

Roads2HyCom

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**DELIVERABLE 6.1-2 PART B
FEED-BACK AND FEED-FORWARD FROM WP4/5 AND DEMONSTRATION
ACTIVITIES – STATIONARY**

**REVIEW OF TECHNICAL, SOCIO-ECONOMIC AND SAFETY
FINDINGS FROM STATIONARY FUEL CELL DEMONSTRATION
ACTIVITIES**

Intelligent Energy

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The European Commission is supporting the Coordination Action "HyLights" and the Integrated Project "Roads2HyCom" in the field of Hydrogen and Fuel Cells. The two projects support the Commission in the monitoring and coordination of ongoing activities of the HFP, and provide input to the HFP for the planning and preparation of future research and demonstration activities within an integrated EU strategy.

The two projects are complementary and are working in close coordination. HyLights focuses on the preparation of the large scale demonstration for transport applications, while Roads2HyCom focuses on identifying opportunities for research activities relative to the needs of industrial stakeholders and Hydrogen Communities that could contribute to the early adoption of hydrogen as a universal energy vector.

Further information on the projects and their partners is available on the project web-sites www.roads2hy.com and www.hylights.org



REVIEW OF TECHNICAL, SOCIO-ECONOMIC AND SAFETY FINDINGS FROM STATIONARY FUEL CELL DEMONSTRATION ACTIVITIES

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Executive Summary

The overall objective of this report was to process current demonstration activities for stationary fuel cells, regarding technical, socio-economic and safety aspects. For this purpose demonstration projects in Europe, North America (USA) and Japan were assessed.

There are considerable differences between transport and stationary sector applications and demonstrations. There is an installed base of some 6000 fuel cells (not all may be functioning) representing some 200 MW of installed power capacity in stationary applications. These have utilised most forms of fuel cell technology (AFC, MCFC, PAFC, PEMFC and SOFC) across a wide range of output powers (from 1kW to over 1MW) and sustained by a wide variety of fuels.

Demonstration projects effectively divide between large stationary, based on PAFC, MCFC and more lately SOFC technologies (approximately 120kW to over 1MW per unit); and small stationary systems, based on PEMFC and SOFC technologies (1kW to around 50kW per unit).

There is limited public access information available on the wide array of demonstration projects, but in general the outcomes indicate that the various fuel cell technologies have successfully proven their merits in terms of technical capability, operability, and availability, and safety. Lifetime and maintenance / service requirement have not always met expectations, but there are aspects that developers have improved considerably since the early demonstrations.

As with the transport sector, the evidence points to the continuing evolution of the various fuel cell technologies utilised for stationary applications, rather than major breakthrough advances.

The limited availability of a hydrogen supply infrastructure does not appear to have unduly constrained the stationary demonstration projects themselves, but may be a limitation to future wider deployment.

This report forms part of the Roads2HyCom Deliverable 6.1-2. A companion report containing a review of fuel cell vehicle demonstration activity is also available to download from www.roads2hy.com (Document Reference R2H6031PU).



1. Introduction

Roads2HyCom (R2H) is a project to assess and monitor Hydrogen and Fuel Cell technologies for stationary and mobile energy application against current and future infrastructures, and the needs of communities which may be early adopters of the technology, in order to support the Commission and stakeholders in planning future activities. Further information about the project can be found on the project website www.roads2hy.com.

The objective of Work Task 6.1-2 is to process demonstration activities for both transport and stationary applications in terms of technical, socio-economic and safety findings. Findings on transport sector applications have been presented separately (see report R2H6031PU prepared by C. Klein, which is available to download from www.roads2hy.com). The purpose of this report is specifically to present findings on stationary fuel cell demonstration activities.

There are considerable differences between transport sector and stationary sector applications and demonstrations. Transport sector applications are based on a few hundreds of vehicles in Europe, Japan and North America, which typically utilise only PEMFC technologies of a relatively narrow power output range and are usually sustained by a gaseous (or occasionally liquid) hydrogen fuelling infrastructure. In contrast there is an installed base of some 6000 fuel cells (although not all may be functioning) representing approximately 200 MW of installed power capacity in stationary applications in Europe, North America (USA) and Japan. These have utilised most forms of fuel cell technology (AFC, MCFC, PAFC, PEMFC and SOFC¹) across a wide range of output powers and have been sustained by a wide variety of fuels (including natural gas, propane, kerosene and digester gas, as well as hydrogen).

