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APEC Sustainable Energy Center



# Research on Forms of Low-Carbon Energy System and Best Practices for APEC Sustainable Cities



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## **Executive Summary**

Many economies of APEC are undergoing rapid urbanization, and their energy demands are growing fast. Simultaneously, economies need to face the challenge of global climate change. Therefore, Low-carbon Energy System is a proactive option, which aims at energy efficiency, clean utilization and large-scale renewable energy consumption as the background. It is composed of multiple types of energy systems and will realize the organic coordination of production, transmission, distribution, transformation, storage, consumption and other links of different energy forms in multiple space-time scales. APEC Ministers and Leaders agreed in 2014 to a goal of doubling the share of renewables in the APEC energy mix, including power generation, by 2030, and have reiterated that goal annually. In 2014, recognizing the critical role of urban economies, APEC began to work toward a concerted approach on strategic urban planning to create sustainable cities. In light of this, in 2015, the 23rd APEC Economic Leaders' Declaration had stated that APEC would collectively commit to a new type of urbanization featuring green, energy-efficient, low-carbon, and people-oriented development. Ningbo Initiative of APEC High-Level Urbanization Forum 2016 declared that APEC economies would boost APEC cooperation on sustainable urban development and develop green cities collectively.

Therefore, APEC Sustainable Energy Center applied for an APEC self-funded project (EWG 12 2018S - Research on Forms of Low-Carbon Energy System and Best Practices for APEC Sustainable Cities), which aims at a better understanding of the low-carbon energy system concept, ideas, advanced technologies, models and application forms; so as to help cities improve the energy efficiency and contribute to cities' sustainability and how cities take the road of sustainable development in the APEC region.

This study analyzes and collects excellent practices from the six dimensions of the energy supply and energy use of a sustainable urban low-carbon energy system. The energy supply of the sustainable urban low-carbon energy system: 1) Clean Utilization of Fossil Energy, 2) Utilization of New and Renewable Energy, 3) Integrated Energy Network of Cities; energy use of sustainable urban low-carbon energy system: 1) Energy-efficient Buildings and Smart Communities, 2) Low-carbon Transportation and Electric Vehicles, and 3) Urban Energy Storage and Energy Management.

According to the geographical environment, APEC cities are divided into three categories, namely island type, peninsula type and inland type. Based on the analysis and statistics of 122 excellent practices, this study puts forward development suggestions from two aspects, urban energy supply based on local conditions and low-carbon and efficient urban energy use, and proposes relevant suggestions for constructing sustainable urban low-carbon energy system for three types of cities in different geographical locations.

According to the energy supply forms of low-carbon energy system of three types of sustainable cities in different geographical locations, the following suggestions are proposed:

1. Island cities: Renewable energy applications mainly based on solar energy and wind energy should be expanded, while ocean energy should be vigorously developed.

2. Peninsula cities: It should expand the utilization of new energy and renewable energy in combination with its own resource and energy endowment, and promote the multi-energy complementary system at the same time.

3. Inland cities: Greater efforts should be made to develop smart grids and comprehensive energy services.

According to the energy use forms of low-carbon energy system in sustainable cities, the following related suggestions are proposed:

1. Technological innovation, energy conservation and emission reduction
2. Comprehensive development and management
3. Improve awareness and education

# **Chapter 1: Sustainable Cities and Low-carbon Energy Systems**

## **1.1 Urban Sustainable Development Issues and Challenges**

With the rapid development of today's economy and the constant changes in social conditions, cities are facing unprecedented challenges. The concentration of the world's population in urban areas is becoming increasingly significant. As of 2015, 3.9 billion people were living in urban areas, representing 52% of the global population of 7.3 billion. By 2050, the world's urban population will reach 6.3 billion, or two-thirds of the projected global population of 9.5 billion<sup>1</sup>. The agglomeration of urban population and the expansion of cities are increasing day by day. The improvement of people's living standards and the upgrading of consumption have brought greater environmental supply pressure to the already tight urban resources. Faced with the tremendous pressure of urbanization and the continuous deterioration of the natural environment, people begin to summarize the experiences and lessons of their predecessors, reflect on their past behaviors, and actively change the inherent lifestyle of human beings, making them beneficial to the sustainable development of natural environment and human society. It is urgent to realize the sustainable development of cities. Urban population growth will continue to place pressure on member economy government not only to deliver basic services such as energy access, affordable housing, public health, disaster risk management and economic development, but to do so in a way that meets sustainable energy goals.

In today's world, cities have the characteristics of population concentration, wealth accumulation, efficient operation, environmental pollution, and prominent social problems, which make them the most comprehensive areas in local sustainable development. The Secretary-General of the United Nations Conference on Environment and Development, Maurice Strong, pointed out that cities were the key to the success of global sustainable development. The concept of "sustainable development" has gone through a tortuous process from being proposed to reaching consensus. In 1987, the World Commission on Environment and Development (WCED) published the Brundtland Report "Our Common Future", which for the first time scientifically discussed the concept of sustainable development. In 1992, the United Nations held the first Earth Summit-

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<sup>1</sup> UN DESA (United Nations Department of Economic and Social Affairs) (2014a), World Urbanization Prospects: The 2014 Revision, CD-ROM Edition, United Nations Department of Economic and Social Affairs, Population Division, United Nations, New York.



Conference on Environment and Development in Rio de Janeiro, Brazil. Five documents and treaties including Agenda 21, and proposed the basic framework of sustainable development, which marked the widespread consensus on "sustainable development" worldwide. In 2002, the United Nations held the second Earth Summit, the World Summit on Sustainable Development, in Johannesburg, South Africa. The conference adopted the famous Johannesburg Declaration on Sustainable Development, which paid great attention to the relationship between people and nature, and urged governments of all economies to take substantive action on environment and development. As the most comprehensive area in sustainable development, cities are also the key to the success of global sustainable development. Both the United Nations and the European Union have formulated corresponding sustainable urban development goals, and have done a lot of work to promote sustainable urban development under the guidance of their respective goals. First Earth Summit-Conference on Environment and Development, Millennium Development Goals (MDGs) signed at the UN Millennium Summit in 2000, and the three global frameworks adopted in 2015 (Sendai Framework for Disaster Risk Reduction 2015-2030, the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), and the Paris Agreement on Climate Change of the United Nations Framework Convention) can be regarded as the three milestones of sustainable development.



**Figure 1- 1 Sustainable Development Goal 7 and 11<sup>2</sup>**

Global urban sustainable development issues have been launched in different fields. In recent years, exploring the sustainable development of cities has become the trend of world development. The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call

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<sup>2</sup> <https://www.un.org/sustainabledevelopment>

for action by all economies - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. In the 17 SDGs, Sustainable Development Goal 7 is Ensure access to affordable, reliable, sustainable and modern energy for all<sup>3</sup>; and Sustainable Development Goal 11 is Make cities and human settlements inclusive, safe, resilient and sustainable<sup>4</sup>.

## **1.2 Urban Energy Challenges and Urban Energy Supply**

### **1.2.1 Urban Energy Challenges**

Energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes, access to energy for all is essential. The city accommodates more than 50% of the world's population, but it accounts for 60% to 80% of energy consumption, and mainly produces up to 70% of greenhouse gas emissions through the consumption of fossil fuels. The world's energy future is inseparable from cities. The high concentration of urban population and economic capital, as well as the characteristics of urban buildings, transportation systems, industrial processes, and energy infrastructure, have severely affected global energy use. Cities are intensive in global energy demand and bear the main part of carbon emissions. Urban energy consumption and carbon emissions are expected to increase with the growth of urban population and urban economic activities. Improving overall energy sustainability in urban areas is an important way to reduce carbon emissions.

One of the key emerging issues that cities have to contend with is climate change, which has been described as one of the greatest challenges of our time, with adverse impacts capable of undermining the ability of all economies to achieve sustainable development. It is no coincidence that climate change has become a pressing international development agenda simultaneously with urbanization. Due to multiple reasons such as economic growth and lifestyle changes, between 1950 and 2005, the level of urbanization increased from 29% to 49%, while global carbon

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<sup>3</sup> <https://www.un.org/sustainabledevelopment/zh/energy/>

<sup>4</sup> <https://www.un.org/sustainabledevelopment/zh/cities/>

emissions from fossil fuel burning increased by almost 500%. Indeed, scientists have reported that 2015 was the hottest year in history by wide margin, as average temperature for the year was 0.75°C warmer than the global average<sup>5</sup>. This has been attributed to increase in greenhouse emissions caused mainly by the burning of fossil fuels, together with the El Niño weather event which releases immense heat from the Pacific Ocean into the atmosphere.

Facing the huge pressure of global climate change, the United Nations adopted the Paris Agreement on Climate Change of the United Nations Framework Convention at COP21 in 2015, setting ambitious targets for the first time to limit warming to 2°C through efforts. At the same time, Sustainable Development Goal 7 is Ensure access to affordable, reliable, sustainable and modern energy for all, working towards this goal is especially important as it interlinks with other Sustainable Development Goals. Focusing on universal access to energy, increased energy efficiency and the increased use of renewable energy through new economic and job opportunities is crucial to creating more sustainable and inclusive communities and resilience to environmental issues like climate change. However, the challenge is far from being solved and there needs to be more access to clean fuel and technology and more progress needs to be made regarding integrating renewable energy into end-use applications in buildings, transport and industry. Public and private investments in energy also need to be increased and there needs to be more focus on regulatory frameworks and innovative business models to transform the world's energy systems.

As an indispensable supporting system for urban carrier operation, energy system is particularly critical in the sustainable goal of urban development. Whether the energy supply and demand mode of a city is sustainable is the key path to identify whether the energy system of a city is sustainable. According to the two specific goals of APEC Energy Working Group, “To double the share of renewables in the APEC energy mix, including in power generation by 2030; and to reduce APEC’s aggregate energy intensity by 45% from 2005 levels by 2035.”, in order to achieve these goals requires perfect forms of sustainable urban energy system, and vigorously develop the relatively low carbon energy system.

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<sup>5</sup> UN HABITAT (2016), WORLD CITIES REPORT 2016, URBANIZATION AND DEVELOPMENT, Emerging Futures

## **1.2.2 Urban Energy Supply**

Cities are centres of energy consumption, urban areas account for around two-thirds of global final energy use. Meeting these energy needs brings both challenges and opportunities. Renewable energy sources within cities exist. Environmental or geothermal heat may be used for space and water heating in buildings, and the rooftop areas or facades of buildings can be used to produce electricity in solar PV systems or to warm water in solar thermal modules. District heating and cooling (DHC) networks, requiring sufficiently high heat or cooling demand densities to be economic, are an example. Thus, while energy supply sources exist within cities, the options vary and cities must rely on energy imports to meet their total energy needs.

Energy imports such as electricity can come from distant centralised sources or more decentralised local sources on the city periphery. Centralised supply options such as large-scale power plants may provide benefits in term of economies of scale but may require transmission infrastructure. Options close to cities that use local fuel sources reduce the transmission needs, but may result in higher specific generation costs if plant sizes are smaller.

## **1.3 Low-carbon Urban Energy System**

In the global contexts, cities occupy only about 2% of the land area, but they carry 70% of GDP, more than 60% of global energy consumption, 70% of greenhouse gas emissions, and 70% of global waste output<sup>6</sup>. Urban areas can play a decisive role in the transition to a cleaner energy future. Sustainable urban energy systems can improve energy security and resilience while delivering multiple benefits for the environment, human health and economic growth. Shifts to more efficient buildings, transport systems, and industrial processes; lower-carbon energy supplies; and integrated energy systems are critical. Enabling these shifts will require strong urban energy policies and increased co-operation between member economies and local governments.

Urban areas account for the greatest shares of both global population and world economic activity, which are two key drivers of societal energy use. As such, the world's urban areas have substantial influence over global energy demand and energy-related environmental emissions. This influence will continue to strengthen as populations and economies continue to grow and

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<sup>6</sup> <http://habitat3.org/the-new-urban-agenda/>

urbanize. In addition to meeting growing demand for urban energy, many governments face the challenges of providing clean energy access and reducing exposure to harmful air pollution. A transition to more sustainable energy systems can not only meet these challenges but also deliver additional benefits, for example by increasing energy security, improving resilience and fostering innovation.

### **1.3.1 Urban Energy System and Components**

Urban areas differ widely in terms of their population, population density, vintage, economic activities and growth rates, climate and land use, but all depend on energy for the various activities that take place within them. Urban areas themselves are systems of interconnected networks and components, and the ways they produce and use energy is also a system – an urban energy system.

It is necessary to understand the components of urban energy systems to identify possible interactions between them. Breaking down an urban energy system into its components also allows for the classification of urban energy systems into different types, and is the first step to analysing drivers for energy use within a particular urban area or city. While there are many ways of defining the components of urban energy systems, they are defined broadly as buildings (comprised of residential and services buildings), transport (comprised of passenger and freight transport), heat and power, industry, water treatment, waste treatment and agriculture. The characteristics of these components can further vary based on their specific locations within an urban geographical area, ranging from high-density urban cores to lower-density peri-urban areas.

### **1.3.2 Definition of Sustainable Urban Low-carbon Energy Systems**

Sustainable urban energy systems are broadly defined as meeting demand for urban energy services while 1) protecting the environment (including mitigating climate change, reducing air pollution and avoiding natural resource depletion); 2) improving the resilience of urban energy infrastructure to external shocks; and 3) achieving economic and human development goals. This research focuses on sustainable urban energy systems that target low carbon. In addition to meeting the requirements of sustainable urban energy systems, such systems must also aim to reduce carbon emissions. The focus of this research is relatively low-carbon scenarios, not absolute low-carbon or zero-carbon energy systems.

### 1.3.3 Energy Supply and Use of Sustainable Urban Low-carbon Energy System

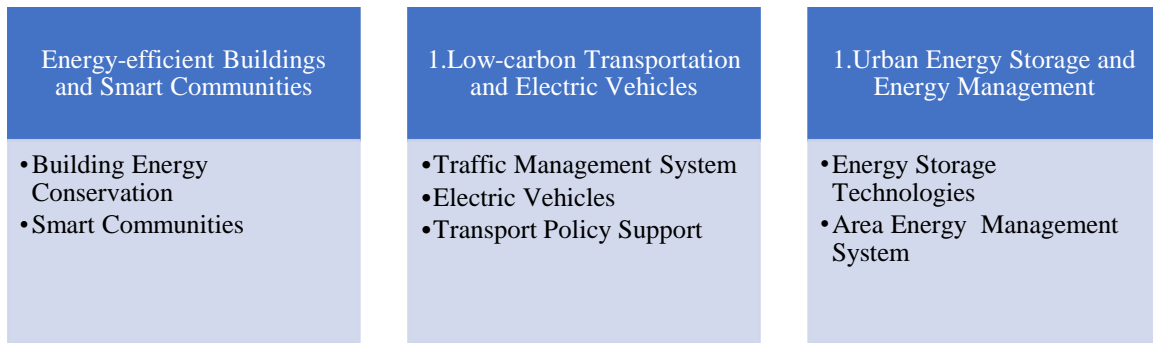
This study analyzes and collects excellent practices from the six dimensions of the energy supply and energy use of a sustainable urban low-carbon energy system. As shown in the list, the energy supply of the sustainable urban low-carbon energy system: 1) Clean Utilization of Fossil Energy, 2) Utilization of New and Renewable Energy, 3) Integrated Energy Network of Cities; energy use of sustainable urban low-carbon energy system: 1) Energy-efficient Buildings and Smart Communities, 2) Low-carbon Transportation and Electric Vehicles, and 3) Urban Energy Storage and Energy Management. From these six urban energy system dimensions, 19 key technical elements are extracted, as shown in the following list.

#### Energy supply of the sustainable urban low-carbon energy system :

<b>1.Clean Utilization of Fossil Energy</b> <ul style="list-style-type: none"><li>•Clean Coal Utilization</li><li>•Natural Gas</li></ul>	<b>1.New and Renewable Energy</b> <ul style="list-style-type: none"><li>•Solar</li><li>•Wind Energy</li><li>•Hydro Power</li><li>•Ocean Energy</li><li>•Geothermal Energy</li><li>•Hydrogen Energy</li><li>•Biomass Energy</li></ul>	<b>1.Integrated Energy Network of Cities</b> <ul style="list-style-type: none"><li>•Smart Grid</li><li>•"Internet+" Smart Energy</li><li>•Interconnection Network</li></ul>
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Urban energy supply systems can be made sustainable by using clean energy and investing in infrastructure to provide cleaner, safer electricity, heat and fuel, and by using smart grids to maximize integration opportunities.

