



China's Nuclear Reactor and Fuel Cycle Markets



– NOTICE –

The Ux Consulting Company, LLC (“UxC”) shall have title to, ownership of, and all proprietary rights in this Report. Under United States federal copyright law (17 USC 101 et seq.) it is illegal to reproduce this Report by any means without written permission from UxC.

The information contained in this Report is obtained from sources that UxC believes to be reliable. UxC makes no warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in this Report and UxC, to the maximum extent permitted by law, assumes no liability for the use or effects of any of the information or data contained in this Report.

It is UxC’s strict policy not to endorse, promote, or recommend any particular securities, currencies, or other financial products or instruments. Nothing contained in this Report is intended to constitute investment, legal, tax, accounting or other professional advice and the reader should not rely on the information provided in this Report for making financial decisions.

The Ux U₃O₈ Price[®] and other Ux Price indicators are developed by The Ux Consulting Company, LLC (UxC) and are proprietary and exclusive intellectual property of UxC. These price indicators are provided to UxC’s customers through the Ux Weekly[®] publication and are made available on UxC’s public website solely at UxC’s discretion. They may not be reproduced or otherwise used without UxC’s express permission.

UxC[®], Ux Weekly[®], Ux U₃O₈ Price[®], Ux[®], and Ux Consulting[®], U-PRICE[®], and SWU-PRICE[®] are trademarks of The Ux Consulting Company, LLC.

Table of Contents

Introduction and Overview	7
Purpose of Report	7
Key Questions on China's Nuclear Markets	8
Structure of Report	8
1 – China's Nuclear Power Policy and Regulations	10
Nuclear Energy in China	10
• Role of Nuclear Power in China's Electricity Mix	11
• Nuclear Power Targets for 2016-2020	12
Five Year Plans	13
• Climate Change Policies	14
• China's Electricity Market Reforms	16
Legislative Changes	16
Relevant Government Agencies	19
• State Council	19
• National Development and Reform Commission (NDRC)	20
• State-owned Assets Supervision and Administration Commission of the State Council (SASAC)	20
• National Energy Commission (NEC)	20
• National Energy Administration (NEA)	20
• China Atomic Energy Authority (CAEA)	21
• Ministry of Environmental Protection (MEP)	21
• National Nuclear Safety Administration (NNSA)	21
Nuclear Safety	22
• Nuclear Reactor Licensing	22
• Technical Support Organizations (TSOs)	24
• Regulatory Challenges	26
• Regulatory Response to Fukushima	27
• IAEA IRRS Mission	29
• Public Opinion Issues	29
2 – China's Domestic Nuclear Power Program	31
New Reactor Decision-Making Process	31
Status of China's Nuclear Energy Program	32
• Operating Reactors	32
• Reactors Under Construction	34
• Planned and Future Reactor Projects	35
Leading Nuclear Companies	36
• China National Nuclear Corporation (CNNC)	36
• China General Nuclear Power Corporation (CGN)	37
• State Power Investment Corporation (SPIC)	40
• Reactor Operating Companies	41
China National Nuclear Power Co. (CNNP)	41
CGN Power	43
State Nuclear Power Technology Company (SNPTC)	45
• China Huaneng Group (CHNG)	46
Chinese Nuclear Company IPOs	46
China Nuclear Power Forecast Scenarios	47
• UxC Forecasts through 2040	48
Reactor Unit Forecasts	48
Nuclear Capacity Forecasts	49
Nuclear Generation Forecasts	50
3 – China's Reactor Technologies and Supply Chain	51
Reactor Technologies	51
• CNP-600	53
• CPR-1000 (M310+)	53
• ACPR-1000	53

