

The Fuel Cell Industry Review 2012



ACKNOWLEDGEMENTS

Fuel Cell Today gratefully acknowledges the contribution of many individuals and companies within the fuel cell industry in providing information for and assistance with the compilation of the Fuel Cell Today Industry Review 2012.

The Fuel Cell Today Industry Review 2012 is based for the most part on information available up to July 2012.

COPYRIGHT & DISCLAIMER

Fuel Cell Today Industry Review 2012 is the copyright of Johnson Matthey PLC trading as Fuel Cell Today. Material from this publication may be reproduced without prior permission provided that Fuel Cell Today is acknowledged as the source.

Johnson Matthey PLC endeavours to ensure the accuracy of the information and materials contained within this report, but makes no warranty as to accuracy, completeness or suitability for any particular purpose. Johnson Matthey PLC accepts no liability whatsoever in respect of reliance placed by the user on information and materials contained in this report, which are utilised expressly at the user's own risk.

In particular, this report and the information and materials in this report are not, and should not be construed as, an offer to buy or sell or solicitation of an offer to buy or sell, any regulated products, securities or investments, or making any recommendation or providing any investment or other advice with respect to the purchase, sale or other disposition of any regulated products, securities or investments including, without limitation, any advice to the effect that any related transaction is appropriate or suitable for any investment objective or financial situation of a prospective investor.

A decision to invest in any regulated products, securities or investments should not be made in reliance on any of the information or materials in this report. Before making any investment decision, prospective investors should seek advice from their financial, legal, tax and accounting advisers, take into account their individual financial needs and circumstances and carefully consider the risks associated with such investment decisions. This report does not, and should not be construed as acting to, sponsor, advocate, endorse or promote any regulated products, securities or investments.

GLOSSARY

AFC – Alkaline Fuel Cell.

APFCT – Asia Pacific Fuel Cell Technology (Taiwan).

APU – Auxiliary Power Unit.

ARRA – American Recovery and Reinvestment Act.

Bar – The bar is a unit of pressure defined in SI units as 100 kilopascals.

Barg – A unit of pressure which is zero-referenced to atmospheric pressure, i.e. it measures the pressure above atmospheric pressure.

BoP – Balance of Plant.

CARB – California Air Resources Board.

CE – Conformité Européenne.

CFCL – Ceramic Fuel Cells Limited (Australia).

CHIC – Clean Hydrogen In European Cities.

CHP – Combined Heat and Power.

CUTE – Clean Urban Transport for Europe.

DMFC – Direct Methanol Fuel Cell.

DOE – Department of Energy (USA).

EU – European Union.

FCEV – Fuel Cell Electric Vehicle.

FCE – FuelCell Energy (USA).

FCH JU – Fuel Cells and Hydrogen

Joint Undertaking (Europe).

Hotbox – A unit integrating the high temperature components of a SOFC.

Hotel load – The electrical load required to power heating, cooking, lighting etc. in a vehicle, but not for motive power.

HT PEMFC – High Temperature Proton Exchange Membrane Fuel Cell.

kW – Kilowatt.

MCFC – Molten Carbonate Fuel Cell.

MHV – Materials Handling Vehicles.

MoU – Memorandum of Understanding.

MW – Megawatt.

NASA – National Aeronautics and Space Administration (USA).

NIP – National Innovation Programme (Germany).

OEM – Original Equipment Manufacturer.

PAFC – Phosphoric Acid Fuel Cell.

PEMFC – Proton Exchange Membrane Fuel Cell.

RD&D – Research Development and Demonstration.

Recovery Act – American Recovery and Reinvestment Act.

Renewable Transport Fuels Obligation (RTFO) – the principle legislation for the regulation of biofuels used for transport (UK).

RoW – Rest of the World.

RPS – Renewable Portfolio Standard (South Korea).

SGIP – Self Generation Incentive Program (California).

SOFC – Solid Oxide Fuel Cell.

UAV – Unmanned Aerial Vehicle.

UPS – Uninterruptible Power Supply.

USB – Universal Serial Bus.

W – Watt.

Contents

Executive Summary	2
Introduction	4
Current State of the Industry	6
Introduction	6
Developments by Application	8
Special Feature 1: <i>Fuel Cells and Government Funding</i>	22
Fuel and Infrastructure	24
Special Feature 2: <i>Data Centres: Primed for Fuel Cell Power</i>	30
Developments by Region	32
Developments by Electrolyte	39
Special Feature 3: <i>The Canonisation of FCEV</i>	44
Outlook	46
Data Tables	48
Annual Unit Shipments 2008–2012	48
Annual Megawatts Shipped 2008–2012	49
Table Notes	50
About the Authors	51

Executive Summary



Overall fuel cell system shipments (excluding toys and education kits) in 2011 were 24,600 – growing by 39% compared to 2010, led by increases in the stationary sector. Annual megawatts shipped were over 100 MW for the first time as commercialisation of the industry took hold.

Shipments of fuel cell systems for stationary power grew substantially from 2010 to 2011, over all categories. Our revised full-year data for 2011 put systems shipped at over 16,000 and in excess of 81 MW, increases of 94% and 133% respectively over 2010.



System shipments for transport applications dropped nearly 40% from 2010 to 1,600 in 2011. This was due to various factors including in 2010 a spike in Asian bus deployments and the launch of several fuel cell electric vehicle demonstration fleets. These were not matched in scale in 2011.

Portable system shipments were flat between 2010 and 2011, growing by 1.5%. The minor sales decline in the APU sector, due to restricted consumer spending in Europe, was countered by shipments of small fuel cell systems from initial production runs of portable electronics chargers.



By the end of 2011, 215 hydrogen refuelling stations were in operation worldwide with twelve new stations being added that year. The stations are located in Europe (85), North America (80), Asia Pacific (47) and the Rest of the World (3).

Regionally, Asia dominates the fuel cell industry in terms of system shipments with 17,000 in 2011, 69% of the global market. North America led the 2011 megawatt data with 59.6 MW, just over 50% of the total; Asia followed second with 36%.



By electrolyte, system shipments in 2011 were dominated by PEMFC (83%), used in the widest range of markets globally. In terms of megawatts, PEMFC dipped due to lower transport deployments but MCFC, used in large prime power installations, grew substantially.

In 2012 we forecast that annual shipments of fuel cell systems will triple to reach a total of over 78,000 for the full year. Annual megawatts shipped are expected to grow by over 60%, to around 176 MW. Increases are expected across all application categories.



The most dramatic growth in system shipments will be in the portable sector with the widespread commercial release of fuel cell chargers for consumer electronics. Three companies have products on sale: Horizon Fuel Cell Technologies' MiniPak, myFC's PowerTrek and Aquafairy's AF-M3000.

Growth in small stationary fuel cell systems, particularly Ene-Farm in Japan, will also contribute to system shipments in 2012, while large stationary power deployments in South Korea are expected to significantly boost the annual megawatt figure.



We anticipate that transport shipments will recover in 2012 thanks to modest increases in fuel cell vehicle, bus and niche transport shipments but primarily due to a doubling of materials handling vehicle shipments in North America.

Hydrogen refuelling stations will continue to be added in 2012 as early markets gear up for the commercial release of fuel cell electric vehicles. Germany, California and Japan have announced plans for more than 200 stations between them by 2016.



The number of systems shipped in 2012 is forecast to increase in all regions with the greatest contributor being sales of portable fuel cell electronics chargers. Annual megawatts shipped are also expected to increase in all regions, particularly Asia and Europe.

PEMFC will remain the dominant electrolyte in system shipments in 2012 but growth will also be seen in SOFC with increased uptake in stationary power applications. Annual megawatts of SOFC, PAFC and MCFC shipped will all increase due to growth in the large stationary power sector.



Introduction

Overview

Fuel Cell Today is the leading source of information and analysis covering the global market for fuel cells. The Fuel Cell Industry Review 2012 is the second edition of our annual publication which presents a global summary of developments in the fuel cell industry during the past four years, a forecast for the current year and an outlook for the future.

The Current State of the Industry chapter covers developments during 2011 and the first half of 2012, discussing each sub-application in turn, followed by regional developments and the latest update for each main fuel cell type. As discussed in this chapter, fuel cells are an extremely versatile technology, with systems ranging from single watts up to megawatts – a million times larger. For this reason we report both the number of systems shipped and the megawatts they generate. Viewing this information together for each of the market sectors provides the best view of the industry.

The Current State of the Industry also contains three special features: the first analyses the impact of government funding on fuel cell adoption, focusing on the success of fuel cell projects funded under the American Recovery and Reinvestment Act of 2009; the second looks at the interest in fuel cells to power data centres; and the third special feature assesses the attitude of the current US Government to fuel cells and transport.

The Outlook chapter discusses our expectations for the full year 2012 and also includes commentary for each of the three main applications covering high-profile global developments taking place in the next three to five years.

Tables of data can be found at the back of this Review, including historical information dating back to 2008. Data are presented for each year in terms of annual system shipments and the total size of those systems in megawatts, both divided by application, region and fuel cell type as described in the section below.

Fuel Cell Applications and Technologies

Fuel Cell Today categorises the use of fuel cells into three broad areas, defined as follows:

Portable fuel cells encompass those designed to be moved, including auxiliary power units (APU);

Stationary power fuel cells are units designed to provide power to a fixed location;

Transport fuel cells provide either primary propulsion or range-extending capability for vehicles.

Application Type	Portable	Stationary	Transport
Definition	Units that are built into, or charge up, products that are designed to be moved, including auxiliary power units (APU)	Units that provide electricity (and sometimes heat) but are not designed to be moved	Units that provide propulsive power or range extension to a vehicle
Typical power range	5 W to 20 kW	0.5 kW to 400 kW	1 kW to 100 kW
Typical technology	PEMFC DMFC	MCFC PEMFC PAFC SOFC	PEMFC DMFC
Examples	<ul style="list-style-type: none"> - Non-motive APU (campervans, boats, lighting) - Military applications (portable soldier-borne power, skid-mounted generators) - Portable products (torches, battery chargers), small personal electronics (mp3 players, cameras) 	<ul style="list-style-type: none"> - Large stationary combined heat and power (CHP) - Small stationary micro-CHP - Uninterruptible power supplies (UPS) 	<ul style="list-style-type: none"> - Materials handling vehicles - Fuel cell electric vehicles (FCEV) - Trucks and buses

Fuel Cell Today also considers fuel and infrastructure, relating to the production, storage and distribution of fuels for fuel cells. Each of these topics is discussed in more detail in the Current State of the Industry chapter.

Shipments by electrolyte refer to the six main fuel cell technology types: proton exchange membrane fuel cells (PEMFC), direct methanol fuel cells (DMFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and alkaline fuel cells (AFC). High temperature PEMFC and low temperature PEMFC are shown together as PEMFC.

For an explanation of the six main types of fuel cell available on the market today, including their advantages and disadvantages, visit our website (www.fuelcelltoday.com).

Geographical Regions

Fuel Cell Today identifies four main geographical regions: Asia, Europe, North America and the Rest of the World (RoW).

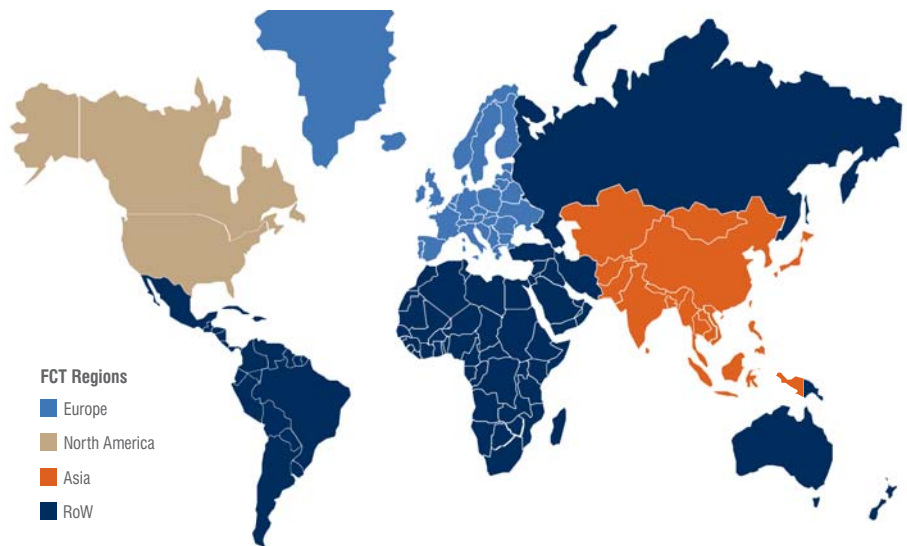
Data Reporting

Shipments are reported by numbers of units (systems) and by total megawatts shipped annually. We report shipments from the final manufacturer, usually the system integrator. These finished systems are then shipped to the final region of adoption, used in our shipment by region classification.

The data presented here may differ from those previously published by Fuel Cell Today. We have taken the decision to exclude data for toys and educational kits from the portable sector in order to

highlight growth in industrial fuel cell use; there is still a commentary on this market in the chapter on portable fuel cells, but shipment figures now reflect end-uses of fuel cells generating electricity for a specific purpose. The overall dataset has also been updated in the light of new information and full-year 2011 data.

The data presented here are based on interviews between Fuel Cell Today and key industry players, publicly available sources such as company statements, press releases or stock market filings, and planned demonstration programmes by companies and governments. Shipment numbers are rounded to the nearest 100 units and megawatt (MW) data to the nearest 0.1 MW. Where power ratings are quoted, these refer to electrical output unless stated otherwise. Our 2012 figures are a forecast for the full year and will be revised and updated in the 2013 Review.



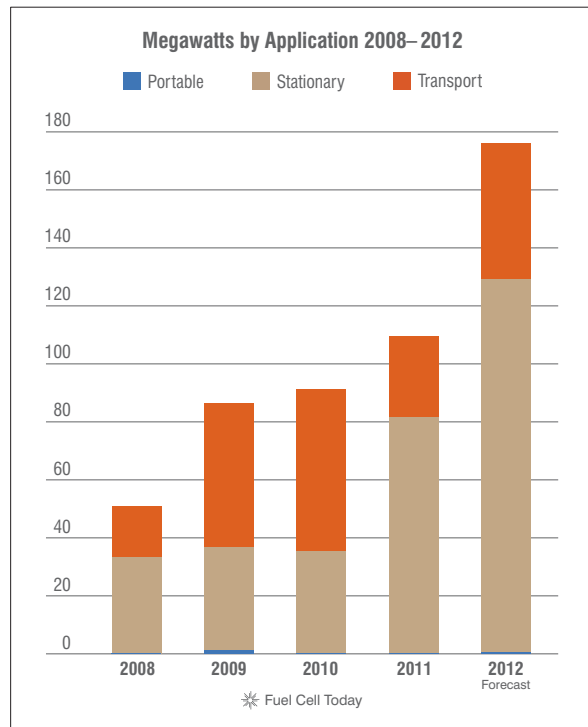
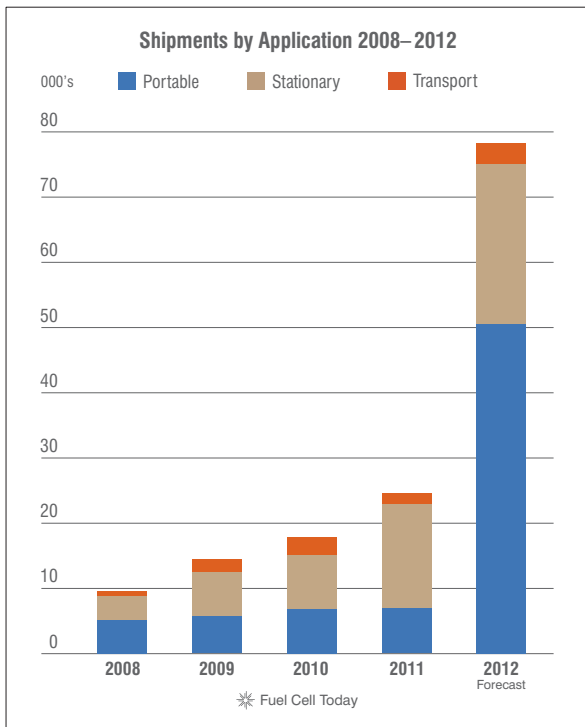
Current State of the Industry

Introduction

Annual fuel cell system shipments increased to 24,600 in 2011 and are expected to surpass 78,000 in 2012

Continued growth in annual fuel cell system shipments was seen worldwide in 2011, increasing 39% compared to 2010 to reach a new high of 24,600 units. So far 2012 has seen that momentum maintained and our expectations are for full-year system shipments to more than triple relative to 2011, reaching 78,200. In megawatt terms, 2011 grew 20% versus the previous year to exceed 100 MW for the first time and we anticipate a further 61% growth in megawatts for 2012, totalling 175.8 MW. A number of high-profile developments took place, including a surge in large stationary fuel cell shipments, continued growth in the residential stationary micro-combined heat and power (micro-CHP) sector and the long awaited commercial launch of three portable fuel cell consumer electronics chargers.

We have revised the way we report our data since the publication of our 2011 Industry Review to remove toys and educational equipment from our graphs and data tables. This sector of the market has provided an important stepping-stone to commerciality for many companies and continues to generate cash. It also serves to educate future generations of the benefits fuel cell technology can offer. With the advent of significant industrial use for fuel cells over the past years, shipments of non-educational systems have grown, but these figures were swamped by the sheer number of educational kits. Therefore, to more accurately reflect end-use industrial fuel cell adoption, we no longer show toys and educational systems in our table totals or graphs. This sector of the market is still covered in our commentary on portable fuel cells which can be found in our Developments by Application section. These changes to our figures affect the portable category, PEMFC and all regions dating back to 2008.



As we stated in our 2011 Industry Review, the fuel cell industry began its road to commercialisation in 2007. This process has not been an easy one, with the problems associated with introducing a new technology to the general public (and even to industrial customers) comprising legislative, manufacturing and cost barriers. Slow-but-steady progress has meant that, historically, announcements purporting significant product shipments have tended to disappoint, often experiencing delays or even being cancelled. This has frustrated investors and customers alike and our historical assumptions for growth were tempered to reflect expected delays.

We believe, however, that a change in certain sectors began in 2011, especially in the stationary market where large orders were announced and completed on time; in some cases, expectations have been met ahead of schedule. This is an unprecedented occurrence in the fuel cell sector.

As a result of this increased activity delivering tangible results, we increased our shipment and megawatt figures for the full year of 2011, and have adopted a more optimistic forecast for 2012. There have been many announcements in the first half of 2012, including a number of fuel cell companies increasing their production capacity. We see this move as a very positive sign that the commercial sales volumes announced in a number of sectors will indeed be delivered according to planned timescales. One particularly positive example is the continued evolution of the deal between FuelCell Energy and POSCO Energy to supply molten carbonate fuel cells (MCFC) to Korea. Megawatt-scale deployments of fuel cells have already taken place in the country and hundreds more megawatts are planned.