#### Energy use of sustainable urban low-carbon energy system :



Rapid urban development presents challenges and opportunities for the stock of energy-efficient residential and commercial buildings, including new building energy standards and deep energy retrofitting of existing buildings, especially in developing economies. Cities can use policies to significantly reduce building energy demand and avoid inefficient urban built environments. Facing the growing demand for urban transportation, we can advocate the use of public transportation and support the popularization of more efficient low-carbon vehicles. Policymakers can implement a wide range of measures to achieve this transition.

## **Chapter 2: Urban Energy Supply based on Local Conditions and Best Practices**

### **2.1 Clean Utilization of Fossil Energy**

Energy is the foundation and power of modernization. The supply of energy is closely related to development and security of member economies. With the rapid development of the global economy, the demand for energy is also increasing day by day, the contradiction of energy constraints is becoming increasingly prominent, and the energy security situation is becoming increasingly severe. The large consumption of fossil energy has brought tremendous pressure on the control of environmental pollution. At the same time, APEC economies have increasingly borne responsibilities in global climate change. With the adjustment of the energy structure, the slowdown in the growth of fossil energy demand will become a trend, but for most economies, the status of fossil energy as the main energy source is difficult to change in the short term. Therefore, promoting the clean and efficient use of fossil energy is one of the solutions to resolve many contradictions. Research and practice are combined to summarize the experience of clean utilization of traditional fossil energy. Taking green and low-carbon as the guide to promote the technological progress and industrial upgrading of the use of fossil energy, further improve the conversion and utilization efficiency of fossil energy, and significantly reduce the level of pollutant emissions.

#### **2.1.1 Clean and Efficient Coal-fired Power Generation**

At present, the major clean and efficient coal-fired power generation technologies in the world include high-parameter, large-capacity supercritical and ultra-supercritical coal-fired power generation technologies, circulating fluidized bed power generation technologies, combined heat and power technologies, and so on. And also, carbon capture and storage (CCS) technology refers to the process of separating CO<sub>2</sub> from industrial or related emission sources, transporting it to the storage location, and isolating it from the atmosphere for a long time. This technology is considered to be a feasible way to reduce greenhouse gas emissions on a large scale and slow down global warming in the future.

##### **1. Supercritical and Ultra-supercritical Coal-fired Power Generation**



The so-called supercritical power generation means that the main steam pressure of coal-fired generating units reaches about 24MPa and the main steam / reheated steam temperature reaches 538-560°C. According to the parameters of ultra-supercritical units currently in operation in the world, it is generally considered that the main steam pressure exceeds 25MPa and the main steam temperature exceeds 580°C is ultra-supercritical. At present, the development of ultra-supercritical units has entered a mature and practical stage, and the high-efficiency coal-fired power generation technology represented by secondary reheating has also been further developed. The world's supercritical and above generating units have been put into operation mainly in China, the United States, Japan, Russia and other economies and regions.

The ultra-supercritical units have been put into operation in China, the United States, Japan, and other economies. By the end of 2017, China had 103 ultra-supercritical units of 1,000mw. At present, the parameters of ultra-supercritical units that have been put into commercial operation can reach 28Mpa(a)/600°C/620°C. Figure 2-1 shows the second phase of Taizhou Power Plant. The project uses ultra-supercritical secondary reheat technology. The designed power generation efficiency reaches 47.92%, the coal consumption for power generation is 256.28g/kWh, and the steam parameters are 31MPa/600°C/610°C/610°C.



**Figure 2- 1 Taizhou Power Plant and the second-stage secondary reheat turbine**

## **2. Circulating Fluidized Bed (CFB) Power Generation**

CFB power generation is a power generation technology that uses a circulating fluidized bed combustion method to heat a working fluid to generate main steam to drive a steam turbine. CFB power generation technology has the advantages of fuel adaptability, large load adjustment range, and easy comprehensive utilization of ash and slag. It is an effective way for large-scale utilization

of inferior fuels. Circulating fluidized bed technology has the main advantages of fuel adaptability, large load adjustment range, and easy handling of ash and slag. It is one of the important technologies for clean coal combustion power generation. In the past 40 years, the technology of circulating fluidized bed has developed rapidly, and it is increasingly widely used worldwide.

As shown in Figure 2-2, in 2012, the supercritical circulating fluidized bed boiler unit (600MW) with the largest single unit capacity in the world was put into operation in China Baima demonstration power station, which is the circulating fluidized bed boiler with the largest single unit capacity in the world. By the end of 2017, China's CFB generating capacity had exceeded 100 million kw, making it the world's largest economy in terms of the number and total capacity of CFB boilers.



**Figure 2- 2 Baima 600MW circulating fluidized bed boiler**

### **3. Combined Heat and Power Generation**

Combined heat and power generation is a technology that uses different types of fossil energy and renewable energy to achieve combined power and heat production in a unified operation. Replacing the distributed, small-capacity coal-fired boilers with heat from cogeneration units can improve energy efficiency while reducing pollutant emissions. Cogeneration has the characteristics of high energy efficiency, and has been widely used in industrial production and people's livelihood. It has the comprehensive benefits of significant energy conservation and environmental improvement.

According to statistics, in 2016, the combined installed capacity of the combined heat and power in the Asia-Pacific region, mainly China, India and Japan, accounted for the largest proportion, approximately 46%. The Asia-Pacific region is a major growth market for cogeneration. At present, combined heat and power has become a public welfare infrastructure for urban pollution control and improvement of people's quality of life in terms of heating for people's livelihood. The combined heat and power generation method provides centralized heating for people's livelihood or industrial parks, which can replace a large number of scattered, inefficient small boilers in the heating area to greatly reduce pollutant emissions and effectively improve regional environmental quality.

## **2.1.2 Natural Gas Utilization**

### **1. Natural Gas Power Generation**

Natural gas is used as the main fuel to drive gas turbines, microturbines, or internal combustion engine generators to run gas-fired power generation equipment. The generated electricity supplies the power needs of users. The waste heat generated from the system power generation is used for heating and cooling to users through waste heat recovery and utilization equipment (waste heat boiler or waste heat direct combustion engine, etc.). In this way, the primary energy utilization rate of the entire system is greatly improved, and the cascade utilization of energy is realized. It can also provide grid-connected power as a complementary energy source, and the economic benefits and efficiency of the entire system will increase accordingly. And also, carbon capture and storage (CCS) technology is considered to be a feasible way to reduce greenhouse gas emissions in the future.



**Figure 2- 3 Shanghai Disney Resort natural gas distributed energy station**



**Figure 2- 4 Gas generation station, New York City, USA**

As shown in Figure 2-3, the Shanghai Disney Resort natural gas distributed energy station. The main equipment of the project uses five general electric JMS624GS-N.L gas turbine generator sets with a power generation capacity of 4035kW and a power generation efficiency of 45.4%<sup>7</sup>. Figure 2-4 shows the natural gas generation station of the Whole Food Supermarket in New York City, USA. The core of the integrated energy system is a 157 kW natural gas generation system, which provides heating and chilled water throughout the year through cogeneration of cold, heat and power, and keeps the store running in the event of a grid failure<sup>8</sup>.

## **2.2 Utilization of New and Renewable Energy**

“To double the share of renewables in the APEC energy mix, including in power generation by 2030” which is one of the two specific goals of the APEC Energy Working Group, indicating the important position of new and renewable energy in energy utilization of APEC region. Combining research with practice, the experience of new and renewable energy utilization is summarized. For the regions with rich renewable energy resources such as ocean energy, wind energy, solar energy and water energy, the proportion of new energy and renewable energy in urban energy consumption should be increased, the dependence of urban development on fossil energy should be reduced, and the energy structure should be optimized, so as to improve the sustainable development capacity of cities.

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<sup>7</sup> [https://www.c40.org/case\\_studies/shanghai-international-tourism-and-resorts-zone-central-gas-distributed-energy-station](https://www.c40.org/case_studies/shanghai-international-tourism-and-resorts-zone-central-gas-distributed-energy-station)

<sup>8</sup> IGU. CASE STUDIES ENABLING CLEAN ENERGIES, 2016.

## **2.2.1 Solar Energy Utilization**

### **1. Centralized Photovoltaic**

Centralized large-scale grid-connected photovoltaic power generation refers to the technical method of building concentrated photovoltaic power stations in areas rich in solar energy resources, forming centralized power stations and connecting them to the power grid for power supply. The installation of concentrated photovoltaic power stations has a large overall capacity and covers a relatively large area. They can be built in remote and empty places with few people. Photovoltaic power stations generally require professionals to maintain operation and maintenance and corresponding auxiliary facilities. In general, the stability of centralized photovoltaic output will be enhanced, the operation mode will be more flexible, and it is convenient for centralized dispatching and unified management. The intensity of participating in the regulation of power grid will be enhanced, which is easy to form scale effect. 20MWp grid-connected photovoltaic power plant project has an installed capacity of 20MW in Qinghai, China, and was formally connected to the grid for power generation in February 2013<sup>9</sup>. French renewable energy company Neoen's 189MW Coleambally solar project in New South Wales, Australia has officially entered commercial operations. The project includes 567,800 solar modules that could produce more than 39 billion MWH of renewable energy annually, enough to power more than 65,000 New South Wales homes<sup>10</sup>.

### **2. Distributed Photovoltaic**

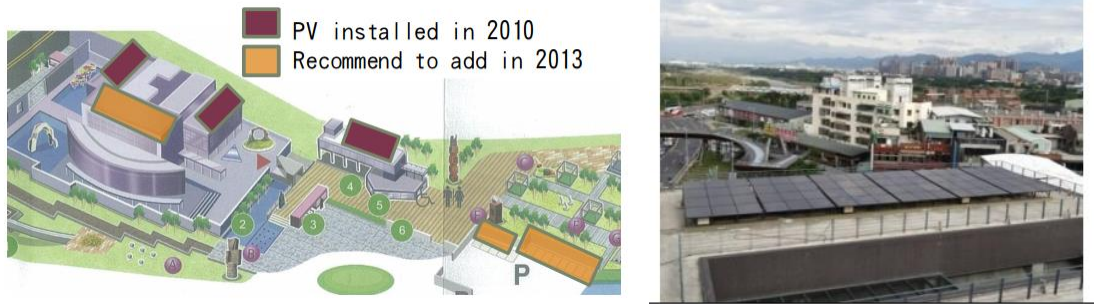
Distributed photovoltaic power generation mainly refers to photovoltaic power generation facilities that are constructed and operated at or near the user's site, and are mainly used by the user side for self-use and with excess electricity connected to the grid. Distributed photovoltaic power generation is generally built on the roofs, plant roofs and vegetable greenhouses to make full use of various spaces. The outstanding feature lies in the geographical dispersion of location, which is smaller and more flexible than centralized.

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<sup>9</sup> [http://www.hopewind.com/20mwp\\_n61](http://www.hopewind.com/20mwp_n61)

<sup>10</sup> <https://www.nengapp.com/news/detail/1286656>





**Figure 2- 5 Distributed Photovoltaic, Chinese Taipei**

In Yingge District, Chinese Taipei, the installed capacity of photovoltaic panels was 36.06kWp in 2010. In 2013, more photovoltaics were planned to be installed on the roofs of car / motorcycle parking lots and ceramic museums (Figure 2-5). The total capacity of renewable energy facilities of Yingge Ceramic Museum will reach 70kWp, and the total power generation is expected to be 63,000kWh / year<sup>11</sup>.

### **3. Solar Thermal**

Solar thermal power generation uses solar energy as a heat source to serve as a power generation system, low-density solar energy is gathered into high-density energy through a concentrator, and solar energy is converted into heat through a heat transfer medium, and performing work through thermal cycling to convert to electrical energy. The main forms include: trough-type CSP technology, tower-type CSP, dish-type CSP and so on.

### **4. Direct Solar Energy Utilization**

Solar energy can be directly converted into thermal energy by flat-plate collectors, heat pumps, etc. Common solar heat utilization methods include solar water heaters, solar heating, solar heat pumps, solar air collectors, and so on.

## **2.2.2 Wind Energy Utilization**

### **1. Wind Power**

<sup>11</sup> <https://www.esci-ksp.org/wp/wp-content/uploads/formidable/New-Taipai-City-Yingge.pdf>

Wind turbines are divided into horizontal-axis wind turbines and vertical-axis wind turbines according to the installation form of the wind turbine shaft. Among them, horizontal-axis wind turbines are the most used form in the world. Currently, wind power generation technologies mainly include onshore wind power generation technology and offshore wind power generation technology.



**Figure 2- 6 Progreso Wind Farm    Figure 2- 7 Otongrui Wind Farm    Figure 2- 8 Donghai Wind Farm**



**Figure 2- 9 Hornsdale Wind Farm**

In 2018, the Progreso Wind Farm in Yucatan Peninsula, Mexico passed the test smoothly (Figure 2-6). There were 28 double-fed wind turbines of 2.5MW on the project site. The grid converters have been operating stably to date<sup>12</sup>. Figure 2-7 shows Otongrui Wind Farm in Hokkaido, Japan. The 100MW offshore wind farm of Shanghai Donghai Bridge is China's first offshore wind power demonstration project (Figure 2-8), which were connected to the grid for

<sup>12</sup> [http://www.hopewind.com/\\_n375](http://www.hopewind.com/_n375)

power generation in June 2010, and passed high-standard completion acceptance in March 2011. As shown in Figure 2-9, the Hornsdale Wind Farm in South Australia has an installed capacity of 309MW<sup>13</sup>.

## **2. Wind Energy Heating Technology**

Wind energy heating technology is a technical method to convert wind energy into thermal energy. The most important of wind energy is a kind of mechanical energy. In addition to the use of mechanical energy to drive generators to generate electricity, it is also a typical idea for heating. At present, the main wind energy heating technologies mainly include three aspects: wind power generation heating, fan stirring heating and wind compressed air heating.

Wind energy generation heating technology heats up the electricity generated by wind energy through the heating equipment containing resistance wire, thus obtaining heat energy; Alternatively, a magnetizing coil is installed between the outer edge of the rotor and the stator to generate eddy current and generate heating. Wind energy stirring and heating is to stir the liquid filled in the container on the rotating shaft of the fan. The vortex formed after stirring can slowly heat the liquid to obtain heat. The efficiency of such direct stirring heating is high. Wind energy compressed air heating uses a fan to drive a centrifugal compressor to perform adiabatic compression of air. This method of compressed air will generate a part of the thermal energy during the compression process. At the same time, the mechanical energy stored by the compressed air can be further converted to generate thermal energy.

### **2.2.3 Hydro Power Utilization**

#### **1. Hydropower**

Hydropower is the use of rivers, lakes, and other high-potential energy flows to the low. The primary energy of hydropower is the potential energy of water. The basic principle is to use the water level drop to convert the potential energy contained in it into the kinetic energy of the turbine, and then use the turbine as the driving force to produce electricity with the turbine generator. Hydropower can be classified according to the method of centralized drop: dam-type hydropower

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<sup>13</sup> <https://www.apricum-group.com/strong-tailwinds-ahead-case-wind-plus-energy-storage/>



plant, diversion hydropower plant, hybrid hydropower plant, tidal hydropower plant and pumped storage power plant; classification based on the degree of runoff regulation mainly includes: unregulated hydropower plant and regulated hydropower plants. The features of this technology include high hydropower generation efficiency, low power generation cost, fast unit startup and easy adjustment.

The Three Gorges Hydropower Station is the largest hydropower station in the world and the largest construction project ever built in China (Figure 2-10). The Three Gorges Hydropower Station has a dam elevation of 185 meters, a water storage elevation of 175 meters, a reservoir length of 2335 meters, and 32 hydropower units with a single unit capacity of 700,000 kW. The Hulu Hydropower Project in Malaysia is located on the Puah River northwest of Kenyair Lake Reservoir in Terengganu (Figure 2-11), 460 kilometers from the capital Kuala Lumpur. The project is a diversion type power station with an installed capacity of 250MW ( $2 \times 125$ MW), a dam height of 78 meters and a dam length of 800 meters. The Indonesia Semangka Hydropower Station is located in South Sumatra, Indonesia (Figure 2-12). It uses the Semangka River to generate electricity. The power station includes two mixed-flow turbines with a total output of 56.6MW, two single-unit capacity 33.3MVA generators and two 33 / 40MVA generator transformer.



**Figure 2- 10 Three Gorges Hydropower Station Figure 2- 11 Hulu Hydropower Figure 2- 12 Semangka Hydropower Station**

## **2. Pumped Energy Storage**

Pumped energy storage uses the power at the time of low load in the power grid to pump water from the lower reservoir to the upper reservoir for energy storage, and then discharge the water back to the lower reservoir for power generation. Pumped-storage power stations use energy conversion to convert trough power to peak power. They do not produce electricity by themselves, but just redistribute the electricity in the grid. When the load of the power system is low, use the

remaining power of the low valley to pump the water from the lower reservoir to the upper reservoir, and save it in the form of the potential energy of the water. Converted to electrical energy and sent back to the grid, completing a cycle, the water level of the upper reservoir rises from the lowest level of power generation to the normal storage level, and then drops from the normal storage level to the lowest level of power generation, and then rise from the lowest water level to the normal storage level again.

