

# Stationary Fuel Cells: Market Shares, Strategies, and Forecasts, Worldwide, 2013 to 2019

## Mountains of Opportunity



Picture by Susan Eustis

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

6 Raymond Street

**Lexington, Massachusetts**

[www.wintergreenresearch.com](http://www.wintergreenresearch.com)

[info@wintergreenresearch.com](mailto:info@wintergreenresearch.com)

781 863 5078

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

**CHECK OUT THESE KEY TOPICS**

Stationary Fuel Cell  
Forecasts  
Stationary Fuel Cell Market  
Development  
Continued Fuel Cell  
Commercialization  
Fuel Cell Operation  
Fuel Environmental Issues  
Power of a Fuel Cell  
Hydrogen Fuel Cell  
Technology  
On Grid And Off Grid Issues  
Impact of Deregulation  
Fuel Cell Issues  
Fuel Cell Reliability

Laws and regulations  
Solid Oxide Fuel Cells  
(SOFC)  
Alkaline Fuel Cells (AFC),  
Phosphoric Acid Fuel Cells  
(PAFC)  
Molten Carbonate Fuel Cells  
(MCFC)  
PEM Technology  
Proton Exchange Membrane  
(PEM)  
Fuel Cells  
PEM Fuel Cells  
Platinum Catalysts

Vision For The New Electrical  
Grid  
Fuel Cell Clean Air Permitting  
Cycle Efficiency  
Gas turbine  
Hybrid Solid Oxide Fuel Cell  
Energy Efficiency  
Fuel Cell  
Fuelcell Energy  
Smart Grid  
Utilities  
Increased Power Density  
Stationary Power  
Applications

**Stationary Fuel Cells: Economies of Scale Provide Growth Strategy**

**Stationary Fuel Cells: Market Shares, Strategies, and Forecasts, Worldwide, 2013-2019**

LEXINGTON, Massachusetts (December 10, 2013) – WinterGreen Research announces that it has published a new study Stationary Fuel Cell Market Shares, Strategy, and Forecasts, Worldwide, 2013 to 2019. The 2013 study has 553 pages, 238 tables and figures. Worldwide markets are poised to achieve significant growth as the Stationary Fuel Cells used to provide distributed power for campus environments achieve better technology and economies of scale. They have achieved grid parity in many cases. They improve and lower energy costs. They threaten to erode utility profitability.

Stationary Fuel Cells are on the cusp of becoming commercially viable, creating companies that are profitable and produce electricity at or below parity with the grid giving every user alternatives to the grid. Bloom Energy has solved the SOFC engineering challenges. Breakthroughs in materials science, and revolutionary designs give Bloom SOFC technology a cost effective, all-electric solution. Vendors have solved the SOFC conundrum, developing new materials that make units affordable and provide energy device economies of scale and support for wind and solar renewable energy sources.

Stationary fuel cells represent the base for distributed power generation worldwide. No more new coal plants, no more extensions to the grid. Distributed power has become mainstream. Distributed generation (DG) refers to power generation at the point of consumption.

<b>REPORT # SH25821919</b>	<b>553 PAGES</b>	<b>238 TABLES AND FIGURES</b>	<b>2013</b>
<b>\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING</b>			

## WinterGreen Research, INC.

Generating power on-site, rather than centrally, eliminates the cost, complexity, interdependencies, and inefficiencies associated with energy transmission and distribution. Distributed energy is evolving in a manner like distributed PC and laptop computing, cars for transportation, and smart phones. As distributed Internet data and telephony have found a place in the market, so also will distributed energy generation become widespread. Distributed power shifts energy generation control to the consumer much to the consternation of the existing utility companies.

Renewable energy is intermittent and needs stationary fuel cells for renewables to achieve mainstream adoption as a stable power source. Wind and solar power cannot be stored except by using the energy derived from these sources to make hydrogen that can be stored. Stationary fuel cells are likely to function as a battery in the long term, creating a way to use hydrogen that is manufactured from the renewable energy sources. It is likely that the wind and tide energy will be transported as electricity to a location where the hydrogen can be manufactured. It is far easier to transport electricity than to transport hydrogen. Hydrogen servers as an energy storage mechanism.

Stationary fuel cell markets need government sponsorship. As government funding shifts from huge military obligations, sustainable energy policy becomes a compelling investment model for government.

Stationary fuel cell markets at \$793.7 million in 2012 are projected to increase to \$9.6 billion in 2019. Growth is anticipated to be based on demand for distributed power generation that uses natural gas. Systems provide clean energy that is good for the environment. Growth is based on global demand and will shift from simple growth to rapid growth measured as a penetration analysis as markets move beyond the early adopter stage. The big box retailers including many, led by Walmart, the data centers, and companies like Verizon are early adopters.

Eventually hydrogen will be used as fuel in the same stationary fuel cell devices. The hydrogen is manufactured from solar farms. Stationary fuel cells have become more feasible as the industry is able to move beyond platinum catalysts.

WinterGreen Research is an independent research organization funded by the sale of market research studies all over the world and by the implementation of ROI models that are used to calculate the total cost of ownership of equipment, services, and software. The company has 35 distributors worldwide, including Global Information Info Shop, Market Research.com, Research and Markets, Electronics.CA, Bloomberg, and Thompson Financial.

WinterGreen Research is positioned to help customers face challenges that define the modern enterprises. The increasingly global nature of science, technology and engineering is a reflection of the implementation of the globally integrated enterprise. Customers trust WinterGreen Research to work alongside them to ensure the success of the participation in a particular market segment.

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

WinterGreen Research supports various market segment programs; provides trusted technical services to the marketing departments. It carries out accurate market share and forecast analysis services for a range of commercial and government customers globally. These are all vital market research support solutions requiring trust and integrity.

## Companies Profiled

### Market Leaders

**Bloom Energy**  
**UTC**  
**Ballard**  
**Plug Power**

**FuelCell Energy**  
**ClearEdge**  
**Hydrogenics**

### Market Participants

**Acumentrics**  
**Advent Technologies**  
**AFC Energy**  
**Alteryx**  
**Ansaldo Fuel Cells 461**  
**Ballard Power Systems**  
**BASF**  
**Blasch Precision Ceramics**  
**SoftBank & Bloom Energy Joint Venture**  
**ClearEdge Power / UTC Power**

**Ceramic Fuel Cells**  
**Delphi**  
**Doosan Corporation**  
**Elcore**  
**Enbridge**  
**Fuji Electric**  
**GE**  
**HydroGen LLC**  
**ITN Lithium Technology**  
**ITN Plasmonics**  
**LG Electronics**

**Nuvera**  
**POSCO Power**  
**Rolls Royce**  
**Samsung**  
**Serenergy**  
**Siemens AG**  
**SoftBank**  
**Southern California Edison**  
**Truma**

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

## About The Company

# WinterGreen Research,

Founded in 1985, provides strategic market assessments in software, communications products, communications services, and advanced technology.

Reports focus on opportunities to expand existing markets or develop new markets. The reports assess corporate positioning, market strategies, and product marketing opportunities. Reports evaluate the impact of new technologies. Reports assess the strategies and positions of leading participants.

The principals of WinterGreen Research have been involved in analysis and forecasting of international business opportunities in healthcare, energy, telecommunications, and advanced computer technology markets for over 30 years.

