Strategic Application of Small Modular Reactor in China's Energy Development

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CONTENT

P A R T 1

Major Challenges faced by Mankind in the 21st Century and the Role of Nuclear Energy

1.1 Major Challenges faced by Mankind in the 21st Century

Mankind in the 21st century is facing a series of major challenges, including energy, climate, and environment, water resources, food, poverty, war, disease and plague, education, population, democracy.

Among the above series of major challenges, there is only one that has truly become the consensus of all countries in the world. That is to control and improve the deteriorating climate change that threatens the living environment of human beings.

Countries all over the world plans to achieve carbon neutrality goals set by the UN Paris Convention:

- The average global temperature rising should be controlled within 2℃ compared with pre-industrialization, and strive to limit it to within 1.5 ℃

1.1 Major Challenges faced by Mankind in the 21st Century

Reaching the goals of the Paris Convention is far more difficult for our country and most developing countries, especially developing countries in Asia, than those countries that achieved industrialization earlier such as many European countries and the United States.

To achieve the goals of the Paris Convention, the key is to speed up the adjustment of the energy structure and adopt new energy sources or innovative measures, including:

- ✓ Renewable energy such as solar and wind
- ✓ Nuclear energy, especially new nuclear energy
- ✓ carbon capture and storage

1.2 the Role of Nuclear Energy

Nuclear energy can play a major role in at least three aspects of energy, environment (climate) and water resources, mainly reflected in the following aspects:

(1) Nuclear energy (including fission energy and fusion energy) is an important energy resource that can permanently provide human beings with a safe, economical and reliable supply of electricity and heat on a large scale;

(2) Nuclear energy is clean energy, which does not emit carbon dioxide, and it plays a major role in improving the ecological environment and controlling climate change;

(3) The relationship between nuclear energy and other clean energy is not a competitive relationship that restricts each other, but a coordinated development relationship that promotes each other.

(4) Nuclear energy can be used not only for power generation, but also for heat supply, seawater desalination, hydrogen production...

1.2 the Role of Nuclear Energy

- In July 2021, the International Atomic Energy Agency(IAEA) has released the latest edition of report of the International State and Prospects of Nuclear Power which highlights the irreplaceable role that nuclear energy will play in mitigating climate change and achieving sustainable development.
- Projections for 2050 suggest that to achieve the goals of the Paris Agreement, current nuclear power capacity will need to be at least doubled by 2050.
- It is the key to deal with the ten relations of nuclear energy development, especially in the following aspect:

√ Further enhance the safety of nuclear energy while improving the competitiveness (economic) of nuclear energy;

√ Assure the guarantee capability of nuclear energy development and Uranium resources;

√ Expand the scope of nuclear energy applications, and actively develop small modular reactors;

√ Radioactive waste and spent fuel disposal;

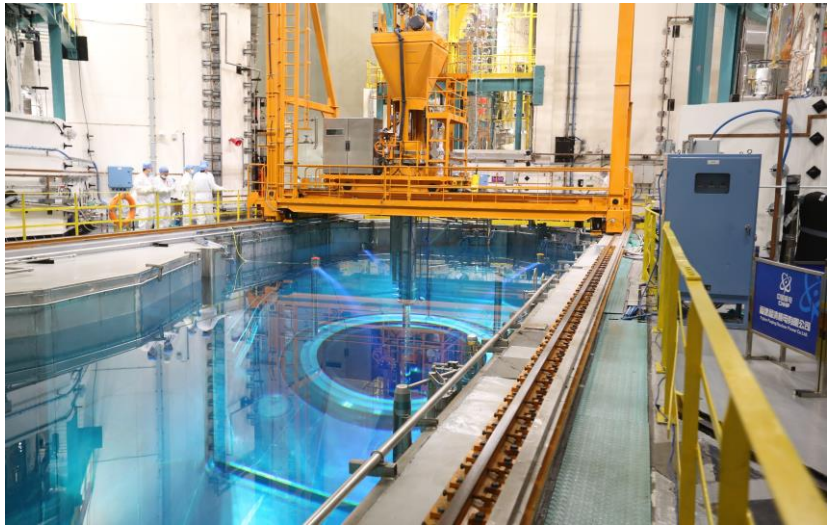
√ Public acceptance (handling security issues and the stakeholder relationships well);

√ Coordinate development relationship with other clean energy sources;

√ Attract social capital to invest in nuclear energy, improve financing capabilities, etc.

