WORLD RESOURCES INSTITUTE

WORKING PAPER

DISTRIBUTED SOLAR ENERGY AND HYDROGEN DEVELOPMENT IN THE GUANGDONG–HONG KONG–MACAU GREATER BAY AREA

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EXECUTIVE SUMMARY

Highlights

- The primary investment and financing challenges for distributed solar photovoltaic (PV) development in the Guangdong–Hong Kong–Macau Greater Bay Area (Greater Bay Area) are difficulties in securing financing from banks, long payback periods, and high financing costs from finance leasing, as well as the lack of a profit-guarantee mechanism. This working paper provides recommendations for policy designs, business models, and innovation of financial tools.
- The primary investment and financing challenges for the hydrogen industry in the Greater Bay Area are an overreliance on government subsidies and investment from state-owned enterprises as well as high costs and investment risks. This working paper recommends establishing a government-guided and diversified investment and financing mechanism.

Background

Achieving China's "dual carbon goals," to peak carbon dioxide emissions by 2030 and become carbon-neutral by 2060, will require new energy resources, including renewable energy and hydrogen. As a national strategic area, the Greater Bay Area should play a leading role in

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Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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CNIFA 中国新能源电力投融资联盟 China New energy Investment and Financing Alliance high-quality development and a green transition of the economy and society. The national commitment to increase the installed capacity of solar and wind power to 1.2 terawatts by 2030 has created numerous new opportunities to promote distributed clean energy. For example, the central government has recently introduced a new policy to promote distributed solar PV throughout designated counties. Increasing interest in hydrogen fuel cell vehicles presents a huge opportunity to promote hydrogen. According to the China Hydrogen Alliance, hydrogen is expected to constitute more than 10 percent of China's total energy consumption by 2050. This working paper therefore focuses on the current status of distributed solar PV and hydrogen in the Greater Bay Area, as well as on investment and financing opportunities.

Conclusions and recommendations for distributed solar PV

Distributed solar PV is developing rapidly in the Greater Bay Area. Industrial and commercial rooftop solar PV in Foshan, Guangzhou, and Dongguan have the greatest potential. The advantages of distributed solar PV are that it is flexible in terms of scale, project owners can consume their self-generated power, and capital demand is relatively small and scattered. But complicated stakeholder arrangements create more uncertainty and complicated profit-sharing mechanisms. The primary challenges for distributed solar PV development include difficulties in securing financing from banks, long payback periods, and high financing costs from finance leasing, as well as the lack of a profit-guarantee mechanism. Considering these challenges, this working paper offers the following recommendations to scale up distributed solar PV development in the Greater Bay Area:

- In terms of policy design, this working paper recommends that the government strengthen overall planning, investigate PV installation resources, and improve the basic data of buildings with existing PV projects as well as buildings with development potential. The government should also incorporate solar PV applications into the overall development plans of new towns, the renovation of old cities, and new green communities.

- In terms of business model, the government should drive the creation of a community of common interests made up of commercial solar PV development companies, manufacturers, grid operators, government, and finance and insurance organizations in order to help users and rooftop owners benefit from business models like energy performance contracting. Financial institutions can work with government and state-owned companies to jointly create financing and investment platforms that provide rapid financing channels for projects in pilot regions. We also recommend market mechanisms such as distributed energy trading market pilots and innovative models of electricity fee collection, including prestored electricity bills.

- In terms of green financial tools and instruments, we recommend promoting financing insurance for PV power stations or loss insurance for power generation volume, and insurance fee discounts to PV investors who meet high standards for quality. Financial institutions can launch more PV loan products for the Greater Bay Area with flexible loan terms, loan amounts, and loan interest rates. We also recommend facilitating investments in distributed PV power plants through asset securitization.

Conclusions and recommendations for hydrogen

The Greater Bay Area has a complete hydrogen supply chain, including production, storage and transportation, refueling stations, fuel cells, as well as hydrogen vehicle design and manufacturing. The city cluster in Guangdong Province led by Foshan has been designated by the central government as a national pilot zone for fuel cell vehicle promotion. The rapid development of renewable energy in Guangdong could allow the Greater Bay Area to produce large-scale green hydrogen. Despite all these positive signs, almost all hydrogen in the Greater Bay Area is produced from fossil fuels, the production of green hydrogen remaining marginal. Hydrogen should be produced using clean energy to support China's decarbonization efforts. Meanwhile, it will be essential to reduce the cost, diversify the usages of hydrogen beyond fuel cell vehicles, and explore new business models. The key challenges the hydrogen industry faces are an overreliance on government subsidies and investment from state-owned enterprises (SOEs) as well as high costs and investment risks. This working paper recommends the following:

- To leverage government guidance, we recommend that the government accelerate establishment and improvements in the hydrogen "1+N" policy system,[1] and create a comprehensive investment monitoring and management system with standardized management practices and open, transparent supervisory structures. Local governments should revise standards for hydrogen storage containers and hydrogen refueling stations and improve related market mechanisms. In order to support the development of green hydrogen, local governments should also explore supportive pricing policies for renewable energies used in the production of hydrogen. There should also be sound coverage of pricing mechanisms for energy storage and exploration of direct participation of hydrogen storage in the electricity market. We also recommend that the government commit limited fiscal resources to supporting key generic technology, especially research and development and industrialization of key and core technologies.

- To establish a diversified financing environment, we recommend that the government develop differentiation policies like differentiated interest rates to provide more financial support for regions and links in the industry chain that are in urgent need of capital and remain relatively high-risk. The government should encourage and guide financial institutions and corporations in establishing industry funds. To increase the volume of venture capital investment and cultivate a more diverse collection of market players, sources of venture capital should be expanded to include institutional investors, private capital, and large domestic companies. We also recommend that hydrogen transportation and end-user hydrogen facilities be incorporated into the Green Industry List and the List of Green Bond Support Projects, providing support through guarantees and finance discounts. For assets that can generate continuous cash flow, financial institutions can provide financing based on assets or credit in conjunction with assets to provide a financing amount and issuing schedule that better suits a project's needs than a credit-evaluation system. Financial institutions can provide interest-rate discounts through the Central Bank's "Carbon-Reduction Support Tools."

1. BACKGROUND

New energy resources such as renewable energy and hydrogen play an important role in China's efforts to reach its "dual carbon goals." By 2030, solar and wind power installations must reach 1.2 terawatts (TW), more than double the 534 gigawatt (GW) capacity in 2020. By 2060, nonfossil fuels must account for over 80 percent of total primary energy consumption. Forecasts by research organizations indicate that by 2030, solar energy will make up two-thirds of all new wind and solar installations; while by 2060, solar installations will reach 2.6 TW.[2] In terms of hydrogen, the China Hydrogen Alliance predicts that by 2030, the gross domestic product (GDP) generated by China's hydrogen industry will reach RMB 1 trillion and demand for hydrogen will reach 37 million tonnes. By 2050, hydrogen will contribute more than 10 percent of China's total end use energy consumption and the annual GDP of the hydrogen industry will reach RMB 12 trillion (China Hydrogen Alliance 2021).

As part of China's national development strategy, the Greater Bay Area should serve as a driving force in high-quality development and pioneer a comprehensive transition to a greener society. We have chosen to analyze distributed solar PV and hydrogen in the Greater Bay Area and, more specifically, how solar developments can take advantage of China's new policy of promoting distributed PV technology throughout selected counties. Also, Guangdong Province has a fully developed hydrogen industry chain that includes production, storage and transportation, hydrogen refueling stations, and hydrogen fuel cells, as well as hydrogen vehicle design and production. This foundation has made the Greater Bay Area China's fastest-developing region for hydrogen. This working paper begins by providing an overview of the current state of development and future potential of distributed solar PV and hydrogen in the Guangdong–Hong Kong–Macao Greater Bay Area. It proceeds to analyze the challenges for investing and financing, then closes with relevant recommendations.

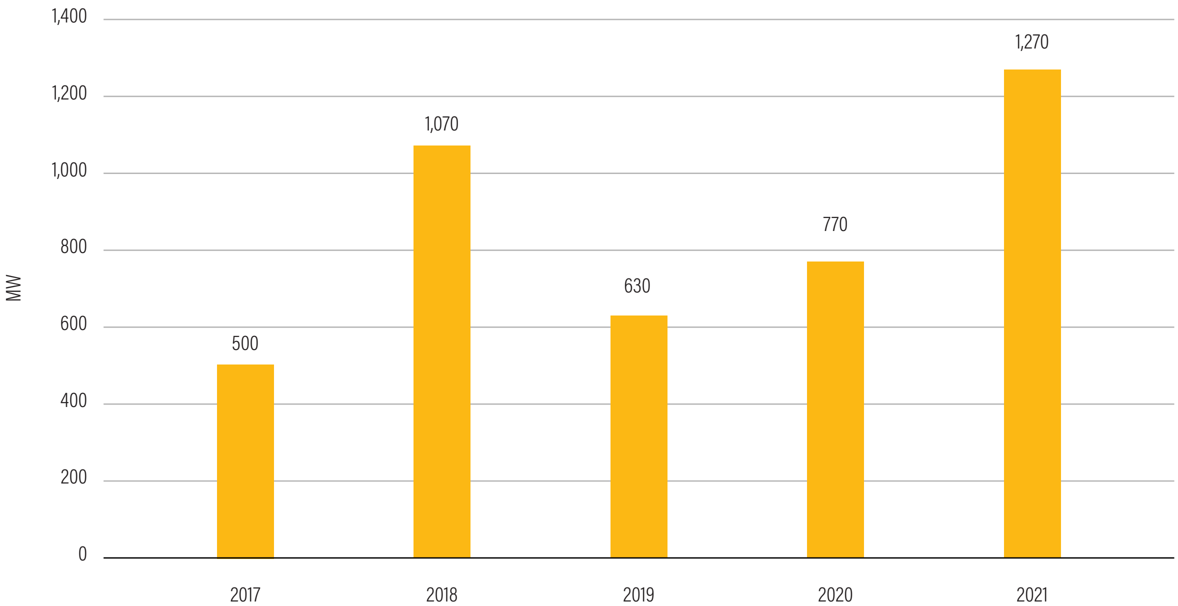
2. DISTRIBUTED SOLAR PV

2.1 Current situation

Distributed solar PV is developing rapidly

In the drive to achieve the 2030 national installed capacity goals for wind and solar power, distributed solar PV has entered a period of rapid growth in Guangdong Province. Newly built installed capacity for distributed solar PV reached 770 megawatts (MW) and 1,270 MW, respectively, in 2020 and 2021, or 1.2 and 2 times the numbers for 2019 (Figure 1).[3] In 2021, the cumulative installed solar PV capacity in Guangdong

Figure 1 | **Growth of the installed capacity of distributed solar energy in Guangdong Province**



Sources: Based on data obtained by the research team from the Guangdong Solar Association.

reached 10.2 GW, ranking it 15th nationwide. Of this, the installed capacity for distributed solar PV was 5.1 GW, ranking it 7th nationwide. Distributed solar PV makes up 3 percent of total installed capacity in Guangdong Province, 17 percent of installed capacity for all renewable energy, and 53 percent of installed solar PV capacity—this is higher than the national average, which is around one-third.[4]

In 2021, faced with a shortage of power supply, Guangdong Province released several new policies on time-based pricing for electricity and marketization of the power industry. These resulted in a 25 percent increase in electricity prices during peak hours (Guangdong DRC 2021a). Customers chose distributed solar PV to relieve cost pressures. One after another, municipal governments issued policies that supported distributed solar PV installation and generation. Subsidies for power generated to the grid for localities throughout Guangdong Province varied between RMB 0.1 and 0.3 per kilowatt-hour (kWh), while subsidies for installation varied between RMB 200 and 300 per kilowatt (kW). The upper limit for installation subsidies varied widely, ranging from RMB 0.2 million to 3 million (Shenzhen Municipal DRC 2022; Zhaoqing High-Tech Zone Bureau of Economy, Trade, and Technology 2021; Guangzhou Huangpu District DRC 2021; Foshan Ronggui Subdistrict Office 2021; Foshan Daliang Subdistrict Office 2021).Driven by these factors, distributed solar PV contributed to 90 percent of the new solar PV installations in Guangdong in the first quarter of 2022 (Zhong 2022).