## Research Methodology

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

## **WinterGreen Research, INC.**

**WinterGreen Research authors use a structured, consistent, and detailed research approach. The methodology supports an analytical approach to market research. In depth comparisons are made of many aspects of the market. Data relating to Industry segments is developed to permit presentation of forecasts and market share positioned to have substantive value.**

**Research involves talking to customers, vendors, and distributors, doing trend analysis and attending local and national meetings, conducting interviews while there.**

**Full spectrum research and information services, including market reports, customized research, and customer interviewing are available, reports and research are positioned to provide strategic value to industry participants, strategic planners, and product managers.**

**New systems combine sales tools and independent industry analysis, seeking to leverage the expertise of the sales force and combine it with the skepticism of the analysts to provide accurate return on investment analysis.**

**This stationary fuel cell shipment analysis is based on consideration of the metrics for the number of campus environments worldwide. Distributor and customer experience using the stationary fuel cell devices is another factor that contributes to development of triangulation regarding market forecasts for the sector.**

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

**Stationary Fuel Cell: Market Shares, Strategies, and Forecasts,  
Worldwide, 2013 to 2019**

**Report Methodology**

This is the 582nd report in a series of primary market research reports that provide forecasts in communications, telecommunications, the Internet, computer, software, telephone equipment, health equipment, and energy. Automated process and significant growth potential are priorities in topic selection. The project leaders take direct responsibility for writing and preparing each report. They have significant experience preparing industry studies. Forecasts are based on primary research and proprietary data bases.

The primary research is conducted by talking to customers, distributors and companies. The survey data is not enough to make accurate assessment of market size, so WinterGreen Research looks at the value of shipments and the average price to achieve market assessments. Our track record in achieving accuracy is unsurpassed in the industry. We are known for being able to develop accurate market shares and projections. This is our specialty.

The analyst process is concentrated on getting good market numbers. This process involves looking at the markets from several different perspectives, including vendor shipments. The interview process is an essential aspect as well. We do have a lot of granular analysis of the different shipments by vendor in the study and addenda prepared after the study was published if that is appropriate.

Forecasts reflect analysis of the market trends in the segment and related segments. Unit and dollar shipments are analyzed through consideration of dollar volume of each market participant in the segment. Installed base analysis and unit analysis is based on interviews and an information search. Market share analysis includes conversations with key customers of products, industry segment leaders, marketing directors, distributors, leading market participants, opinion leaders, and companies seeking to develop measurable market share.

Over 200 in depth interviews are conducted for each report with a broad range of key participants and industry leaders in the market segment. We establish accurate market forecasts based on economic and market conditions as a base. Use input/output ratios, flow charts, and other economic methods to quantify data. Use in-house analysts who meet stringent quality standards.

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**



## WinterGreen Research, INC.

Interviewing key industry participants, experts and end-users is a central part of the study. Our research includes access to large proprietary databases. Literature search includes analysis of trade publications, government reports, and corporate literature.

Findings and conclusions of this report are based on information gathered from industry sources, including manufacturers, distributors, partners, opinion leaders, and users. Interview data was combined with information gathered through an extensive review of internet and printed sources such as trade publications, trade associations, company literature, and online databases. The projections contained in this report are checked from top down and bottom up analysis to be sure there is congruence from that perspective.

The base year for analysis and projection is 2010. With 2010 and several years prior to that as a baseline, market projections were developed for 2011 through 2017. These projections are based on a combination of a consensus among the opinion leader contacts interviewed combined with understanding of the key market drivers and their impact from a historical and analytical perspective. The analytical methodologies used to generate the market estimates are based on penetration analyses, similar market analyses, and delta calculations to supplement independent and dependent variable analysis. All analyses are displaying selected descriptions of products and services.

This research includes referencde to an ROI model that is part of a series that provides IT systems financial planners access to information that supports analysis of all the numbers that impact management of a product launch or large and complex data center. The methodology used in the models relates to having a sophisticated analytical technique for understanding the impact of workload on processor consumption and cost.

WinterGreen Research has looked at the metrics and independent research to develop assumptions that reflect the actual anticipated usage and cost of systems. Comparative analyses reflect the input of these values into models.

The variables and assumptions provided in the market research study and the ROI models are based on extensive experience in providing research to large enterprise organizations and data centers. The ROI models have lists of servers from different manufacturers, Systems z models from IBM, and labor costs by category around the world. This information has been developed from WinterGreen research proprietary data bases constructed as a result of preparing market research studies that address the software, energy, healthcare, telecommunications, and hardware businesses.

### YOU MUST HAVE THIS STUDY

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# Stationary Fuel Cells: Market Shares, Strategy, and Forecasts, 2013 to 2019

## Table of Contents

### Stationary Fuel Cells Executive Summary

The study is designed to give a comprehensive overview of Stationary Fuel Cells equipment market segment. Research represents a selection from the mountains of data available of the most relevant and cogent market materials, with selections made by the most senior analysts. Commentary on every aspect of the market from independent analysts creates an independent perspective in the evaluation of the market. In this manner the study presents a comprehensive overview of what is going on in this market, assisting managers with designing market strategies likely to succeed.

Stationary Fuel Cell Market Driving Forces	37
Platinum Catalysts	41
Stationary Fuel Cell Market Shares	41
Stationary Fuel Cell Market Forecasts	43

### Stationary Fuel Cells Market Definition And Market Dynamics

<b>1</b>	<b>STATIONARY FUEL CELL MARKET DYNAMICS AND MARKET DESCRIPTION</b>	<b>45</b>
1.1	Stationary Fuel Cell Market Dynamics and Market Description	45
1.1.1	Stationary Fuel Cell Ownership Models	45
1.2	Distributed Power Generation	46
1.2.1	On-Site Power:	46
1.2.2	Utility Grid Support:	47
1.3	Solid Oxide Fuel Cells (SOFC)	51

# WinterGreen Research, INC.

1.3.1	Next Generation SOFC	51
1.3.2	Bloom Energy Solid Oxide Fuel Cells	52
1.4	ClearEdge Power Moving away from HT-PEMFC Technology	52
1.5	Distributed Power Generation	53
1.5.1	Distributed Clean and Continuous Power Generation	53
1.5.2	Benefits of Bloom Energy	54
1.5.3	Stationary Fuel Cell Technology	54
1.6	Industrialization Requires Sustainable, Highly Efficient Energy	55
1.6.1	Fuel Cell Cogeneration	56
1.6.2	Stationary Fuel Cells Address Global Energy Challenge	56
1.6.3	Petroleum	57
1.7	Value Of Export Market Electricity	58
1.8	Fuel Cell Operation	60
1.8.1	Fuel Cells Definition	66
1.8.2	Fuel Cell Insulating Nature Of The Electrolyte	68
1.8.3	Inconsistency Of Cell Performance	70
1.8.4	Fuel Cell Performance Improvements	70
1.8.5	Transition To Hydrogen	71
1.9	Fuel Environmental Issues	72
1.9.1	Environmental Benefits Of Using Fuel Cell Technology	74
1.9.2	Greenhouse Gas Emissions	77
1.10	Battery Description	78
1.11	Fuel Cell Functional Characteristics	79
1.12	Water In A Fuel Cell System	82
1.13	Power Of A Fuel Cell	83
1.13.1	Gas Control	84
1.13.2	Temperature Control	84
1.14	Fuel Cell Converts Chemical Energy Directly Into Electricity And Heat	85
1.14.1	Types Of Fuel Cells	85
1.15	Hydrogen Fuel Cell Technology	88
1.15.1	Types Of Fuel Cells	88
1.15.2	Alkaline Fuel Cells	91
1.15.3	Phosphoric Acid Fuel Cells	92
1.15.4	Molten Carbonate Fuel Cells	94
1.15.5	Solid Oxide Fuel Cells	96
1.15.6	PEM Technology	98