In the portable sector shipments were relatively flat between 2010 and 2011, increasing by only 1.5%. Three portable fuel cell electronics chargers were launched this year and therefore we expect even modest sales into this lucrative market to grow portable shipments seven-fold in 2012. With the small size of portable units, mostly in the sub-kilowatt range, they do not significantly affect the total megawatt figure, which for portable applications remained broadly flat between 2010 and 2011, but is expected to grow 50% in 2012 from a low base.

The stationary sector exceeded our expectations in 2011 by almost doubling when compared to 2010, a 94% increase. There is true momentum in this sector and our forecasts show further growth of 53% in annual shipments is in store for the full year of 2012. In terms of megawatts, this sector is the biggest contributor, doubling in 2011 and overtaking transport (27.6 MW) to exceed 80 MW.

The annual system shipments of fuel cells for transport applications continue to fluctuate due to the timing of demonstration projects which contribute large numbers in one year and then little in the following years. We saw a 38% dip in annual system shipments for 2011 *versus* 2010, with decreases in all sub-categories except scooters. However overall unit shipments are expected to almost double in 2012 compared to 2011 and be 19% more than in 2010, led by sales of fuel cell materials handling vehicles (MHV). Megawatts for the transport sector remain largely flat with the differences in size of the various fuel cell systems having a variable impact each year, for example buses *versus* MHV. This means that despite 2012 having 19% more shipments than 2010, it is expected to account for 16% fewer megawatts. Sales of automotive fuel cells are expected to dominate the whole industry once they become commercially available and price competitive. The automotive industry is currently gearing up to this, and so from 2012 we expect a boost to transport shipments.

The fuel cell industry is beginning to deliver on its promises – at times exceeding expectations

Sales are accelerating in the stationary power sector, almost doubling from 2010 to 2011

Developments by Application

Portable

Annual fuel cell shipments in the portable sector grew a modest 1.5% between 2010 and 2011, primarily due to a minor decline in sales in the auxiliary power unit (APU) sector, partially a result of restricted consumer spending in Europe. This shortfall was met with an increase in shipments of smaller fuel cell systems helped by initial production runs of portable electronics chargers.

Early 2012 has seen a return to growth for the APU sector that we expect to continue throughout the year, bolstered by renewed interest from the military. 2012 also sees the commercial launches of several portable electronics chargers, including the myFC PowerTrek and the Horizon MiniPak, which will result in a seven-fold increase of portable fuel cell shipments from 6,900 units in 2011 to 50,500 units in 2012.

System shipments will be boosted by fuel cell chargers for consumer electronics

Educational Fuel Cells and Toys

Since 2007 companies such as Horizon Fuel Cell Technologies, Heliocentris and h-tec have been helping to raise public awareness and understanding of fuel cell technology through the commercialisation and mass shipment of milliwatt-scale PEMFC toys and education kits. The importance of these products cannot be overemphasised – allowing tomorrow's consumers to gain an understanding of fuel cell technology is important for long-term industry progression. Indeed, the commercialisation and popularity of these systems has been a precursor to the commercialisation of more practical and industrial fuel cells over the last few years.

These milliwatt-scale fuel cells currently ship more than 200,000 units per annum with steady growth of approximately 15–25% year-on-year but contribute little to total megawatts shipped. The sheer number of these systems masks growth in the more applied markets and so for this reason, and to better understand developments in the rest of the fuel cell industry, in particular the portable and PEMFC sectors, educational fuel cells and toys will no longer be included in our tables and figures.



Auxiliary Power Units

SFC Energy (SFC) was one of the first companies to successfully commercialise a fuel cell consumer product and the first to do so in the APU sector. Here its range of DMFC products targeted at consumers, industrial users and military users has continued to dominate ever since thanks to effective marketing and the creation of a methanol retail distribution infrastructure. 2011 saw a 20% drop in consumer purchases of SFC's EFOY line of leisure APU, aimed primarily at the high-end camping market. A troubled European financial landscape restricting high-value consumer spending was largely responsible for this.

In industry, the EFOY Pro series has proven itself in a wide range of applications that require long-lasting, low-emission, discreet power solutions. A popular application has been the integration of EFOY Pro systems to power equipment in rapid response vehicles. Volkswagen Commercial Vehicles has been installing EFOY Pro units in its toll inspection vehicles since 2009 and in June 2012 placed a repeat order with SFC for a further 242 systems, bringing the total to close to 650

equipped vehicles. Elsewhere, the UK Yorkshire Ambulance Service is installing systems into over a hundred of its vehicles after a successful trial.

An emerging niche for the units is in the monitoring and observation of wildlife, which is noise sensitive and requires extended run times. These, alongside a low heat profile, are also requirements of defence use and SFC has enjoyed a good relationship with the German Bundeswehr for many years. In March 2012 SFC expanded its military reach with the delivery of 50 FC 100 military APU systems to the US Army Operational Test Command.

The EFOY Pro line experienced 24% growth from 2010 to 2011, though this was not enough to counterbalance the drop-off in leisure sales. Despite this, SFC's total revenue increased by 16% in 2011 as a result of increased higher-value defence sales and assimilated profits from Dutch power management specialists PBF Group BV, which SFC acquired in late 2011. With its acquisition of PBF, SFC can now offer more complete packaged power solutions.

With many specific industrial niches that can benefit from fuel cells, the technology's use in APU has been an area of interest for fuel cell manufacturers and industry players alike. DMFC is a relatively expensive cell technology and is most cost-effective in small, low-power stack configurations under 100 W. There are a number of products emerging for applications that require higher output APU. Danish company Serenergy uses methanol fuel, but processes it ahead of a 350 W high-temperature PEMFC (HT PEMFC), which it is marketing in a variety of applications.

Tightening global emissions regulations for heavy-duty diesel vehicles are a strong driver for fuel cell APU. Topsoe Fuel Cell, in collaboration with a number of partners including Volvo, is developing a 1.5 kW SOFC diesel-fuelled APU for use in trucks, which it showcased at the Group Exhibit Hydrogen + Fuel Cells at the 2012 Hannover Messe; the unit will be in full demonstration by 2014. Delphi and PowerCell Sweden are also targeting this niche with upcoming SOFC and PEMFC products, respectively. Both Boeing and Airbus are investigating fuel cell APU for hotel load on their aircraft; Boeing is testing a unit amongst other progressive technologies on a modified 737-800 throughout September 2012. Topsoe Fuel Cell is also investigating a 6 kW SOFC system for ship APU with Wärtsilä.



Tightening global emissions regulations for heavy-duty diesel vehicles are a strong driver for fuel cell APU

Consumer Electronics

In 2008 Angstrom (which has subsequently been acquired by BIC) impressed the media by integrating a hydrogen fuel cell system into a popular slim-line Motorola mobile phone. Although we are still some way away from seeing fuel cells fully integrated into commercial mobile phones, progress is being made in size and cost reduction. For example in October 2011 patent applications filed by Apple were published, revealing that the company was working on lightweight monopolar fuel cells for integration into its ever-slimmer devices. Further applications in December 2011 showed how the company could integrate the units directly into its MacBook laptops and into an external charging system for iPads and iPhones. It is this latter application that is rapidly emerging as a commercial reality for fuel cells.

At the 2010 Consumer Electronics Show, held in Las Vegas, Horizon Fuel Cell Technologies (Horizon) revealed its MiniPak portable PEMFC electronics charger to the world. With a 2 W USB output the unit runs from solid-state hydrogen cylinders, refillable from a desktop electrolyser. The



units were trialled extensively throughout 2011 to positive reviews. In February 2011 Sweden's myFC and Japan's Aquafairy demonstrated water-activated PEMFC portable chargers at the Mobile World Congress in Barcelona and the FC Expo in Japan, respectively, to excited audiences.

Aquafairy began domestic sales of its AF-M3000 system in April 2011 and demand has been healthy; it plans to release a less expensive second-generation product shortly for mass manufacture. May 2012 saw the first commercial sales of myFC's PowerTrek device, which is launching across thirteen major global markets in

a staggered manner to allow the company to meet strong demand for the system. In August 2012 Horizon began commercial sales of its MiniPak through REI, North America's largest retail chain for recreational outdoor gear, as well as many other American, European and Asian retail outlets.

Lilliputian Systems and eZelleron are both developing SOFC products for this market. Lilliputian's system will run on butane cartridges and should offer market-leading fuel efficiency when it launches through US retailer Brookstone at the end of 2012. eZelleron's micro-tubular SOFC product can be fuelled with conventional cigarette lighters; a commercial launch is expected within the next few years.

Fuel Cell Today anticipates tens of thousands of unit shipments of portable fuel cell chargers in 2012 and these are predominantly responsible for the dramatic rise in total unit shipments from 2011 to 2012. Fuel cells thrive in applications where incumbent technologies are easy to displace and this early market has huge potential revenue – the mobile phone travel charger segment is valued at more than €11 billion, according to myFC. Fuel Cell Today expects to see this sector flourish in the next few years.

Annual shipments of fuel cell systems for stationary power grew substantially from 2010 to 2011, with existing installations providing a robust track-record

Stationary

Annual shipments of fuel cell systems for stationary power installations grew substantially from 2010 to 2011, over all categories. This application includes large stationary systems (generally over 100 kW) for prime power applications, as well as smaller units (below 50 kW and usually below 10 kW) for micro-CHP and UPS. All of these are seeing increased uptake, resulting in impressive increases in both the number of systems and megawatts shipped.

Our revised figures for 2011 put the number of stationary systems shipped during the full year at over 16,000 and the number of megawatts at over 81 MW, up from 8,300 and 35 MW in 2010, increases of 94% and 133% respectively. A number of factors combined to create this surge: more products maturing and reaching the market, with existing installations providing an increasingly robust track-record to convince customers; feed-in tariffs and subsidies continuing, but no longer providing the sole stimulus as the desire for energy security and independence intensify in, particularly, Japan and the USA; additionally, fuel cell products are proving to be more convenient and reliable to own and operate than incumbent technologies in markets with unmet needs such as telecommunications backup power.

Prime Power

Installations of large stationary fuel cell power systems to date have mostly been in the USA and South Korea, and both these markets are experiencing rapid growth. Our revised number for 2011

in this category shows a quite astonishing increase over 2010 of 160% (based on megawatts), boosted in particular by FuelCell Energy and Bloom Energy continuing to expand into the market and developments in South Korea. We do not foresee another proportional increase of this magnitude in 2012, due to the waning of the low base effect, the limited number of suppliers in this sector, and constraints on current manufacturing capacity. That said, we anticipate year-on-year growth of almost 50% over 2011 as demand continues to rise. This is discussed further in the Outlook section of this review.

The US market at the moment is essentially split between three major suppliers and three fuel cell technologies: Bloom Energy (SOFC), UTC Power (PAFC), and FuelCell Energy (MCFC). FuelCell Energy also supplies MCFC stacks to POSCO Energy in Korea, formerly POSCO Power, the dominant supplier of large fuel cell systems in that country.

In 2011 Bloom Energy introduced a new model of its Energy Server: the ES-5700 has an output of 200 kW, double that of the older model, and there was immediate uptake alongside continued use of the 100 kW ES-5400 in baseload power applications, where the systems offer high electrical efficiency. Among other sales, AT&T ordered Energy Servers for eleven of its sites in California, a total capacity of 7.5 MW, for completion in 2012. NTT America also deployed Energy Servers at its Lundy data centre in San Jose, California; these receive cleaned biogas from a nearby dairy farm via the natural gas pipeline.

Bloom Energy's product is proving an increasingly popular choice for data centres and in March 2012 the company launched its 'Mission Critical Practice', a service that aims to secure the energy supply for critical government and business IT systems. By providing highly reliable power independently of the electricity grid, fuel cell systems help to improve data security and minimise the effect of grid disruptions (for more information on this application please refer to the Special Feature on page 30). Bloom Energy has already garnered two very substantial data centre orders in 2012: eBay is to install 6 MW of fuel cell power at its flagship data centre in Utah and Apple has ordered 5 MW for its North Carolina data centre; both are to use biogas. These will mark the largest non-utility fuel cell installations in the USA to date.

Having already quadrupled the size of its California manufacturing facility early in 2011, Bloom Energy is now looking to double production capacity with the construction of a new manufacturing facility in Newark on the US East Coast, to complement the existing factory. It broke ground in April 2012 and production at the new facility will start in 2013.

Despite a dip in shipments in 2011, UTC Power saw demand for its 400 kW PureCell® Model 400 system continue with orders from new and repeat customers. Like Bloom Energy, UTC Power's customer portfolio includes household names: Coca-Cola and Whole Foods Market have both installed PureCell 400s to run in combined heat and power (CHP) mode, when the very high system efficiency (90%) allows for reduced emissions. Also in 2011, Cox Communications took delivery of four PureCell 400s for baseload power; these are fuelled with natural gas but Cox is offsetting emissions by purchasing three quarters of its requirement from a company supplying the pipeline with biogas.



Demand for fuel cell prime power is rising in the USA and Korea

An 11.2 MW installation in Korea is the world's largest fuel cell power plant to date

UTC Power's sales are expected to return to growth in 2012, especially as the company is now tapping demand in the Korean market. In July 2012 it was announced that Pyeongtaek Energy Service, a subsidiary of SK E&S, the leading energy service provider in South Korea, has purchased fourteen PureCell Model 400 systems, a total of 5.6 MW. Seven of these will ship in 2012 for the first phase of the project and the aim is to be fully operational by the end of 2013. The fuel cells will provide baseload power and heat to Pyeongtaek city, in the greater Seoul area, helping to meet commitments under the Renewable Portfolio Standard (RPS).

For FuelCell Energy (FCE), 2011 saw an impressive number of deployments in the USA and several large installations in Korea. FCE supplies this market through its Korean partner POSCO Energy: FCE ships stacks to POSCO Energy, which integrates them into systems using balance of plant (BoP) components manufactured at its own facility in Pohang. (Note that Fuel Cell Today logs the shipment of the completed system rather than the shipment of the stack to Korea.) During the year, POSCO Energy completed a fuel cell power plant in Busan (5.6 MW) and another in Daegu; the latter installation is the world's largest fuel cell power plant to date, generating 11.2 MW of electricity for the grid, as well as high-grade heat for a neighbouring water treatment facility.

Most of FCE's US deployments in 2011 were in California, with many of these at water treatment facilities or other locations where a bio-waste stream is available. These Direct FuelCell® plants are being fuelled with biogas or anaerobic digester gas and the customers are benefiting from California's Self Generation Incentive Program (SGIP) and federal incentives that provide payments of thousands of dollars per kilowatt for fuel cell systems running on renewable fuel. This application is discussed in more detail under Developments by Electrolyte.



Growth in MCFC shipments is expected for 2012; FCE can currently manufacture up to 90 MW per year at its plant in Connecticut and as of 30 April 2012 its backlog stood at 52.4 MW. In Korea in particular, where there have been a number of megawatt-class installations already, demand for fuel cell baseload power is growing rapidly and delivery of stacks to POSCO Energy under a 70 MW order has been accelerated. The Seoul Metropolitan Government intends to install 50 MW of distributed fuel cell power in 2012, mainly to support the subway system, towards a target total for the city of 230 MW; although there has been no confirmation from FCE or POSCO Energy at the time of writing, we expect that this 50 MW will be MCFC.

Fuel cell micro-CHP offers an opportunity to significantly lower energy use in buildings

PEMFC technology is starting to make inroads into the prime power market, with Dantherm (a subsidiary of Ballard Power Systems) supplying a 50 kW system to GS Plotech in Korea for a waste-to-energy application and a 150 kW system to one of Anglo American Platinum's mining operations in South Africa. Ballard also manufactures a 1 MW PEMFC system, the CLEARgen™, further shipments of which are expected in 2012. In 2011, Solvay's chlorine plant in Lillo (near Antwerp) took delivery of a 1 MW PEMFC system from Nedstack to run on by-product hydrogen from the plant.

Micro-Combined Heat and Power

Fuel cell micro-CHP offers an opportunity to significantly cut building energy use (and therefore emissions) in the near term because it can make use of existing fuel distribution infrastructure. Most units are being plumbed into the existing natural gas or town gas grids, from which households traditionally draw energy for heating and hot water. However, the fuel cell units use this fuel to

co-produce a relatively high proportion of electricity with the heat so that the household power requirement is also catered for, displacing grid electricity. Fuel cell electrical and overall efficiency is high, and further efficiency can be gained through the use of distributed rather than centralised generation of electricity. Estimates put the achievable reduction in carbon dioxide emissions at around 30% – this despite the use of fossil fuel.

The Japanese residential fuel cell scheme accounts for the majority of shipments in this application, under the Ene-Farm brand. By 2010, it was clear that the scheme was well on its way to being a success, delivering significant cost reductions and performance improvements and allowing subsidies to come down, and by the end of the year fuel cell heating and power had been brought to over 13,500 households in total.

**More than twice
as many Ene-Farm
units were sold in
2011 than in 2010**

Good growth in sales was expected in 2011, but what no one could have anticipated were the events of March 2011, when the Tōhoku earthquake and tsunami struck Japan and were followed by the Fukushima nuclear incident. Amid the effects of the devastation to the east of the country, further nationwide grid power shortages resulted from the shutting down of all Japan's nuclear power plants shortly thereafter. The effect on fuel cell sales was profound: more than twice as many Ene-Farm units were sold in 2011 than in 2010, as people sought to reduce energy consumption and dependence on the grid. The subsidy programme had exhausted its budget for the 2011 fiscal year by July, was restarted at the beginning of October, and was again depleted by the end of the year.

The specifications of the Ene-Farm systems were more closely tailored to the requirements of the average Japanese home by the release of a new model in 2011, with a smaller footprint and 3% greater efficiency. This unit also has a rated power output of 0.7 kW or 0.75 kW, down from 1 kW. An SOFC model was added to the scheme for the first time in 2011, under the ENEOS brand, but PEMFC models continue to dominate. We expect 20,000 Ene-Farm shipments in 2012; this will effectively double the number of micro-CHP units installed in Japan, bringing them to a cumulative total of around 40,000.

**In Germany more
than 250 fuel
cell micro-CHP
systems have
been installed
under the Callux
programme**

Other markets, although in earlier stages of deployment than Japan, are now beginning to see fuel cell micro-CHP installations in the hundreds.

In Germany, by May 2012 over 250 fuel cell systems from Baxi Innotech, Hexis and Vaillant had been installed under the Callux field test programme, and these had amassed a combined one million hours of operation. Callux is one of several residential micro-CHP demonstration projects in the National Innovation Programme (NIP) and installations continue. Baxi, Hexis and Vaillant have been joined by Ceramic Fuel Cells Limited (CFCL) and new start-up Elcore in the *Initiative Brennstoffzelle* (Fuel Cell Initiative), working to accelerate the commercialisation of residential fuel cells in Germany. The products are a mix of PEMFC and SOFC.





Over the course of 2011 and early 2012, CFCL announced several multi-unit orders for its modular and integrated micro-CHP products from Germany, the Netherlands, the UK and Australia (where it is headquartered), with shipments underway. CFCL is also providing a number of units to the UK and Hamburg for the SOFT-PACT demonstration project with E.ON.