1.3 China’s great achievements in nuclear energy development

1. Formed a complete nuclear power industry industrial chain system;
2. By the end of 2021, there are 53 nuclear power units in operation, 16 units are under construction, and the total installed capacity in operation is 54.6 million kilowatts, which is the second largest in the world and has a good operating performance.
3. Formed a strong technological innovation capability, developed the third-generation nuclear power technology Hualong One and CAP1400 with independent intellectual property rights. Important achievements have been made in the research and development of the fourth-generation nuclear energy system, small modular reactors and fusion reactors, which have created a strong foundation for the future development of our country's nuclear power and its going global.

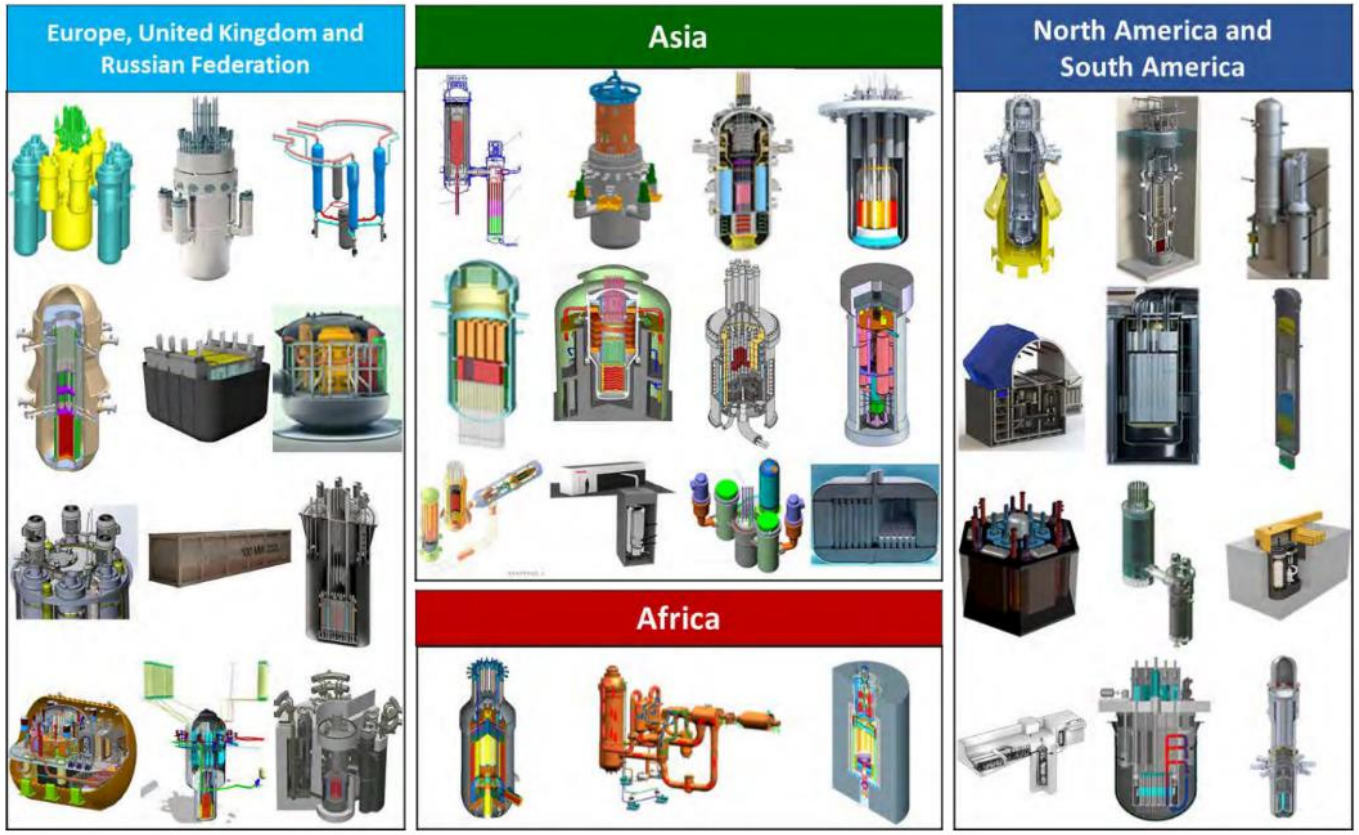


P A R T 2

Small Modular Reactors(SMR) Have Become a Hot Spot for Global Nuclear Energy Development

2.1 Development Status of Small Modular Reactors Abroad

In the past 20 years, in order to adapt to the general trend of global energy decarbonization, countries with developed nuclear energy have been striving to expand the scope of nuclear energy application, and the development of multi-purpose small modular reactors has become a hot spot in global nuclear energy development. 72 small modular reactors technologies are included according to the “Advances in Small Modular Reactor Technology Developments” published by the IAEA in 2020.

