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Stationary fuel cells – Insights into commercialisation

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ABSTRACT

Stationary fuel cell systems have been under development for several decades and have been demonstrated for a number of years across Asia, Europe and North America. Commercialisation of these systems is now accelerating with small and large scale systems being installed worldwide. Successful commercialisation requires a dual approach to identifying both early adopters in specific market segments whilst also seeking to reduce costs on a year on year basis. This paper provides an oversight of the current status of commercialisation and explores the key cost and market segmentation challenges.

Introduction

Fuel cell systems for stationary applications offer the promise of substantial benefits for end users: more power and heat for the same amount of fuel with lower emissions. These benefits are available across a range of sizes from 1 kWe, or even smaller, suitable for domestic Combined Heat and Power (CHP) use, through hundreds of kWe to MWe sized units ideal for commercial and industrial CHP and power only uses. The end user and emissions benefits have been explored in a number of reports and papers over the past several years. However, even with these benefits stationary fuel cell systems still face the challenge of commercialisation, of selling products to end users profitably and sustainably over the longer term.

Stationary fuel cell systems

Stationary fuel cell systems have been under development for several decades in the world's regions: notably USA and Canada, Japan and South Korea, and Europe. Principal developers include Fuel Cell Energy, Accumentrics, Bloom Energy and UTC (now ClearEdge) and Ballard in North America; Panasonic, Toshiba and JX in Japan; Posco in South Korea; and a host of systems producers in Europe: Topsoe Fuel Cells, Intelligent Energy, Baxi Innotech, Dantherm Power, Hexis, CFCL, Ceres Power, Vaillant, AFC, Elcore, RBZ and SOFC Power.

Stationary fuel cells systems have been ‘sold’ for a number of years, often with significant government support, but numbers have been relatively small. However, the move towards commercialisation has accelerated in the past few years. Data from the 2013 Fuel Cell Industry Review [1] points to shipments of 24,000 units in 2012, totalling 125 MW of power capacity. These figures represent increases of 50% and 53% respectively over 2011. Although the percentage increases are less than between 2011 and 2010, importantly they remain considerable in volume terms. It is also worthwhile to note that stationary fuel cell system shipments both in terms of numbers and power capacity dominate the fuel cell sector outside small portable recharging units.

The growth in stationary fuel cell systems shipments reflects in particular the growth of installations of micro-CHP

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units (from less than 1 kWe to several kWe). Nowhere has this been more evident than in Japan over the past few years under the Ene-Farm programme. Since 2009 installations totalled about 40,000 to the end of 2012; with a further 35,000–40,000 expected to be installed in 2013 [2]. These increases are significant given the targets set out by METI of Japan for 1.4million micro-CHP fuel cell systems by 2020, leading to 5.3 m by 2030 [3]. Substantial per annum increases of installations are necessary to realise these targets.

Elsewhere in the world progress has not been as rapid as in Japan, but there is nonetheless a growing population of micro-CHPs units in the field. In Europe the Callux programme in Germany had installed more than 300 units by the end of 2012 [4], with further units planned. In addition two European FCH JU (Fuel Cell and Hydrogen Joint Undertaking) supported demonstration projects are planning on installing more than a further thousand units: the ene.field consortium is in the process of installing 1000 fuel cell micro-CHP units across twelve European countries [5], whilst SOFT-PACT is undertaking its second phase with up to 100 installations projected [6].

Growth in larger sized stationary fuel cell systems has been somewhat more modest, but nonetheless steady with units of hundreds kWe to MWe, being installed in North America, Europe and South Korea. In North America both Fuel Cell Energy and Bloom Energy have delivered increasing numbers of MCFC and SOFC units to a range of operators, including respectively Pepperidge Farm and Central Connecticut State University, both in Connecticut, USA [7], and Walrmart in Arizona, and Delmarva power in New Castle, Delaware, USA [8]. Towards the end of 2013 Bloom Energy announced that it had installed 100 MWe of its energy servers in the USA [8].

South Korea has also established a number of larger fuel cells units, with the world largest fuel cell park recently completed in Hwasung City in Korea with a total generating capacity of 59 MWe [9] This growth in Korea, plus elsewhere in the world, has driven the increase in orders placed with Fuel Cell Energy for its MCFC units. It reported a back-log of 123 MWe [10] in its latest Q3 reporting period and in this quarter it operated an annualised production rate of 70 MW.