• CP-1000 (M310+) (former CNP-1000).....	54
• ACP-1000.....	55
• HPR-1000 (Hualong One).....	56
• High Temperature Reactors (HTRs) / HTR-PM.....	57
• VVER-1000 (AES-91).....	58
• AP1000.....	58
• CAP1400.....	59
• EPR.....	61
• Small Modular Reactors (SMR).....	62
ACP100S.....	62
ACPR50S.....	63
China's Reactor Supply Chain.....	64
• Nuclear Reactor Design and Engineering.....	64
China Institute of Atomic Energy (CIAE).....	64
Shanghai Nuclear Engineering and Design Institute (SNERDI).....	64
State Nuclear Electric Power Planning, Design & Research Institute (SNPDRI).....	65
Shandong Electric Power Engineering Consulting Institute (SDEPCI).....	65
State Nuclear Power Engineering Company (SNPEC).....	65
State Nuclear Power Automation System Engineering Company (SNPAS).....	66
CNNC Nuclear Power Institute of China (NPIC).....	66
China Nuclear Power Technology Research Institute (CNPRI).....	66
CGN Suzhou Nuclear Power Research Institute.....	66
Institute of Nuclear and New Energy at Tsinghua University.....	66
• Nuclear Power Plant Construction and Project Management.....	67
CGN China Nuclear Power Engineering Co. (CNPEC).....	67
CNNC China Nuclear Power Engineering Corporation (CNPE).....	67
CNNC China Zhongyuan Engineering Corporation (CZEC).....	67
China Nuclear Engineering and Construction Corporation (CNEC).....	67
China Nuclear Industry Fifth Construction Company (CNFC).....	67
China Nuclear Industry 22nd Construction Company (CNI 22).....	68
China Nuclear Industry 23 rd Construction Company (CNI 23).....	68
Huaxing Construction Company (HXCC).....	68
CHINERGY Co. Ltd.....	68
Zhejiang Thermal Power Construction Company (ZTPC).....	68
SEPCO Electric Power Construction Co. (SEPCO).....	68
• Heavy Component Manufacturing.....	69
China First Heavy Industries (CFHI).....	69
China National Erzhong Group.....	69
Shanghai Electric Group Company Ltd. (SEC).....	69
Dongfang Electric Corporation Ltd. (DEC).....	70
Shandong Nuclear Power Equipment Manufacturing Co. (SNPEMC).....	70
Harbin Electric Corporation (HEC).....	70
• Component Manufacturing Capacities.....	71
Reactor Technology Localization.....	72
4 – China's Reactor Export Ambitions.....	74
Overarching Policies and Initiatives.....	74
Developing Nuclear Technology.....	75
China's Strengths and Challenges.....	75
• Construction Experience.....	75
• Supply Chain.....	76
• Financing.....	76
• Regulatory Issues.....	77
• Political Considerations.....	78
Current Projects.....	78
• Pakistan.....	79
• Romania.....	79
• Argentina.....	79
• United Kingdom.....	80
Potential New Projects.....	80
• Czech Republic.....	80
• Turkey.....	80

