# **Nuclear Power in China**

www.world-nuclear.org/info/.../China--Nuclear-Power/ (Updated January 2015)

Tianwan 1&2 Costs \$1500/kW see p. 33 Tianwan 3&4 Costs \$1790/kW see p. 47

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- Mainland China has 23 nuclear power reactors in operation, 26 under construction, and more about to start construction.
- Additional reactors are planned, including some of the world's most advanced, to give more than a three-fold increase in nuclear capacity to at least 58 GWe by 2020, then some 150 GWe by 2030, and much more by 2050.
- The impetus for increasing nuclear power share in China is increasingly due to air pollution from coal-fired plants.
- China's policy is for closed fuel cycle.
- China has become largely self-sufficient in reactor design and construction, as well as other aspects of the fuel cycle, but is making full use of western technology while adapting and improving it.
- China's policy is to 'go global' with exporting nuclear technology including heavy components in the supply chain.

Most of mainland China's electricity is produced from fossil fuels, predominantly from coal. Two large hydro projects are recent additions: Three Gorges of 18.2 GWe and Yellow River of 15.8 GWe. In 2012 gross electricity generation was 4994 TWh (not including Hong Kong) on IEA figures, this being 3785 TWh from coal, 86 TWh from gas, 97 TWh from nuclear, 872 TWh from hydro, and 147 TWh from non-hydro renewables. Net export to Hong Kong was 10 TWh, adding to its 39 TWh generation (27 TWh from coal, 11 TWh from gas). Rapid growth in demand has given rise to power shortages, and the reliance on fossil fuels has led to much air pollution. The economic loss due to pollution is put by the World Bank at almost 6% of GDP, <sup>1</sup> and the new leadership from

March 2013 has prioritised this.\* Chronic and widespread smog in the east of the country is attributed to coal burning.

\* Official measurements of fine particles in the air measuring less than 2.5 micrometres, which pose the greatest health risk, rose to a record 993 micrograms per cubic metre in Beijing on 12 January 2013, compared with World Health Organization guidelines of no higher than 25.

The State Council expected CNY 2.37 trillion (\$380 billion) to be spent on conservation and on emissions cuts in the five years through 2015. In August 2013 it said that China should reduce its carbon emissions by 40-45% by 2020 from 2005 levels, and would aim to boost renewable energy to 15% of its total primary energy consumption by 2020. In 2012 China was the world's largest source of carbon emissions – 2626 MtC (9.64 Gt CO<sub>2</sub>), and its increment that year comprised about 70% of world total increase. In March 2014 the Premier said that the government was declaring "war on pollution" and would accelerate closing coal-fired power stations. In November 2014 the Premier announced that China intended about 20% of its primary energy consumption to be from non-fossil fuels by 2030, at which time it intended its peak of CO<sub>2</sub> emissions to occur. The distribution of energy resources relative to demand poses some challenges, notably for north-south coal transport and east-west power transmission.

<u>Electricity consumption</u> in 2012 rose only 5.5% to 4.9 trillion kWh, and it was expected to grow between 6.5% and 8.5% in 2013. In 2011 it rose 11.7% to 4693 billion kWh, according to the China Electricity Administration. Its 2010 increase of 14.56% to 4190 billion kWh corresponded with a 10% growth in GDP, according to the China Electricity Council. Some 3090 billion kWh of this (74%) was in industry.

Nuclear power contributed 2.1% of the total production in 2013 – 105 billion kWh according to IAEA. In 2011 coal provided 3723 TWh, gas 84 TWh and hydro 699 TWh.

<u>Installed generating capacity</u> at the end of 2012 reached 1145 GWe 19% up in two years. Capacity growth is expected to slow, reaching about 1600 GWe in 2020, and 2000 GWe in 2025. Coal accounted for 59% of the newly-added capacity in 2012.

At the end of 2010, fossil fuelled capacity (mostly coal) reached 707 GWe, hydro capacity was 213 GWe (up 16.6 GWe in the year), nuclear capacity was 10.8 GWe and wind capacity reached 31 GWe. Investment in electricity dropped to CNY 705 billion (\$107 billion) for the year. A 2013 report from the NDRC said that China added 15 GWe of wind energy capacity in 2012 and 3 GWe of solar. It endorsed targets to add 21 GWe of hydroelectric capacity, 18 GWe of wind and 10 GWe of solar in 2013. Another 12 GWe of solar PV is to be added in 2014, and a target of 70 GWe for 2017 announced. A further 100 GWe of wind capacity is expected over 2014-18.

These capacity increase figures are all the more remarkable considering the forced retirement of small inefficient coal-fired plants: 26 GWe of these was closed in 2009 and 11 GWe in 2010, making 71 GWe closed since 2006, cutting annual coal consumption by about 82 million tonnes and annual carbon dioxide emissions by some 165 million tonnes. China is well advanced in developing and deploying supercritical and ultra-supercritical coal plants, as well as moving quickly to design and deploy technologies for integrated (coal) gasification combined cycle (IGCC) plants. Nevertheless it consumed about 4.3 billion tonnes of coal in 2013, more than half the world total, and coal comprised more than 70% of China's primary energy. By 2020 it is expected to use some 5 billion tonnes of coal annually, while aiming to cut consumption in the northern areas spanning Beijing, Hebei, and Tianjin.

The grid system run by the State Grid Corporation of China (SGCC) and China Southern Power Grid Co (CSG) is sophisticated and rapidly growing, utilising ultra high voltage (1000 kV AC and 800 kV DC) transmission. By 2015 SGCC is investing CNY 500 billion (\$75.5 billion) to extend the UHV grid to 40,000 km. By 2020, the capacity of the UHV network is expected to be some 300 GW, which will function as the backbone of the whole system, having 400 GWe of clean energy sources connected, of which hydropower will account for 78 GW, and wind power from the north a further significant portion. At present up to half of the wind output is wasted – 2.8 TWh in 2012, because of limited grid connections, according to a China Daily report. At the end of 2009, China had budgeted to spend \$600 billion upgrading its grid. By 2020 operational transmission losses are expected to be 5.7%, down from 6.6% in 2010.

Among the main listed generators, Huaneng Power produced 203.5 billion kWh from its domestic plants in 2009, 10.2% up on 2008. Datang Power produced 141.9 billion kWh, 12% up on 2008. Huadian Power produced 107.5 billion kWh, 6.75% above 2008. CPI Development produced 43.9 billion kWh, 2.0% above 2008 level. The main nuclear operators are China National Nuclear Corporation (CNNC) and China General Nuclear Power Group (CGN).

Electricity generation is only one part of China's rapid development; roads, air transport and a 16,000 km high-speed rail system (powered by electricity) by 2020 are others. A record 486 km/h rail speed between Beijing and Shanghai was achieved in 2010, and by January 2011, 8358 km of 200 km/hr+ track was operational. By the end of 2011, 13,073 km of such track is expected to be in service after further investment of CNY 700 billion (\$106 billion). Also the world's longest bridge – the 42 km Qingdao Haiwan bridge in Shandong province is being built.

## Energy policy and clean air

While coal is the main energy source, most reserves are in the north or northwest and present an enormous logistical problem – nearly half the country's rail capacity is used in transporting coal. Because of the heavy reliance on old coal-fired plant, electricity generation accounts for much of the country's air pollution, which is a strong reason to increase nuclear share. China has overtaken the USA as the world's largest contributor of carbon dioxide emissions.\* Gas consumption in 2013 was forecast to be 165 billion cubic metres, up 11.9% on 2012. China has shale gas resources, but much of it is in the northwest which is very arid, so water supply is a constraint. By 2035 the US Energy Information Administration expects China's gas to come equally from conventional, coal bed and shale sources.

\* The US Energy Information Administration predicts that China's share in global coal-related emissions will grow by 2.7% per year, from 4.9 billion tonnes in 2006 to 9.3 billion tonnes in 2030, some 52% of the projected world total. Total carbon dioxide emissions in China are projected to grow by 2.8% per year from 6.2 billion tonnes in 2006 to 11.7 billion tonnes in 2030 (or 28% of world total). In comparison, total US carbon dioxide emissions are projected to grow by 0.3% per year, from 5.9 billion tonnes in 2006 to 7.7 billion tonnes in 2030.

China's energy consumption per unit of gross domestic product met a target reduction of 20% from 2005 levels by the end of 2010, according to the National Development and Reform Commission (NDRC). The energy intensity targets for the following five years are expected to be about 17%. Per capita electricity consumption was 3510 kWh in 2012.

In March 2013 the NDRC announced new plans for seawater desalination.\* China aims to produce 2.2 million m3/day of desal water by 2015, more than three times the 2011 level. More than half of the freshwater channelled to islands and more than 15% of water delivered to coastal factories will come from the sea by 2015, according to the plan.

\* The list includes the cities of Shenzhen and Zhoushan, Luxixiang Island in Zhejiang Province, Binhai New Area in Tianjin, Bohai New Area in Hebei, and several industrial parks and companies. The NDRC has asked the listed regions and companies to actively promote the application of desalted water and encourage its use in daily supplies. The cost is likely to be some CNY 21 billion (\$3.35 billion).

A white paper on Energy Policy was released by the State Council on 24 October 2012. This included raising the proportion of clean, low-carbon fossil energy and non-fossil energy in the energy mix, and promoting the efficient and clean utilization of coal. It aims to increase the shares of non-fossil fuels in primary energy consumption. "China will invest more in nuclear power technological innovations, promote application of advanced technology, improve the equipment level, and attach great importance to personnel training. China's installed capacity of nuclear power is expected to reach 40 GWe by 2015." The installed generating capacity of wind power is expected to reach 100 GWe by the end of 2015, and that of solar energy is expected to exceed 21 GWe by then, with a total solar heat collection area of 400 million square metres.

In September 2014 a national climate change plan prepared by NDRC was approved by the State Council. This set emission and clean energy targets for 2020. The carbon emission intensity target is 40-45% reduction from 2005 to 2020, with good progress of almost 29% by the end of 2013. It aims to increase the shares of non-fossil fuels in primary energy consumption to about 15% by 2020 – at the end of 2013 it was 9.8%. The plan also sets the target for China to increase forest coverage by 40 million hectares within the next five years to 2019. The government said it would speed up efforts to establish a carbon emission permit market, as well as deepening international cooperation under the principles of "common but differentiated responsibilities," equity, and respective capability. UN emission reduction targets after 2020 are likely to be addressed in the 13th Five-Year Plan about 2016.

The State Council published the *Energy Development Strategy Action Plan, 2014-2020* in November 2014. The plan aims to cut China's reliance on coal and promote the use of clean energy, confirming the 2012 target of 58 GWe nuclear in 2020, with 30 GWe more under construction. The plan calls for the "timely launch" of new nuclear power projects on the east coast and for feasibility studies for the construction of inland plants. It says that efforts should be focused on promoting the use of large pressurized water reactors (including the AP1000 and CAP1400 designs), high temperature gas-cooled reactors (HTRs) and fast reactors. It also says that research should be conducted to "improve the nuclear fuel cycle system" including reprocessing of used fuel.

More broadly, the share of non-fossil fuels in the total primary energy mix should increase from 9.8% in 2013 to 15% in 2020, while coal's share shrinks from 67% to 62%, according to the plan. Installed generating capacity of hydro, wind and solar power is expected to reach 350 GWe, 200 GWe and 100 GWe, respectively, by 2020.

## Nuclear power

Nuclear power has an important role, especially in the coastal areas remote from the coalfields and where the economy is developing rapidly. Generally, nuclear plants can be built close to centres of demand, whereas suitable wind and hydro sites are remote from demand. Moves to build nuclear power commenced in 1970 and about 2005 the industry moved into a rapid development phase. Technology has been drawn from France, Canada and Russia, with local development based largely on the French element. The latest technology acquisition has been from the USA (via Westinghouse, owned by Japan's Toshiba) and France. The State Nuclear Power Technology Corporation (SNPTC) has made the Westinghouse AP1000 the main basis of technology development in the immediate future, particularly evident in the local development of CAP1400 based on it.

This has led to a determined policy of exporting nuclear technology, based on China's development of the CAP1400 reactor with Chinese intellectual property rights and backed by full fuel cycle capability. The policy is being pursued at a high level politically, utilising China's economic and diplomatic influence, and led by the initiative of CGN commercially, with SNPTC and most recently CNNC in support.

By around 2040, PWRs are expected to level off at 200 GWe and fast reactors progressively increase from 2020 to at least 200 GWe by 2050 and 1400 GWe by 2100.

Prior to 2008, the government had planned to increase nuclear generating capacity to 40 GWe by 2020 (out of a total 1000 GWe planned), with a further 18 GWe nuclear being under construction then. However, projections for nuclear power then increased to 70-80 GWe by 2020, 200 GWe by 2030 and 400-500 GWe by 2050. Following the Fukushima accident and consequent pause in approvals for new plants, the target adopted by the State Council in October 2012 became 60 GWe by 2020, with 30 GWe under construction. National policy has moved from 'moderate development' of nuclear power to 'positive development' in 2004, and in 2011-12 to 'steady development with safety'. See further comment under Post-Fukushima Review below. Then in 2014 the NEA announced that it was aiming for world leadership in nuclear technology, with detailed plans to come in April 2015. The precise direction and priorities of such plans are likely to be strongly contested among the likely players, notably CNNC, CGN and SNPTC.

In December 2011 the National Energy Administration (NEA) said that China will make nuclear energy the foundation of its power-generation system in the next "10 to 20 years", adding as much as 300 GWe of nuclear capacity over that period. Two weeks earlier the NDRC vice-director said that China would not swerve from its goal of greater reliance on nuclear power. In September 2013 SNPTC estimated that 4-6 new units per year would be needed to 2015 then 6-8 units during the 13th Five-Year Plan Period (2016-2020), increasing to 10 units each year after 2020. In December 2014 the NEA said that China could manufacture eight full sets of reactor equipment per year.

In September 2010, the *China Daily* reported that China National Nuclear Corporation (CNNC) alone planned to invest CNY 800 billion (\$120 billion) into nuclear energy projects by 2020. In order to fund the company's expansion target, CNNC planned to list its subsidiary, CNNC Nuclear Power Co Ltd in 2011, to attract strategic investors, but this apparently did not occur.

In July 2013 the NDRC set a wholesale power price of CNY 0.43 per kWh (7 US cents/kWh) for all new nuclear power projects, to promote the healthy development of nuclear power and guide investment into the sector. The price is to be kept relatively stable but will be adjusted with technology advances and market factors, though many consider it not high enough to be profitable. It is reported that the price for power from Sanmen may in fact be about 5% higher. Nuclear power is already competitive, and wholesale price to grid has been less than power form coal plants with flue gas desulfurization, though the basic coal-fired cost is put at CNY 0.3/kWh.

## **Hong Kong supply**

Hong Kong gets much of its power from mainland China, in particular about 70% of the output from Daya Bay's 1888 MWe net nuclear capacity is sent there. A 2014 agreement increases this to 80%. The Hong Kong government plans to close down its coal-fired plants, and by 2020 to get 50% of its power from mainland nuclear (now 23%), 40% from gas locally (now 22%) and 3% from renewables. Another option, with less import dependence, is to increase domestic generation from gas to 60%, and maintain mainland nuclear at 20%.

Hong Kong utility China Light & Power has equity in CGN's Daya Bay (25%) power plant, is negotiating concerning a possible 17% share in Yangjiang, and may take equity in a further CGN nuclear plant. Since 1994 it has been getting up to one-third of its power from Daya Bay output, and this contract now runs to 2034. According to CLP data, nuclear power cost HK 47 c/kWh in November 2013, compared with 27 cents for coal and 68 cents for gas, which provides the main opportunity to increase supply.