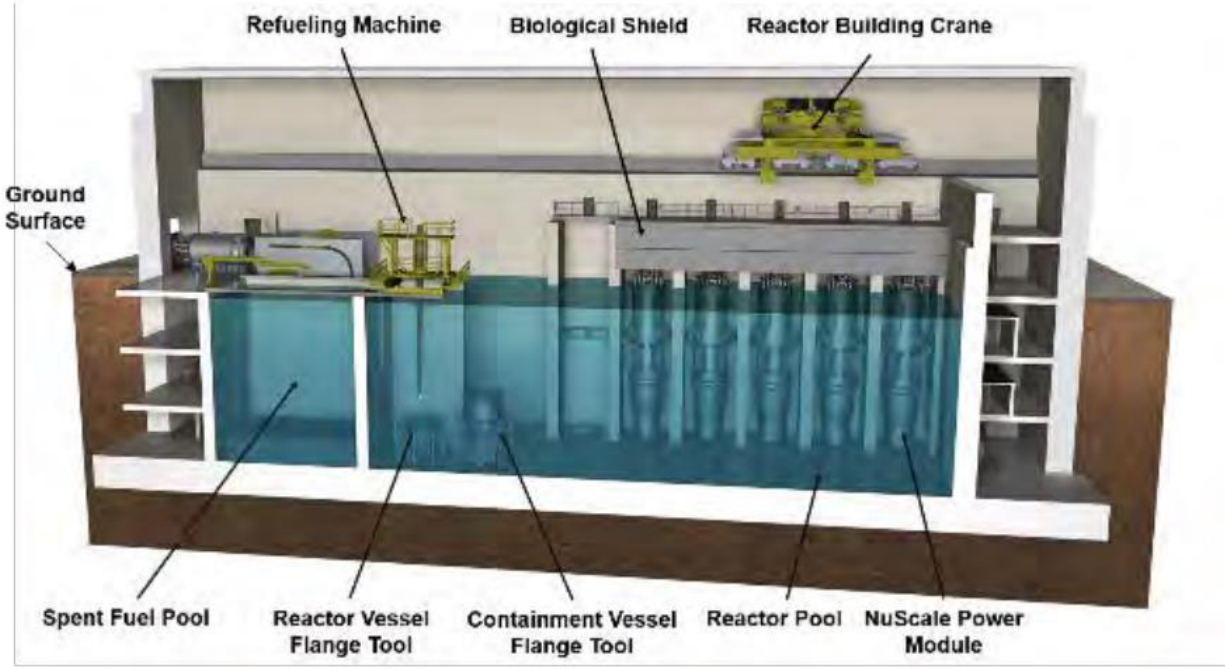


2.2 International Typical Small Modular Reactors

(1) NuScale (NuScale Power, LLC, United States of America)

The NuScale Power Module™ (NPM) is a small, light-water-cooled pressurized-water reactor (PWR). NuScale design is a modular reactor for electricity production and non-electrical process heat applications, and also for reducing carbon dioxide emissions. The NuScale plant is scalable and can flexibly add NPMs to meet different demands.

In 2016, NuScale Power submitted the Design Certification Application (DCA) to the NRC. The design certification review is on track with final design approval expected in 2021. The first plant has a target commercial operation date of 2027 for the first plant, to be built in Idaho.