Distributed solar PV in industrial and commercial buildings contributes the highest share of PV and has the largest development potential

Applications for distributed solar PV exist in industrial, public, commercial, and residential buildings, as well as poverty-alleviation and agriculture settings. About 85 percent of Guangdong Province's distributed solar PV is on industrial and commercial rooftops,[5] with the highest concentration in the Pearl River Delta region, where manufacturing and service industries are also highly concentrated. A high electricity tariff and subsidies offered by the cities of Guangzhou, Dongguan, and Foshan have resulted in a positive development trend for distributed solar PV. In 2021, the installed capacity of newly built distributed solar PV in industrial and commercial rooftops in Guangdong Province was 958 megawatts, ranking it fourth in the country, surpassed only by Zhejiang (1.8 GW), Jiangsu (1.4 GW), and

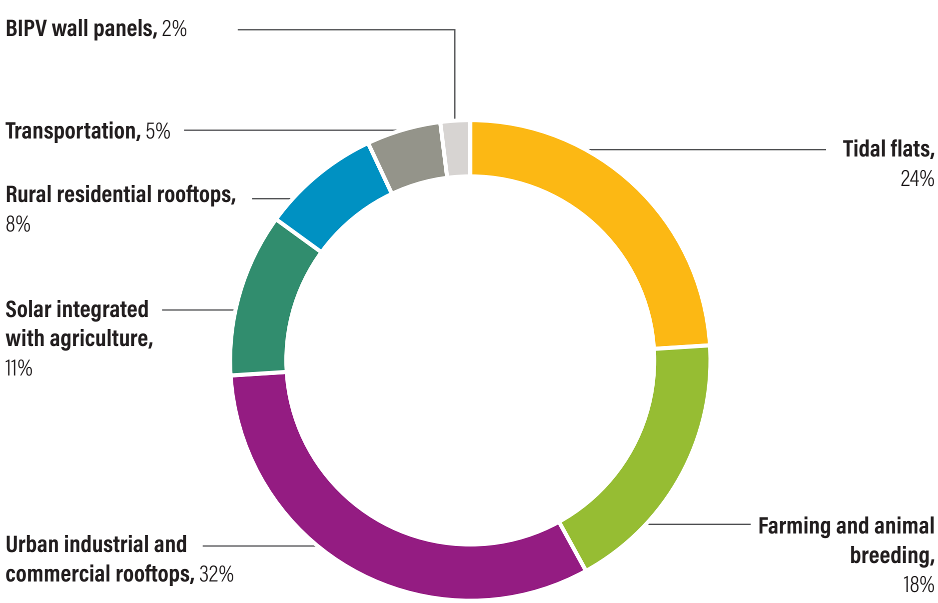
Shandong (1.0 GW) (NEA 2022). Case Studies 1 and 2 in the appendix offer examples of solar PV on industrial and commercial rooftops.

The theoretical potential of solar PV installations in Guangdong Province is around 2,572 GW. The greatest potential is for urban industrial and commercial rooftops, followed by tidal flats, farming and animal breeding, solar integrated with agriculture, rural residential rooftops, transportation, and Building Integrated Photovoltaics (BIPV) wall panels.[6] The potential of each is shown in Figure 2.

Manufacturing and service industries are well developed in Guangdong Province, with many small and medium-sized enterprises. The demand for lowering electricity costs, conserving energy, and reducing emissions is very strong since the electricity price for industrial and commercial users in the daytime in Guangdong Province is high, ranking fifth in the country.[7] This makes the prospects for solar PV development expansive. The benchmark feed-in tariff for coal power in Guangdong Province is RMB 0.453/kWh, ranking first nationwide. Assuming the hours for power generation to be 1,000 per year, the solar PV projects in Guangdong Province are extremely competitive in terms of profitability, even without subsidies.

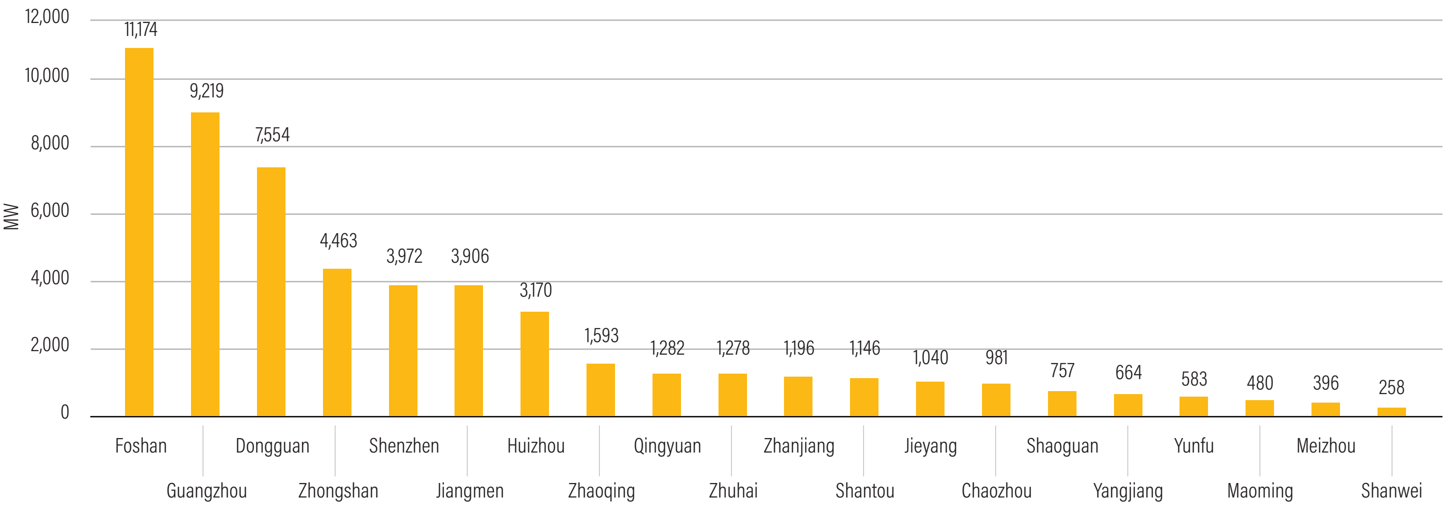
By establishing an identification system for rooftop solar PV resources, we have been able to obtain the location and area of rooftops larger than 2,000 square meters (m^2) for five levels: provincial, municipal, district, community, and rooftop. We have found that the majority of these rooftops were industrial and commercial, while the total number was 105,977 rooftops, with a total area of 653 million m^2. Calculations show that the total potential installed solar PV capacity is 46,649 megawatts, while annual potential technical power production is approximately 67 billion kWh. The total investment cost would be approximately RMB 175.4 billion. If potential power production is fully realized, this would supply 10 percent of the power demand. As of the end of 2021, the cumulative distributed solar PV installations in Guangdong Province accounted for approximately 11 percent of the total technical potential. The nine cities in the Pearl River Delta region rank as follows in resource potential: Foshan, Guangzhou, Dongguan, Zhongshan, Shenzhen, Jiangmen, Huizhou, Zhaoqing, and Zhuhai (GIEC n.d.), as shown in Figure 3.

Figure 2 | **Distribution of theoretical potential for solar PV installation scenarios in Guangdong Province**



Note: BIPV = Building Integrated Photovoltaics.
Source: Obtained by the research team based on survey data from the Guangdong Solar Association.

Figure 3 | **Potential PV installed capacity on rooftops larger than 2,000 m² in each city in Guangdong Province**



Source: GIEC (n.d.).

Regional advantages in Guangdong, Hong Kong, and Macau

The limited geography and natural resources of Hong Kong and Macau restrict their potential for developing distributed solar PV. However, their innovative practices in the financial sector are worth learning from. For example, in 2015, the Hong Kong Government released its feed-in tariff scheme, which allows residential distributed solar PV projects to produce energy and sell it to power companies. In 2020–21, Hong Kong issued green bonds to support energy conservation and emissions reduction in buildings. A portion of this policy included rooftop solar PV systems (see appendix, Case Study 3). In addition, Hong Kong businesses also piloted blockchain transactions in the distributed solar PV sector (see appendix, Case Study 4).

Slow progress in county-wide promotion of distributed solar PV

In 2021, China launched a new policy to promote distributed solar PV development at the county-wide level. This policy required that, in the selected pilot counties, not less than 50 percent of government building rooftops, not less than 40 percent of public building rooftops, not less than 30 percent of industrial and commercial building rooftops, and not less than 20 percent of rural residential building rooftops be developed to install distributed solar PV. There were 32 pilot programs in 18 prefecture-level cities in Guangdong Province, with a total capacity of over 11 GW approved by the central government. The number of pilot projects ranked sixth nationwide. The 14 pilot programs in the nine cities of the Greater Bay Area accounted for 44 percent of all programs in Guangdong Province and around 50 percent of total capacity.

However, our findings show that very few of the pilot projects met requirements for all types of buildings. Most project developers are state-owned companies and power companies and PV manufacturers within the province. These pilots are currently in the resource review and construction phase.

Our analysis concludes that county-wide distributed solar PV development in Guangdong Province faces the following major challenges:

Institutional obstacles. Each region has its own requirements regarding the installation of PV and its brackets. Developers need to obtain a building permit, follow installation height restrictions, construction material requirements, and provide proof of property rights. In some regions, only property certificates are accepted as proof of property rights. This prevents the construction of PV on many buildings (such as village collective buildings) that do not have property certificates for historical reasons. The supervision mechanisms are incomplete. Currently, the safety of construction is the responsibility of the investor and project owner. Some operators lack the necessary safety training and knowledge, a problem exacerbated by inadequate oversight from government institutions. As a result, the operation and connection of PV systems to the grid can encounter hidden dangers.

