INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 1088–1102

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The cost of domestic fuel cell micro-CHP systems

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ARTICLE INFO

Article history:
Received 27 July 2012
Received in revised form
18 October 2012
Accepted 22 October 2012
Available online 27 November 2012

Keywords:
Fuel cell
Domestic CHP
Economic assessment
Learning by doing
Cost target
Cost reduction

ABSTRACT

Numerous academic and industrial estimates place the cost of future mass-produced small stationary fuel cell systems at around $1000 per kW, which compares well with targets set by agencies such as the US Department of Energy. Actual sale prices do not fit so neatly with these targets, and are currently 25–50 times higher even though mass production began three years ago.

This paper explores the void between academic projections and commercial reality. It presents a systematic review of cost data from manufacturers in Europe, Asia and the US, along with near-term projections from manufacturers and other relevant organisations. Using these data, the potential for cost reductions through industry scale-up and learning by doing are quantified. The minimum feasible price of a typical 1 kW natural gas combined heat and power system is then estimated from industry data.

Based on the findings, even a heroic effort by industry is unlikely to reduce the price of small domestic-scale systems to the $1000/kW mark. By aligning the scope and boundaries of cost estimates with the realities of domestic microgeneration systems, we show that a long-term target of $3000–5000 for 1–2 kW systems is more realistic, and could feasibly be attained by 2020 at the current rate of progress.

1. Introduction

Forty years after the economics of fuel cells were first assessed [1], academics and government agencies are still reliant on general estimates and targets for system cost [2–4]. In itself this should not be a problem, as all emerging technologies (e.g. third generation nuclear, carbon capture and storage or energy storage) are subject to significant cost uncertainty, and it should be reasonable to assume that the targets laid out in well-informed national roadmaps and technology forecasts can be met with consistent progress from industry.

However, information on historical and current prices for fuel cells is not widely disseminated due to commercial secrecy and low production volumes. There has been no way to determine whether the projections given in literature and by manufacturers are feasible, optimistic or completely unobtainable. The prices that are likely to be obtained in the near future are of great importance, as governments and companies alike must decide how to distribute limited funding for R&D activities and subsidies for early-stage deployment.

Residential combined heat and power (CHP) is widely regarded as a promising application for polymer electrolyte

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Abbreviations: CCS, carbon capture and storage; CHP, combined heat and power; CPI, consumer price index; DFMA, design for manufacture and assembly; DOE, U.S. Department of Energy; FCV, fuel cell vehicle; IEA, International Energy Agency; KOGAS, Korea Gas Corporation; METI, Japanese Ministry of Economy Trade and Industry; NREL, National Renewable Energy Laboratory; OEM, original equipment manufacturer; PAFC, phosphoric acid fuel cell; PEMFC, proton exchange membrane fuel cell, polymer electrolyte membrane fuel cell; PPP, purchasing power parity; SECA, Solid State Energy Conversion Alliance; SOFC, solid oxide fuel cell; USD, US dollar.

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http://dx.doi.org/10.1016/j.ijhydene.2012.10.090

membrane (PEMFC) and solid oxide (SOFC) fuel cells, tapping in to the worldwide market of over 15 million mains-gas connected domestic boiler and furnace replacements per year [5,6]. These systems can be fuelled by widely available natural gas, and produce grid-synchronised AC power alongside low-grade heat for space heating and domestic hot water. Governments in Japan, South Korea, Germany and the US are supporting significant research and development programmes for these systems.

A complete packaged product typically consists of:

- The main fuel cell system:
  - A fuel cell stack (converts hydrogen to heat, electricity and water);
  - A fuel processing system (converts natural gas (or other hydrocarbons) to hydrogen + CO_2);
  - A grid-tie inverter (to convert low-voltage DC to AC with export ability);
  - Heat exchangers (to transfer waste heat from the exhaust and coolant loops to an external system);
  - Balance of plant (pumps, valves, sensors, pipework, electronic control systems, etc.)
- Additional thermal management:
  - An auxiliary boiler to supply peak heat demands (usually integrated into the fuel cell system);
  - A high-efficiency heat store (so that a low-capacity fuel cell can supply the majority of the building's heat demand);
- Control, interaction and feedback:
  - Touch-screen LCD interface;
  - Remote control system;
  - Smart-meter for measuring consumption and production;
  - Internet-based remote monitoring and control.

