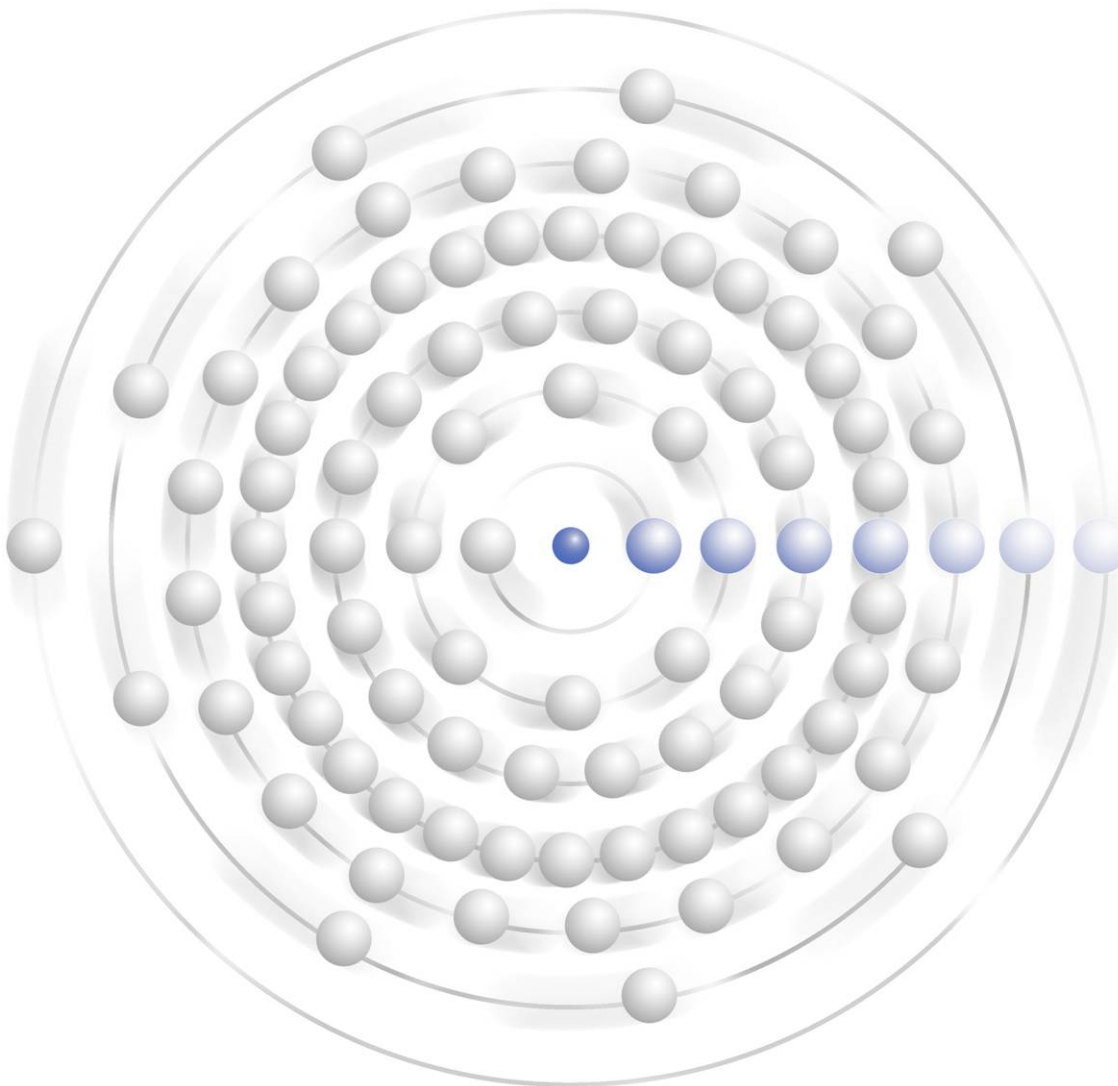




# Nuclear Zirconium Alloy Market



**– 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.

# Table of Contents

<b>Introduction &amp; Overview</b>	<b>6</b>
Availability of Data.....	6
What's New in the 2011 Report? .....	7
Structure of the Report.....	8
<b>1 – General Zirconium Overview</b>	<b>10</b>
Occurrence.....	10
General Uses .....	12
• Zirconium Metal .....	14
Nuclear Applications .....	14
• New Nuclear Zirconium Alloys Under Development.....	16
Zircon Resources and Production.....	17
• Reserves and Resources.....	17
• Zircon Mining .....	17
• Zircon Production.....	19
Zircon Consumption and Prices.....	22
• Consumption of Zircon.....	22
• Market Dynamics .....	24
• Zircon Prices.....	25
The Influence of China.....	26
Conclusions.....	27
<b>2 – Manufacturing Processes for Nuclear Fuel Cladding</b>	<b>29</b>
Production of Zirconium Sponge.....	29
• Zircon Sand Processing and Hafnium Removal .....	29
• Final Sponge Production.....	30
Manufacture of Zirconium Alloy Ingots.....	31
Manufacture of Zirconium Alloy Plate, Sheet, Bar Stock, and Tube-Reduced Extrusions (TREN).....	31
Production of Nuclear Fuel Tubing.....	34
<b>3 – Nuclear Zirconium Alloy Materials &amp; Product Suppliers</b>	<b>36</b>
Zirconium Sponge Producers.....	37
• China.....	38
State Nuclear WEC Zirconium & Hafnium Company (SNWZH) .....	38
Guangdong Orient Zirconic Ind. Sci. & Tech. Company Ltd. (Orient Zirconic) .....	38
Jiangxi Kingan Hi-Tech Company, Ltd. (Kingan).....	39
• France.....	39
AREVA Zirconium Division (formerly CEZUS).....	39
• India .....	40
Nuclear Fuel Complex (NFC) .....	40
• Russia.....	41
Chepetsky Mechanical Plant (CMP) .....	41
• Ukraine.....	42
Zirconium.....	42
• United States .....	43
ATI Wah Chang (AWC) .....	43
Western Zirconium (WZ) .....	43
Producers of Zirconium Alloy Plate, Sheet, Bar Stock, and TREN .....	44
• Argentina.....	46
Fabricación de Aleaciones Especiales, SA (FAE) .....	46
• China.....	46
State Nuclear Baoti Zirconium Industry Company, Ltd. (SNZ).....	46
Other Chinese Facilities .....	46
• France.....	47