However, in line with the report on the transport applications sector, it is also the case that the amount of publicly available data for stationary applications is limited or at best very 'patchy'. There may be many reasons for this (such as technology supplier concerns with releasing information to competitors; a utility or agency wishing to demonstrate and validate technology for its own specific purposes rather than for public presentation, etc.), but the inevitable result is that the findings and lessons learned are predominantly based on fuel cell demonstration experiences where a major stakeholder or independent review agency has assessed the demonstration project(s) or overall programme for scientific, academic or government 'value for money' reasons.

The next section provides first an overview of major stationary projects and then gives details of specific activities for Europe, together with the equivalent experiences for North America (USA) and Japan. This is followed by a section covering the results and lessons learned from these activities.

¹ A description of these different technologies may be found on the Roads2HyCom WIKI H2&FC Resources website http://www.ika.rwth-aachen.de/r2h/index.php/Main_Page



2. Stationary Fuel Cell Projects - Overview

Surveys made by *Fuel Cells 2000* and *Fuel Cell Today* [1], [2] of large and small stationary fuel cell projects shows that there are some 900 'large' (>50kW) stationary fuel cells installed globally with a power capacity of some 200MW (an average of 222kW per large fuel cell installed); together with some 5000 'small' (<50kW) stationary fuel cells with a power capacity of some 7MW (estimated).

The large stationary fuel cells installed are typically based on MCFC and PAFC technologies, with some PEMF and SOFC systems involved (see Figure 1 below, courtesy of *Fuel Cell Today*). The small stationary fuel cells are typically based on PEMFC and SOFC technologies (see Figure 2 below, also courtesy of *Fuel Cell Today*).

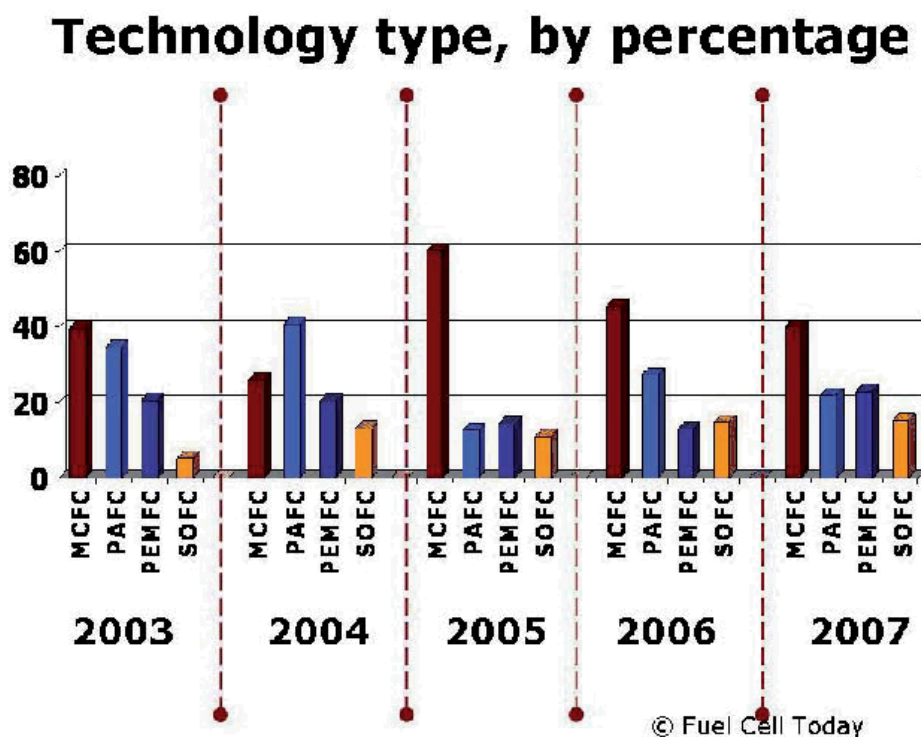


Figure 1: Fuel cell technology for 'large' fuel cell systems installed
(Courtesy of *Fuel Cell Today*)