Challenges

Stationary Fuel Cell Systems potentially offer solutions to the varied energy issues that face Europe, and other regions of the world. The European Union's 20-20-20 targets for emissions, efficiency and energy sources point to a need to do things differently, and stationary fuel cell systems can be part of the solution.

The stationary fuel cell value proposition is complex. Costs are clearly important, but so are the other benefits: the environmental benefits of lower emissions, the relatively quiet operation and the promise of autonomy from mainstream power suppliers for end users. Such benefits nonetheless need to be matched by three key operational and economic criteria: reliability, durability and affordability.

Fuel cell systems must be able to offer reliability of supply equal to centralised power grids; they should have an operational lifetime equivalent to existing domestic and commercial boilers and generators; and they need to be 'competitive' in terms of cost of delivered power and heat (and cooling where applicable).

Arguably stationary fuel cell systems have made steady progress towards reliability and durability targets over the past decade; the greatest challenge remains that of cost, but even here progress is being made.

The cost challenge

The prospect of wide scale commercialisation of stationary fuel cell systems will ultimately depend on cost. Evidence available in the market place suggests that the costs of stationary fuel cell systems are currently available for between €25,000 and €4000/kWe. Work undertaken by the NREL [11] in the USA shows that prices of 249 units, either completed or to be installed in the USA to the end of 2012, ranged from $3000 to $21,000/kWe (€2200–€15,500/kWe). These are prices and not costs and are without incentives. With incentives ranging from $2000 to $5500/kWe the prices fall to $1000 to $19,000/kWe.

The wide range in costs reflects the size and maturity of the units; with smaller units being considerably more expensive than larger units on a cost/kWe basis.

Larger fuel cell units of 100 kWe plus in size are currently the cheapest in terms of cost per kWe installed. Anecdotal evidence suggest that units produced by Fuel Cell Energy and UTC (now ClearEdge) are increasingly economic without any form of public support. These units are suitable for CHP applications for large buildings, for example offices, with a number of units recently located in Europe, including London [12].

Smaller fuel cell systems in the kWe range are more expensive with cost/price several times those of the larger units. Actual costs are difficult to determine, but numbers announced in the Japanese Ene-Farm project for residential units are in the €20,000–€25,000/kWe range.

With cumulative sales of larger fuel cell systems in the hundreds and smaller residential units in the thousands (Panasonic [13] reported sales to end of December 2012 of 21,000, and Toshiba [14] 11,000 at the end of November 2011) it is clear that there is a market, and a growing market at that, for stationary fuel cell systems.

Cost targets

In assessing the commercialisation potential of stationary fuel cell systems emphasis is placed upon cost targets which need to be met to achieve mass market success. These are most developed for the domestic micro-CHP products, and they have often been set by the public sector. METI in Japan has reiterated the 2008 estimate that micro-CHP fuel cell systems must meet a target of ¥500,000–¥600,000 by 2020 (€3700–€4450) in the period 2020 to 2030 [15]; in the USA the DoE sees a figure of $1000/kWe by 2020 for a 2 kWe unit [16] released in 2011, whilst the European FCH JU in Europe has a target of €5000/kWe plus household heating by 2020 as set out in the revised Multi-Annual Implementation Plan [17].

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It is clear that there is considerable variation in the target costs, even allowing for different currencies, different concepts of a CHP system and different time horizons. Whatever the provenance of these targets they are challenging for a sector where the current costs for micro-CHP fuel cell systems are currently in the €20,000/kWe range. Yet it is clear that steps towards commercialisation of stationary fuel cell systems are being made with demonstrations in Europe, but most significantly early market deployment in Japan.

Public support

One means to address the issue of the current overly expensive stationary fuel cell systems is to provide some form of financial support from the public sector.

Public support is an important early market incentive for stationary fuel cells systems, be this in the form of capital subsidies (e.g. North Rhine-Westphalia in Germany [18]); or capital support and feed-in-tariff style pricing (e.g. South Korea [19]); or capital and other incentives available in the USA, usually at the State level, where incentives vary up to $5500/kWe. This support goes some way towards negating the higher prices of stationary fuel cell systems when compared with competitive systems.

There is also the argument that by increasing sales of units and hence overall volume, public support facilitates a faster movement down the cost reduction curve than would otherwise happen.

