A GREEN CEPC USING THE POWER OF NUCLEAR WASTE

Z.C. Liu#, J. Gao, IHEP, Beijing, 100049, China

Abstract

China is proposing to build an efficient Higgs factory, CEPC, a 52 km ring under the ground, to search the mysteries of the particle physics. This large circular collider would allow the Higgs boson to be studied with greater precision than at the much smaller Large Hadron Collider (LHC) at CERN. However, several hundreds of MW wall power is needed to run such a huge machine. With the development of China's nuclear power, a huge amount of long-lived nuclear waste needs to be safe disposed. The nuclear waste can be safely disposed by Accelerator Driven Sub-critical System (ADS) and provide electric power at the same time. Both CEPC and ADS are based on the superconducting accelerator technology and the power of the CEPC can be fully covered by the ADS. A green CEPC running in China is possible in the future.

INTRODUCTION

The Standard Model (SM) of particle physics can describe the strong, weak and electromagnetic interactions under the framework of quantum gauge field theory. The theoretical predictions of SM are in excellent agreement with the past experimental measurements. After the discovery of the Higgs particle, it is natural to measure its properties as precise as possible, including mass, spin, CP nature, couplings, and etc., at the current running Large Hadron Collider (LHC) and future electron positron colliders, e.g. the International Linear Collider (ILC). The low Higgs mass of ~125 GeV makes possible a Circular Electron Positron Collider (CEPC) as a Higgs Factory, which has the advantage of higher luminosity to cost ratio and the potential to be upgraded to a proton-proton collider to reach unprecedented high energy and discover New Physics. CEPC is the development in energy frontier of particle physics, and the next step of BEPC and BEPCII. As the energy is about 125GeV for the circular machine, it is a huge machine that ever built in china in fundamental research. The machine will be in a ~50km tunnel underground to keep electron and positron colliding. As the project is only for the fundamental research, it is a large non-profit and high operation cost machine. The construction cost will be much larger than the BEPCII. Huge energy consuming is a problem must be in concern as the machine will consume several hundred MW wall power in operation.

CEPC POWER CONSUMING

The CEPC is large circular collider with ~50km ring. Figure 1 shows the schematic layout of CEPC. The booster, CEPC and SppC will share the same tunnel. Table 1 shows the main parameters of the CEPC. The beam SR loss will be 51.7MW/turn. As there will be two beams in the ring, about 100MW/turn beam power will be lost. Considering the RF power source, cryogenic system and so on, the total power consuming will be about 300MW. Comparing will LHC and ILC, it is about two times of the LHC power consuming and about the same as ILC [1].

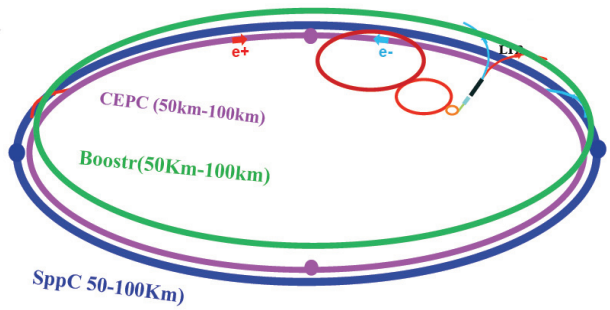

Figure 1: The road map of ADS linac project.

ENERGY PROBLEM IN CHINA

China has a population of about 1.3 billion. Now the average energy consumption per person is less than one half of the world level and less than one tenth of the developed country's level. However, the fast development of economy at annual rate of 7-10% has been kept for more than 20 years, and it will last for much more years. China will keep the fast development country for a long time. China has been the second largest energy producing and consumption country [2]. The population of China will be 1.5 billion at 2050, conservatively predicted capacity of electricity will be 1200~1500GWe. China will probably be the first largest CO_2 producer at 2025 [2]. And in the near future, China will become the first largest energy producing and consumption country. Therefore, China faces serious pollution and energy shortage in the future. Renewable energy, sustainable energy and nuclear energy must be considered to solve the pollution problem and energy shortage. Now China has made great effort to develop renewable energy, sustainable energy and nuclear energy. Figure 2 shows the renewable and sustainable energy that mainly used in China.