## **2.2.4 Ocean Energy Utilization**

Tidal power generation technology is currently the most mature ocean energy development technology. Despite the high investment required, the life of tidal power systems is also very long. It is generally believed that the design life of tidal energy power generation systems is higher than 20 years, and can even reach the level of ordinary hydroelectric power generation facilities. The traditional way to use tidal energy is to build a dam near the estuary to form a closed harbor. At high tide, the seawater flows into the dam to drive the turbine to generate electricity. While at low tide, the seawater flows out of the dam and pushes the turbine to continue to generate electricity.

## **2.2.5 Geothermal Energy Utilization**

### **1. Geothermal Steam Power Generation**

Geothermal steam power generation systems use geothermal steam to drive turbines to generate electricity. This mature technology, safe and reliable operation, is the main form of geothermal power generation. The double-cycle power generation system, also known as the organic working medium Rankine circulation system, takes low-boiling organic matter as the working medium. The working medium in the flow system obtains heat from the geothermal fluid and generate organic steam, which in turn drives the turbine and drives the generator to generate electricity. The full-flow power generation system sends all the fluid at the geothermal wellhead, including all steam, hot water, non-condensable gases and chemical substances, directly into the whole without treatment. Expansion work is performed in the fluid power machinery, and then discharged or collected in the condenser. The dry-hot rock power generation system, which uses the idea of underground dry-hot rock to generate electricity, injects cold water into the dry-hot rock from one well and takes out steam from the heated rock from another well.

The Yangbajing project in China, uses the new technology of screw expansion power generating units (Figure 2-13) to install geothermal generating units in deep wells for gas generation. The annual power generation of a single machine reaches 6-7 million kWh, which directly saves about 3,500 tons of standard coal. The project marks that Chinese companies have taken the lead in the field of geothermal power generation.



**Figure 2- 13 The Yangbajing project in China**

## **2. Geothermal Heat Pump Utilization**

The thermodynamic cycle is one of the ways that energy is converted, and it has to satisfy the laws of thermodynamics. The cycle of converting thermal energy into mechanical energy is a positive cycle, and the transfer of thermal energy with mechanical energy is a reverse cycle. Both heat pumps and refrigeration cycles are reverse cycles. The heat obtained by the heat pump cycle is the heat transferred from the cold source and the mechanical energy (or electrical energy) consumed, which is far greater than the heat obtained by the direct conversion of mechanical energy (or electrical energy). Ground source heat pump systems are completely unconstrained by the ambient temperature, mainly including groundwater heat pumps, river and lake water source heat pumps, and soil source heat pumps.

The ground source heat pump system project of the Shandong University Museum in Qingdao, China, is located in the Qingdao campus of Shandong University. The total construction area is about 40,000 square meters, one underground and six floors above the ground, and the building height is about 35.4 meters. The ground source heat pump bears the cooling load of the air

conditioner about 2653kW, and the total heat load is about 2079kW. The machine room is located on the ground floor. The outdoor buried tube heat exchanger is arranged in the green belt and sports field on the east, west, and south sides of the outdoor site of the project<sup>14</sup>.

## 2.2.6 Biomass Energy Utilization

### 1. Biomass Biogas and Ethanol

Biomass-based biogas, mainly uses organic waste, straw, water, human and animal manure, and other biomass. Under anaerobic conditions, it is converted to methane by facultative anaerobic bacteria and obligate anaerobic bacteria for life and production. The production of ethanol from biomass mainly uses cellulose, hemicellulose, lignin, sugars, etc. in biomass, and uses microbial fermentation technology to form ethanol, which replaces petroleum for use to a certain extent.

### 2. Biomass Power Generation



**Figure 2- 14 Coconut Power Plant, Thailand    Figure 2- 15 Veracruz Sugar Power Plant, Mexico**

Biomass power generation is the use of biomass energy generation, is a renewable energy generation, including agricultural and forestry waste direct combustion power generation, agricultural and forestry waste gasification power generation, garbage incineration power generation, landfill gas power generation, methane power generation. As shown in Figure 2-14, the coconut residue power plant in Samut Sahun Province, Makhach, Thailand has an output of 9.9MW and an efficiency of 90%. The power plant uses coconut residue as fuel<sup>15</sup>. As shown in

<sup>14</sup> <http://www.wofuny.com/Article/dyrbalssdd.html>

<sup>15</sup> DP Clean Tech Group, [www.dpcleantech.com](http://www.dpcleantech.com).

Figure 2-15, the Mexican Veracruz Sugar Power Plant is located in Tres Bayes. The power output of the power plant is 40MW. The power plant provides steam and electricity to the sugar plant, and the remaining power is transmitted to the owners through the power grid<sup>16</sup>. The Bentong Biomass Power Plant in Pahang, Malaysia uses the remaining wood chips from the accessory furniture plant and the residues extracted from palm oil as fuel<sup>17</sup>.

## **2.3 Urban Integrated Energy Network**

Urban integrated energy network is an important strategic support to promote the energy revolution. It is of great significance to improve the comprehensive energy efficiency, promote the opening and upgrading of the energy market, and enhance the level of international energy cooperation. The construction of "Internet +" smart energy has become an important part of the development of comprehensive energy system, and the multi-energy complementary project is an important part of the construction of "Internet +" smart energy. The development of an integrated energy system can help improve energy efficiency, reduce environmental pollution, develop smart grids, strengthen energy security, optimize the energy mix, and provide effective technical means to significantly reduce energy consumption in the short term.

### **2.3.1 Smart Grid**

Smart grid is the intelligence of the power grid, also called "Grid 2.0". It is based on an integrated, high-speed two-way communication network. It uses advanced sensing and measurement technology, advanced equipment technology, and advanced control methods. And the application of advanced decision support system technology to achieve the goals of reliable, safe, economic, efficient, environmentally friendly and safe use of the power grid. Its main characteristics include self-healing, motivating and protecting users, resisting attacks, and providing to meet the needs of user's power quality, allowing access to various forms of power generation, starting the electricity market and optimizing the efficient operation of assets.

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<sup>16</sup> TGM, 2016, [www.grupotgm.com.br](http://www.grupotgm.com.br); COWI A/S, [www.cowi.com](http://www.cowi.com).

<sup>17</sup> International Finance Corporation. *Converting Biomass to Energy*, 2017.

## **2.3.2 Multi-energy Complementary System**

"Multiple energy complementary system" is an evolutionary form of energy supply mode. It guarantees a safe supply of energy and covers a variety of energy types. It can provide diversified energy products such as electricity, heat, and cold to meet diverse energy supply and demand models coupling and integrated energy supply mode to achieve maximum benefits.

The multi-energy complementary system includes two modes: one is a user-side multi-energy complementary model for end-users with multiple energy needs such as electricity, heat, cold, and gas; the second is the power-side multi-energy complementary mode for the combination of wind power, solar energy, hydropower, coal, natural gas and other resources in large-scale comprehensive energy bases.

### **1. Terminal Integrated Energy Supply System**

GCL energy center "Six-in-One" multi-distributed renewable energy complementary project is the largest application case of micro-energy network in China. The project is constructed and implemented with GCL energy center, the headquarters base of GCL group in China, located in Suzhou, Jiangsu Province, China, as the carrier, as shown in Figure 2-16 and 2-17. Through the implementation of the "Six-in-One" distributed renewable energy complementary project, the first and second phase photovoltaic power generation system can provide 808kW of electricity, and the natural gas distributed heat, cold and electricity triple supply system can provide 400kW of electricity and 400kW of heating/cooling energy. The second phase ground source heat pump system can provide 5000kW of heating/cooling energy. The breeze power generation system can provide 60kW of electricity. At the same time, it is equipped with a 200kW energy storage system that regulates the stability of the entire micro-energy network. The self-supply rate of the energy center exceeds 50% (the shortfall is supplemented by the municipal power supply), and the energy saving of the entire building reaches more than 30%<sup>18</sup>.

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<sup>18</sup> Project information is provided by GCL Intelligent Co., Ltd.





Figure 2- 16 "Six-in-One" distribution diagram

Figure 2- 17 GCL Energy Center Phase I & II

## 2. Multi-energy Complementary System

Dongfushan Island is the easternmost inhabited island in the eastern part of China's coast, 45km away from Shenjiamen Town, Putuo District, Zhoushan, Zhejiang Province. There are about 300 permanent residents throughout the island. The comprehensive demonstration project of Dongfushan Island's scenic diesel storage seawater desalination belongs to the island micro-grid power generation system. The project aims to solve the local military and civilian's power and water supply difficulties, and aims to use the island's renewable energy reasonably and efficiently. The power supply mode is supplemented by diesel power. The project covers an area of about 14.7 acres, with a total installed capacity of 510kW, of which renewable energy installed capacity is 310kW, and the project is equipped with 7 wind turbines with a single capacity of 30kW, a 100kW photovoltaic power generation system, a 960kWh energy storage battery, and a 300kVA optical storage integrated bidirectional Converter, a 200kW diesel generator and a 50t/d desalination system. The project site photos are shown in Figure 2-18. The total investment of the project is 23 million RMB.



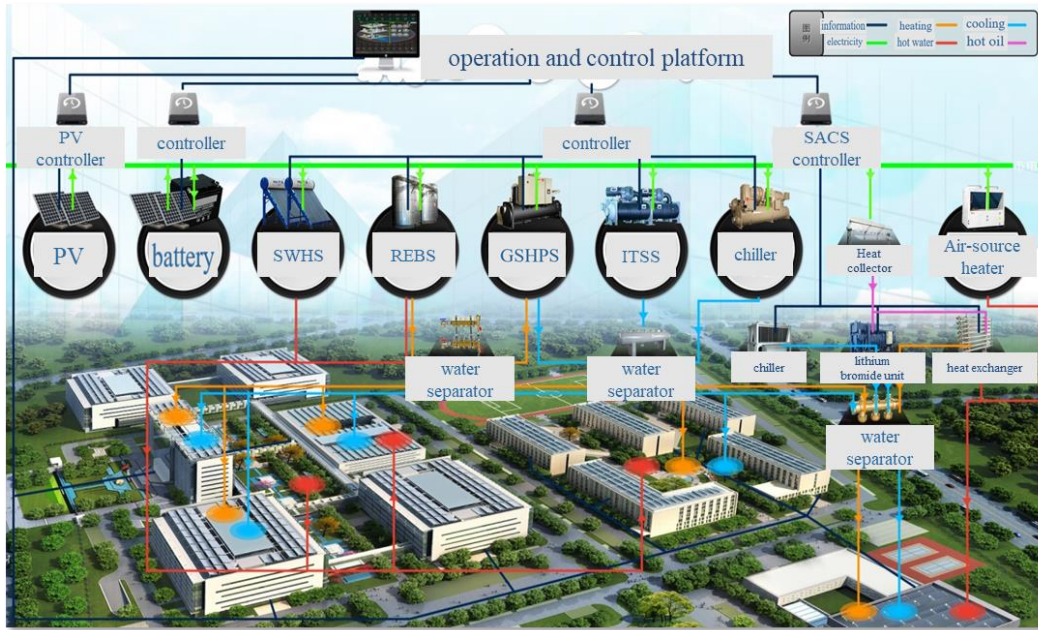
**Figure 2- 18 Dongfushan Island Demonstration Project Site**

### **2.3.3 Integrated Energy System**

Integrated energy system refers to the integrated system of energy production, supply and marketing formed through organic coordination and optimization of energy generation, transmission and distribution (energy supply network), conversion, storage, consumption and other links in the process of planning, construction and operation. The purpose of building a social integrated energy system is to effectively improve the efficiency of the comprehensive utilization of social energy, to achieve a sustainable supply of social energy, and to improve the flexibility,



security, economy and self-healing ability of the social energy supply system. According to incomplete statistics, at least 70 economies in the world have carried out research on integrated energy system technology<sup>19</sup>, with the aim of promoting sustainable supply of energy in the future. There is no doubt that the technology related to integrated energy system will become an important technical commanding point and technical growth point in the international energy field and one of the important technological development directions of the energy industry.



**Figure 2- 19 Composition of Smart Energy Microgrid System, Tianjin, China**

The State Grid Corporation North Customer Service Center is located by Dongli Lake in Dongli District, Tianjin, China, with a total construction area of 142,800 square meters. As a large-scale park integrating production, office and living, the northern park has already realized the construction of a green composite energy network and smart service-oriented innovation park construction, and obtained green building logo certification. Relying on the key technologies of the park's smart energy microgrid, a comprehensive coordination of a variety of energy sources including “electricity, cooling, heating, and hot water” has been successfully established in the northern customer service center of the State Grid Corporation. The supply of the park's smart energy microgrid project has realized the large-scale and efficient application of renewable energy

<sup>19</sup> European Commission. Intelligent energy-Europe: For a sustainable future [EB /OL] .  
<http://ec.europa.eu/energy/intelligent>.

such as solar energy, air thermal energy and geothermal energy in the park. The energy facilities of this project include ground source heat pumps, ice storage equipment, regenerative electric boilers, solar hot water systems, photovoltaic systems, power distribution networks, operation control platforms, etc. The total construction investment is 187.017 million RMB. The average annual electricity cost savings of the project is 8.115 million RMB, the building energy saving rate reaches 68%, renewable energy provides 90% cooling capacity, 93.2% heating power, and photovoltaic power generation accounts for 9.5%. Figure 2-19 shows the composition of the smart energy microgrid system of the North Customer Service Center<sup>20</sup>.

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<sup>20</sup> Project information is provided by State Grid Corporation of China.

## **Chapter 3: Low-carbon and efficient Urban Energy Use and Best Practices**

### **3.1 Energy-efficient Buildings and Smart Communities**

The rapid development of cities has brought opportunities and challenges for energy-efficient residential and commercial buildings, including energy efficiency standards for new buildings and deep energy retrofits for existing buildings. Among them, due to the inconsistent building standards in developing economies and the age of buildings, particular attention needs to be paid to their energy use and renovation. By analyzing the energy demand of urban buildings and summarizing the energy-saving technologies of urban buildings, the active and passive combination can reduce the energy consumption of buildings. In winter, the building can make full use of solar radiation to generate heat, reducing the heat loss of the maintenance structure. In summer, use natural ventilation to reduce cooling energy consumption. At the same time, the development of zero-energy, near-zero and net-zero energy buildings will provide a carrier for building energy-saving technologies. Cities, as a complex of energy consumption, provide a very important opportunity to enhance the integration of energy-efficient buildings and regional low-carbon energy systems, and promote the development of smart communities. The smart community integrates the overall cooling, heating, and electrical loads of the building complex with energy dynamic big data, will monitor the energy usage of each system at any time by combining the Internet of Things, mobile Internet, cloud computing, automatic control and other technologies, so as to realize the monitoring of energy nodes, remote control of electrical equipment and analysis of energy use.

#### **3.1.1 Building Energy Conservation Technology**

##### **1. Introduction to Building Energy Conservation Technology**

Energy flows from urban energy suppliers to buildings (consumers), and then consumes energy for human activities in the building through cooling, heating, lighting, socket loads, etc. In the field of energy-efficient buildings, carbon emission reduction requires efficient measures at both the energy supply stage and the energy consumption stage, with priority given to load reduction, utilization of natural and renewable sources of energy, and adoption of efficient

equipment and management systems. The means to reduce the load mainly include the use of building insulation / cold materials with high air tightness and insulation, installation of shading systems, low-e glass, roof greening, lighting planning and energy saving behavior. The means of using natural energy include natural ventilation, daylighting systems, photovoltaic cells, solar collectors, geothermal heat pumps, etc. The means of efficient equipment and management systems include chillers, heat recovery, air and water economizers, heat storage systems, BEMS, etc.