## **Regulation and safety – general**

The National Nuclear Safety Administration (NNSA) under the China Atomic Energy Authority (CAEA) was set up in 1984 and is the licensing and regulatory body which also maintains international agreements regarding safety. It reports to the State Council directly, but is perceived to be insufficiently independent of the CAEA, which plans new capacity and approves feasibility studies for new plants (see also SCRO report below). In relation to the AP1000, NNSA works closely with the US Nuclear Regulatory Commission.

NNSA is responsible for licensing all nuclear reactors and other facilities, safety inspections and reviews of them, operational regulations, licensing transport of nuclear materials, waste

management, and radiation protection including sources and NORM. It licenses staff of nuclear manufacturers through to reactor operators. It is responsible for environment impact assessment of nuclear projects. The 2003 Law on Prevention and Control of Radioactive Pollution passed by Congress is supplemented by a number of Regulations issued over 1986 to 2011 with the authority of State Council.

Nuclear power plant licences issued by NNSA progress from siting approval, then construction permit (12 months before first concrete), fuel loading permit, to operation licence.

China has shown unprecedented eagerness to achieve world's best standards in nuclear safety (as also in civil aviation). It has requested and hosted 12 Operational Safety Review Team (OSART) missions from IAEA teams to October 2011, and each plant generally has one external safety review each year, either OSART, WANO peer review, or CNEA peer review (with the Research Institute for Nuclear Power Operations, RINPO). In December 2013 the NNSA with its Japanese and South Korean counterparts agreed to form a network to cooperate on nuclear safety and quickly exchange information in nuclear emergencies. NNSA is also part of the ASEAN+3 Forum on

## **Nuclear Safety.**

In 2013 the CAEA signed a cooperation agreement with the OECD's Nuclear Energy Agency (NEA), confirming China as a 'key partner' with OECD.

Following the Fukushima accident in Japan in March 2011, the government suspended its approval process pending a review of lessons which might be learned from it, particularly regarding siting of reactors with plant layout, and control of radiation release. Safety checks of operating plants were undertaken immediately, and review of those under construction was completed in October 2011. Resumption of approvals for further new plants was suspended until a new nuclear safety plan was accepted and State Council approval given in October 2012 (see also Post-Fukushima review below).

Following the Fukushima accident, concern regarding possible river pollution will mean delays until at lest 2015 to the inland AP1000 plants which were due to start construction in 2011.

## SCRO report on nuclear investment and safety

In January 2011 a report from the State Council Research Office (SCRO), which makes independent policy recommendations to the State Council on strategic matters, was published. While approving the enormous progress made on many fronts, it cautioned concerning provincial and corporate enthusiasm for new nuclear power plants and said that the 2020 target should be restricted to 70 GWe of new plant actually operating so as to avoid placing undue demand on quality control issues in the supply chain. Another 30 GWe could be under construction. It emphasised that the priority needed to be resolutely on Generation-III technology, notably the

AP1000 and derivatives. However, ambitious targets to deploy AP1000s with reduced foreign input had proved difficult, and as a result, more of the Generation-II CPR-1000 units are under construction or on order. Only China is building Gen-II units today in such large numbers, with 57 (53.14 GWe) on the books<sup>4</sup>.

SCRO said that reactors built today should operate for 50 or 60 years, meaning a large fleet of Gen-III units will still be in operation into the 2070s, when even Gen-III reactors would have given way to Generation-IV and perhaps even to commercial nuclear fusion. The country should be 'careful' concerning 'the volume of second generation units under construction... the scale should not be too large' to avoid any perception of being below international standards of safety in future, when most of the world's Gen-III reactors are retired. The SCRO noted the 100-fold increase in probabilistic safety brought by Gen-III, and that future generations would continue the trend.

Another factor potentially affecting safety is the nuclear power workforce. While staff can be technically trained in four to eight years, 'safety culture takes longer' at the operational level. This issue is magnified in the regulatory regime, where salaries are lower than in industry, and workforce numbers remain relatively low. SCRO said that most countries employ 30-40 regulatory staff per reactor in their fleet, but the National Nuclear Safety Administration (NNSA) has only 1000 staff – a figure that must more than quadruple by 2020. The SCRO recommended that 'The NNSA should be an entity directly under the State Council Bureau, making it an independent regulatory body with authority.' It is currently under the China Atomic Energy Authority, although it is understood to report to the State Council directly

The report said that 32 further reactors 34.86 GWe had been approved by the state at end 2010, with 25 (27.73 GWe) then under construction.

The SCRO calculated that nuclear development would require new investment of some CNY 1 trillion (\$151 billion) by 2020, not counting those units being built now. These projects rely mainly on debt, funds are tight, and 'investment risks cannot be discounted'. This cost figure could rise if supply chain issues impact schedules, with repercussions for companies borrowing to build and for the economics of the Chinese nuclear program overall. A major recommendation was to sort out bottlenecks in the supply chain for AP1000 reactors.

#### Post-Fukushima review

Following the Fukushima accident in March 2011, the State Council, announced on March 16 that it would suspend approvals for new nuclear power stations and conduct comprehensive safety checks of all nuclear projects, including those under construction (with an immediate halt required on any not satisfactory). It also suspended work on four approved units due to start construction in 2011\*. About 34 reactors were already approved by the central government of which 26 were being built. The Shidaowan HTR, though ready for first concrete, was also delayed. After three months the

inspections of operating plants had been completed, and those on plants under construction were completed by October (though construction had continued).

\* Fuqing 4, 5 & 6, Yangjiang 4. Fuqing 4 and Yangjiang 4 started construction late in 2012

In May 2012 a new safety plan for nuclear power was approved in principle. The State Council considered a report on civil nuclear facilities including changes made since the Fukushima accident, and affirmed that the fundamental principle of China's nuclear safety and radioactive pollution prevention is to put safety and quality first. It is now explicit that Chinese regulations are to fully incorporate the safety standards of the International Atomic Energy Agency (IAEA). In an unprecedented move to improve the transparency of nuclear regulation the government then formally solicited public comments on its nuclear safety plan which must ensure that no 'serious incident' (INES Level 3) or greater occurs at any reactor. So far in China no nuclear incident has been over INES level 2. The plan involves significant expenditure across all of the country's facilities.

On 24 October 2012 the premier outlined a modified approach to nuclear power construction at a State Council meeting, signaling that approvals for new plants could recommence. Construction of 25 reactors had continued following March 2011, and several are now on line. He said that nuclear power development would continue at a steady pace, with safety paramount so that that new reactors will have to comply with new-generation safety standards, and plans for inland plants would be put on hold until 2015. The nuclear capacity target for 2020 became 58 GWe in operation and 30 GWe under construction. Over 2013-15, 13 GWe is to be added, and over 2016-20, 30 GWe more.

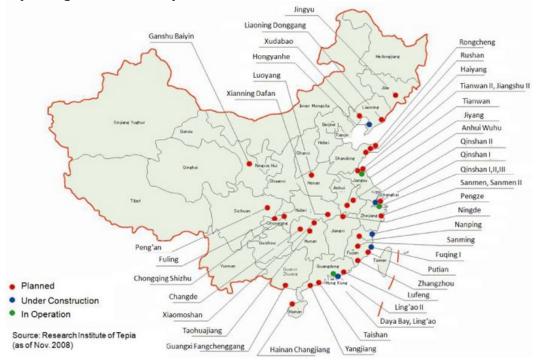
State Council approved the "12th 5-year Plan for Nuclear Safety and Radioactive Pollution Prevention and Vision for 2020", compiled by the Ministry of Environment. It suggested that China will need to spend RMB 80 billion (\$13 billion) on improving nuclear safety at 41 operating and under construction reactors over the next three years to 2015. "China has multiple types of nuclear reactors, multiple technologies and multiple standards of safety, which makes them hard to manage," it said, adding that the operation and construction of nuclear reactors must improve. The chairman of CNNC commented that it was not technology or finance now holding back the sector in China, but the need to gain public acceptance, especially for inland projects. Nevertheless, "the pace of approvals will certainly be slower but the overall direction cannot be changed," he said. Further details followed the 18th National Congress in 2012.

The bottom line of safety requirements is that radioactive releases should never cause "unacceptable effects on the environment or the public", and that advanced nuclear technology should "practically eliminate the possibility of release of significant quantities of radioactive substances from nuclear power units" built from 2016.

A series of research and development (R&D) projects was launched by the NEA in February 2012 to improve safety-related technology and the country's emergency response capabilities at indigenous nuclear power plants in the event of an extreme disaster beyond design basis. The 13 R&D projects were conducted by CNNC, CGN and the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University. They include the development of passive emergency power supply and cooling water systems, development of passive containment heat removal systems, developing hydrogen control devices, measures for the prevention and mitigation of used fuel accidents, and analysing the impact of multiple simultaneous external events and response measures. Other projects studied the monitoring and treatment of contaminated ground and water.

All were expected to be complete in 2013. Referring particularly to the CPR-1000 reactors being widely built in China, the National Energy Administration (NEA) said that "Implementing the measures will comprehensively enhance safety of Generation II+ nuclear power technology in our country, and significantly reduce the core damage frequency and large early release frequency" to "internationally recognized levels" required for Generation III reactors. The outcome of this is the ACC1000 reactor design described below.

In July 2010 a 22-strong IAEA team from 15 countries carried out a two-week Integrated Regulatory Review Service mission to review of China's regulatory framework for nuclear safety. The IAEA made a number of recommendations but said that the review had provided "confidence in the effectiveness of the Chinese safety regulatory system and the future safety of the vast expanding nuclear industry."



Sites of Nuclear Power Plants in China

## Reactor technology

China has set the following points as key elements of its nuclear energy policy:

- PWRs will be the mainstream but not sole reactor type.
- Nuclear fuel assemblies are fabricated and supplied indigenously.
- Domestic manufacturing of plant and equipment will be maximised, with self-reliance in design and project management.
- International cooperation is nevertheless encouraged.

The technology base for future reactors remains officially undefined, though two designs are currently predominant in construction plans: CPR-1000 and AP1000, though plans for the former have been scaled back post-Fukushima. Beyond them, high-temperature gas-cooled reactors and fast reactors appear to be the main priorities.

A major struggle between the established China National Nuclear Corporation (CNNC) pushing for indigenous technology and the small but well-connected State Nuclear Power Technology Corp (SNPTC) favouring imported technology was won by SNPTC about 2004. In particular, SNPTC proposed use of indigenized 1000+ MWe plants with advanced third-generation technology, arising from Westinghouse AP1000 designs at Sanmen and Haiyang (see section below on Embarking upon Generation III plants). Westinghouse has agreed to transfer technology to SNPTC over the first four AP1000 units so that SNPTC can build the following ones on its own. In 2014 SNPTC signed a further agreement with Westinghouse to deepen cooperation in relation to AP1000 and CAP1400 technology globally and "establish a mutually beneficial and complementary partnership".

In February 2006, the State Council announced that the large advanced PWR was one of two high priority projects for the next 15 years, depending on "Sino-foreign cooperation, in order to master international advanced technology on nuclear power and develop a Chinese third-generation large PWR". In September 2006, the head of the China Atomic Energy Authority said that he expected large numbers of third-generation PWR reactors derived from foreign technology to be built from about 2016, after experience is gained with the initial AP1000 units.

This trend was given impetus by the reappraisal of safety following the Fukushima accident.

#### **EPR**

Two Areva EPR reactors are being built at Taishan, and two more are planned. (see section below on Embarking upon Generation III plants.) Areva says the reactors are 4590 MWt, with net power 1660 MWe.

In October 2008, Areva and CGN (then: CGNPC) announced establishment of an engineering joint venture as a technology transfer vehicle for development of the EPR and possibly other PWR plants

in China and later abroad. The Wecan JV, 55% CGN subsidiary China Nuclear Power Engineering Co. and 45% Areva, was set up in December 2009 and based in Shenzhen, though by mid-2011 the CGN share was held by China Nuclear Power Technology Research Institute (CNPRI), another subsidiary. Overseas projects involving CGN appear now to hold the only potential for expanding the role of Areva's EPR technology involving China.

## AP1000, CAP1000

The Westinghouse AP1000 is the main basis of China's move to Generation III technology, and involves a major technology transfer agreement. It is a 1250 MWe gross reactor with two coolant loops. The first four AP1000 reactors are being built at Sanmen and Haiyang, for CNNC and China Power Investment Corp (CPI) respectively. Six more at three sites are firmly planned after them, at Sanmen, Haiyang and Lufeng (for CGN), and at least 30 more are proposed to follow. A State Council Research Office report in January 2011 emphasised that these should have priority over alternative designs such as CPR-1000, and this position strengthened following the Fukushima accident.

The reactors are built from modules fabricated adjacent to each site. The timeline is 50 months from first concrete to fuel loading, then six months to grid connection for the first four units, with this expected to reduce significantly for the following units. In October 2009, SNPTC and CNNC signed an agreement to co-develop and refine the AP1000 design, and this position strengthened following the Fukushima accident. (See also section below on Embarking upon Generation III plants).

CNEA estimated in May 2013 that the construction cost for two AP1000 units at Sanmen are CNY 40.1 billion (\$6.54 billion), or 16,000 Yuan/kW installed (\$2615/kW), instead of CNY 32.4 billion earlier estimated. This is about 14% higher than the latest estimate for the CPR-1000, but likely to drop to about CNY 13,000/kW (\$2120/kW) with series construction and localisation as envisaged. Grid purchase price is expected to exceed CNY 0.45/kWh at present costs, and drop to the standard CNY 0.43/kWh with series build and reduced capital cost.

SNPTC also refers to a CAP1000, which is a local standardization of the design, transitional to CAP1400. It is said to have reduced cost and improved operation and maintenance attributes. The base design, commenced in 2008, is complete, the detailed design, started in April 2010, was due by June 2013. Early in 2012 SNPTC had organized SNERDI (nuclear island and general designer) and SNPDRI (for conventional island) to localize the design for both inland and coastal sites, for Xianning, Pengze and Taohuajiang.

Alstom has an agreement with Dongfang Electric Corporation for turbine and generator packages for future AP1000 projects to be based on Alstom's Arabelle technology. Alstom and DEC have supplied more than half of the turbine generator sets for Chines nuclear power plants to 2013.

#### **CAP1400**

Westinghouse announced in 2008 that it was working with SNPTC and Shanghai Nuclear Engineering Research & Design Institute (SNERDI) to develop jointly a passively safe 1400-1500 MWe design from the AP1000/CAP1000, for large-scale deployment. SNPTC initially called it the Large Advanced Passive PWR Nuclear Power Plant (LPP or APWR). It is one of 16 Key National Projects in China. This development with SNERDI opens the possibility of China itself exporting the new larger units with Westinghouse's cooperation.

In December 2009, the State Nuclear Plant Demonstration Company – a 55-45% joint venture company by SNPTC and China Huaneng Group – was set up to build and operate an initial demonstration unit of the larger two-loop design, the CAP1400, at Huaneng's Shidaowan site. The new company signed a set of agreements with SNERDI and the State Nuclear Power Engineering Company (SNPEC) in November 2010 to proceed with the project. Basic design of the 4040 MWt (c1400 MWe) reactor was completed in 2012, major components are ordered and being manufactured. It will have 193 fuel assemblies, MOX capability, 50 GWd/t burn-up and improved steam generators. Seismic rating is 300 gal. Dongfang Electric is to design and build the turbine generator under contract to SNPTC. The basic design was approved by the National Energy Administration (NEA) in January 2014. Site works were complete in April 2014, with final NNSA approvals in September, following a 17-month review. In December 2014 SNPTC said it was ready to pour first concrete and SNPTC hoped to have it operating by the end of 2018. Westinghouse is providing technical consulting services to SNPTC for the design. More than 80% of the components will be indigenous.

