam reforming of light hydrocarbons, partial oxidation, coal gasification, and water electrolysis.

Hydrogen hardly exists in hydrogen molecules in nature but exists in oxides or carbides ($H_2O$, $C_nH_m$). Therefore, to obtain hydrogen from water, hydrocarbons, etc., energy should be applied, resulting in a chemical reaction that breaks the H-O or C-H bond. Heat and electricity are generally used as energy input, but there are also light and radiation methods (Table 2.10).

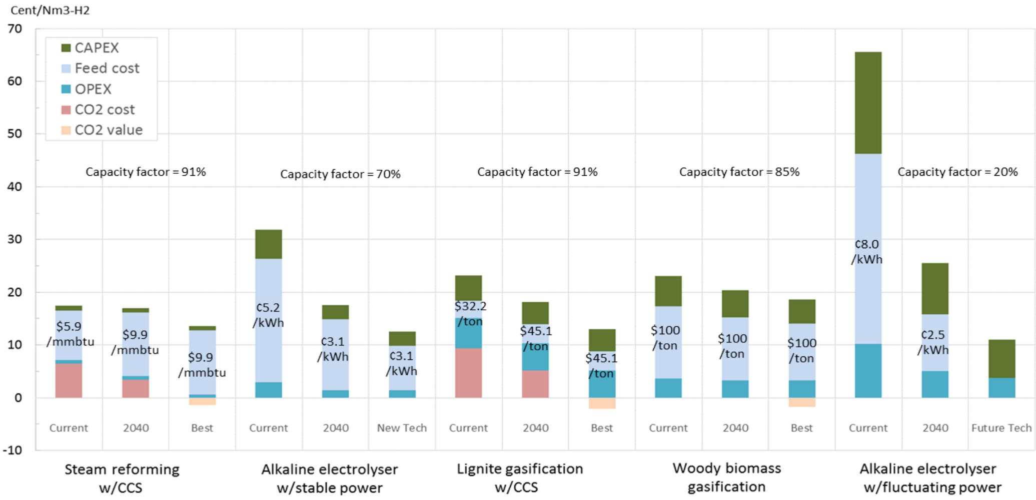
**Table 2.10: Technologies to Produce Hydrogen**

| | | Input Energy | | |
|---|---|---|---|---|
| | | **Heat** | **Electricity** | **Others** |
| Feedstock | Hydrocarbon | ● Steam reforming<br>● Partial oxidation<br>● Autothermal reforming<br>● Thermal cracking | - | - |
| | Water | ● Thermochemical water splitting | ● Alkaline electrolysis<br>● Polymer electrolyte membrane<br>● High-temperature stream reforming | ● Photolytic<br>● Biological<br>● Radiation |

Source: Created from US DOE (https://www.energy.gov/eere/fuelcells/hydrogen-production-processes).

Steam reforming of natural gas is currently the cheapest, while alkaline water electrolysis using VRE is the most expensive method (Kimura and Li, 2019). The latter is costly because the electric power supply for water electrolysis is not stable. Thus, the capacity factor of the water electrolysis device is low. Therefore, the hydrogen production cost is halved if a high operating rate can be ensured with stable power. In the future, technological improvements may reduce the cost of alkaline water electrolysis, making it possibly the most economical hydrogen production method.

**Figure 2.5: Cost of Large-Scale Hydrogen Production**




**1 : Feed Cost of Lignite gasification is based on FOT price in Intra-regional Group Countries.*
**2 : CCS cost is based on $70/t-CO2 for current and $48/t-CO2 for 2040 (CCS/Utilization Singapore Perspectives).*

Source: Kimura and Li (2019).

The following sections estimate China's hydrogen supply potential using coal gasification, steam reforming of natural gas, and water electrolysis.

## 2.2. Coal gasification

### 1) Method

China uses coal in all sectors, such as industry, buildings, and power generation. However, recently, China has curbed coal use to mitigate severe air pollution. In addition, China announced its ambition to become carbon neutral by 2060, accelerating the move away from coal.

On the other hand, China's coal self-sufficiency rate in 2019 was a high 96%, implying a surplus of coal supply capacity if domestic coal demand declines in the future. Therefore, in this study, the difference between the future outlook of 'coal production under the WITHOUT carbon-neutral scenario' and 'coal demand under the WITH carbon-neutral scenario' is the amount of coal supply that can be used to produce hydrogen. The stated policy scenario (STEPS) in IEA (2020a) will be adopted for the former and the SDS in IEA (2020a) will be adopted for the latter.