However, it is important not to over-emphasise the importance of such financial support on end users decision making beyond the marginal cases. The support available in Japan for CHP systems such as the Ene-Farm micro-CHP systems are significant at ¥450,000 in 2012 [20] (€3350), but this is still only about a quarter of the total unit price, including tax. Additional subsidies are available at the regional/city level such as ¥50,000 in Nagoya [21]. Nonetheless, the gap between the cost of a fuel cell micro-CHP and the benefits, as subsidies or energy savings, is still substantial even taking account of savings of another ¥230,000 on hot water boilers.

Furthermore such support and subsidies cannot form the basis of a sustainable competitive market for stationary fuel cell systems because such support usually tapers off over time and is eventually stopped entirely. In South Korea the very generous support from Government available in the early years of the deployment process, is now reported to be being scaled back, due in part to the expense to the public purse [22].

The longer term success of stationary fuel cell systems will therefore depend upon on costs reductions, and more innovative marketing activities.

Early market deployment

Although the mass market is the ultimate objective for stationary fuel cell systems, with widespread adoption and commercialisation across all sectors targeted, the market for this technology, indeed any new technology, begins with the early markets. These are markets where small numbers of units are deployed, where developers can gain experience and iron out issues, and can start to move down the cost reduction curve.

In these early markets the deployment of stationary fuel cell systems is likely to be driven by a number of factors, of which cost will be one. With all new technologies and products there are always ‘early adopter’ style customers who are willing to purchase products or services above the prevailing price offered by competitive products or solutions. In addition there are early markets where due to specific local circumstances the proposition of a new product or solution need not be as stringent as in other markets.

The best example in recent years of early markets for fuel cell and hydrogen technology has been the work undertaken by the UK H2 Mobility project [23]. This public-private collaboration is examining the ways and means of achieving commercialisation of fuel cell vehicles in the UK. Using surveys and focus groups the project identified segments in the UK car buying population that are sufficiently interested in fuel cell vehicles to be willing-to-pay, in theory at least, a price premium for a fuel cell vehicle. Two sectors were identified: ‘Innovative Greens’ and ‘Well off Technology Enthusiasts’. Although representing only about 10% of the car buying public they nonetheless represent a potential early market for fuel cell vehicles in the UK.

A similar activity is required for the stationary fuel cell sector. It is apparent that although costs are important, there are early markets where the total value proposition of stationary fuel cell systems is attractive to end users. Amongst the various reasons reported for customer purchase decisions are the ‘green credentials’ of lower emissions and higher fuel efficiencies, whilst more practical operational considerations, most notably autonomy and reliability of supply are as equally, if not more important, and customers are willing to pay a premium, albeit it may not be very great.

Market segmentation

It is critical that stationary fuel cell developers think about segmenting the market for their products to identify the early deployment opportunities. There are markets where the relatively high cost of fuel cell systems, be it residential or commercial, can be justified on the basis of the additional value associated with ‘green’ credentials or other benefits.

In Japan under the Ene-Farm programme although subsidies are available for the sale of residential CHP fuel cell systems, it is also evident that many sales are being made as part of the sale of a residence, a house or an apartment. As such rather than selling separate CHP fuel cell systems, customers are being offered these units as part of the sale of a house or an apartment. Customers, therefore, are not buying a CHP fuel cell system, but a more environmentally friendlier house or apartment. The total costs of the fuel cell system are part of the much larger cost of a house or an apartment.

In another part of the world it is reported that in London planning authorisations for commercial developments are considered more favourably when there are ‘green’ credentials associated with the proposed development. Several large commercial developments in London in the past few years have been constructed with large fuel cell CHP units incorporated [24]. These units, capable of on-site power and heat generation, are perceived as environmentally friendly and improve the attractiveness of the development as a whole to the planning authorities. As such they have helped facilitate the approval process, a benefit valued by developers.

It is also reported that the CHP fuel cell system installed as part of the Quadrant Development in the Regent Street area of London proved attractive to a retailer and an office user seeking to rent space in central London [25]. The 'green' credentials of the building and the fuel cell system matched the users' own identify and values. This latter point is important to emphasise for corporate users, which have a consideration for the environment as part of their own identity, for both customers and their own employees.