Technology Development 2003 - 2006

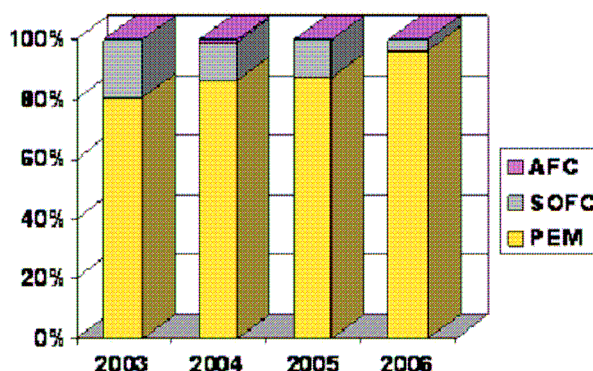


Figure 2: Fuel cell technologies utilised for small stationary applications
(Courtesy of Fuel Cell Today)

MCFC and PAFC technologies are relatively mature, with the PAFC the most commercially developed of the systems. There are developers and manufacturers of these technologies in Europe, North America and Japan and the first installations were made in each key market in the early to mid 1990's.

The US Department of Defense (DOD) demonstration programme (installations during 1994 – 1997 and demonstration through to 2003) and Climate Change Rebate support programme (1995 – 2004) encouraged installations in both the USA and in Europe (see Sections 3.1 and 3.2 below).

The size of plant is typically 200-250kW, operating on a natural gas feed, in a base load grid support (or back-up, grid independent power in an outage) and often as a CHP application. Plant sizes have reached 1MW and installations at waste treatment centres have utilised anaerobic and other digester gases, LNG and waste derived liquid methanol fuel feeds.

Demonstrated performances of MCFC and PAFC systems have been quite impressive, with high availability (typically 66-72% availability) and an average efficiency of around 40% (LHV). The longest running operational unit had achieved >43,000 hours (in 2005).

PEMFC technologies are also relatively mature and there has been considerable technical advancement since the early 1990's. In stationary applications though there are continuing limitations to performance related to MEA durability and overall system lifetime: 5-8,000 hours may be an acceptable target for PEM systems in automotive applications, whereas the target for stationary power is 40,000+ hours.

There is also the issue of hydrogen source. A pure hydrogen source is ideal, but not often readily available. Natural gas reformation is the most widely adopted fuel source for stationary fuel cells but either the reformer requires a gas clean up to



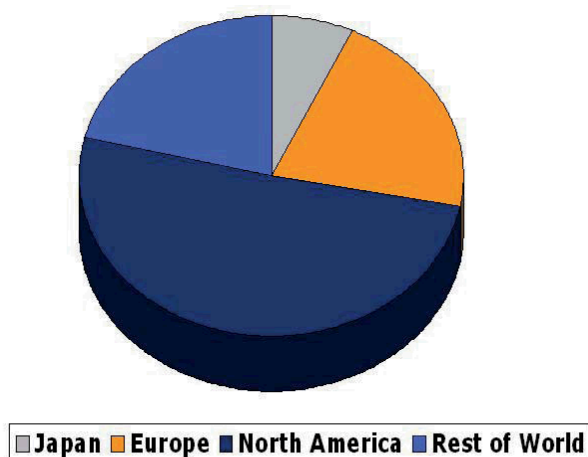
provide relatively pure hydrogen to the PEM fuel cell, or the fuel cell requires modification to cope with a reformat gas stream and in particular to CO levels which can damage the anode catalyst (anode catalysts are intolerant to CO at operating temperatures around 80°C and require an air bleed to oxidise the CO or a more tolerant or/and higher temperature anode catalyst). Consequently, stationary PEMFC demonstration programmes have as much focused on the reformer development as the PEMFC system itself.

SOFC systems are utilised for both small (domestic & commercial CHP) and large (cogeneration and fuel cell / turbine hybrid systems) stationary power applications. While there have already been some long running demonstrations (such as in the Netherlands, Japan and Canada), the technology is still undergoing intensive development, for both tubular and planar cell designs. SOFC technology has the advantage that their high operating temperature allows external or direct internal reforming of a source fuel – again natural gas is typically the fuel of choice. Internal reforming has a number of advantages (reduced balance of plant and parasitic loads) but in practice pre-reforming or / and gas clean up has been necessary (at least to remove or mitigate the presence of higher hydrocarbons and stenching odorants added to pipeline gas).

AFC systems have been planned for stationary applications but do not appear to have been realised in any major demonstration programmes to date.

The following sections assess stationary demonstration activities on a regional basis. Figure 3 below (courtesy of *Fuel Cell Today*) shows, for 2007 only, the region of operation for 'large' stationary fuel cell activities. Note that the same distribution does not apply for 'small' stationary fuel cells, where Japan now (2006-2007) predominates in the number of new installations.