CNNC and SNPTC have talked of export potential, and SNPTC said that "exploration of the global market" for the CAP1400 would start in 2013, particularly in South America and Asia. In mid-2013 SNPTC quoted approx. \$3000/kW capital cost and 7 c/kWh.

CAP1400 may be followed by a larger, 3-loop CAP1700 design if the passive cooling system can be scaled to that level. Agreements with Westinghouse stipulate that SNPTC will own the intellectual property rights for any derivatives over 1350 MWe. SNPEC is doing the engineering under a team from SNERDI, the Shandong Electric Power Engineering Consulting Institute (SEPECI), and the State Nuclear Power Equipment Manufacturing Company (SNPEMC), which will make the components.

## CNP-1000, also CNP-600, CNP-300 (ACP 300, ACP600, ACP1000)

CNNC had been working with Westinghouse and Framatome (now Areva) at SNERDI since the early 1990s to develop a Chinese standard three-loop PWR design, the CNP-1000. This is developed from the 2-loop Qinshan CNP-300 unit (scaled up to the two-loop CNP-600 units, also at Qinshan), with high (60 GWd/t) burn-up, 18-month refueling cycle and 20 more (but shorter) fuel

assemblies than the French-origin units.<sup>b</sup> In 1997, the Nuclear Power Institute of China (NPIC) at Chengdu became involved in the reactor design and, early in 2007, SNERDI was reassigned to concentrate on the AP1000 program.

CNNC has been keen to create its own brand of advanced second-generation reactor with full intellectual property rights, and wanted to build two initial CNP-1000 plants at Fangjiashan, adjacent to Qinshan near Shanghai, under the 11th Economic Plan, though the design probably would not have been ready. In early 2007, the CNP-1000 development was put on hold, though this aborted export plans then for two CNP-1000 units to Pakistan.

Further CNP-600 units are being built at Qinshan and Changjiang, Hainan. CNNC says they are free of French intellectual property rights. CNNC is also developing the design to the ACP600 which it calls a third-generation design and expected to be built on Hainan or in the northwest Gansu province and exported.<sup>c</sup> It will have double containment, 18-24 month refueling cycle, digital I&C, and 60-year plant life.

In October 2011 CNNC announced that its independently-developed ACP1000 was entering the engineering design stage, initially for Fuqing units 5&6, with 1100 MWe nominal power and load-following capability. In May 2013 CNNC said it had finished a preliminary safety analysis report, and was working on construction design in order to be ready for construction by the end of the year. CNNC expected to start building the first in 2014, at Fuqing, with 85% local content, and the second there in 2015. In April 2013 it announced an export agreement for an ACP1000, for Pakistan. CNNC asserts full intellectual property rights for the CNP series of reactors, which have evolved to the ACP series. However, when the National Energy Administration ordered a rationalization of CNNC's and CGN's 1000 MWe class designs, the ACP1000 morphed into the ACC1000 or Hualong One – see description below. Meanwhile the IAEA approved the ACP1000 design in its Generic Reactor Safety Review process in December 2014, though the IAEA points out that this does not "constitute any kind of design certification".

Two new 300 MWe CNP-300 PWR units are being built at Chasma in Pakistan by the China Zhongyuan Engineering Corporation. They are similar to those already commissioned in 2000 and 2011, and similar to Qinshan 1 – China's first indigenously-designed (by SNERDI) nuclear power plant.

CNNC was seeking to sell the CNP-300 to Belarus and in Africa, and these will probably now become ACP300.

#### ACP100 small modular PWR

A 'key project' on the 12th Five-Year Plan is CNNC's multi-purpose small modular reactor, the ACP100. Preliminary design was completed in 2014 ready for construction start in 2015 and

operation in 2017, but it awaits NDRC approval. The design is based on the larger ACP (and CNP) units, or AP1000, has passive safety features and will be installed underground. Seismic tolerance is 300 Gal. It has 57 fuel assemblies 2.15m tall and integral steam generators (287°C), so that the whole steam supply system is produced and shipped a single reactor module. It has passive cooling for decay heat removal. Its 310 MWt produces about 100 MWe, and power plants comprising two to six of these are envisaged, with 60-year design life and 24-month refueling. Or each module can supply 1000 GJ/hr, giving 12,000 m³/day desalination (with MED). Industrial and district heat uses are also envisaged, as is floating nuclear power plant (FNPP) application. Capacity up to 150 MWe is possible.

CNNC New Energy Corporation (CNNC-CNEC), a joint venture of CNNC (51%) and China Guodian Corp, is planning to build two ACP100 units in Putian county, Zhangzhou city, at the south of Fujian province, near Xiamen and not far from Fuqing, as a demonstration plant. This will be the CNY 5 billion (\$788 million) phase 1 of a larger project. Construction time is expected to be 36-40 months, starting 2015 for the two Putian units. CNNC has applied for NDRC approval. A second proposal was approved for two further CNNC-CNEC units at Zhangzhou-Gulei, but this is suspended by local government opposition.

The project involves a joint venture of three companies for the pilot plant: CNNC as owner and operator, the Nuclear Power Institute of China (NPIC) as the reactor designer and China Nuclear Engineering Group being responsible for plant construction. CNNC-CNEC signed a second ACP100 agreement with Hengfeng county, Shangrao city in Jiangxi province, and a third with Ningdu county, Ganzhou city in Jiangxi province in July 2013 for another ACP100 project costing CNY 16 billion. Further inland units are planned in Hunan and Jilin provinces, and CNNC has signed ACP100 development agreements also with Zhejiang and Heilongjiang provinces. Export potential is considered high, with full intellectual property rights. CNNC-CNEC will construct major parts of the reactors in Bashan, Jilin province.

### **CAP150 Small modular PWR**

This is an integral PWR, with SNPTC provenance, being developed from the CAP1000 in parallel with CAP1400 by SNERDI, using proven fuel and core design. It is 450 MWt/ 150 MWe and has 8 integral steam generators (295°C), and claims "a more simplified system and more safety than current third generation reactors". It is pitched for remote electricity supply and district heating, with three-year refueling and design life of 80 years. It has both active and passive cooling and in an accident scenario, no operator intervention required for seven days. Seismic design basis 300 Gal. In mid 2013 SNPTC quoted approx. \$5000/kW capital cost and 9 c/kWh, so significantly more than the CAP1400.

#### **CAP-FNPP**

Another SNERDI project is a reactor for floating nuclear power plant (FNPP). This is to be 200 MWt and relatively low-temperature (250°C), so only about 40 MWe with two external steam generators and five-year refueling. See also entry below re Russian FNPP agreement.

## CPR-1000, M310+, ACPR1000

The CPR-1000 is a significantly upgraded version of the 900 MWe-class French M310 three-loop technology imported for the Daya Bay nuclear power plant in the 1980s and also built at Ling Ao. Known as the 'improved Chinese PWR' and designated Generation II+, it features digital instrumentation and control and a design life of 60 years. Its 157 fuel assemblies (4.3 m long) have calculated core melt frequency of 1x10<sup>-5</sup> and a release probability an order of magnitude lower than this

Standard construction time is 52 months, and the claimed unit cost was under CNY 10,000 (US\$ 1600) per kilowatt, though 2013 estimates put it at about \$2300/kW domestically. With a capacity of 1080 MWe gross (1037 MWe net), Ling Ao Phase II is the first plant to be designated as the CPR-1000 design. The CPR-1000 was being widely and quickly deployed for domestic use, with 57 likely to be built, as of end of 2010. Following the Fukushima accident, numbers will be much lower, and there will be no further approvals. Six were operating by September 2014, with 16 under construction. Tianwan 5&6 may be the last ones built.

China Guangdong Nuclear Power Corporation (CGN) led the development of the CPR-1000 and established a nearly complete domestic supply chain. However, Areva retains intellectual property rights, which constrains overseas sales since the Chinese would need agreement from Areva on a case-by-case basis. The six CNNC-built units (Fuqing and Fangjiashan) are often designated M310+.

CGN refers to later units as CPR-1000+, incorporating design improvements which bring it close to Generation III standard. The first of these are Yangjiang 3&4, with some design modifications, followed by units 5&6 which are more fully transitional to ACPR1000 and are being called that. Of more significance was its evolution to the **Advanced CPR – ACPR1000** – with full Chinese intellectual property rights, launched by CGNPC in November 2011 with some fanfare regarding its safety attributes, which comply with international requirements. CGN has been in cooperation with Dongfang Electric, Shanghai Electric, Harbin Electric, China First Heavy Industries, China Erzhong and other companies since 2009 to develop the ACPR1000, a three-loop unit with double containment and core-catcher.

CGN made it available for local build on schedule from 2013 with the first at Yangjiang, units 5&6, to be followed by Hongyanhe 5&6 and Lufeng 1&2 (now to be AP1000). In September 2012

Fangchenggang 3&4 was identified as the demonstration project, with construction start at the end of 2014, but meanwhile construction started on Yangjiang 5&6, which CGN said had evolved to be an ACPR1000 design. Fangchenggang 3 was to be the reference plant for CGN's bid to build the Sinop plant in Turkey. Overnight construction cost is expected to be \$2500/kW.

A further development, ACPR1000+, was envisaged for export, from 2014, but was abandoned with the rationalisation to Hualong 1 described below. It was to have a 60-year life and 300 Gal seismic capability. The conceptual design gained IAEA approval through its Generic Reactor Safety Review process in May 2013, though the IAEA points out that this does not "constitute any kind of design certification".

In January 2012, CGN with Areva and EdF agreed on a partnership to develop a Generation III reactor based on the CPR-1000, the ACE1000 (Areva-CGN-EdF1000). Mitsubishi Heavy Industries, already designing the similar-size Atmea1 with Areva, says it will not be involved. The ACE1000 concept is reported to be evolutionary, with single but reinforced containment, active safety systems with three 100% loops (so can do maintenance on one of them outside outages). No more has been heard of this plan.

#### **ACPR small modular PWRs**

Not to be outdone by CNNC in the small modular field, CGN has two small ACPR designs: an ACPR100 and an ACPR50S, both with passive cooling for decay heat and 60-year design life. Both have standard type fuel assemblies and fuel enriched to <5% with burnable poison giving 30 month refueling. The **ACPR100** is an integral PWR, 450 MWt, 140 MWe, having 69 fuel assemblies. Reactor pressure vessel is 17m high and 4.4 m inside diameter, operating at 310°C. It is designed as a module in larger plant and would be installed underground.

The offshore **ACPR50S** is 200 MWt, 60 MWe with 37 fuel assemblies and two loops feeding four external steam generators. Reactor pressure vessel is 7.4m high and 2.5 m inside diameter, operating at 310°C. It is designed for mounting on a barge as floating nuclear power plant (FNPP) or possible submersible. The applications for these are similar to those for the ACP100, but the timescale is longer and none is expected on line before 2023.

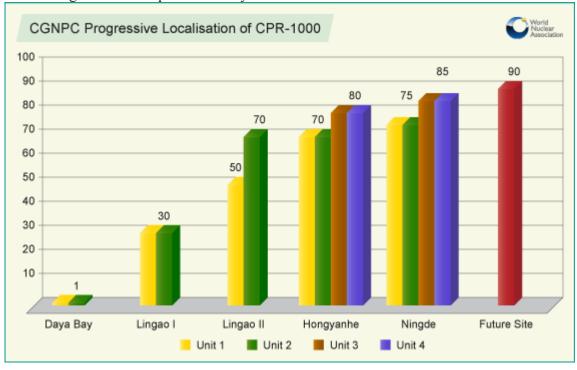
## Hualong 1 – rationalisation of ACP1000 and ACPR1000+

Since 2011 several rounds of negotiations between CNNC and CGN have grappled with the task of "merging" the two designs as ordered by the National Energy Administration (NEA) while allowing for some differences, with impetus given by the regulator. Both are three-loop designs based to some extent on the French M310, but the cores are very different: one (ACP1000) has 177 fuel assemblies 3.66m long, the ACPR1000 has 157 assemblies 4.3 m long, so physically merging the

basic designs was impractical, and in the event the ACP1000 design prevailed, though it was less mature. Some features of the ACPR1000 are incorporated, at least in the CGN version.

The Hualong 1 thus has 177 fuel assemblies 3.66 m long, 18-24 month refuelling interval, equilibrium fuel load will be 72 assemblies with 4.45% enriched fuel. It has three coolant loops delivering 3150 MWt, 1150 MWe, double containment and active safety systems with some passive elements, and a 60-year design life. Average burn-up is 45,000 MWd/tU. Seismic tolerance is 300 Gal. Instrumentation and control systems will be from Areva-Siemens, but overall 90% will be indigenous components. Target cost in China is \$2800-3000/kWe, though recent estimates mention \$3500/kW. The CNNC and CGN versions will be very similar but not identical, they will have slightly different safety systems and each organisation will maintain much of its own supply chain. The new design has been called Hualong 1000, ACC1000 and finally Hualong 1.

The first units will be Fangchenggang 3&4 (CGN) and Fuqing 5&6 (CNNC). The 'rationalisation' was helped by greater commonality in ownership of the two companies as set out in September 2012 though still not implemented a year later.



## **VVER**

Russia's Atomstroyexport was general contractor and equipment provider for the Tianwan 1&2 AES-91 power plants using the V-428 version of the well-proven VVER-1000 reactor of 1060 MWe capacity. The reactors incorporate Finnish safety features and Siemens-Areva instrumentation and control (I&C) systems. Russia's Energoatom is responsible for maintenance from 2009. Tianwan units 3&4 will use the same version of the VVER-1000 reactor with Areva I&C systems.

In 2013 Atomergoproekt said it was promoting the VVER-TOI to CNNC and engineering companies.

## **Russian Floating Nuclear Power Plants**

In May 2014 the China Atomic Energy Authority (CAEA) signed an agreement with Rosatom to cooperate in construction of floating nuclear cogeneration plants (FNPP) for China offshore islands. These would be built in China but be based on Russian technology, and possibly using Russian KLT-40S reactors – Russia's TVEL anticipates providing fuel for them. In July 2014 Rusatom Overseas signed a further agreement, this time with CNNC New Energy, for the joint development of FNPPs – both barge-mounted and self-propelled – from 2019.

#### Candu

From 1998 Atomic Energy of Canada Ltd (AECL) built the two-unit Qinshan Phase III plant on schedule and under budget and estimates that it could be replicated for 25% lower cost. Any replication would be on the basis of involving local engineering teams, not on a turnkey basis, but the technology is now well understood and the decades-old Candu-6 design would likely pose fewer problems for technology transfer than state-of-the-art third-generation designs from Westinghouse and Areva. (The Candu-6 units at Wolsong 2-4 in Korea had substantial local content, reaching 75% localization with unit 4.)

In September 2005, AECL signed a technology development agreement with CNNC which opened the possibility of it supplying further Candu-6 reactors and undertaking fuel cycle developments based on them. This agreement with CNNC was passed to its subsidiary, the Nuclear Power Institute of China (NPIC). From 2008 it has focused on joint development of the Advanced Fuel Cycle Candu Reactor (AFCR) – see R&D section of China Fuel Cycle paper.