Since 2006, the number of fuel cells installed in South Korea each year under the national residential fuel cell project has been inching upwards and more than 350 units are expected to be added in 2012. The PEMFC micro-CHP systems are being supplied by domestic manufacturers GS Fuel Cell, Hyosung, and Fuel Cell Power. In November 2011 Hyundai Hysco achieved new and renewable energy system certification and has now also received government approval to begin manufacturing micro-CHP fuel cell systems.

In the USA, by the end of 2011 ClearEdge had over 100 installations of its 5 kW ClearEdge5 HT PEMFC unit in California. We have seen signs of increasing interest in HT PEMFC for this application, with three systems on

display at the 2012 Hannover Messe: the German-made RBZ inhouse5000, the GreenGen NG-5 from Athens-based Tropical, and the ClearEdge5.

Grid-Support and Off-Grid Power

Fuel cell technology in these applications, for example providing backup power for telecommunications infrastructure, is demonstrably superior to incumbent technology (diesel generators or batteries), with a lower total cost of ownership. Yet this sector is currently the smallest contributor to stationary fuel cell shipments and, while steady, growth to 2011 has been modest.

We believe this is set to change, heralded by an acceleration of shipments in 2012. Products have been subject to comprehensive demonstration and validation, which is starting to bear fruit. The value proposition offered by fuel cells in this application has been enhanced by declining costs of production, along with on-going improvements to the technology and to fuel supply and distribution. All of this is now opening the way to widespread adoption and profitability for the companies active in this market. Much of the potential for growth lies in Asia, Africa and Latin America: countries with insufficient or unreliable electricity grids and escalating telecommunications use present a significant opportunity, and this is where suppliers are increasingly turning their attention.

Multinational telecommunications company CommScope estimates that by 2013 wired and wireless operators worldwide will be spending over \$10 billion on the generation of power for their networks. It launched a fuel cell powered backup solution in 2008, with fuel cells supplied by Hydrogenics, and in 2011 the partnership was cemented by CommScope's acquisition of Hydrogenics shares and joint collaboration on product development and commercialisation. Trials of the product were conducted in India, where CommScope says an estimated 1.8 billion litres of diesel are used each year to fuel wireless networks, and it is working to establish a hydrogen distribution network there to support a commercial product launch.

It will face competition from other entrants to the Indian market: for example, in July 2011 Dantherm announced a collaboration with India's Delta Power Solutions and field trials began. A purchase order for 30 Dantherm fuel cell systems for Idea Cellular's wireless telecommunications network followed in November; these units are replacing diesel generators and are fuelled with industrial by-product hydrogen from nearby caustic soda production. Dantherm and Delta Power have

Fuel cell technology offers a superior solution in telecoms backup power

expanded their collaboration to encompass data centre UPS and other industrial and distributed power generation applications in India. Alteryg is also targeting India with a local strategic partner.

In June 2012, Ballard announced an operational trial of 50 Dantherm systems at 30 sites in China Mobile's telecommunications network; China Mobile is looking for a sustainable, cost-effective replacement for lead-acid batteries and, if successful, the trials will lead to commercial deployment. VN Technologies, VelaTel Global Communications' fuel cell subsidiary, has also run tests for China Mobile, with the first round just concluded at the time of writing, and has been commissioned to do the same for China Telecom Corporation. And it is not only China's telecommunications giants that are interested in fuel cell power: government-owned SGCC (State Grid Corporation of China), the largest energy supplier in the world, has started implementing Jupiter backup power products from FutureE to support grid equipment and prevent interruptions.

ReliOn expects to see significant uptake in India and China as well as other developing markets; it is forecasting a growth surge this year, largely delivered by markets outside the USA. In July 2012, it launched new products for heavy-duty applications: grid replacement or supplement where grid outages are frequent and prolonged, and is expanding its scope beyond telecommunications backup power.

ReliOn is also working on integrating a fuel processor so that its systems can run on methanol, with commercial release slated for the end of the year. In this it is following in the footsteps of IdaTech, which launched a methanol-fuelled system in 2010 and then followed this up in 2011 with the launch of a branded methanol fuel, bio-HydroPlus.



In July 2012, Ballard announced that it would be acquiring assets from IdaTech, including product lines and distributor and customer relationships. A key factor cited in this decision was the popularity of IdaTech's methanol-fuelled products with customers in Indonesia, Mexico and South Africa, where frequent and extended-run backup power is needed. Ballard is IdaTech's stack supplier, but with this agreement is taking a more active role in market development; South Africa in particular is a market of special interest for Ballard.

This is not to say that the US market has stalled: ReliOn, IdaTech and Alteryg all found an early market there and, while expanding their global reach, continue to supply systems for domestic customers who reap the benefits of reliable power. Alteryg in particular has recently announced some very large US orders, including a total of 22 MW of its 10 kW and 15 kW Freedom Power fuel cell systems for mobile phone company MetroPCS for which deployments are underway. According to Alteryg, MetroPCS tested batteries, generators and fuel cells and found fuel cells to be more convenient, more reliable, and cheaper to run.

Off-grid and grid-support systems can be virtually autonomous if they generate their own fuel and obviate the need for fuel deliveries. These systems work by incorporating an electrolyser and hydrogen storage with the fuel cell and integrating these with a source of electricity. This can be grid power when available or, more relevant to energy security, on-site solar or wind power. Water can be recycled and replenished with filtered rainwater to minimise even the need for water top-ups. This is a particularly exciting area of development, with a number of demonstrations testing the principle and commercial products being launched to exploit it, and it is likely to prove a key enabler for fuel

Off-grid and grid-support systems can be virtually autonomous if they generate their own fuel

Transport shipments returned to growth in 2012, following a temporary drop in 2011

cell products in certain markets in the future. Examples of this technology include FutureE's Jupiter Independence and Electro Power Systems' ElectroselTM.

Transport

Between 2010 and 2011 annual shipments in the transport sector dropped nearly 40%, from an all-time high of 2,600 shipments in 2010 to 1,600 shipments in 2011. This was the cumulative result of factors spanning several years in a number of transport applications. 2010 saw a spike in Asian bus deployments, but the fuel cell bus market is sporadic and there was no similar spike in 2011. 2009 and 2010 also saw the launch of several large fuel cell electric vehicle (FCEV) demonstration fleets that were not matched in scale by any 2011 FCEV deployments. Add to this flat growth in the MHV market as North American users transitioned from American Recovery and Reinvestment Act (Recovery Act)-supported sales to fully self-financed orders and we can see clearly the reason for this temporary drop in transport shipments in 2011.

We expect to see 90% growth in 2012 with transport shipments exceeding 3,000 units. This strong return is thanks to modest increases in FCEV, bus and niche transport shipments but primarily due to a doubling of MHV shipments, predominantly in North America.



Fuel cells for materials handling vehicles are selling without subsidies

Materials Handling Vehicles

In 2009 Plug Power began sales of its GenDrive[®] PEMFC battery replacement systems for MHV in the USA, driven by funding from the Recovery Act; for more information on this please see our special feature on page 22. Sales through to 2011 were subsidised by the Recovery Act but during the year we began to see unsubsidised repeat orders from household names such as Walmart, Wegmans, Coca-Cola, Sysco and BMW. A subsidised introduction to the technology

allowed companies to experience the many benefits that fuel cells can offer when used to power MHV – merits which have now proven capable of driving sales without government subsidy. Plug Power experienced five-fold growth in 2011, entering 2012 with a backlog of more than 1,900 units. The company expects to have shipped more than 4,000 units (cumulatively) by the end of 2012; Fuel Cell Today has no reason to doubt that its success will continue.

Oorja Protonics offers a different approach to the MHV market: instead of replacing lead-acid batteries with fuel cells, it offers a DMFC charger that sits on top of the existing battery and extends its operation. With this solution there is no need for a hydrogen infrastructure; methanol can be shipped with ease across the USA. However, the fuel cell systems add additional weight, do not allow for the complete removal of expansive battery charging stations and the batteries will continue to underperform in chilled environments. Perhaps for these reasons, and having not received the same level of government funding support as Plug Power, demand for these systems has not been as strong to date. This situation may be about to improve, see page 41.

Outside the USA, Plug Power is looking to expand its success internationally. In November 2011 it announced that it was launching a joint venture with Air Liquide fuel cell subsidiary Axane in France to market its products in Europe, leveraging Air Liquide's existing commercial presence. The JV, HyPulsion, combines Plug Power's fuel cell products with Air Liquide's hydrogen infrastructure offering, creating a complete solution for customers. HyPulsion's first major order came from IKEA,

which will be upgrading its entire warehouse operation in Southern France with GenDrive systems in 2013.

Elsewhere in Europe, UK electrolyser manufacturer ITM Power in June 2012 became the exclusive European distributor of Infintium Fuel Cell Systems' range of PEMFC MHV products, which it will market with its hydrogen generation systems to offer European customers a completely utility-independent materials handling solution. UK retailer Marks & Spencer successfully trialled the solution at its Bradford distribution centre for six weeks in spring 2011.

With enthusiasm for fuel cell MHV in the USA, Fuel Cell Today expects to see this application develop successfully in the European market.

Light Duty Vehicles

FCEV are accepted by many as the only viable long-term successor to today's diesel and petrol passenger vehicles. Almost every major global automaker is developing FCEV, seven of which signed a memorandum of understanding (MoU) in September 2009 addressed to the oil and energy industries signalling that "from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised" and urging them to deploy the necessary supporting infrastructure in Europe and elsewhere. Hydrogen stations are beginning to appear more frequently, and we expect this to accelerate substantially in the next three years in anticipation of FCEV.

Shipments of FCEV dropped 55% between 2010 and 2011, though this is not as negative as it may seem when put into context. 2010 saw the launch of General Motor's large-scale Project Driveway end-user demonstration and a large demonstration fleet of fuel cell Volkswagen Passats in China. Whilst 2011 saw the first batch of Hyundai ix35 FCEV hit the roads alongside continued demonstration and acceptance testing of Daimler's Mercedes-Benz B-Class F-CELL and other FCEV, these were not of the same magnitude as the previous year's demonstrations.

2012 will see a return to growth for FCEV, at approximately 45%, bolstered by the further release of B-Class F-CELL vehicles for demonstration in a number of German provinces and end-user acceptance testing in a Californian lease scheme, as well as continued deployments of the ix35 FCEV, which is being used in several demonstration programmes across Europe.

The prominence of Hyundai and Daimler in the FCEV market in 2012 is no coincidence: both are planning to begin commercialising their FCEV offerings before 2015, Hyundai from 2013 and Daimler from 2014. The commercial models will be the same as, or very similar to, the vehicles each company is demonstrating at the moment and so engagement with potential customers such as local governments and fleet operators is prudent.

This is different from the approach of the automakers that will be commercialising in 2015 or after, who have stopped production of demonstration vehicles to focus on the design and production of new commercial models. A concept of Toyota's planned commercial FCEV, the FCV-R, was shown at consumer car shows in Tokyo, Detroit and Geneva and shows a transition from the SUV format used in demonstration (more space for components and hydrogen storage) to a luxury sedan format, which targets a consumer price range in which the initially high cost of the fuel cell can be partially absorbed.



Almost every major global automaker is developing fuel cell electric vehicles



Fleets will be an important stepping stone to the widespread commercialisation of FCEV; their return-to-base operation makes them ideal candidates for early sales of FCEV and associated infrastructure. London is demonstrating this principle superbly having launched a fleet of five fuel cell black cabs which were used to transport VIPs between the Olympic village and Heathrow Airport, where a new Air Products public hydrogen station opened in August to support the fleet.

Continued public demonstrations are necessary to keep stakeholders and the public engaged with the technology. Following the example set by Mercedes-Benz's F-CELL World Drive in early 2011, H2moves Scandinavia will be completing a Hydrogen Road Tour throughout September and October 2012 with FCEV from four OEMs visiting a circuit of European destinations.

Although early shipments of FCEV are likely to be limited in size and primarily constrained to fleet use, we expect FCEV to eventually dominate fuel cell shipments by a considerable margin when the technology infiltrates the lucrative consumer car market.

Several commercial bus manufacturers are participating in fuel cell bus demonstrations

Buses

When discussing fuel cell buses, it must be made clear that this sector is still in the early adoption phase; annual deployments are still well below 100 and, as such, the stopping or starting of a project or two can have a disproportionate effect on relative growth. Our numbers show a decrease in fuel cell bus deployments from 2010 to 2011 but, as mentioned above, 2010 saw a spike in demonstration projects in Asia, coinciding with high-profile events across the region. Were this spike removed, fuel cell bus shipments would have been quite flat from 2009 through 2011 as demonstrations in Europe and North America continued at a steady pace.

We anticipate a slight increase in fuel cell bus shipments in 2012, but there is a bigger story here than is told by just the shipment numbers. The number of commercial bus manufacturers now involved in developing and trialling fuel cell models, coupled with the innovation and cost reductions we are seeing from the suppliers of fuel cell systems for this application, indicates a high level of commercial interest and preparation for widespread deployment. We believe this could happen as early as 2014.

European bus manufacturers that have supplied buses for recent demonstrations include Van Hool, Rampini, VDL, APTS and Wrightbus – with fuel cells from Ballard, UTC Power and Hydrogenics in most cases – and of course Daimler, which uses its own fuel cells (the same module as that in its FCEV, with two being used in each bus). Van Hool has had a couple of fairly sizeable shipments: eleven buses for the Zero Emission Bay Area (ZEBA) demonstration in California from the beginning of 2011 and five buses for Oslo under CHIC (the Clean Hydrogen in European Cities project) in June 2012. Van Hool is cementing its commitment to fuel cell buses as a key partner in the new High V.LO City project which is to deploy fourteen buses in various European locations; co-financed by the FCH-JU it will run from 2012 to 2016, in parallel with CHIC.

Daimler is also involved in CHIC and in December 2011 supplied five Mercedes-Benz Citaro fuel cell buses for Canton Aargau in Switzerland, the country's first deployment. London's CHIC buses have been supplied by Wrightbus, so there is a good mix of manufacturers in this project. There are other European demonstrations; for example, Hamburg has taken delivery of seven Citaro fuel

cell buses over 2011/2012 under the NaBuz demonstration project, funded through the German NIP and cooperating with CHIC. Demonstrations of two buses each in sister projects in Amsterdam and Cologne are using Phileas buses from APTS in the Netherlands.

In addition to Van Hool, US deployments are using buses from domestic manufacturers DesignLine USA, EIDorado, and Proterra. In 2011 a 'Buy America' compliant fuel cell bus was deployed at SunLine Transit Agency in Palm Springs, California. This EIDorado bus uses a Ballard fuel cell, with propulsion and power management systems from BAE Systems, and was developed under the US Federal Transit Administration's National Fuel Cell Bus Program (NFCBP). Four more such buses are on the cards for further US deployments.



Also under the NFCBP, design has started on the ECOSaver fuel cell electric bus to be manufactured by DesignLine USA using a Ballard fuel cell. The bus will be demonstrated at The Ohio State University in Columbus over two years, with the project being managed by the Center for Transportation and the Environment (CTE). Early this year, CTE and project partners announced delivery of a previously-trialled Proterra fuel cell bus to Austin, Texas. The bus was purpose built by Proterra from the ground up as a lightweight, zero-emission bus, with fuel cell modules developed by Hydrogenics, rather than being retrofitted as is usually the case. In May 2012, the Mass Transportation Authority of Flint, Michigan, unveiled its new hydrogen fuel cell bus, the first of its kind to be used by a Midwest transportation agency. This Van Hool bus is powered by a UTC Power PureMotion® PEMFC. A third round of funding for the NFCBP was announced early this year; demonstrations of fuel cell buses under real-world conditions continue to be undertaken by a number of regional transit authorities and partnerships around the country.

Asian bus manufacturers to watch are the big OEMs, specifically Toyota Hino and Hyundai, who like Daimler have the advantage of in-house fuel cell development. In India, Tata Motors – India's largest automobile company and the world's third largest bus manufacturer – unveiled its fuel cell bus concept, the Starbus, at the New Delhi Auto Expo 2012. Tata also signed a non-binding MoU with Ballard for the delivery of twelve fuel cell stacks over this year and next, with the stacks expected to power fuel cell buses planned for demonstration in various Indian cities.

While the drive for clean air and reduced emissions is a compelling reason to adopt fuel cell buses in cities, for true commercialisation some cost reduction and improvements in durability still need to be accomplished. Ballard has a product in development that it believes will help achieve this: its seventh generation fuel cell module is being designed-to-cost in an intensive development programme, and redevelopment of other elements of the drivetrain and ancillaries is also underway. The aim is for the total cost of ownership of a fuel cell bus to match that of a comparable diesel hybrid bus by 2014. A parallel aim is to increase the lifetime of fuel cell units to match that of internal combustion engines in conventional buses in their first lifetime, which means at least 30,000 hours of operation, and it is expected that this target will be met in the second half of 2014. Hydrogenics is also refining its fuel cell bus modules to be very compact, light and simple to integrate, and is producing these in various outputs to suit bus size and level of integration; the company currently offers a warranty to 20,000 hours of stack operation. Automotive OEMs have achieved significant cost reduction of their fuel cell modules towards their FCEV launch targets, and we can expect the fuel cell bus products from these manufactures to benefit considerably as a result. Daimler's

**Fuel cell bus
costs are reducing
and lifetimes are
increasing**

next generation Citaro fuel cell hybrid buses boast a 25% greater range, 35% increase in fuel cell efficiency and a 50% greater durability than its previous generation bus used in the CUTE project while at the same time reducing fuel consumption by 45%.

Other

This vehicle category covers fuel cells used in propulsive systems for marine and air transport, trucks, trains and other heavy vehicles, two- and three-wheelers and non-road-legal four-wheel vehicles, as well as other niche transport applications such as unmanned vehicles. Numbers are increasing in this category, and some of the most exciting recent developments have been in scooters, trucks and locomotives.

Commercial production of fuel cell scooters is starting in Taiwan in 2012

Scooters are popular as a cost-effective means of inner-city transport across the world, particularly in Asia where fast-paced urbanisation is resulting in congested cities in which scooters provide the most nimble means of personal transportation. In these cities air pollution from an increasing number of vehicles is a real problem and is negatively impacting the health and quality of life of the city-dwellers. This is creating strong demand for affordable zero-emission scooters, demand that several fuel cell manufacturers are looking to meet.

Fuel cell developer Intelligent Energy collaborated with Suzuki Motor Corporation on the development of the Suzuki Burgman fuel cell scooter, which in March 2011 became the first fuel cell vehicle to receive EC Whole Vehicle Type Approval, the necessary certificate for the mass sale of vehicles in Europe. Japan's Nippon Steel took receipt of the first commercial delivery of a fuel cell Burgman two months later in May. A fleet of up to five Suzuki Burgman fuel cell scooters has been commissioned under the European HyTEC project; they will be tested for up to two years by London's Metropolitan Police starting later this year. Meanwhile, Intelligent Energy and Suzuki have set up a joint venture in Japan called SMILE FC System Corporation, to develop and manufacture air-cooled fuel cell systems for a range of industry sectors, beginning with the commercialisation of the Burgman scooter.