2.2 International Typical Small Modular Reactors

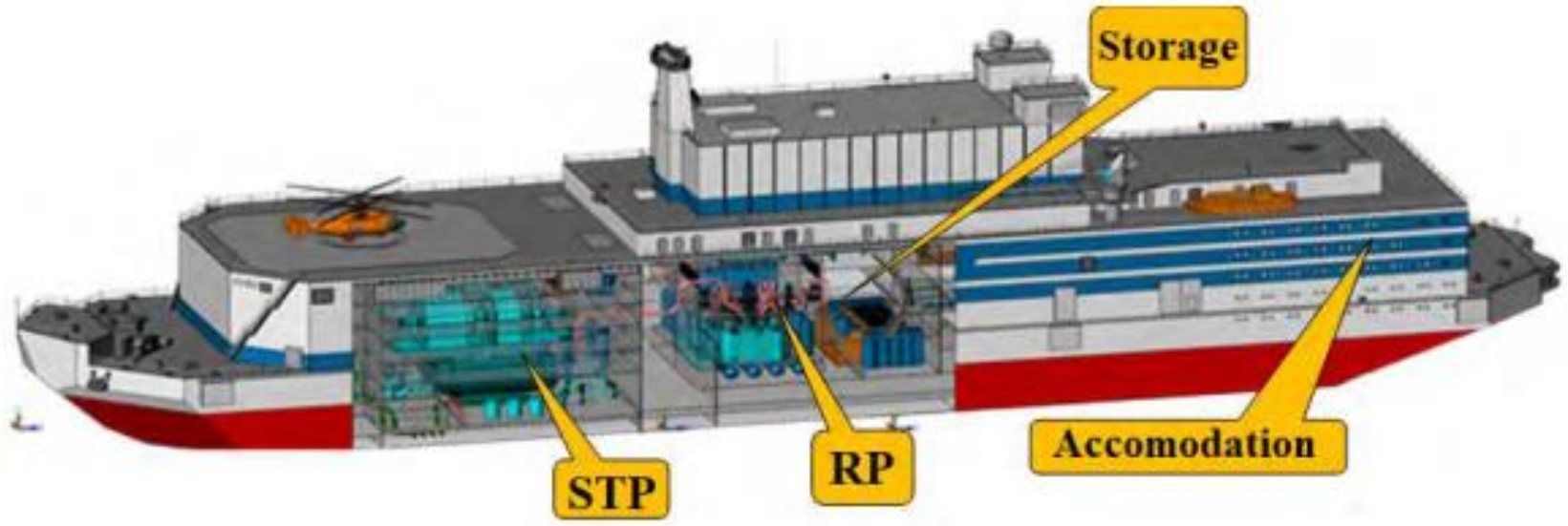
Parameter	Value
Complete power plant	
Nominal net output electric power (deduct auxiliary power)	570MWe
NPM	12
NPM	
Reactor Type	Integral PWR
Coolant/moderator	Light water
Thermal/electrical capacity	160 MW(t) / 50 MW(e)
Primary Circulation	Natural circulation
System Pressure	12.8 Mpa
Core Inlet/ Outlet Coolant Temperature	258℃/314℃
Evaporator	Two inter-woven once-through helical-coil steam generators, Subcritical superheated regeneration steam
Core	
Assembly array	17x17 square
Number of fuel assemblies in the core	37
Reactivity control mechanism	Control rod drive, boron
Approach to safety systems	Passive
Design life (years)	60
RPV height/diameter (m)	17.8/3.0

Table： Main technical parameters of NuScale

2.2 International Typical Small Modular Reactors

(2) KLT-40S (JSC “Afrikantov OKBM”, Russian Federation)

The KLT-40S is a PWR developed for a floating nuclear power plant (FNPP), which is intended to provide cogeneration capabilities for power and heat supply to isolated consumers in remote areas. It has started commercial operation in December 19th 2019 in the town of Pevek in Chukotka region.



2.2 International Typical Small Modular Reactors

Parameter	Value
Thermal Capacity	150MW
Electrical Capacity	70MW (Rated)
	38MW (Maximal)
Heating	50 Geal/h (Rated)
	146.8 Geal/h (Maximal)
Primary Loop Pressure	12.7 Mpa
Primary Loop Temperature	350℃
Steam Production	240t/h
Steam Pressure	3.82MPa (abs)
Steam Temperature	290℃
Refuelling Cycle	30-36 months
Design Life	40 years
Platform Size	140 x 30 x 10 (m)
Total Drainage Quantity	~21000t