Project registration and resulting revenue distribution. The rental roof model has the special characteristics of being large-scale, low-threshold, and easy to promote. It can be used in a contiguous and centralized construction model. However, the decentralized nature of property rights for roofs in residential buildings makes it impossible to combine multiple roofs into one project. Meanwhile, electricity companies require electricity sales revenues from residential PV projects to be deposited directly into residents' personal account. This precludes investment companies from directly filing and applying for photovoltaic installation according to the residential PV process under the name of the project company. Project costs are increased by difficulties such as the need to negotiate profit-sharing arrangements between the company and residents.

The electricity tariff. The China Southern Power Grid, which covers Guangdong, Guangxi, Yunnan, Guizhou, and Hainan Provinces, currently buys electricity from residential PV projects at a rate calculated by taking the benchmark feed-in tariff of coal power and subtracting a 13 percent tax. In contrast, the State Grid Corporation of China, which covers the remainder of the country, calculates the rate for residential PV projects by using the local benchmark feed-in tariff of coal power. This has resulted in decreased profits and increased investment payback times for residential PV operators in the Guangdong region. In regard to user bill-settlement periods, the State Grid generally settles on a monthly basis, while the China Southern Power Grid settles on a quarterly, six-month, or annual basis. This increases the payback times for commercial rental PV models and can increase costs for businesses.

Planning. The development of PV lacks a unified masterplan. It also has no standardization or channeling of basic data on solar resources and no current development landscape. Under the "dual carbon goals," local governments are still figuring out how to effectively develop green renewable energy such as PV with available resources. They lack a comprehensive plan and prioritized and phased goals for the development of renewable energy. Outside of pilot project zones, the development and promotion of renewable energy, including PV, are seemingly left to independent entities. Planning for area redevelopment and urban renewal fails to consider the use of PV in integrated multistructure projects.

Unique characteristics of distributed PV projects

Distributed solar PV projects have the following characteristics:

The project scale is flexible. The capacity of distributed solar PV projects ranges from several kilowatts to 20 MW, with power output that is far smaller than large-scale ground-based solar PV power stations. Their modular design determines the scale of the project and can be adjusted based on the size of the roof. Installation methods are also relatively flexible and are suitable for areas with special requirements.

Energy can be simultaneously generated and used. The voltage of power generated by large-scale ground power stations is increased and fed directly into the grid. Energy generated from distributed solar PV systems is connected to a distribution network that is very secure. Furthermore, the requirement that the power be used locally as much as possible eliminates the need for long-distance transmission and reduces line losses.

Capital requirements are low and the projects are scattered. Distributed solar PV projects are limited by resources and rooftop space, which means that they are relatively small-scale, individual projects that require low levels of financing. If the investor is a company, its funding source could be equity financing or debt financing, similar to that for a ground-based power station. If financing procedures resemble those of a large, grid-connected power station, the small project would be less attractive. If the investor is a natural person, due to the lack of corporate entities, some financing models cannot be adopted, and it is difficult to obtain bank loans due to insufficient credit and guarantee.

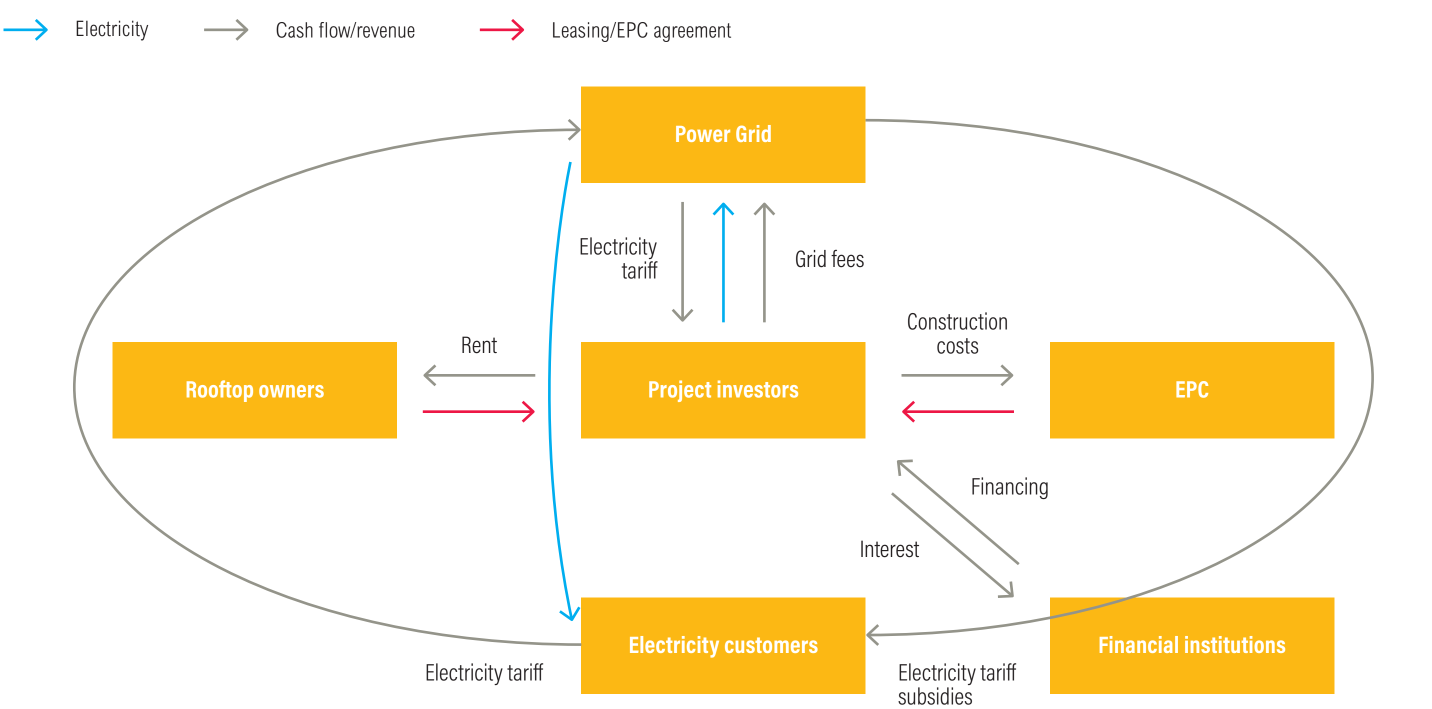
The large number of stakeholders means that the distribution of profits is varied. A typical distributed solar PV project involves the following parties in the course of development, construction, and operation:

- Financial institutions: banks, insurance companies, bonding companies, securities companies, and financial leasing companies who provide financing.
- Project investors: a company or natural person, usually also the project owner, who provides the necessary capital to invest in the project.
- Project operators: the same entity as the project investor, or a different entity, responsible for the follow-up operation and management of the project.
- Engineering, procurement, and construction (EPC) companies.
- Rooftop owners: schools, residences, hospitals, factories, and the like.
- Grid companies: businesses that provide grid connections, measure power generation and power use, and pay feed-in tariffs.
- Users: electricity users, some of them rooftop owners, who use and pay for electricity.

Uncertainties in distributed solar PV projects mainly include the following: longevity of the project owner and project operator; capacity of the rooftop, including age and leakage concerns; limited scale; individual projects' need to complete the full series of registration procedures; lack of a standard rooftop design; varied user requirements and difficulties in construction and management; and difficulty in collecting electricity fees. Distributed solar PV projects may well face problems in the course of implementation that result in the project's no longer being used, such as transfer of ownership of the rooftop. This creates uncertainty in the course of general operations.

The diversity of stakeholders also results in more possibilities for commercial models with more diverse profit-distribution where the project investor collects electricity fees, the grid operator collects grid service fees, the owner of the rooftop collects rent, the user enjoys reduced electricity fees, financial institutions/creditors collect interest, as shown in Figure 4. The multiplicity of profit-sharing parties lowers the return on distributed solar PV projects.

Figure 4 | **Participants in distributed solar energy generation and income models for a typical PV project**



Note: EPC = engineering, procurement, and construction.
Source: Authors.

2.2 Investment and financing challenges

Difficulties in obtaining bank financing

Distributed solar PV business models include project-owner investment, bank loans, financial leasing, and cooperative development. Bank loans and, in particular, financial leasing are the two main financing models at present.

Banks are generally unwilling to provide financing. Their concerns are that the distributed solar PV projects are small-scale and scattered, and that their construction periods are short but operational periods are long. This increases the management costs. When the process for an RMB 100 million loan project is the same as that for an RMB 1 million loan project, banks are more inclined to finance large-scale projects. In addition, banks pay more attention to the nature of their customers and are more inclined to provide financing to state-owned enterprises. Most distributed solar PV project developers are private enterprises. Due to the consideration of risk and cost control, banks are rarely involved in supporting distributed solar PV projects. For enterprises, the conditions set down by banks are stringent, and approvals require considerable time, especially to obtain credit approval. The addition of prerequisites for solar PV projects to connect to the grid also stops companies in their tracks and forces them to turn to flexible finance lease companies.

In the context of implementing the national inclusive finance strategy, promoting the revitalization of financial services in rural areas, and supporting the development of green finance businesses, some banks have launched PV loans in recent years to provide financing for enterprises or individuals. The term of these loans is generally three to five years. The implementation of PV loans in the Greater Bay Area is relatively limited and recent, and the effects need to be verified over time.

Finance leases, the main source of financing, are costly and short-term

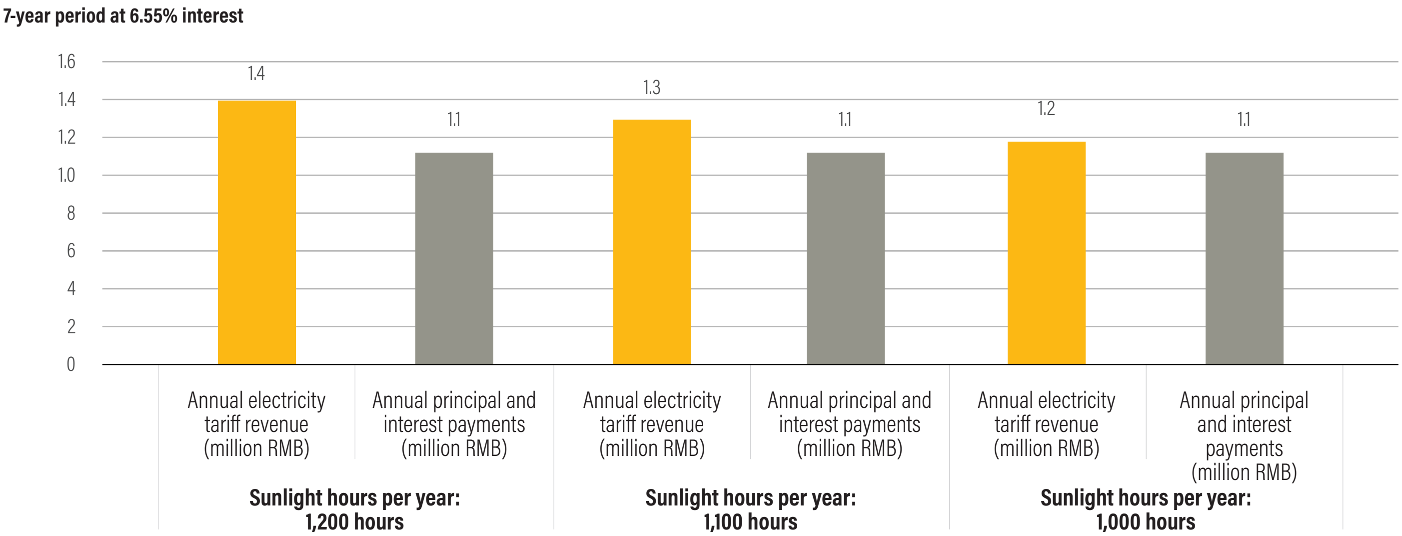
Currently, finance lease companies provide financing to most of the solar PV industry. The capital costs to project owners include interest on loans, guarantor fees, and leasing fees. These are more expensive than those for bank loans, and overall costs can be increased by 15–30 percent compared with the base interest rate. In order to reduce risk, some banks invest in distributed solar energy projects through their own lease companies.