AREVA Zirconium Division (formerly CEZUS).....	47
• India .....	48

Nuclear Fuel Complex (NFC) .....	48
• Korea .....	48
POSCO .....	48
• Russia .....	49
Chepetsky Mechanical Plant (CMP) .....	49
• Sweden .....	49
Sandvik Materials Technology (SMT) .....	49
• United States .....	50
ATI Wah Chang (AWC) .....	50
Western Zirconium (WZ) .....	50
Zirconium Alloy Scrap Recycle .....	50
Manufacturers of Nuclear Fuel Tubing .....	51
• Argentina .....	52
Fabricación de Aleaciones Especiales, SA (FAE) .....	52
• Canada .....	52
General Electric Hitachi Nuclear Energy Canada (GEH Canada) .....	52
Cameco Fuel Manufacturing, Inc. (CFMI) .....	52
• China .....	53
State Nuclear Baoti Zirconium Industry Company, Ltd. (SNZ) .....	53
CNNC-AREVA Shanghai Tubing Co. (CAST) .....	53
• France .....	54
AREVA Zirconium Division (formerly CEZUS) .....	54
• Germany .....	54
AREVA Zirconium Division (formerly CEZUS) .....	54
• India .....	54
Nuclear Fuel Complex (NFC) .....	54
• Japan .....	55
Mitsubishi Materials Corporation (MMC) .....	55
Zirco Products (ZP) .....	55
• Korea .....	56
KEPCO Nuclear Fuel (KNF) .....	56
• Russia .....	57
Chepetsky Mechanical Plant (CMP) .....	57
• Sweden .....	57
Sandvik Materials Technology (SMT) .....	57
• United Kingdom .....	58
Fine Tubes, Ltd. .....	58
• United States .....	58
Global Nuclear Fuel-Americas (GNF) .....	58
Sandvik Special Metals Corporation (SSM) .....	58
Veridium .....	59
Westinghouse Specialty Metals Plant (SMP) .....	59
Possible Future Developments .....	60
<b>4 – Nuclear Fuel Fabricators &amp; Zirconium Components Supply</b> .....	<b>61</b>
Fabrication Market Overview .....	61
Key Players .....	62
• AREVA .....	62
• Global Nuclear Fuel .....	62
• Westinghouse Electric Company .....	63
• TVEL Fuel Company .....	63
• KEPCO Nuclear Fuel .....	63
• National and Regional Fuel Suppliers .....	64
Fabrication Supply & Demand .....	64
Fabrication Market Dynamics .....	68
Zirconium Alloy Components and the Fuel Fabrication Process .....	69
• Fuel Cladding .....	70
• End Plugs or Caps .....	70
• Fuel Rods .....	70
• Spacer Grids .....	71