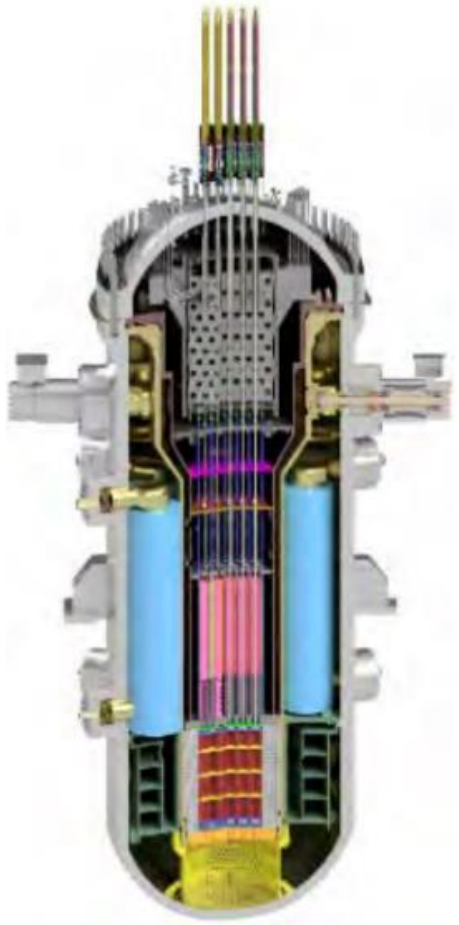
Table： Main technical parameters of NuScale

2.2 International Typical Small Modular Reactors

(3) SMART (KAERI, Republic of Korea and K.A.CARE, Saudi Arabia)

The System-integrated modular advanced reactor (SMART) is an integral PWR. It is a multi-purpose application reactor for electricity production and sea water desalination.

The R & D of SMART started in 1997. Korea Atomic Energy Research Institute (KAERI) received the standard design approval from Korean Nuclear Safety and Security Commission (NSSC) in 2012. A safety enhancement program to adopt passive safety system in SMART began in March 2012, and the testing and verification of the PRHRS and PSIS were completed in the end of 2015. In 2015, a pre-project engineering agreement was signed between the Republic of Korea and the Kingdom of Saudi Arabia for deployment of SMART. This PPE project was successfully completed in 2019.



2.2 International Typical Small Modular Reactors

Parameter	Value
Thermal/Electrical Capacity	330MWt / 100MWe
Thermal Cycle Type/Efficiency	Indirect Rankine cycle/30.3%
Primary Coolant/Circulation	Light water/Forced circulation
Primary Loop Pressure	15 MPa
Core Inlet/Outlet Coolant Temperature	296℃/323℃
Core Diameter x Height	1831.6mm x 2000mm
Fuel Type/Fuel Enrichment	UO_2 / 4.8% , U-235
Refuelling Cycle	30 months
Plant Footprint	90 000m^2
Reactivity Control Mechanism	Control rod driving mechanisms and soluble boron

Table： Main technical parameters of NuScale

2.3 Technical Trend and Characteristics of International Small Modular Reactor Technology Development

There are more than 30 countries using nuclear power in the world, but only more than 10 countries have the capacity to develop small modular reactors. Among them, the United States and Russia account for half of the total number of small modular reactors under development and construction in the world.It is not difficult to see that the two countries attach great importance to and make efforts in developing new fields of nuclear energy application from the strategic perspective of long-term utilization of nuclear energy.

PART 3

Development Status and Market Prospects of Small Modular Reactors in China

3.1 Development Status of Small Modular Reactors in China

In order to expand the scope of nuclear energy application and meet the needs of low-carbon energy development, over the past 10 years, many R&D institutes have actively developed various small modular reactor technologies in different application fields and market demands. Some of these small modular reactor technologies are under construction or will soon be under construction.

3.1 Development Status of Small Modular Reactors in China

China's small modular reactors have extensive demand and development prospects in various fields of the national economy, and will play an important role in achieving low-carbon energy.

(1) Replace the backward thermal power capacity

- During the 13th Five-Year Plan period, the construction of coal-fired power generation capacity was suspended or postponed to 150 million kilowatts, and the backward production capacity was eliminated by more than 20 million kilowatts. In particular, it is necessary to phase out and shut down coal-fired power units below 300000 kilowatts that do not meet the requirements, and include coal-fired self-contained units in the scope of phase out. The above policies bring development opportunities to small modular reactors.
- At present, the technology of replacing small-scale thermal power with small modular reactor technology at the original site in China is basically mature and has a promising future. As this technology is a new thing, in addition to the economy and the public's concern about safety, the market development needs to be strengthened. Small modular reactors have advantages for power supply in remote areas, large and medium-sized enterprises, and cogeneration power supply in industrial parks. In countries and regions with small power grids and lack of other clean energy, electric power generation with small modular reactors is more suitable.