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

1.15.7	Proton Exchange Membrane (PEM) Fuel Cells	98
1.15.8	PEM Fuel Cells	101
1.15.9	Proton Exchange Membrane (PEM) Fuel Cell	102
1.15.10	Proton Exchange Membrane (PEM) Membranes And Catalysts	103
1.15.11	Common Types Of Fuel Cells	105
1.16	Stationary Power Applications	106
1.16.1	Traditional Utility Electricity Generation	106
1.17	On Grid And Off Grid Issues	107
1.17.1	Stationary Public Or Commercial Buildings Fuel Cell Market	108
1.17.2	Distributed Power Generation	109
1.18	Impact Of Deregulation	110
1.18.1	Excess Domestic Capacity	110
1.18.2	Power Failures	111
1.19	Fuel Cell Issues	111
1.19.1	Solid Oxide Fuel Cells	113
1.19.2	Fuel Cell Workings	114
1.19.3	Environmental Benefits Of Fuel Cells	116
1.19.4	Fuel-To-Electricity Efficiency	117
1.20	Boilers	118
1.20.1	Domestic Hot Water	118
1.20.2	Space Heating Loops	118
1.20.3	Absorption Cooling Thermal Loads	119
1.21	Fuel Cell Reliability	119
1.21.1	Power Quality	120
1.21.2	Licensing Schedules	120
1.21.3	Modularity	121
1.22	Fuel Cell Supply Infrastructure	121
1.23	Laws And Regulations	121
1.23.1	National Hydrogen Association	121
1.23.2	Military Solutions	122

## Stationary Fuel Cells Market Shares And Market Forecasts

2.	<b>STATIONARY FUEL CELL MARKET SHARES AND MARKET FORECASTS</b>	<b>122</b>
2.1	Stationary Fuel Cell Market Driving Forces	123

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

2.1.1	Platinum Catalysts	127
2.2	Stationary Fuel Cell Market Shares	127
2.2.1	Bloom Energy (SOFC) Fuel Cell Comprised Of Many Flat Solid Ceramic Squares	131
2.2.2	FuelCell Energy (MCFC)	133
2.2.3	ClearEdge	134
2.2.4	ClearEdge / UTC Phosphoric Acid Fuel Cells (PAFCs)	135
2.2.5	Ballard and IdaTech PEM	135
2.2.6	Acumentrics	136
2.3	Stationary Fuel Cell Market Forecasts	138
2.3.1	Stationary Fuel Cell Units Market Forecasts	139
2.3.2	Vision For The New Electrical Grid	143
2.3.3	Fuel Cell Clean Air Permitting	144
2.4	SOFC Fuel Cell Forecasts	146
2.4.1	SOFC Stationary Fuel Cell Forecasts: Unit Shipment and Installed Base Market Penetration Analysis	149
2.4.2	SOFC ROI Models	151
2.4.3	SOFC Fuel Cell Markets	151
2.4.4	SOFC Specialized Ceramics	154
2.4.5	SOFC Stationary Fuel Cell Market Description	155
2.4.6	Bloom Energy SOFC	156
2.4.7	SOFC Methanol Fuel Cells, On The Anode Side, A Catalyst Breaks Methanol	156
2.5	PEM Stationary Fuel Cell Forecasts	157
2.5.1	PEM Telecom Fuel Cell Back Up Power Systems	161
2.5.2	PEM Fuel Cell: High Temperature –	162
2.5.3	PEMFC Efficiency	162
2.5.4	Challenges for PEMFC Systems	163
2.5.5	Operating Pressure	164
2.5.6	Long Term Operation	164
2.5.7	Proton Exchange Membrane Fuel Cell (PEM) Residential Market	166
2.6	Molten Carbonate Fuel Cell (MCFC)	167
2.6.1	MCFC Molten Carbonate Uses Nickel and Stainless Steel as Core Technology	167
2.6.2	MCFC Stationary Fuel Cell Market Analysis	168
2.6.3	Molten Carbonate Fuel Cell (MCFC) Fuel Cell Technology	171
	95% Combustion Efficiency	171

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

2.7	UTC PAFC Platinum Costs	171
2.7.1	PAFC 172	
2.7.2	Phosphoric Acid Fuel Cell (PAFC) Technology	173
2.8	Distributed Campus Environments For SOFC, PEM, MCFC, and MCFC Stationary Fuel Cells	174
2.8.1	Government Support for Fuel Cell Technology	176
2.8.2	Competition For Distributed Generation Of Electricity	177
2.8.3	Stationary Fuel Cell Applications	178
2.9	Energy Market Forecasts	180
2.9.1	FuelCell Energy Fuel Cell Stack Module MCFC Costs	184
2.9.2	FuelCell Energy Cost Breakdown	185
2.9.3	FuelCell Energy Fuel Cell Stack Module	186
2.9.4	FuelCell Energy Materials Cost Reduction via Increased Power Density	186
2.9.5	Fuel Cell Energy Achieving Higher MCFC Power Density	188
2.9.6	SOFC Unfavorable Fuel Cell Market Characteristics	192
2.9.7	Phosphoric Acid Fuel Cells (PAFCs)	197
2.10	PEM Membrane, Or Electrolyte	197
2.10.1	PEM Proton-Conducting Polymer Membrane, (The Electrolyte)	199
2.11	Delivered Energy Costs	203
2.11.1	Nanotechnology Platinum Surface Layer on Tungsten Substrate For Fuel Cell Catalyst	206
2.11.2	SOFC Fuel Cell Prices	208
2.12	PEM, SOFC, MCFC, and PAFC Stationary Fuel Cell Applications and Uses:	208
2.13	MCFC, SOFC, PEMFC Projected Cost Long Term	210
2.14	Stationary Fuel Cells Strengths and Weaknesses	211
2.15	Fuel Cell Return On Investment Analysis	213
2.15.1	Addressable Market	215
2.16	Stationary Fuel Cell Prices	215
2.16.1	Solid-Oxide Fuel Cell Stack Prices	215
2.16.2	MCFC Stationary Fuel Cell Prices	216
2.17	Stationary Fuel Cell Market Regional Analysis	220
2.17.1	Stationary Fuel Cells U.S.	222
2.17.2	Fuel Cells California	222
2.17.3	Regional Stationary Fuel Cell Competition	224
2.17.4	CPUC Recently Approved 6 Utility Owned Fuel Cell Projects	228

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

2.17.5	Stationary Fuel Cell Installations in California	230
2.17.6	California Fuel Cell Installations	232
2.17.7	Campus Fuel Cell Food Processing Agricultural Applications / Gills Onions Stationary Fuel Cells	232
2.17.8	Oxnard DFC Installations	233
2.17.9	Europe and Japan	234
2.17.10	Korea	235
2.17.11	European Photovoltaic Industry Association and Greenpeace Global Investments In Solar Photovoltaic Projects	248
2.17.12	German Stationary Fuel Cells	248
2.17.13	Japanese Sales Prospects	252
2.17.14	New Sunshine Project (Japan)	253
2.17.15	Fuel Cell Development in Japan	254
2.17.16	Fuel Cell Cogeneration in Japan	255
2.17.17	Softbank / Bloom: Bloom Energy Japan	255
2.17.18	Japanese Government Subsidies	257
2.17.19	Fuel Cell Cogeneration In Japan	258
2.17.20	Establishing Codes And Standards Are Very Important For Advancing Fuel Cell Systems In Japan	258
2.17.21	FuelCell Energy Geographic Market Participation	259
2.17.22	FuelCell Energy within Korea	259
2.17.23	FuelCell Energy Korean Market Partner POSCO Energy	260
2.17.24	FuelCell Energy Within the United States	261
2.17.25	FuelCell Energy Bridgeport Project	263
2.17.26	FuelCell Energy in Canada	264
2.17.27	FuelCell Energy in Europe	265
2.17.28	FuelCell Energy European Market Developments	266