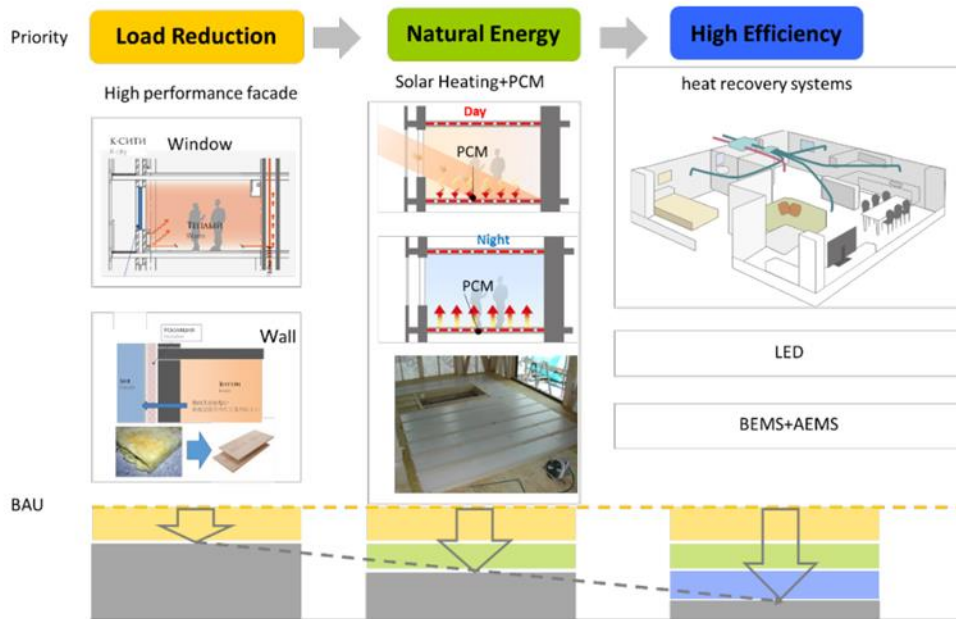
## **2. Typical case analysis of Building Energy Conservation Technology**

### **(1) Energy-efficient buildings in Krasnoyarsk, Russia**

Due to the long cold season and inefficient heating equipment, heating energy consumption is the most important component of building energy consumption in Russia. Comprehensive energy-efficient buildings should consider both demand-side and supply-side low-carbon energy saving technologies, including load reduction, efficient use of natural energy and efficient equipment introduction (Figure 3-1). The first step in energy conservation is load reduction, which can be controlled through high-performance building enclosures, including insulation, sun reflection and shading, and curtain wall engineering. Building insulation is also the foundation and the most important guarantee for building energy conservation in cold areas. The energy performance of buildings usually depends on the thickness of the insulation material, and internal and external insulation materials are also needed when necessary. Sun reflection and shading is also a way to reduce the load. Considering that buildings in cold areas have high thermal insulation and may face overheating in summer, it is possible to reduce the summer heat load by shading the sun, and also reduce the energy consumption of building lighting by indirectly utilizing the sun. In addition, the airflow window can be exposed to the thermal environment near the window, which can avoid the rapid heat transfer inside and outside the building through the vertical airflow layer inside the double glazing, as well as avoid cold wind and prevent dew condensation<sup>21</sup>.

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<sup>21</sup> [https://aperc.ieej.or.jp/publications/reports/lcmt/LCMT\\_Phase\\_7\\_Policy\\_Review\\_final\\_report.pdf](https://aperc.ieej.or.jp/publications/reports/lcmt/LCMT_Phase_7_Policy_Review_final_report.pdf)



**Figure 3- 1 Energy-efficient Building Plan in Krasnoyarsk, Russia**

**(2) Bullitt Center -Zero Carbon Emissions Commercial Building, Seattle, USA**

The Bullitt Center is a commercial building certified by the Living Building Challenge, a project designed to increase building energy efficiency. The Bullitt Center has installed an energy consumption monitoring system, including energy and water, that allows managers to make timely assessments of the building's energy efficiency from real-time monitoring data on the dashboard<sup>22</sup>.

In addition, the Bullitt Center has designed a series of measures to achieve the goal of "zero-carbon commercial buildings" (Figure 3-2): A 14303 square foot photovoltaic roof and external wall could provide enough solar energy for the whole building. An underground reservoir capable of holding 56,000 gallons was set up to collect and reuse rainwater; a 400-foot geothermal wall and a six-story composting toilet were constructed. All the rooms in the building have 30-foot wide windows, so the interior of the building can reach 82% natural daylight, providing fresh air and plenty of light for the staff. After two years of operation, the Bullitt Center generates 60% more energy than it consumes, which means that tenants do not need to pay for energy consumption and truly achieve "zero carbon emissions in buildings."

<sup>22</sup> <https://millerhull.com/project/bullitt-center/>

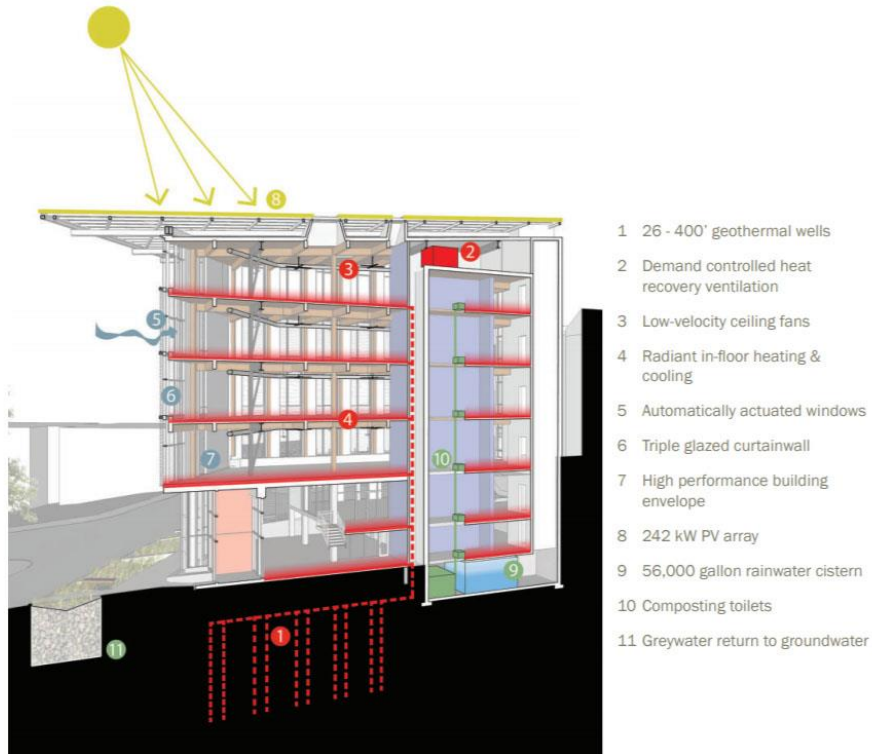


Figure 3- 2 Schematic diagram of Bullitt Center

### 3.1.2 Smart Communities for Energy-efficient Buildings and Regional Energy Integration

#### 1. Introduction to Smart Communities

Smart community refers to a new concept of community management and a new model of social management innovation in the new situation. Taking full advantage of the Internet and the Internet of Things, it involves many areas such as smart buildings, smart homes, road network monitoring, personal health and digital life, and gives full play to the advantages of the developed information and communication (ICT) industry, excellent telecommunications business, and information infrastructure.

Through the construction of ICT infrastructure, certification, security and other platforms and demonstration projects, people will accelerate the development of key industrial technologies, build a smart environment for community development, and form a new mode of life, industrial development and social management based on mass information and intelligent filtering, so as to build a new community form for the future.

## 2. Typical case analysis of Smart Communities

### (1) Kesennuma Smart Community, Japan

As a model project promoted by Japanese smart communities, the main function of Kesennuma smart community is to perform intelligent energy management on energy consumption facilities of marine product processing enterprises (Figure 3-3). Businesses purchase electricity from new PPS for use by power-consuming facilities, and communities use the Community Energy Management System (CEMS) and Enterprise Energy Management System (EEMS) to reduce and transfer peak power in industrial parks, where EV and PHV are used as peak and emergency batteries. Kesennuma smart community provides energy management and microgrids for the industrial park, and performs peak cooling, peak transfer, and emergency demand response control for the entire area, which can reduce the cost of community energy use and CO<sub>2</sub> emissions.

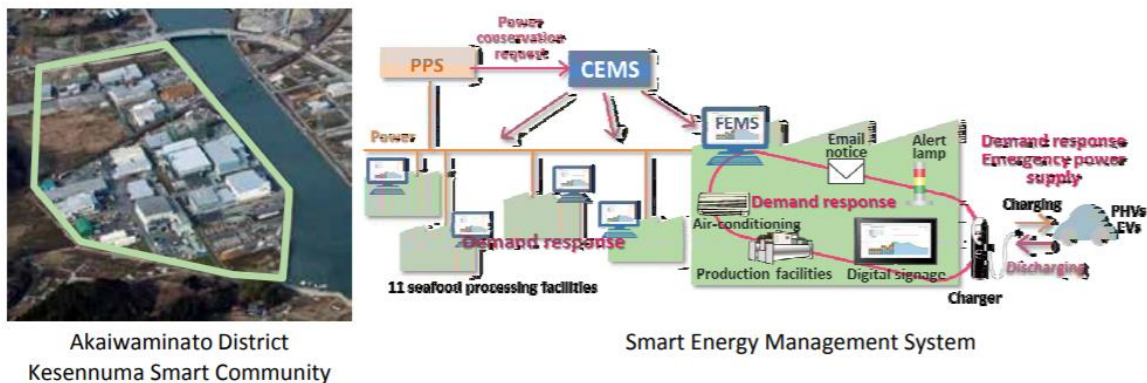


Figure 3- 3 Kesennuma Smart Community, Japan

### (2) Smart Energy Community in Tongzhou Canal Core Area, Beijing, China

Tongzhou New City (Figure 3-4) adopts the largest combined cooling, heating and power supply system and water source heat pump supply system in Beijing, and vigorously promotes the use of clean energy such as natural gas, fully develops new and renewable energy such as solar energy, shallow geothermal, river water source and waste heat from sewage. In addition, Tongzhou New City will introduce technology systems such as ultra-low energy consumption systems, prefabricated building systems, green building systems, science and technology systems, and humanistic building systems to build residential buildings in Tongzhou New City toward a low-carbon green direction. Tongzhou New City has obtained the Beijing Ultra-low Energy



Demonstration Project Certification, and has also obtained the Passive House Certification from the German Passive House Research Institute. In addition, a 3d digital energy management platform based on BIM technology, including energy consumption monitoring, energy consumption analysis, energy saving accounting and other functions, is planned to combine cloud technology, big data, energy expert services and energy management to create a truly green and energy-saving building in the operation and maintenance stage<sup>23</sup>.



Figure 3- 4 Smart Energy Community in Tongzhou Canal Core Area, Beijing, China

### 3.2 Low-carbon Transportation and Electric Vehicles

Urbanization, population growth and income growth are the driving forces behind the increasing demand for urban transportation. While meeting urban transportation needs, the impact on the environment and public health needs to be minimized, which requires cities to reduce emissions of greenhouse gases and air pollutants and traffic congestion, as well as improve energy efficiency and energy diversification. At the management and operation level, low-carbon transportation is achieved by optimizing the comprehensive transportation system for space transportation resource allocation, improving the efficiency of transportation organization, and improving the efficiency of transportation means. To some extent, the increasing demand for transportation has promoted the development of urban public transportation and the popularization of electric vehicles. At the user level, the goal of emission reduction can be achieved by replacing personal traditional powered vehicles with new energy vehicles. In addition, in order to achieve sustainable urban transportation, member economies and local governments need to issue a series of policies as a supervision and encouragement.

<sup>23</sup> <http://www.dayuntongzhou.com/web/ct6228>



### **3.2.1 Urban Traffic Conditions**

In 2015, transportation CO<sub>2</sub> emissions accounted for about 23% of global energy consumption CO<sub>2</sub> emissions. In 2013, the energy use of urban transportation activities accounted for about 40% of the total energy use. It can be seen that by optimizing the urban transportation management system, changing user behavior and implementing transportation support policies, transportation has huge carbon emission reduction potential in the future, and can promote the development of low-carbon economy and the improvement of energy efficiency. However, in the APEC region, CO<sub>2</sub> emissions from fuel combustion are expected to increase by 32% by 2035 compared to 2015.

### **3.2.2 Low-carbon Traffic Management System**

#### **1. Introduction to Low-carbon Traffic Management System**

The low-carbon traffic system is based on basically satisfying the transportation needs for socio-economic development, reducing fossil energy consumption and greenhouse gas emissions as much as possible to reduce the negative impact on the environment. The core of the construction of low-carbon urban traffic system is to improve energy consumption structure, but the improvement of energy structure needs a long process. At present, the construction of a low-carbon traffic management system mainly includes the following measures:

- 1) Accelerate vehicle technology innovation, promote the transformation of automotive power systems, and develop new energy vehicles.
- 2) Support and encourage green transportation modes.
- 3) Improve the operational efficiency of transportation systems.

#### **2. Typical case analysis of Low-carbon Traffic Management System**

##### **(1) Public Transport Priority System in Sagamihara, Japan**

The Public Transportation Priority System (PTPS) refers to a traffic system that prioritizes signal control of buses, such as setting up bus lanes, and issuing warnings to vehicles that occupy bus lanes and vehicles that run through red lights. It consists of a bus positioning system and a

road traffic control system. The communication system senses the proximity by installing lights at road intersections and devices installed on buses, and coordinates with traffic lights to control the operation of buses. When a bus approaches an intersection, the management system turns a red light to a green light and warns cars occupying the bus lane. This system strengthens the dispatching of bus operations, such as ensuring the timely operation of public transit cars, reducing the waiting time for buses at road intersections, and improving the safety factor of buses; It improves the convenience for citizens to take buses, which can reduce the average travel time by 16% -17% during peak hours, and also increases the number of citizens using buses<sup>24</sup>.

## **(2) Slow Traffic System in Hangzhou, China**

Slow traffic refers to the mode of transportation mainly composed of walking and cycling traffic, with a maximum speed of  $\leq 20$ km/h. The slow traffic system is composed of a pedestrian system and a non-motor vehicle system, and simultaneously has the functions of the urban system and the transportation system. It integrates transportation, leisure, communication and commerce, and has the advantages of flexibility, short distance, land saving and high efficiency. Hangzhou is committed to developing a slow traffic system, which mainly includes non-motor vehicle traffic system and pedestrian system. The non-motor vehicle traffic system can use different pavement materials or colored pavement to separate the motor vehicle and non-motor vehicle traffic flow. The pedestrian system is provided by setting up sidewalks, greening and landscape, pedestrian sign system, etc. (Figure 3-5). In addition, Hangzhou is also committed to increasing conventional public transportation lines and improving the bus network, opening BRT lines, planning and constructing multiple rail transits, opening water bus transportation systems, encouraging bicycle travel, constructing multiple walking paths, promoting the use of new energy vehicles and buses.

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<sup>24</sup> WHITE PAPER ON LAND, INFRASTRUCTURE, TRANSPORT AND TOURISM IN JAPAN, 2017



**Figure 3- 5 West Lake Area Walking System Plan**

### **(3) Singapore Electronic Toll System**

Singapore began to implement the electronic toll system in 1998. It is the first economy and city in the world to establish the system in urban areas. The ERP system is a non-stop toll system (Figure 3-6). Unlike road toll systems in other economies, Singapore's road toll system charges higher congestion tolls during peak hours and lower rates or no fees at other times. According to the congestion road pricing system "congestion pricing", the purpose is to reduce the use of cars during the rush hours, thereby reducing traffic congestion and traffic emissions, while encouraging passengers using more low-carbon way to travel, such as walking, cycling or riding Public transport rail / bus as an alternative.



Figure 3- 6 EPR System, Singapore

### 3.2.3 Electric Vehicles

#### 1. Introduction to Electric Vehicles

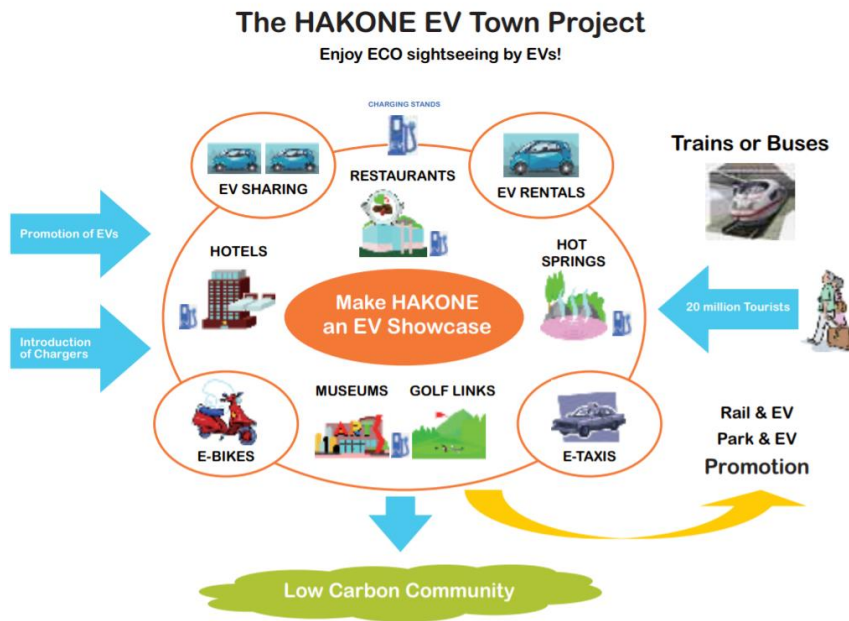
There are many types of new energy vehicles, which can be specifically divided into Blade Electric Vehicles (BEV), Hybrid Electric Vehicle (HEV), Fuel Cell Electric Vehicle (FCEV), Hydrogen Powered Vehicle (HPV), and Extended-range Electric Vehicle.