Region of Operation 2007



© Fuel Cell Today

Figure 3: Region of operation of 'large' stationary applications
(Courtesy of Fuel Cell Today)



2.1 Stationary Fuel Cell Demonstration Activities - Europe

It has been difficult to obtain a coherent overview of the many fuel cell demonstration programmes that have been undertaken in Europe. There is no central database of wider programmes or specific projects and no repository of results and achievements (or otherwise). This prevents the possibility of drawing representative conclusions on stationary applications and experiences.

It is certain though that Europe has had considerable involvement in the running of large stationary projects. Examples of these have included:

- **Austria: 300kW MCFC system installed at Linz waste water treatment plant;** part of EU supported EFFECTIVE programme testing biogas; one other **300kW MCFC system installed at Owschlag, Germany** as part of the same program;
- **Germany:** Germany has been the most active EU state in large stationary applications and is the location of the majority of large stationary projects utilising some 8MW or more of PAFC, MCFC and SOFC plant. Includes the following examples:
 - **2 x 250kW MCFC ('HotModule') system for CHP** to supply up to 40 homes in winter and 300 homes in summer in the **Dinslaken** area; operational in 2004 and supported by NordRhein Westphalia region
 - **250kW MCFC ('HotModule') system for power to Vattenfall Innovation park in Berlin;** bi-fuel natural gas or/and methanol (from city waste); operational in 2004;
 - **3 x 250kW MCFC ('HotModule') systems** installed in 2003 at **Bad Berka and Gruenstadt hospitals** for base load power supply (surplus exported to the grid) and at **Karlsruhe Michelin** tire plant; the latter had logged 17,000 hours by late 2005. Part of Ministry of Economics & Technology (BMWi) Future Investment Program
 - **5 x 250kW MCFC ('HotModule') systems** installed in 2001-2002 in **Munich, Magdeberg, Bad Neustadt, Bielefeld and Essen** for back-up CHP and grid connection; the units had variously logged 12,000 hours, 19,000 hours and 21,000 by late 2004;
 - **250kW MCFC installed in 2006 at Ahlen wastewater treatment plant** operating on sewage digester gas for CHP application by RWE;
 - **250kW SOFC plant installed 2004 at Herrenhausen power plant, Hannover** for grid power and local heat;
 - **300kW hybrid turbine CHP system** operated for one year at RWE Meteorit Park, Essen
 - **2 x 200kW PAFC systems installed in 2001 at Bocholt (hospital) and Frankfurt (industrial park);** the hospital based system set the European record for 8000 hours of continuous running in its first year of operation and saved 500 tons CO₂;
 - **6 x 200kW PAFC systems installed during 1997-98 in Oranienburg (power plant); Halle; Hamburg (residential building**



- CHP); Kaltenkirchen; Saarbrücken and Nuremberg;** all as part of US Climate Change Programme
- **2 x 250kW PEMFC systems installed in 2002 in Mingolsheim and Oberhausen;** one system for 12 months testing under EDISON program which logged 6,000 hours operation at 75% efficiency; the other operating at Fraunhofer Institute;
 - **Italy: 300kW SOFC gas turbine hybrid system,** ‘thermo electric power station’ at **Morengo** run for a 12 month demonstration period, achieving an electrical efficiency of 58%; **100kW MCFC plant installed at ENEL site** for proof of concept testing (completed)
 - **Netherlands: 100kW SOFC plant installed in 1997 at Westervoort** running on pipeline natural gas and ran for 16,700 hours at a peak power of 140kW and electrical efficiency of 46% (then transferred to Essen, Germany for a further 3,700 hours operation and finally to Turin, Italy for grid support);
 - **Spain: 250kW MCFC (‘Hot Module’) installed at the Izar shipyard** in Cartagena for CHP purposes running on natural gas; operational in 2003 and had logged 18,000 hours by end 2005; **300kW MCFC unit at Pinto waste treatment plant** (part of EU ‘EFFECTIVE’ project run during 2004); **500kW hybrid MCFC gas turbine at Guadalix** installed in 2004 as part of FOAK programme; earlier **100kW MCFC plant tested at Guadalix Iberdrola site** (completed);
 - **Sweden: Sydkraft and Vattenfall tests of PAFC systems;**
 - **UK:** installation and operation of a **200kWe PAFC for CHP** and private wire network for electricity generation for a project initiated and run by a local government council. Installed in 2001 and operated under review to late 2003, the fuel cell operated for 14,000 hours and exceeded 90% availability with an electrical efficiency of >37% (LHV). The thermal load was not fully utilised so overall efficiency was ~57% whereas ~85% overall efficiency could in principal have been achieved. Environmental performance showed NOx and CO levels were minimal.