Figure 2: Renewable and sustainable energy in China.

#zcliu @ihep.ac.cn

ISBN 978-3-95450-172-4

Table 1: CEPC Main Parameters

Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	Circumference [C]	m	54752
Number of IP[N_{IP}]		2	SR loss/turn [U_0]	GeV	3.11
Bunch number/beam[n_B]		50	Bunch population [Ne]		3.79E+11
SR power/beam [P]	MW	51.7	Beam current [I]	mA	16.6
Bending radius [r]	m	6094	momentum compaction factor [a_p]		3.36E-05
Revolution period [T_0]	s	1.83E-04	Revolution frequency [f_0]	Hz	5475.46
emittance (x/y)	nm	6.12/0.018	b_{IP}(x/y)	mm	800/1.2
Transverse size (x/y)	mm	69.97/0.15	$x_{x,y}$/IP		0.118/0.083
Beam length SR [$s_{s.SR}$]	mm	2.14	Beam length total [$s_{s.tot}$]	mm	2.65
Lifetime due to Beamstrahlung (simulation)	min	47	lifetime due to radiative Bhabha scattering [t_L]	min	52
RF voltage [V_{rf}]	GV	6.87	RF frequency [f_{rf}]	MHz	650
Harmonic number [h]		118800	Synchrotron oscillation tune [n_s]		0.18
Energy acceptance RF [h]	%	5.99	Damping partition number [Je]		2
Energy spread SR [$s_{d.SR}$]	%	0.132	Energy spread BS [$s_{d.BS}$]	%	0.119
Energy spread total [$s_{d.tot}$]	%	0.163	n_g		0.23
Transverse damping time [n_x]	turns	78	Longitudinal damping time [n_e]	turns	39
Hourglass factor	Fh	0.658	Luminosity /IP[L]	$cm^{-2}s^{-1}$	2.04E+34

By the end of 2012, China has the total installed power generation capacity of 1144910MW, including hydropower 248900MW, thermal power 819170MW (71.5%), nuclear power 12570MW, wind power 60830MW and solar power 3280MW. By the end of August 2013, China has wind power 68450MW, solar power 8980MW, nuclear power 14780MW and biomass energy 8000MW [3]. That is 8.5% of the total.

And in 2015, the renewable and sustainable energy will be hydropower 2900000MW, wind power 100000MW, nuclear power 40000MW, solar power 35000MW, biomass power 13000MW [3]. That is about 32% of the total electricity power.

China still keep very high investment on renewable energy. In 2013, China invested 56 billion U.S. dollar on renewable energy, for the first time more than Europe. Europe invested 48 billion U.S. dollar, on the second place. The third is USA with 36 billion U.S. dollar. India and Brazil also invested 6 and 3 billion U.S. dollar separately.

By the end of August 2013, the electric energy production is 14780MW. That is 1.23% of total electric energy production(~1200000MW). Before the Fukushima Daiichi accident, there are 15 operational reactors, 26 under construction reactors and 18 planed reactors. Figure 3 shows the reactors location in China [2]. Now China has 21 operational reactors and on the sixth place of the world nuclear power country. There are 27 reactors under construction in China by the end of September 2014. Figure 4 shows the number of reactors in operation of the countries worldwide [4]. Figure 5 shows the number of reactors under construction of the countries worldwide [5].

In 2020, there will be 58GW reactors in operation which is 4% of total electricity capacity and 30GW reactors under construction. It means that about 7 new units need to be constructed per year from now to 2020. In about 2050, there will be 240GW nuclear power in China [2].