## Stationary Fuel Cells Product Description

<b>3</b>	<b>STATIONARY FUEL CELL PRODUCT DESCRIPTION</b>	<b>268</b>
3.1	Fuel Cells	268
3.2	Solid Oxide Fuel Cells (SOFC)	268
3.2.1	Next Generation SOFC	268
3.3	Bloom Energy Solid Oxide Fuel Cells	269

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

3.3.1	Bloom's Energy SOFC Specifications	271
3.3.2	Bloom Energy Server Architecture	275
3.4	Ceramic Fuel Cells SOFC	277
3.4.1	Ceramic Fuel Cells BlueGen	277
3.4.2	Ceramic Fuel Cells Gennex Fuel Cell Module	282
3.4.3	Ceramic Fuel Cells Engineered Mixed Oxide Powders	282
3.5	LG 282	
3.5.1	LG Solid Oxide Fuel Cells SOFC Technology	285
3.6	SKKG Cultural and Historical Foundation / Hexis SOFC	288
3.7	Viessmann Group	288
3.8	The Ceres Fuel Cell	289
3.8.1	Ceres Power Core Technology	290
3.9	Acumentrics	292
3.9.1	Acumentrics Fuel Cell Systems Work	294
3.9.2	The Fuel Reformer	296
3.9.3	Acumentrics Small Tubes	297
3.9.4	Acumentrics Specialized Ceramics	298
3.9.5	Acumentrics Fuel Cell Technologies Ltd Trusted Power Innovations	299
3.10	Samsung	300
3.11	Delphi Solid Oxide Fuel Cells	301
3.11.1	Delphi / Independent Energy Partners (IEP)	301
3.11.2	Delphi SOFC	302
3.11.3	Delphi Solid Oxide Fuel Cell Auxiliary Power Unit	302
3.12	LG Solid Oxide Fuel Cells	307
3.13	Phosphoric Acid Fuel Cell (PAFC) Stationary Fuel Cells	310
3.14	ClearEdge Proton Exchange Membrane PEM Fuel Cells	311
3.14.1	ClearEdge PureCell® Model 5 System	311
3.14.2	ClearEdge PureCell® Model 400 System	317
3.14.3	ClearEdge PureCell® Model 400 System	318
3.14.4	ClearEdge fuel Cell Fleet Surpasses 1 Million Hours Of Operation	321
3.14.5	Phosphoric Acid Fuel Cells (PAFCs)	322
3.14.6	ClearEdge UTC Product : The PureCell™ Model 400 Power Solution Features :	327
3.14.7	ClearEdge UTC PureComfort® Solutions	328
3.14.8	ClearEdge UTC PureComfort® Power Solutions Save Energy	331
3.14.9	ClearEdge UTC CO2 Emissions Reduction	332
3.14.10	ClearEdge UTC PureComfort® Power Solutions	336

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**



# WinterGreen Research, INC.

3.15	Molten Carbonate Fuel Cell (MCFC) Power Plants	336
3.16	FuelCell Energy	337
3.16.1	FuelCell Energy Power Plants Operating On Natural Gas	338
3.16.2	FuelCell Energy DFC Power Plant Benefits:	341
3.16.3	FuelCell Energy DFC Power Plant Benefits:	342
3.16.4	FuelCell Energy Cost Breakdown	345
3.16.5	FuelCell Energy Fuel Cell Stack Module	346
3.16.6	FuelCell Energy Materials Cost Reduction via Increased Power Density	346
3.16.7	FuelCell Energy Balance-of-Plant Cost Reduction With	
	Volume Production	351
3.16.8	FuelCell Energy Conditioning, Installation, and Commissioning	351
3.16.9	FuelCell Energy to Supply 1.4 MW Power Plant to a California Utility	353
3.16.10	FuelCell Energy Adding Power Generating Capacity At The Point Of Use Avoids Or Reduces Investment In The Transmission And Distribution System	353
3.16.11	FuelCell Energy DFC1500	354
3.16.12	FuelCell Energy Fuel Cells Within South Korean Renewable Portfolio	355
3.16.13	Enbridge and FuelCell Energy Partner	358
3.16.14	FuelCell Energy Power Plants	359
3.17	Proton Exchange Membrane PEM Stationary Fuel Cells	360
3.18	Ballard	361
3.18.1	Ballard and IdaTech's PEM	363
3.18.2	Ballard	364
3.18.3	Ballard / IdaTech	367

## Stationary Fuel Cells Technology

<b>4</b>	<b>STATIONARY FUEL CELL TECHNOLOGY</b>	<b>370</b>
4.1	Fuel Cell Emissions Profile	370
<input type="checkbox"/>	4.1.1 Direct FuelCell Technology	370
4.2	Verizon Launches Massive Green Energy Project to Power 19 Company Facilities Across the Country	375
4.3	Fuel Cells Offer An Economically Compelling Balance Of Attributes	377
4.4	Stationary Fuel Cell Government Regulation	378
4.5	Fuel Cell Type Of Electrolyte Used	380
<input type="checkbox"/>	4.5.1 PEM Fuel Cells	381

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

□ 4.5.2 Fuel Cell Stacks	385
4.6 IdaTech Fuel Processing Technology	387
4.7 Phosphoric Acid Fuel Cells (PAFC)	388
4.7.1 PAFC Platinum-Based Catalyst	388
4.8 Molten Carbonate Fuel Cells (MCFC)	390
□ 4.8.1 FuelCell Energy Degradation of the Electrolyte Support	391
4.8.2 MCFC Stack Cost Analysis	393
4.8.3 Molten Carbonate Fuel Cell Results	394
4.9 Solid Oxide Fuel Cells (SOFC)	396
4.9.1 SOFC Fuel Cell/Turbine Hybrids	399
4.9.2 Acumetrics Tubular SOFC, Solid Oxide Fuel Cell Technology	399
4.10 Fuel Reformer	400
4.10.1 Specialized Ceramics	401
4.10.2 Ceramic Fuel Cells	402
4.11 Fuel Cell Description	403
4.12 Alkaline Fuel Cells (AFC)	408
4.13 Nanotechnology Enables Overcoming Stationary Fuel Cell Cost Barriers	409
4.13.1 DMFC Micro And Portable Fuel Cells Components and Labor Costs	409
4.13.2 SOFC Fuel Cells Components and Labor Costs:	410
4.13.3 MCFC Fuel Cells Components and Labor Costs:	411
4.13.4 PAFC Fuel Cells Components and Labor Costs:	412
4.14 Solar Energy Complements Fuel Cell Technology	413
4.15 DMFC Fuel Cell Already Viable Market	415
4.15.1 DMFC Micro And Portable Fuel Cells Components and Labor Costs	415
4.15.2 Polymer-Electrolyte Membrane PEM	416
4.15.3 PEM Nano Metals And Alloys	417
4.15.4 PEM 418	
4.16 Platinum Catalyst	419
4.16.1 Nanotechnology Platinum Surface Layer on Tungsten Substrate For Fuel Cell Catalyst	419
4.16 2 Nanotechnology Platinum Catalyst Mid Size Stationary Fuel Cells	420
4.16.2 Water Electrolysis Technology	420
4.17 Fuel Cell Nickel Borate Catalyst	421
4.17.1 Fuel Cell High Cost Products	421
4.17.2 Development of Hydrogen Technologies Critical For The Growth of the Fuel Cell Industry	421