## **HTR**

In February 2006, the State Council announced that the small high-temperature gas-cooled reactor (HTR) was the second of two high priority National Major Science & Technology Projects for the next 15 years. This aims at exploring co-generation options in the near-term and producing hydrogen in the long term.

The small HTR-PM (HTR Pebble-bed Modular) units with pebble bed fuel and helium coolant were to be 200 MWe reactors, similar to that then being developed in South Africa, but plans have evolved to make them twin 105 MWe reactors so that they can retain the same core configuration as the prototype HTR-10. The twin units, each with a single steam generator, will drive a single steam turbine. Core height is 11 metres, and steam will be at 566°C. The engineering of the key structures,

systems, and components is based on Chinese capabilities, though they include completely new technical features.

China Huaneng Group (CHNG) is the lead organization in the consortium to build the demonstration Shidaowan HTR-PM with China Nuclear Engineering & Construction Group (CNEC) and Tsinghua University's INET, which is the R&D leader. Chinergy Co., a joint venture of Tsinghua and CNEC, is the main contractor for the nuclear island. Thermal efficiency of 40%, localisation 75% and 50-month construction for the first unit is envisaged. The initial HTR-PM will pave the way for commercial versions which will have multiple 100 MWe modules connected to a shared turbine, of 200 MWe, 300 MWe, or 600 MWe. An earlier proposal was for 18 (3x6) further 210 MWe units at the same site – total 3800 MWe (see Shandong Shidaowan project below, and Research and development section in page on *China's Nuclear Fuel Cycle*).

#### Fast neutron reactor

Longer-term, fast neutron reactors (FNRs) are seen as the main technology, and CNNC expects the FNR to become predominant by mid-century. A 65 MWt fast neutron reactor – the Chinese Experimental Fast Reactor (CEFR) – near Beijing achieved criticality in July 2010, and was grid-connected a year later. Based on this, a 600 MWe pre-conceptual design was developed. The current plan is to develop an indigenous 1000 MWe design to begin construction in 2017, and commissioning 2023. This is known as the Chinese Demonstration Fast Reactor (CDFR) project 1. It is intended to be followed by a CFR1000 for commercial operation from 2030, according to China Institute of Atomic Energy.

In addition to CDFR project 1, in October 2009, an agreement with Russia confirmed earlier indications that China would opt for the BN-800 technology as CDFR project 2. The 880 MWe gross BN-800 reactor which has been built by OKBM Afrikantov at Beloyarsk in Siberia is the reference design and the first two in China were planned to start construction in 2013 at Sanming, Fujian province, with the first to be in operation in 2019 (see see section below on Sanming). However, negotiations on price have delayed the project and NIAEP-Atomstroyexport now expects the first contracts to be in place at the end of 2014.

See also Fast neutron reactors section in page on China's Nuclear Fuel Cycle.

## **Embarking upon Generation III plants**

In September 2004, the State Council approved plans for two units at Sanmen, followed by six units at Yangjiang (two to start with), these to be 1000 or 1500 MWe reactors pioneering Generation III nuclear technology from overseas. The Sanmen (in Zhejiang province) and Yangjiang (in Guangdong province) reactors were subject to an open bidding process for third-generation designs,

with contracts to be awarded in mid-2006 – in the event, mid-2007 – putting them clearly into the 11th Five Year Plan.

## **Bidding process**

This open bidding process underlined the extent to which China is making itself part of the world nuclear industry, and yet at first remaining somewhat ambivalent about that.

Three bids were received for the four Sanmen and Yangjiang reactors: from Westinghouse (AP1000 reactors), Areva (EPR) and Atomstroyexport (VVER-1000 model V-392). The State Nuclear Power Technology Corporation (SNPTC), directly under China's State Council, was in charge of technology selection for new plants being bid from overseas.

Some 200 experts spent over a year evaluating Generation III designs and in September 2006 most of the 34 assigned to decide voted for the AP1000. The key factors in choosing this were passive design, simplified safety system, modular construction giving more rapid build and better cost control, and smaller components allowing more ready localization.

The USA, French and Russian governments were reported to be giving firm support as finance and support arrangements were put in place. The US Export-Import bank approved \$5 billion in loan guarantees for the Westinghouse bid, and the French Coface company was expected similarly to finance Areva for its bid. The US Nuclear Regulatory Commission gave approval for Westinghouse to export equipment and engineering services as well as the initial fuel load and one replacement for the four units. Bids for both two-unit plants were received in Beijing on behalf of the two customers: China General Nuclear Power Co (CGN) for Yangjiang, and China National Nuclear Corporation (CNNC) for Sanmen. Bids were for the nuclear portion of each plant only, the turbine tenders to be called for subsequently.

Bids were assessed on level of technology, the degree to which it was proven, price, local content, and technology transfer – which apparently became the major factor. Areva and Westinghouse were short-listed. However, the decision on reactor type was delayed, and came under review at the highest political level, with CNNC evidently pushing for the use of indigenous second-generation designs for both sites.

In December 2006, 22 months after the bids were submitted and after several revisions to them, the Westinghouse AP1000 reactor design was confirmed for the four units – two each at Sanmen and Yangjiang. Early in 2007, the two units planned for the Yangjiang site were switched to Haiyang in the more northerly Shandong province, making way for two EPR units Areva was in negotiations to build at Yangjiang. Later in 2007, plans for the EPRs under consideration for Yangjiang were

transferred to another Guangdong site – Taishan – since there was pressure to build a lot of capacity quickly at Yangjiang.

## Sanmen 1&2 and Haiyang 1&2

A framework agreement was signed at the end of February 2007 between Westinghouse and SNPTC specifying Haiyang and Sanmen for the four AP1000 units. In July 2007, Westinghouse, along with consortium partner Shaw, signed the contracts with SNPTC, Sanmen Nuclear Power Company (51% owned by CNNC), Shangdong Nuclear Power Company (61% owned by CPI) and China National Technical Import & Export Corporation (CNTIC) for four AP1000 reactors. Specific terms were not disclosed but the figure of \$5.3 billion for the first two was widely quoted. In December 2007 the Chinese and US governments signed the intergovernmental agreement for the construction of AP1000 projects in China and technology transfer.

Sanmen site works commenced in February 2008 and full construction on Sanmen 1 – the world's first AP1000 unit – officially commenced on 19 April 2009. The reactor is expected to begin operation at the end of 2015 with the second less than one year later. First concrete at Haiyang 1 was in September 2009, and the pressure vessel was installed in January 2012. The Haiyang units are expected to commence operation in 2016. Construction has been slower than planned, the main problem being with US-made main coolant pumps (four in each reactor). This appeared to be resolved late in 2014

## AP1000 construction and equipment contracts

Westinghouse and Shaw Group have an engineering, procurement, commissioning and start-up as well as project management contract with SNPTC for the first four reactors (Sanmen & Haiyang). Also Shaw has a contract with State Nuclear Power Engineering Corp. Ltd, a SNPTC subsidiary, for technical support for the first two Dafan, Xianning units in Hubei province, including engineering and design management, project controls, quality assurance, construction management and project management.

In April 2007, Westinghouse signed a \$350 million contract with Doosan Heavy Industries in Korea for two pressure vessels and four steam generators for Sanmen 1 and Haiyang 1. The pressure vessels for the other two units are being made by Chinese manufacturers: China First Heavy Industries (CFHI, also known as YiZhong) for Sanmen 2 and Shanghai Electric Group Corporation (SEC) for Haiyang 2. Steam generators for Sanmen 2 and Haiyang 2 were manufactured by Harbin Power Equipment Co., Ltd. (HPEC, now Harbin Electric Co, HEC) and SEC, respectively, though a contract for Sanmen 2 steam generators was let to Spain's ENSA in 2011. The Sanmen 1 reactor pressure vessel arrived on site from Doosan in July 2011.

All four steam turbine generators were supplied by Mitsubishi Heavy Industries (MHI). In a \$521 million deal, Sanmen Nuclear Power ordered two turbine generator packages from MHI at the end of September 2007, with Shandong Nuclear Power ordering another two early in 2008. MHI's Takasago Machinery Works manufactured the turbines, including rotors and blades. Mitsubishi Electric Corporation is supplying the generators and Harbin Electric Co (HEC), partnering with MHI, was responsible for turbine casings, piping and associated facilities. The turbines will reportedly boost the capacity of the reactors from their designed 1175 MWe to 1250 MWe gross.

In 2014 Westinghouse said that the second plant at each site saw a 30% reduction in manpower requirements compared with the first unit. The company is also working on the next eight units in China and expects about a 50% productivity increase compared with the first two Chinese AP1000 units.

The AP1000 Technology Transfer agreement to SNPTC covered 34 task packages in 7 categories, and in 2011 the process was still under way, with 78% of the documentation done by August. Some 27 sublicence agreements involved 30 entities.

In November 2010, further contracts were signed between SNPTC and Westinghouse, including one for Westinghouse to provide SNPTC with technical consulting services in research and development of the CAP1400 nuclear power plant, to be developed by SNPTC with Chinese intellectual property rights. Westinghouse said that having shared design technology with SNERDI, it expected 100% localization by 2015.

In January 2011, a further agreement was signed with SNPTC to deploy further AP1000 units, and to extend the 2008 technology cooperation agreement for another two years. SNPTC said the deal also included measures "to develop cooperation in the field of overseas markets." Another agreement was signed with China Baotou Nuclear Fuel Co "to design, manufacture and install fuel fabrication equipment that will enable China to manufacture fuel" for AP1000 units. The latter \$35 million contract involves supply and installation of US equipment at Baotou.

In June 2011 Westinghouse confirmed that as part of the earlier construction agreement it would transfer intellectual property rights to SNPTC. In September 2014 Westinghouse said that it expected to be involved in orders for eight further units, followed by 12 more inland and 12 on the coast. It expected "to have 20 AP1000 units under construction in the next five years in China."

#### Taishan 1&2 EPR

In February 2007, EDF entered a cooperation agreement with CGN (then: CGNPC) to build and operate a two-unit EPR power station at Yangjiang in Guangdong province. This deal was not expected to involve the technology transfer which is central to the Westinghouse contracts, since

the EPR has multiple redundant safety systems rather than passive safety systems and is seen to be more complex and expensive, hence of less long-term interest to China. However, negotiations with Areva and EDF dragged on and in August 2007 it was announced that the EPR project had been shuffled to Taishan (in Guangdong) so that six CPR-1000 units previously planned for that site could be built at Yangjiang as soon as possible.

At a November 2007 ceremony attended by Chinese president Hu Jintao and French president Nicolas Sarkozy in Beijing's Great Hall of the People, Areva initialed an €8 billion contract with CGN for the two EPRs at Taishan plus supply of fuel to 2026 and other materials and services for them. The whole project, including fuel supply, totals €8 billion, of which the nuclear reactors themselves were reported to be about €3.5 billion. Steam turbine generators costing €300 million are included in the larger sum. The Guangdong Development Commission quoted the total investment in both units as CNY 49.85 billion (\$7.3 billion). The joint venture partners will put up CNY 16.45 billion and the balance will be borrowed with guarantee from the Central Bank of France. French export credits for the project are reported as €1.7 billion (\$2.4 billion), covering purchase of equipment such as pressure vessel and steam generators for unit 1 from French suppliers.

In August 2008, EDF and CGN signed the final agreements for the creation of Guangdong Taishan Nuclear Power Joint Venture Company Limited (TNPC). EDF will hold 30% of TNPC for a period of 50 years (the maximum period permitted for a joint venture in China), CGN 70%. TNPC will oversee the building, then own and operate the plant. EDF is paying €600 to 800 million over four years for this share, subject to approval by the National Development and Reform Commission (NDRC) and the Ministry of Commerce. (EDF is project manager and architect for the Flamanville 3 EPR project in France, and this initiative consolidates its change in corporate strategy outside France.)

CGN authorised construction at Taishan in July 2008 and first concrete was poured in October 2009, though the official inauguration ceremony was not until 21 December. The first unit was expected to be connected to the grid early in 2014 with commercial operation two months later, and the second was to be completed in 2015, but they are at least two years behind. The major components for unit 1 are imported: the pressure vessel from Mitsubishi Heavy Industries (MHI) in Japan and the steam generators from Areva Chalon/St. Marcel in France, but those for unit 2 are all built in China: the pressure vessel by Dongfang Electric (DEC), the steam generators by DEC (two) and Shanghai Electric (two). The Arabelle steam turbines and 1750 MWe generators are being purchased separately from Alstom and Dongfang Electric Co respectively. The first generator was shipped by DEC in August 2013. In March 2012 Areva said unit 1 was 69% complete, with reactor pressure vessel delivered.

In April 2013 Areva, EDF and CGN signed a tripartite agreement for "deeper industrial and commercial cooperation" in building new nuclear power plants and improving all CGN units. However, as of 2013 it appears that not more than two further EPR units will be built in China.

## **Indigenous Generation III plants**

Late in 2012 the National Energy Administration (NEA), reflecting State Council views, made it clear that indigenous reactor designs needed to be progressed to Generation III safety standards. See comments above on ACP1000, ACPR1000 and ACC1000.

## **Nuclear growth**

The first two nuclear power plants in mainland China were at Daya Bay near Hong Kong and Qinshan, south of Shanghai, with construction starting in the mid-1980s. Localisation has risen from 1% at Daya Bay to 64% at Ling Ao and 85% at Yangjiang.

China's concerted nuclear expansion began with the National Development and Reform Commission's (NDRC's) Tenth Economic Plan for the years 2001-2005, with increased self-reliance. (China's first economic plan was in 1953 and began China's centrally planned industrialization under Mao Zedong.) It incorporated the construction of eight nuclear power plants, though the timeline for contracts was extended, putting the last two projects into the 11th plan. The Eleventh Economic Plan for the years 2006-2010 set even more ambitious goals than the Tenth for new nuclear plant construction, and marked a watershed in China's commitment to third-generation reactors, such as the Sanmen plant in Zhejiang province and Haiyang plant in Shandong province (see section above on Reactor technology) as well as maturing of CPR-1000 technology. The 11th Five-Year Plan (2006-10) also had firmer environmental goals than previously, including reduction of 20% in the amount of energy required per unit of GDP, *i.e.* 4% reduction per year.

In 2007, it was announced that three state-owned corporations had been approved by NNSA to own and operate nuclear power plants: CNNC, CGN and China Power Investment Corporation (CPI). Any other public or private companies are to have minority shares in new projects, which is proving a severe constraint on the ambitions of the country's main power utilities (including Huaneng, Huadian, Datang and Guodian), all of which have set up nuclear subsidiaries or become involved in nuclear projects. CGN is increasingly preeminent in actual nuclear power plants.

The 12th Five-Year Plan (2011-15) included construction start on phase II of Tianwan, Hongyanhe, Sanmen and Haiyang, as well as phase I of inland sites: Taohuajiang, Xianning, and Pengze (2 reactors each except Taohuajiang: 4). By the end of the 12th Five Year Plan some 25 GWe of new capacity was planned to be operational, making some 40 GWe, and 45 GWe more might be added by the end of the 13th Five Year Plan. The 12th Five-year science & technology plan released in July 2011 called for building a demonstration CAP-1400 plant for grid connection in 2015 and the demonstration HTR-PM to begin test operation at Shidaowan before 2015. Construction starts were delayed following the Fukushima accident, and all the inland plants were put on hold.

More than 16 provinces, regions and municipalities announced intentions to build nuclear power plants in the 12th Five Year Plan 2011-15. so that nuclear plants were operating or under construction in all coastal provinces except Hebei. Provinces put together firm proposals by 2008 and submitted them to the central government's National Development and Reform Commission (NDRC) for approval during 2009. NRDC consideration is via the new National Energy Administration (NEA). A great many proposals were received, many of which will be deferred to the 13th Plan.