• BWR Water Rods/Channels .....	71
• BWR Fuel Channels .....	71
• PWR Guide Tubes/Thimbles and Instrument Tubes .....	72
• End Fittings .....	72
• Construction of the Assembly .....	72
Zircaloy Tubing & BWR Channel Supply to Fabricators .....	74
• Argentina.....	74
• Belgium.....	74
• Brazil.....	74
• Canada.....	74
• China.....	74
• France.....	75
• Germany.....	75
• India.....	75
• Japan.....	75
• Korea.....	75
• Romania.....	76
• Russia.....	76
• Spain.....	76
• Sweden.....	76
• United States.....	76
<b>5 – Nuclear Zirconium Supply &amp; Demand Analysis .....</b>	<b>77</b>
UxC Nuclear Zirconium Demand Modeling.....	77
• Unaccounted for Zirconium Demand .....	78
Global Supply and Demand for Nuclear-Grade Zirconium Alloy.....	79
• Zirconium Alloy Demand Forecasts.....	79
• Zirconium Alloy Supply Forecast .....	80
Global Supply and Demand for Zircaloy Tubing .....	82
• Zircaloy Tubing Demand Forecasts.....	82
• Zircaloy Tubing Supply Forecast .....	83
Regional Supply and Demand Balances.....	85
• Regional Demand Distributions .....	85
Zirconium Alloy .....	85
Zircaloy Tubing.....	86
• Analysis of Regional Supply and Demand Balances.....	87
Reactor Type Supply and Demand Balances .....	89
• Reactor Type Demand Distributions.....	89
Zirconium Alloy.....	89
Zircaloy Tubing.....	91
• Analysis of Reactor Type Zirconium Supply and Demand Balances.....	91
<b>6 – Overall Conclusions and Market Analysis .....</b>	<b>92</b>
Wither Zircon?.....	92
The Zirconium Alloy Market in the Post-Fukushima World.....	94
Zirconium Alloy Market Supply and Demand Trends.....	96
Nuclear-Grade Zirconium Prices.....	97
<b>Appendix A: Zirconium Weight Calculations for Fuel Assemblies .....</b>	<b>98</b>
<b>Appendix B: UxC Nuclear Power Forecasts .....</b>	<b>99</b>
UxC Base Case Reactor Forecast.....	99
Alternative UxC Reactor Forecast Cases .....	102
Post-Fukushima Changes to UxC Nuclear Power Forecasts .....	103
<b>Appendix C: UxC Nuclear Power Regions .....</b>	<b>104</b>
<b>Appendix D: Statistics on Reactor Technologies and Vendors .....</b>	<b>105</b>