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

4.17.3	PEM and SOFC For Home Units	425
4.18	PAFC and Stationary fuel cells	425
4.19	For MCFC:	425
4.20	For PAFC:	426
4.21	Fuel Cell Components	427
4.21.1	Fuel Processor (Reformer)	429
4.22	Fuel Cell Stack	433
4.23	Power Conditioner	433
4.24	Nano Composite Membranes	435
4.25	Pall Filtering of Hydrogen	438
4.26	IdaTech 440	

## Stationary Fuel Cells Company Description

<b>5</b>	<b>STATIONARY FUEL CELL COMPANY PROFILES</b>	<b>442</b>
5.1	Stationary Fuel Cell Acquisitions	442
5.1.1	2013: ClearEdge Power Acquires UTC Power	442
5.1.2	BASF Exits High-Temperature Proton Exchange Membrane Fuel Cell Business	442
5.1.3	GE	443
5.1.4	Air Liquide Invests in Plug Power	443
5.1.5	Ballard Buys IdaTech	443
5.1.6	Viessmann Group Acquires 50 Percent Share in Hexis AG	443
5.1.7	Acumentrics Acquired Fuel Cell Technologies Ltd	444
5.1.8	FuelCell Energy / Versa Power Systems Acquisition	444
5.1.9	Rolls Royce Sells Its Stationary Fuel Cell Operations Interests to LG	445
5.1.10	Other Transactions and Consolidation of Stationary Fuel Cell Market	445
5.2	Acumentrics	445
5.2.1	Acumentrics Technologies Ltd Rugged UPST <sup>TM</sup>	446
5.2.2	Acumentrics UPS Products	446
5.2.3	Acumentrics / Fuel Cell Technologies Ltd Trusted Power Innovations	448
5.2.4	Acumentrics / Fuel Cell Technologies	450
5.3	Advent Technologies	451
5.3.1	Advent Technologies Investors	452

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

5.3.2	Advent Technologies Target Markets For HT-PEMFC	452
5.3.3	Advent Target Markets	452
5.4	AFC Energy	454
5.5	Altery	455
5.5.1	Altery Mass Production And Commercial Deployment Of Rugged, Low Cost Fuel Cells 456	
5.5.2	Altery Global Leader In Telecom/Critical Infrastructure	458
5.6	Ansaldo Fuel Cells	461
5.7	Ballard Power Systems	463
5.7.1	Ballard Power Systems / IdaTech LLC / ACME Group (Gurgaon, Haryana)	463
5.7.2	Ballard Expanded Single Fuel Cell	466
5.7.3	Ballard Hydrogen	466
5.7.4	Ballard Buys IdaTech	467
5.7.5	IdaTech acquires Plug Power's LPG Off-Grid, Backup Power	
	Stationary Product Lines	469
5.7.6	IdaTech Applications	470
5.7.7	IdaTech Wireline Communications Networks	470
5.7.8	Ballard Third Quarter 2013 Revenue	471
	Ballard Third Quarter 2013 Highlights	472
5.8	BASF	475
5.9	Blasch Precision Ceramics	475
5.10	Bloom Energy	475
5.10.1	Bloom Energy Fuel Cells Customer Adobe	477
5.10.2	Bloom Energy / University Of Arizona NASA Mars Space Program	479
5.10.3	SoftBank & Bloom Energy Form Joint Venture	480
5.11	ClearEdge Power / UTC Power	481
5.11.1	ClearEdge / United Technologies	482
5.12	Ceramic Fuel Cells	482
5.13	Delphi 482	
5.13.1	Delphi Automotive LLP Revenue	483
5.13.2	Delphi Solid Oxide Fuel Cell Auxiliary Power Unit	483
5.14	Doosan Corporation	484
5.15	Elcore 485	
5.16	Enbridge	487
5.17	FuelCell Energy	490
5.17.1	FuelCell Energy Production Capacity	491

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

# WinterGreen Research, INC.

5.17.2	FuelCell Energy POSCO 121.8 MW Order	492
5.17.3	FuelCell Energy / Versa	493
5.17.4	FuelCell Energy	493
5.17.5	FuelCell Energy Revenue 2012	495
5.17.6	FuelCell Energy / Versa Power Systems, Inc. Acquisition	496
5.17.7	FuelCell Energy Market Activity	497
5.17.8	FuelCell Energy Versa Power Systems Solid Oxide Fuel Cell Development:	498
5.17.9	FuelCell Energy / Versa Systems Solid Oxide Fuel Cells	498
5.17.10	FuelCell Energy DFC 3000 Cost Savings	501
5.17.11	FuelCell Energy Production and Delivery Capabilities	502
5.17.12	FuelCell Energy Food & Beverage Processing	506
5.17.13	FuelCell Energy Strategic Alliances and Market Development Agreements	507
5.17.14	FuelCell Energy Energy Service Company Partners —	509
5.17.15	FuelCell Energy Business Strategy	511
5.18	Fuji Electric	511
5.19	GE 511	
5.19.1	GE Unmanned Aircraft	515
5.19.2	GE HPGS	516
5.20	HydroGen LLC	516
5.21	ITN Lithium Technology	518
5.21.1	ITN's Lithium EC sub-Division Focused On Development And Commercialization of EC	519
5.21.2	ITN's SSLB Division Thin-Film Battery Technology	520
5.21.3	ITN Lithium Air Battery	520
5.21.4	ITN Fuel Cell	522
5.21.5	ITN Thin-film Deposition Systems	524
5.21.6	ITN Real Time Process Control	525
5.21.7	ITN Plasmonics	529
5.22	LG Electronics	530
5.22.1	LG Business Divisions and Main Products	534
5.22.2	LG Telemonitoring Smartcare System	537
5.22.3	Rolls Royce Sells Its Stationary Fuel Cell Operations Interests to LG	540
5.23	Nuvera 540	
5.24	Plug Power	541
5.25	POSCO Power	541
5.26	Rolls Royce	542
5.27	Samsung Everland	542
5.27.1	Samsung	543

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

5.27.2	Samsung Finds Talent And Adapts Technology To Create Products	546
5.27.3	Samsung Adapts to Change, Samsung Embraces Integrity	547
5.27.4	Samsung Telecom Equipment Group	548
5.27.5	Samsung Electronics Q2 2013 Revenue	549
5.27.6	Samsung Memory Over Logic	550
5.28	Serenergy	551
5.29	Siemens AG	551
5.30	SoftBank	552
5.31	Southern California Edison	552
5.32	Truma	552

## Stationary Fuel Cells List of Tables and Figures

Table ES-1	38
Stationary Fuel Cell Market Driving Forces	38
Table ES-2	39
Stationary Fuel Cell Market Growth Drivers Worldwide	39
Table ES-3	40
Worldwide Stationary Fuel Cell Market Campus Segments	40
Figure ES-4	42
Stationary Fuel Cell Market Shares, Dollars, 2012	42
Figure ES-5	43
Stationary Fuel Cell Shipment Market Forecasts, Dollars, Worldwide, 2013-2019	43
Figure 1-1	48
Traditional Power Distribution Network vs. Fuel Cell Solution	48
Table 1-2	57
Methods Of Producing Energy	57
Table 1-3	59
Key Aspects Of Fuel Cell Stack Costs	59
Figure 1-4	61
Fuel Cell Operation	61
Table 1-5	62
Fuel Cell Operation	62
Figure 1-6	63