Finance lease companies enjoy the same beneficial policies as banks, paying business taxes and other fees based on margin. For manufacturers, lease companies purchase parts to rent out from PV manufacturers. For developers, finance leasing not only effectively provides capital and resources but also improves their cash flow management and enables them to obtain financing more easily. Sale-leaseback is currently a very common operating model in this market, with rental periods of five to eight years and annual interest of 8–12 percent. Models that do not require a guarantee suit the needs of some distributed solar developers who have secured initial funding and already completed construction but need to recover some of their capital before beginning operations.

Currently, distributed solar energy primarily relies on leasing companies for financing, which creates challenges such as high costs and short-term agreements. The lifespan of PV power stations is generally 25 years and the normal financing period from banks for ground-based power stations is generally over 15 years. However, the period for lease financing used by distributed solar power stations is only five to eight years, which seriously constrains the ability of distributed solar power stations to pay back these loans. If a project uses a lease company for financing, it will be unable to generate any returns for the project owner within the first five years because all of the income will be used to pay back loans.

Take a 2 MW rooftop distributed solar PV project, for example. The investment cost is RMB 4 per watt, while the average income from electricity tariffs is RMB 0.7 per kWh (an average of direct sales to customers and feed-in fees from extra power). If the total investment cost of a project is RMB 8 million and loans make up 70 percent of this (RMB 5.6 million), the interest rate is 6.55 percent, and the loan period is seven years. In areas that average around 1,200 power-generation hours per year, the resulting income from electricity sales will be RMB 1.416 million. After loan repayments of RMB 1.124 million, in addition to maintenance costs, capital returns are around 8 percent. However, in the Greater Bay Area, the income generated from a full-sun range of between 950 and 1,050 hours can cover little more than the principal and interest payments (Figure 5). During years with reduced sunlight, investors may have to make up the difference out of their own pocket.

Figure 5 | **Examples of financing for distributed solar energy projects**



Source: Authors.

Limited revenue protection mechanisms

There are risks involved in distributed solar energy projects, from the quality of batteries to the construction of power stations to operations. The appropriate use of financial tools such as insurance to mitigate this risk is becoming a trend. Distributed solar energy projects are already using insurance to deal with risk during their construction and operating phases to satisfy the demands of financing institutions. However, revenue protection, which is most awaited by the market, has been difficult to implement. The main reason is that the amount of electricity produced through distributed solar PV projects is mainly decided by the grid. Neither insurance companies nor operators are able to manage the amount of electricity that can be produced. This has forced insurance companies to gradually give up on project revenue protection.

2.3 Recommendations

Policy innovation

The government should strengthen overall planning, carry out PV installation resource investigations, and improve the basic data of buildings with existing PV projects as well as buildings with development potential. In addition, the government should promote the deepening of the low-carbon development model in planning for the Greater Bay Area and new towns by incorporating solar PV applications into the overall development plan and further increase PV applications in new districts, renovation of old cities, and new green communities.

Taking advantage of the recently introduced new policy from the central government to promote distributed solar PV throughout designated counties, the Greater Bay Area can follow the principles of governmental guidance, market operations, and an innovation approach to select specific districts and counties suitable for a consolidated installation program to maximize market scale. Led by commercial developers that are supported by innovative investment services and insurance policies, the Greater Bay Area would be able to promote commercial operations of distributed solar energy for selected regions. Those with priority development rights for rooftops should be given the option of transferring or contracting those rights to PV development companies if they do not wish to develop rooftops themselves.

Innovation in the business model

In addition to finance lease options, there should be many other channels for financing in distributed solar PV projects. The government should drive the creation of a community of common interests made up of commercial solar PV development companies, manufacturers, grid operators, government, and finance and insurance organizations in order to help users and rooftop owners benefit from business models like energy performance contracting. This will ultimately result in sustainable business development models.

Financial institutions can work with government and state-owned companies to jointly create financing and investment platforms to provide projects in pilot zones with rapid financing channels. Financing platforms can establish project libraries, taking advantage of Shenzhen's technological dominance, Hong Kong's financial prowess, and Guangdong's industrial superiority to create a technologically driven financial accelerator to match distributed PV projects with financial institutions. These platforms can operate in a market-based way, gradually moving away from reliance on the borrower's creditworthiness and toward reliance on the project's quality. The platforms' core architecture is vital. The only way risk can be mitigated is by creating an optimized selection process to filter projects before awarding financing.

Market mechanisms can also be used to promote the consumption of distributed solar power. It is essential to implement trading market pilots to develop the infrastructure for transactions in the PV market, study the trading and price mechanism, solve the problem of imbalance of electricity production and consumption of individual buildings, and improve profits from distributed PV projects. The buildings can be explored as virtual power plants that integrate electricity generation, storage, and consumption mechanisms for participating in the electricity market. Innovative models of electricity fee collection should be considered for projects that prioritize on-site consumption of the electricity generated, prestored electricity bills, and cooperating with local power grid companies to collect on behalf of others.

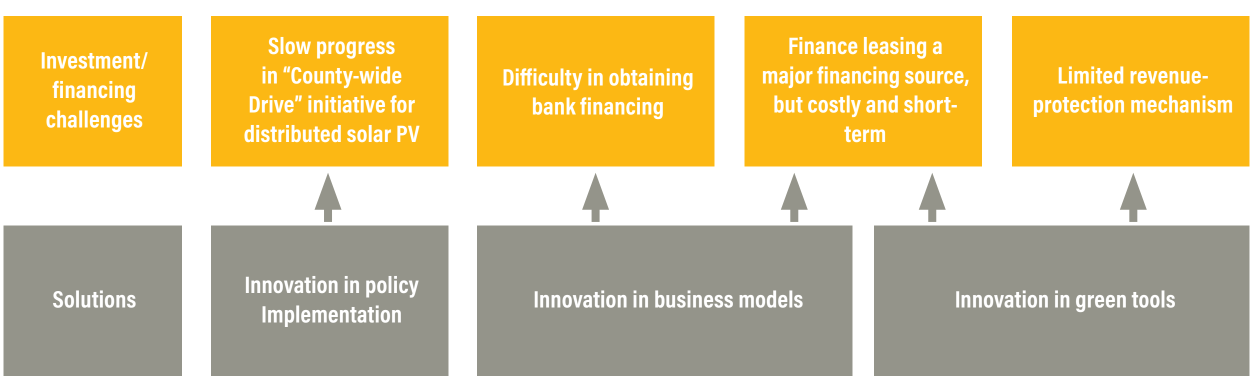
Innovation in green financial tools and instruments

We recommend expanding financing channels through insurance product innovation. A good insurance system will ensure both the quality of PV power stations and project financing. Quality insurance is already very common, and there is also insurance for clean energy such as offshore wind and nuclear power. We recommend promoting financing insurance for PV power stations or loss insurance for power generation volume. We also encourage insurance companies to provide discounts to PV investors who meet high standards for quality.

Financial institutions can launch more PV loan products for the Greater Bay Area. Our study of the effects of existing PV loan products in various regions suggests that the loan term, loan amount, and loan interest rate should promote the development of distributed PV. For example, related products can consider a flexible loan interest rate linked to the performance of power generation where the financial institution approves a lower interest rate when the power generation meets a certain required level.

We also recommend facilitating investments in distributed PV power plants through asset securitization. Asset securitization converts illiquid property assets into tradable investment products, allows banks to recycle capital (i.e., they can sell their loans to institutional investors and then finance new projects), provides fixed-income investment varieties for institutional investors, broadens investment fields, and diversifies investment risk for the institutional investors buying the securities. In addition, ordinary investors can participate in PV financing. Recommendations are summarized in Figure 6.

Figure 6 | **A summary of recommendations for distributed solar energy**



Source: Authors.