Taiwanese company Asia Pacific Fuel Cell Technologies (APFCT), with strong domestic demand, has been busy developing its own fuel cell scooter. After successfully testing a fleet of ten scooters, APFCT won a contract from the Taiwanese Ministry of Economic Affairs for a further 80 scooters for demonstration and validation in July 2011. APFCT has partnered with Italian electrolyser manufacturer Acta to develop a refuelling system for APFCT's commercial scooter model, which has two compact hydrogen canisters slotted in behind the seat. The canisters are dispensed from vending machines that are fitted with solar power and an Acta electrolyser to automatically refill canisters with hydrogen. Empty canisters can be simply changed out and replaced with full

canisters from one of these machines. APFCT has a production target of 1,000 fuel cell scooters for 2012 and it is anticipated that a fleet of up to 2,000 APFCT scooters and 100 fuel vending machines will be deployed on a Taiwanese green island tourist destination in the near future. Acta and APFCT are also investigating a zero-carbon transportation solution for Hawaii, which wants to reduce reliance on imports of foreign oil.



Turning to utility vehicles, in 2011 a Danish consortium began demonstrations of a fuel cell powered small landscaping truck, called the EcoMotion. It uses an HT PEMFC system from Serenergy that is fuelled by methanol reformed on board the truck. The EcoMotion

is targeted at ground maintenance applications such as cemeteries, parks, zoos, golf courses and so on, and a safe, cheap and convenient liquid fuel is key to enabling these applications. It competes primarily with diesel-fuelled equipment and to some extent electrical equipment, and offers a number of clear advantages that are now driving commercial sales: silent operation, very low emissions, high fuel efficiency and long run-time per tank, without the need for constant refuelling or recharging.

In July 2011, California's Vision Industries received a Letter of Intent from Total Transportation Services for the purchase of one hundred fuel cell Tyrano class 8 heavy-duty trucks. Subsequent to a successful trial of one truck, the order was finalised in May 2012 with a total value of \$27.7 million. Total Transportation Services also has the option to purchase an additional three hundred trucks. The Tyrano electric trucks use a 33 kW fuel cell from Hydrogenics as a range extender and are targeted at drayage operations such as hauling freight containers from port terminals in the twin Ports of Los Angeles and Long Beach to rail yards and other distribution facilities, as much as 26 miles (42 km) away by road. Driven by stringent clean air requirements in California, the ports are investing in electric trucks but are looking for ways to reduce downtime due to recharging of batteries and to increase the range of trucks pulling very heavy cargo. Vision Industries will also be cooperating with Cargotec USA on a fuel cell terminal tractor demonstration for the Technology Advancement Program, a clean-air initiative sponsored by the twin ports. Both types of vehicle would be operated in return-to-base mode and as such hydrogen refuelling can be accomplished from a single station in the port; a number of nearby facilities produce hydrogen in industrial quantities.

**Californian clean
air requirements
are driving fuel cell
adoption**

Over in Europe, in March 2012 Proton Power Systems announced the successful integration of subsidiary Proton Motor's fuel cell range extender into a Smith Electric Vehicles truck, the commercial Newton model. In addition to extended range, the system enhances power, particularly during cold-temperature start, protects the batteries and supports ancillary load. Commercial sales of the first twenty vehicles into the German market are starting this year.

In May 2012, the world's largest platinum producer Anglo American Platinum launched a fuel cell powered mine locomotive prototype. The locomotive was developed in collaboration with Vehicle Projects, Trident South Africa, Battery Electric and Ballard Power Systems. Five locomotives are to be tested, initially on the surface and then underground at Anglo American Platinum's Dishaba mine in South Africa. The aim is to prove fuel cells as a viable technology for clean and safe underground transportation.



Special Feature 1

Fuel Cells and Government Funding

On February 13, 2009, at the recommendation of President Obama, Congress passed the American Recovery and Reinvestment Act (Recovery Act) of 2009 which was signed into law by the President four days later. The Recovery Act was a direct response to the economic crisis and has three main goals:

- **Create new jobs and save existing ones**
- **Spur economic activity and invest in long-term growth**
- **Foster unprecedented levels of accountability and transparency in government spending**

The Recovery Act intended to achieve those goals by providing: tax cuts and benefits for millions of working families and businesses, funding for entitlement programs, federal contracts, grants and loans such as unemployment benefits, which altogether amounted to \$787 billion. In 2011, this original expenditure was increased to \$840 billion.



Within the broader Recovery Act the US Department of Energy (DOE) Fuel Cell Technologies Program manages the hydrogen and fuel cell project portfolio. Its goal is to accelerate the commercialisation and deployment of fuel cells and fuel cell manufacturing, installation, maintenance, and support services. These projects received \$41.6 million from the Recovery Act and an additional \$54 million cost share from industry participants, giving a total of around \$96 million. Twelve project grants were awarded, focusing on fuel cells for materials handling vehicles (MHV) such as forklift trucks, portable fuel cells and stationary fuel cells (either for combined heat and power, backup power or auxiliary power units). Four of the twelve project grants are now complete and the remaining eight will remain active into 2013.





additional deployments. For example, the North American food distributor Sysco deployed 98 fuel cell lift trucks with DOE cost share, and is planning to convert more than 900 additional battery-powered lift trucks to fuel cell technology with no DOE funding before 2014 at seven of its sites. By the end of June 2012, it planned complete fleet conversion in four of these sites to fuel cells. FedEx also augmented its fleet of 35 Recovery Act-funded fuel cells with five

Job creation was a major focus of the Recovery Act following the effects of the global financial crisis in 2008 and a website was set up (recovery.gov) under the auspices of the Recovery Act to monitor this. According to the website, the Recovery Act fuel cell projects have retained or created between 22 and 71 jobs per quarter, excluding indirect and supply chain jobs.

At the outset, the Recovery Act planned to install more than 500 fuel cells for communications backup towers and, including MHV, have up to 1,000 fuel cells in total deployed by 2012.

The deployment of fuel cell MHV fleets has demonstrated the suitability of fuel cell technology to provide reliable service in this application without the need for battery technology. More than one million hours of operation have been accumulated by the fleet of Recovery Act funded fuel cell MHV, operating at eight facilities in seven states across the country. The technology is also now offered as part of standard catalogue items, with Crown Equipment offering 29 qualified fuel cell forklift combinations.

The economics of replacing battery technology with fuel cells has also been studied by the National Renewable Energy Laboratory which reported that a total cost of ownership comparison between fuel cell and battery MHV indicated significant cost savings for refuelling labour, power pack maintenance, and infrastructure space.

The supplementary benefits as a result of Recovery Act funding have spurred

more systems, purchased without funding. In fact, DOE-funded (including Recovery Act funds) fuel cell MHV have led to 3,500 additional forklifts planned or deployed with no DOE funding.

The fuel cell backup power systems deployed with funding from the Recovery Act have demonstrated the reliability of the technology, operating in fifteen states with a success rate, when called upon, of 99.7%. The longest runtime in response to an unplanned grid outage was 29 hours. Successful DOE-funded (including Recovery Act funds) fuel cell emergency backup power systems have led to 1,300 additional systems planned or deployed with no DOE funding.

At the most recent review of DOE projects in May 2012, the latest update on Recovery Act fuel cell deployment stated 668 fuel cell backup power units operational and 1,172 operational fuel cell units in total (including MHV), exceeding the project's initial targets. While achieving these targets and helping to maintain jobs in the fuel cells and hydrogen sectors are admirable accomplishments, of potentially greater importance is the demonstration of additional benefits resulting from the Recovery Act, which has resulted in commercial purchases of fuel cells without subsidies.

	2010	2011	2012
Percentage of funding spent**	63	84	89
Jobs created or saved/quarter*	35–71	22–46	-
Fuel Cell lift trucks deployed**	308	504	504
FC backup systems operational**	190	607	668

*excluding supply chain and indirect jobs **cumulative totals

Fuel and Infrastructure

**By the end of 2011
215 hydrogen
stations were
in operation
worldwide**

Hydrogen Refuelling Stations

By the end of 2011, 215 hydrogen refuelling stations were in operation worldwide, according to the TÜV SÜD-run website h2stations.org, with twelve new stations being added that year. These stations are divided regionally as follows: 85 in Europe, 80 in North America, 47 in Asia Pacific and three in the rest of the world. While the website lists a further 122 stations currently in the final stages of planning, many more are proposed to be added worldwide in time for the arrival of FCEV in the next few years.

In Europe, Switzerland opened its first hydrogen refuelling station in May 2012. Located in Brugg, the station will service a fleet of fuel cell buses. The buses have been operating since December 2011, but are now able to refill at the station which produces 50% of its hydrogen on site using electrolysis, the electricity for which comes from renewable sources such as hydroelectricity, wind and solar power, and biomass. Slovenia also intends to install hydrogen infrastructure after plans for two refuelling stations were announced in June 2012; it is hoped these stations will attract fuel cell vehicle deployments to the country.



The Nordic countries continue to push the development of hydrogen infrastructure with a new station opening at the Arctic Driving Centre in Finland and two stations opening in Norway, one in Oslo and the second in Lilleström. The Oslo station uses renewable electricity to drive electrolysis, generating up to 200 kg of hydrogen per day, dispensing it at 700 bar and filling a tank in less than three minutes. Danish company H2Logic has been particularly active in the region, delivering four 700 bar stations in the last twelve months alone.

WaterstofNet, a non-profit organisation financed by the Flemish and Dutch governments and industry to promote the adoption of hydrogen, has also announced continued deployments of hydrogen stations. One of the stations, located in Brussels, will be used to refuel forklifts, buses and other vehicles. It features Hydrogenics' fifth-generation HYSTAT™ 30 water electrolyser and a 350 bar dispenser to supply up to 65 kg of clean hydrogen per day. Hydrogenics also won a contract at the end of 2011 to supply the electrolyser to Brugg. The unit will provide up to 130 kg of clean hydrogen at 350 bar.

Across the North Sea, January 2012 saw the launch of UKH₂Mobility; bringing together thirteen industry participants with three UK government departments and the European Fuel Cells and Hydrogen Joint Undertaking (FCH JU), the project will investigate the potential for hydrogen as a fuel for ultra-low carbon vehicles in the UK. Facilitated by McKinsey & Co., a positive outcome to the first stage of the project will lead to the development of a strategy and business case to roll out hydrogen infrastructure for the anticipated 2014/2015 launch of FCEV. Also in the UK, BOC announced plans to double the capacity of its Teesside hydrogen trailer filling facility. The unit was opened in March 2011 and compresses hydrogen gas into specially constructed road-trailer units for distribution to customers around the country. The expansion is aimed at meeting growing demand for hydrogen gas in the UK.

Germany is leading the way in the European region with plans for hydrogen refuelling infrastructure, having launched its H₂ Mobility project in 2009. Currently Germany has fourteen publicly accessible hydrogen stations, but plans to increase this to 50 by 2015. Klaus Bonhoff, Managing Director of the German National Organisation for Hydrogen and Fuel Cell Technology (NOW), was quoted stating this number would be sufficient for initial FCEV demand. The next stage plans to introduce nationwide hydrogen coverage by 2025 with a total of 1,000 stations. Current intentions are for the German government to provide financial support to the initial rollout, recouping that money at a later date once the infrastructure is in place. From 2025 onwards, the hydrogen infrastructure is expected to grow in tandem with growth of the fuel cell vehicle fleet. Bonhoff added that one third of primary energy use in Germany is for the transport sector and the country is currently spending €200 billion more per year in this sector than it did ten years ago; therefore, in his view, investment in a hydrogen infrastructure will pay off.

Germany plans to have 50 hydrogen stations by 2015

Germany opened Europe's largest hydrogen refuelling station in early 2012, capable of delivering 750 kg of hydrogen per day. The station is located in Hamburg and services both fuel cell buses and cars with the €10 million (\$13.58 million) cost shared between Vattenfall (Germany's third largest electricity producer) and the German Federal Ministry of Transport. Half of the station's hydrogen is produced on-site *via* water electrolysis, with the remainder delivered.



Bonhoff also commented that current methods of hydrogen production from natural gas will not be viable in the future, and that electrolysis and the use of hydrogen to store excess electricity as a transport fuel will be required. Germany already has demonstration stations producing hydrogen using solar power, overcoming the emissions associated with reforming natural gas to hydrogen. In March 2012, the Fraunhofer Institute for Solar Energy Systems inaugurated a solar hydrogen refuelling station in Freiburg, using an electrolyser from Proton OnSite, with its electricity requirement partly covered by photovoltaic panels on the roof of the station and neighbouring buildings. The station can dispense hydrogen at 700 bar, which is suitable for a range of fuel cell vehicles. Wind-to-hydrogen is also taking shape in the country with a TOTAL refuelling station opening near Berlin supplied with hydrogen generated using wind-powered water electrolysis. The electricity is provided from a nearby 6 MW wind farm linked to a hybrid power plant operated by a consortium including Enertrag, DB Energie, Vattenfall and TOTAL Germany. The hydrogen can either be sold as a fuel for FCEV, or it can be mixed with biogas and used in a CHP plant providing electricity to the grid.

Japan is reviewing regulations to facilitate 100 hydrogen stations by 2015

Japan is also at the forefront of hydrogen infrastructure development, and is planning to build a network of 700 bar refuelling stations to support the first wave of FCEV from 2015. To this end the Japan Petroleum Energy Center (JPEC) was commissioned by the Japanese Research Association of Hydrogen Supply / Utilization Technology (HySUT) and the New Energy and Industrial Technology Development Organization (NEDO) to develop a proposal for the revision of existing technical standards and regulations. JPEC contracted German regulation specialists TÜV SÜD to review the technical requirements and applicable regulations for licensing, constructing and operating hydrogen refuelling stations in Germany and Europe. The results of this study will be incorporated into a revision of Japan's legal regulations for hydrogen refuelling stations, paving the way for the safe construction and operation of Japanese hydrogen stations.

Regulations surrounding hydrogen refuelling in Japan have historically been highly conservative, with over-stringent restrictions on the distance pumps must be set back from the highway and their location relative to residential areas. With plans for 100 hydrogen stations by 2015, these restrictions were reviewed in 2012 with a view to facilitating station siting and construction. The government will also subsidise these projects to help construction costs and attract partners.



Honda continues its comprehensive approach to fuel cells and hydrogen, and opened a solar-powered hydrogen station on the grounds of its office in Saitama Prefecture in March 2012. This was the first Japanese installation of a system able to produce, store and dispense hydrogen with zero carbon dioxide emissions at point of use and Honda hopes to further optimise this system for home use in the future. The system uses high-pressure electrolysis to produce 1.5 kg of hydrogen per day, sufficient to run an FCX Clarity for 150 km (90 miles), making it ideal for home hydrogen production.

North America also continues to develop its refuelling infrastructure to attract FCEV. An Air Products hydrogen

California will need 68 stations to support the first wave of fuel cell electric vehicles

station featuring a Proton OnSite electrolyser was built in Michigan to refuel buses and other fuel cell vehicles, and the site plans to integrate solar panels in the future, taking it fully off-grid. The theme of zero-carbon hydrogen is one which is gaining momentum worldwide, and one which will be key for the fuel cell industry, severing the link between the fossil fuel, transport and energy markets. In California, the state's Energy Commission adopted its third annual transportation energy Investment Plan aiming to change the types of vehicles Californians drive and the fuels they use. The latest plan earmarks a total of \$100 million in state funds with \$8.5 million of this to support hydrogen refuelling stations and to demonstrate fuel cell technology. California hopes to attract tens of thousands of FCEV after 2015. In January 2012 the California Air Resources Board (CARB) unanimously approved a package of new emissions rules for cars and light trucks through to 2025. The Advanced Clean Cars programme combines the control of smog-causing pollutants and greenhouse gas emissions into a single set of requirements for model years 2017 to 2025. The programme is targeting zero-emission or plug-in hybrid vehicles to account for one in seven new cars sold in California in 2025 with more than 1.4 million zero-emission and plug-in hybrid vehicles expected on the road in the state that year. California plans to have 68 hydrogen refuelling stations by January 2016 and is working on getting the funding commitments to make this happen. New York and Connecticut are also intending to boost hydrogen refuelling infrastructure for the commercial launch of FCEV.

Electrolysis

Electrolysis offers one of the best options for decarbonising hydrogen production and, with the ability to produce high-quality hydrogen on demand, the attraction for the fuel cell industry is obvious. A number of fuel cell and electrolyser companies have recently announced collaborations to this end, working together to integrate electrolysers with fuel cells, resulting in semi-autonomous off-grid electricity generation solutions. UK company ITM Power (ITM) announced a supply and distribution agreement with Horizon Fuel Cell Technologies (Horizon) whereby Horizon has exclusive selling and marketing rights for ITM's small-scale electrolysers in the Association of Southeast Asian Nations, India, Pakistan and Bangladesh as well as non-exclusive rights in Horizon's other markets (a total of 35 including the USA and Japan). Horizon also signed a letter of intent with Acta SpA at

Electrolysis offers one of the best options for decarbonising hydrogen production

the start of 2012 for the evaluation, development and supply of electrolyser systems using Acta's hydrogen production technology. Subject to the successful completion of the evaluation stage, Horizon intends to incorporate Acta's stacks into its own electrolyser equipment, most likely its HydroFill home hydrogen generator, which Horizon announced was available for commercial sale, along with its MiniPak portable fuel cell charging unit for consumer electronics, in retail outlets from the end of July 2012.

Acta launched four new hydrogen production products at the 2012 Hannover Messe. These included rack-mounted hydrogen generators (producing between 200 and 1,000 litres of hydrogen per hour and also a solar-powered stand-alone version of its 200 litre per hour unit. Additional autonomy for fuel cells in remote locations can be achieved using a module that can harvest rainwater.

ITM Power also continued to actively promote its large-scale electrolyser technology throughout 2011 and into 2012, providing its HFuel vehicle refuelling unit at a number of high-profile industry events across Europe. HFuel was awarded CE certification, enabling commercial sales of the system to commence in the EU and, after a rigorous assessment and inspection by TÜV SÜD, HFuel was granted regulatory approval allowing it to be operated and sold in Germany. ITM also joined forces with German hydrogen dispenser company GHR, signing an agreement to collaborate on 700 and 350 bar hydrogen refuelling products for the German FCEV market. GHR has several years' experience developing and selling mobile hydrogen dispensers in Germany and, after successful product demonstrations, a rollout is expected in line with FCEV growth in the country.



Electrolyser technology is widely expected to demonstrate similar lifetimes to the fuel cell products it will accompany, and North American manufacturer Proton OnSite recently announced in-house lifetime tests have achieved the milestone of 70,000 hours' operation (equivalent to eight years). This is believed to demonstrate one of the longest commercial PEM electrolyser lifetimes on the market.