The approvals process in China has three stages:

- 1. Siting and feasibility study, with project approval from NDRC.
- 2. Construction, requiring first a construction permit and later a fuel loading permit from NNSA.
- 3. Commissioning, leading to NNSA operating permit.

In 2014 CPI had plans to achieve 14 GWe of operational capacity by 2020, with 10 GWe under construction then, at nine sites with 40 units. All of this except phase I of Hongyanhe (4xCPR-1000) would be AP1000.

The complex ownership structure of Chinese nuclear plants is described in Appendix 1: Government Structure and Ownership, and China's considerable heavy engineering and manufacturing capacity is detailed in the information page on Heavy Manufacturing of Power Plants. The capacity at the end of 2013 was for eight sets of reactor equipment per year – over 8000 MWe.

On the people and skills front, 47 colleges and research institutes have nuclear major, and more than 2000 graduate each year (4000 in 10th Five-Year Plan, 11,000 in 11th Five-Year Plan).

#### **Nuclear technology exports**

China has a determined policy at NDRC level of exporting nuclear technology, based on development of the CAP1400 reactor with Chinese intellectual property rights and backed by full fuel cycle capability. The policy is being pursued at a high level politically, utilising China's economic and diplomatic influence. CNNC and SNPTC are focused on the export potential of the CAP1400, and SNPTC aims at "exploration of the global market" from 2013, particularly in South America and Asia.

## **Export sales and prospects for Chinese nuclear power plants**

Country	Plant	Type	Est. cost	Company	Status, financing
Pakistan	Chasma 3&4	CNP-300	\$2.37 billion	CNNC	Under construction, Chinese finance 82% of \$1.9 billion
	Karachi Coastal	Hualong One?	\$9.6 billion	CNNC	Planned, \$6.5 billion vendor finance, maybe 82% China finance
Romania	Cernavoda 3&4	Candu 6	€6.5 billion	CGN	Planned, Chinese finance
Argentina	Atucha 3	Candu 6		CNNC	Planned, with local involvement
Turkey	?	AP1000 or CAP1400		SNPTC	Exclusive negotiation

In Pakistan, two new 300 MWe CNP-300 PWR units are being built at Chasma, joining the two built there earlier. In 2013 CNNC announced an export agreement for twin ACP1000 units, for Pakistan's Karachi Coastal Power station, costing \$9.6 billion. This will now probably involve Hualong One technology.

In May 2014 Romania's Nuclearelectrica signed an agreement with CGN to explore the prospect of building two new reactors at Cernavoda, which currently has two Candu 6 reactors. In November 2013 two nuclear cooperation agreements were signed by Nuclearlectrica with CGN, one a letter of intent relating to construction of units 3&4.

In July 2014 a high-level agreement was signed by Argentine and Chinese presidents towards construction of Atucha 3 as a PHWR unit. CNNC will provide most of the equipment and technical services under long-term financing. Candu Energy will be a subcontractor to CNNC. In September the utility NASA signed a commercial framework contract with CNNC to progress this, with CNNC's Qinshan Phase III units as reference design for a Candu 6 unit. It will have \$3.8 billion in local input and \$2 billion from China and elsewhere under a long-term financing arrangement.

SNPTC is keen to export the CAP1400 reactor, and considers Turkey and South Africa to be good prospects. In November 2014 SNPTC signed an agreement with Turkey's utility EUAS and Westinghouse to begin exclusive negotiations to develop and construct a four-unit nuclear power plant in Turkey. In December 2014 it signed two agreements in South Africa with a view to nuclear power plant construction, and CNNC signed another there.

## Operating nuclear plants: varied beginnings to 2010

Daya Bay, Ling Ao Phase I

These are essentially on the one site in Guangdong province, close to Hong Kong. The Daya Bay reactors are standard 3-loop French PWR units supplied by Framatome and designated M310, with GEC-Alstom turbines. Electricite de France (EDF) managed construction, starting August 1987, with the participation of Chinese engineers. Commercial operation of the two Daya Bay units was in February and May 1994. There were long outages in 1994-96 when Framatome had to replace major components. Reactor vessel heads were replaced in 2004. The plant produces about 13 billion kWh per year, with 70% transmitted to Hong Kong and 30% to Guangdong.

The Ling Ao Phase I reactors are virtually replicas of adjacent Daya Bay units. Construction started in May 1997 and Ling Ao 1 started up in February 2002 entering commercial operation in May. Ling Ao 2 was connected to the grid about September 2002 and entered commercial operation in January 2003. The two Ling Ao reactors use French M310 technology supplied by Framatome (now Areva), but with 30% localisation. They are reported to have cost \$1800 per kilowatt.

Daya Bay and Ling Ao I & II together comprise the 'Daya Bay nuclear power base' managed by Daya Bay Nuclear Power Operations & Management Co (DNMC), part of China General Nuclear Power Group (CGN). For Ling Ao Phase II, see below.

## Qinshan

Qinshan 1 in Zhejiang province 100 km southwest of Shanghai, is China's first indigenously-designed and constructed nuclear power plant (though with the pressure vessel supplied by Mitsubishi, Japan). Design of the 300 MWe PWR was by the Shanghai Nuclear Engineering Research & Design Institute (SNERDI). Construction work spanned 6.5 years from March 1985, with first grid connection in December 1991. It was shut down for 14 months for major repairs from mid-1998.

In October 2007, Qinshan 1 was shut down for a major upgrade. The entire instrumentation and control system was replaced, along with the reactor pressure vessel head and control rod drives. Areva NP supervised the work, which is likely to lead to life extension beyond the original 30 years.

Qinshan Phase II units 1&2 are locally-designed and constructed 2-loop PWR reactors, scaled up from Qinshan 1, and designated CNP-600. Local content was 55%. Unit 1 started up at the end of 2001 and entered commercial operation in April 2002. Unit 2 started up in March 2004, with commercial operation in May 2004. Units 3 & 4 are similar, with local content of 77%. After 53 months construction, unit 3 was grid connected on 1 August 2010, and entered commercial

operation 12 weeks later<sup>8</sup>. Unit 4 was grid-connected in November 2011 and entered commercial operation in April 2012. CNNC claims that Qinshan phase II "is the first independently-designed, built, managed and operated large commercial nuclear power station in China."

Construction of the second stage of Qinshan Phase II was formally inaugurated at the end of April 2006, though first concrete had been poured for unit 3 in March. That for unit 4 was poured in January 2007. Local content of the two 650 MWe CNP-600 reactors is more than 70% and they entered commercial operation in 2010 and 2012.

In 2004, CNNC announced that the next two Qinshan units would be 1000 MWe indigenous units (in effect Fangjiashan, adjacent to Qinshan 1, has taken over this role).

Qinshan Phase III units 1&2 use the Candu 6 pressurised heavy water reactor (PHWR) technology, with Atomic Energy of Canada (AECL) being the main contractor of the project on a turnkey basis. Construction began in 1997 and unit 1 started up in September 2002 and unit 2 in April 2003. They are each about 678 MWe net.

## Tianwan phase I

Tianwan Phase I at Lianyungang city in Jiangsu province is a Russian AES-91 power plant (with two 1060 MWe V-428 VVER reactors) constructed under a cooperation agreement between China and Russia – the largest such project ever. **The cost is reported to be \$3.2 billion (\$1500/kW), with China contributing \$1.8 billion of this.** Completion was delayed due to corrosion in the steam generators which resulted in some tubes having to be plugged with a net loss of capacity of about 2%. The first unit was grid connected in May 2006 and put into commercial operation in June 2007. The second was grid connected in May 2007, with commercial operation in August 2007. Design life is 40 years.

## Ling Ao Phase II

While the bidding process for the delayed Generation III plants from overseas vendors was in train over more than two years (see section above on Embarking upon Generation III plants), the China General Nuclear Power Group (CGN) signed contracts with Chinese designers and manufacturers for two reactors as Phase II of the Ling Ao power station (also known as Ling Dong). Construction started in December 2005 with the 1080 MWe (gross), 1037 MWe (net) units. They are transitional M310 - CPR-1000 units of 1037 MWe net. Unit 1 is about 50% localized and unit 2 is 70% localized, built under the project management of China Nuclear Power Engineering Corporation (CNPEC), part of CGNPC. Low-speed Arabelle turbine-generator sets were provided by Alstom. In June 2009, the first Chinese-made reactor pressure vessel for a 1000 MWe class reactor was delivered for unit 2, from Dongfang (Guangzhou) Heavy Machinery Co. Unit 1 started up in June 2010 with grid connection in mid-July, 54 months after construction start, and entered commercial

operation in September. Unit 2 is expected to commence operation in 2011. Unit 2 was grid connected in May, 60 months after construction start, and commenced commercial operation on schedule in August 2011. The plant is managed by Daya Bay Nuclear Power Operations & Management Co (DNMC).

**Operating nuclear reactors** 

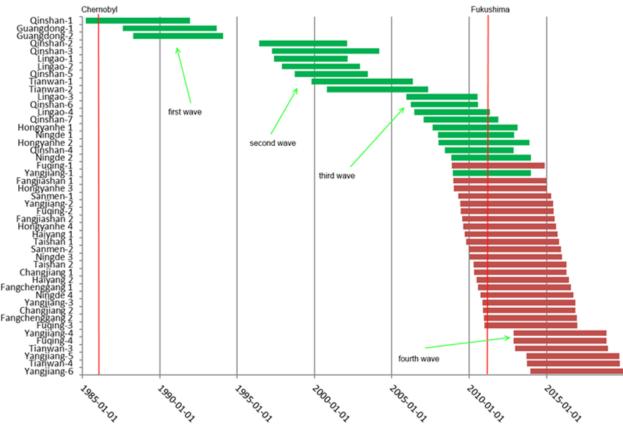
Operating nuclear re						
Units	Province	Net capacity (each)	Туре	Operator	Commercial operation	
Daya Bay 1&2	Guangdong	944 MWe	PWR (French M310)	CGN	1994	
Qinshan Phase I	Zhejiang	298 MWe	PWR (CNP-300)	CNNC	April 1994	
Qinshan Phase II, Zhejiang 1&2		610 MWe	PWR (CNP-600)	CNNC	2002, 2004	
Qinshan Phase II, 3&4	Zhejiang	620 MWe	PWR (CNP-600)	CNNC	2010, 2012	
Qinshan Phase III, 1&2	Zhejiang	678 MWe	PHWR (Candu 6)	CNNC	2002, 2003	
Fangjiashan 1&2	Zhejiang	1020 MWe	PWR (CPR-1000) (M310+)	CNNC	Dec 2014, (early 2015)	
Ling Ao Phase I, 1&2	Guangdong	938 MWe	PWR (French M310)	CGN	2002, 2003	
Ling Ao Phase II, 1&2	Guangdong	1026 MWe	PWR (M310 - CPR-1000)	CGN	Sept 2010, Aug 2011	
Tianwan 1&2	Jiangsu	990 MWe	PWR (VVER-1000)	CNNC	2007, 2007	
Ningde 1&2	Fujian	1020 MWe	PWR (CPR-1000)	CGN & Datang	April 2013, May 2014	
Hongyanhe 1&2	Liaoning	1024 MWe	PWR (CPR-1000)	CGN & CPI	June 2013, May 2014	
Yangjiang 1	Guangdong	1021 MWe	PWR (CPR-1000)	CGN	March 2014	
Fuqing 1	Fujian	1020 MWe	PWR (CPR-1000) (M310+)	CNNC & Huadian	Nov 2014	
Total: 23		20,115 MWe				

In addition, the China Experimental Fast Reactor (CEFR) is grid-connected and producing 20 MWe. It is included in IAEA figures for operational reactors.

## Nuclear plants under construction and planned

China General Nuclear Power (CGN) expected to spend \$ 9.5 billion on its Ling Ao Phase II, Yangjiang and Taishan nuclear power plants by 2010 and to have 6000 MWe on line by then, with 12,000 MWe under construction. Work is under way at all these sites and others. It also planned to start on the Lufeng plant in Guangdong and Wuhu in Anhui province, but awaited NDRC approval. It is expecting to have 34,000 MWe nuclear capacity on line by 2020, providing 20% of the province's power, and 16,000 MWe under construction then. From 2010 it expected to commission three units per year and, from 2015, four units per year. CGN is also, due to State Council policy, committed to developing significant wind capacity through CGN Wind Co. It projects a total of 500 MWe by 2020.

## **China Nuclear Power Plant Construction**



*Jesper Antonsson (data from PRIS) 2014. Red = estimated completion.* 

In 2006, China National Nuclear Corporation (CNNC) signed agreements in Liaoning, Hebei, Shandong and Hunan provinces and six cities in Hunan, Anhui and Guangdong provinces to develop nuclear projects. CNNC has pointed out that there is room for 30 GWe of further capacity by 2020 in coastal areas and maybe more inland such as Hunan "where conditions permit". In October 2007, CNNC's list of projects included Chuanshan (Jiangsu province), Jiyang (Anhui), Hebao Island (Guangdong), Shizu (Chongqing), Xudabao/ Xudapu (Liaoning) and Qiaofushan (Hebei) amongst others.

Since then, announcements from CNNC, CGN and others are reported in the individual reactor reports in the second half of this paper.