This list of components is based on the systems currently being developed and marketed. Not all of them are essential; in particular the control and feedback systems could be reduced to the level present on conventional boilers and air conditioning systems. While a large heat store is not strictly necessary, fuel cell performance is severely inhibited when little or no storage is available [7].

When considering fuel cells for domestic-scale distributed generation, academic and industrial estimates place the cost of a mass-produced fuel cell stack at around $500 per kW, with an additional $500–1000 per kW for other components in a complete micro-CHP system. These estimates compare well with targets set by agencies such as the US Department of Energy (DOE), which had aimed (in 2007) to demonstrate fossil fuelled PEMFC CHP systems for under $750/kW by 2011 and under $450/kW by 2020 [8]. These targets were recently revised to $1200/kW by 2015 and $1000/kW by 2020, for a complete 2 kW natural gas fuelled PEMFC system [9,10]. Similarly, the DOE's SECA programme established cost targets for 3–10 kW stationary SOFC systems, initially starting at $800/kW by 2005, then falling to $700/kW by 2008 and $400/kW by 2010 [11,12]. Their cost reduction efforts now aim to demonstrate fuel cell stacks for $175/kW and complete systems for $700/kW [13].

Actual sale prices have not fitted so neatly with these targets. They are currently 25–50 times higher, even though some manufacturers have now started volume production. The most commercially mature systems retail for around $25,000 per kW in Japan, three years after they were launched by three manufacturers (see Table 2 later). Prices have fallen by more than half in just four years [14]; however, to meet the DOE's targets the world's most advanced systems would require a cost reduction of around 90% in the next three years.[1]

In an independent review conducted by NREL, "the majority of stakeholders believe that the DOE cost targets are unnecessarily aggressive for [the 1 kW] power level and that the technology is capable of reaching an end product (including water tank) selling price to the utilities of $5000–7000/kW by 2012–2015" [15]. The targets may prove to be counterproductive if they damage the technology's reputation by leaving stakeholders unimpressed at the apparent lack of progress against unrealistic goals.

This void between academic theory and commercial reality raises some important questions for economists and policy makers alike. Three possibilities could reconcile these differences, each with very different implications for the commercial prospects of the technology:

- Current prices are highly inflated and do not represent the underlying cost of manufacturing these systems;
- As the technology matures, learning by doing will allow current prices to naturally fall to the projected levels;
- The projected targets for mass production do not reflect the reality of manufacturing complete systems.

This paper begins with an overview of the current commercial status of stationary fuel cells. In an attempt to assess these possibilities, it then reviews the available price data for fuel cell micro-CHP systems, focussing on the most commercially advanced systems from Europe, Japan and South Korea. It demonstrates how rapidly these prices are declining, showing that billions of systems would have to be produced to reach the DOE targets, based on past experience. By breaking down the costs of producing a domestic fuel cell system, we propose that these targets under-estimate the importance of the balance of plant required for system integration, and do not cover all of the major components that would be required to fulfil the needs of domestic energy demands. A more realistic target of $3500 is proposed for a complete system, and the paper finishes by discussing the implications of these findings, and exploring ways in which this target could be reached more rapidly.

All prices in this paper are given in 2010 US Dollars (USD) to aid comparisons. Original prices were first inflated in their native currencies to 2010 money values using the consumer price index (CPI) rates given by the International Monetary Fund, and then converted from 2010 national currencies to 2010 USD using the purchasing power parity (PPP) exchange rates for 2010 from the same source [16]. This ensures that our experience curves use consistent money values, as each is based on data from a single country, and that our currency conversions accurately portray costs relative to other items consumers might buy. Where nominal exchange rates differ

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[1] The cost of manufacturing these systems (as opposed to their prices) is not precisely known, but even if a substantial mark-up of 100% at present were to fall to zero by 2020, the underlying cost would have to fall from $12,500 to $1200.