- Applicable types: ACP100, HTR-PM-200, etc.

3.1 Development Status of Small Modular Reactors in China

At present, the construction of Hainan Changjiang multi-purpose small modular reactor science and technology demonstration project (ACP100) developed by CNNC has been started in July this year. The reactor has a power of 125MWe and a construction period of 58 months. It can be used for power generation and cogeneration.

Parameter	Value
Reactor type	Integral PWR
Coolant	Light water
Thermal/electrical capacity, MW(t)/MW(e)	385 / 125
Refuelling Cycle (months)	24
Design life (years)	60
RPV height/diameter (m)	10 / 3.35
Number of fuel assemblies in the core	57
Reactivity control mechanism	Control rod drive mechanism (CRDM), Gd2O3 solid burnable poison and soluble boron acid

Table： Main parameter of ACP100

3.1 Development Status of Small Modular Reactors in China

(2) Domestic and industrial heating

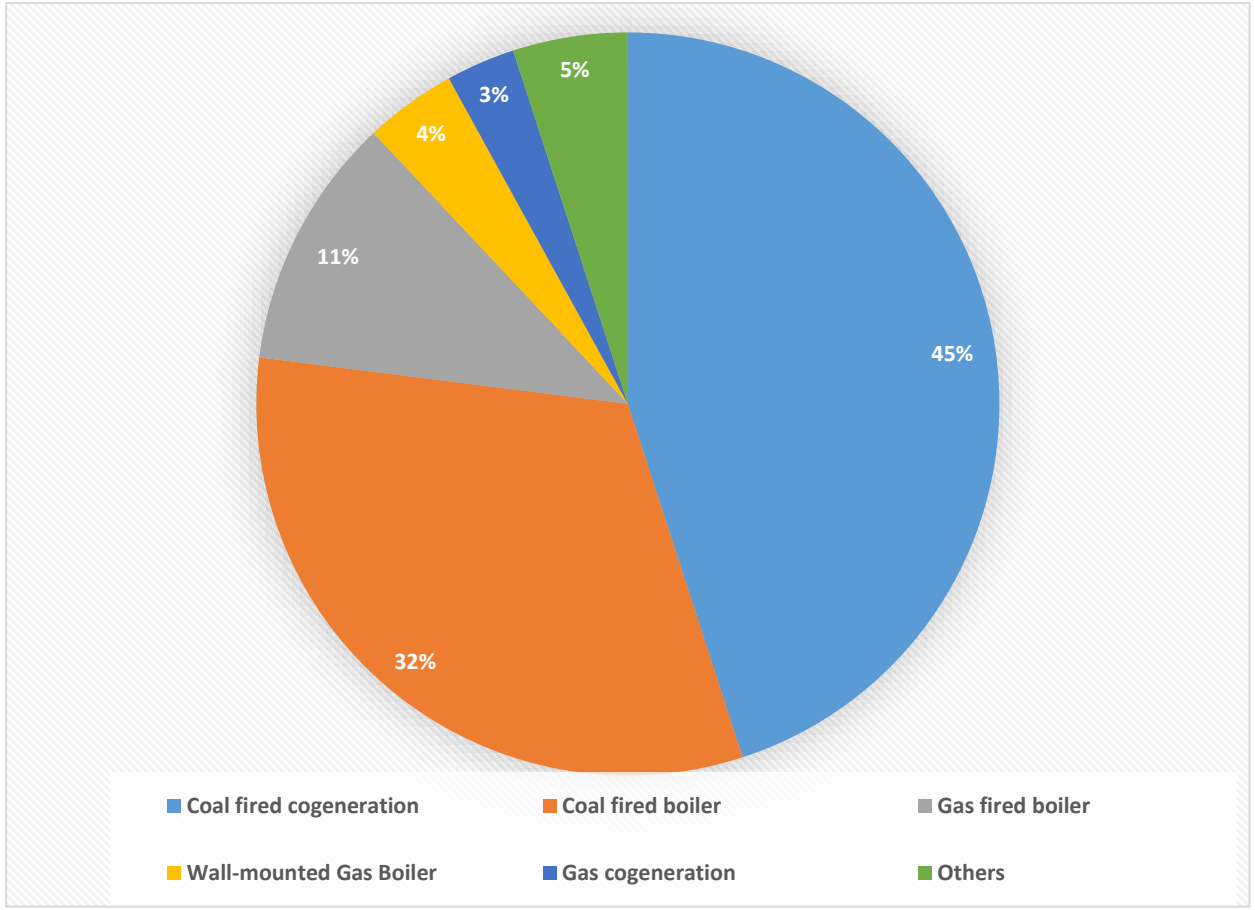
- According to the China Statistical Yearbook of 2020 published by the National Bureau of statistics, China's total heat supply increased slowly from 2013 to 2019. In 2019, the total amount of steam heating in China was about 651 million gigajoules, which has an increase of 12.71% over 2018. The total amount of hot water heating is about 3.275 billion GJ, which has an increase of 1.18% over 2018. Steam heating is mainly used in enterprises or industrial parks in petroleum, chemical, metallurgy, paper, and other industries. Hot water heating is mainly used for urban household heating, especially in northern China.
- In December 2017, the national development and Reform Commission and other ten ministries and commissions jointly issued the Planning for Clean Heating in Winter in Northern China (2017-2021) and the Three-year Action Plan to Fight Air Pollution in 2018. Both proposed to effectively promote clean heating in northern China, and made great achievements. The air quality was greatly improved, the pollution was less, and the blue sky was more. However, the heat source was mainly high-quality fossil fuels.
- Nuclear heating technology is mature and has broad application prospects in the field of low-carbon heating, but whether it can be adopted depends on many factors. The public's concern about safety, the price acceptance ability, and the attitude of governments at all levels are the main challenges.