• South Africa	81
• Saudi Arabia	81
• Thailand	81
• Malaysia.....	81
• Indonesia	81
• Other Countries.....	81
Future Outlook for Chinese Reactor Exports	82
5 – China’s Uranium Industry	83
China’s Domestic Reactor Requirements	83
China’s Known Uranium Resources and Development	85
• History of China’s Domestic Uranium Exploration	85
• China’s Known Uranium Resources	86
Future Increases in Identified Resources	87
• Prospects for China’s Domestic Uranium Production	88
Key Players Involved in Uranium Exploration and Mining.....	89
Uranium Production in China	90
• Development of Uranium Production	90
• Major Uranium Production Companies	91
• New Uranium Production Centers	92
Yili Production Center.....	93
Tongliao Production Center.....	93
Ordos Production Center.....	94
Fuzhou Production Center.....	94
Guangdong Production Center	95
Others.....	95
• Planned Uranium Production Capacity	96
Chinese Overseas Uranium Investments.....	97
• Overseas Uranium Exploration and Mining	97
• International Trade.....	99
Sources of Imported Uranium.....	100
Supply and Demand Analysis	101
Summary and Conclusions	102
6 – China’s Conversion Industry	103
China’s Conversion Demand	103
• Domestic Reactor Requirements	103
• UF ₆ Inventory Building	103
• Nuclear Fuel Exports	104
• Overall Conversion Demand Forecasts.....	104
• China’s UF ₆ Feed Requirements	106
China’s Conversion Industry	107
• History and Overview.....	107
• China’s Conversion Plants.....	108
Jiuquan Plant 404.....	108
Hengyang Plant 272	109
Integrated Nuclear Fuel Complexes	110
• Analysis of Domestic Conversion Capacity	111
• China’s UF ₆ Imports.....	111
China’s Conversion Supply and Demand Balances.....	113
• Conversion Supply Forecasts	113
• Supply and Demand Comparisons	114
China’s Role in the Global Conversion Market	115
Summary and Conclusions	116
7 – China’s Enrichment Industry	117
Overview of China’s Enrichment Program	118
China’s Enrichment Requirements Forecast.....	119
History of China’s Enrichment Industry and Technologies.....	120
• Gaseous Diffusion Technology	120
• Gas Centrifuge Imports from Russia.....	121
• Domestic Centrifuge Development	121

Key Supporting Companies and Organizations.....	122
Current Chinese Enrichment Facilities.....	123
• Lanzhou Enrichment Plant (Plant 504).....	123
• Hanzhong Enrichment Plant (Plant 405).....	124
• Emeishan Enrichment Facilities of Plant 814.....	125
Projected Enrichment Expansion in China to 2030.....	127
• Integrated Nuclear Fuel Complexes.....	127
• Long-Term Expansion of Enrichment Capacities.....	128
• China's Future SWU Capacities.....	129
Possible Range of Future Expansion.....	129
UxC SWU Capacity Forecast Scenarios.....	130
Imports and Exports of SWU/EUP.....	131
China Customs Data.....	132
China's Position in the World Enrichment Markets.....	133
• Nuclear Reactor Export Ambitions.....	133
• Nuclear Fuel Sales Ambitions.....	134
Summary and Conclusions.....	135
8 – China's Fuel Fabrication Industry.....	136
Corporate Structure and Manufacturing Facilities.....	136
Fuel Fabrication Operations.....	137
• Yibin Fabrication Plant.....	137
• Baotou Fabrication Plant.....	138
• Fuel Assembly Research & Development.....	139
• New Fabrication Facilities.....	140
• Other Fabrication-related Ventures.....	140
Current and Future Fabrication Markets.....	141
• Domestic Market.....	141
• Foreign Markets.....	142
China's PWR Fuel Assemblies.....	142
Planned Capacity Expansions.....	145
Possible Future Developments.....	145
9 – China's Back-End Nuclear Fuel Cycle Program.....	146
Spent Fuel Management.....	146
• Spent Fuel.....	146
Spent Fuel Management Policy.....	146
Spent Fuel Storage.....	147
• Reprocessing.....	148
Reprocessing Proposals.....	150
• Belfer Report Recommendations.....	151
• Analysis.....	152
Public Protests Halt Siting Work for Reprocessing Plant.....	153
• Analysis.....	154
High Level Radioactive Waste Management.....	155
Low and Intermediate Level Radioactive Waste Management.....	156
10 – Conclusions and Final Analysis.....	157
Importance of Nuclear Power to China.....	157
Major Trends and Issues for China's Nuclear Reactor Program.....	158
• Pace of Reactor Construction.....	158
• Reactor Technology Development.....	158
• Electricity Market Reforms.....	159
• Public Opinion.....	159
• Reactor Exports.....	160
Major Trends and Issues for China's Nuclear Fuel Cycle Program.....	161
• Uranium.....	161
• Conversion.....	162
• Enrichment.....	162
• Fabrication.....	162
China's Position in the Global Nuclear Markets.....	163