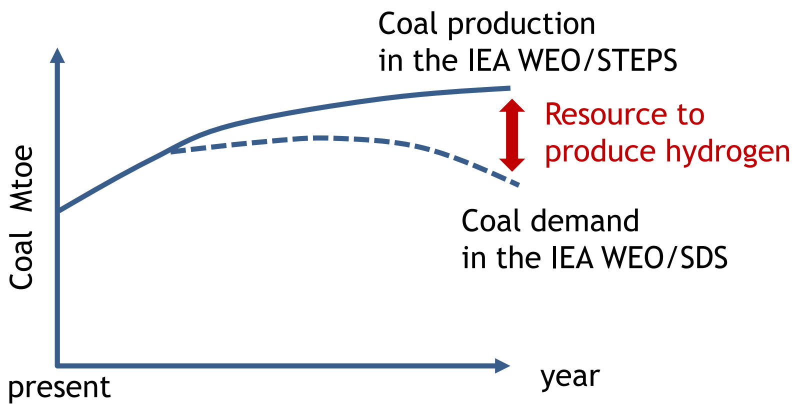
$$\text{Available coal for H2 production} = \text{Coal production under the WITHOUT carbon} - \text{neutral scenario} - \text{Coal demand under the WITH carbon} - \text{neutral scenario}$$

where:

the WITHOUT carbon-neutral scenario = Stated policy scenario (STEPS) in IEA (2020a)

the WITH carbon-neutral scenario = Sustainable development scenario (SDS) in IEA (2020a)

**Figure** Error! Use the Home tab to apply 0 to the text that you want to appear here.**2.6: Available Coal to Produce Hydrogen**




SDS = sustainable development scenario, WEO = world economic outlook.
Source: Author.

2) Assumptions

It is necessary to determine the gasification efficiency of coal to estimate the amount of hydrogen production. Thus, this study adopted an analysis of JST (2019), which estimates the amount of hydrogen produced from the two types of coal: lignite coal and bituminous coal.

3) Estimated hydrogen supply potential

Table 2.11 shows the big difference in hydrogen production efficiency per calorific value between lignite coal and bituminous coal. Therefore, the hydrogen production amount is similar regardless of coal type.

**Table 2.11: Estimated Hydrogen Production Potential from Coal**

| | | 2018 | 2030 | 2040 |
|---|---|---|---|---|
| Coal production/STEPS | Mtoe | 1,860 | 1,854 | 1,693 |
| Coal demand/SDS | Mtoe | 1,986 | 1,366 | 732 |
| Available coal to produce H2 | Mtoe | | 488 | 961 |
| | | | | |
| *If produced from lignite coal* | | | | |
| Production efficiency | ton-coal/tonne-H2 | | 21 | 21 |
| Lignite coal (NCV) | MJ/kg | | 11.5 | 11.5 |
| Production efficiency | toe-coal/toe-H2 | | 2.0 | 2.0 |
| H2 production | Mtoe | | 242 | 477 |
| | Bcm | | 947 | 1,866 |
| *If produced from bituminous coal* | | | | |
| Production efficiency | ton-Coal/ton-H2 | | 8.7 | 8.7 |
| Bituminous coal (NCV) | MJ/kg | | 26.2 | 26.2 |
| Production efficiency | toe-coal/toe-H2 | | 1.9 | 1.9 |
| H2 production | Mtoe | | 257 | 506 |
| | Bcm | | 1,004 | 1,977 |

NCV = net calorific value, SDS = sustainable development scenario, STEPS = state policy scenario.
Source: Created from IEA (2020a), JST (2019).

4) Potential of carbon capture and storage (CCS)

The process of gasifying coal inevitably generates CO2. Since using hydrogen aims to decarbonise the energy supply, the generated CO2 should be captured and stored. Therefore, the study evaluates the potential of applying the CCS technology in China.

The GCCSI (2020) estimated China's CCS potential at 3,077 gigatonnes. However, storage potential is currently rarely used, and most of it classified undiscovered.

**Table 2.12: Potential of CCS in China**

| Classification | CO2 Storage Resource (Gt) Project and no project | CO2 Storage Resource (Gt) Project specified only |
|---|---|---|
| Stored | 0.0003 | 0.0003 |
| Capacity | 0 | 0 |
| Sub-Commercial | 105 | 0.031 |
| Undiscovered | 3067 | 0 |
| Aggregated* | 3077 | 0.03 |

* The aggregated resource represents the summed storage resource across all maturity classes and as such should not be viewed as representative of the potential of the country.
Capacity = economically viable resources; Sub-commercial = discovered but economic viability uncertain and some may inaccessible; Undiscovered = geographically unconfirmed resource.
Source: GCCSI (2020).

By assuming the realisation rate, we can obtain the usable CCS potential. We assume three different rates for sub-commercial resources: 25%, 50%, and 75%. For undiscovered resources, we assume a 5% realisation rate since there is enormous uncertainty to commercialise.

Then the study estimates an expected life of usable CCS capacity by dividing an available CCS capacity by CO2 emission from coal gasification. Table 2.13 shows the evaluated results – that CCS capacity may be satisfactory to produce necessary blue hydrogen in 2040.