One of the highest cost contributors to high-pressure hydrogen production using electrolysis is compression. Direct high-pressure electrolysis is being developed to address this and HyET has developed a laboratory-scale electrolyser that can produce hydrogen at up to 800 bar; this would be a high enough pressure to fuel the new generation of FCEV requiring 700 bar hydrogen. Commercially, Proton OnSite has developed a PEM electrolyser, as part of a project funded by the US Department of Energy (DOE), that can produce hydrogen at 350 bar. High-pressure electrolysis could be a significant factor in producing hydrogen at a cost comparable to today's fossil fuels.

Electrolyser technology itself is relatively mature, but new ways to exploit its features, such as coupling it to renewable electricity supplies, are being marketed by many companies around the world. A number of companies, such as Canada's Hydrogenics and the UK's ITM Power, offer large-scale electrolysers designed to work with renewable power sources, either to generate low-carbon transport fuel or for grid balancing duty.

High-pressure electrolysis could produce cost-effective hydrogen

Electrolysers can be integrated with variable renewables to help stabilise the grid

If the grid cannot accept renewable electricity, it can be stored as hydrogen

Renewable Energy

A consistent theme throughout 2011 and into 2012 has been the integration of renewables with electrolyser and fuel cell technologies to provide a range of benefits in terms of energy storage, grid stability and decarbonisation of the electricity grid. With an ever-increasing contribution to electricity generation from renewables such as wind and solar power, their inherent variability can cause instability in the electricity grid. Conventionally, additional capacity, known as spinning reserve, has been built to cover any fluctuations in the balance of electricity supply and demand. This tends to take the form of gas turbines, which have rapid response times but lower efficiencies compared to other generation methods. The goal of increasing the grid contribution of renewables is to decarbonise our electricity networks, and spinning reserve goes against these intentions. Integrating electrolysers with renewables allows for the variability to be smoothed out – something of key importance to grid managers. If the grid cannot accept renewable electricity, it can be stored as hydrogen until such time as it is required or, if the economics are favourable, it can be sold as a fuel to local FCEV fleets. Electrolysers can also offer a demand-side management option whereby a constant load producing hydrogen can be shed with rapid response times, ensuring grid stability is maintained. Hydrogenics has been active in this market and has projects running in both Germany and Canada to provide megawatt-scale electrolysers for grid-scale storage of electricity as hydrogen.

Also in Germany, the country's largest independent energy cooperative, Greenpeace Energy, is developing a solution for Northern Germany it calls 'windgas'. It plans to construct a wind-powered electrolyser to produce hydrogen that will be injected into Gasunie's natural gas network. The necessary infrastructure for the production and supply of hydrogen through the gas network, including the Greenpeace Energy electrolyser, should be in operation in 2013.

The UK is also interested in this technology and the Isle of Wight 'Ecoland' project proposes large-scale hydrogen storage will be vital to facilitating its goals of achieving an increased contribution from renewable electricity. It is partnering with UK-based ITM Power to develop this technology, both to store grid electricity and to produce hydrogen as a transport fuel. Also in the UK, major industrial gas company Air Products called upon the UK government to support the creation of a renewable hydrogen market. It called for renewable hydrogen to be included in the Renewable Transport Fuels Obligation, and for additional support to be offered to manufacturers.

The ultimate prize for the hydrogen economy is still the development of an 'artificial leaf' to efficiently produce hydrogen using solar power. Researchers at the Massachusetts Institute of Technology published developments in 2011 of an artificial leaf built using affordable materials and operating



without external wires or control circuits. The device generates hydrogen when placed in water and exposed to sunlight at approximate efficiencies of 2.5% (commercial photovoltaic cells operate at $\geq 10\%$), but will need further development of gas collection methods and efficiency improvements if it is to become commercially viable.

Portable Hydrogen

Portable hydrogen cylinders are finding application in a number of portable fuel cell applications, including lighting and signage, and both BOC and Air Products launched new lightweight cylinders aimed at this market in 2011. BOC's system is aimed for use with its Hymera portable fuel cell system; the cylinder only weighs 10 kg and contains two normal cubic metres of hydrogen. It has an integrated

valve regulator and output pressure is controllable from 0 to 10 bar. Air Products' SmartFuel cylinder features snap-on connections and a hand-operated on/off valve. It also boasts enhanced safety features including a built-in regulator, which controls the pressure to 3.5 barg (4.5 bar).

To coincide with the launch of fuel cell portable electronics chargers, a range of solid state hydrogen storage devices are now on the market. Horizon has launched its HydroStik, and myFC and Aquafairy are both marketing their solid cartridges which produce hydrogen on contact with water.

Solid-state hydrogen storage devices for portable fuel cells are now on the market

Liquid Fuels

Liquid fuels can offer a number of benefits in fuel cell applications, especially when high-pressure hydrogen is not available. Methanol is one of the most attractive liquid fuels at the current time, either for direct use, or reformed at the point of use to produce hydrogen on demand. Stationary backup power fuel cell applications in particular are looking to exploit the benefits of methanol, using a methanol-water mix which can be easily transported to the remote locations where the fuel cells are installed. Element 1 Corp (e1) from North America has introduced a range of nineteen inch rack-mounted hydrogen generators, fuelled by a methanol-water mix. The generators can produce between 15 and 110 litres of hydrogen per minute, sufficient to power fuel cells in the range of 1 kW to 7.5 kW. IdaTech has launched a branded fuel, Bio-HydroPlus, for its PEMFC critical backup power systems. The fuel is a mixture of bio-methanol and deionised water and allows it to offer customers a complete backup power solution. The bio-methanol comes from Netherlands-based bio-diesel producer BioMCN and is produced through the conversion of crude glycerine, a residue from the company's bio-diesel production. BioMCN also signed an agreement with Nordic Green for the latter to sell bio-methanol in the Nordic and Baltic countries, targeting fuel cell applications.



Liquid fuels such as methanol can offer a number of benefits in fuel cell applications

Other

Cella Energy continues development of its novel polymer-based solid-state hydrogen storage technology and in 2011 it announced the opening of a new facility at NASA's Kennedy Space Center (KSC) in Florida, USA. Cella's technology offers the potential to store hydrogen without high-pressure tanks and, with NASA-KSC being a significant user of hydrogen, reducing the need for high pressure storage may offer increased safety. Cella is also developing its technology for use in UAV, where hydrogen and fuel cells can offer extended operation in the field.

Two online resources were launched in 2011 relating to the use of hydrogen as a fuel. The first, the Hydrogen Storage Materials Database (<http://hydrogenmaterialssearch.govtools.us/>) by the US DOE's Office of Energy Efficiency and Renewable Energy (EERE), is a comprehensive open access database aimed at the research and development community. The listings include properties such as synthesis conditions, sorption and release conditions and impurities formed during release.

The second website, HyFacts (<http://hyfacts.eu/>), was funded by the European Commission and developed by a consortium of companies led by TÜV SÜD Akademie. The site's goal is the 'Identification, Preparation and Dissemination of Hydrogen Safety Facts to Regulators and Public Safety Officials', which it will pursue through the provision of training and education materials, a directory of RCS (regulations, codes and standards), details of relevant events and courses, links to other websites of interest and a members' zone.

Data Centres: Primed for Fuel Cell Power

The internet is an important and intrinsic part of day-to-day life across the world. Supporting expanding internet services are vast data centres that have significant energy requirements and substantial carbon footprints.

Data centres accounted for between 1.7–2.2% of US energy consumption and 1.1–1.5% globally between 2005 and 2010,¹ figures that will only rise with the exponential increase in internet-connected personal devices.

In 2008 the US Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) predicted that by the end of this year the power costs for average data centre equipment over its lifetime would exceed the original capital investment, and with the continued implementation of conventional data centre technologies the carbon footprint of global data centres could exceed that of the airline industry by 2020.² There is a strong drive to increase the efficiency³ and sustainability of both data centre servers and equipment as well as the buildings themselves. Recent innovations in data centre building sustainability have been led by internet services giants such as Google and Apple, who have been largely unaffected by the global economic downturn.

With internet services now supporting large parts of the global economy and with businesses and societies where constant connectivity is ever-more important, on-site uninterruptible power supplies (UPS) at data centres are a necessity. These are typically hugely expensive battery systems or environmentally-detrimental diesel generators. The reliability, efficiency, grid-independence and low-to-zero emissions of fuel cells are a perfect match for this application. Rack-mountable fuel cells have been available for data centre

backup power purposes since 2007 from a wide variety of manufacturers and although very adept, these units tend not to exceed 30 kW in power, with the majority under 10 kW. However, a different fuel cell solution for data centres has begun to emerge in the last year.

Fuel cells are scalable by nature and can meet power demand on a scale far grander than that of conventional UPS solutions. Large stationary fuel cell systems can be used to reverse the conventional data centre energy model: on-site, clean, affordable and uninterruptible power with a continuous fuel supply from the natural gas grid can be used to provide prime power with the electricity grid relegated to the role of backup power system.

Fuel cell capital expenditure can rival that of competing large-scale technologies but is compensated for by savings in operating expenditure and lifetime emissions reductions. Following a successful series of small installations at the offices of several Silicon Valley giants, Californian solid oxide fuel cell manufacturer Bloom Energy is now installing megawatt-scale prime power solutions at data centres operated by these same large technology players, who are keen to reduce emissions, increase uptime and free themselves from the grid. These are companies that have a strong desire to improve their environmental image and who have the financial means to invest in solutions on a lifetime cost basis.

Apple and eBay have both committed to multi-megawatt scale installations of Bloom Energy Servers at data centres in North Carolina and Utah, respectively. Recognising this interest, Bloom launched a Mission Critical Practice in March 2012 to specifically target opportunities in data centres. There is a viable case for fuel cells in low-carbon power alone, but it is not the only benefit they can offer to the data centre industry.

Tightly packing many racks of constantly operating computer equipment next to each other results in a lot of heat and approximately 40% of an average data centre's energy demand comes from cooling,⁴ though this can be as high as 70%.⁵ The thermal dynamics



of the building play a large part in this and measures such as controlled heat airflow, evaporative cooling towers, air-source water cooling, absorption refrigerators, reflective roofing and LED lighting are implemented at many data centres to increase their efficiency. Google has even gone so far as to site a major data centre next to the Baltic Sea in Hamina, Finland where the cooling system utilises the abundant cold seawater – a system so effective that the centre requires no chillers.

With cooling accounting for much of a data centre's energy demand, the high-grade by-product heat from certain fuel cells can be used to help cool the data centre with the use of absorption/adsorption refrigerators and heat pumps, creating an even stronger value proposition. Furthermore, fuel cells can generate low (approximately 15%) oxygen concentration air as a by-product, in which it is impossible for fire to exist – this provides a valuable failsafe to data centre owners running large numbers of expensive and closely packed servers, and is an added value that can help offset the capital expenditure of installing the fuel cell system. This is a benefit that both Fuji Electric and AFC Energy are exploiting in the marketing of their fuel cell systems *via* N2telligence, with Fuji Electric in particular looking to target data centres as it commercialises its PAFC systems in Europe.

With such myriad benefits we expect to see global megawatts of fuel cells installed in this application rise rapidly from late 2012 with the aforementioned installations catalysing interest amongst other high-volume data centre owners and large stationary fuel cell manufacturers.

¹ Jonathan Koomey, 'Growth in Data Center Electricity Use 2005 to 2010', 1 August 2011: <http://www.analyticspress.com/datacenters.html>

² US Department of Energy Office of Energy Efficiency and Renewable Energy, 'Quick Start Guide to Increase Data Center Energy Efficiency', 17 October 2008: http://www1.eere.energy.gov/femp/pdfs/data_center_qsguide.pdf

³ US Environmental Protection Agency, 'EPA Report to Congress on Server and Data Center Energy Efficiency', 2 August 2007: http://www.energystar.gov/ia/partners/prod_development/downloads/EPA_Report_Exec_Summary_Final.pdf

⁴ US Department of Energy Office of Energy Efficiency and Renewable Energy, 'Data Center Energy Consumption Trends', 30 May 2009: http://www1.eere.energy.gov/femp/program/dc_energy_consumption.html

⁵ Google, 'Data center efficiency: Free cooling and water management', retrieved 7 March 2012: <http://www.google.com/about/datacenters/inside/efficiency/cooling.html>



Data Centres with Fuel Cell Prime Power

APPLE Maiden, North Carolina, USA

Apple's flagship 500,000 square foot North Carolina data centre, which is a primary resource for the company's iCloud, iTunes and App Store services, is installing 4.8 MW of Bloom Energy Servers producing 42 million kWh of power annually. Combined with a 100-acre 20 MW solar array producing a further 42 million kWh, the data centre will be 60% powered by on-site renewables, with the remaining 40% met by grid-delivered purchased renewable energy.



FUEL CELL:
Bloom Energy Server
FUEL: Biogas **MW:** 4.8
ONLINE: 3Q 2012

EBAY South Jordan, Utah, USA

30 Bloom Energy Servers will provide 52.5 million kWh of electricity annually, meeting the entire demand for prime power at the site; this will be the first large-scale data centre to use exclusively fuel cells for prime power. It also currently holds the title of the largest non-utility fuel cell installation planned for the USA.



FUEL CELL:
Bloom Energy Server
FUEL: Biogas **MW:** 6
ONLINE: 2Q 2013

AT&T Various locations, California, USA

The US mobile telecoms giant has installed a total of 7.5 MW of Bloom Energy Servers across eleven Californian sites, including at data centres for UPS purposes.



FUEL CELL: Bloom Energy Server
FUEL: Biogas **MW:** 7 **ONLINE:** 1Q 2012

NTT AMERICA San Jose, California, USA

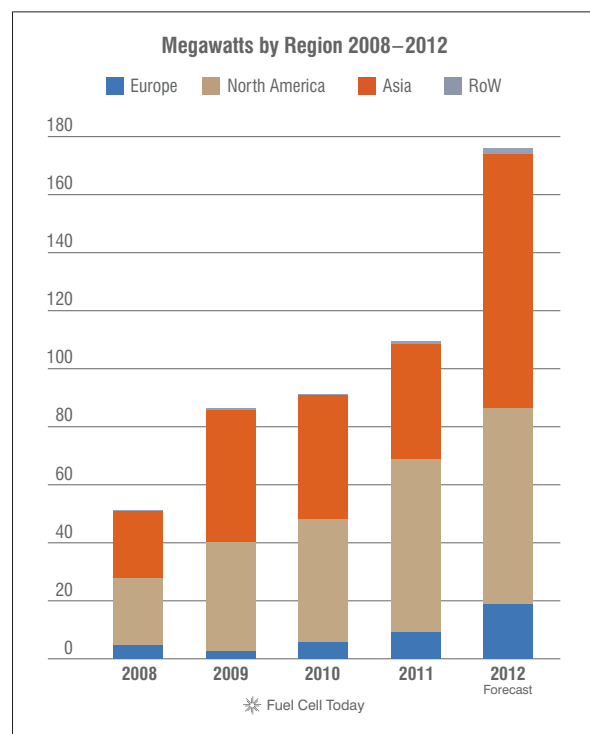
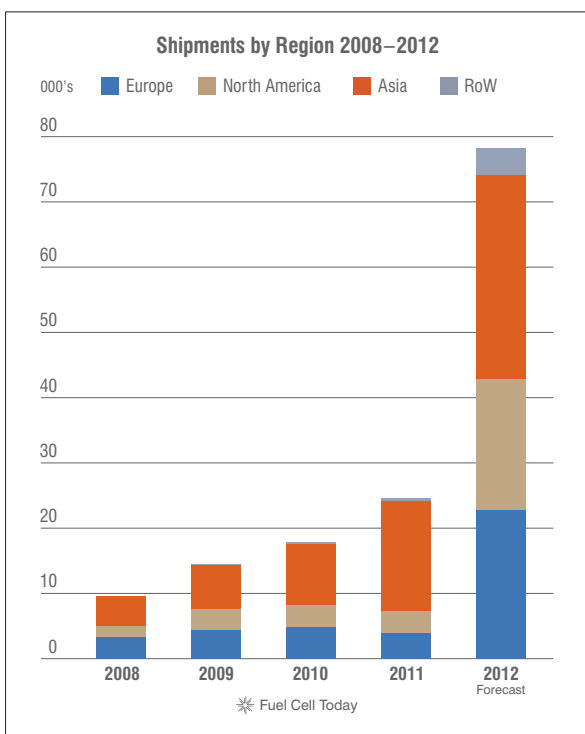
The US division of successful Japanese communications company NTT has installed five 100 kW Bloom Energy Servers at its American data centre facility in California.



FUEL CELL: Bloom Energy Server
FUEL: Biogas **MW:** 2.5 **ONLINE:** 2Q 2011

Developments by Region

Fuel Cell Today divides the world into four regions in order to track the development of fuel cell markets geographically. These are: Europe; North America, Asia, and the Rest of the World (RoW); the map in the Introduction on page 5 shows the regional boundaries. Note that shipments are classified according to where the fuel cell system is delivered, i.e. the point of end use, and not where the stack or system is manufactured.



All regions are seeing increased uptake of fuel cell products

Annual unit shipments to Europe decreased slightly between 2010 and 2011, primarily due to a 20% drop in sales of consumer APU products during the economic crisis (sales are expected to recover in 2012). However, a corresponding decrease in megawatts shipped to Europe is not seen in 2011 – in fact, there is a perceptible increase. To a minor extent this can be attributed to growth in fuel cell micro-CHP in the region (these fuel cell systems have kilowatt power ratings compared to power ratings of hundreds of watts for portable APU), but the major contributor was the installation of a 1 MW PEMFC power plant by Nedstack at Solvay's chlorine plant in Lillo, Belgium. A large increase in both metrics is expected for Europe in 2012: unit shipments will be boosted by sales of fuel cell chargers for portable electronic equipment but are set to grow in a number of other categories too, and megawatts will increase on the back of wider deployment of fuel cell buses and cars.

No increase in the number of fuel cell systems shipped to the North American region is evident in 2011; for growth in this market one must look to megawatts, which reveal the escalation in fuel cell installations for large stationary power generation in the USA (although relatively few, these systems

have power outputs ranging from hundreds of kilowatts to megawatts and thus have the most significant impact on the megawatt figure). Installations of this size will continue in 2012, keeping the megawatt figure healthy, while unit shipments will benefit from accelerating sales of fuel cell materials handling equipment and the introduction of portable fuel cell chargers.

From 2010 to 2011, unit shipments to Asia increased significantly, as they have done since 2008 and for mostly the same reason: the success of the Ene-Farm programme for residential fuel cell heat and power in Japan. Annual sales under the scheme more than doubled from 2010 to 2011, partly due to the aftereffects of the Tōhoku earthquake and tsunami, and another substantial increase is expected this year. Further growth will be added by sales of fuel cell chargers for portable electronic equipment across Asia in 2012. In terms of megawatts, Asian shipments remained flat between 2010 and 2011 with steady activity in the large stationary power sector, specifically in South Korea. It seems almost unreasonable to expect megawatts shipped to Asia to more than double in 2012; however, the Seoul Metropolitan Government has committed to a target of 50 MW of fuel cell power to be installed in the city by the end of 2012, and (at the time of writing) looks on track to meet this target. This is over and above other large installations in Korea planned by POSCO Energy.