Appendix A – UxC Interview with Dr. Hui Zhang, Harvard University	164
Appendix B – Dr. Hui Zhang Presentation to UxC 2016 Seminar	170

List of Figures

Figure 1. Reactors in Operation and Under Construction in China	10
Figure 2. China’s Electric Power Capacities in 2015	11
Figure 3. China’s Electric Power Generation by Source in 2015	12
Figure 4. China’s Electric Power System Reform Policies	18
Figure 5. China’s Nuclear Bureaucracy and State-Owned Enterprises	19
Figure 6. China’s Nuclear Regulatory Structure	22
Figure 7. China’s Reactor Licensing Process	23
Figure 8. Nuclear and Radiation Safety Center Organizational Structure	25
Figure 9. Nuclear Regulatory Human Resources Developments in China	25
Figure 10. Government Decision-Making Flow Chart for China’s Energy Sector	32
Figure 11. CNNC Organization Chart	37
Figure 12. CGN Nuclear Power Operations Organization Chart	38
Figure 13. CGN Other Businesses Organization Chart	39
Figure 14. SPIC and SNPTC Merged Organization Overview	40
Figure 15. CNNP Companies	41
Figure 16. CGN Power Companies	43
Figure 17. SNPTC Companies	45
Figure 18. UxC Reactor Unit Forecasts for China, 2008-2040	48
Figure 19. UxC Nuclear Capacity Forecasts for China, 2008-2040	49
Figure 20. UxC Nuclear Generation Forecasts for China, 2008-2040	50
Figure 21. Domestic and Foreign Reactor Designs in China	52
Figure 22. Evolution of Reactor Technology in China	52
Figure 23. Evolution of the CP-1000 Design	54
Figure 24. Evolution of the ACP-1000 Design	55
Figure 25. HPR-1000 Units at Fuqing Nuclear Power Plant	56
Figure 26. HTR-PM Plant Layout	57
Figure 27. Construction Progress of Sanmen and Haiyang AP1000s in China	59
Figure 28. General Overview of the CAP1400	60
Figure 29. China Huaneng Shandong Shidaowan Site	60
Figure 30. EPRs at Taishan Nuclear Power Plant	61
Figure 31. Potential Uses for ACP100S	62
Figure 32. Potential Uses for ACPR50S	63
Figure 33. SNERDI Reactor Technology Capabilities	65
Figure 34. Shanghai Electric Subsidiaries Involved in the Nuclear Business	70
Figure 35. Manufacturing Capacities of Heavy Nuclear Components in China	71
Figure 36. SNPTC Reactor Technology R&D	72
Figure 37. International Cooperation for CAP1400 Demonstration Project	73
Figure 38. Construction Site of Chasma 3 & 4 in Pakistan	79
Figure 39. UxC Base Case Forecast for China Uranium Requirements, 2008-2030	84
Figure 40. Increases in China’s Identified Uranium Resources, 1996-2014	88
Figure 41. Qinlong Mine (left) and ISR Mine in Yili, Xinjiang (right)	92
Figure 42. Fuzhou Uranium Mill	95
Figure 43. Natural and Enriched Uranium Imports into China, 2001-2016	100
Figure 44. China Uranium Supply vs. Demand, 2000-2030	101
Figure 45. UxC Conversion Demand Forecast Cases for China, 2008-2030	104