- Applicable types: ACP100, HTR-PM-200, CAF150, NHR200-II, DHR-400, etc.

3.1 Development Status of Small Modular Reactors in China

(2) Domestic and industrial heating

- Heat source. The heat source of urban central heating in China has basically formed a pattern in which CHP is the main heat source, regional boiler room is the auxiliary, and other heat sources are supplemented. 80% of the heat source carbon uses coal as the main fuel, and coal-fired boilers, gas-fired boilers, and coal-fired cogeneration are the main heating methods. In the dominant central heating, cogeneration and boilers are the main ones, with coal-fired cogeneration accounting for 45%, coal-fired boilers accounting for 32%, gas-fired boilers accounting for 11%, and other sources. The backward production capacity with high pollution and low efficiency exceeds 50%.



3.1 Development Status of Small Modular Reactors in China

(2) Domestic and industrial heating

- Heating area. The urban central heating area in the northern is about 13.1 billion ㎡, the urban central heating area is about 11 billion m^2, and the central heating rate is about 85%. Among them, the residential building area was 8.2 billion m^2, accounting for 75%, and the public building area was 2.8 billion m^2, accounting for 25%. With the development trend of urbanization, the area that needs heat supply in the north is increasing.
- Industrial steam supply. China's industrial steam supply demand is large and growing rapidly, and nuclear energy has great development space. Under the guidance of the "carbon peaking and carbon neutrality goals", it is expected that by 2030, the potential market size of small modular reactors in this field will reach 6000 MWt. The replacement of traditional fossil energy by small modular reactor nuclear energy for industrial steam supply has been actively and steadily promoted in many industrial parks through demonstration projects.

Small Modular Reactor Heating Demonstration Project Under Promotion

- CAF150, developed by the State Power Investment Corporation, is being actively and orderly promoted as the Jiamusi nuclear heating demonstration project. The project plans to build a 4 x 200MWt integrated heating reactor. The first phase of the project is 2 x 200MWt, the maximum heating capacity is 8 million square meters, or the steam supply is 500 tons / hour. The project is planned to start in 2021 with a construction period of 36 months.