## List of Figures

Figure 1. Zircon Sand .....	10
Figure 2. Microphotograph of Zircon Sand.....	11
Figure 3. Countries with Major Zirconium Resources .....	12
Figure 4. Applications for Zirconium Materials .....	13
Figure 5. Zirconium End Uses by Sector, 2000, 2008 & 2012 .....	14
Figure 6. Zircon Mining Process.....	17
Figure 7. Zircon Mining Pond .....	18
Figure 8. Zircon Mining Dredging Operations .....	18
Figure 9. World Zirconium Reserves Distribution, 2010.....	20
Figure 10. World Zirconium Mine Production Distribution, 2010.....	21
Figure 11. Zirconium Mineral Concentrates Production, 2000-2010.....	21
Figure 12. Zircon Supply, Demand, and Price, 1997-2010 .....	22
Figure 13. Zircon Supply vs. Demand Forecast, 1990-2020.....	24
Figure 14. Zircon Sand Pricing, 1995-2010.....	25
Figure 15. Zircon Sand Pricing, January 2010-July 2011 .....	26
Figure 16. Typical Zirconium Sponge.....	30
Figure 17. Typical Zirconium Alloy Sheet.....	32
Figure 18. Typical BWR Fuel Assembly Spacer Grid.....	32
Figure 19. Typical Zirconium Alloy Bar Stock.....	33
Figure 20. Typical Zirconium Tube-Reduced Extrusions (TRES) .....	33
Figure 21. Pilgering Process .....	34
Figure 22. Schematic of the Pilgering Process .....	35
Figure 23. Zirconium Alloy Nuclear Fuel Cladding.....	35
Figure 24. Nuclear Zirconium Sponge Producer Capacity Shares .....	37
Figure 25. Nuclear Zirconium Alloy Producer Capacity Shares .....	45
Figure 26. Nuclear Zirconium Alloy Tubing Manufacturer Capacity Shares .....	52
Figure 27. UxC LWR Fuel Fabrication Supply & Demand Forecast, 2008-2030.....	66
Figure 28. Typical BWR Fuel Assemblies .....	69
Figure 29. Typical PWR Fuel Assembly.....	70
Figure 30. Typical Fuel Rod .....	71
Figure 31. Typical BWR (right) and PWR (left) Skeletons/Cages .....	73
Figure 32. UxC Estimates for Global Zirconium Alloy Demand, 2008-2030 .....	79
Figure 33. UxC Global Zirconium Alloy Supply Forecast, 2008-2020.....	81
Figure 34. UxC Estimates for Global Zircaloy Tubing Demand, 2008-2030 .....	82
Figure 35. UxC Global Zircaloy Tubing Supply Forecast, 2008-2020.....	83
Figure 36. Regional Distribution of Zirconium Alloy Demand, 2008-2030 .....	86
Figure 37. Regional Distribution of Zircaloy Tubing Demand, 2008-2030 .....	87
Figure 38. Regional Distribution of Zirconium Alloy Supply .....	88
Figure 39. Regional Distribution of Zircaloy Tubing Supply .....	88
Figure 40. Reactor Type Distribution of Zirconium Alloy Demand, 2008-2030.....	90
Figure 41. Reactor Type Distribution of Zircaloy Tubing Demand, 2008-2030.....	91
Figure B-1. UxC Nuclear Generating Capacity Forecast, 2008-2030.....	99
Figure B-2. UxC Base, High, and Low Case Nuclear Capacity Forecasts, 2008-2030 .....	102
Figure B-3. Post-Fukushima Changes to Base/Low/High Nuclear Forecast Cases .....	103
Figure C-1. Map of NPO Countries by Region .....	104
Figure D-2. Percentages of Different Operating Reactor Types .....	105
Figure D-3. Percentages of New Reactor Types, 2009-2020 .....	106
Figure D-4. Percentages of New Reactor Vendors, 2009-2020.....	106

## List of Tables

Table 1. Chemical Composition of Principal Zr Alloys (%) .....	15
Table 2. World Zirconium Mine Production and Reserves .....	20
Table 3. World Nuclear Zirconium Sponge Producers .....	37
Table 4. World Zirconium Alloy Plate, Sheet, Bar Stock & TREX Producers.....	45
Table 5. World Nuclear Zirconium Alloy Tubing Manufacturers .....	51
Table 6. Current Worldwide LWR Fabrication Capacity in 2011 .....	65
Table 7. UxC Estimates for Global Zirconium Alloy Demand, 2008-2020 .....	79
Table 8. UxC Estimates for Global Zircaloy Tubing Demand, 2008-2020 .....	82
Table 9. Regional Distribution of Zirconium Alloy Demand, 2008-2020.....	86
Table 10. Regional Distribution of Zircaloy Tubing Demand, 2008-2020.....	87
Table A-1. Zirconium Alloy Weight and Tubing Calculations for Fuel Assembly Designs .....	98
Table B-1. Reactor Units & Nuclear Capacities Anticipated by Country by 2030 .....	100
Table B-2. UxC Base, High, and Low Case Nuclear Reactor and Capacity Forecasts, 2008-2020.....	102
Table D-1. Operating Reactor Types.....	105
Table D-2. New Reactor Types, 2009-2020 .....	105
Table D-3. New Reactor Vendors, 2009-2020 .....	106

## Introduction & Overview

The Ux Consulting Company, LLC (UxC), is pleased to present the third edition in its report series, *Nuclear Zirconium Alloy Market*.