# Nuclear reactors under construction and planned

Plant	Province	MWe gross	Reactor model	Project control	Construction start	Operation
Hongyanhe units 3&4	Liaoning	2x1119	CPR-1000	CGN, with CPI	3/09, 8/09	early 2015, late 2015
Ningde units 3&4	Fujian	2x1089	CPR-1000	CGN, with Datang	1/10, 9/10	2015, 2016
Fuqing unit 2	Fujian	1087	CPR-1000 (M310+)	CNNC, with Huadian	6/09	8/2015
Yangjiang unit 2	Guangdong	1087	CPR-1000	CGN	8/09	mid-2015
Yangjiang 3&4	Guangdong	2x1086	CPR-1000+	CGN	11/10, 11/12	2015, 2017
Sanmen units 1&2	Zhejiang	2x1250	AP1000	CNNC	3/09, 12/09	2/2016, mid-2016
Haiyang units 1&2	Shandong	2x1250	AP1000	CPI	9/09, 6/10	12/2015, 3/16
Taishan units 1&2	Guangdong	2x1750	EPR	CGN	10/09, 4/10	late 2016, 2017
Shandong Shidaowan	Shandong	210	HTR-PM	Huaneng	12/12	2017
Fangchenggang units 1&2	Guangxi	2x1080	CPR-1000	CGN	7/10, 2011	3/2015, 2016
Changjiang units 1&2	Hainan	2x650	CNP-600	CNNC & Huaneng	4/10, 11/10	4/2015, 12/2015
Fuqing units 3&4	Fujian	2x1080	CPR-1000 (M310+)	CNNC & Huadian	12/10, 11/12	late 2015, 2017
Tianwan units 3&4	Jiangsu	2x1060	VVER-1000 V- 428M	CNNC	12/12, 9/13	2/2016, 3/2017
Yangjiang units 5&6	Guangdong	2x1080	ACPR1000	CGN	9/13, 12/13	2018, 2019
Shidaowan units 1&2	Shandong	2x 1400	CAP1400	SNPTC & Huaneng	2014, 8/2015	4/2019, 10/2019
Fuqing units 5&6	Fujian	2x1150	Hualong 1	CNNC & Huadian	2014, 2015*	2018-
Hongyanhe units 5&6	Liaoning	2x1150	Hualong 1 or ACPR1000 or AP1000	CGN, with CPI	2015-16*	11/2019, 8/2020
Fangchenggang units 3&4	Guangxi	2x1150	Hualong 1	CGN	late 2015*	
Ningde units 5&6	Fujian	2x1080	ACPR1000 or Hualong 1	CGN & Datang	2015-17*	
Xudabao/Xudapu units 1&2	Liaoning	2x1250	AP1000	CNNC, Datang	2014-15*	2019, 2020
Sanmen units 3&4	Zhejiang	2x1250	AP1000	CNNC	2014-16*	
Haiyang units 3&4	Shandong	2x1250	AP1000	СРІ	2014-16*	
Lufeng (Shanwei) units 1&2	Guangdong	2x1250	AP1000	CGN	2014-15*	2019, 2020
Fangchenggang units 5&6	Guangxi	2x1080	AP1000	CGN	2015-17	
Bailong	Guangxi	2x1250	AP1000	CPI	2015-17	

Plant	Province	MWe gross	Reactor model	Project control	Construction start	Operation
units 1&2						
Huizhou units 1&2	Guangdong	2x1250	AP1000	CGN	2015-18	
Putian, Zhangzhou units 1&2	Fujian	2x100	ACP100	CNNC & Guodian	2015	2017
Tianwan units 5&6	Jiangsu	2x1080	CPR-1000	CNNC	2015-17	
Taishan units 3&4	Guangdong	2x1750	EPR	CGN	2015-18	
Changjiang units 3&4	Hainan	2x650	CNP-600, ACP-600, CPR600 or ACPR1000	CNNC & Huaneng	2015-18	
Zhangzhou units 1-4	Fujian	4x1250	AP1000	Guodian & CNNC	?	
Sanming units 1&2	Fujian	2x880	BN-800	CNNC	?	2025?
26 under construction	28,461 MWe					
38 Planned (coastal)	40,820 MWe					
Taohuajiang units 1-4	Inland units Hunan	planned by 4x1250	AP1000	CNNC	2016 -18*	
Pengze units 1&2	Jiangxi	2x1250	AP1000	СРІ	2016-17*	
Xianning (Dafan) units 1&2	Hubei	2x1250	AP1000	CGN	2016-17*	
Wuhu units 1&2	Anhui	2x1250	AP1000	CGN		
Hengfeng units 1&2	Jiangxi	2x100	ACP100	CNNC & Guodian		
Ningdu units 1&2	Jiangxi	2x100	ACP100	CNNC & Guodian		
Xiaomoshan units 1&2	Hunan	2x1250	AP1000	CPI		
Longyou (Zhexi) units 1&2	Zhejiang	2x1250	AP1000	CNNC		
Yanjiashan/Wanan/Ji'an1&2	Jiangxi	2x1250	AP1000	CNNC		
Shaoguan units 1-4	Guangdong (inland)	4x1250	AP1000	CGN		
Tongren units 1&2	Guizhou	2x1250	AP1000	CGN		2020
26 planned (inland)		27,900 MWe				
	Planned:	2x1080 6x1150 38x1250 2x1100 2x1750 2x1400 2x880 2x650 6x100				

Plant	Province	MWe gross Reactor model		Project control	Construction operation start	
		= 68,720				
Total: 90	Under const Planned	28,461 68,720				

Where construction has started, the dates are marked in bold. Those here not under construction are marked as 'planned' in the WNA reactor table. At 17 January 2015, 26 under construction: 28,461 MWe; 64 planned: 40,820 MWe (gross) coastal plus 27,900 inland and deferred until 2015-16, total 68,720 MWe.

Fangjiashan is sometimes shown as a development of Qinshan Phase I. \* approved by NDRC, but construction delayed post-Fukushima

# Further nuclear power units proposed

Plant	Province	MWe gross	Expected model	Project control		Construction	Start up
Nanchong (Nanchun, Sanba)	Sichuan	4x1080	ACPR1000	CGN			
Shidaowan units 3&4	Shandong	2x1400	CAP1400 or AP1000	SNPTC Huaneng	&		
Tianwan units 7&8	Jiangsu	2x1200	VVER- 1200 (AES- 2006)	CNNC			
Xianning (Dafan) units 3&4	Hubei	2x1250	AP1000	CGN			
Shidaowan units 5&6	Shandong	2x1400	CAP1400 or AP1000	SNPTC Huaneng	&		
Shandong Shidaowan	Shandong	18x210	HTR-PM	Huaneng			
Haiyang units 5&6	Shandong	2x1250	AP1000	CPI			
Hongshiding (Rushan) units 1&2	Shandong	2x1100	ACP1000?	CNNC			
Cangzhou units 1&2	Hebai	2x1250	AP1000	CNNC Huadian	&		
Xiaomoshan units 3&4	Hunan	2x1250	AP1000	CPI			
Pingnan/Baisha units 1&2	Guangxi	2x1250	AP1000	CPI			
Pingnan/Baisha units 3&4	Guangxi	2x1250	AP1000	СРІ			
Xudabao /Xudapu units 3-6	Liaoning	4x1250	AP1000	CNNC Datang	with		
Lufeng	Guangdong	4x1250	AP1000?	CGN			

Plant	Province	MWe gross	Expected model	Project control	Construction Start
(Shanwei) units 3-6					_
Yingtan	Jiangxi	2?		Huaneng	
Nanyang units 1-6	Henan	6x1250?	AP1000 (if CPI)	CNNC CPI)	(or
Xinyang units 1-4	Henan	4x1080	ACPR1000	CGN	
Changde (Chenzhou, Hengyang)	Hunan	4x1000?		CNNC Guodian?, CGNPC	&
Zhangzhou units 5&6	Fujian	2x1250	AP1000	CNNC Guodian	&
Jiyang/Chizhou units 1&2	Anhui	2x1250?	AP1000	CNNC	
Sanmen units 5&6	Zhejiang	2x1250	AP1000	CNNC	
Fuling units 1&2	Chongqing	2x1250	AP1000	CPI	
Jingyu units 1&2	Jilin	2x1250	AP1000	CPI Guodian	&
Donggang units 1&2	Liaoning	2x1000	?	Huadian	
Subtotal: 80 units		76,000+ MWe			
		Further p	proposals (less	s definite or	further away)
Cangzhou units 3-6	Hebai	4x1250	AP1000	CNNC Huadian	&
Jiyang/Chizhou units 3&4	Anhui	2x1250?	AP1000?	CNNC	
Cangnan units 1-6	Zheijiang	6x1000		CGN/Huan	eng
Zhexi/Longyou units 3&4	Zhejiang	2x1250	AP1000	CNNC	
Haijia /Haifeng units 1&2	Guangdong	2x1000?		CGN	
Jinzhouwan units 1&2	Liaoning	2x1000			
Fuling units 3&4	Chongqing	2x1250	AP1000	CPI	
Jingyu units 3&4	Jilin	2x1250	AP1000	CPI Guodian	&
Liangjiashan units 1&2	Jilin	2x1250?	AP1000	CGN Guodian	&
Changchun Jiutai units 1&2	Jilin	2x1250?	AP1000	CGN Guodian	&
Songjiang units 1&2	Shanghai	2x1250?	AP1000	CGN Guodian	&
Wuhu units 3&4	Anhui	2x1250	AP1000	CGN	

Plant	Province	MWe gross	Expected model	Project control	Co	onstruction	Start up
Pengze units 3&4	Jiangxi	2x1100	AP1000	СРІ			
Bailong units 3&4	Guangxi	2x1250	AP1000	CPI			
Heyuan/Jieyang units 1-4	Guangdong	4x1000		CNNC?			
Xiaomoshan units 5&6	Hunan	2x1250	AP1000	CPI			
Haiyang units 7&8	Shandong	2x1250	AP1000	CPI			
Pingnan/Baisha units 1-4	Guangxi	4x1250	AP1000	CPI			
Hengren units 1-4	Liaoning	4x1250	AP1000	CPI			
Zhanjiang units 1-4	Guangdong	4x1250	AP1000	CPI			
Lanzhou/Baiyin	Gansu	2?		CNNC			
Xiangtan	Hunan	4x1250	AP1000	Huadian			
Donggang units 3&4	Liaoning	2x1000		Huadian			
Shizu	Chongqing	2x		CNNC			
Qiaofushan	Hebai	2x		CNNC			
Songzi/Xianning units 5&6	Hubei	2x1250	AP1000	CGN			
Guangshui	Hubei	4x1250	AP1000	CGN			
Zhingxiang	Hubei	4x1250	AP1000	CNNC, Datang			
Hebaodao	Guangdong	2x		CNNC?			
Yibin	Sichuan	2x		CNNC			
Zhangzhou- Gulei units 1&2	Fujian	2x100	ACP100	CNNC-CNE	EC		
Sanming units 3&4	Fujian	2x880?	BN-800?	CNNC	20	15	
Jiamusi	Heilongjiang	1000	CPR-1000	Huaneng CNNC, CGN	& or		
Subtotal: about 88 units		50x1250 2x1400 14x1000 2x880 c.18x210 2x100 <b>Approx.</b> 94,000 <b>MWe</b>					
Total: about 156		160,000+ MWe					

All PWR except Shidaowan HTR-PM and Sanming BN-800. Some of these entries are based on sketchy information. For WNA reactor table, 80% of numbers and capacity from this table are listed as 'Proposed': 123 units and 128 GWe.

## Hongyanhe, LHNP

This is the first nuclear power station receiving central government approval to build four units at the same time, and the first in northeast China. Construction of the first unit of the Hongyanhe nuclear power plant in Dalian, Liaoning, started in August 2007. It is the first nuclear power project in the 11th Five-Year Plan, with owner and operator being Liaoning Hongyanhe Nuclear Power Co, a joint venture of CGN and CPI (45% each) with Dalian Construction Investment Group. It uses CPR1000 reactors.

The National Nuclear Safety Administration (NNSA) issued a construction licence for units 3&4 in March 2009, and first concrete for unit 3 was poured soon afterwards. CGN will be responsible for the project construction and the operation of the first five years after commercial operation, with full participation of CPI. The cost of all four 1080 MWe CPR-1000 units in the first construction phase is put at CNY 50 billion (US\$ 6.6 billion). China Nuclear Power Engineering Corporation (CNPEC), part of CGN, is managing the project. Shanghai Electric won a \$260 million contract for equipment and Alstom providing the four low-speed Arabelle turbine-generator sets for \$184 million. Localisation is above 70% for units 1&2 and over 80% for units 3&4.

First power from unit 1 was expected in July 2012, but after delays over 2011 it started up in January 2013 and was grid connected in February, with commercial operation in June. The project incorporates a 10,080 m<sup>3</sup>/day seawater desalination plant using waste heat to provide cooling water. Unit 2 started up in October 2013, was grid connected in November, with commercial operation in May 2014. Unit 3 started up in October 2014.

In May 2010, the NRDC approved preliminary work on the CNY 25 billion two-unit second phase of the plant (units 5&6), and site work began in July. The National Nuclear Safety Administration (NNSA) and the Environment Ministry approved the project in September 2010, construction start was expected 2011 but now appears likely in 2015, following a State Council announcement. NDRC approval was reported in September 2014, using ACPR1000 reactors (hence maybe Hualong), though CPI documentation says AP1000. Localisation is to be above 80%.

# Ningde, NDNP

Construction of CGN's six-unit Ningde nuclear power plant commenced in 2008. This is on three islands in Fuding city in northeast of Fujian province, and the first construction phase comprises four CPR-1000 units. Ningde Nuclear Power Co Ltd (NDNP) was set up in 2006 as a joint investment of CGN (46%), China Datang Corporation (44%) and Fujian Energy Group Co., Ltd. The project was approved by the National Development & Reform Commission (NDRC) in

September 2006, and local content will be about 75% for units 1&2 and 85% for units 3&4. It marks a significant step into nuclear power for Datang.

Construction of the first unit started in February 2008, and it was grid connected in December 2012 after 58 months. It was declared in commercial operation in April 2013, with the others due to follow to 2015. First concrete for the second unit was in November 2008, it achieved criticality in December 2013 and was grid connected in January 2014, with commercial operation in May. Construction start for the third was in January 2010 and for the fourth at the end of September 2010. Total cost for four units was put at CNY 52 billion (\$7.6 billion). Dongfang Electric is supplying turbine generators for units 1-4, using Alstom Arabelle low-speed technology, at least for units 3&4. The pressure vessel and steam generators for unit 1 are from Dongfang (DFHM), those for unit 2 are from Shanghai Electric (SEC), those for units 3&4 from China First (CFHI).

In February 2014 the NEA approved preliminary work for units 5&6, which are set apart from phase 1 units 1-4 and may be ACC1000.

#### **Fuging**

Construction of the six-unit Fuqing nuclear power plant 170 km south of Ningde also commenced in 2008 at Qianxe, Fuqing city in Fujian, near Fuzhou. The Fujian Fuqing Nuclear Co Ltd was set up in May 2006 with 45 or 49% held by China Huadian Corp. CNNC is responsible for the project which is using CGN's CPR-1000 reactors since alternatives are not licensed. First concrete for unit 1 was poured in November 2008, for unit 2 in June 2009, and for unit 3 in December 2010. Commercial operation is expected over 2014 to 2016. Site works are under way for further units there, total expected cost for all six being CNY 88 billion (\$14.3 billion). Construction of unit 4 started in September or October 2012, almost immediately after NNSA authorization. Unit 1 started up in July 2014, with unit 2 expected to do so in mid-2015. Unit 1 was grid connected in August after 69 months construction and entered commercial operation in November. Units 3&4 are expected in operation in early 2016 and 2017 respectively.

Construction of the project is by China Nuclear Power Engineering Co. (CNPE) and the reactor pressure vessels are supplied by China First Heavy Industries, as for Fangjiashan. In June 2008, Dongfang Electric Group announced a CNY 5 billion (\$725 million) contract for Alstom Arabelle low-speed steam turbine generators for the Fuqing and Fangjiashan plants. Units 3&4 have Areva instrument & control systems.

Late in 2010, CNNC was proposing the CNP1000 for units 5&6, noting "pre-project under way". In October 2011 CNNC said that units 5 & 6 would be the first ACP1000 units, and in December 2013 it was announced that they would have Areva-Siemens instrument and control systems, with construction starting in 2014 and 2015. In January 2014 CNNC said that they would be CNNC's first Hualong 1 units.

## Yangjiang, YNPS

Yangjiang city in western Guangdong province had originally been earmarked for the country's first Generation III plants (see section above on Embarking upon Generation III plants). After plans changed in the light of pressing generation needs in the region, Yangjiang will be the second nuclear power base of the China General Nuclear Power Group (CGN). Development of all six units of the Yangjiang plant was approved in 2004, with CPR-1000 later confirmed as the basic technology for it. Local content is about 83% for units 1&2, and is expected to be 85% for units 3&4 and maybe 90% for 5&6 of the evolved design – the first ACPR1000 reactors. Total cost was expected to be CNY 73 billion (\$12.1 billion).

Construction of the first of two CPR-1000 units by CNPEC started in December 2008, for commercial operation in 2014. Unit 1 criticality was achieved in December, with grid connection at the end of the month and commercial operation in March 2014.

Construction of unit 3 started in November 2010, unit 4 in November 2012, immediately after NNSA authorization, then the final two (as the second construction phase) followed from September 2013, with the last to be built by 2018. Units 3&4 are the first of an improved CPR-1000 design sometimes referred to as CPR-1000+. Construction of unit 5 as ACPR1000 began in mid-September 2013 and unit 6 late in December 2013.