**Seoul is to install
50 MW of fuel cell
power in 2012**

The Rest of the World becomes visible on our charts for the first time in 2011 and will grow in 2012, due in large part to uptake of fuel cell chargers, but also helped by installations of fuel cells for backup power and other applications in South Africa, Australia, the Caribbean and the Middle East.

Europe

In December 2011 the European Commission (EC) presented an €80 billion (\$108 billion) package for research and innovation funding in the EU from 2014 to 2020, Horizon 2020. This eighth funding framework will supersede Framework Programme 7, which runs from 2007 to 2013 and which spawned the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) – a public-private partnership comprising the EC, a research grouping (N.ERGHY) and an industry grouping (NEW-IG). Coordinating funding for RD&D in the hydrogen and fuel cell sectors with the aim of accelerating market introduction, the FCH JU has funded a wide range of projects in hydrogen production, storage and refuelling, transport, stationary power, CHP, early markets and cross-cutting issues.

**London's RV1 bus
route is the world's
first to be fully
serviced by fuel
cell buses**

The 2011 call for proposals had a budget of €109 million (\$148 million), up from €89.1 million (\$121 million) in 2010. In transportation a strong focus of the FCH JU has been fuel cell buses: inner-city, return-to-base, centrally organised fleets are ideal candidates for early adoption of fuel cell technologies. CHIC, the €26 million (\$35.3 million) Clean Hydrogen in European Cities project, continued its work to integrate fuel cell buses into everyday public transport operations, including the projects in Aargau and Oslo, mentioned earlier, running buses from Daimler and Van Hool respectively. Five fuel cell buses have been in operation in London since early 2011 and these are to be complemented with a further three buses in September 2012, making the RV1 route the world's first bus route to be fully serviced by fuel cell buses.



In the same vein as CHIC, the High V.LO-City project was launched in March 2012. With a budget of €31.5 million (\$42.8 million) co-financed by the FCH JU, the project will see the deployment of five fuel cell buses in the transport networks of three environmentally different European cities: Brussels in Belgium, Imperia in Italy and Aberdeen in the UK. HyTEC, a collaborative project between London and Copenhagen, aims to put three classes of fuel cell transport into the hands of end-users. The

There is strong support in Europe for fuel cells in transportation



project, the demonstration phase of which runs from 2012–2014, made its first delivery in July 2012 with five fuel cell black cabs presented to the City of London. These are to be followed with the fleet of Intelligent Energy Suzuki Burgman scooters for London's Police mentioned earlier, ten FCEV for Copenhagen in early 2013 and up to a further ten taxis for London before 2014.

Europe has also been proactive in its support of FCEV, anticipated for commercial release around 2015. HyER, the European Association for Hydrogen, Fuel Cells and Electromobility in European Regions, brings together more than 30 European regions to collect project data and develop fact-based policy at European, national and local levels in order to develop deployment channels for initial FCEV customer bases.

In June 2012 the German government and a number of German industry partners signed a letter of intent to expand the country's hydrogen refuelling infrastructure to 50 stations by 2015. Germany is extremely progressive in its approach to hydrogen and fuel cells and its National Hydrogen and Fuel Cell Technology Innovation Programme (NIP) is unique in its breadth: a total budget of €1.4 billion (\$1.9 billion) has been invested over a ten-year period from 2006–2016, the largest such programme that Fuel Cell Today is aware of.

The Clean Energy Partnership (CEP) heads up the FCEV and associated infrastructure efforts of the NIP. It is a partner-driven platform aiming to advance the development and deployment of FCEV in Germany. The project is currently in its third and final phase, culminating in the market introduction of series-volume FCEV in 2016;

market preparation is the primary focus with extensive operation of test vehicles.

Fuel cell vehicles are being promoted by government-driven projects in several other European countries. Following the successful example set by Germany's H₂Mobility programme, January 2012 saw the launch of UKH₂Mobility, a public–private partnership between three UK government departments, thirteen industry bodies and the FCH JU. It aims to investigate the potential for hydrogen as a vehicle fuel in the UK; a report on its findings will be published in late 2012.

In Scandinavia, Hyundai joined the H2moves commercialisation programme in November 2011; November also saw the opening of a renewably-driven electrolyser hydrogen station in Oslo. Also as part of H2moves, Hydrogen Sweden is organising a European road tour of FCEV in September and October (see Transport section), taking fuel cell transport to the public in five countries.

Interest in hydrogen as a transportation fuel is high in Denmark and Norway in particular. Norway has two resources for producing hydrogen in abundance: natural gas and hydroelectricity to drive electrolysis, and this underlies its support for FCEV. The Norwegian Hydrogen Council, which advises the government, has recently published a new action plan for 2012 to 2015. In Denmark, where the aim is to have an energy system free of fossil fuel by 2050, the use of hydrogen as an energy carrier to manage the introduction of a high proportion of wind energy is seen as strategically crucial. The government is following recommendations from a recent Danish industry coalition roadmap to implement hydrogen for transport and early in 2012 it announced an Energy Plan for 2020 that includes initiatives for hydrogen infrastructure and FCEV.

In the stationary sector, the FCH JU LASER-CELL project aims to develop innovative, high-volume production technologies for the manufacture of alkaline fuel cell components, led by UK developer AFC Energy. A number of projects are underway to advance micro-CHP fuel cell technology

including SOFT-PACT, which will deploy 40 Ceramic Fuel Cells Limited (CFCL) BlueGen micro-CHP systems for field testing; five have been installed in the UK to be followed by at least a further eight by the end of the year, as well as ten systems for Hamburg. The Callux programme has seen hundreds of micro-CHP fuel cells from a number of domestic manufacturers installed in Germany. Another boost for fuel cells in Germany came from the Federal Office of Economics and Technology's introduction of a capital subsidy for micro-CHP products, an extension of the CHP Act, which requires 25% of Germany's electrical generation to come from small and large scale CHP by 2020. The upcoming Ene.Field programme will expand demonstration into several other countries, including the UK, Italy and the Netherlands, amongst others.

With such apparent market interest, we have seen several non-European stationary fuel cell companies lay inroads to Europe in the last year. Of these, Australian SOFC micro-CHP manufacturer CFCL has been the most visible, involving itself in a number of European demonstration programmes; it also has a fuel cell manufacturing plant in Germany. Panasonic is opening a £2 million (\$3.2 million) fuel cell research and development centre in Wales in September 2012 to focus on European micro-CHP opportunities; the company has seen great success under the Japanese Ene-Farm programme. Also a member of Ene-Farm is JX Nippon Oil & Energy, which opened a German test lab in July 2012; it plans to sell SOFC micro-CHP systems into the German market from 2015. In the large stationary sector, Connecticut-based MCFC manufacturer FuelCell Energy entered a European joint venture with the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) in June 2012 in order to investigate commercial opportunities in Europe.

The FCH JU opened its fifth call for proposals in January 2012 with a budget of €77.5 million (\$105.2 million). Although this is lower than 2011 and 2010 it is not a reflection of the Eurozone crisis or any external influences; the FCH JU operates on a Multi-Annual Implementation Plan, which has an overall budget and is translated into annual research priorities each year that feed topics in the call for proposals.

North America

The headline story for fuel cells in North America is dominated by the government from two angles. Firstly the continued financial support for the technology from the DOE coming from the American Recovery and Reinvestment Act (Recovery Act) has exceeded its initial targets in terms of fuel cell deployments. This success is expected to continue with end users in the applications originally supported by the Recovery Act (stationary backup power and MHV fleets) now purchasing fuel cell units without subsidies. New projects are focusing on smaller fleets of MHV, looking to encourage the adoption of methanol fuel cell range extenders, and also fuel cell vehicle fleets in areas such as airports. See Special Feature 1 in this report for an update on the Recovery Act.

The second story from the North American region has been the U-turn of opinion by US DOE Energy Secretary Steven Chu. Special Feature 3 on page 44 covers this in greater detail. From initially not considering fuel cells as a viable technology for transport, Chu has now recognised the current potential of the technology in many applications and has begun to voice his support for fuel cells.

In the USA, while centrally governed by federal legislation, each state has its own legislators, therefore most US legislation originates at the state level, which can and does vary greatly from one state to the next. Historically this has led to a patchwork of support for fuel cells and this

Several non-European stationary fuel cell companies are entering the European market

The American Recovery and Reinvestment Act has exceeded its initial targets in terms of fuel cell deployments



Nationwide deployment of fuel cell vehicles in the USA could be delayed by a lack of coordinated legislation

situation continues, with some states offering incentives for fuel cell technology and others not. Rhode Island established a feed-in tariff in 2011 for distributed renewable energy generators of up to 5 MW to include fuel cells using renewable fuel sources. California's flagship SGIP was set to expire in 2011, having run for ten years. The California Public Utilities Commission which runs the programme approved a budget to continue funding distributed electricity generation in the state through to 2015. Indiana has its Clean Energy Portfolio Standard which sets a voluntary goal of 10% clean energy by 2025 (based upon 2010 levels). Incentives are available to public utilities who meet the criteria of installed clean energy (4% from 2013 to 2018, 7% from 2019 to 2024 and 10% from 2025) which includes fuel cells. From July 2011, Connecticut authorised municipalities to exempt Class I renewable energy projects (including fuel cells using renewable or non-renewable fuels), from paying building permit fees. The state also launched its "Connecticut Hydrogen and Fuel Cell Deployment Transportation Strategy: 2011–2050." The strategy promotes a transition to a hydrogen economy and the deployment of zero-emission, hydrogen fuel cell buses state-wide with a view to increasing transportation efficiency, improving environmental performance, increasing economic development, and creating new jobs. The strategy also suggests that there are many specific locations for hydrogen refuelling stations along state highways or at locations that could potentially be used by state fleets or other public or private-sector fleets.

A similar patchwork of legislation has held back the potential for a nationwide deployment of fuel cell vehicles with no coordinated plan to introduce infrastructure, such as those seen in Germany, Japan and the UK. Certain states, such as California, continue to advance the installation of hydrogen refuelling stations and these areas are most likely to attract the first commercial FCEV fleets.

Asia

South Korea has embraced fuel cell technology for large prime power plants. Its Renewable Portfolio Standard (RPS) mandates a proportion of renewable energy generation for power producers with capacity exceeding 500 MW, rising from 2% in 2012 to 10% by 2022. Fuel cells receive the highest weighting of any technology in the RPS and this is helping to drive growing demand.

As mentioned in Developments by Application, the world's largest fuel cell power plant began operating in Daegu in late November, generating 11.2 MW of clean baseload power. FuelCell Energy serves the Korean market *via* local integrator and distributor POSCO Energy (formerly POSCO Power) and it was POSCO that supplied the fuel cell systems for this plant, as it has done for a number of power plants in Ilsan, Busan, Yeosu, Seoul and other cities, most either 2.4 MW or 5.6 MW. In 2011, FuelCell Energy received an order from POSCO for a total of 70 MW of fuel cell kits to be delivered over a two-year period and POSCO now expects to order a further 120 MW for delivery from 2013.

A 60 MW fuel cell power plant is being constructed in Korea



This demand is anticipated because large installations are planned: POSCO is to supply 60 MW of MCFC systems for a facility in Hwaseong opening in 2013, and we believe this could be the first of many. On a municipal level, the Seoul Metropolitan Government has indicated its interest in fuel cell technology: it has said that it will build 29 fuel cell power plants by 2014 to supply 230 MW of electricity to the city, with 50 MW to be installed by the end of 2012 (primarily as distributed power to the subway system), likely supplied by POSCO. While the RPS was obviously a consideration, Seoul has recently experienced severe power outages that have affected essential services and the reliability of fuel cells was an important factor in this decision.

On a national level, the Ministry of Knowledge Economy announced in May 2012 that it is launching a pilot project to create the world's largest hydrogen-powered town in Korea, due to start in 2012. The hydrogen will be sourced from industrial by-product and candidate cities are those near petrochemical plants or other sources. In this project, PEMFC systems with 1 kW, 5 kW and 10 kW output will be installed in 150 residential buildings and ten commercial and public buildings.

Japan was the pioneer of such a scheme, when in 2009 the Fukuoka HyLife project was launched as a four-year demonstration to test the viability of fuel cells for residential use in the world's first hydrogen town. Ene-Farm systems were installed in 150 homes in Fukuoka town by Nippon Oil Corporation and Seibu Gas Energy Co. The project is still attracting interest and is to be extended until 2016 due to its success. The Ene-Farm programme itself continues to go from strength to strength, as discussed in Developments by Application.

Japan, of course, is also preparing to be one of the early markets for commercial FCEV. In January 2011, thirteen Japanese companies – automakers and fuel suppliers – announced that they would work together to support the introduction of fuel cell cars and a hydrogen supply network throughout Japan. Automakers Toyota, Honda and Nissan committed to cost reductions and a launch of FCEV in four of Japan's principal metropolitan areas in 2015, while fuel suppliers are aiming to construct around 100 hydrogen stations by that year. Industry grouping HySUT is tasked with the planning and development for these hydrogen stations and addressing the legislative constraints on siting of hydrogen stations – for more information on this please see the section on Fuel and Infrastructure.

Fuel cell developments in China in the past year have been centred on telecommunications backup power, and it is easy to see why. China is home to a vast and rapidly expanding mobile phone network, but it has a disjointed and, in some areas, unreliable national grid. Power cannot be guaranteed so battery backup is widely used in the telecommunications industry: there are 30 to 50 billion RMB (\$4.7 to \$7.8 billion) of battery sales per year in China for the telecoms industry alone. These cater to more than 1 million cell sites in the country so far, and ten to twenty thousand new cell sites are added per year. This is potentially a very lucrative market for fuel cells, which offer a number of advantages compared to battery technology.

Developments in China during the past year have centred on telecoms backup power

Field trials are underway with international fuel cell suppliers (see the section on Grid-Support and Off-Grid Power) but domestic companies also intend to address this market. Wuhan New Energy has been demonstrating a telecoms backup power unit since 2009 with no recorded problems in operation. Pearl Hydrogen Technology is also involved in this field and is targeting 100 hours per year runtime and a ten-year lifetime for its systems; it currently has a small number of fuel cell prototypes in operation for evaluation purposes. Shanghai Everpower Technologies has around 6 kW of backup power units currently undergoing tests and Sunrise Power is also in discussions with the big three network providers (China Mobile, China Unicom and China Telecom) about fuel cell deployment.

Like China, India's mobile phone market is booming and it too is installing fuel cell backup power systems as telecommunications network infrastructure strives to keep up with new subscribers.



The Taiwanese market for fuel cells is focusing on backup power and scooters, with demonstration projects underway for both. Telecoms backup projects are using a mix of Ballard-powered systems and domestically produced systems. Fuel cell scooters are at a more advanced stage with small-series production targeted for this year (see the Transport section).

Unreliable grid power in some countries is boosting interest in fuel cells

The provision of reliable power can also be a problem in Southeast Asia. PT Hutchison CP Telecommunications has deployed more than 400 fuel cell systems across Sumatra, Java, Bali and Lombok to improve network availability. The region may also prove to be receptive to fuel cell baseload power generation: in late 2011, FuelCell Energy announced that it would be expanding into this region with the sale of a sub-megawatt DFC module to partner POSCO Energy for installation at a popular waterpark resort in Jakarta, Indonesia. POSCO Energy will be looking to develop a market for megawatt-class power plants in Indonesia, Thailand, Malaysia and Singapore.

Rest of the World

The 'rest of the world' (RoW) region as we define it is highly disparate, with essentially the only commonality being the relative lack of fuel cell activity to date. Yet these countries often have characteristics that make them particularly suitable for fuel cells and they present some of the most exciting opportunities for growth. It is thus unsurprising that fuel cell suppliers are beginning to turn their attention to these countries. What is particularly encouraging is that end-users within the RoW region are starting to seek out fuel cell technology to solve problems in energy supply.

In South Africa, the world's largest platinum producer Anglo American Platinum Limited began demonstrating a fuel cell powered mine locomotive prototype in May 2012, the first of a series of five. Developed by an international consortium, the loco is also part of a partnership between Anglo American Platinum and Ballard Power Systems targeting a number of stationary and motive power applications of fuel cells in South Africa. Although initially being tested on the surface, the intention is for the locos to operate in underground mining works: independence from the grid is sought but the cost and weight of batteries are impractical and diesel fumes are hazardous.

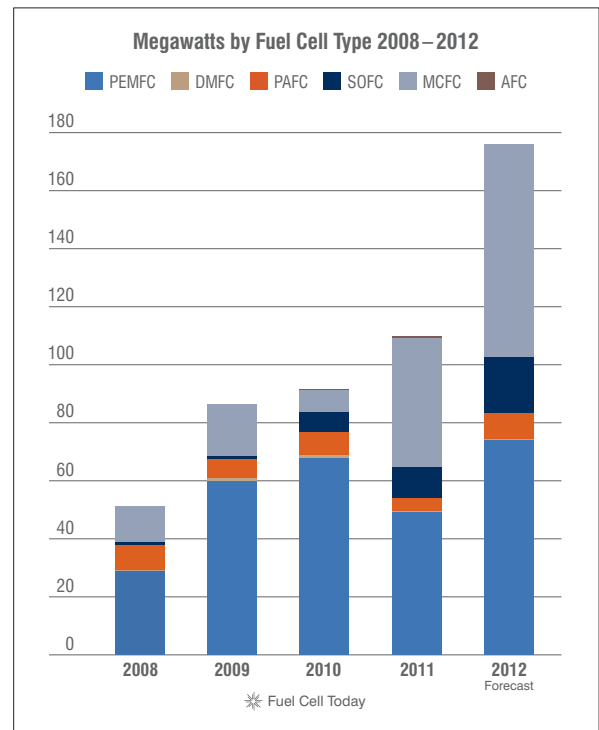
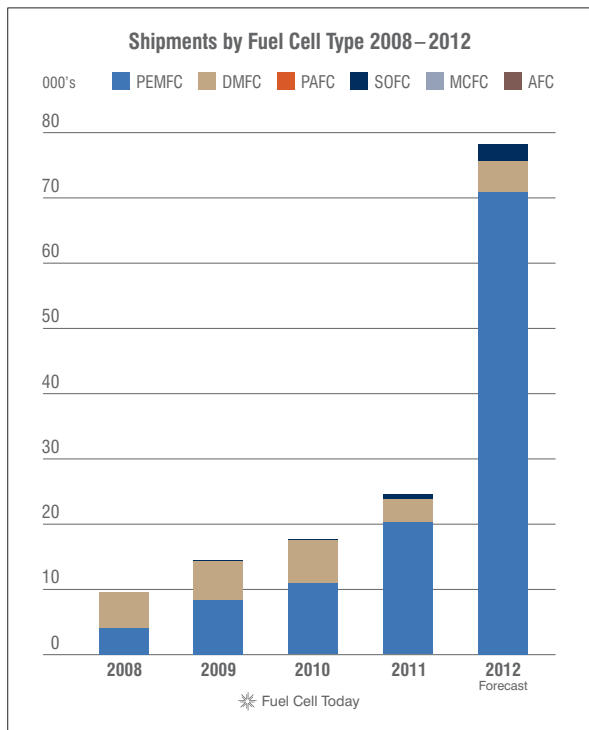
In July 2012, Ballard's interest in the South African market was cited when it announced it had acquired product lines and other key assets from IdaTech, a specialist manufacturer of fuel cell systems for backup power: Ballard will be working with existing IdaTech customers in South Africa, with whom more than 150 systems have already been deployed. IdaTech's methanol-fuelled product line has proven popular with telecommunications companies in countries such as Indonesia, Mexico and South Africa, where extended-run backup power is needed during frequent grid outages and diesel generators offer a less than ideal solution.