#### 2. Typical case analysis of Electric Vehicles Use

##### (1) Promotion measures for electric vehicles in Kanagawa, Japan

As of December 31, 2011, Kanagawa had more than 2,100 electric vehicles and had 109 DC quick chargers and 341 other charging sockets (100/200v). In order to reduce the burden on electric vehicle users, the commission had adopted a variety of incentives such as providing subsidies and reducing taxes.

Hakone is committed to building demonstration sites for electric vehicles and a low-carbon community. The Hakone government and some companies plan to cooperate with hotels, enterprises, tourist attractions, museum, golf courses and restaurants to install electric vehicle charging facilities to provide tourists with convenient travel tools, such as electric cars and electric bicycles (Figure 3-7).



**Figure 3- 7 The Hakone EV Town Project**

## (2) Hydrogen Fueled Electric Vehicle in Shanghai, China

In September 2018, six hydrogen fuel cell buses were put into use in Jiading District, Shanghai. It is a bus jointly developed by Chinese automobile manufacturer SAIC Group and Shanghai Sunway Bus Company. It is more spacious than ordinary buses, with a length of nearly 12 meters, a width of 2.5 meters and a height of 3.5 meters (Figure 3-16). Its main power source can store 21 kg of hydrogen and has a maximum driving range of 560 kilometers. The exhaust gas from hydrogen fuel cell buses is water, which does not cause environmental pollution. In addition, the vehicle can monitor the hydrogen concentration of the system in real time and automatically shut off the hydrogen supply protection system, collision protection system and other devices on the bus to ensure its safety.



Figure 3- 8 Hydrogen Fueled Electric Vehicle in Shanghai, China

### 3.2.4 Transport Policy Support

#### 1. Types of Transport Policies

In order to achieve low-carbon transportation, the government needs to formulate mandatory or incentive measures to reduce the economic and environmental costs of the transportation system, including the cost of waiting time caused by traffic congestion, and the health costs caused by traffic accidents, exhaust emissions, noise, etc. The policy tools that can reduce economic and environmental costs mainly include market control measures (such as taxation, limit trade, etc.), command-control methods, and combined control measures. From the perspective of the effects of the policy measures implemented by the economy, combined control measures are the most effective, which can flexibly solve different types of traffic problems in different regions, such as different levels of traffic congestion in large urban areas, and different types of vehicles implementing multiple types of fuel tax.

In addition, transport policies can be divided into local and economies' levels. Local-level traffic control policies are also known as Travel Demand Management (TDM). TDM is mainly divided into three categories: pricing strategies, regulatory measures, and encouragement of public transportation and non-motor vehicle travel. Economies-level traffic control policies change people's transportation behavior by implementing a variety of incentives, such as fuel taxes, fuel economy regulations, vehicle purchase taxes, low-carbon fuels and other market incentives.



## **2. Typical case analysis of Transport Policy Support**

### **(1) Krasnoyarsk, Russia**

The core policy of Krasnoyarsk transportation plan is to coordinate public transportation and automobile transportation by optimizing the driving mode of motor vehicles, mainly including the following three aspects: strengthening the construction of public transportation networks; controlling road parking to reduce the traffic congestion load; optimizing traffic management, for example, by using IT technology to promote the operation of public transportation.

### **(2) Foshan, China**

Foshan is one of the five demonstration cities in China for the United Nations Development Program's public transport commercialization project. The government has formulated a new energy vehicle industry development plan. During the "Thirteenth Five-Year Plan" period, Foshan plans to invest 900 million RMB to support the promotion and application of new energy buses and infrastructure construction. Foshan will actively introduce well-known new energy vehicle manufacturers to form a new energy vehicle industry development leader.

## **3.3 Urban Energy Storage and Energy Management**

In the pursuit of low-carbon and efficient use of energy in the city, particularly important link is urban energy storage and energy management. Combined with APEC practices, this section summarizes urban energy storage technologies and forms as well as area energy management systems. Urban energy storage technology is mainly divided into electricity storage and heat storage. Power storage technology mainly includes three aspects: energy storage technology, grid connection technology and monitoring technology. The forms of heat storage can be divided into thermochemical heat storage, sensible heat storage and phase change heat storage. Energy management is mainly for energy equipment management, energy planning, energy consumption and benefit analysis to achieve low-carbon goals. Energy management systems can be divided into areas ranging from smart building systems for single buildings to energy management systems for urban areas. While studying the area energy management system, it can be connected with smart

grid or "Internet +" of smart energy, and energy management and supply network can be used to form an organic network.

### **3.3.1 Energy Storage Technologies and Forms**

#### **1. Introduction to Energy Storage Technologies and Forms**

The application of energy storage technology in renewable energy generation can suppress the random and intermittent power fluctuations of renewable energy generation such as wind power and photovoltaics, and improve the capacity of renewable energy consumption. According to the charge-discharge response characteristics of the energy storage system, the energy storage system can be divided into power-type energy storage system and energy-type energy storage system. The power-type energy storage system is represented by supercapacitors, superconducting energy storage and flywheel energy storage. It has the characteristics of fast response, long cycle life and small capacity, and is suitable for compensating short-term power fluctuations. Energy-type energy storage system is represented by storage battery, pumped energy storage and compressed air, which has the characteristics of large capacity and slow response, and is suitable for compensating long-term power fluctuations.

Gas storage technologies mainly include compressed air energy storage and hydrogen storage technologies.

Heat storage technology is an important way of energy storage. High temperature heat storage technology is widely used in solar-thermal power generation, which can smooth out the output instability caused by unstable lighting conditions and improve the dispatching ability of solar-thermal power stations. The allocation of large capacity heat storage can increase the power generation hours of the power station, and even realize the all-day power generation of the solar-thermal power station, so as to improve the economic benefits of the power station. At present, high temperature heat storage technology has been widely used in the field of trough and tower solar-thermal power generation. At present, heat storage technology can be roughly divided into three categories: sensible heat storage, phase change heat storage, and chemical thermochemical heat storage.



## 2. Typical case analysis of Energy Storage Technologies

### (1) Hydrogen Energy Storage System (HES), California, USA

California uses hydrogen to store solar energy and wind power. Figure 3-9 shows the Hydrogen Energy Storage System (HES). When the supply of renewable energy exceeds demand, the excess electricity will be directed to a solid oxide electrolysis system (SOE) to produce hydrogen, which is then pressurized in a bipolar compressor and then injected into an underground storage facility. When the demand for electricity is greater than the supply of renewable energy, hydrogen can be extracted from the storage facility and expanded by the turbine before reaching the solid oxide fuel cell systems (SOFC). The pressurized gas is controlled by one-dimensional radial heat transfer and convective heat transfer within HES. The working temperature of the HES system is 900 degrees Celsius, the average temperature of the natural gas storage facility is 318K, the SOE output pressure is 101Kpa, and the isentropic efficiency of the compressor is 0.82<sup>25</sup>.

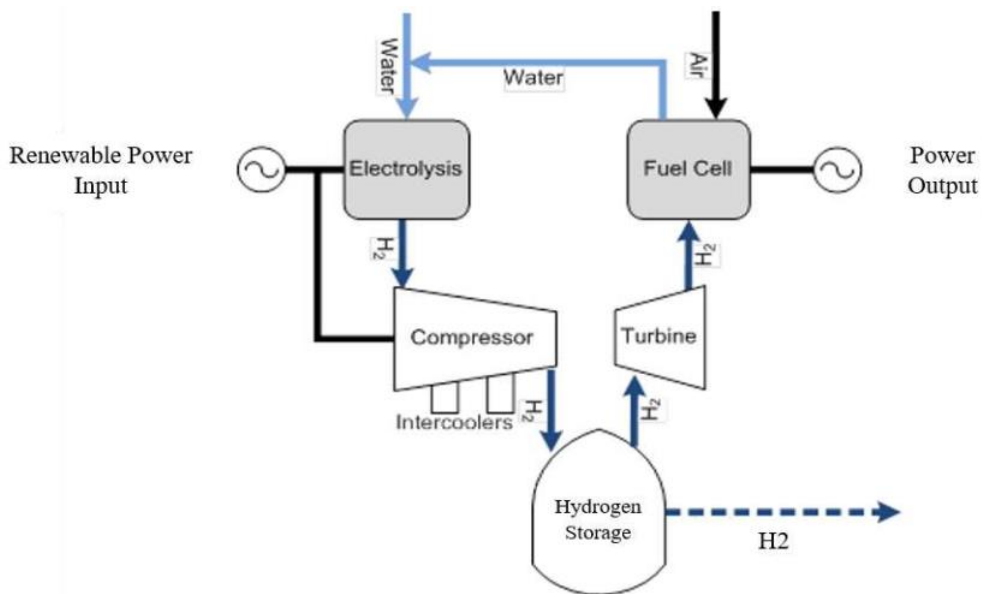


Figure 3- 9 Hydrogen Energy Storage System (HES)

<sup>25</sup> Dynamic Modeling of California Grid-Scale Hydrogen Energy Storage

### **(3) Battery Energy Storage System (BESS), Misiones, Chile**

In 2011, AES Gener established a 544MW thermal power plant in Misiones, in northern Chile. Due to the grid's dependence on transmission or generation losses, each generator retains the ability of the system to respond to primary and secondary reserves. In addition, AES Gener has also developed a 20MW/5MWh containerized grid energy storage system to perform grid supported standby capacity functions. Based on the continuous monitoring of the power system by the storage unit, the system is able to immediately respond to any significant frequency deviation up to 20MW (i.e. the loss of the generator or transmission line). The system provides sufficient instant power response to maintain grid functions. Since commissioning in December 2011, the storage unit has successfully performed the required critical reserve capacity function, which provides a very fast response. Compared with the reserve capacity provided by thermal power plants, fast response also helps the system to recover quickly and maintain stability.



**Figure 3- 10 Battery Energy Storage System (BESS)**

### **3.3.2 Aera Energy Management System**

#### **1. Introduction to Aera Energy Management System**

Energy Management System (EMS) adopts a layered distributed system structure, which collects and processes energy consumption data of various categories such as electricity, gas, and water, and analyzes the energy consumption of buildings to achieve energy saving effects. The

functions of the energy management system are mainly divided into three parts: online real-time data management, offline data management, and connection with ERP. In addition, according to the different service objects, energy management system is also divided into Community Energy Management System (CEMS), Home Energy Management System (HEMS), and Building Energy Management System (BEMS).

## **2. Typical case analysis of Aera Energy Management System**

### **(1) Community Energy Management System, Yokohama, Japan**

After the March 2011 earthquake in Japan, the demand for Community Energy Management Systems has increased. Yokohama, one of Japan's largest cities, aims to establish "new energy infrastructure and social systems" to minimize carbon dioxide emissions. The main goals of a community energy management system are to reduce the use of fossil fuels and increase the generation ratio of renewable energy sources such as photovoltaics and wind power. It is usually achieved by exchanging surplus power between regions and actively developing power-saving devices. The use of electricity through a storage battery (high-capacity secondary battery) can achieve the purpose of using electricity efficiently. Yokohama's community energy management system (Figure 3-11) integrates fixed batteries with Home Energy Management Systems and Building Energy Management Systems to absorb fluctuations in power output from renewable energy sources. Efficient energy management is achieved by managing demand-side and stationary energy storage. In addition, the Yokohama Home Energy Management System can introduce a combination of multiple photovoltaic and energy-saving equipment into houses and buildings, and minimize costs by combining insulation modifications and efficiency extensions (Figure 3-12)<sup>26</sup>.

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<sup>26</sup> [http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1296405826983/7699103-1296623042596/4\\_2Okazaki\(Yokohama\)2.pdf](http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1296405826983/7699103-1296623042596/4_2Okazaki(Yokohama)2.pdf)

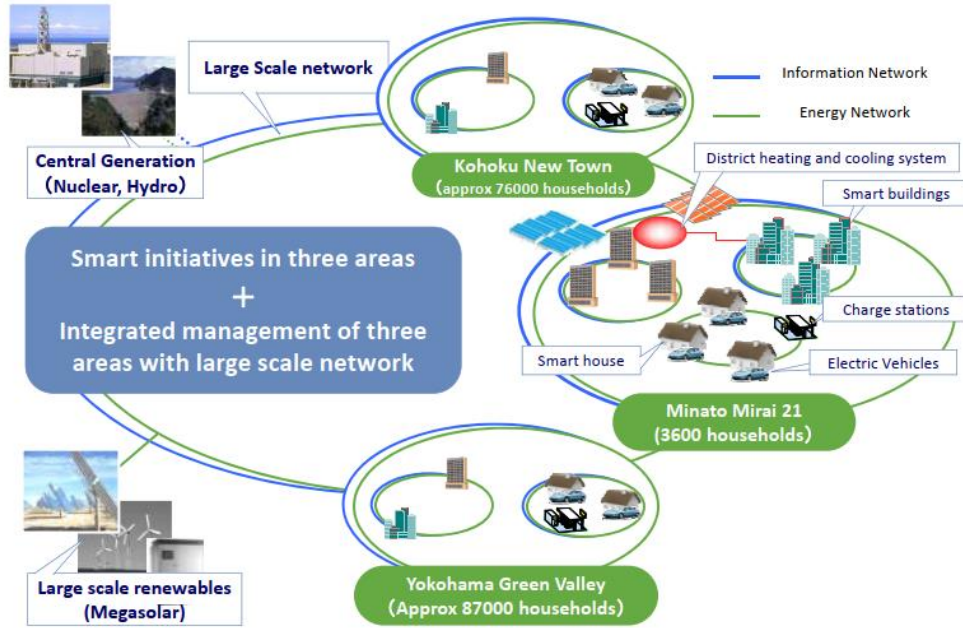


Figure 3- 11 Community Energy Management System

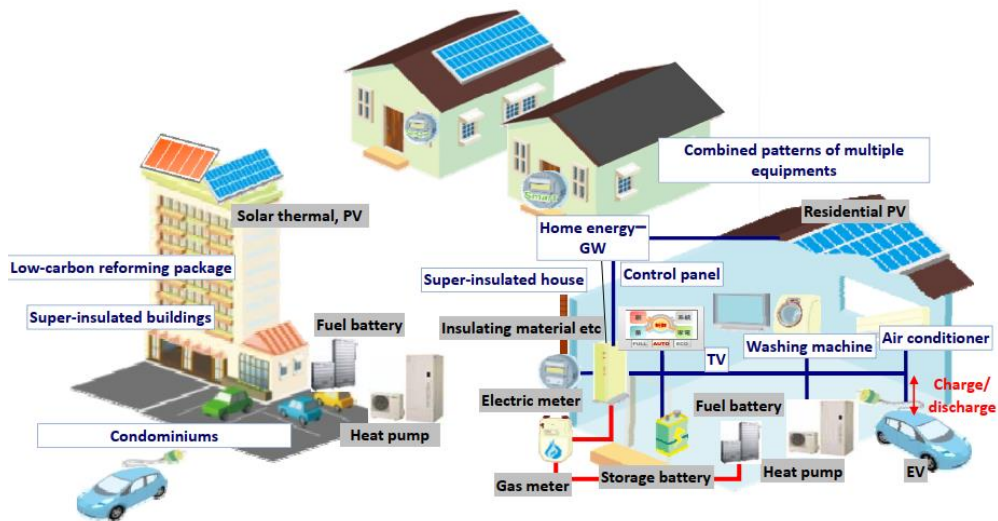
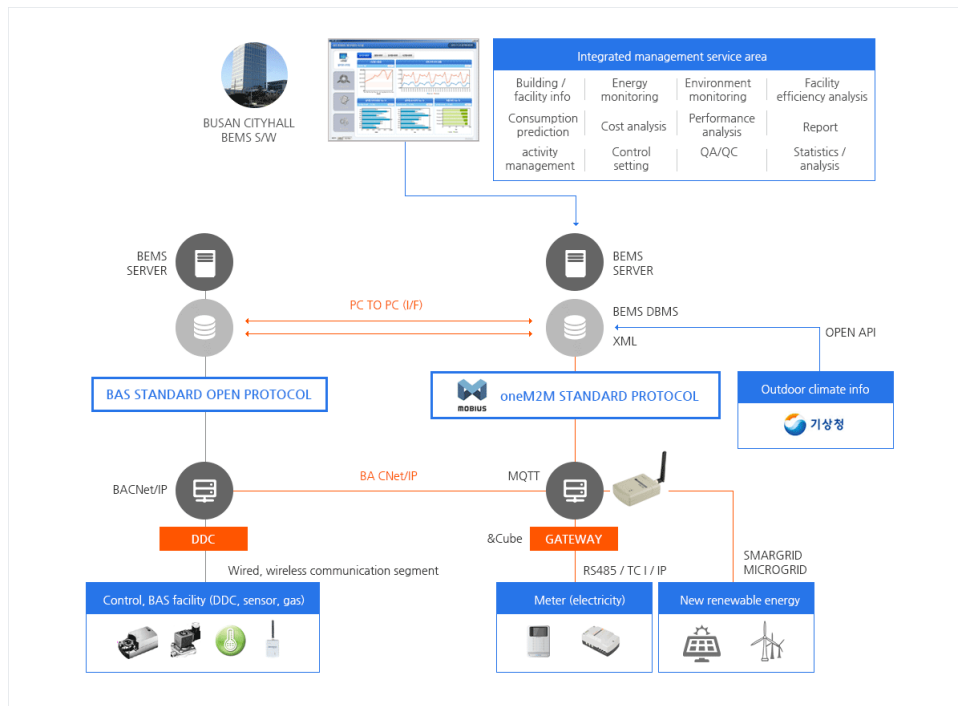


Figure 3- 12 Home Energy Management System

### (3) Intelligent Building Energy Management System, Busan, South Korea

Busan City Hall has established a smart building energy management and energy saving system based on the Internet of Things, including building management, energy information management, and report management (Figure 3-13). Among them, building management includes the management of facilities, meters and sensors; energy information management includes

approved energy KPI, energy standard data, code management and real-time event management; report management refers to energy reporting based on HTML 5, which are used to manage offline work and data analysis to save energy more effectively. In addition, the Busan municipal government has installed two-way energy meters and sensors to monitor and analyze energy consumption, which facilitates real-time energy monitoring. The real-time energy monitoring service system includes facility monitoring, energy consumption information, and energy information management. Among them, facility monitoring system includes the monitoring of the distribution of power and other facilities to be provided by the system and the specific statistical analysis of energy consumption; energy consumption information refers to energy consumption and energy saving under different weather and time conditions; energy information management refers to the system's ability to give early warning based on the history of energy consumption. The management system can overcome the limitations of traditional BEMS web services, and can use the Internet of Things platform for open energy management in time and space and use feedback (based on HTML 5 reports and real-time energy consumption information) to achieve efficient energy saving<sup>27</sup>.