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Stationary Fuel Cell Distributed Power Generation	63
Figure 1-7	64
Conventional Power System with Central Generation	64
Figure 1-8	65
Utility Power Systems with Distributed 1MW Fuel Cell System	65
Table 1-9	67
Fuel Cell Characteristics	67
Table 1-10	68
Fuel Cell Description	68
Table 1-11	69
Fuel Cell Categories	69
Table 1-12	71
Fuel Cell Performance Improvements	71
Table 1-13	73
Environmental Concerns Relating To Energy	73
Table 1-14	75
Environmental Benefits Of Using Fuel Cell Technology	75
Table 1-15	75
Fuel Cell Advantages Compared To Internal Combustion Engine	75
Table 1-15 (Continued)	76
Fuel Cell Advantages Compared To Internal Combustion Engine	76
Table 1-16	77
Low-carbon production systems	77
Table 1-17	80
Fuel Cell Functional Characteristics	80
Table 1-17 (Continued)	81
Fuel Cell Functional Characteristics	81
Table 1-18	83
Characteristics Of Water In Fuel Cells	83
Table 1-19	86
Types Of Fuel Cells	86
Table 1-20	87
Classes Of Fuel Cells	87
Table 1-21	88
Fuel Cell Applications	88

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Table 1-22	89
Types Of Fuel Cells	89
Table 1-23	90
Classes Of Fuel Cells	90
Table 1-24	91
Fuel Cell Applications	91
Table 1-25	92
Alkaline Fuel Cell Features	92
Table 1-26	93
Phosphoric acid fuel cells applications	93
Table 1-27	94
Phosphoric Acid Fuel Cell Features	94
Table 1-28	95
Molten Carbonate Fuel Cells	95
Table 1-29	97
Solid Oxide Fuel Cell Features	97
Table 1-30	100
Proton Exchange Membrane (PEM) Fuel Cell Functions	100
Table 1-30 (Continued)	101
Proton Exchange Membrane (PEM) Fuel Cell Functions	101
Table 1-31	112
Fuel Cell Issues	112
Table 1-32	113
Fuel Cell System	113
Table 1-33	115
Conceptual Operation of a Fuel Cell.	115
Table 1-34	116
Fuel Cell System Relative Efficiencies	116
Table 1-35	120
Fuel Cell Reliability Research And Development Issues	120
Table 2-1	124
Stationary Fuel Cell Market Driving Forces	124
Table 2-2	124
Stationary Fuel Cell Market Growth Drivers Worldwide	125
Table 2-3	126

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**



# WinterGreen Research, INC.

Worldwide Stationary Fuel Cell Market Campus Segments	126
Figure 2-4	128
Stationary Fuel Cell Market Shares, Dollars, 2012	128
Table 2-5	129
Stationary Fuel Cell Market Shares, Dollars, 2012	129
Figure 2-6	132
Bloom Energy Server	132
Figure 2-7	133
FuelCell Energy Electrochemical Device	133
Figure 2-8	138
Stationary Fuel Cell Shipment Market Forecasts, Dollars, Worldwide, 2013-2019	138
Table 2-9	139
Stationary Fuel Cell Shipment Market Forecasts Dollars, Worldwide, 2013-2019	139
Figure 2-10	141
Stationary Fuel Cell Shipment Market Forecasts, Units, Worldwide, 2013-2019	141
Table 2-11	142
Stationary Fuel Cell Shipment Market Forecasts Units, Worldwide, 2013-2019d	142
Table 2-12	145
Stationary Fuel Cell Market Forces	145
Figure 2-13	147
Stationary SOFC Fuel Cell Market Forecasts, Dollars, Worldwide, 2013-2019	147
Figure 2-14	148
Stationary Fuel Cell SOFC Market Forecasts, Number Shipped, Worldwide, 2013-2019	148
Table 2-15	149
Solid Oxide Fuel Cells (SOFC) Stationary Fuel Cell Shipment Market Forecasts, Units and Dollars, Worldwide, 2013-2019	149
Table 2-16	150
Solid Oxide Fuel Cells (SOFC) Stationary Fuel Cell Shipment Installed Base and Market Penetration Forecasts Units, Worldwide, 2013-2019	150
Figure 2-17	153
Reducing Hydrogen Crossover Using Nanotechnology	153
Table 2-18	155
Ceramic Fuel Cells Advantages	155

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Figure 2-19	158
Stationary Fuel Cell PEM, Market Forecasts, Dollars, Worldwide, 2013-2019	158
Table 2-20	159
Proton Exchange Membrane Fuel Cell PEM Stationary Fuel Cell Shipment Market Forecasts, Units and Dollars, Worldwide, 2013-2019	159
Figure 2-21	160
Stationary Fuel Cell Proton Exchange Membrane (PEM) Market Forecasts, Units, Worldwide, 2013-2019	160
Table 2-22	163
PEMFC Efficiency	163
Table 2-23	165
Stationary Fuel Cell Long-Term Operation	165
Table 2-24	167
MCFC Technology Development Functions	167
Table 2-25	169
MCFC Near-zero NOX, SOX and low CO2 emissions	169
Figure 2-26	170
FuelCell Energy 2.4 MW Fuel Cell Power Plant Incheon, South Korea	170
Table 2-27	171
MCFC Stationary Fuel Cell Technology	171
Table 2-28	174
Stationary Fuel Cell Distributed Campus Environments Target Markets Worldwide, 2013	174
Table 2-29	175
Stationary Fuel Cell Shipment SOFC, PEM, MCFC, and MCFC Market Forecasts, Dollars, Worldwide, 2013-2019	175
Table 2-30	176
Stationary Fuel Cell Shipment SOFC, PEM, MCFC, and MCFC Market Forecasts, Units, Worldwide, 2013-2019	176
Figure 2-31	179
Stationary Fuel Cell Applications	179
Figure 2-32	180
Global Demand For Electric Power	180
Figure 2-33	181
Cost of Electricity Grid and Stationary Fuel Cell	181

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Table 2-34	193
Complete Fuel Cell Power Plant	193
Table 2-35	193
Opportunity for PAFC Cost Reductions Opportunity Area	193
Table 2-36	194
PAFC Stack Costs	194
Figure 2-37	198
Fuel Cell Image	198
Table 2-38	199
PEM Stack Costs	199
Figure 2-39	204
Delivered Energy Costs	204
Table 2-40	208
Stationary Fuel Cell Markets	208
Table 2-42	211
Stationary Fuel Cells Strengths and Weaknesses	211
Table 2-43	214
Cost Comparison of Available Technologies for a 5kW Plant	214
Table 2-44	216
MCFC Stack Costs	216
Table 2-45	220
Stationary Fuel Cell Regional Market Segments, Dollars, 2012	220
Table 2-46	221
Stationary Fuel Cell Regional Market Segments, 2012	221
Figure 2-47	223
Stationary Fuel Cell Installations in California	223
Figure 2-47 (Continued)	224
Stationary Fuel Cell Installations in California	224
Figure 2-48	228
Efficient Pipeline Pressure Reduction	228
Table 2-49	231
Types Of Campus Fuel Cell Power Plants	231
Figure 2-50	233
FuelCell Energy 600 KW DFC, Gills Onions Oxnard, CA	233
Figure 2-51	237