Finally there is the issue of the potential autonomy for power and heat that fuel cell systems can provide end users. This manifests itself in terms of having a certain independence from the power grid, which is attractive where blackouts are an actual regular, or potential, occurrence and which have a 'cost'; be it inconvenience for domestic users, or lost production or productive time for commercial and industrial users. Fuel cell systems with grid gas connections have proven to be highly reliable in terms of power and heat provision [26] for end users. Similarly stationary fuel cell systems offer end users the prospect of better control over their energy costs. As energy costs continue to rise, for example in Europe, the attractiveness to large energy users of autonomy from the grid is likely to prove increasingly attractive.

These examples of early market deployment demonstrate the importance of identifying those opportunities where the value of a stationary fuel cell system to an end user can be enhanced through additional benefits over and above simple cost competitiveness, or where the fuel cell system is part of a larger offering.

Dual approach

Whilst it is true that early markets will support a price premium for products that meet the needs of particular segments of the market, a successful transition to the mass market will require prices to be competitive with the alternatives. Credible cost reduction pathways are necessary for stationary fuel cell systems to achieve the longer term aim of mass market adoption. Developers therefore face the challenge of both addressing market segmentation, but also of defining achievable cost reductions over, if not the short term, at least the medium term. Cost reduction strategies therefore become critical.

Reducing costs

Reducing the cost of stationary fuel cells is and will be a function of better technologies and better manufacturing activities, as well as better business processes amongst developers.

Crucially it will also be a function of the interaction of these activities: better technologies which are easier and cheaper to manufacture, operated by an effective and efficient production business. The manufacturing scale-up of current designs alone will not necessarily deliver the cost reductions required for widespread commercialisation, neither will better technology alone deliver these cost reductions, and both will require better businesses.

Considerable weight seems to be given in part of the fuel cell community to the concept that scaling-up alone, and hence scaled manufacturing, will deliver the cost reductions necessary to achieve competitive costs. In simplistic terms: all that needs to be done to achieve commercialisation of stationary fuel cell systems is to produce thousands and tens of thousands of the current designs to reduce the cost. Certainly moving from hand-built and batch production processes to large scale, and more automated manufacturing will deliver cost reductions. So too will the development of more experienced and sophisticated supply chains where fuel cell producers have greater purchasing power to leverage reductions in the cost of input materials, components and sub-systems. However, as is the case for other products reducing costs in the manufacture of fuel cell systems will also require the development of technologies that are easier and simpler to manufacture, for example through design for manufacture processes.

Similarly there is also a view in other parts of the fuel cell community that better technologies alone will deliver the necessary costs reductions, a view that can be likened to the 'silver bullet'. All that is needed is the one new technology to transform the prospects of the community, for example replacing expensive materials or components with cheaper, better versions. Again better technologies will deliver lower costs, for example reducing the precious metal loadings in reforming subsystems or expensive cell or membrane materials. However, given the complex nature of fuel cell systems with many different materials, and components and sub-systems one technology alone will not deliver the total cost reductions required.

Finally, the current structure of the fuel cell community will need to evolve and the skill base widened if the move towards commercialisation and lower costs is to be achieved. Fuel cell developers often have specific skills and expertise usually around the core technologies, be these electrochemical, mechanical and system designers or others. Manufacturing and procurement skill sets, the ability to operate complex production businesses, and the sales and marketing capabilities are either limited or completely absent. The core technology skill sets will still be required, but on their own they will not be sufficient for commercialisation.

Predicting cost reductions

Experience with other innovative energy technologies shows that costs can be expected to fall as a function of 'experience curves' as noted in the IEA and OCED report on Experience Curves for Energy Technology policy [27]. This report, albeit somewhat dated, provides a series of examples of the experience curves for innovative energy technologies such as solar pv and wind turbines where costs were seen to fall as cumulative sales increased. Rates for various energy technologies range between 10% and 20%. Cost reductions in technologies could be a function of better technologies, better manufacturing and simply better business processes within technology developers and producers, as well as greater manufacturing volumes.

Applying experience curves to stationary fuel cell systems is difficult given the paucity of data on costs and the limited period that 'customer ready' (if not mass production) systems have been available. Staffell and Green in their 2013 paper [28] looked at past and future cost paths for micro-CHP fuel cell systems. Based on a range of data their work is similar to cost ranges of €25,000–€4000 per kWe noted above. More importantly the paper looked at learning rates, similar to experience curves, for energy technologies and PEM fuel cell systems. This identified a rate of about 20% for the Ene-Farm fuel cell systems produced between 2004 and 2009, a rate which reduced to 15% for the additional units produced to 2012. The decline in the rate may reflect the growing maturity of the systems as well as the fact that 'early cost reduction wins' are not necessarily repeatable over time. Taking account of other data Staffell and Green estimated a learning rate of 16% for PEM micro-CHP systems, and calculated that the costs of such systems could fall to the METI target of $3500 after 70 million systems had been sold.