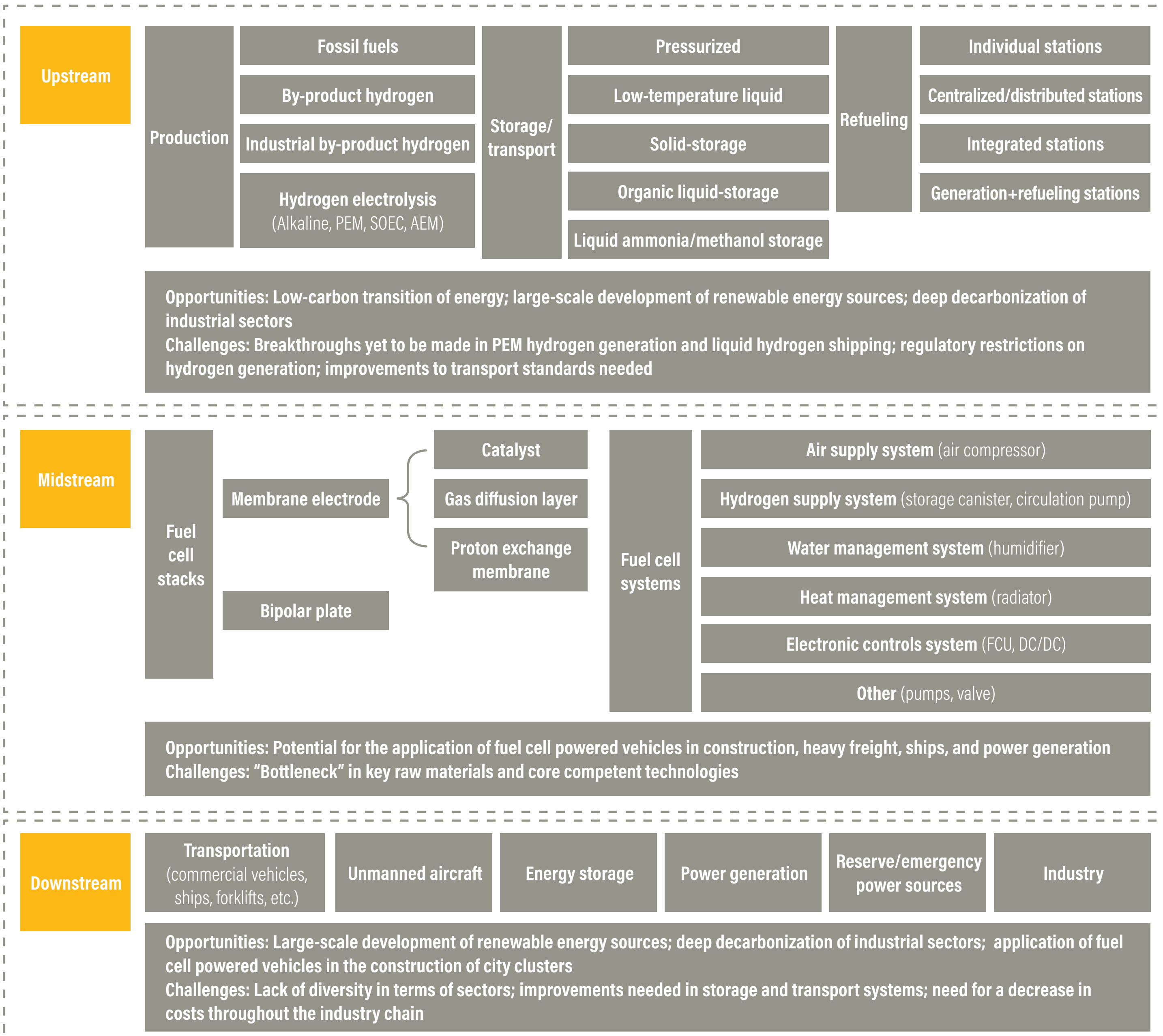
3. HYDROGEN

3.1 Current situation

Hydrogen industry shows positive growth

Driven by national industry policies, China's hydrogen industry has shown positive growth trends and has begun to master the main technologies and manufacturing techniques in hydrogen production, transportation, hydrogen refueling, fuel cells, and systems integration (see Figure 7). There are over 1,000 companies in the industry chains of the Yangtze River Delta Region, the Greater Bay Area, and the Beijing-Tianjin-Hebei Region. These areas have seen the small-scale application of fuel cell vehicles.

Figure 7 | **Structure of the hydrogen industry chain with opportunities and challenges**



Note: AEM = anion exchange membrane; DC = direct current; FCU = fused connection unit; PEM = proton exchange membrane; SOEC = solid oxide electrolysis cell.
Source: Authors.

The cities in Guangdong Province have made a series of efforts in research and development (R&D) and the industrialization of core technologies, as well as in the promotion of hydrogen vehicles and hydrogen refueling infrastructure. Guangzhou is an innovative R&D center for fuel cell vehicles, a manufacturing base for whole vehicles and key components, and a core region for pilot application of fuel cell vehicles in the Greater Bay Area. Foshan is a technology and standard innovation center; a manufacturing center for fuel cells, core components, and vehicles; and a pioneering pilot area rooted in traditional leading industries. Dongguan is a manufacturing and R&D base for fuel cell core components and home to production from propane dehydrogenation by-product hydrogen. Zhongshan is home to industries producing liquid hydrogen equipment and core components of fuel cells. Yunfu is a manufacturing base for high-end fuel-cell vehicles. Zhuhai is a source of industrial by-product hydrogen. Yangjiang has great offshore wind potential that can be used for green hydrogen production.

The Greater Bay Area is home to over 300 hydrogen companies, which cover the manufacturing of key core components like catalysts, membrane electrodes, air compressors, fuel cell stacks and systems, high-end equipment production, fuel cell and whole-vehicle manufacturing, as well as the production and transportation of hydrogen (Figures 8 and 9). Annual output value has exceeded RMB 10 billion, making the area the largest concentration of hydrogen and fuel cell vehicles in the country (Guangdong DRC 2021b). It has also seen the rise of industry leaders like GAC Group, FAW Car Company, CleanEst Energy, SinoHyKy, Sinosynergy, Jiping Energy, and General Hydrogen. Joint efforts by government and businesses have resulted in the rapid development of hydrogen infrastructure projects in the Greater Bay Area, with the scale of end-user applications continually expanding. Model projects, including hydrogen-powered ships, cogeneration, and hydrogen-powered communities, have also been gradually implemented.

Figure 8 | **Hydrogen companies in Guangdong Province**

Drive motor

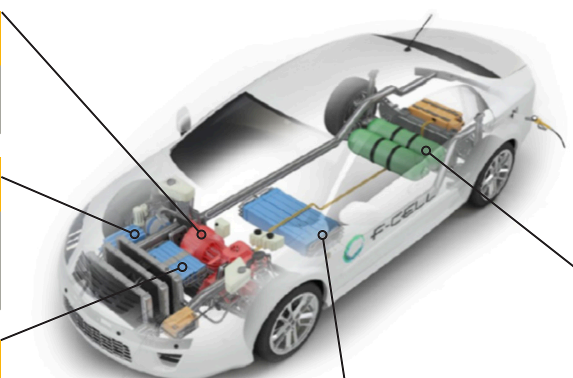
Broad-Ocean Motors

DC/DC

Guangshun New Energy, Broad-Ocean Motors

Electric control unit

Mostly independently sourced by engine manufacturer



Fuel cell stacks

Generation: Foshan Gas, Guangdong Petroleum, Huate Gas, Linkye Gas, Yangjiang Hydrogen, Grand Resource
Storage/shipping: CIMC ENRIC, Fullcryo
Refueling station construction/operation: Sinopec New Energy, Guolian Hydrogen, Grand Blue
Refueling station equipment: Sunwise

High-pressure hydrogen gas tank

Sunwise Technologies

Whole-vehicle design

Commercial: Foton AUV, Guangri Trucks, Feichi Bus, Discovery Motors, Guangzhou Municipal Environmental Machine and Equipment Factory, Winnerway Motors, Guangdong Hanhe, Foday Auto
Passenger: GAC Passenger
Streetcars: CRRC Sifang

Fuel cell stacks and system

Fuel cell stacks

Sinosynergy, Cemt Guangdong, Telos Auto, Pearl Hydrogen, Vision Battery, Smart Hydrogen Technologies, Guangdong Yunliang

Systems integration

Broad-Ocean Motors, Sinosynergy, Discovery Motors, Cemt Guangdong, CleanEst Energy, Hongli Hydrogen, Hydra Vision, Xiongchuan Hydrogen, Lead Motion

Core components and materials

- PEM: EM Technology;
- Compressors: Wenli Technologies, GSE New Energy, Broad-Ocean Motors, Haozhi Motors
- Bipolar Plates: Cemt Guangdong, Sinosynergy, Guangdong Taiji, Baotan Graphite, Jinyalong, Jiayu Carbon
- Catalysts: Jiping New Energy
- Membrane Electrodes: Guangdong Taiji, SinoHyKey, Dongguan Zhongchuang
- Hydrogen Circulation Systems: CleanEst Energy, Broad-Ocean Motors, GSE New Energy
- Gas Diffusion Layers: General Hydrogen

Note: DC = direct current; PEM = proton exchange membrane.
Source: Foshan Institute of Environment and Energy.

In September 2020, the Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Science and Technology, the National Development and Reform Commission, and the National Energy Administration jointly issued a "Notice on Developing Application Pilots for Fuel Cell Vehicles." It proposed changing policies that subsidize the purchase of fuel cell vehicles into a support policy for pilot applications (MOF et al. 2020). This would provide incentives for city clusters that meet criteria in tackling key problems in the industrialization and pilot application of key core technologies in fuel cell vehicles. As of May 2022, five city clusters (the Beijing-Tianjin-Hebei region, Shanghai, Guangdong, Henan, and Hebei) had been approved as pilots.

In addition, the abundance of offshore wind, geothermal, and nuclear power in Guangdong Province is conducive to the development of "green hydrogen." As of the end of 2019, the total scale of new energy generation facilities throughout the province had reached 51.53 GW.[8] Of this, 16.14 GW was nuclear energy and 12.89 GW was wind, PV, and biofuels.[9] According to the *Guangdong Province Action Plan for Cultivating Strategic Emerging Industry Clusters in New Energy (2021–25)*, by 2025, the scale of new energy installations will have reached approximately 102.5 GW, of which wind, PV, and biofuels will make up 42 GW. Hydrogen production will reach nearly 80,000 tonnes, hydrogen fuel cells production capacity will reach around 5 GW, and storage capacity will reach around 2 GW (Guangdong DRC et al. 2020).

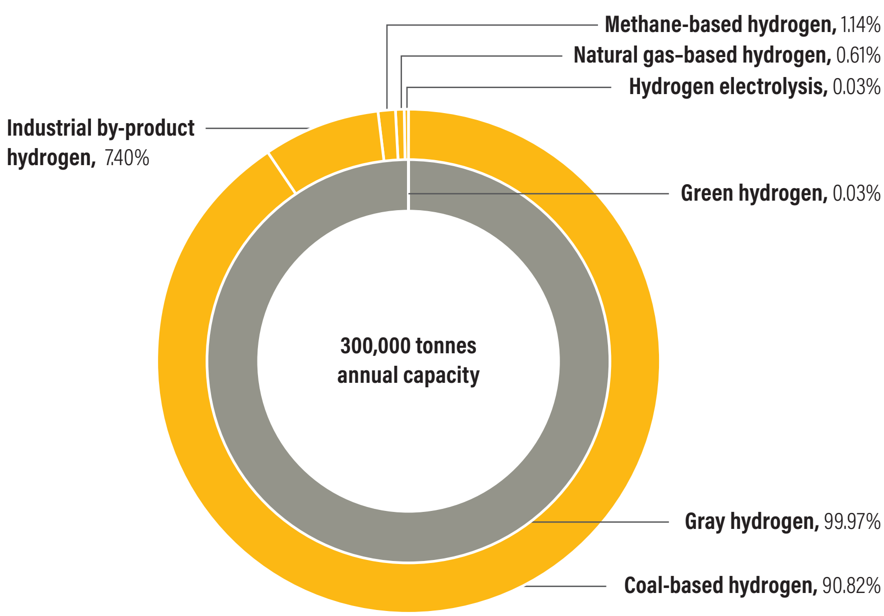
Hong Kong and Macau are not capable of producing hydrogen and should put more thought into end-user application scenarios and issues related to the transportation of hydrogen. In Hong Kong, for example, the application of hydrogen is being actively explored for the generation of electricity and transportation, with the hope that cooperation with mainland China can ensure future supplies of hydrogen.