However, we need to remind that CCS capacity is not infinite. Thus, the supply of blue hydrogen is physically limited.

**Table 2.13: Available Capacity and Life of CCS in China**

| **Storage Capacity** | | | | | |
|---|---|---|---|---|---|
| Sub-commercial | | | | | |
| Potential | Gt-$CO_2$ | 105 | 105 | 105 | 105 |
| Realisation rate | % | 25% | 50% | 75% | 75% |
| Available capacity | Gt-$CO_2$ | 26 | 53 | 79 | 79 |
| Undiscovered | | | | | |
| Potential | Gt-CO2 | 3,067 | 3,067 | 3,067 | 3,067 |
| Realisation rate | % | 0% | 0% | 0% | 5% |
| Available capacity | Gt-$CO_2$ | 0 | 0 | 0 | 153 |
| Toral available capacity | Gt-$CO_2$ | 26 | 53 | 79 | 232 |

| **Life of CCS** | | | | | |
|---|---|---|---|---|---|
| Carbon content of 'Other bituminous coal' | kg-C/GJ | 25.8 | | | |
| CO2 content of 'Other bituminous coal' | ton-CO2/toe | 3.96 | | | |
| Consumable coal amount to produce blue H2 under each available CCS capacity | Mtoe | 6,628 | 13,255 | 19,883 | 58,601 |
| Life of CCS | | | | | |
| If coal consumption is 55 Mtoe/yr (able to supply for H2 demand in 2030) | year | 121 | 241 | 362 | 1,065 |
| If coal consumption is 100 Mtoe/yr (able to supply for H2 demand in 2040) | year | 60 | 121 | 181 | 533 |

Source: Created from GCCSI (2020).

### 2.3. Natural Gas Steam Reforming

The demand for natural gas, clean fossil energy, is growing in China. Fuel shift from coal to natural gas effectively reduces air pollution and CO2 emissions. Thus, demand is expected to continue increasing in the future.

Meanwhile, the dependence on natural gas supply for import is increasing in China. The self-sufficiency rate fell below 100% in 2007 and had continued to decline, reaching 59% in 2019. When applying the same method as coal to estimate the available amount, no natural gas resource is available in China to produce hydrogen in the future.

This import dependence will continue in the future despite the prospect of domestic natural gas production increasing. Therefore, valuable domestic natural gas should first be used to meet natural gas demand. Also, it is economically irrational to produce hydrogen from expensive imported natural gas. Therefore, in this study, the hydrogen production potential from steam reforming of natural gas is set to zero.

For reference, the following chemical formula expresses the steam reforming of natural gas; theoretically, 4 mol of hydrogen can be obtained from 1 mol of methane. The formula assumes that 70% of reforming efficiency in high heat value basis (Iseki, 2012) uses the pressure swing adsorption technique.

$$CH_4 + 2H_2O = 2CO_2 + 4H_2$$

**Table 2.14: Estimated Hydrogen Production Potential from Natural Gas**

| | | 2018 | 2030 | 2040 |
|---|---|---|---|---|
| Natural gas production/STEPS | Mtoe | 135 | 202 | 234 |
| Natural gas demand/SDS | Mtoe | 233 | 356 | 411 |
| Available natural gas suppy to produce H2 | Mtoe | | -154 | -177 |
| | | | | |
| Production efficiency | Mtoe/Mtoe-H2 | | 0.70 | 0.70 |
| H2 production | Mtoe | | 0 | 0 |
| | Bcm | | 0 | 0 |

SDS = sustainable development scenario, STEPS = stated policy scenario.
Source: Created from IEA (2020a), Iseki (2012).

### 2.4. Alkaline Water Electrolysis

1) Potential of renewable energy

Although the use of renewable energy is increasing in China, the development potential remains. For example, producing hydrogen by water electrolysis is possible by using it as input energy.

Therefore, first, the study surveys the potential of renewable energy that to produce hydrogen. Table 2.15 estimates the remaining renewable energy resources to produce hydrogen.

**Table 2.15 Remaining Potential of Major Renewable Energy Sources to Produce Hydrogen**

| | Technical Potential (IRENA) | Prospected Power Generation Capacity in 2040 (IEA WEO, SDS) | Estimated Remaining Potential in 2040 |
|---|---|---|---|
| Hydropower | 400–700 GW (average 550 GW) | 563 GW | - |
| Wind/onshore | 1,300–2,600 GW (average 1,950 GW) | 929 GW | 1,000 GW |
| Wind/offshore | 200 GW | | |
| Solar PV/utility | 2,200 GW | 2,124 GW | 500 GW |
| Solar PV/rooftop | 500 GW | | |

PV = photovoltaic, SDS = sustainable development scenario, WEO = world energy outlook.
Source: IRENA (2014), IEA (2020a).