Using a different approach to costs Strategic Analysis of the USA, under a sub-contract to the NREL [29], showed how the costs of a 'typical' modelled SOFC fuel cell system, ranging from 1 kWe to 100 kWe, would reduce with the ramp up in production. Using a model for manufacture and typical subsystems, e.g. fuel cell stack, fuel processing power electronics and controls, a 1 kWe SOFC unit available for $11,830 when manufactured in 100 units per annum would reduce to $5108 at the 50,000 units per annum mark, i.e. a halving of the costs. A 100 kWe system would reduce from $532 to $402 per kWe.

Of interest is the view that the majority of the cost is dominated by the fuel cell stack and the fuel processing subsystems. Further, the primary cost reduction for smaller SOFC units will stem from improvements to the fuel cell subsystem, whilst cost reductions for the fuel processing system will be difficult: balance of plant component costs reduction opportunities, such as compressors, pumps, sensors and heat exchangers, are considered to be fairly small. Similarly other sub-systems such as power electronics are considered fairly stable cost wise.

The Strategic Analysis work certainly shows how substantial cost reductions can be made as volume rises, but it is not apparent whether account was made of the inevitable improvements to design and technology associated with any innovative product, and the impact these have on cost. Furthermore the estimate for a 1 kWe fuel cell system at $11,830 seems to be rather low when compared to data and information available in the market place.

The Staffell and Green and Strategic Analysis are both sobering pieces of work, but there are reasons to be more optimistic for cost reductions of stationary fuel cell systems by looking at real world examples of cost reductions.

Fuel cell system cost reduction in practice

Identifying real examples of cost reductions in the fuel cell field is difficult given the limited numbers of units in service and the increase in production experience to date. However, evidence from the Japanese Ene-Farm project over the past few years provides examples of what has been achieved by leading businesses in the field. Both Panasonic and Toshiba have made public announcements in the past few years about the costs of their products and progress in reducing these costs alongside product improvements.

Panasonic, with Tokyo Gas, announced in January 2013 that it had reduced the price (excluding installation) of its domestic PEM fuel cell system to ¥1,995,000 by approximately ¥760,000, a reduction of 27.5% from its 2011 model. This itself was a reduction from its 2009 model (selling at ¥3,465,000 [30]) of 20%. A year or so earlier in January 2012 Toshiba, with Osaka Gas, announced that it had reduced the price of its domestic fuel cell system by ¥650,000–¥2,604,000, a 25% reduction in cost [14]. In both cases sales increases were anticipated and further cost reductions expected.

The Panasonic announcement also included further information on the performance and other aspects of the unit. The cost reduction was associated with an improvement of lifetime from 50,000 h to 60,000 h; a reduction in components by 20%; reduced weight by 10% and reduced size overall. Of significance was a reduction in noble metals in the fuel processing subsystem by 50% and platinum catalyst by 50%. Total efficiency, both heat and power, was calculated at 95% LHV.

Toshiba noted that it had reduced costs of its newer unit through, for example, reducing platinum content by 20% and the number of cells by 15%, whilst the number of components was down 40%, achieved by simplifying the system and integrating pipes for example. Additionally Toshiba stated that the fuel efficiency of its unit both in electrical and heat terms was improved to provide a total efficiency at LHV of 94%.

It is evident from the cases of Panasonic and Toshiba that cost reductions are possible over time, but that they are not simply a function of numbers of units produced and installed, or technology improvements, but a mix of both production increases and technology and product improvements, made by it should be added, experienced and capable businesses.

Conclusions

The early commercialisation of stationary fuel cell systems can be achieved in early markets able to support a price premium. Stationary fuel cell system developers must be able to identify and effectively address these early markets. In addition to compete in the larger mass markets stationary fuel cell systems developers will need to achieve cost reductions through credible cost reduction strategies. These costs reductions will be a function of better technologies and more units produced, as well as better business capabilities and processes.

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