An overview of small stationary fuel cell activities indicates that Germany is also the most significant location for demonstration projects. These have been based on mostly on PEM technologies and include alpha and beta stage demonstrators of natural gas fuelled CHP systems by European Fuel Cell, Idatech; ZBT, and Plug Power/Vaillant.

Small stationary domestic and commercial SOFC CHP systems have been deployed by Sulzer Hexis (approximately 210 x 1kWe + 2.5kWth SOFC natural gas fuelled systems deployed at different sites in Germany by VNG, E.ON, RWE, EnBW and EWR during 2001 to 2004); Fuel Cell Technologies (5kW system) and Ceramic Fuel Cells (1kW micro-CHP).



2.2 Stationary Fuel Cell Demonstration Activities - North America (USA)

North America has been the centre of fuel cell development and demonstration activities, across all fuel cell technologies, from the early 1990's onwards. This is only just starting to be overshadowed by demonstration activities in Japan. This has been supported and sustained by US Federal DOE and DOD programs together with State and other funding. Project objectives have included an assessment of the current status of the technologies; their evolution toward technology readiness during the course of a program, providing feedback to fuel cell and hydrogen R&D, together with measured performance monitoring at a wide variety of installation purposes, at differing geographic locations, climatic conditions, and with a variety of sources of fuelling.

An overview of the major USA programs (in no particular order) is provided in the following subsections.

2.2.1 DoD PAFC Demonstration Programme

PAFC systems were installed at 30 U.S. Department of Defense bases [3] between 1994 and 1997. The objectives of the PAFC Demonstration were to:

- Demonstrate fuel cell capabilities in real world situations,
- Stimulate growth and economies of scale in the fuel cell industry,
- Determine the role of fuel cells in DoD's long term energy strategy

In fiscal year 1993, (FY93), the U.S. Congress appropriated \$18 million to advance the use of PAFCs at DoD installations. An additional \$18.75 million was appropriated in FY94 to expand the program. The U.S. Army Construction Engineering Research Laboratory (USACERL) was assigned the mission of managing the fuel cell demonstration projects for the DoD. USACERL's specific tasks included developing turnkey PAFC packages, devising site criteria, screening DoD candidate installation sites against selection criteria, evaluating viable applications at each candidate site, coordinating fuel cell site designs, installation and acceptance of the PAFC power plants, and performance monitoring and reporting.

PAFC Demonstration sites represent a broad spectrum of facilities and locations throughout the major Services. These include eight categories of buildings and span 17 states, from Alaska to Florida.

Seven of the fuel cells are configured to provide back-up electrical power should the utility grid experience a power outage. Thermal output from the fuel cell is used for heating boiler make-up water, domestic hot water, space heating, condensate return, process hot water, etc. An overview of the PAFC system's performance from point of commissioning to the completion of the program in early 2003 is provided in **Table 1** (see <http://dodfuelcell.cecer.army.mil/pafc/index.php4>) :



Table 1: Fuel Cell Fleet Performance through January 31, 2003

847,199	Hours of Operation
142,730	MWHrs Produced
10,548	MMBtu of Thermal Delivered
66.2%	Power Plant Fleet Availability

2.2.2 DoD Fuel Cell Climate Change Rebate Programme

In 1995, US Congress appropriated funds for the Office of the Deputy Under Secretary of Defense, Environmental Security (ODUSD-ES) to establish a competitive, cost-shared, near-term Climate Change Fuel Cell Project (H.R. 103-747) with the overall goal to expedite the market introduction of fuel cell systems. The rebate provided up to \$1,000 per kilowatt of power plant capacity (but not to exceed one-third of the total project cost based on capital and installed costs, pre-commercial operation). The Programme [4] ran between 1995 and 2004 with Grants disbursed totalling US\$37.5 million for a total of 274 installed units with 19.6MW of output capacity.

Funding was allocated annually on the basis that:

- Applicants had to demonstrate a commitment to purchase and use fuel cell power plants with a rated capacity of at least 3 kW
- Applicants could not be a fuel cell vendor, manufacturer or developer
- Priority was given to projects sited at DoD installations
- All fuel cell technologies were acceptable with no restrictions on fuel type.
- Projects representing diverse sizes, applications, fuels and locations were desirable
- The applicant's fuel cell vendor had to offer a full one year commercial warranty on fuel cell operation
- Projects had to comply with the US National Environmental Policy Act and other regulatory requirements

Although any technology was acceptable, 104 of the 274 units installed were PEMFCs, and 3 were SOFCs. The other units, and the majority of the installed power capacity, were MCFC or PAFC systems (see <http://dodfuelcell.cecer.army.mil/climate/index.html>).