Australia is another country where providing backup power for telecommunications can be a challenge, simply because so many stations are remote. This adds cost and complexity to any form of maintenance including hydrogen deliveries, so Sustainable Energy Fuel Cells Australia (SEFCA) is working with electrolyser manufacturer Acta to offer the Australian market an alternative, integrated solution: fuel cell backup power with on-site generation of hydrogen. The first field trials are expected to commence shortly. On the consumer side, fuel cell chargers for mobile phones will be made available in Australia this year. Residential (micro-CHP) fuel cells are also receiving attention: for example in May 2011 energy network operator Ausgrid ordered 25 BlueGen fuel cell units from Ceramic Fuel Cells Limited to be installed in homes in Newcastle, New South Wales, as part of the AUD 100 million (\$103 million) 'Smart Grid, Smart City' project.

We expect to start seeing developments in Latin America as a number of companies are registering interest in this market, including Ballard which is partnering with WEG Industries to investigate opportunities in bus, rail and mining transport in Brazil; and FuelCell Energy, which has entered into a partnership with Abengoa SA to develop localised stationary fuel cell power plants for Brazil and other countries.

Developments by Electrolyte

Fuel cells cannot be considered a single technology, but a collection of technologies that operate on the same principle. These technologies, which are generally classified according to the type of electrolyte used, have their own characteristics and offer a different combination of benefits in each case. (For more information on fuel cell basics please see the 2011 Industry Review or visit www.fuelcelltoday.com.) Fuel Cell Today considers six main fuel cell types: PEMFC (including HT PEMFC), DMFC, MCFC, PAFC, SOFC and AFC.



Unit shipments are dominated by PEMFC, as its versatility makes it useful in a range of markets. It is the dominant technology in transportation applications and in small stationary power applications (including the Japanese Ene-Farm programme). It is also the most popular choice in consumer electronics applications, which account for most of the escalation in shipment numbers we expect to see in 2012. To date, the remainder of shipments have largely been DMFC, which has seen commercial success for some years now in the portable generator and APU markets. However, in 2012 we anticipate clearly visible growth in the number of SOFC systems shipped as the technology establishes itself in the Ene-Farm programme and in small stationary applications in Europe, amongst others.

PEMFC dominate unit shipments but are generally used in smaller systems

The figures for megawatts by technology look very different, as expected. Comparing the two charts, the dominance of MCFC, SOFC and PAFC in the large stationary power market is evident, as is the fact that PEMFC and DMFC are generally used in smaller systems. The megawatt chart also reveals a dip in PEMFC capacity shipped in 2011, caused primarily by a reduction in transportation deployments; we expect this to recover in 2012. Particularly significant growth was seen in 2011 in the megawatts of MCFC deployed, due to high demand from South Korea and FuelCell Energy capitalising on opportunities in the USA. We anticipate further expansion for MCFC in 2012, as well as increases for SOFC and PAFC.

Proton Exchange Membrane Fuel Cells

PEMFC technology continues to dominate shipments in the industry with 2011 growing by 87.2% compared to 2010. This dominance is due in part to the versatility of the technology, allowing for its use in a wide variety of applications. The technology is based on platinum-containing electrodes which offer a combination of durability and activity that is difficult to match using alternative technologies. This versatility comes at a cost however as platinum is a globally traded commodity, and thus susceptible to fluctuations in price outside the control of the fuel cell industry. Attempts to reduce or remove platinum from PEMFC systems are a continual research effort in universities and commercial R&D facilities alike and success in this effort is needed to enable the cost reductions required for widespread commercialisation. A Canadian project launched in 2012 is aiming to do just this and is focusing on automotive fuel cells, attempting to remove up to 80% of the current platinum content. The \$8.1 million project has been majority-funded by the Automotive Partnership Canada, which has contributed \$5 million. Six other companies are involved, including the Automotive Fuel Cell Corporation (AFCC), Ballard Power Systems, Hyteon Inc., BIC Inc., GM Canada, and Hydrogenics. The project hopes to have prototypes ready for testing within five years.

In Japan, catalyst manufacturer N.E. Chemcat announced in January 2012 that it would license low-platinum catalyst technology from Brookhaven National Laboratory in the USA. The catalyst is based on a core of palladium inside a single-atom shell of active platinum and claims to contain one-tenth the platinum of conventional catalysts. N.E. Chemcat hopes to exploit this technology in FCEV.

While numerous methods have been proposed to lower the platinum content of fuel cells, in practice it is very difficult to do so. Platinum offers the best activity and durability when used in the harsh environment inside a working fuel cell. In practice, advanced catalysts which optimise platinum use without requiring exotic manufacturing methods are most likely to succeed.

Platinum catalysts are highly active and durable, but thrifiting is important to reduce costs



The recycling of fuel cells at the end of their useful life to recover platinum will also be vital to the long-term sustainability of the fuel cell industry. A UK project involving Johnson Matthey Fuel Cells was launched in February 2012, which will investigate the recovery of high-value materials from fuel cell membrane electrode assemblies. This project will receive a share of £4.5 million (\$7.2 million) allocated to twelve projects by the UK government-backed Technology Strategy Board and focusing on efficient and sustainable use of resources.

The optimisation of PEMFC in its end-use markets is also a route to cost reduction, and the Japanese Ene-Farm range of products underwent a size reduction to do just this. Originally rated at 1 kW, the next generation fuel cell systems have been downsized to either 700 W or 750 W; a better

fit for the average Japanese home. Despite this downsizing of the PEMFC system, Tanaka Precious Metals reported a 67.2% increase in catalyst shipments to this application between 2010 and 2011 – highlighting the dramatic increase in shipments of Ene-Farm residential micro-CHP systems.

HT PEMFC continues its development with a small number of commercial deployments to date. Technical issues such as lifetime and durability must still be overcome in certain applications in order for the technology to increase its share of the fuel cell market.

Direct Methanol Fuel Cells

DMFC are best suited to applications under 100 W and have made their name through SFC Energy's successful line of consumer and industrial APU products. The company continues to dominate in this technology type, and 2011 saw the popular EFOY consumer line superseded by the new EFOY COMFORT range, which offers higher performance, quieter operation, and easier controls.

DMFC MHV are expected to receive support from the US government

Oorja Protonics offers a DMFC battery charger for MHV in the USA. The company has demonstrated its technology in cooperation with NREL at customer sites such as Unified Grocers and, with expected funding from the Recovery Act to support small-scale fuel cell MHV fleets, we expect DMFC shipments in this application to see growth over the next year.

There are a number of other companies developing DMFC solutions, but the majority are yet to reach commercial readiness. The compact size of DMFC stacks and the ease of storage and distribution of methanol make it a compelling option for portable electronics. Diagrams in Apple patent applications published in December 2011 that show how the company may integrate fuel cells into future MacBook products suggest that the prospective fuel cell technology is DMFC, a good indication of the broad interest in this technology.

Molten Carbonate Fuel Cells

From 2010 to 2011, the megawatts of MCFC shipped annually increased almost six times, clearly indicating the commercialisation of this technology. We anticipate further growth of some 65% in 2012. However, MCFC systems are large, often megawatt-scale, so annual system shipments are still fewer than fifty, giving a zero in our rounded data.

FuelCell Energy (FCE) has cornered the market for MCFC systems in power generation and, as mentioned earlier in this review under Developments by Application, in 2011 it supplied a number of its Direct FuelCell (DFC) plants for use in California with biogas or anaerobic digester gas (ADG). Operators of these plants benefit from a state subsidy for electricity generated from renewable fuel, and MCFC technology lends itself to this application as the high operating temperature means it can be fuelled directly with methane, which is then reformed within the fuel cell itself.

Total megawatts shipped of MCFC have increased six-fold from 2010 to 2011

These are for the most part cogeneration plants, making efficient use of the fuel by producing usable, high-grade heat with electricity. But DFC plants can also be operated in trigeneration mode, producing hydrogen as a by-product. This was demonstrated in 2011 at the Orange County Sanitation District treatment facility in California. FCE installed a DFC plant that runs on ADG and produces 250 kW of electricity for use at the facility as well as hydrogen that is used at the nearby Air Products hydrogen refuelling station for fuel cell vehicles. The heat is recycled into



POSCO Energy is to manufacture MCFC stacks under licence from FuelCell Energy from 2014

the fuel cell to boost the reforming process, producing an excess of hydrogen that can be used externally; this also aids in cooling the fuel cell, relieving what is usually an electric load and thus having the additional benefit of raising the electrical output of the overall system.

In March 2012 FCE and Air Products signed an MoU to collaborate on the development of DFC plants for this type of application. The company is also looking to pursue biogas applications elsewhere. Towards the end of 2011 it entered into a partnership with Abengoa SA to develop the market for stationary fuel cell power plants in Europe and Latin America, specifically the opportunity presented by municipal waste facilities and other industries generating liquid biofuels and biogas and requiring both electricity and process heat.

This is not the only market expansion on the cards for FCE. Korean demand, which accounts for a great deal of the MCFC megawatts shipped to date, continues to increase. POSCO Energy has been receiving stack shipments from FCE under an order for 70 MW and in early 2012 said it anticipates placing a follow-up order for 120 MW, with delivery commencing in 2013. This will be covered by manufacturing capacity at FCE's Connecticut plant, but the need for more capacity is on the horizon; also announced was that POSCO Energy is to manufacture stack components under licence from FCE at its Pohang facility from October 2014.

Solid Oxide Fuel Cells

SOFC are rapidly increasing in popularity in stationary applications that were previously dominated by PEMFC and in some instances PAFC; SOFC shipments grew by more than 300% between 2010 and 2011. SOFC can offer higher electrical efficiencies than PEMFC and PAFC, but produce less usable heat; they are best suited to continuous operation in electricity-led applications.



California's BloomEnergy has enjoyed significant interest in its SOFC systems for large stationary applications in the last year. Technological improvements in the hotbox have seen the company's standard offering increase from 100 kW to 200 kW and the addition of a Delaware manufacturing facility in 2012 will open a customer base on the US East Coast.

SOFC shipments grew by more than 300% between 2010 and 2011

At a residential scale, Australian manufacturer Ceramic Fuel Cells Limited (CFCL) has continued to successfully market its micro-CHP systems in a number of locations. Germany is seen to be the most advanced European market for micro-CHP and CFCL has entered with the opening of a volume manufacturing facility in Heinsburg. The Callux domestic demonstration programme has allowed German manufacturers Hexis and Vaillant to field test their SOFC micro-CHP systems with installations across Germany. SOFC is also finding application in higher-output APU applications.

The vast majority of SOFC are planar cells, with the ceramic catalyst arranged in thin plates. Operating at high temperatures can make the plates susceptible to cracking during power cycles; this is exacerbated when the stack is subjected to vibration, such as in APU use. A number of companies are developing tubular SOFC designs that can alleviate these issues but to date these systems have been small. German start-up eZelleron has developed a micro-tubular SOFC design that produces 1 W of power from a tube 47 x 3 mm in size.

With a number of funded RD&D projects advancing SOFC as a technology, we expect to see it continue to develop rapidly, with more than 300% growth again between 2011 and 2012.

Phosphoric Acid Fuel Cells

Megawatts of PAFC shipped dipped in 2011 but we expect a return to growth in 2012. The number of systems shipped in each year is below fifty and this is the reason for the zero in our data tables, which display shipment numbers rounded to the nearest 100. Commercial PAFC systems are used in large stationary power generation applications and the two suppliers in this market are UTC Power in the USA and Fuji Electric in Japan, both of which primarily cater to their domestic markets.

UTC Power's PureCell system has the larger installed base. It offers its customers a number of advantages: availability exceeding 95% with more than ten million operating hours logged; stacks designed to last for ten years, with overall product life of twenty years; overall efficiency (i.e. in CHP mode) of up to 90%, thus lowering energy costs; and the system has load following capability. As a result it continues to sell steadily into the US market despite stiff competition from relative newcomers FuelCell Energy and Bloom Energy (offering MCFC and SOFC systems respectively). As discussed under Developments by Application, UTC Power is now also selling into South Korea and has received an order for fourteen PureCell Model 400 systems to be delivered to one of the country's leading energy suppliers over 2012 and 2013.

**PAFC suppliers
are branching out
from their domestic
markets**

Meanwhile, Fuji Electric announced early in 2012 that Daimler had ordered a 100 kW unit through vendor N2telligence for installation in its Hamburg Mercedes-Benz dealership. This was soon followed by news that Fuji Electric has acquired the credentials necessary to allow it to sell its fuel cells directly into the EU, the company's first commercial export venture; it is aiming for sales of ¥1 billion (\$12.5 million) in two years. Fuji Electric also supplied one of its PAFC units to a US-Japanese collaborative project in New Mexico, the Albuquerque Business District Smart Grid Demonstration Project, launched in May 2012. The project objective is to innovate smart grid control to overcome the challenges presented by the intermittency associated with renewable energy sources.

Despite reports (at the time of writing) that United Technologies Corp is looking to sell UTC Power, both Fuji Electric and UTC Power are still targeting cost reduction and we anticipate growth in PAFC deployments in 2012 and beyond.

Alkaline Fuel Cells

Development of AFC technology continues to be dominated by UK company AFC Energy which is targeting low power density stationary markets for initial deployments. AFC Energy has had its Beta unit on test at Akzo Nobel's chlor-alkali facility in Bitterfeld, Germany, generating electricity since the end of 2011. The success of this project has led to the planned installation of its next generation Beta Plus system at a new chlor-alkali facility operated by Industrial Chemicals Limited in the UK. Plans for this system are to upgrade it to 1 MW after successful testing. This would then be the largest fuel cell installation in the UK.

Looking further into the future, AFC Energy signed an agreement with Waste2Tricity (W2T) in April 2012 for the inclusion of alkaline fuel cells in W2T's commercial waste-to-energy plants. This confirms an initial agreement from 2009 where W2T intended to incorporate AFC technology in its waste gasification plants to generate electricity from municipal waste.

**AFC technology
is targeting low
power density
stationary
applications**

At the end of 2011, alkaline polymer membrane fuel cell developer CellEra announced a \$9.2 million funding round, led by Vodafone Ventures and an Israeli capitalist in collaboration with a number of private partners and Israel Cleantech Ventures, CellEra's largest shareholder. CellEra hopes its platinum-free technology will allow for cost reduction and prove attractive to mobile operators.

Special Feature 3

The Canonisation of FCEV

In a now infamous interview with the MIT Technology Review in May 2009, US Secretary of Energy Steven Chu dismissed hydrogen fuel cells for transport as a technology for ‘the distant future’. The context of this interview was the early decision of the Obama administration to cut funding for the Department of Energy’s fuel cell programme and to move its emphasis from transportation to stationary power generation applications.



As described elsewhere in this Review, notably the special feature on the ARRA stimulus package (see page 22), the Obama administration has been active and effective in advancing the commercialisation of fuel cells. However, Dr Chu’s sardonic conclusion on fuel cell vehicles – “if you need four miracles, that’s unlikely: saints only need three miracles” – and the DOE’s change of priorities successfully kiboshed efforts to introduce FCEV to the US market.

Much can change during a US presidential term, and this includes, by his own account in 2012, Dr Chu’s mind on the viability of FCEV. Something that has remained constant over this period is the planning, effort and investment in other regions towards the introduction of FCEV in 2015 – most notably in Japan and northern Europe. In September 2009, industry partners in Germany signed a memorandum of understanding to evaluate the building of a hydrogen infrastructure and support the introduction of FCEV in 2015. This led to a plan, supported by a June 2012 letter of intent and government funding, to build the first phase of the network with 50 stations across the country. In Japan, a memorandum signed in January 2011 sees the car makers and

energy companies working towards a network of 100 stations to support a 2015 FCEV launch. The recent announcements that show companies and countries on course to meet this target are detailed in the Fuel and Infrastructure section of this Review on page 24. So have the miracles happened, or were they only needed in America, or was it something else that was needed?

Miracle 1: Hydrogen Production

Dr Chu’s point was that hydrogen is currently produced primarily by reforming natural gas and that in the process “you are giving away some of the energy content of the gas, which is a very valuable fuel”. Although this appears to be an argument about energy efficiency, it cannot be: it is better to reform gas and put the hydrogen in a fuel cell than put the gas in an internal combustion engine. Dr Chu now says that the most important reason for his change of mind on fuel cells is the new abundance of natural gas in the USA, which makes it clear that the efficiency in question is economic. So it appears for him the ‘miracle’ has happened, and it is fracking.

What has not changed is the odd assumption that hydrogen must come from natural gas. This view is particularly





well-demonstrated, and vehicles first leased in California in, ironically, 2009 have shown three years of everyday usability. Since the last Review, several vehicle manufacturers have stated that FCEV can and will be cost-competitive with diesel hybrid drivetrains. Large manufacturers are

surprising since, in the 'four miracles' interview, Dr Chu discusses producing hydrogen by electrolysis using surplus nuclear, solar or wind electricity. He proposes using it to generate electricity in a fuel cell when required. The European analysis, exemplified by the new Danish energy plans, recognises the value of water electrolysis in an electricity network with a high proportion of generation from wind power and other intermittent renewables. However, the major benefit is in the use of electrolyzers as dispatchable load to absorb excess supply. The hydrogen can indeed be turned back into electricity, or employed as a feedstock for fuels and chemicals, but it is used to the greatest economic and environmental advantage as a transport fuel.

willing to stand behind their products and introduce them commercially in 2015.

It is certain that performance, cost and durability will be improved, but a developing market for the product is necessary to provide both experience and the justification for the effort required. Full technical maturity comes from, not before, market application.

Miracle 4: "The distribution infrastructure isn't there yet"

It truly would be miraculous if we woke one morning and found a fully formed hydrogen distribution infrastructure suddenly 'there'. But ways are being found to make it happen more progressively.

This example shows one of the great benefits of hydrogen: that it can be a bridge between two of the great energy silos – electrical power and transport – delivering supply side benefits. The other great advantage is that it can be made by many other routes which improve both CO₂ emissions and national self-reliance. In 2011 and 2012, projects have demonstrated the manufacture of hydrogen from solid waste, sewage and biomass.

The California Air Resources Board's Advanced Clean Cars program, announced in January 2012, includes the Clean Fuels Outlet regulation which requires the oil companies that currently provide Californian road fuel to start providing hydrogen in line with the introduction of FCEV.