Parameter	Value
Core rated power	200MWt
Design life	60 years
Refuelling Cycle	24 months
Normal operating pressure of reactor coolant system	9.0 Mpa(a)
Core Inlet/Outlet Coolant Temperature	202℃/272℃

Table: Main parameter of CAF150

Small Modular Reactor Heating Demonstration Project Under Promotion

- The low-temperature heating reactor NHR200-II jointly developed by CGN and Tsinghua University is actively and orderly promoted as the preliminary work of Guizhou low-temperature heating reactor commercial demonstration project with the support of government departments at all levels. The project plans to build six NHR200-II low-temperature nuclear heating units, two in phase I, to provide industrial steam (500t / h) for Guizhou Dalong Economic Development Zone. The first one is planned to start in December 2022, which is the first commercial application of comprehensive utilization of nuclear energy and low-temperature heating technology in China.

Parameter	Value
Thermal/Electrical Power	200MWt / 50MWe
Design Life	60 years
Normal Operating Pressure of Reactor Coolant System	8.0 Mpa(a)
Core Inlet/Outlet Coolant Temperature	232℃/280℃
Steam Output	323 t/h

Table: Main parameter of NHR200-II

Small Modular Reactor Heating Demonstration Project Under Promotion

- The DHR-400 pool type low-temperature heating reactor developed by CNNC is currently carrying out a demonstration project in Liaoyuan, Jilin Province. The heating area of a single reactor is about 10 million square meters. It is planned to achieve FCD in 2022 and be completed and put into operation in 2024.

Parameter	Value
Reactor type	Split reactor
Design Life	60 years
Refuelling Cycle	15 months
Reactor thermal power / efficiency	400MWt / 98%
Pool diameter / height	10.0m / 26.0m
Core height / equivalent diameter	2.4m / 2.02m
Core Inlet/Outlet Coolant Temperature	68℃ / 98℃

Table: Main parameter of DHR-400 pool

Small Modular Reactor Heating Demonstration Project Under Promotion

The demonstration project of Shidaowan high temperature gas cooled reactor nuclear power station(HTR-PM-200) was led by China Haneng, jointly constructed by Tsinghua University and China Nuclear Power Group, with an installed capacity of 200000 kW(2 x 250MWt). The construction was started in Rongcheng, Shandong Province in December 2012. HTR-PM-200 adopts a pebble bed high temperature gas-cooled reactor. The primary heat carrier is helium. The core inlet temperature is 250 ° C and the outlet helium temperature is 750 ° C. The conventional island adopts the mature superheated steam turbine cycle scheme, with two stacks and one unit.

HTR-PM-200 is planned to be completed and put into operation within the year.

Parameter	Value
Thermal/Electrical Power	2 x 250MWt / 211MWe
Core Height / Diameter	11m / 3m
Helium Pressure	7MPa
Core Inlet/Outlet Coolant Temperature	250℃ / 750℃
Main Steam Temperature	500-570℃
Main Seam Pressure	11-13.5MPa

Table: Main parameter of HTR-PM-200

3.2 Market demand prospect of small modular reactors in China

(3) Seawater desalination and hydrogen production

- Water resources in North China and some coastal areas are seriously insufficient. According to statistics, the total area of water shortage in North China is 580000 square kilometers. There are more than 300 cities in China that lack water to varying degrees, with an annual water shortage of 5.8 billion cubic meters, mainly concentrated in North China, some coastal and provincial capitals and industrial cities. There are 6 provinces and districts with per capita water resources less than 500 cubic meters.
- The market for seawater desalination is very large, and it exceeded 1 million tons / day in 2015. It is estimated that by 2030, the small modular reactors used for seawater desalination in China will reach 1000 MWT, and the prospect of "going out" is promising. Economy is the core issue affecting the promotion and application of nuclear seawater desalination. At present, the cost of nuclear seawater desalination in China is 5 yuan per cubic meter, which is basically the same as the price of commercial water.

3.2 Market demand prospect of small modular reactors in China

(3) Seawater desalination and hydrogen production

- Hydrogen production is developing rapidly at home and abroad (especially in the Middle East), and hydrogen will be widely used in the future energy market. Many countries regard hydrogen energy as the future energy. In the Research Report on the Development of China's Hydrogen Energy and Fuel Cell Industry released in 2018, it is mentioned that by 2050, hydrogen will account for at least 10% of China's end-use energy system and become an important part of China's energy strategy. Ultra high temperature gas cooled reactor with core outlet temperature of 950-1000 ℃ will play an important role in the field of nuclear hydrogen production.

- Applicable types: HTR-PM-200, ACP100, CAF150, etc.

Thanks for watching