Lower costs and increased efficiency expected in the supply of hydrogen

1. *Production: Hydrogen needs to be produced using clean energy to support China's decarbonization efforts. The falling prices of renewable energy and technological progress in electrolytic cells will help reduce production costs.*

While the hydrogen industry in the Greater Bay Area has grown over the past years, supplies of hydrogen in the Greater Bay Area mainly rely on fossil fuel–based

Figure 9 | **Production capacity for hydrogen in the Greater Bay Area in 2020**



Source: Unpublished internal research by China Hydrogen Alliance and Foshan Environment and Energy Institute.

production, such as coal-based hydrogen, natural gas reforming, and methanol cracking, as well as purified industrial by-product gases. In 2020, the annual production capacity for hydrogen in the Greater Bay Area was around 300,000 tonnes, over 90 percent of which was concentrated in the eastern and western areas of Guangdong Province. Of this, 90 percent was coal-based hydrogen, 7.4 percent was from industrial by-product gas, and only 0.03 percent used electrolysis technology.[10] In the future, hydrogen from electrolysis, especially when paired with renewable energy sources, will be a key development trend, which will be essential to support China in reducing its carbon emissions and achieving its dual carbon goals. Low-cost cold-storage electricity is currently being explored in the Greater Bay Area[11] to lay the groundwork for development in hydrogen production from electrolysis.

Coal-based hydrogen has the lowest production cost. When the price of coal is RMB 200–1,000 per tonne, hydrogen production costs are RMB 6.8–12.1 per kilogram (kg). When the price of natural gas is RMB 1–5 per normal cubic meter (Nm^3), hydrogen production costs range from RMB 7.5 to 24.3/kg. The costs of hydrogen produced using industrial by-products vary widely. Hydrogen produced from coke oven gas ranges from RMB 9.3 to 14.9/kg; hydrogen produced using by-products from chlor-alkali chemical processes costs between RMB 13.4 and 20.2/kg; hydrogen produced from synthetic amino alcohols ranges from RMB 14.6 to 22.4/kg; and general costs using alkane dehydrogenation range from RMB 14 to 20.2/kg. Hydrogen from alkaline electrolysis is the most economical in the case of hydrogen production by electrolysis, but production costs depend on the electricity tariff (these make up around 85 percent of costs) and based on current efficiency rates of 5 kWh/Nm^3 hydrogen and an electricity tariff of RMB 0.6/kWh, hydrogen production costs would be RMB 40–50/kg.

China's alkaline electrolysis technology and ability to produce the necessary equipment is on par with other countries and is the main hydrogen production technique used for green hydrogen. There are clear advantages in the combination of proton exchange membrane (PEM) technology used in hydrogen from electrolysis and renewable energy. However China's PEM hydrogen production is in the initial stages of development, with a relatively large gap between China and developed countries. It will therefore be essential to develop low-cost, high-output PEM hydrogen from electrolysis fuel cell stacks and key materials. The cost of hydrogen from electrolysis depends on the price of electricity produced using renewable energy sources and the scaled development of electrolysis technologies, equipment, and related industries. Research by the China Hydrogen Alliance suggests that by 2030 the cost of power production using newly installed PV and wind installations will be reduced to RMB 0.2/kWh, while the cost of hydrogen from electrolysis using renewable energy sources will drop to RMB 15/kg. This will make costs competitive with carbon capture, utilization, and storage (CCUS)–compliant coal-based hydrogen production (China EV100 2021).

2. *Storage and transportation: 20 MPa tube trailers currently in use are not suited for the storage and transport demands of China's rapidly developing hydrogen sector. Exploring hydrogen transport solutions at 30 MPa and greater can help decrease storage and transport costs.*

Hydrogen can be stored in three forms: gas, liquid, and solid. Storage and transportation are currently one of the most important elements in the development of hydrogen. China currently generally uses 20 megapascal pressure unit (MPa) high-pressure gas hydrogen storage canisters and tube trailers for storage and transportation. The technology and equipment are mature and hydrogen gas can be filled and extracted quickly, but it is inefficient, a single vehicle can only transport 300–400 kg of hydrogen, and transport distances have a clear impact on cost.[12] When transport distances are between 50 and 500 kilometers (km), transport costs range from RMB 7.3 to 33.8/kg. As distance increases, transport costs rise dramatically. Developed countries are already using tube trailers that carry high-pressure composite hydrogen canisters rated for over 30 MPa. Compared with 20 MPa trucks, these see a 40 percent reduction in weight and an increase in the concentration of hydrogen gas of 64 percent, lowering transport costs 1.8 times. When the remaining pressure is 7 MPa, gas discharge increases 93 percent, and when remaining pressure is 5 MPa, this value increases by 82 percent (Foshan IEE 2021).

The main issues in the use of pipelines to transport hydrogen are large investments in the initial stages of construction and immature equipment and technologies at station locations. However, in the long term, pipelines have the potential to transport larger volumes, reducing energy consumption and lowering costs. And with increasing demand for large-scale storage and transport of hydrogen gas, pipelines could also be used for liquid hydrogen, high-pressure hydrogen gas, and solid hydrogen storage, thus diversifying the methods used to store and transport hydrogen. In the future, large-scale, long-distance hydrogen pipeline technology will help speed up the promotion and commercial application of hydrogen.

3. *Hydrogen refueling: Large-scale application and further increased localization of equipment production are the keys to reducing the construction cost of hydrogen refueling stations.*

Technology used in hydrogen refueling stations can be divided into those that use external hydrogen sources and those that use in-station ones. China has mainly adopted external high-pressure hydrogen refueling stations. The construction costs of a station capable of providing 1,000 kg per day are around RMB 12 million (not including land costs), of which compressors make up around 30 percent.[13] As the scale and domestic production of equipment continue to increase, there will be room for the cost of equipment used in hydrogen refueling stations to come down.

Currently, the Greater Bay Area is mostly converting or expanding existing infrastructure, such as petroleum and natural gas fueling stations, to accommodate hydrogen refueling facilities and thereby create integrated energy service stations. Foshan encourages the integrated installation of hydrogen refueling with petroleum and natural gas fueling stations and electric charging stations, with a goal of constructing 57 hydrogen refueling stations by 2030 in Foshan (Foshan Municipal Government 2018). In 2021, Sinopec Guangdong Oil constructed 3 petroleum/hydrogen integrated refueling stations in Foshan and Yunfu.[14] Currently, Guangdong Oil is actively exploring the possibility of linking the upstream and downstream industry chains in hydrogen to accelerate the distribution of its petroleum/hydrogen refueling stations, thus integrating production, transport, and refueling and establishing an economically competitive domestic commercial model for hydrogen.

Insufficient institutional innovation

Hydrogen is still regulated as a dangerous industrial chemical product, and technical standards for its storage and transport remain incomplete. With the exception of the construction of newly approved hydrogen refueling stations, the production of hydrogen is still not permitted in integrated petroleum/hydrogen or integrated natural gas/hydrogen refueling stations. The land on which existing petroleum and natural gas fueling stations are located is commercial, but after hydrogen production equipment is installed at these stations, the designation of the land becomes industrial. This makes it very difficult to obtain governmental approvals and pass safety inspections. The issue of land designation for hydrogen refueling stations has created barriers to their construction and operation, which is not beneficial to commercial development.

In addition, there are still no administrative bodies clearly responsible for the upstream industry chain. For example, since there is not yet a clearly designated monitoring or approvals body for the construction of hydrogen refueling stations, many cities approve construction projects as special exceptions, which means that no standardized administrative mechanism has been formed. As an example, Box 1 shows how Foshan approved its hydrogen refueling stations.

Box 1 | How Foshan approved its hydrogen refueling stations

Currently there is no national or provincial-level regulation in place for the construction of hydrogen refueling stations. The city of Foshan led the way in developing pilot programs for integrated gasoline/hydrogen refueling stations and integrated production/refueling stations, overcoming the challenges in construction. In 2015, the barrier of administrative approval for hydrogen refueling stations was resolved by clearly designating government agencies in charge of housing and construction as responsible for refueling stations. In 2017, the first commercial hydrogen refueling station in China was constructed in Foshan, and the experience gained was shared with other cities in China. In 2018, Foshan issued its first set of support policies for the construction and operation of hydrogen refueling stations as well as the operation of hydrogen fuel cell vehicles.

The potential for end-user application has not yet been fully explored, with the current focus only on fuel cell vehicles

The transportation sector is a breakthrough opportunity for hydrogen and fuel cell batteries in downstream application. Currently in the Greater Bay Area, the use of hydrogen in transportation has reached an initial scale in public transportation and logistics in the cities of Foshan, Guangzhou, Shenzhen, and Zhongshan. As of the end of 2021, there were over 3,000 fuel cell vehicles in Guangdong Province, mainly vehicles used in logistics (approximately 65 percent) and public transportation (approximately 35 percent). They covered an operating distance of over 30 million kilometers. However, application in passenger vehicles remains limited. The main reason for this is the cost of producing passenger vehicles and existing infrastructure, which is incapable of supporting large-scale promotion of passenger vehicles. Logistics vehicles powered by fuel cells are not particularly economical, in either purchasing or operating costs, and private enterprises are unwilling to purchase them. However, the potential application of hydrogen-based transportation in logistics for fresh foods, freight, urban construction, and port services, as well as intercity passenger services, regional commuting, and long-distance "East-West Guangdong" freight routes has yet to be fully explored. In later stages of development, channels for commercial development should be gradually explored in the expansion of energy storage, petrochemicals, iron and steel, and buildings.

3.2 Investment and financing challenges

The initial stages of development in a new industry often require support through policies and subsidies, but the key to the ultimate success of any industry is a sustainable business model. Once the hydrogen industry is linked with financial capital, large-scale commercial development of hydrogen fuel cell vehicles will be possible. Scaling up will drive improvements in technology that lower costs, thus further promoting the commercial application of hydrogen in industry, energy storage, power generation, and buildings, establishing a positive cycle. However, investment and financing in hydrogen in the Greater Bay Area currently face the following challenges:

An unsustainable government-led model based on subsidies

The hydrogen industry is in a formative stage of development, and many enterprises rely on government subsidies to maintain operations. In the battery industry, lithium batteries can easily attract tens of billions of RMB in investment, but hydrogen fuel cells are still in the initial venture capital stage of investment, and the industry's development is mainly dependent on government guidance and fiscal subsidies. Long-term reliance on government support is unsustainable for two reasons. First, fiscal capital from the government is limited and can only guide industry development. Based on the recent policy to replace subsidies with other incentives for fuel cell vehicles, the best time for promoting rapid development with large-scale subsidies may have passed. Fiscal capital will be used more to support generic technology and industrialization in key parts of the industry chain. Second, subsidies may result in blind capacity growth and slower advances in technology; they may restrict commercial development such that "bad money drives out good," compromising the sustainable development of hydrogen.

High costs and investment risk across the industry

Currently, China is in the initial stages of hydrogen development, and high costs plague the Greater Bay Area as well as other regions of the country.

- While green hydrogen may be mainstream in the future, the current cost of hydrogen from electrolysis is too high and prohibits the scaled development of renewable energy sources in hydrogen production. There is a great deal of potential in the Greater Bay Area for offshore wind power, but the cost is far greater than using PV or onshore wind to produce hydrogen.