**Figure 3- 13 Intelligent Building Energy Management System**

<sup>27</sup> <http://k-smartcity.kr/english/service/service08.php>

## **Chapter 4: Forms of Low-carbon Energy System for APEC Cities**

### **4.1 Geographical Classification of APEC Cities**

#### **4.1.1 Classification Basis of Cities**

The purpose of city classification is to better understand and study cities so as to obtain more favourable plans for urban development. There are many cities, and the disparity of the population, area, different geographical environment, political, economic and cultural development level is not very balanced, infrastructure conditions are different. Different cities in the education of science and technology, living, health, public security, environmental protection and other social development as well as the city transportation, postal communication, residential, power supply, water supply, gas supply and other infrastructure development level is uneven. In addition, the economic and social development of cities is extremely unbalanced, and there are great differences between cities. This leads to the current ambiguous definition of city types.

Up to now, studies on classification of cities are very extensive, and the basis of classification varies from person to person. However, it can be concluded that the classification of cities is mainly based on single indicators representing urban population, society, economy, resources and environment, or on comprehensive indicators combining static indicators and dynamic indicators. Through sorting out the literature, it can be seen that the classification of cities can be carried out mainly from the generation and development of cities, geographical and spatial form, scale, functions and properties.

The urban classification method has experienced a gradual improvement process from qualitative description to quantitative analysis, from single variable to multivariate analysis, and from subjectivity to objectivity. However, there is no unified classification standard. Therefore, to study the form of urban energy system, APEC cities should be classified from the perspective of driving factors of urban energy use. Drivers of urban energy use can nevertheless be organised and analysed as follows:

1) Drivers linked to the geophysical environment: The constraints imposed by a city's location, the prevailing climate conditions, or the resources at its disposal including proximity to other economic centres.

2) Socio-demographic drivers: From the social and economic structure, to household occupation, to cultural aspects which drive the growth of a city.

3) Drivers linked to the built infrastructure: The energy and transport infrastructure, the design and density of buildings, and the degree of connection of socio-economic activity.

4) Institutional drivers: The architecture of urban governance, including the governance of the energy system.

While these are distinct drivers of urban energy use, they are all linked and influence one another through strong feedbacks and synergies. City location or prevailing socio-economic structures drive the economic activity of a city. The institutional structure and governance of a city, or the characteristics of the energy system, are in turn driven by the geophysical characteristics of a city.

#### **4.1.2 Geographical Classification of APEC Cities**

Due to the complexity of the classification of cities, this study classifies cities according to their geographical environment characteristics. The 21 member economies of APEC are geographically spread across North America, South America, east Asia and Oceania.

According to the geographical environment, APEC cities are divided into three categories, namely island type (approximately 13%), peninsula type (approximately 27%) and inland type (approximately 60%). There are many island-type areas in the APEC region, which are also prone to various disasters. The accessibility, stability and resilience of energy resources should be considered. As trade and economic centers, more peninsular cities in the APEC region play a crucial role in the development of various economies. With a large population, rapid economic development and large energy demand, multi-energy complementarity should be considered in the face of energy issues. Inland cities account for the largest proportion of the total number of cities in the APEC region, and they are also an important area for the low-carbon development of urban energy systems. Since more traditional fossil energy is used, it is necessary to focus on expanding the utilization scale of new and renewable energy, and vigorously develop technologies such as smart grids.



## **4.2 Collection of Best Practices in Sustainable Urban Low-carbon Energy System**

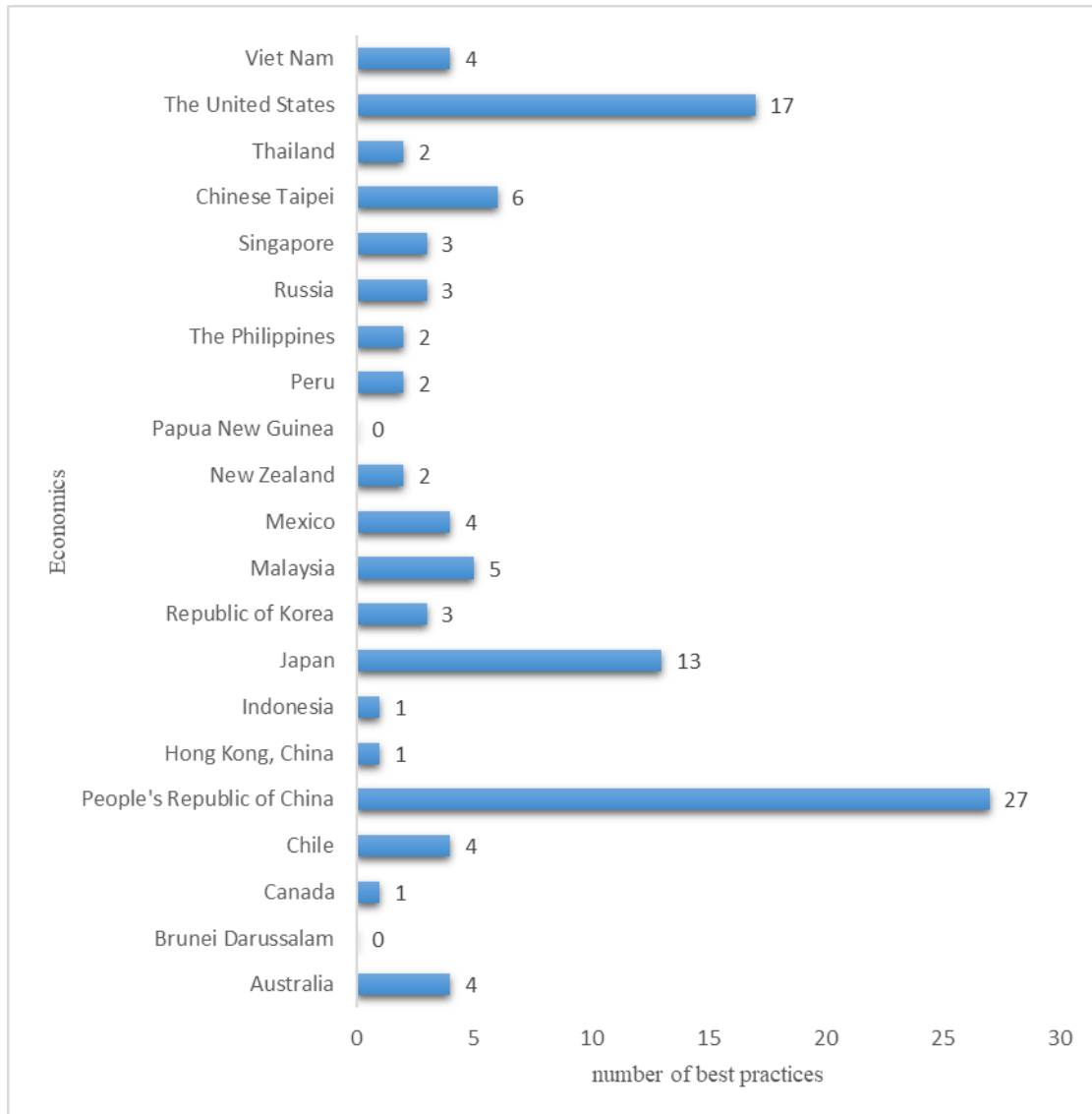
### **4.2.1 Sources and Distribution of Best Practices**

In order to study the forms of low-carbon energy systems in three types of APEC cities, a total of 122 practical cases were collected in this study, of which 104 were from APEC economies. The main three sources of the case are: 1) 7 cases of APEC Low Carbon Model Towns<sup>28</sup>; 2) project data of the APEC Energy Smart Community Initiative Knowledge Sharing Platform<sup>29</sup>; 3) relevant research and project introduction of publications and reports of various international organizations. Case collection and screening should meet certain criteria, and projects should be selected on a large scale with complete energy data. The 104 APEC cases were from 19 economies, and no practical cases have been collected from Brunei Darussalam and Papua New Guinea, as shown in Figure 4-1. Through the distribution of cases, it can be seen that there are a large number of excellent practice projects collected in China, followed by the case projects of developed economies such as the United States and Japan. At the same time, the excellent practices of other APEC economies are also analysed.

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<sup>28</sup> The APEC Low-Carbon Model Town (LCMT) project aims to combine energy-efficient buildings, transport and power systems to create communities that affordably reduce energy use and carbon emissions while creating pleasant living conditions. The LCMT project is a part of APEC's Energy Smart Communities Initiative (ESCI). <https://aperc.or.jp/publications/reports/lcmt.html>

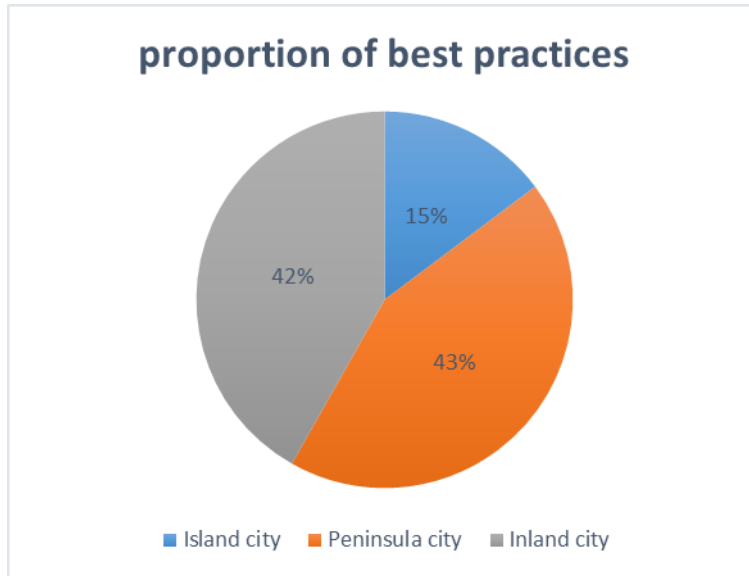
<sup>29</sup> The Energy Smart Communities Initiative (ESCI) covers four main pillars—Smart Transport, Smart Buildings, Smart Grids, and Smart Jobs and Consumers—along with the cross-cutting examples of Low Carbon Model Towns. ESCI Best Practices Awards Program, <https://www.esci-ksp.org/archives/11559>



**Figure 4- 1 Distribution of the number of best practices among economies**

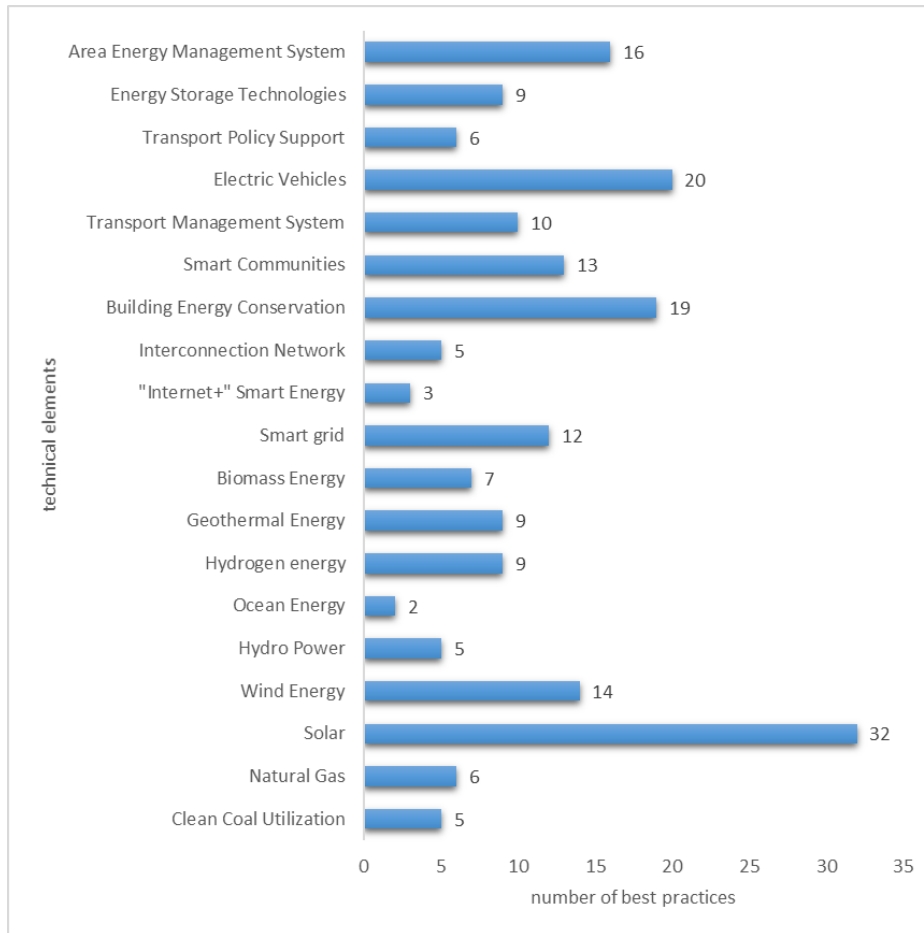
#### **4.2.2 Statistics and Analysis of Best Practices**

According to the classification of the three types of APEC cities in this study, a total of 122 cases of practical cases were collected and classified, as shown in Figure 4-2. Among them, 18 were island city projects, accounting for 15% of the total number of cases. The number of peninsula city projects was 53, accounting for 43% of the total cases. The number of inland city projects was 51, accounting for 42% of the total. The practical case projects of peninsula cities and inland cities account for a large proportion.



**Figure 4- 2 The proportion of best practices of three types APEC cities**

At the same time, 122 cases of best practice were further analysed, including the statistics of 19 key elements of urban energy supply and energy use. As shown in Figure 4-3, the urban energy supply end included 12 elements, and the urban energy use end included 7 elements. According to statistics, in 122 cases of practice, solar energy, wind energy and smart grid are widely used in urban energy supply; building energy conservation technology, electric vehicle and aera energy management system are widely used in urban energy use.