Figure 46. UxC UF ₆ Feed Requirements Forecast Cases for China, 2008-2030	106
Figure 47. Jiuquan Conversion Plant 404	108
Figure 48. Hengyang Plant 272	109
Figure 49. China Conversion Imports Contained in UF ₆ /EUP, 2000-2016	112
Figure 50. UxC Conversion Supply Forecast Cases for China, 2008-2030	113
Figure 51. UxC Base Supply vs. Demand Forecast for China, 2008-2030	114
Figure 52. China vs. Rest of World Conversion Supply, 2008-2030	115
Figure 53. UxC Forecast Scenarios for China's SWU Requirements, 2008-2030	119
Figure 54. Lanzhou Enrichment Plant	123
Figure 55. Hanzhong Enrichment Plant	125
Figure 56. Emeishan Enrichment Plant at Shuangfu	126
Figure 57. UxC Forecast Cases for China SWU Capacities, 2008-2030	130
Figure 58. China SWU/EUP Imports, 2000-2016	132
Figure 59. Chinese PWR Fuel Assemblies at CNFC's Yibin Plant	143
Figure 60. CNFC's CF3 Fuel Assembly	144
Figure 61. Beilong Low & Intermediate-Level Waste Site	156
Figure 62. China Electricity Generation by Source and CO ₂ Intensity in EIA New Policies Scenario	157
Figure 63. China vs. Rest of World Nuclear Capacity, 2008-2040	163

List of Tables

Table 1. China's Operating Nuclear Reactors (Listed by Startup Date)	33
Table 2. Nuclear Reactors Under Construction in China (Listed by Construction Start)	34
Table 3. Near Term Planned Reactors in China	35
Table 4. CNNP's Nuclear Power Plants	42
Table 5. CGN Power's Nuclear Power Plants	44
Table 6. SPIC's Nuclear Power Plants	45
Table 7. UxC Reactor Unit Forecasts for China, 2016-2030	48
Table 8. UxC Nuclear Capacity Forecasts for China, 2016-2030	49
Table 9. UxC Nuclear Generation Forecasts for China, 2016-2030	50
Table 10. Major Equipment Localization Rate for First Four AP1000 Units in China	73
Table 11. Current Foreign NPP Projects with Chinese Involvement	78
Table 12. China's Project Annual & Cumulative Uranium Demand (2016-2030)	83
Table 13. China's Identified Uranium Resources (RAR and IR)	86
Table 14. Regional Distribution of Chinese Identified Uranium Resources	87
Table 15. Existing Uranium Production Centers in China (as of May 2016)	91
Table 16. Annual Uranium Imports into China, 2000 to 2015 (in MTU equivalent)	100
Table 17. China Conversion Demand Forecast Cases, 2016-2030	105
Table 18. China UF ₆ Feed Requirements Forecast Cases, 2016-2030	106
Table 19. UxC Conversion Supply Forecast Cases for China, 2016-2030	113
Table 20. China's Current and Near-Term Enrichment Capacities	118
Table 21. Possible Future China SWU Capacities	129
Table 22. UxC Forecast Cases for China SWU Capacities, 2016-2030	130
Table 23. China's Imports and Exports of SWU/EUP, 2002-2016	132
Table 24. Status of Spent Fuel Storage at NPPs in China (as of 2013)	148
Table 25. High/Low Estimates of Reprocessing Capital and Operating Costs	149
Table 26. Status of Spent Fuel Storage at China's Nuclear Plants	151

Introduction and Overview

The Ux Consulting Company (UxC) is pleased to present this special report on **China's Nuclear Reactor and Fuel Cycle Markets**, which provides a comprehensive perspective on all the key aspects of China's nuclear power and fuel cycle industries and initiatives as of the end of 2016.

Purpose of Report

No country in the world today is more consequential for the nuclear markets than China. UxC continuously monitors and updates its research and analysis of China's nuclear program in all areas, including the front-end nuclear markets and the domestic and reactor export programs. In order to enhance its deep understanding of this critical country, UxC also works with leading experts on China's nuclear program, including Dr. Hui Zhang of Harvard University's Belfer Center for Science and International Affairs. Through these efforts, UxC has prepared this new 2016 special report to present the latest information and analysis of all critical aspects of China's nuclear industry.

This new report provides in-depth coverage and forecasts for China's nuclear power and reactor exports as well as the individual front-end fuel cycle component markets of uranium, conversion, enrichment, and fabrication, and also an overview of the back-end fuel cycle program. Additional insights and discussions on the current role and potential future direction of China's nuclear program are also included.