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Korea's Energy Mix 2030	237
Figure 2-52	238
Korea's Energy Application Sectors	238
Figure 2-53	240
Korean NRE New and Renewable Energy	240
Figure 2-54	241
Korean Research & Development in NRE	241
Figure 2-55	243
Korean Local Plan for Promoting NRE	243
Figure 2-56	244
FuelCell Energy Environmental Tangible Benefits	244
Figure 2-57	245
Hybrid Electric Vehicles Costs	245
Figure 2-58	246
US Energy Costs	246
Figure 2-59	247
Hydrogen Cost From On Site Steam	247
Figure 2-60	251
German Bonus for Electricity Produced Through CHP Units	251
Table 2-61	252
Japanese Sales Prospects	252
Figure 3-1	269
Bloom ES-5700 Fuel Cell	269
Figure 3-2	271
Bloom's Energy SOFC Specifications	271
Table 3-3	273
Bloom Energy SOCF Fuel Cell Specifications	273
Table 3-3 (Continued)	274
Bloom Energy SOCF Fuel Cell Specifications	274
Figure 3-4	276
Bloom Energy Server	276
Table 3-5	277
Bloom Performance Gain From Modular Architecture	277
Figure 3-6	278
Ceramic Fuel Cells BlueGen Products	278

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Figure 3-7	279
Ceramic Fuel Cells BlueGen Installation	279
Figure 3-8	281
Ceramic Fuel Cells BlueGen Efficiency Comparison	281
Figure 3-9	283
LG 1 MW SOFC System	283
Figure 3-10	284
LG Fuel Cell Power Generation Used to Power Electronics and Excess Sold to Grid	284
Figure 3-11	285
LG Integrated Planar Solid Oxide Fuel Cells SOFC	285
Figure 3-12	286
LG Integrated Planar Solid Oxide Fuel Cells SOFC 60 Cell Technology	286
Figure 3-13	287
LG Integrated Planar Solid Oxide Fuel Cells SOFC	287
Figure 3-14	290
Ceres Power SOFC Fuel Cell	290
Figure 3-16	294
Acumentrics Fuel Cell Systems Functions	294
Figure 3-17	297
Acumentrics Small Tubes	297
Table 3-19	299
Acumentrics Tubular Solid Oxide Fuel Cells Functions	299
Figure 3-20	304
Delphi Solid Oxide Fuel Cells	304
Table 3-21	305
Delphi Solid Oxide Fuel Cells Benefits	305
Table 3-22	306
Delphi Solid Oxide Fuel Cells Typical Applications	306
Figure 3-23	307
Delphi Solid Oxide Fuel Cells Transportation Application	307
Figure 3-24	308
LG Fuel Cell Process	308
Table 3-25	309
LG Solid Oxide Fuel Cells Features	309

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Table 3-25 (Continued)	310
LG Solid Oxide Fuel Cells Features	310
Figure 3-26	312
ClearEdge PureCell® Model 5 System Generates 5 kW	312
Figure 3-27	314
PureCell® Model 5 System Specifications	314
Table 3-28	315
ClearEdge The Model 5 System Benefits	315
Table 3-29	316
ClearEdge The Model 5 System Functions	316
Table 3-30	317
ClearEdge The Model 5 system Functions	317
Figure 3-31	318
ClearEdge PureCell® Model 400 System	318
Figure 3-32	320
ClearEdge PureCell® Model 400 System Characteristics	320
Figure 3-33	323
UTC Power Fuel Cells Also Qualify For LEED® (Leadership in Energy and Environmental Design) Points.	323
Table 3-34	324
UTC PureCell system Features	324
Figure 3-35	325
UTC Fuel cell Supplier To NASA For Space Missions For Over 40 Years	325
Table 3-36	326
UTC Performance Characteristics POWER	326
Figure 3-37	328
ClearEdge UTC PureCell Solution Emissions	328
Table 3-38	329
ClearEdge UTC Stationary Fuel Cell Energy Efficiency Positioning	329
Table 3-39	330
ClearEdge UTC Microturbine Chiller/Heater and System Level Functions	330
Table 3-40	331
ClearEdge UTC stationary Fuel cell Benefits :	331
Table 3-41	333
ClearEdge UTC Stationary Fuel Cell Emissions Benefits	333

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Table 3-42	333
ClearEdge UTC Stationary Fuel Cell Emissions CO2 Emissions Reduction Calculations	333
Figure 3-43	335
ClearEdge UTC Pollutant Emissions Comparisons	335
Table 3-44	336
ClearEdge UTC PureComfort® Power Solutions	336
Table 3-45	339
FuelCell Energy Power Plant Advantages:	339
Table 3-46	341
FuelCell Energy Product Advantages	341
Table 3-47	342
FuelCell Energy Fuel Cell Power Plant Models	342
Table 3-48	343
FuelCell Energy DFC Power Plant Benefits:	343
Figure 3-49	344
Fuel Cell Electrochemical Device	344
Figure 3-50	348
Direct Fuel Cell (DFC) Power Plants Offer The Highest Efficiency Which Is Key To Customer Value	348
Figure 3-51	350
FuelCell Energy 1 MW DFC California State University - Northridge	350
Table 3-52	352
FuelCell Energy Cost Reduction Opportunities for the DFC 1500 Power Plant Operating On Pipeline-Quality Natural Gas	352
Figure 3-53	358
Enbridge and FuelCell Energy	358
Figure 3-54	359
Direct Fuel Cell Power Plant	359
Table 3-55	362
Ballard Power Systems Comprehensive Portfolio Of Fuel Cell Products	362
Table 3-56	363
Ballard Power Systems Fuel Cell Products	363
Figure 3-57	366

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Ballard Power Systems Cleargen Multit-Megawatt Fuel Cell System	366
Figure 3-58	367
IdaTech Fuel Cell System	367
Table 3-59	368
Ballard / IdaTech ElectraGen ME System Functions	368
Table 3-60	369
Ballard / IdaTech ElectraGen ME System Functions	369
Table 4-1	370
Favorable Emissions Profile Of DFC Power Plants	370
Table 4-2	372
DFC Technology Advantages	372
Table 4-3	373
Fuel Cell Types Of Electrical Efficiency, Operating Temperature, Expected Capacity Range, And Byproduct Heat	373
Table 4-4	374
Fuel Cell Technologies	374
Table 4-5	374
Fuel Cells By Fuel	374
Figure 4-6	377
Fuel Cells Offer An Economically Compelling Balance Of Attributes	377
Figure 4-7	378
Efficiency Differences Among Fuel Cell Technologies	378
Table 4-8	380
Stationary Fuel Cell Products Regulation	380
Table 4-9	381
Fuel cell Types By T Electrolyte	381
Figure 4-10	382
Polymer Electrolyte Membrane (PEM) Fuel Cells	382
Figure 4-11	384
PEM Fuel Cell Operation	384
Figure 4-12	385
Fuel Cell Stacks	385
Figure 4-13	386
Fuel Cell Stack Components	386
Table 4-14	390