**Figure 4- 3 Statistics on key technical elements of urban energy supply and use**

## **4.3 Forms of Low-carbon Energy System for Island Cities**

### **4.3.1 Regional Characteristics and Energy situation**

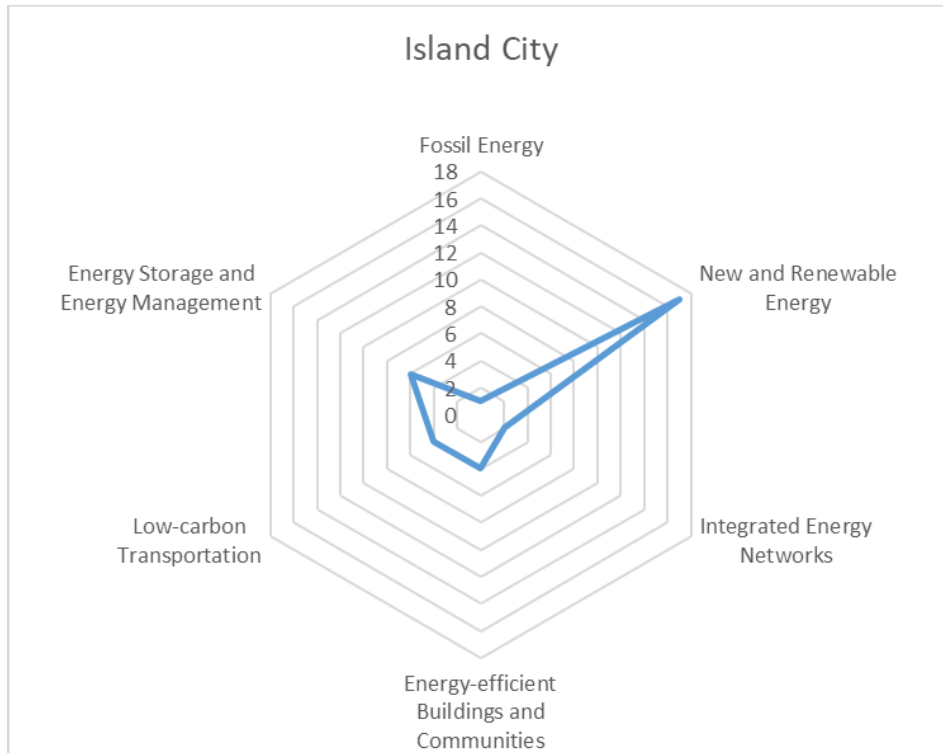
With the vigorous development of APEC economies and the successive establishment of special economic zones in coastal cities, the strategic position and economic impact of the coast and its islands have become apparent. At present, although the economic development of the coastal islands and the living standards of residents have improved, for most of the islands, the problem that still needs to be solved is energy. The energy development and utilization of islands are extremely unbalanced, and the power supply of islands can be roughly divided into: 1) power from the mainland through submarine cables; 2) power supply of its own fuel power station; 3) power generation by small diesel engines; 4) power supply from small power stations. Because of the geographical location of each sea area, the energy status of the islands also varies greatly.

Island cities are relatively independent and have poor connections with the mainland and other islands. In addition, the island's own resources and energy resources are limited, and the ecological environment is relatively fragile. When determining the form of low-carbon energy systems for island cities, the main consideration is the form of low-carbon energy system with the purpose of increasing energy resilience and energy access.

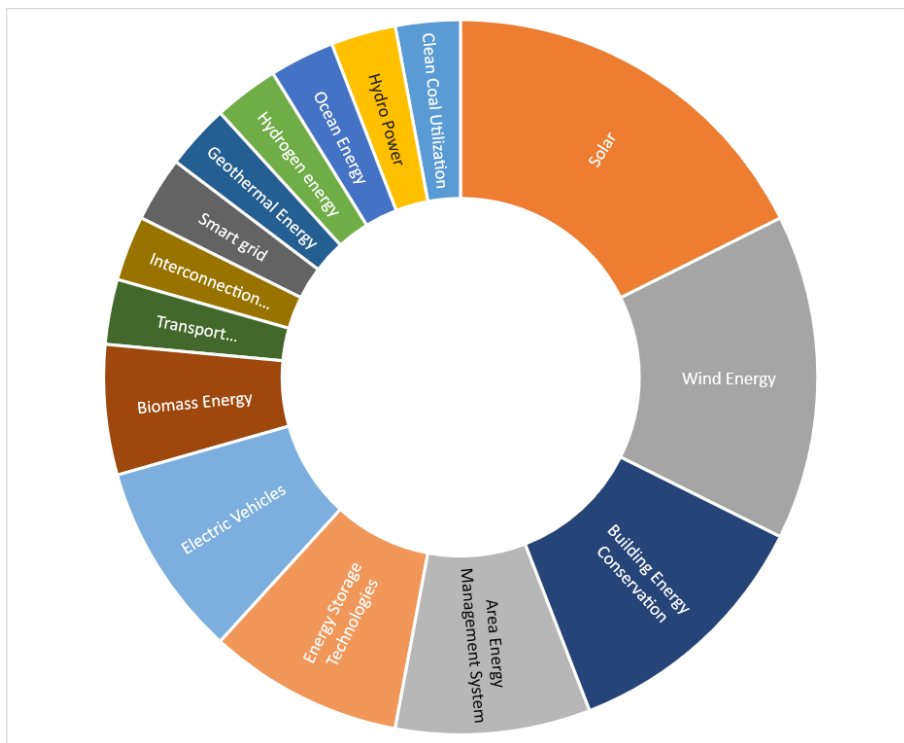
### **4.3.2 Forms of Low-carbon Energy System**

Based on the statistics of 18 island-type city projects, the six dimensions (fossil energy, new and renewable energy, integrated energy networks, energy-efficient buildings and communities, and low-carbon transportation, energy storage and energy management) of energy supply and use of low-carbon energy systems in island-type cities are analysed. As shown in Figure 4-4, the development and planning of new and renewable energy utilization dominate at the energy supply side of urban energy systems; meanwhile, at the energy use side of urban energy systems, the development of energy-efficient buildings and communities, low-carbon transportation, energy storage and energy management is relatively average and accounts for a small proportion.

Based on the analysis of the 19 key technical elements of the island city projects on the energy supply and use side of urban energy system, as shown in Figure 4-5, the most widely utilized technologies are solar utilization, wind energy utilization, building energy conservation, area energy management system, energy storage and electric vehicle utilization.

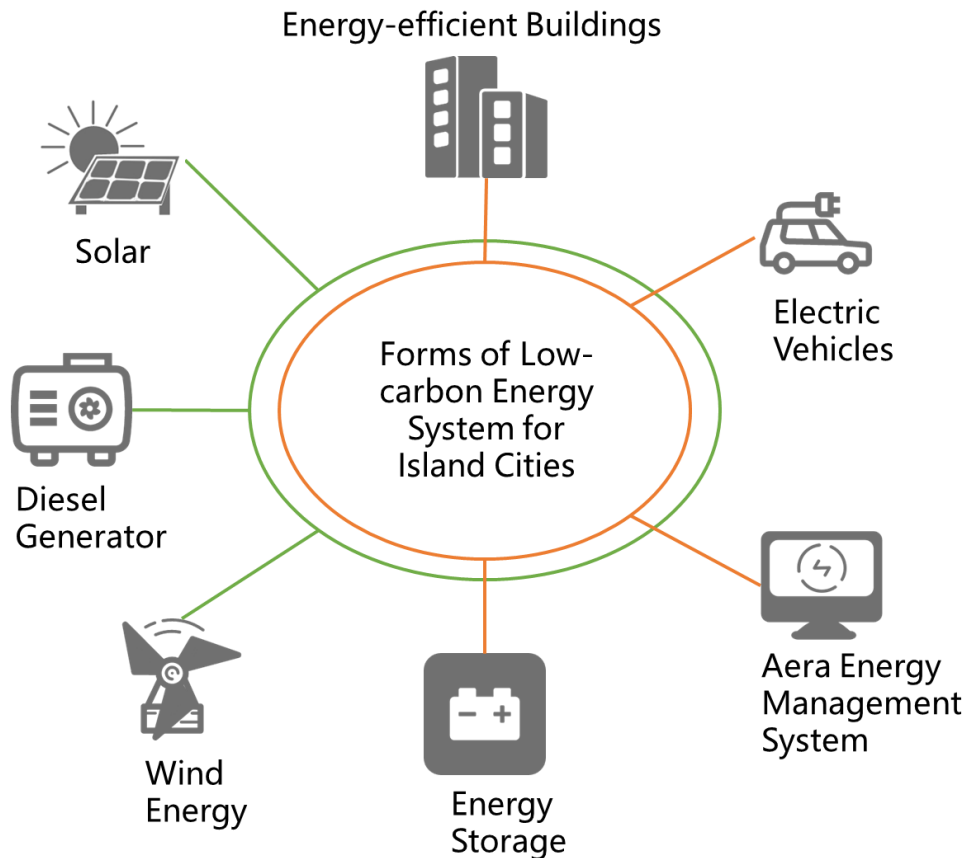


**Figure 4- 4 Energy supply and use of low-carbon energy system in island cities**



**Figure 4- 5 Development of key technical elements of urban energy system in island cities**

Most island-based cities use diesel as the energy source for their survival. The energy use side does not consider the energy efficiency of buildings or the utilization of smart energy. The transportation mode adopts the traditional energy use method, with a small proportion of energy storage, unable to meet the demand, and low energy management efficiency. In the transformation to low-carbon energy system, the form can be considered as follow. Urban energy supply retains some diesel oil and maximizes the use of new and renewable energy (solar, wind, ocean, etc.). Other types of energy are adjusted according to scale. Urban energy use should consider the combination of energy-efficient buildings and smart communities, low-carbon transportation, urban energy storage and energy management, as shown in Figure 4-6 (where the green connection line represents the energy supply side and the orange connection line represents the energy use side).



**Figure 4- 6 Forms of low-carbon energy system for island cities**



## **4.4 Forms of Low-carbon Energy System for Peninsula Cities**

### **4.4.1 Regional Characteristics and Energy situation**

A peninsula refers to a landform that extends halfway into the ocean or lake and half that is connected to the mainland or a larger island. The remaining three sides are surrounded by water. From the perspective of distribution characteristics, the world's major peninsulas are on the fringe of the mainland. The peninsula is a common surface morphology. The unique geographical location of the peninsula closely links the ocean and the land.

Due to the regulating effect of ocean water, the peninsula is comfortable and pleasant in winter and summer. It is beneficial to the growth of crops and produces a variety of special agricultural products. Energy resources include tidal energy, thermal energy, offshore wind power, and subsea oil.

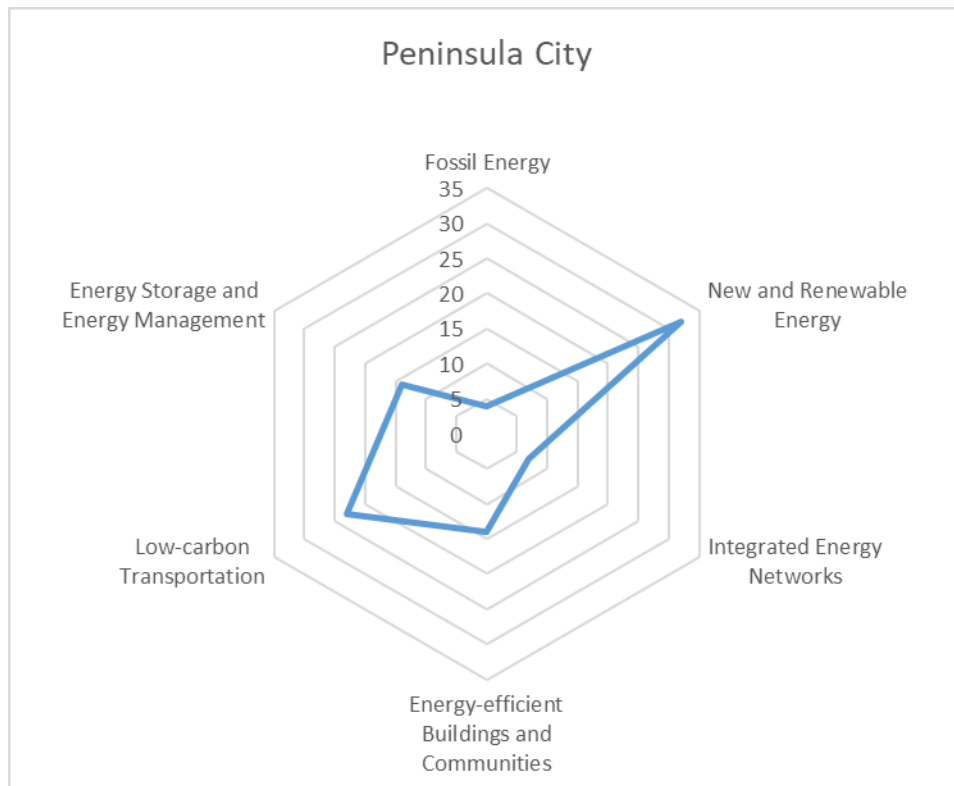
The characteristics of peninsula-type cities are between island-type cities and inland-type cities, and their geographical location is offshore, so they should give full play to their geographical advantages in the selection of energy system forms, that is, maximize the utilization of ocean-related energy.

### **4.4.2 Forms of Low-carbon Energy System**

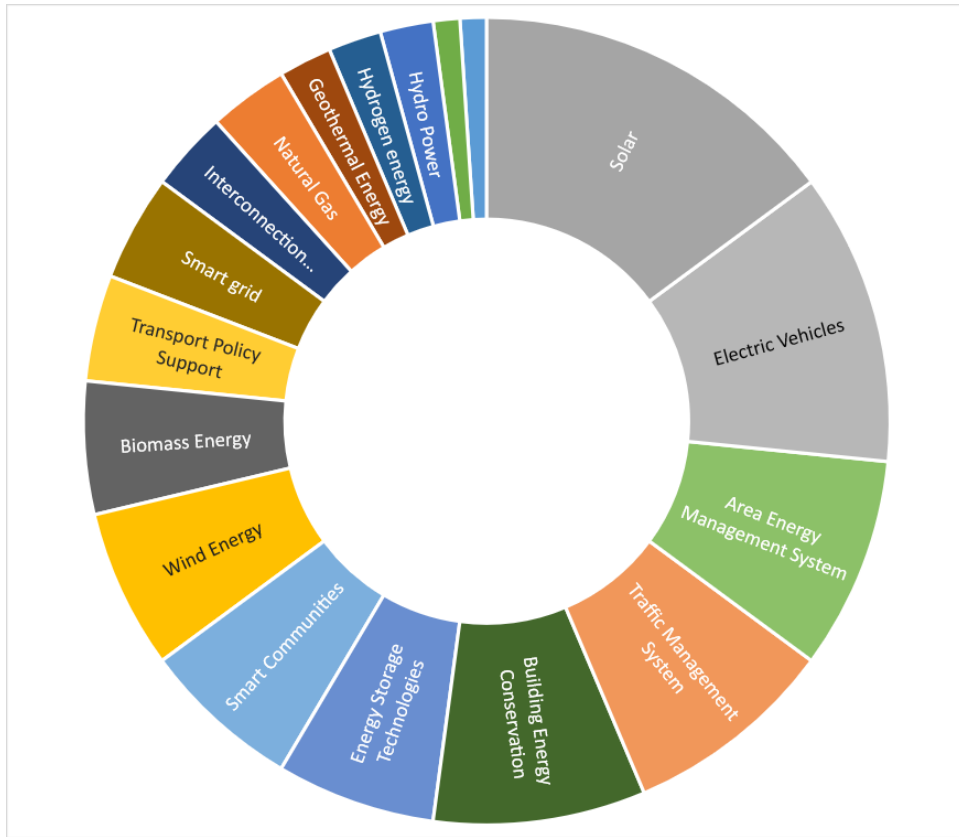
Based on the statistics of 53 peninsula-type city projects, the development of the six dimensions of energy supply and energy use of low-carbon energy system in the peninsula-type cities is analysed, as shown in Figure 4-7. The development and planning of new and renewable energy utilization dominate at the energy supply side of urban energy systems, clean fossil energy utilization and integrated energy networks have expanded development compared with island-type cities. At the same time, at the energy use side of low-carbon energy system, the development and planning of low-carbon transportation account for a large proportion, and the development of energy efficient buildings and communities, energy storage and energy management are equal, showing a relatively average development mode in these three dimensions. Comparing the situation of peninsula city and island city, it can be seen that the energy development model of peninsula city is the expansion model of island city to some extent. Vigorously advocate the use of new and renewable energy sources, while expanding the development of low-carbon

transportation, energy-efficient buildings and communities, energy storage and energy management.

Based on the analysis of the 19 key technical elements of the peninsula city projects on the energy supply and use side of urban energy system, as shown in Figure 4-8, the most widely utilized technologies are solar utilization, electric vehicle utilization, aera energy management system, traffic management system, building energy conservation, energy storage technology, smart communities, wind energy utilization and biomass energy utilization.