- Transportation costs are closely linked to distance and transport volumes. Currently, the effective volume of a single shipment of hydrogen using a tube trailer is around 300 kg, which is only 1–2 percent of a normal freight shipment and makes it very uneconomical. High-pressure gas storage and transportation requires investment in the manufacturing of high-pressure containers, and the cost of liquid storage technologies still has to come down; pipelines, meanwhile, require large investments in the construction of infrastructure.

- As a key link in the industry chain, the number and distribution of hydrogen refueling stations directly affects the cost of hydrogen storage and transportation. The cost of land for hydrogen refueling stations is high, and the period of return is relatively long. It costs upward of RMB 20–30 million to build 1 hydrogen refueling station, while the same amount could build 4 petroleum fueling stations or 40 electric charging stations.[15] Hydrogen refueling stations still mainly rely on government subsidies. Furthermore, the core technologies used in compressors for 70 MPa hydrogen refueling stations remain behind international levels. While complete fueling equipment is gradually being manufactured domestically, key components like valves and flow meters that are not mass-produced are still imported, greatly increasing construction costs. Case Study 5 is an example of the cost of a hydrogen refueling station in Foshan.

- The high cost of hydrogen fuel cell vehicles results mainly from the cost of fuel cell systems and imported key components. In 2018, the overall cost of a domestically produced fuel cell vehicle was RMB 1.5 million, while electric vehicles and ICE vehicles with the same specifications were, respectively, one-sixth and one-tenth of that cost.[16] The relatively high price of hydrogen has also made vehicles more expensive to operate. Case Study 6 is an example of the cost of purchasing and operating a hydrogen bus in Foshan.

Uneven distribution of investment and financing in the industrial chain

Fuel cells are one of the main areas of investment for capital markets, with the number of investments steadily increasing. In 2019, there were 27, and in 2020 there were 31 (China EV100 2022). According to a recent research report (Orange Group 2022), of the 50 nonlisted companies in the hydrogen and fuel cell vehicle sector that it focused on, 36 had obtained financing in 2021. Of these, 30 companies (83 percent) were in the fuel cell vehicle industry chain (15 of them system/fuel cell stack companies), and 6 companies (17 percent) were in the hydrogen industry chain. Overall, distribution of investment in the hydrogen sector is uneven. Investors are more interested in companies involved in the core components and system integration for fuel cells. However, as rapid development of hydrogen supplies as a limiting factor in sustainable industry development becomes clearer, capital markets will gradually begin to pay more attention to upstream hydrogen production, storage, and transportation.

Lack of market diversity and investment concentrated in a few leading enterprises

Investment in the hydrogen industry in China mainly comes from national and local SOEs and industry funds with very few financial investors. Out of 97 national SOEs, currently one-third are engaged in hydrogen (SASAC 2021). Of these, traditional energy SOEs like those engaged in oil, gas, and electricity are the most proactive. Business expansion is done in one of two ways. The first is to choose "small, efficient, and top" businesses in the industry as representatives, using them to enter the market before their value becomes high. In 2020, Sinopec Group established the Enze Foundation (fund total of RMB 5 billion, with RMB 2 billion for the first phase) (*China Petrochemical News 2020*). Its first investment in new energy was in a provider of hydrogen equipment. Sinopec became the second-largest shareholder in the Shanghai-based REFIRE Group, which works on R&D and industrialization of key components in hydrogen. The Shenergy Group became a shareholder of Xebec, which controls technologies for refining hydrogen gas and is also cooperating with Hyfun Energy (Shanghai) and Sunwise New Energy (Shanghai) on the construction of hydrogen refueling stations. The second way is for leading companies to use their advantage in resources, technology, and capital to create strong partnerships and make the most of individual strengths to establish industry funds and cooperate on projects. In June 2019, the China Three Gorges Corporation funded Dongfang–Three Gorges Industry Fund Management (Chengdu) in conjunction with Dongfang Electric and Chengdu Venture Capital. It also established the Dongfang Electric Hydrogen Fund, which leverages the strengths of Dongfang Electric in hydrogen fuel cells' core technologies, China Three Gorges in resource allocation and investment, and Chengdu Venture Capital in industry implementation, marketing, and general financing. The fund focuses on investment in the hydrogen industry chain, new storage technologies, and clean energy technologies.

3.3 Recommendations

A government-guided investment mechanism to promote scaled investment

Currently, the greatest challenge facing investment in hydrogen in the Greater Bay Area is that the hydrogen industry is in the initial stages of development, with its main driving force coming from government policies and subsidies rather than the market. The majority of projects are small-scale, high-cost, and uneconomical. Resolving this problem will require diversified and scaled development of upstream and midstream R&D and end-user applications.

- We recommend that the government accelerate the establishment of and improvements in the hydrogen "1+N" policy system and, at the same time, clarify the standards, and time period for fiscal and taxation support. We also recommend that improvements be made in institutional arrangements, including the creation of a comprehensive investment monitoring and management system with standardized management practices and open, transparent supervisory structures. This will help drive sustainable and stable growth in the hydrogen and fuel cell markets and will give investors a clear view on these markets' direction, pace, and potential. This will also help investors obtain transparent and objective policy information and increase their confidence, thereby driving a sustained increase in the scale of investment and creating a beneficial cycle of industry development and financing markets.
- Local governments should also revise standards for hydrogen storage containers and hydrogen refueling stations, where appropriate, in order to facilitate the development and construction of hydrogen refueling stations. To support the development of green hydrogen, which is key to China's decarbonization, they should also explore supportive pricing policies for renewable energies used in the production of hydrogen and improve related market mechanisms. There should also be sound coverage of pricing mechanisms for energy storage and exploration of direct participation of hydrogen storage in the electricity market.
- We recommend that the government focus limited fiscal resources on supporting key generic technology, especially R&D and industrialization of core technologies, including those that support the production of green hydrogen.

A multichannel financing environment to provide differentiated capital supports for different links in the hydrogen industry chain

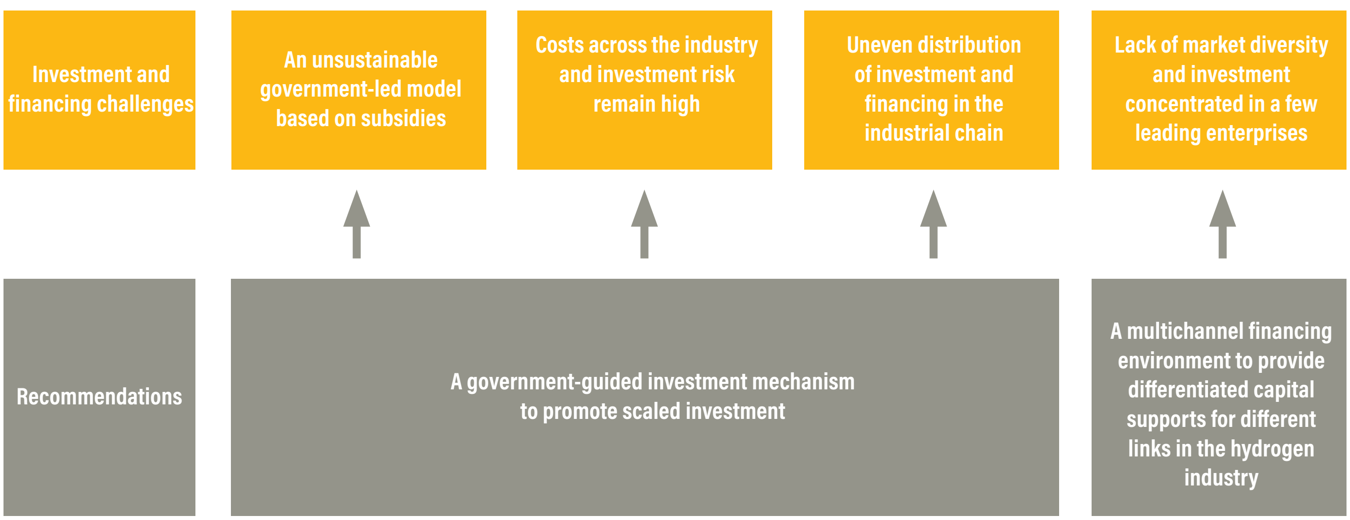
In terms of financing sources, the financing environment for hydrogen has changed greatly compared to that for PV, wind, and electric vehicles a dozen years ago. A portion of fiscal capital resources have been transferred to government-controlled funds, and conditions for listing on capital markets put greater emphasis on tech companies. Compared with traditional energy, support in new energy sources such as hydrogen and energy storage will rely more on private and corporate funds. More equity financing will replace the debt financing that was used in traditional companies and more diverse financing methods will be needed. We offer two recommendations in this regard:

- The government should actively encourage and guide financial institutions and corporations in establishing industry funds. Sources of venture capital should be expanded to include institutional investors, private capital, and large domestic companies, increasing the volume of venture capital investment and cultivating a more diversified collection of market players.
- Currently, the Green Industry List and the List of Green Bond Support Projects (2021 edition) include the production of hydrogen refueling equipment, the construction and operation of hydrogen refueling stations, and the construction and operation of facilities that use hydrogen. We recommend that hydrogen transportation and end-user hydrogen facilities be incorporated into the Green Industry List and the List of Green Bond Support Projects, providing support through guarantee and finance discounts.

In terms of the amount of financing, financial institutions have clear rules that establish upper limits for financing through a system of credit evaluation. Taking into consideration the existing support from central and local governments for the industry, financial institutions will participate in hydrogen in a number of ways. The industry is hoping that, for assets able to generate continuous cash flow, financial institutions can provide financing based on assets or based on credit in conjunction with assets to provide a financing amount and issuing schedule that better suits the needs of a project over a credit evaluation system.

In terms of interest rates, we recommend that the government develop differentiation policies like differentiated interest rates to provide more financial support for regions and links in the industry chain that are in urgent need of capital and remain relatively high-risk. This would attract investors to scatter their investments in companies in different localities, different links in the industry chain, and at different stages of development. Risk can be mitigated by investing in companies at multiple stages of development, staged capital inputs, portfolio investment, joint investment, contractual constraints, administrative consulting, and strict executive business plans. Financial institutions licensed to operate nationwide[17] can apply for low-cost capital using the "Carbon Reduction Support Tools," released by the People's Bank of China in November 2021, which support sectoral carbon emissions reduction. The tools open beneficial interest-rate financing for key sectors that have a clear impact on reducing carbon emissions, and they mobilize more private capital to participate in the carbon emissions market. Using the "Carbon Reduction Support Tools," financial institutions provide low-interest loans to companies in key carbon reduction sectors; the interest rate should be on par with the loan prime rate for the same period. Then the "Carbon Reduction Support Tools" target financial institutions licensed to operate nationwide and provide capital support for 60 percent of the principal of carbon reduction loans issued to companies by financial institutions, with an interest rate of 1.75 percent over a period of one year. This can be rolled over twice and requires collateral (PBoC 2021). Recommendations are summarized in Figure 10.