Yangjiang 1-6 will be operated under Yangjiang Nuclear Power Co Ltd (YJNPC) management. In July 2010, Hong Kong-based power utility China Light and Power (CLP) agreed to take a 17% stake in Yangjiang – the equivalent of one reactor. However, in September 2013 CGN halted negotiations with CLP, following delays due China's review of nuclear safety. These are expected to resume in 2014, and CLP expects eventually to take some equity in the plant.

#### **Fangjiashan**

Construction of CNNC's Fangjiashan plant started at the end of December 2008. It is close to the Qinshan plant in Zhejiang province and essentially an extension of it, using two CPR-1000 reactors, designated M310+ by CNNC. Construction of the CNY 26 billion (\$4.2 billion) project was by China Nuclear Power Engineering Co. (CNPE) and the reactor pressure vessels are supplied by China First Heavy Industries, as for Fuqing. In June 2008, Dongfang Electric Group announced a CNY 5 billion (\$725 million) contract for Alstom Arabelle low-speed steam turbine generators for the Fuqing and Fangjiashan plants. Localisation is 80%. First criticality of unit 1 was in October 2014 with grid connection in November and commercial operation in December 2014 and was grid connected in mid-January 2015. Unit 2 started up in December 2014. The project is 72% owned by CNNC, with the remainder held by Zhejiang Provincial Energy Group Co Ltd. The two units will bring the Qinshan total effectively to nine, with 6540 MWe.

#### Sanmen

At the end of 2006, the Westinghouse AP1000 reactor design was selected for Sanmen in Zhejiang province (and for Yangjiang in Guangdong province, with the latter site changed to Haiyang). Contracts with Westinghouse and Shaw for two units were signed in July 2007. Site works under CNNC commenced in February 2008 and an engineering, procurement and construction (EPC) contract was signed in March 2009 between SNPTC + CNNC and China Nuclear Engineering & Construction Group (CNEC) for both units, which will be overseen by Westinghouse and Shaw (now CB&I). Other stakeholders are Zhejiang Provincial Energy Group Co Ltd, CPI Nuclear Power Co Ltd, and China Huadian Corp.

Construction on Sanmen 1 – the world's first AP1000 unit – officially commenced on 19 April 2009. The pressure vessel, from Doosan, was installed in September 2011. The reactor was expected to begin operation in December 2014 with unit 2 less than a year later. Construction on unit 2 commenced in mid-December 2009. The pressure vessel and steam generators for unit 2 are being made in China. MHI supplied the turbine generators for both units. CNEA in 2013 said the cost would be about \$2610/kW. In March 2014 NNSA said that start-up would be delayed to December 2015 due to design changes and component problems. See section on

### **Embarking upon Generation III plants above.**

Another six units are envisaged for the Sanmen site.

#### Haiyang

Shangdong Nuclear Power Company (a subsidiary of CPI) signed contracts with Westinghouse and Shaw for two AP1000 units in July 2007. First concrete was poured in September 2009 for unit 1 and June 2010 for unit 2. The 5000 cubic metre base mat of each was placed in a single pouring of less than 48 hours. The pressure vessel and steam generators for unit 2 are being made in China. MHI supplied the turbine generators for both units. These units were expected to commence operation in December 2014 and March 2015, but in March 2014 NNSA said that start-up would be delayed into 2015 due to design changes and component problems. See section on Embarking upon Generation III plants above.

The site will eventually have six or eight units, and in March 2009, the NDRC approved preliminary works for units 3&4 at the CPI site. In February 2014 the MEP approved construction start on these, which are expected to cost CNY 31.4 billion (\$5.1 billion).

Haiyang will be a CPI training base for AP1000 staff, along with a set-up at Yantai.

#### Taishan

The first two EPRs planned for Taishan in Guangdong province form part of an €8 billion contract signed by Areva and the China General Nuclear Power Group (CGN) in November 2007. The

Taishan project (sometimes referred to as Yaogu) is owned by the Guangdong Taishan Nuclear Power Joint Venture Company Limited (TNPC), a joint venture between EDF (30%) and CGN. First concrete was poured in October 2009, and unit 1 is expected to be commissioned in 2016, with unit 2 a year later. Areva is sourcing the main components for both units from Japan and China and expects net capacity to be 1660 MWe each. See section on Embarking upon Generation III plants above.

Site works are reported to be proceeding for units 3&4.

## **Shandong Shidaowan HTR-PM**

A demonstration high-temperature gas-cooled reactor plant, with twin reactor modules driving a single 210 MWe steam turbine, was initially approved in November 2005, to be built at Shidaowan (Shidao Bay) in Weihai city, Shandong province, by Huaneng Shandong Shidaowan Nuclear Power Company Ltd (HSNPC). It will be part of the Rongcheng Nuclear Power Industrial Park project. The HSNPC joint venture is led by the China Huaneng Group Co – the country's largest generating utility but hitherto without nuclear capacity, and still without NNSA authority to build nuclear plants itself. Huaneng Power International is investing CNY 5 billion in the project, which received environmental clearance in March 2008. An important 20% stake in the project is held by Tsinghua University INET, reflecting its innovative technology. With site work complete, following NDRC approval construction started in mid-2011. Commercial operation is expected in 2017. (information on CGNPC and Tsinghua web sites) NB though involving twin reactors this is shown as a single reactor unit in WNA Tables.

The EPC (engineering, procurement, construction) contract was let in October 2008, and involves Shanghai Electric Co and Harbin Power Equipment Co. A simulator contract signed in May 2010 was between HSNPC, Chinergy and CGNPC Simulator Co. In November 2010 Huaneng Group signed an agreement with US-based Duke Energy to train nuclear plant staff.

After three years of negotiation, in March 2011 a contract was signed with SGL Group in Germany for supply of 500,000 machined graphite spheres for HTR-PM fuel by the end of 2013. A new HTR fuel production plant is being set up at Baotou.

This will be the demonstration plant for further modules at the site, total possibly 3,800 MWe. (See also Research and development section in page on China's Nuclear Fuel Cycle.)

#### Shidaowan PWRs

In November 2007, China Huaneng Group (CHNG) signed an agreement with CGN for the Huaneng Nuclear Power Development Co Ltd to build four CPR-1000 reactors at Shidaowan, Rongcheng, Weihi city, in Shandong province in an \$8 billion deal. A letter of intent regarding the first two was signed in 2008. The project then became focused on the CAP1400, with SNPTC as the lead partner and two CAP1400 reactors as phase 1.

The State Nuclear Power Demonstration Plant Company (SNPDP) is a 55-45% joint venture company set up in December 2009 by SNPTC and China Huaneng Group (CHNG) to have overall responsibility for building and operating the first CAP1400 reactors and subsequent CAP1700

reactors (see Reactor technology section above), two CAP1400s being envisaged as demonstration units at Shidaowan. SNPTC will be in charge of building these.

The Environment Impact Assessment Report (EIAR), the Site Safety Assessment Report (SSAR) and construction application were submitted to Ministry of Environment Protection and NNSA in March 2012, and NNSA approval of both was expected in mid-2014. Site works for the first two CAP1400 units totaling 3.24 GWe were complete by April 2014. First concrete for unit 1 was expected at the end of August 2014, with 56-month construction giving operation in April 2019. Unit 2 first concrete is due in August 2015 and operation in October 2019.

In June 2014 the Ministry of Environment Protection was seeking comment on SNPTC plans for CAP1400 units 3&4, expected to cost CNY 42.3 billion. However, Huaneng, which owns the Rongcheng Industrial Park site, is keen to build four AP1000 as phase 2, and this is unlikely to be resolved before phase 1 construction is well under way. It has been suggested that if six CAP1400 units are built, Huaneng may have majority ownership of three. The eventual capacity of Shidaowan over 20 years is expected to be very large.

# Fangchenggang

The Fangchenggang Nuclear Power Project is located at Hongsha village, in the Beibu Gulf (Beibu Wan) Economic Zone on the southeast coast of Bailong Bay in the coastal city of Fangchenggang in the Guangxi Autonomous Region (45 km from the Vietnam border in south China). It is sometimes referred to as 'Fangcheng Port' and in 'Western China'. Following an agreement in July 2006, the first stage (two 1080 MWe CPR-1000 units out of six planned) of the plant was approved by NDRC in October 2008, and again in July 2010. First concrete for unit 1 was poured in July 2010, and for unit 2, late in 2011. About 87% of the first two units will be sourced in China.

In October 2009, a general construction contract was signed with CNPEC. Guangxi Fangchenggang Nuclear Power Co., Ltd., a joint venture between China Guangdong Nuclear Power Group (61%) and Guangxi Investment Group (39%), is responsible for the construction and operation. CPI was earlier involved. The first unit is expected to begin commercial operation in July 2015, the second a year later. Total budget is CNY 70 billion (\$10.26 billion), with CNY 26 billion (\$3.87 billion) for stage 1. In December 2011 it was reported that Guangxi was accelerating construction to relieve power shortage, and allow for exports to Vietnam. (There is also a Fangchenggang supercritical 2400 MWe coal-fired power station operated by CLP Guangxi Fangchenggang Power Company Limited, a 70:30 equity-basis joint venture between China Light & Power and Guangxi Water & Power Engineering (Group) Co., Ltd.)

CGN from September 2012 planned that Stage 2, units 3&4, should be the initial ACPR1000 demonstration units, with construction start in 2014. However, no authorization was forthcoming, and since January 2014 these are to be CGN's inaugural ACC1000/Hualong 1000 units, based on CNP1000, with construction starting at the end of 2015. Cost is put at about CNY 30 billion (\$4.9 billion). Stage 3 (units 5&6) – which are AP1000s – may proceed first.

#### **Bailong**

This is a CPI project about 30 km from Fangchenggang in Guangxi province, with two AP1000 reactors in stage 1 and two more in stage 2. It is reported to be delayed by local opposition, and may be an alternative to stage 3 of Fangchenggang.

#### Huizhou

This is a CGN project in Huangbu town, Huidong county, Huizhou city on Red Bay close to Daya Bay, with two AP1000 reactors in its first stage and four more to follow. Initial investment by CGN and Huizhou city was estimated at CNY 80 billion in 2011. The project company is China Guangdong Huizhou Nuclear Power Co. The project passed its initial feasibility assessment by the provincial Development and Reform Commission in 2011. Some site works have been undertaken.

### Tianwan Phases II, III & IV

In October 2006, a preliminary agreement for two further 1060 MWe AES-91 VVER reactors as the second construction phase at Tianwan in Lianyungang city of Jiangsu province was signed with Russia's Atomstroyexport. Preliminary approval from NDRC was received in August 2009, and the project was then expected to cost \$3.8 billion (\$1790/kW).

Protracted discussion on pricing for the Russian components of the plant delayed the project. Eventually, a contract for the engineering design of units 3&4 was signed in September 2010 between Jiangsu Nuclear Power Corporation and Atomstroyexport, and the general contract came into force in August 2011 with protocol signed by China Atomic Energy Authority and Rosatom. Final approval from NDRC was received in January 2011. The EPC contract with CNNC's China Nuclear Engineering & Construction Group (CNEC) was signed in October 2011. A civil engineering contract was let to China Nuclear Industry Huaxing Construction Company (HXCC) in May 2012, and to China Nuclear Industry 23 Construction Co for component installation in July. Both are CNEC subsidiaries. An intergovernmental protocol was signed in December 2012, with first concrete poured that month. In August 2013 the China Development Bank signed a loan agreement with Jiangsu Nuclear Power Co. for CNY 16 billion for phase II.

Atomstroyexport is providing 30% of the V-428M phase II units for €1.3 billion (€613/kW), including nuclear island equipment (reactor, steam generators, pressurisers, primary piping. etc.) and some related equipment. It is not acting as the principal contractor, though it insists on retaining intellectual property rights. Jiangsu Nuclear Power Corporation is responsible for about 70% of the project, namely, the civil work, turbine island with equipment and related infrastructure on the site. Iskorskiye Zavody, part of OMZ, is supplying the major components covered by the Russian €1.3 billion part of the phase II plant. This includes two reactor pressure vessels with internals and upper units. Delivery was to be completed in 2014. (The company already took part in making the major equipment for Tianwan 1&2, including reactor pressure vessels.) ZiO-Podolsk is

making the steam generators. The turbine generator sets will probably be sourced from Dongfang Electric, using Alstom Arabelle low-speed technology. Areva I&C systems are being used.

First concrete for unit 3 was poured in December 2012, and that for unit 4 in September 2013. Commercial operation is due in 2018 and 2019.

There has been some confusion about the technology for **phase III**, units 5&6. Due to urgency in meeting power demands, it appeared likely that units 5&6 (phase III) might be built ahead of 3&4, as CPR-1000 units, based on those at Fangjiashan. This technology prospect appeared to lapse with post-Fukushima sidelining of the design. But the CNNC website in October 2014 had them as 1000 MWe units, consistent with the 2012 decision to build as CPR-1000. An EPC contract between Jiangsu and CNPE was signed in February 2011, making CNPE the project manager, but saying then that Units 5&6 were likely to be VVER-1200s. Dongfang Electric has a contract to supply turbine generators using Alstom Arabelle low-speed technology.

Phase IV is less ambiguous. In December 2012 Russian sources reported discussions with CNNC regarding phase IV of Tianwan (units 7&8), using VVER technology. In October 2013 China National Nuclear Power Co Ltd (CNNP) said that the technology might be VVER-1200/AES-2006 rather than VVER-1000/AES-91. Atomernergoproekt has quoted Leningrad's V-491 reactors as reference units for later Tianwan units, now apparently just 7&8. In October 2014 Russia's energy minister said that he expected Atomstroyexport to supply units 7&8 at Tianwan.

#### Hongshiding (Rushan)

In November 2006, an agreement was signed by CNNC to proceed with the first two units of the Hongshiding nuclear plant at Hongshiding in Weihai or Rushan city, Shandong province, costing \$ 3.2 billion, with construction to begin in 2009 and first power in 2015. However, it appears to have been deferred. Six units now likely to be ACP1000, totaling 6600 MWe are envisaged at the site, with Shandong Hongshiding Nuclear Power Co. Ltd as developer.

#### Changjiang

CNNC's Changjiang nuclear power plant on Hainan Island started construction in April 2010 for operation of the first unit early in 2015 and the second later in 2015. It will eventually comprise four 650 MWe PWR units (CNP-600) based on those at Qinshan Phase II. Total cost of the first pair is put at about CNY 20 billion (\$2.8 billion). Units 3 & 4 will be built as the second phase of construction. Huaneng Power International (HPI), part of China Huaneng Group (CHNG), holds a 30% share in Hainan Nuclear Power Co Ltd. More than 70% of the plant's equipment is to be made in China.

#### Xudabao

CNNC's Xudabao or Xudapu nuclear power station is in Xingcheng City, Huludao (Hulu island), in coastal Liaoning province. The CNY 110 billion (US\$18 billion) Xudabao project will comprise six AP1000 or CAP1000 reactors, with units 1&2 in the first phase. Site preparation was under way in November 2010, and NNSA granted site approval for two units in April 2014. Final approval was reported in September 2014, and operation is due in May 2018, according to CNECC.