In the SDS, which assumes a significant reduction of CO2 emission, the hydropower capacity in 2040 will be 563 GW, almost the same as the hydropower potential estimated by IRENA (2014). In other words, the possibility to generating additional hydropower will be nearly exhausted by 2040. Thus, there is no remaining potential for producing hydrogen.

For wind power, when comparing the combined potential of on-shore and off-shore with the prospected power generation capacity in 2040, 1,000 GW of surplus capacity remains. Similarly, solar photovoltaic (PV) power generation will result in 500 GW of surplus capacity in 2040. This way, while aiming for decarbonisation, renewable energy would mostly be used to decarbonise electricity. Thus, the amount left for hydrogen production is limited.

In China, part of the generated electricity is being curtailed. It is possible to produce hydrogen by using the ‘otherwise curtailed’ electricity.

2) Assumptions

The study assumes the following:

- Able to commercialise 75% of the remaining potential
- Apply average capacity factor in 2018, i.e. 55% for wind and 28% for solar PV
- Apply 5 kWh/Nm3-H2 of production efficiency (from a few catalogue data).

3) Estimated hydrogen supply potential

Table 2.16 shows the estimated results.

**Table 2.16. Estimated Hydrogen Production Potential from Renewable Energy**

| | | 2018 | 2030 | 2040 |
|---|---|---|---|---|
| *Wind power* | | | | |
| Potential | GW | 2,150 | 2,150 | 2,150 |
| Capacity/SDS | GW | 184 | 614 | 929 |
| Generation/SDS | TWh | 366 | 1,360 | 2,256 |
| Remaining development potential | GW | | 1,221 | 1,221 |
| Realisation rate | | | **75%** | **75%** |
| Capacity factor | | | **55%** | **55%** |
| Production efficiency | kWh/Nm3-H2 | | **5.0** | **5.0** |
| H2 production | Bcm | | 882.3 | 882.3 |
| | Mtoe | | 225.8 | 225.8 |
| | | | | |
| *Solar PV* | | | | |
| Potential | GW | 2,700 | 2,700 | 2,700 |
| Capacity/SDS | GW | 175 | 1,106 | 2,124 |
| Generation/SDS | TWh | 177 | 1,466 | 2,974 |
| Remaining development potential | GW | | 576 | 576 |
| Realization rate | | | **75%** | **75%** |
| Capacity factor | | | **28%** | **28%** |
| Production efficiency | kWh/Nm3-H2 | | **5.0** | **5.0** |
| H2 production | Bcm | | 212.1 | 212.1 |
| | Mtoe | | 54.3 | 54.3 |
| | | | | |
| *Otherwise curtailed electricity from wind power and solar PV* | | | | |
| VRE power generation | TWh | 543 | 2,827 | 5,230 |
| Curtailment rate | | | **25%** | **25%** |
| Hydrogen storage rate | | | **50%** | **50%** |
| VRE power for hydrogen production | TWh | | 353 | 654 |
| Hydrogen production efficiency | kWh/Nm3-H2 | | **5.0** | **5.0** |
| Hydrogen production (= consumption) | Bcm | | 70.7 | 130.7 |
| | Mtoe | | 18.1 | 33.5 |

PV = photovoltaic, SDS = sustainable development scenario, VRE = variable renewable energy.
Source: Created from IEA (2020a), various catalogue data of manufacturers.

### 2.5. Supply and Demand Balance

When combining the estimated hydrogen demand and supply potential, a sufficient supply seems to meet the demand until 2040.

**Table 2.17: Summary of Estimated Results**

| | | 2030 | 2040 |
|---|---|---|---|
| **Total demand** | **Mtoe** | **29** | **58** |
| Transport | Mtoe | 4 | 11 |
| Fuel cell | Mtoe | 18 | 33 |
| Power generation | Mtoe | 7 | 14 |
| | | | |
| **Total supply** | **Mtoe** | **548** | **805** |
| Coal gasification | Mtoe | 250 | 492 |
| Natural gas steam reforming | Mtoe | 0 | 0 |
| Water electrolysis using REs | Mtoe | 298 | 314 |

RE = renewable energy.
Source: Author.

However, we need to be reminded of two points. First, the available CCS capacity to produce blue hydrogen is uncertain and limited. Although CCS has potential, significant geological and economic uncertainties in actual development exist. In addition, the amount that can be stored is finite; therefore, the supply of blue hydrogen is limited.

Second, the potential of VRE is also limited. Decarbonisation of electricity is essential to achieve the ambitious carbon-neutrality target; a large amount of VRE is also required for this application. Therefore, optimisation of VRE use will be necessary for the future, i.e. balancing between direct use as electricity and fuel to produce hydrogen.

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