The initial report, issued in November 2008, was intended to be a one-of-a-kind snapshot of the then-contemporary zirconium alloy industry. However, the highly favorable response to that original report, and to the April 2010 report update, convinced us that there is an ongoing need and desire for current information on this important topic. Thus, we have added the *Nuclear Zirconium Alloy Market* to our list of periodic reports, and our latest findings and conclusions are presented herein.

Nuclear-grade zirconium alloys and components are employed in the fabrication of fuel assemblies used in the vast majority of nuclear reactors currently operating, under construction, and planned around the world. Even as the nuclear renaissance has been derailed in many countries, at least temporarily, by the Fukushima accident, many aspects of the international nuclear fuel supply chain continue to be of concern.

The supply of nuclear-grade zirconium alloys – from the mining of zircon mineral sand through the manufacture of cladding and components used in finished fuel assemblies – has not escaped this scrutiny. Therefore, the primary objective of this report is to factually and analytically approach the current and expected future direction of the nuclear-grade zirconium alloy market to help arrive at some clear conclusions about how producers of fuel assemblies for nuclear reactors will obtain the necessary zirconium alloys for their finished products.

This up-to-date report offers UxC's most recent analyses and opinions of the various sectors that make up the nuclear-grade zirconium sponge, alloy, materials and tubing markets. Additional details are included on the interplay of the nuclear fuel fabrication and zirconium alloy supply markets and of the fabrication process itself. We then assess major trends in this unique industry by analyzing the global and regional supply and demand balances for nuclear-grade zirconium alloy and tubing as well as the supply and demand situation based on reactor fuel types. We conclude with some final observations on the global market as well as the current status and expectations for future price developments for the related zirconium alloys and tubing.

---

### Availability of Data

During the preparation of the original report, it became evident that many of the various processors and fabricators of nuclear-grade zirconium sponge, alloys, and fuel assembly components were reluctant to publish or even discuss the details of their businesses. Much of their data are considered proprietary and thus restricted from inclusion in reports such as this. Consequently, in the first report in this series, there were some gaps in the data.

When developing the 2010 report, we were able to identify additional sources of information and to fill in a number of the blanks. Further sources have since been developed for the current 2011 effort. Thus, we believe that this report provides a significantly more comprehensive and more accurate picture of the industry than the earlier documents.

To supplement our own data collection process, we provided each of the principal processors and producers with a draft of the portion of the report that described its operations. If corrections were received, the appropriate changes were made in the text. If our data were confirmed, or if no response was forthcoming, the original language, based on the best information available from public and private sources, was used. Where possible, we confirmed data from one source with a second, independent source. We would like to express our sincere appreciation to all of those companies who responded to our inquiries.

We believe that the information contained herein is accurate or, as a minimum, representative of the operations, production levels, etc. of the companies discussed in the succeeding chapters of the report. However, the possibility still exists that there may be a few errors or that the information has changed since the data were obtained. In a couple of instances, there were no available non-proprietary data, and, therefore, the missing information is listed as “not available” in the affected data tables.

---

## What’s New in the 2011 Report?

---

In this November 2011 edition of the *Nuclear Zirconium Alloy Market* report, we have continued to employ the format and content of the previous document, but have updated all of the relevant information to reflect current circumstances. But other improvements have been made as well.

Beginning about two years ago, the markets for zircon sand and some of the downstream zirconium products entered a period a great volatility. Shortages of zircon led to explosive increases in prices for raw materials and created substantial uncertainty as to the future performance of these markets. Consequently, we have substantially expanded our analysis of this market from that in the previous report and highlighted the role of China, both as the world’s largest importer of zircon sand and the largest exporter of processed zirconium products. That discussion also contains a much more detailed description of the zircon mining and refining process.