Over the past five years since Fukushima, there have been many changes and new developments that have affected China's approach to nuclear power. This report provides factual data and holistic analysis on all key aspects of the country's nuclear program, including the current drivers and potential future direction of China's nuclear industry.

It should be understood that much of this report is a compilation of materials that UxC has presented in its various standard publications, although major efforts have been made to enhance each section through additional information, and analysis. Moreover, all sections of this report include material updated as of December 2016, including UxC's own analysis as well as information obtained through research of various open sources covering nuclear energy developments in China.

Key Questions on China's Nuclear Markets

The following list presents some of the major questions and concerns surrounding China's nuclear power and fuel cycle programs:

- How fast can China's nuclear power fleet grow?
- What reactor technologies will China look to build in the future?
- How many reactors will China have operating in 2020, 2030, and 2040?
- Where will Chinese companies build reactors outside of the country?
- How much of its uranium needs will China be able to satisfy through domestic and foreign mine projects?
- How quickly can China ramp-up its UF₆ conversion capabilities?
- What are China's intentions in terms of enrichment capacity expansions and SWU exports?
- What types of fuel assemblies will China manufacture in the future?
- How will China manage its spent nuclear fuel and radioactive waste?

This report attempts to respond to these and other questions while providing a comprehensive review and assessment of China's current nuclear program and its prospects.

Structure of Report

In addition to this **Introduction and Overview**, this detailed report includes separate chapters of the different aspects of China's nuclear program as follows:

Chapter 1 – China's Nuclear Power Policy and Regulations presents the current state of nuclear power and related government policy in China, including official targets for future growth. This chapter also covers key issues, including electricity market reforms, the government agencies involved in creating nuclear policy, as well as China's approach to nuclear safety regulations.

Chapter 2 – China's Domestic Nuclear Power Program provides a detailed description of the three major nuclear power companies in China and their many reactor projects, including nuclear plants in operation, under construction, and in planning. This chapter also presents UxC's proprietary nuclear power forecasts for China through 2040.

Chapter 3 – China's Reactor Technologies and Supply Chain gives an overview of all the main nuclear reactor technologies and their developments in China. Additionally, a discussion of China's domestic reactor supply chain and efforts to localize technology from overseas suppliers is also included.

Chapter 4 – China’s Reactor Export Ambitions reviews and analyzes China’s recent push to export its nuclear power plant technologies and to become more involved in international nuclear projects around the globe.

Chapter 5 – China’s Uranium Industry shifts to the first part of China’s nuclear fuel cycle program. This chapter takes a detailed look at all of China’s efforts to secure natural uranium (U_3O_8) from domestic and international sources to ensure stable nuclear fuel supplies for the long-term.

Chapter 6 – China’s Conversion Industry takes a detailed look at China’s evolving uranium conversion industry and examines prospects for future expansion.

Chapter 7 – China’s Enrichment Industry reviews all the details surrounding China’s uranium enrichment industry with a special focus on its gas centrifuge development program and recent efforts to become a global supplier of SWU.

Chapter 8 – China’s Fuel Fabrication Industry reviews the current state of China’s nuclear fuel fabrication industry and its efforts to develop its own indigenous fuel designs.

Chapter 9 – China’s Back-End Nuclear Fuel Cycle Program provides an overview of the state of spent fuel and radioactive waste management in China.

Chapter 10 – Conclusions and Final Analysis presents UxC’s final analysis of the current state of China’s nuclear market and the outlook for future developments in both the reactor and fuel cycle sectors.

Additional research and informational items related to China’s nuclear program and industry are found in the following **Appendices** at the end of the report:

Appendix A – UxC Interview with Dr. Hui Zhang, Harvard University

Appendix B – Dr. Hui Zhang Presentation to UxC 2016 Seminar