Figure 10 | **A summary of recommendations for the hydrogen industry**



Source: Authors.

APPENDIX. METHODOLOGY AND CASE STUDIES

In addition to literature review, research methods also rely on interviews and surveys. Distributed solar photovoltaic (PV) technology has had enough time to mature, and the challenges faced in financing are clear. Surveys and interviews have been helpful in finding practical solutions. Hydrogen, in contrast, is still in the early stages of development, so there is limited research available on the business model and financing. In this case, we had to rely more on on-site surveys to obtain information.

In terms of the scope of data, the Greater Bay Area refers to Hong Kong, Macau, and nine cities in the Pearl River Delta region: Guangzhou, Shenzhen, Foshan, Zhuhai, Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing. However, in terms of the availability of data, the scope for solar PV data is limited to Guangdong Province. Data for hydrogen also was limited to Guangdong Province because some of the hydrogen was supplied from Guangdong Province cities outside the Greater Bay Area.

The project team conducted interviews on distributed PV and hydrogen in the Greater Bay Area. Interviewees included representatives of Guangdong Solar Energy Association, Guangzhou Development New Energy Co. Ltd., Guangzhou Mingzhu Industrial Park, Guangzhou Baiyun International Conference Center, and Dahu Agriculture-Solar Integrated Photovoltaic Power Station in Lianping County, Heyuan City, Longjie Agriculture-Solar Integrated Photovoltaic Power Station in Lianping County, Heyuan City, Agriculture-Solar Integrated Photovoltaic Power Station in Zijin County, Heyuan City, Taishan Fishery-Solar Integrated Photovoltaic Power Station in Jiangmen City, the Budweiser Foshan factory, logistics enterprises, financing leasing companies affiliated with the China Southern Power Grid, and so on. The interviews focused on the applications, operation models, investment and financing models, financial status, problems in project operation, and future development potential and directions of distributed PV and hydrogen in Guangdong Province and the Greater Bay Area.

Case Study 1. Distributed PV power generation project on an industrial rooftop: Rooftop PV power generation project of Guangzhou Wanbao Refrigerator Co. Ltd. in Mingzhu Industrial Park

Project overview

The project is located in the new factory of Guangzhou Wanbao Refrigerator Co. Ltd. in Mingzhu Industrial Park, Conghua District, Guangzhou. The three new cement rooftops, one electricity room rooftop, and one parking shed of Guangzhou Wanbao Refrigerator Co. Ltd. provide 16,600 square meters (m^2) of available rooftop area. The project adopts 6,204 pieces of 275 watt peak (Wp) polycrystalline silicon PV modules with the highest conversion efficiency of 16.8 percent and an installed capacity of 1.7 megawatts (MW). Two grid connection points are set up, both in the 0.4 kilovolt (kV) voltage class.

The project took two months to build and was put into operation in May 2018. During the operation, the average annual utilization time is 945 hours, and the average annual power generation is 1.47 gigawatt-hours (GWh). The project prioritizes on-site consumption of the electricity generated (more than 90 percent of electricity generated is for self-consumption), and the electricity is connected to its building distribution system with a tariff discount of 10 percent.

Business model

As the project builder, Guangzhou Development New Energy Co. Ltd. is responsible for the financing, construction, operation, and maintenance of the whole project. Guangzhou Wanbao Refrigerator Co. Ltd. pays Guangzhou Development New Energy Co. Ltd. at a 10 percent discount on the electricity tariff. The electricity sold to the grid is paid by the power supply company to Guangzhou Development New Energy Co. Ltd. at the fair tariff. Guangzhou Wanbao Refrigerator Co. Ltd. obtains the project capacity subsidy (RMB 0.2 per watt), and the power generation subsidy (RMB 0.15 per kilowatt-hour [kWh]) is obtained by Guangzhou Development New Energy Co. Ltd.

Financial situation

Total investment: RMB 10.41 million
Financing: 30 percent company funds, 70 percent bank loan

Loan term: 12 years
Total electricity sales revenue: RMB 33.21 million (based on 25-year life cycle)
Self-use tariff: 0.7489 yuan/kWh
On-grid tariff: 0.453 yuan/kWh, same as the benchmark feed-in tariff of coal power in Guangdong Province
Average tariff: 0.6897 yuan/kWh
Investment payback period: 8 years
Internal rate of return on project investment: 12 percent

Case Study 2. Distributed PV power generation project on a commercial rooftop: Guangzhou Baiyun International Conference Center rooftop distributed PV power generation project

Project overview

This project, owned by Guangzhou Development New Energy Co. Ltd., is a rooftop distributed PV power generation system with an area of about 40,000 m^2, established on Buildings A, B, C, D, and E of Guangzhou Baiyun International Convention Center. With a total installed capacity of about 3.3 MW, the project uses high-efficiency 440 Wp polycrystalline silicon modules.

The fair-price project was completed in August 2019 and officially put into operation in January 2020. During operation, the average annual effective utilization time for power generation is about 956 hours, and the average annual power generation capacity is 2.81 GWh. The project prioritizes on-site consumption of the electricity generated (80 percent of electricity generated is for self-consumption, and 20 percent is transmitted to the grid). The electricity is connected to its building distribution system, with a tariff discount of 10 percent.

Business model

As the project builder, Guangzhou Development New Energy Co. Ltd. is responsible for the financing, construction, operation, and maintenance of the whole project. Baiyun International Convention Center pays Guangzhou Development New Energy Co. Ltd. at a 10 percent discount on the electricity tariff. The electricity sold to the grid is paid by the power supply company to Guangzhou Development New Energy Co. Ltd. at the fair tariff.

Financial situation

Total investment: RMB 18.81 million (RMB 9.9 million for components, RMB 8.25 million for EPC expenditure, RMB 660,000 for other expenditures)
Financing: 30 percent company funds, 70 percent bank loan
Loan term: 12 years
Total electricity sales revenue: RMB 41.86 million (based on 25-year life cycle)
Self-use tariff: 0.7489 yuan/kWh
On-grid tariff: 0.453 yuan/kWh, same as the benchmark feed-in tariff of coal power in Guangdong Province
Average tariff: 0.6897 yuan/kWh
Investment payback period: 12 years

Case Study 3. Hong Kong–issued green bonds to support green building development

As of February 2021, Hong Kong has issued HK$10.6 billion in green bonds to support several green building projects, among them the West Kowloon Government Offices, Inland Revenue Tower in the Kai Tak Development, the Treasury Building, Queen Mary Hospital Phase 1 Redevelopment, and East Kowloon Cultural Center. These green building energy conservation and emission reduction measures include distributed photovoltaic power generation projects.

Case Study 4. Combination of blockchain and distributed photovoltaics

Link REIT, the largest real estate investment trust in Hong Kong, partnered with blockchain startup Allinfra in 2019 to tokenize assets. It started with a solar power pilot to tokenize PV projects installed on Link's real estate assets in Hong Kong. Through the tokenization of solar projects, the blockchain can record financial impacts, ownership, and associated environmental impacts. Tokens will be stored on the Ethereum blockchain, with technical support from Allinfra. For Link REIT, a blockchain can provide greater asset liquidity, as well as energy management and sales automation in its real estate portfolio. Immutable records of data can further improve efficiency and more reliable insights. Using a blockchain for solar projects also can support a company's environmental, social, and governance (ESG) initiatives.

Case Study 5. Hydrogen refueling station in Foshan

For a hydrogen refueling station completed in 2018 in Foshan, for example, a total of RMB 18 million was invested in construction. The high cost of construction was mainly caused by the higher cost of their equipment, such as hydrogen storage facilities and compressors, compared with those of oil and gas stations. The operation and maintenance costs are also high. The unit price of a hydrogen filling gun made in Germany is around RMB 100,000, and, if damaged, it needs to be sent back to Germany for repair. A domestically produced filling gun costs half as much. This hydrogen refueling station employs 11 sales and 10 management staff. The total annual costs of this hydrogen refueling station are about RMB 6 million, including RMB 500,000 for electricity fees. The current sales volume is about 1 tonne per day. Based on the calculation of an eight-year payback period, if the gross profit is RMB 20 per kilogram (kg) and 821 kg of hydrogen are sold per day, the stations can break even.

Case Study 6. Application of the hydrogen fuel cell bus: The Foshan case

How much does it cost to purchase and operate a hydrogen fuel cell bus? We took Foshan's hydrogen bus as an example to make a simple calculation. The cost of purchasing a vehicle is around RMB 1.8 million, each of the central and local governments are providing RMB 500,000 per vehicle purchased, and companies need to pay RMB 800,000 for each vehicle by themselves. Fuel is another major cost. The price of hydrogen fuel in July 2021 was about 80 yuan/kg in Foshan. Hydrogen subsidies for hydrogen refueling stations were about 20 yuan/kg during 2018–21, so the price after subsidy is about 60 yuan/kg. The hydrogen bus consumes about 8.5 kg of hydrogen to travel 100 km and runs about 250 km per day, so the fuel cost of a hydrogen bus each year is about RMB 620,000, of which RMB 160,000 are subsidized by the government and RMB 460,000 are paid by the enterprises themselves.

ENDNOTES

1. In order to achieve China's carbon emission peak and carbon neutrality goal, China's national and subnational governments are developing a "1+N" policy framework. "1" refers to the guiding opinions that set out the overarching principles of all forthcoming policies aiming to facilitate China's peaking and neutrality goal. The "N" will include a "carbon peaking action plan"—a 10-point plan that states the government's expectations regarding actions key sectors are required to take to peak emissions. This will cover actions from all major emitting sectors (energy, industry, infrastructure, and transport) as well as other key policy areas for climate action (circular economy, technology, finance, economic policies, carbon trading, nature-based solutions).

2. Obtained by the research team from Guangzhou Institute of Energy Conversion and State Grid Energy Institute.

3. Obtained by the research team using survey data from the Guangdong Solar Association.

4. Obtained by the research team based on survey data from the Guangdong Solar Association.

5. Obtained by the research team based on survey data from the Guangdong Solar Association.

6. Obtained by the research team based on survey data from the Guangdong Solar Association.

7. According to the public information for each province's electricity price.

8. Based on related materials from the Foshan Institute of Environment and Energy.

9. Based on related materials from the Foshan Institute of Environment and Energy.

10. Based on research from the Foshan Institute of Environment and Energy.

11. Based on research from the Foshan Institute of Environment and Energy.

12. Based on research by the Foshan Institute of Environment and Energy.

13. Based on research by the Foshan Institute of Environment and Energy.

14. Based on research by the Foshan Institute of Environment and Energy.

15. Developed based on open-source information from the Foshan Institute of Environment and Energy.

16. Based on research by the Foshan Institute of Environment and Energy.

17. See bank list at http://www.pbc.gov.cn/tiaofasi/144941/3581332/3587928/2018080814530235173.pdf.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure that our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.