No report on any aspect of the nuclear industry can ignore the impact of the massive March 11, 2011 earthquake and tsunami in Japan, which devastated the Fukushima Daiichi Nuclear Power Plant. All of the analyses in this report have taken account of the implications of the Fukushima accident on the current status and future prospects of the industry.

Perhaps Fukushima’s greatest impact is on the future growth of nuclear power around the world and, therefore, the demand for nuclear fuel assemblies and the zirconium alloy components which comprise them. The demand projections for alloys and tub-

ing described herein have taken specific account of the post-Fukushima world, which looks quite different from what we and others anticipated before that accident.

The current demand projection incorporates detailed UxC calculations of the zirconium weight and tube content in all the major nuclear fuel assemblies in the world, including improved estimates of the quantities of material used in various assembly designs. Moreover, the forecasts make use of UxC's recently refined *UxC Requirements Model* (URM) to forecast global reactor fuel loading requirements and the resulting demand for zirconium alloy materials and products. The URM projects demand on a reactor by reactor basis taking account of each plant's refueling schedule (and/or construction schedule for new plants), the specific fuel assembly design used in that plant, the size of the reload batch (or initial core) and the zirconium-alloy content of the fuel assemblies. This has resulted in a far more accurate presentation than that used previously.

We also noted that many of the subscribers to the previous reports represented organizations which did not participate directly in the fuel fabrication market. Thus, for those not familiar with the technical aspects of the fabrication industry, we have added a discussion of the design of BWR and PWR fuel assemblies, the zirconium alloy components of which they are constructed, and the fuel fabrication process itself.

---

## Structure of the Report

---

This report includes separate chapters for various aspects of the nuclear-grade zirconium alloy market, supply and demand, and other related areas. Following this **Introduction & Overview**, the report includes:

**Chapter 1 – General Zirconium Overview** provides a broad summary of the zirconium mineral occurrence, resource base and industrial applications, including the role of zirconium alloy production in the nuclear fuel industry. It describes the mining and refining of zircon sand and, most importantly, it addresses, in some detail, the current and projected supply, demand and price of zircon in the international marketplace with emphasis on China's critical role.

The General Zirconium Overview discussion helps to put the specific nuclear-grade zirconium alloy market analysis in better perspective, as there are numerous applications for the zirconium mineral beyond nuclear reactor fuel. Additional discussion is provided on the broader global market for zircon and how this impacts the specific nuclear-grade zirconium alloy market.

**Chapter 2 – Manufacturing Processes for Nuclear Fuel Cladding** discusses the manufacturing processes and the overall “nuclear zirconium cycle” for production of the materials and components used in nuclear fuel assemblies.

**Chapter 3 – Nuclear Zirconium Alloy Materials & Product Suppliers** offers a profile of each of the companies involved in nuclear-grade zirconium alloy materials and product supply. This includes all the companies in the world involved in zirconium

um sponge and alloy production and processing through manufacture of sheet, plate, bar stock and tube-reduced extrusions (TREX), as well as tubing and other component manufacture.

**Chapter 4 – Nuclear Fuel Fabricators & Zirconium Components Supply** provides a brief overview of the global nuclear fuel fabrication industry and indicates the source of each fabricator’s fuel assembly tubing and other components. It also includes a discussion of the individual components which make up fuel assemblies and describes the fuel fabrication process.

**Chapter 5 – Nuclear Zirconium Supply & Demand Analysis** offers UxC’s most recent analysis of the global supply and demand balance for nuclear fuel-related zirconium alloy products. In addition, this chapter includes analysis of the zirconium supply and demand on the basis of regional breakdowns as well as on the basis of the different reactor types installed around the world.

**Chapter 6 – Overall Conclusions and Market Analysis** summarizes our findings on the nuclear-grade zirconium market analysis and offers some final thoughts on the current situation and forecast of future trends. This chapter also provides UxC’s analysis of the current nuclear-grade zirconium alloy prices and expectations for future price developments.

Finally, the attached **Appendices** include the data and assumptions used in many of the analyses discussed in the body of the report.