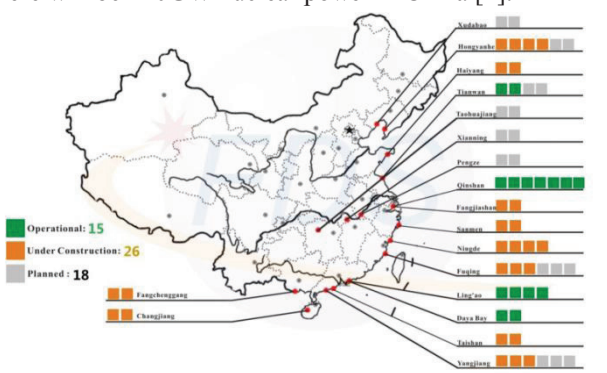

Figure 3: China's nuclear power reactors before Fukushima Daiichi accident [2].

However, the nuclear power plant will produce large amount of nuclear waste. For 1000MW nuclear power plant, there will be 10s of tons nuclear waste per year. After processing, it becomes $4m^3$ high radiation nuclear waste, $20m^3$ medium radiation nuclear waste, $140m^3$ low radiation nuclear waste and $200m^3$ non-radiation nuclear waste.

There are 150 tons of high radiation nuclear waste per year in China (2008 data). And there will be 3200 tons per year in 2030. Nuclear waste is a serious problem and must be solved in the future. It is a bottle neck for nuclear power development in China.

ISBN 978-3-95450-172-4

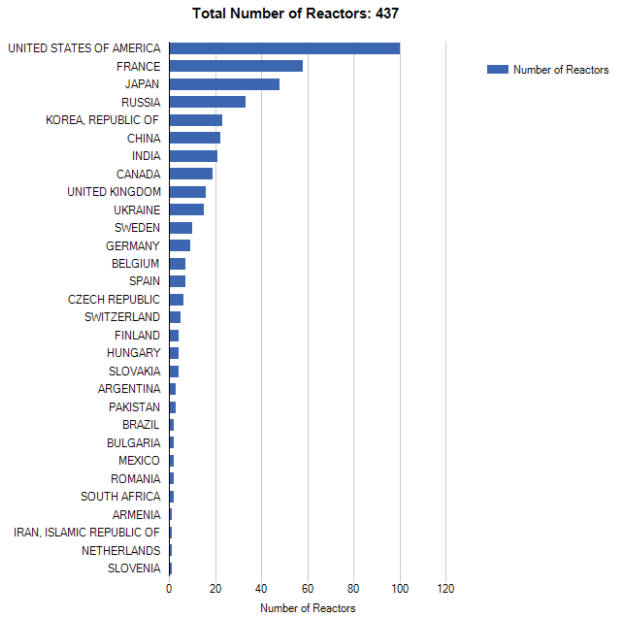

Figure 4: Number of reactors in operation.

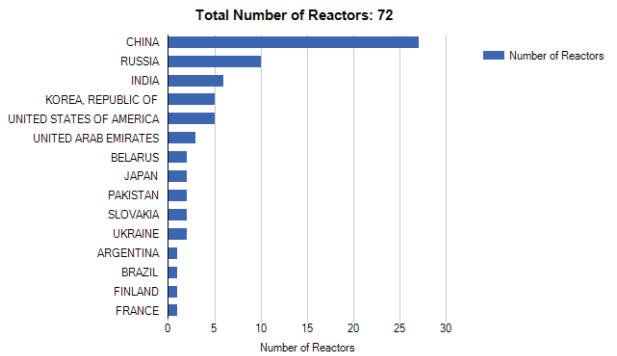

Figure 5: Number of reactors under construction.

ADS PROGRAM

China is developing the Accelerator Driven Sub-critical System (ADS) which is composed of a nuclear reactor operating in subcritical mode and a main linac providing the required complement neutrons. The aim of the ADS project is to dispose the nuclear waste. And the ADS is also a good choice of solving future energy shortage by safe utilization of nuclear power. Figure 6 shows the schematic of the ADS proton linac project.

The ADS program launched in 2011 and plan to construct demonstration ADS transmutation system at ~2030s through three stages. The first stage is to built a 10MW research facility at ~2023 to solve the key technology. There will be a 10MeV injector in operation by the end of 2016. The second stage is to built a 100MW experimental facility by the end of ~2030. The third stage is to built a 1000MW demo facility at ~2040. Therefore, the CEPC power can be partially or fully supplied by ADS.