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**



# WinterGreen Research, INC.

Opportunity for PAFC Cost Reductions Opportunity Area	390
Table 4-15	394
Molten Carbonate Fuel Cell R&D areas to be addressed	394
Figure 4-16	395
MCFC Cost Components of Electricity vs. Fuel Cell Capital Cost	395
Figure 4-17	397
Siemens Westinghouse's 250-Kilowatt Atmospheric Pressure Combined Heat And Power Fuel Cell System	397
Table 4-18	403
Ceramic Fuel Cells Advantages	403
Figure 4-19	404
Bloom Energy Fuel Cell Description	404
Figure 4-20	405
Bloom Energy Fuel Cell Description (2)	405
Figure 4-21	406
Bloom Energy Fuel Cell Description (3)	406
Figure 4-22	407
Bloom Energy Fuel Cell Description	407
Figure 4-23	408
Bloom Energy Fuel Cell Description (5)	408
Figure 4-24	414
Fuel Cell Flow Plates	414
Figure -4-25	422
Home Hydrogen Refueler	422
Figure 4-26	424
Fuel Cell Components	424
Figure4-27	428
How A Fuel Cell Works	428
Figure4-28	431
Stationary Fuel Cell Steam Reformer	431
Figure 4-29	432
Hydrogen Reformer Components	432
Figure 4-30	435
1 Fuel Processor (Reformer)	435
2 Fuel Cell Stack	435

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

3 Power Conditioner	435
Figure 4-31	436
Reducing Hydrogen Crossover Using Nanotechnology	436
Figure 4-32	437
Comparison of the Performance of Nanocomposite Membranes	437
Figure 4-33	439
Catalytic Reformer and Refinery Hydrogen System	439
Table 5-1	446
Acumentrics Technologies Ltd Rugged UPS™	446
Table 5-2	447
Acumentrics UPS™ Products Target Markets	447
Table 5-3	447
Acumentrics UPS™ Customers	447
Table 5-4	448
Acumentrics Rugged-UPS™ Designs	448
Figure 5-5	449
Acumentrics Fuel Cell Power Generator	449
Table 5-6	450
Acumentrics Tubular Solid Oxide Fuel Cells Functions	450
Figure 5-7	451
Acumentrics / Fuel Cell Technologies (FCT) Fuel Cell Test Station QA Testing Area	451
Figure 5-8	457
Altery Mass Production Of Rugged, Low Cost Fuel Cells	457
Figure 5-9	458
Altery Fuel Cells	458
Figure 5-10	459
Altery Freedom PowerFuel Cell, Generator, Unconditioned Batteries and Conditioned Batteries Comparison TCO	459
Table 5-11	460
Altery's Market Leading Freedom Power™ Systems	460
Figure 5-12	465
Ballard® Fuel Cell	465
Table 5-13	467
Ballard Hydrogen Systems	467

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

Table 5-14	477
Bloom Energy Customers	477
Table 5-15	486
Elcore Stationary Fuel Cell Technical Details	486
Figure 5-16	487
Enbridge Overview	487
Table 5-17	489
Enbridge Statistics	489
Figure 5-18	490
Enbridge Hybrid Fuel Cell	490
Table 5-19	491
FuelCell Energy Positioning	491
Table 5-20	497
FuelCell Energy Leading Customers	497
Figure 5-21	499
Versa Systems Solid Oxide Fuel Cells	499
Figure 5-22	500
Versa Systems Solid Oxide Fuel Cell Technology	500
Figure 5-23	501
FuelCell Energy DFC 3000 Cost Savings	501
Figure 5-24	502
FuelCell Energy Production Capabilities	502
Table 5-25	503
FuelCell Energy Active Project Pipelines	503
Figure 5-26	504
FuelCell Energy Tangible Environmental Benefits	504
Figure 5-27	505
FuelCell Energy Efficiency Differences Between Technologies	505
Table 5-28	506
FuelCell Energy Markets	506
Table 5-29	509
FuelCell Energy Partner Descriptions	509
Table 5-30	521
ITN Technologies	521
Figure 5-31	522

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**

# WinterGreen Research, INC.

ITN Thin Film Battery Technology	522
Figure 5-32	523
ITN Battery	523
Figure 5-33	524
ITN Thin-Film Deposition Systems	524
Figure 5-34	525
ITN's Thin-Film Deposition Systems	525
Table 5-35	527
ITN Thin-Film Deposition Systems Products and Services Offered	527
Table 5-36	528
ITN Thin-Film Deposition Systems	528
Figure 5-37	530
ITNIYN Fuel Cells	530
Figure 5-38	531
LG Corp Holding Structure	531
Figure 5-39	533
LG Global Sales	533
Figure 5-40	534
LG Business Divisions and Main Products	534
Table 5-41	535
LG Product Offerings	535
Figure 5-42	536
LG Global Network	536
Figure 5-43	538
LG Faster and Smarter Technology Innovation	538
Figure 5-44	539
LG Global Marketing	539

REPORT # SH25821919

553 PAGES

238 TABLES AND FIGURES

2013

\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING

## **ABOUT THE COMPANY**

**WinterGreen Research**, research strategy relates to identifying market trends through reading and interviewing opinion leaders. By using analysis of published materials, interview material, private research, detailed research, social network materials, blogs, and electronic analytics, the market size, shares, and trends are identified. Analysis of the published materials and interviews permits WinterGreen Research senior analysts to learn a lot more about markets. Discovering, tracking, and thinking about market trends is a high priority at WinterGreen Research. As with all research, the value proposition for competitive analysis comes from intellectual input.

**WinterGreen Research**, founded in 1985, provides strategic market assessments in telecommunications, communications equipment, health care, Software, Internet, Energy Generation, Energy Storage, Renewable energy, and advanced computer technology.

Industry reports focus on opportunities that expand existing markets or develop major new markets. The reports access new product and service positioning strategies, new and evolving technologies, and technological impact on products, services, and markets. Innovation that drives markets is explored. Market shares are provided. Leading market participants are profiled, and their marketing strategies, acquisitions, and strategic alliances are discussed. The principals of WinterGreen Research have been involved in analysis and forecasting of international business opportunities in telecommunications and advanced computer technology markets for over 30 years.

The studies provide primary analytical insight about the market participants. By publishing material relevant to the positioning of each company, readers can look at the basis for analysis. By providing descriptions of each major participant in the market, the reader is not dependent on analyst assumptions, the information backing the assumptions is provided, permitting readers to examine the basis for the conclusions.

### **About The Principal Authors**

**Ellen T. Curtiss**, Technical Director, co-founder of WinterGreen Research, conducts strategic and market assessments in technology-based industries. Previously she was a member of the staff of Arthur D. Little, Inc., for 23 years, most recently as Vice President of Arthur D. Little Decision Resources, specializing in strategic planning and market development services. She is a graduate of Boston University and the Program for Management Development at Harvard Graduate School of Business Administration. She is the author of recent studies on worldwide telecommunications markets, the top ten internet equipment companies, the top ten contract manufacturing companies, and the Top Ten Telecommunications market analysis and forecasts.

**Susan Eustis**, President, co-founder of WinterGreen Research is a senior analyst. She has done research in communications and computer markets and applications. She holds several patents in microcomputing and parallel processing. She has the original patents in electronic voting machines where she was featured in People Magazine in 1976. She has new patent applications in format varying, multitasking, and electronic voting. She is the author of recent studies of the Solar Renewable Energy, Wind Energy, Thin Film Batteries, Business Process Management marketing strategies, Internet equipment, biometrics, a study of Internet Equipment, Worldwide Telecommunications Equipment, Top Ten Telecommunications, Digital Loop Carrier, Web Hosting, Web Services, and Application Integration markets. Ms. Eustis is a graduate of Barnard College. Susan Eustis was named as top female executive of the year by Who's Who Worldwide in 2012. She was named page one of the top 100 Industry leaders in Who's Who in 2013.

**REPORT # SH25821919**

**553 PAGES**

**238 TABLES AND FIGURES**

**2013**

**\$3,800 SINGLE COPY -- \$7,600 WEB SITE POSTING**