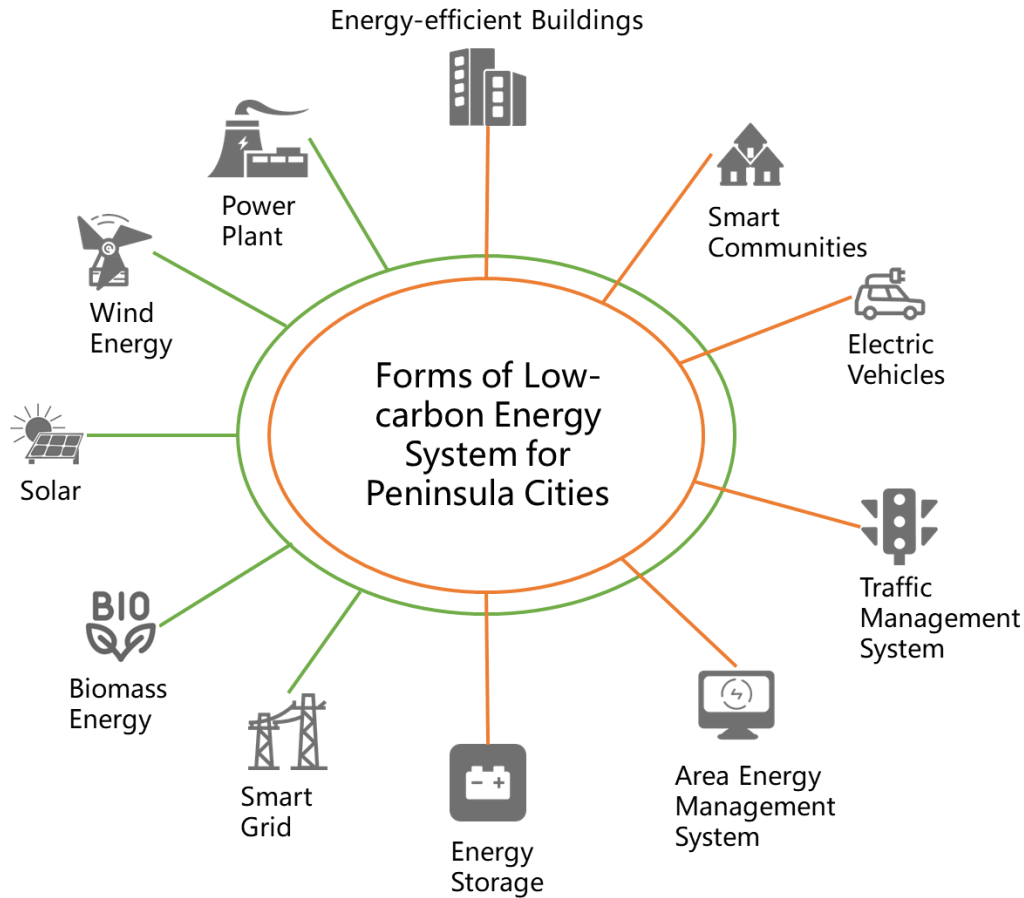


**Figure 4- 7 Energy supply and use of low-carbon energy system in peninsula cities**



**Figure 4- 8 Development of key technical elements of urban energy system in peninsula cities**

Most of the peninsula-type cities use the traditional coal and natural gas as the main energy source for energy supply side. The coverage of smart energy utilization on the energy use side is relatively small, and the transportation mode adopts traditional energy use method, resulting in low energy management efficiency. In the transformation to low-carbon energy system, the form can be considered as follow. Urban energy supply retains some traditional fossil energy, expands the use of new and renewable energy (increasing the utilization ratio of tidal energy and ocean energy), promotes multi-energy complementary systems, and uses urban integrated energy networks. Urban energy use should consider the combination of energy-efficient buildings and smart communities, low-carbon transportation and electric vehicles, urban energy storage and energy management, as shown in Figure 4-9.



**Figure 4- 9 Forms of low-carbon energy system for peninsula cities**

## **4.5 Forms of Low-carbon Energy System for Inland Cities**

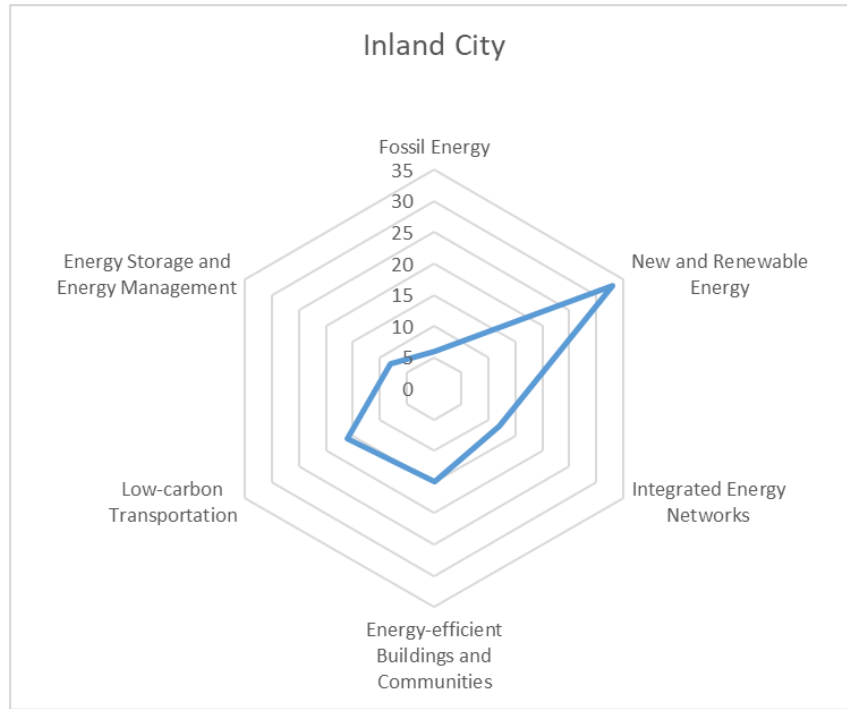
### **4.5.1 Regional Characteristics and Energy situation**

Landform types of inland cities are diverse, and the basic landform types include mountain, plateau, hill, plain and basin. Inland cities account for the largest proportion of the total number of cities in the APEC region, and are also an important area to address the low-carbon development of the urban energy system. Since more traditional fossil energy is used, the scale of utilization of new and renewable energy should be expanded. Due to the close regional connection, inland cities should construct the form of comprehensive energy network and strive to develop smart grid and other technologies.

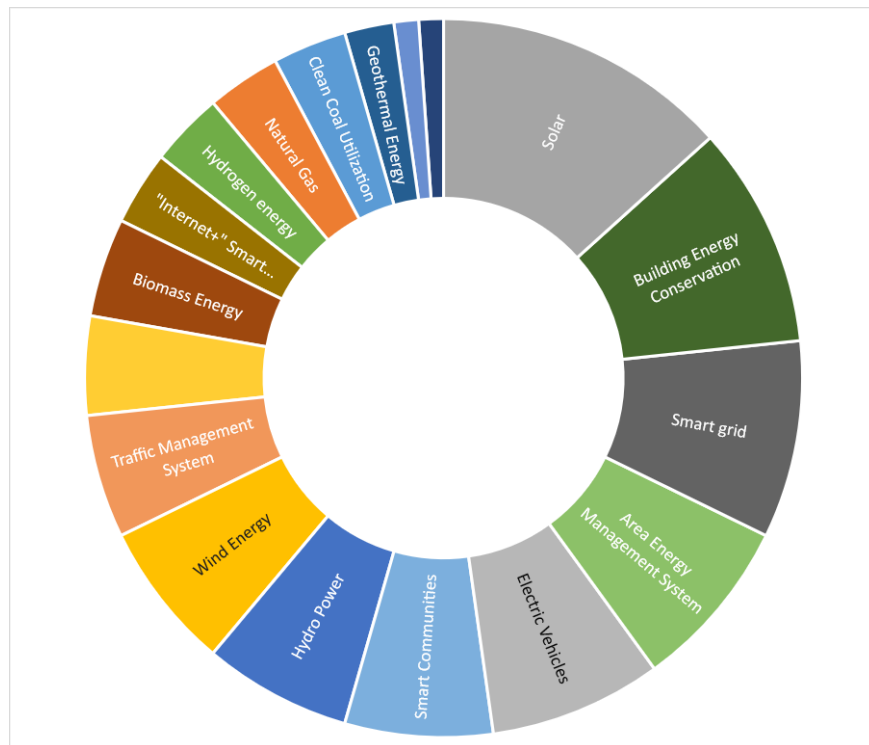
## **4.5.2 Forms of Low-carbon Energy System**

Based on the statistics of 51 inland-type city projects, the development of the six dimensions of energy supply and energy use of low-carbon energy system in inland cities is analysed, as shown in Figure 4-10. The development and planning of new energy and renewable energy utilization account for more. Secondly, the application of integrated energy networks has significantly expanded compared to island and peninsula cities. At the same time, at the energy use side of low-carbon energy system, the development and planning of energy-efficient buildings and communities and low-carbon transportation account for a large part, while the development of energy storage and energy management is relatively small. Compared with island and peninsula cities, it can be seen that the energy development model of inland cities is different. Vigorously advocate the utilization of new energy and renewable energy and the application of integrated energy network, and develop energy-efficient buildings, communities and low-carbon transportation at the same time. The development of energy storage and energy management should be the focus of subsequent development.

Based on the analysis of the 19 key technical elements of the inland city projects on the energy supply and use side of urban energy system, as shown in Figure 4-11, the most widely utilized technologies are solar utilization, building energy conservation, smart grid, aera energy management system, electric vehicle utilization, smart communities, hydro power, wind energy utilization and traffic management system.

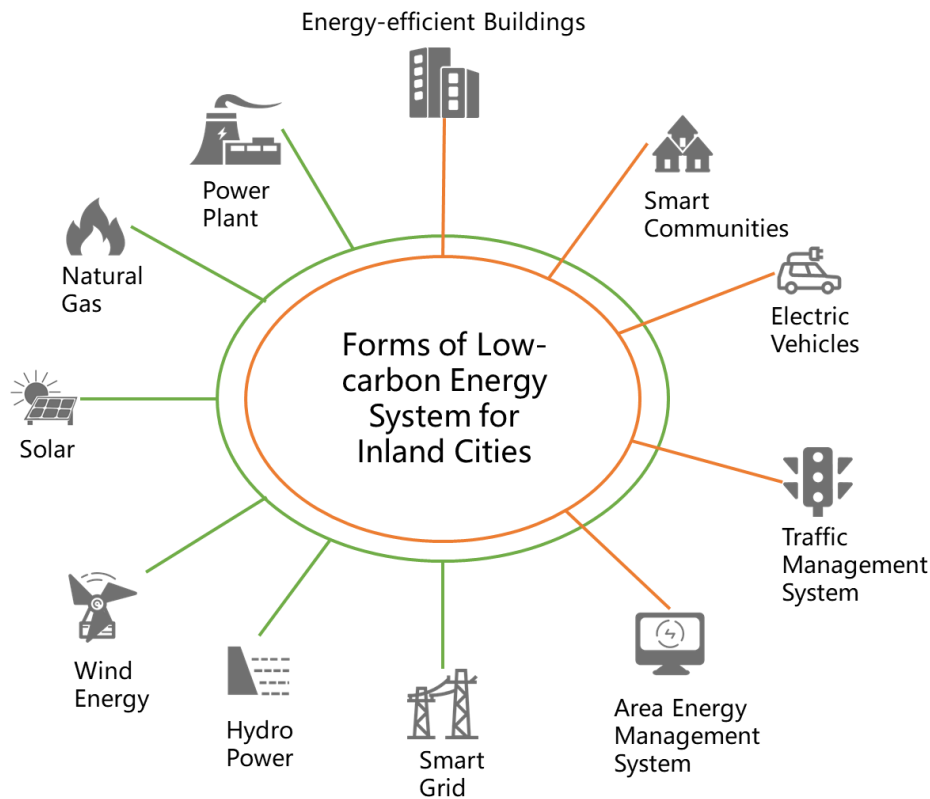


**Figure 4- 10 Energy supply and use of low-carbon energy system in inland cities**



**Figure 4- 11 Development of key technical elements of urban energy system in inland cities**

Inland cities mostly use traditional coal as the main energy source for energy supply. The coverage of smart communities on energy use side is relatively small. The traditional energy use method accounts for a large proportion in the transportation mode, and energy management fails to meet their needs. In the transformation to low-carbon energy system, the form can be considered as follow. Urban energy supply should increase the rate of clean utilization of traditional energy, while using the integrated energy networks. Urban energy use should consider the combination of energy-efficient buildings and smart communities, low-carbon transportation and electric vehicles, and urban energy storage and energy management, as shown in Figure 4-12.



**Figure 4- 12 Forms of low-carbon energy system for inland cities**

## **4.6 Recommendations for Building a Sustainable Urban Low-carbon Energy System**

In the transition to cleaner energy in the future, sustainable urban energy systems that target low carbon can improve energy security and energy resilience, while delivering multiple benefits to the environment, human health, and economic growth. It is crucial important that selecting



forms of perfect sustainable urban energy system and relatively low-carbon energy systems for the implementation of the UN Sustainable Development Goals in the Goal 7 (Affordable and Clean Energy) and Goal 11 (Sustainable Cities and Communities), as well as the APEC energy working group of two specific goals (“To double the share of renewables in the APEC energy mix, including in power generation by 2030; and to reduce APEC’s aggregate energy intensity by 45% from 2005 levels by 2035.”).

Based on the analysis and statistics of 122 excellent practices, this study puts forward development suggestions from two aspects, urban energy supply based on local conditions and low-carbon and efficient urban energy use, and proposes relevant suggestions for constructing sustainable urban low-carbon energy system for three types of cities in different geographical locations.

#### **4.6.1 Focus on Developing Urban Energy Supply based on Local Conditions**

According to the city's geographical location, resources and energy endowment, it is particularly important to focus on the development of urban energy supply methods that adapt to local conditions. According to the analysis in the "APEC Energy Outlook" report, under the BAU scenario, APEC will not be able to achieve the goal of "doubling the share of renewable energy in the APEC primary energy mix by 2030 compared to 2010". Based on this prediction, the large-scale development of renewable energy in APEC region has become a focus of concern. Through the analysis of excellent practical cases, solar energy, wind energy and smart grid are widely used in urban energy supply. Among them, the use of solar energy accounted for the largest share, especially the photoelectric application. The development of renewable energy has become a trend driven by the APEC energy goals. It is not hard to see the APEC's efforts in the development of renewable energy through the proportion of renewable energy applied in practice, such as solar energy and wind energy. However, in order to achieve the energy goals of APEC, the development of renewable energy based on local conditions will be the focus of future work. At the same time, the number of applications such as smart grid, multi-energy complementary system and comprehensive energy service is also increasing gradually. At the urban energy supply side, a comprehensive energy supply system has been built, ranging from single energy supply to multiple energy supply and from traditional power supply mode to intelligent regulation.

According to the energy supply forms of low-carbon energy system of three types of sustainable cities in different geographical locations, the following suggestions are proposed:

1. **Island cities:** Renewable energy applications mainly based on solar energy and wind energy should be expanded, while ocean energy should be vigorously developed.

2. **Peninsula cities:** It should expand the utilization of new energy and renewable energy in combination with its own resource and energy endowment, and promote the multi-energy complementary system at the same time.

3. **Inland cities:** Greater efforts should be made to develop smart grids and comprehensive energy services.

#### **4.6.2 Comprehensively Improve Low-carbon and Efficient Urban Energy Use**

Compared with urban energy supply, low-carbon and efficient urban energy use should be comprehensively improved in the sustainable urban low-carbon energy system. Through the analysis of urban energy use from the three dimensions of buildings, transportation, energy storage and energy management, it can be seen that the development of the three dimensions of sustainable urban low-carbon energy system is relatively balanced. Among them, the application of building energy conservation technologies, electric vehicles, and area energy management systems are widely used. Through the analysis of the energy use side forms of low-carbon energy systems in three types of sustainable cities in different geographical locations, the combination forms of energy efficient buildings and smart communities, low-carbon transportation and electric vehicles, and urban energy storage and energy management should be considered in all urban energy use.

According to the energy use forms of low-carbon energy system in sustainable cities, the following related suggestions are proposed:

1. **Technological innovation, energy conservation and emission reduction:** Efforts should be intensified to carry out technological innovations in the three dimensions of urban energy use side that energy-efficient buildings and smart communities, low-carbon transportation and electric vehicles, and urban energy storage and energy management.

**2. Comprehensive development and management:** Energy-efficient buildings, low-carbon transportation, and energy storage facilities at urban energy use side should be comprehensively constructed, and an integrated energy management system should be vigorously promoted for the integrated management of urban energy use.

**3. Improve awareness and education:** Urban energy use side is oriented towards users. Users' awareness of energy conservation and environmental protection should be enhanced, low-carbon behaviors should be encouraged, and sustainable concepts should be cultivated. At the same time, the training and publicity on the use of new technologies will be intensified to provide support for the use of low-carbon energy systems in sustainable cities.