ADS has been recognized as a good option for nuclear waste transmutation. And now it has been supported by CAS as a long-term program. ADS can provide electric power to the society as a nuclear plant. The fuel can be nuclear waste or thorium (Th-232) since it is three times as abundant in the earth's crust as uranium. Figure 7 shows the principle of the ADS. The proton accelerator using superconducting cavity will accelerate the proton beam to 1.5GeV and then the beam hit the liquid metal target in the reactor to produce enough neutron to start the subcritical transmutation in the reactor cooled by PbBi. The heat of the reaction will be conducted out and transferred to electricity to power the ADS self-system and provide to the society.

Figure 6: The road map of ADS linac project.

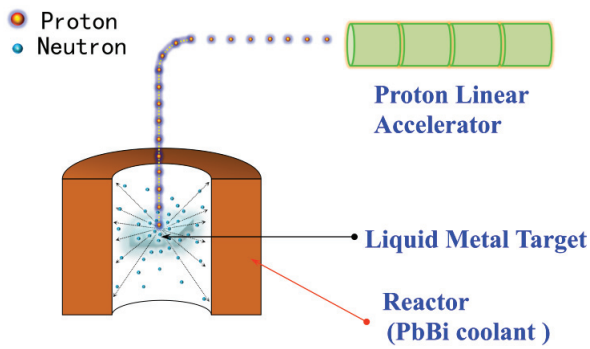

Figure 7: Principle of ADS.

Many accelerator technologies have been developed by the ADS R&D, such as superconducting technology, RF power source, cryomodule and 2K helium system. Table 2 shows the technology that can be shared by CEPC and ADS. Figure 8 -12 show the equipment of ADS that can be shared by CEPC.

Table 2: Technology Shared by CEPC and ADS

Shared Tech.	CEPC	ADS
Superconducting technology	✓	✓
RF system	✓	✓
Power source	✓	✓
Cryogenic system	✓	✓
SC Magnet	✓	✓
Vacuum	✓	✓

ISBN 978-3-95450-172-4

Figure 8: Superconducting spoke cavity power source (left), superconducting magnet power source (middle), RFQ cavity power source (right).

Figure 9: Superconducting spoke021 cavity.

Figure 10: Superconducting spoke021 cavity (up) and 650MHz elliptical 082 cavity (down).

Figure 11: 12 meters long cryomodule for Euro-XFEL .

Figure 13 shows the schematic layout of the green CEPC in the future. The nuclear waste from the traditional nuclear power plant will be used in the ADS system and provide electric power to the national smart grid. Part of the electric power will be send to the society and the other part will be send to the CEPC to keep the facility on operation. Both CEPC and ADS share the same technology.

Figure 12: 2K cryogenic LHe system.

Figure 13: Green CEPC in the future.

SUMMARY

CEPC is a large machine and need huge power of about 300MW. That is about two times of LHC. Huge power consumption and high operation cost must be in consideration. For the future large accelerator project, the world scientist promote using clean energy and keep the accelerator running at a green mode. Now China is developing nuclear power, but the bottle neck of nuclear power development is the nuclear waste. However, ADS can safely solve this problem and provide electric power. CEPC and ADS based on a lot of same technology, such as superconducting technology and so on. The CEPC construction can be motivated by the ADS technology improvement and run in a green mode.

REFERENCES

[1] Denis Perret-Gallix, The Green ILC, LCWS, Tokyo Univ. Nov. 2013.

[2] Yican Wu, Accelerator Driven System (ADS) : A Nuclear Technology Bridge between Fission and Fusion Energy in China, ICENES-16, Madrid, Spain, (2013).

ISBN 978-3-95450-172-4

[3] 全国人大常委会执法检查组在关于检查 《中华人民共和国可再生能源法》实施情况报告.
[4] http://www.iaea.org/PRIS/WorldStatistics/Operation-alReactorsByCountry.aspx.
[5] http://www.iaea.org/PRIS/WorldStatistics/UnderCon-structionReactorsByCountry.aspx.

ISBN 978-3-95450-172-4