Miracle 2: "We don't have a good storage mechanism yet"

Nobody is waiting for a miracle in this area. Vehicle manufacturers have rejected liquid hydrogen for on-board storage and are not waiting for solid-state (hydride) storage technology. A standard has been developed around 700 bar pressurised gaseous storage in polymer-lined, fibre-wound tanks. This gives the same driving range as a gasoline tank of equivalent volume and weight, albeit with more limitations on the shape of the tank.

The European and Japanese approach is one of joint commitment between vehicle manufacturers, government, and those who want to supply the fuel.

The cost of hydrogen infrastructure is modest by the standards of energy and infrastructure spending, and no more than is required for charging battery-electric vehicles. The Danes have calculated the public investment required to enable the introduction of FCEV and the creation of the network between 2015 and 2025 (the point at which no further support is needed) as €345 million (\$468 million), or as they put it, "the cost of one bottle of wine for every Dane per year" over the period. They are getting on with it.

Miracle 3: "Fuel cells aren't there yet"

The technical readiness of fuel cells must be judged on their performance, cost and durability. Performance is

Needed are new approaches developed from an agreed understanding of the rewards of success. Or as another scientist-turned-politician Chaim Weizmann said, "Miracles sometimes occur, but one has to work terribly hard for them."

Outlook

All sectors will continue growth through 2012, with fuel cell MHV and UPS now selling without subsidies

2011 was by far the most successful year in the history of fuel cells. Growth in shipments was recorded in the majority of applications and we expect all sectors to continue growth through 2012. Government-led projects have supported the commercialisation of fuel cells for many years in Asia, Europe and North America and this has led to cost reduction, technological advancements and customer acceptance. Fuel cells for MHV and UPS applications are now selling without subsidies and so these regions can now plan to reduce their support, confident that purchases of fuel cell units will continue.

Portable

Fuel cell APU continue to find application in a wide variety of industrial markets. Products are available which run using a variety of fuels from diesel through methanol to hydrogen, offering a range of benefits and convenience of refuelling to the user. Future markets for APU include heavy-duty diesel trucks, aeroplanes and boats, but further development and testing is required before we could expect widespread adoption.

The long-awaited launch of a number of fuel cell consumer electronics chargers in 2011 and 2012 has marked a turning point in this sector. For many years it has proved too difficult to miniaturise fuel cell technology to a level where it could realistically compete with external battery supplies. Continued development is expected to result in units small enough to integrate inside consumer devices and large multinational companies, such as Apple and Research In Motion, are patenting in this field.

Stationary

In the stationary sector, growth is expected for both small and large systems, in residential, industrial and prime power applications. The well-established Japanese Ene-Farm residential micro-CHP scheme will continue and the emergence of similar schemes in other areas such as Ene.Field in Europe will allow for continued cost reduction and optimisation of fuel cell technology. Sales of backup power systems to the telecommunications industry will continue to grow and, with significant interest emerging in China and elsewhere, there is huge potential for both independent and grid-connected systems. The introduction of methanol-fuelled telecommunication backup fuel cells and semi-autonomous units incorporating electrolyzers opens this market up further, enabling more remote locations, where delivering hydrogen is difficult, to take advantage of fuel cell technology.

Large stationary fuel cell installations are receiving increased interest from multinational companies looking for ways to reduce the carbon footprint of their operations. Further megawatt-scale deployments in the USA are expected of the three main large fuel cell types in this market: molten carbonate, solid oxide and phosphoric acid. Korea also continues to install large stationary molten carbonate fuel cells under its RPS and its interest shows no sign of receding. It sees fuel cells as a key part of its future energy portfolio, and to meet its target of 10% renewable energy contribution to the total energy mix (currently 2%) there is significant potential for further growth in the country. POSCO Energy has signed an MoU with FuelCell Energy for the former to manufacture components for DFC systems from 2014. This is a significant development in their relationship because currently only balance of plant is made in Korea. This will expand the global capacity for MCFC units and Korean production is likely to be aimed at meeting RPS targets.

Large fuel cell installations are receiving increased interest from multinational companies looking to reduce their carbon footprint

Transport

The global automotive industry sells in excess of 80 million vehicles per year, and for fuel cells a portion of this market remains the long-term prize in this sector. A great deal of work is underway to ensure both the vehicles and the fuel will be ready for the proposed launch – which is now only three years away. Historically, many announcements relating to the commercial launch of FCEV have been made and have not delivered on their promises, with a lack of cohesion and no clear plan being partly to blame. Things are different now, with clear roadmaps in place in countries like Germany and Japan to introduce the necessary level of hydrogen refuelling stations to support initial deployments of FCEV. These two countries alone have plans for more than 150 hydrogen refuelling stations by 2015. Fuel cell technology and vehicle development continues with companies such as Daimler opening a FCEV stack production facility, Nissan showcasing its newest stack technology and Toyota's FCV-R model demonstrated at major global consumer car shows. It was also recently photographed road-testing its fuel cell unit inside an unmarked Lexus HS.

Clear roadmaps are in place in Germany and Japan to introduce hydrogen refuelling stations and support initial deployments of FCEV

The market for materials handling vehicles has enjoyed several years of support in the USA and this looks set to continue. The large fleets of hydrogen fuel cell MHV have proven their viability, repeat orders are being placed without subsidies and US companies are looking to expand their operations overseas. We now expect government focus to shift slightly towards small fleets where the installation of a hydrogen infrastructure is not currently cost efficient. DMFC range extenders are likely to enjoy success here, with a simple bolt-on solution and a straightforward liquid-refuelling model offering numerous benefits to small fleet operators.

Fuel cell buses continue to be developed with interest in many countries worldwide. In Europe a coalition of major bus manufactures, fuel cell technology providers, regional transit companies, hydrogen infrastructure providers and the FCH JU are currently involved in a study coordinated by McKinsey to identify the market potential of different powertrains for buses. Preliminary results from this study are expected soon.

The US DOE is also proposing to support the development of specialised fuel cell vehicles in locations such as airports. While it is difficult to reduce emissions at airports associated with aeroplanes, there are many other vehicles in operation which could be converted to hydrogen fuel cells and contribute to reducing overall emissions.

Fuel cells of many different shapes and sizes are currently in operation around the world providing safe and reliable electricity and heat

In Asia, hydrogen fuel cell scooters are set for deployment in a number of countries. These vehicles will compete with battery-powered variants, both having zero-tailpipe emissions, but with batteries being a mature and in some cases cheaper technology, the market penetration of fuel cell scooters will remain low at first, but has significant potential.

Conclusion

Fuel Cell Today considers 2012 to be the fifth year of commercialisation for fuel cells in certain markets. Many different types and sizes of fuel cells are currently in operation around the world providing electricity and heat safely and reliably. The total cost of these systems is also decreasing, such that repeat orders for fuel cells are being placed by customers without the need for financial support. We believe that these trends will continue and demand for fuel cells will go from strength to strength.

Data Tables

Annual Unit Shipments 2008–2012

Shipments by application					
'000 Units	2008	2009	2010	2011	2012
Portable	5.1	5.7	6.8	6.9	50.5
Stationary	3.6	6.7	8.3	16.1	24.6
Transport	0.8	2.0	2.6	1.6	3.1
Total	9.5	14.4	17.7	24.6	78.2

Shipments by region					
'000 Units	2008	2009	2010	2011	2012
Europe	3.3	4.4	4.8	3.9	22.8
N America	1.7	3.2	3.3	3.3	20.0
Asia	4.5	6.7	9.5	17.0	31.2
RoW	0.0	0.1	0.1	0.4	4.2
Total	9.5	14.4	17.7	24.6	78.2

Shipments by fuel cell type					
'000 Units	2008	2009	2010	2011	2012
PEMFC	4.1	8.5	10.9	20.4	70.9
DMFC	5.4	5.8	6.7	3.6	4.7
PAFC	0.0	0.0	0.0	0.0	0.0
SOFC	0.0	0.1	0.1	0.6	2.6
MCFC	0.0	0.0	0.0	0.0	0.0
AFC	0.0	0.0	0.0	0.0	0.0
Total	9.5	14.4	17.7	24.6	78.2

■ Throughout the five-year period, portable shipments have been underpinned by sales of fuel cell APU into the leisure segment. Portable unit shipments are poised to accelerate rapidly in 2012 with the launch of fuel cell consumer electronics charging devices. Shipments of stationary fuel cells have ramped up steadily since 2008 with deployments of micro-CHP, particularly in Asia, as well as UPS in North America. In the transport sector, hundreds of fuel cell materials handling vehicles have been shipped, particularly since the start of large-scale demonstration programmes from 2008/2009.

■ Asia has been the dominant region of fuel cell adoption for the past five years with growth in 2008/2009 as the commercial deployment of Japanese fuel cell micro-CHP products took place. North America saw strong growth in 2009 with the roll-out of FCEV and materials handling demonstration fleets under the Recovery Act, sales of portable fuel cells, stationary prime power and UPS shipments but remained flat for the following three years.

■ Until 2008, DMFC was the leading type of technology due to its use in portable APU. Since then, applications which use PEMFC have grown rapidly. PEMFC technology dominates fuel cell shipments due to its widespread use in small stationary, transport and portable applications. Due to the relatively small number of PAFC, AFC and MCFC units shipped and the impact of rounding, no values appear in the table above.

Annual Megawatts Shipped 2008–2012

Megawatts by application					
MW	2008	2009	2010	2011	2012
Portable	0.3	1.5	0.4	0.4	0.6
Stationary	33.2	35.4	35.0	81.4	128.4
Transport	17.6	49.6	55.8	27.6	46.8
Total	51.1	86.5	91.2	109.4	175.8

Megawatts by region					
MW	2008	2009	2010	2011	2012
Europe	5.0	2.9	5.8	9.4	19.2
N America	23.0	37.6	42.5	59.6	67.4
Asia	22.8	45.3	42.5	39.6	87.3
RoW	0.3	0.7	0.4	0.8	1.9
Total	51.1	86.5	91.2	109.4	175.8

Megawatts by fuel cell type					
MW	2008	2009	2010	2011	2012
PEMFC	28.9	60.0	67.7	49.2	73.8
DMFC	0.3	1.1	1.1	0.4	0.5
PAFC	8.6	6.3	7.9	4.6	8.8
SOFC	1.3	1.1	6.7	10.6	19.5
MCFC	12.0	18.0	7.7	44.5	73.2
AFC	0.0	0.0	0.1	0.1	0.0
Total	51.1	86.5	91.2	109.4	175.8

■ In terms of megawatts shipped, 2011 broke the 100 MW barrier for the first time. The stationary sector is now the largest, indicating the importance of large stationary installations as well as the high number of micro-CHP units adopted in Asia. The impact of materials handling vehicles and FCEV demonstration programmes can be seen from 2009 onwards when there was a rapid increase in megawatts shipped in the transport sector. Although portable fuel cells are important in terms of unit shipments, due to their small size they are a minimal contributor in terms of shipments by megawatt.

■ Over the last five years, North America and Asia have competed for position as the leading region of adoption by megawatt. This is largely explained by the role of large stationary prime power and CHP/UPS in those regions. The USA and South Korea have been leading the adoption of large, multi-megawatt stationary units in recent years.

■ PEMFC technology is used in a range of application segments, for instance in transport and stationary applications, and has a power range up to hundreds of kilowatts. Therefore PEMFC has dominated the shipments by megawatt since 2008. Due to the large size of many stationary MCFC and SOFC units, the dominance of PEMFC by megawatt is waning and likely to be overtaken soon.

Table Notes

- Our 2012 figures are a forecast for the full year.
- The regional numbers represent system shipments by region of adoption.
- Unit numbers are rounded to the nearest 100 units. An entry of zero indicates fewer than 50 systems were shipped in that year.
- Megawatt numbers are rounded to the nearest 0.1 MW. An entry of zero indicates less than 100 kW was shipped in that year.
- Portable fuel cells refer to fuel cell units designed to be moved. They include fuel cell APU, and consumer electronics. Toys are no longer reported in the portable total to allow for greater visibility of industrial systems.
- Stationary fuel cells refer to fuel cell units designed to provide power at a fixed location. They include small and large stationary prime power, backup/uninterruptible power supplies, combined heat and power, and combined cooling and power.
- Transport fuel cells refer to fuel cell units that provide propulsive power or range extender function to vehicles, including UAV, cars, buses, and materials handling vehicles.
- Our geographical regions are broken down as follows: Asia includes all Asian countries including Japan; Europe comprises all eastern and western European countries, including Iceland; North America comprises Canada and the United States; the Rest of the World region includes all other countries.
- Shipments by fuel cell type refer to the electrolyte. The six main electrolyte types are included here; high temperature PEMFC and conventional PEMFC are shown together as PEMFC. Other types of fuel cell such as microbial fuel cells are not included in our numbers as these are generally still at the R&D stage.
- The data presented here are based on interviews between Fuel Cell Today and key industry players, publicly available sources such as company statements or stock market filings, and planned demonstration programmes by companies and governments.
- The data presented here may differ from those previously published by Fuel Cell Today: Fuel Cell Today's applications have been redefined to remove toys and educational kits from the portable sector; shipment figures are based on region of system adoption; and the dataset has been updated in the light of new information.

About the Authors

Dr Dan Carter

Manager and Principal Analyst

Dan joined Fuel Cell Today in January 2011, having worked as an industry analyst for more than five years at Johnson Matthey researching and forecasting the automotive, electronics, chemicals and fuel cell industries. Dan has presented at international industry events around the world and has extensive experience of the Asian fuel cell markets. He is a chemist by training and graduated with an MChem (Hons) from the University of Wales, Swansea and a PhD in Inorganic Chemistry from the University of Nottingham.



Marge Ryan

Market Analyst

Marge joined Fuel Cell Today in February 2011, having previously worked on the editorial staff of the journal Platinum Metals Review. Marge has a particular interest in sustainable development and in stationary fuel cells for both industrial and residential applications. She has a BSc in Chemical Engineering from the University of Cape Town and spent five years working as an engineer for Impala Platinum in South Africa before immigrating to the UK in 2006.



Jonathan Wing

Market Analyst

Jonny joined Fuel Cell Today in April 2011 having graduated from the University of Reading with a BSc in Environmental Science. Jonny took a particular interest in energy resources during his studies and his thesis focused on micro-generation. A digital enthusiast, Jonny has travelled globally and is particularly interested in portable fuel cells and their integration into consumer electronics, the commercialisation of fuel cell electric vehicles and European initiatives.



Online materials

NEWS

Every weekday the Fuel Cell Today team scours the latest information and press releases to write news updates for our readers. By independently assessing all of the news that we choose to write and publish, readers can expect impartial and concise updates. Our updates can be followed as they happen on Twitter.



ANALYSIS

Every fortnight a Fuel Cell Today analyst writes a short article on a topic of interest in the fuel cell industry. Comprehensive surveys of fuel cell developments in specific countries, applications or technology areas are published throughout the year, as well as live coverage and reports from industry events the team attends.

EVENTS

Fuel Cell Today hosts an extensive directory of upcoming events across the world where fuel cells and hydrogen are primary themes or are of potential relevance. Results are refinable by region, technology and application. Photos and updates from larger events that the team attends are posted on Twitter.

INDUSTRY DIRECTORY

The internet's largest compendium of companies working in the fuel cell and hydrogen industries, along with related suppliers. Searchable by region, technology and application the directory provides key contact information to assist companies in developing the supply chain.

BACKGROUND INFORMATION

Using fuel cells two-page information sheets highlight specific applications where fuel cells can offer benefits today. The website also offers a history of fuel cells, information on technology types, overall benefits, a list of frequently asked questions and a glossary of terms.

REGISTER

By registering for free with Fuel Cell Today readers can subscribe to daily news summaries by email, upload their company profile for addition to the Industry Directory, submit events for inclusion on the site and subscribe to fortnightly analysis updates by email.

All this content and more is available free of charge online.

To find out more and subscribe please scan the code or visit:

www.fuelcelltoday.com

 [/company/fuel-cell-today](https://www.linkedin.com/company/fuel-cell-today)



PICTURE CREDITS

Fuel Cell Today is grateful to the following people and organisations for their help in providing illustrations for the Fuel Cell Today Industry Review 2012. For copyright information or permission to use any of these images, please contact the relevant organisation.

Aerial photograph of the London Olympic Park, outside covers
German 50 hydrogen stations launch, inside covers
Executive Summary images credited below, except ix35 p.2
Map of geographical regions, p.5
EFOY Comfort, p.8
AVL SOFC APU, p.9
myFC PowerTrek, p.10
UTC PureCell, p.11
Korean stationary fuel cell plant, p.12
Callux fuel cell, p.13
CFCL BlueGen, p.14
ReliOn backup power fuel cell, p.15
Fuel cell materials handling vehicles, p.16
Toyota FCV-R, p.17
Heathrow Airport hydrogen station with fuel cell taxicab, p.18
Fuel cell bus, p.19
EcoMotion maintenance vehicle, p.20
Fuel cell locomotive, p.21
Special Feature 1, p.22
Arctic hydrogen station, p.24
Hamburg hydrogen station, p.25
Saitama hydrogen station, p.26
HFUEL and Burgman scooter, p.27
Portable hydrogen cylinders, p.28
e1 hydrogen generator, p.29
Special Feature 2, p.30
Fuel cell bus, p.33
Fuel cell MHV and hydrogen station, p.35
Korean fuel cell power plant, p.36
Jupiter fuel cell backup system, p.37
Platinum bars and grain, p.40
Orange County fuel cell installation, p.41
Bloom Energy Servers, p.42
Special Feature 3, p.44
About the authors, p.51

Press Association Images
BMVBS
Hyundai
Fuel Cell Today
SFC Energy
Fuel Cell Today
myFC
UTC Power
POSCO Energy
Callux
Ceramic Fuel Cells Limited
ReliOn
Sysco Foods
Toyota Motor Company
Air Products
UTC Power
EcoMotion
Johnson Matthey
US DOE/Sysco Foods/ReliOn
H2 Logic
Vattenfall Europe
Honda Motor Company
ITM Power
Air Products/BOC
Element 1
Bloom Energy/Apple/Deseret News
PostBus Switzerland Ltd.
Sysco Foods
POSCO Energy
FutureE
Johnson Matthey
FuelCell Energy
Bloom Energy
Fuel Cell Today/Mercedes-Benz/Honda/Toyota
Fuel Cell Today

Note on currencies:

Unless stated otherwise, all currencies are quoted in US Dollars (\$). The following exchange rates, based on average exchange rates from 1st January 2011 to 1st July 2012, have been used:

\$1 = €0.7364

\$1 = \$0.9693 (Australian)

\$1 = ¥79.7435

\$1 = RMB 6.4155

\$1 = £0.6272

www.fuelcelltoday.com

Design: Wonderberry UK Ltd.

Print: Fulmar Colour Printing Co. Ltd.





Fuel Cell Today, Gate 2, HQ Building,
Orchard Road, Royston,
Herts SG8 5HE, UK

Tel: +44 (0) 1763 256326

www.fuelcelltoday.com