CNNC's Liaoning Nuclear Power Company Ltd owns the plant, with Datang International Power Generation Co holding 20% equity, and State Development and Investment Corporation (SDIC) 10%. The general contractor is China Nuclear Power Engineering Company Ltd (CNPE), and negotiations for an EPC contract for units 1&2 were taking place in December 2011. In October 2010, the Northeast Electric Power Design Institute (NEPDI), Changchun, Jilin, a subsidiary of China Power Engineering Consulting Corporation (CPECC), signed a survey and engineering contract for the plant. When Taohuajiang plant was deferred, the main reactor parts were transferred to Xudapu. Manufacture of the steel containment was launched in July 2013 by Shandong Nuclear Power Equipment Manufacturing Co Ltd (SNPEMC).

# Lianyungang

CGN has several plans in Northern China, and among other possible projects it has applied for several reactors at Lianyungang, Jiangsu province, very close to CNNC's Tianwan plant. A proposal has been submitted to the NRDC. However, the further development of Tianwan makes it unlikely, and if implemented, it will not proceed before about 2025. It is not included in the above Table or any statistics.

#### Lufeng

CGN Lufeng Nuclear Power Corporation is making efforts to start on the first two units (of six) of the Lufeng (Shanwei) plant in the Tianwei district in eastern Guangdong. An EPC contract was signed with SNERDI in September 2013, environmental approval was in June 2014, and NDRC approval for two AP1000 units was reported in September 2014. It will be a CNPEC project. It is in the 12th Five-Year Plan, and construction start late in 2014 is likely. The AP1000 plant equipment manufactured for Xianning is being deployed there for units 1&2, and it will be CGN's first AP1000 plant. Investment to June 2014 was CNY 37.4 million. Commercial operation is expected in 2019 and 2020, if not earlier.

#### Putian & Zhangzhou-Gulei

China Guodian's first nuclear power venture, with CNNC holding 51% of CNNC New Energy Corporation, will initially have two small modular ACP100 reactors, at Putian on the coast in Fujian province, near Xiamen, as a demonstration plant. These are integral PWRs, with passive cooling for decay heat removal. This will be the CNY 5 billion (\$788 million) phase 1 of a larger Zhangzhou project. CNNC said that the units could provide electricity, heat and desalination. Construction time

is expected to be 36-40 months, starting 2015. It involves a joint venture of three companies for the pilot plant: CNNC as owner and operator, the Nuclear Power Institute of China as the reactor designer and China Nuclear Engineering Group being responsible for plant construction.

A second proposal is for two ACP100 units on the other side of the peninsula, at Zhangzhou-Gulei, but though approved by SASAC in November 2011, it is stalled due to opposition from local government. CNNC New Energy Corporation (CNNC & Guodian) is seeking alternative sites.

#### Zhangzhou

The larger project will be undertaken by Nuclear Guodian Zhangzhou Energy Co. Ltd., and will comprise four AP1000 reactors as phase I and two more as phase II. CNNC says it has received preliminary approval, and in May 2014 local government gave approval, with phase 1 costing CNY 54.4 billion. The company was established in November 2011, by CNNC or China Nuclear Power International Inc (51%) and China Guodian Corporation (49%). The proposal was submitted to NDRC in August 2010.

# Songjiang

This is to be developed in Shanghai's Songjiang district by CGN with China GD Power Development Co Ltd, a subsidiary of Guodian, and in connection with a framework cooperation agreement with the State Grid Corporation of China. It is not expected to be approved before about 2020.

#### **Sanming**

In October 2009, an agreement was signed by CIAE and CNEIC (a CNNC subsidiary responsible for technology imports) with Russia's Atomstroyexport to start pre-project and design works for a commercial nuclear power plant with two BN-800 fast neutron reactors (referred to as Chinese Demonstration Fast Reactors) at Sanming city, an inland part of Fujian province. A site survey and preliminary feasibility study had been undertaken in 2007-08. CNNC in April 2010 established Sanming Nuclear Power Co Ltd as a joint venture company with the Fujian Investment & Development Corp and local government, and initiated a full feasibility study.

Construction was due to start in 2013, once an intergovernmental agreement was in place, expected in 2012, but still pending in 2014. The local content was targeted at 70%, and the first unit was to be in operation in 2018, with the second following about a year later. A second phase, with units 3&4, was due to commence in 2015. The plant would be similar to the OKBM Afrikantov BN-800 design built in Russia at Beloyarsk 4, which started up in 2014. Negotiations on price have delayed the project and NIAEP-Atomstroyexport now expects the first contracts to be in place at the end of 2014. However, it appears that policy regarding fast reactors remains uncertain, and the first commercial demonstration units are now not expected to be on line before 2025.

#### Inland nuclear power plants

These have been delayed significantly from the dates for the larger units planned before mid-2011. This was announced as being due to concerns regarding possible pollution of rivers. Taohuajiang, Xianning and Pengze are all in the 12th five-year plan to start construction, but the premiere's announcement in October 2012 deferred approvals for inland plants until after 2015. However, the delay has involved an assertion of central government control over eager provincial governments with their own economic development agendas. NEA approvals are likely to start for these in 2016. In September 2014 three projects were mentioned as likely first construction starts sssfor 13th 5-year plan from 2016: Taohuajiang in Hunan, Pengze in Jiangxi, and Dafan in Hubei.

### **Taohuajiang**

CNNC's Taohuajiang nuclear power plant on the Zi River in Taojiang county, Yiyang city, near Yueyang in inland Hunan province is likely to be China's first inland nuclear power plant. It was expected to start construction in September 2010, and some CNY 3 billion of site works are complete, but construction is delayed to 2015 or 2016. (It is also referred to as the Taohua [peach blossom] River project.) CNNC set up Hunan Taohuajiang Nuclear Power Co Ltd. to build and operate the plant. Initially this was to be 4x1000 MWe at a total cost of CNY 34 billion, but it is now to be a four-unit CAP1000 project costing over CNY 70 billion. The main contractor is China Nuclear Industry 23rd Construction Co Ltd; China Erzhong is contracted to supply the main pressure vessel forgings, and Dongfang Electric Corp will supply other major components. Germany's GEA Group is to construct the cooling tower for unit 1: a natural draft unit some 200 metres high and 160 m in diameter, with 15,000 square metres drenching area. Subsequent towers will have increasing local content.

The project was approved by the NDRC in November 2005, and in 2008 the project was approved for preliminary construction. Site works have been undertaken to the extent of CNY 3.8 billion. The design by SNERDI under SNPTC and SNPDRI was submitted to the NNSA in February 2010 for licensing. A general framework agreement for construction was signed by CNNC with CNPE Corporation as EPC contractor in December 2010. The first unit was originally expected in commercial operation in 2015, and the fourth in 2018. However, after all the inland projects were deferred the reactor components were transferred to Xudapu/Xudabao, and the site workforce was laid off. Construction start is now expected in 2016.

#### Xianning/Dafan

In August 2008, CGN and Hubei Energy Group Ltd set up the Hubei Nuclear Power Company as a joint venture and announced plans to build a nuclear power plant at Dafan in Xianning city of the inland Hubei province. Site works for this plant (four AP1000 units) have been undertaken to the extent of CNY 3.4 billion. Construction of the first two units was expected to start in 2011, but is

delayed to 2016. The reactor pressure vessel for the first unit is contracted to China First Heavy Industries, and the first two 209 metre high cooling towers to Belgium's Hamon Thermal. The cost of four AP1000 reactors is put at CNY 60 billion (\$8.8 billion). This would have been CGN's first AP1000 plant, but the equipment has been reassigned to Lufeng. A further phase is estimated to cost CNY 45 billion.

The large pre-assembled modules that will make up the bulk of the new AP1000s are to come from a new inland facility owned by new firm Hubei Nuclear Power Equipment Company.

Reports of a Songzi plant may refer to later stages of Dafan, though possible projects in Yangxin county have been mentioned.

The Hubei Nuclear Power Co is also reported to be planning a four-unit AP1000 plant at Guangshui city in the northeast of the province.

#### **Pengze**

CPI's Pengze Nuclear Power Project in Jiangxi province is to have four AP1000 reactors costing CNY 60 billion (\$8.8 billion). The site has been prepared for the first two units, and safety and environmental approvals were obtained in May 2009. CPI signed the EPC contract framework for phase 1 (units 1 & 2) in August 2009, the engineering project contract was reported to be between CPI Jiangxi Nuclear Power Co Ltd and CPIC. The equipment procurement was reported to be between CPIC and China Power Complete Equipment. CPI aimed to start construction in 2010, for 2013 start-up, but construction has been delayed, evidently to 2016. Site works amount to CNY 3.4 billion.

The project is inland in Juijiang city, across the Yangtze River from Wangjiang in Anhui province. The cooling towers are being designed by Belgium's Hamon Thermal for the State Nuclear Electric Power Planning Design and Research Institute (SNPDRI). The project has been opposed by Wangjiang in neighbouring Anhui province, which has plans for several nuclear plants iteself, including Wuhu (Fanchang) and Jiyang (Chizhou), with Anqing Congyang and Xuancheng along the Yangtze River also mentioned.

#### Xiaomoshan

The Xiaomoshan nuclear power plant on the Yangtze River in Huarong county, Yueyang city, Hunan province (inland), is a priority project for CPI. It will eventually have six AP1000 reactors and be built by Hunan Nuclear Power Company Ltd in two phases. NDRC approval was given in 2006 but as of mid-2010 NNSA approval was awaited. Site preparation has been undertaken and first concrete was expected late in 2010. The cost is put at CNY 70 billion (\$10.25 billion) for the first four units, funded by SNPTC and Wuling Electric Power Development Co. (a CPI subsidiary). The Heimifeng pumped storage plant will be associated with it.

## Yanjiashan/Wanan/Ji'an

In August 2009, CNNC (51%) signed a joint venture agreement with Jiangxi Ganneng Co. Ltd and Jiangxi Ganyue Expressway Co Ltd (49% between them) setting up Jiangxi Nuclear Power Co to build the Wanan Yanjiashan nuclear power project at Ji'an in the Jiangxi province. CNNC contracted a feasibility study of Yanjiashan nuclear power program in July 2010. Pre-project work was reported as under way in November 2010. (This is also reported as a CPI project.)

#### Hengyang

Also in August 2009, CNNC signed an agreement with Hengyang city in Hunan province to build a nuclear power plant there or nearby. This is about 200km south of its Taohuajiang project at Yiyang city in Hunan. China Guodian Corporation, one of the country's largest power producers, is involved in the project though it has no nuclear capacity so far.

# **Zhongxiang**

CNNC's Hubei Zhongxiang nuclear power project is at Zhongxiang city in central Hubei, with China Datang. The 5000 MWe plant is undergoing a detailed feasibility study, but further details are unknown

# **Cangzhou Haixing**

China Huadian plans the Cangzhou Haixing nuclear plant with six AP1000 reactors in Cangzhou city, Hebei province, 90 km inland from Tianjin. A CNY 100 billion investment is envisaged by the China Nuclear Huadian Hebei Nuclear Power Co. CNNP has 51% of the project company, Huadian Power International 39% and Jinto Energy Investment 10%. Initial investment in the two-unit first stage is CNY 8.443 billion (\$1.36 billion). In April 2014 the NEA approved the project and ordered site selection to begin, focused on Xiaoshan and Bianzhuang. Wuhu

The Wuhu nuclear plant on the Yangtze River in the Bamaoshan area, Fanchang county, of Anhui province was planned to have four 1000 MWe CPR-1000 units, but is now designated for AP1000s to be constructed in two phases. CGN's proposal for two units of phase 1 has been submitted, some preparatory work has been undertaken and the Anhui Wuhu Nuclear Power Co has been set up, with 51% CGN ownership. The environmental impact statement was released for public comment in January 2010. The first unit is due on line in 2016.

## **Jiyang**

Besides Wuhu, CNNC was reported as starting a feasibility study on another four-unit nuclear plant in the Anhui province, at Jiyang in Chizhou city, in December 2008.

Ningdu/Ganzhou

CNNC New Energy Corp, the joint venture of CNNC (51%) and Guodian Corp, has also signed a preliminary agreement for small modular reactors with Ganzhou city in Jiangxi province.

# Hengfeng/Shangrao

CNNC New Energy Corp, the joint venture of CNNC (51%) and China Guodian Corp, has also signed an agreement for small modular reactors with Hengfeng county, Shangrao city in Jiangxi province.

#### Nanchun/Nanchong/Sanba, Yibin

In 2005, Sichuan province proposed Nanchun/ Nanchong city east of Chengdu as a suitable site for a nuclear power plant and sought approval for it from the National Development and Reform Commission (NDRC), which was not given, possibly because of seismic concerns. In March 2009, the provincial government signed an agreement with CGN to pursue the plan for a Nanchun nuclear power plant, involving the Nuclear Power Institute of China (NPIC), headquartered in Chendu. Preliminary plans in 2008 were for a 4000-6000 MWe Sanba nuclear power plant on the Jialing River, at a cost of CNY 25 billion (\$3.7 billion). Majority ownership would be CGN.

Another Sichuan agreement for a nuclear power plant project has been signed between CNNC and Yibin city, south of Chengdu.

#### Shaoguan

CGN's Shaoguan nuclear plant will comprise four AP1000 reactors and is expected to cost RMB 50 billion. It will be located in Baitu Town of Qujiang District in Shaoguan City, and will be the first inland nuclear power project in Guangdong. The Shaoguan Nuclear Power Co was established in April 2010.

#### Xiangtan

In December 2009, China Huadian Corp signed an agreement with Xiangtan city government in Hunan to undertake studies for a CNY 60 billion power plant comprising four 1250 MWe reactors. A refined proposal was expected in September 2010. This will apparently be the fourth nuclear project for China Huadian.

#### Longyou/ Zhexi

In October 2008 a project proposal was submitted to NDRC by CNNC and Zhejiang Energy Group Co Ltd for a nuclear power plant in Hangzhou, western Zhejiang province, with four AP1000 reactors, though earlier reports had four 1000 MWe units to be built in two phases from late 2010. The proposed site is Tuanshi, Longyou county. Pre-project work was reported as under way in November 2010.

## Jingyu

CPI plans to spend CNY 85 billion to build the six-unit Jingyu or Chisong nuclear power plant in Jingyu county near Baishan, in southern Jilin province, with four AP1000 units to be in stage 1. The project is still in the preliminary feasibility stage, though site preparation is under way. Construction start was scheduled for 2012.

### Jiutai, Liangjiashan

These two nuclear power plants planned for northern Jilin province close to Changchun, are to be developed by CGN with China GD Power Development Co Ltd, a subsidiary of Guodian, and in connection with a framework cooperation agreement with the State Grid Corporation of China. They are not expected to be approved before about 2020.

# Nanyang

To be a six-unit CNNC plant in Henan province. Pre-project work was reported as under way in November 2010.

## **Tongren**

In July 2014 Guizhou province announced that it had contracted with CGN to built two 1250 MWe reactors at Tongren city for CNY 35 billion, by 2020. The site is being decided among Dejiang, Sinan and Yanhe counties. CGN has also agreed to build two 100 MWe nuclear units for CNY 3 billion, and a 1000 MWe wind farm for CNY 5 billion.

#### **Further Information**

#### **Notes**

- a. According to the China Electricity Council, electricity consumption in 2010 increased 14.6% to 4190 billion kWh, corresponding with a 10% growth in gross domestic product (GDP). Some 3090 billion kWh of this was in industry. China's energy consumption per unit of GDP met a target reduction of 20% from 2005 levels by the end of 2010, according to the National Development and Reform Commission (NDRC). The energy intensity targets for the following five years are expected to be about 17%. [Back]
- b. The CNP series of reactors is also referred to as the CP series. [Back]
- c. The ACP600 design appears to be an advanced version of the CNP-600. CNNC expects to complete development of the ACP600 design by 2013. [Back]

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