2.2.3 US DoD Residential PEM Demonstration Project

The DoD Residential PEM Demonstration Project began in 2001 (FY01) with the purpose to demonstrate domestically-produced, residential-scale, stationary PEM fuel cells at military facilities, managed by the Fuel Cell Team at the United States Army Engineer Research and Development Center / Construction Engineering Research Laboratory (ERDC/CERL) [4]. Further project funding saw the continuation of projects through to the end of 2004.

Five contractors were selected for the FY01 PEM demonstration solicitation, representing a total of 21 PEM fuel cells at nine U.S. military sites. Five contractors were selected for the FY02 PEM demonstration, representing a total of 26 PEM fuel cells at 15 U.S. military sites. Eight contractors were selected for the FY03 PEM demonstration, representing a total of 29 PEM fuel cells at 20 U.S. military sites. Four contractors were selected for the FY04 PEM demonstration, representing 15 PEM fuel cells at 12 U.S. military sites. The core set of requirements were that:

- All PEM fuel cells to be produced in the U.S
- Units to be installed at U.S. military facilities
- Fuel cell contract awardees were responsible for siting and installation requirement.
- Fuel cells to provide 1 year of fuel cell power with 90% unit availability.
- All units to have comprehensive maintenance contract for minimum 1 year demonstration period
- Data performance monitoring to be conducted for each PEM unit
- Contract had to include an option for removal of fuel cell and site restoration
- Location had to be in a specified U.S. geographic region
- Applications were not required to be residential facilities, commercial and remote building applications also permitted
- The demonstration PEM fuel cells could include any fuelling option based on:
 - Fuel Type - natural gas, propane, hydrogen, other
 - Fuel Options - fuel switching, no fuel switching, fuel blending
 - Electrical Interface - grid-connected, grid-independent, both (alternating)
 - Thermal Interface - cogeneration, no cogeneration
 - Unit Configurations - individual, multiple units

The demonstration programme offered access to the results of the installation, performance, maintenance requirements and (any) failure analysis at each site. Overall, the performance achieved was as given below in Table 2 (see



<http://dodfuelcell.cecer.army.mil/res/index.php4>):

Table 2: Fuel Cell Fleet Performance

523,378	Hours of Operation
1,293,133	Total kWh
23.7%	Average Electrical Efficiency
86%	Power Plant Fleet Availability

2.2.4 DOE Hydrogen Program

The DOE Hydrogen Program was launched in 2004 to implement the President's Hydrogen Fuel Initiative. Its mission is to research, develop and validate hydrogen production, storage and fuel cell technologies and to overcome non-technical barriers to commercialisation of these technologies. The program integrates basic and applied research, development and demonstration and other supporting activities to advance hydrogen and fuel cell technologies. The Offices of Energy Efficiency and Renewable Energy, Nuclear Energy, Fossil Energy and Science are all involved, as is the Department of Transportation in the Hydrogen Fuel Initiative. Funding so far has reached US\$734 million (2004-2007).

Different sub programs focus on validation and demonstration of fuel cells, fuel cell materials, and fuel cell systems (such as the Learning Demonstration on Fuel Cell Stack Durability).

2.2.5 SECA Development Program

The US Solid State Energy Conversion Alliance (SECA) was initiated in the fall of 1999 bringing together government, industry, and the scientific community to promote the development of environmentally friendly solid oxide fuel cells (SOFC) for a variety of energy needs. SECA is an alliance of industry groups who individually plan to commercialize SOFC systems for pre-defined markets; research and development institutions involved in solid-state development and demonstration activities; and government organizations that provide funding and management for the program. The SECA alliance was formed to accelerate the commercial readiness of SOFCs in the 3 kW to 10 kW for use in stationary, transportation, and military applications. The National Energy Technology Laboratory (NETL), manages the SECA program for the Office of Fossil Energy.

Phase 1, testing and validation of SOFC prototypes, ran between mid 2005 to December 2006 and demonstrated:

- Average efficiency of 38.5%, with a high of 41%, exceeding the DOE target of 35%.
- Average steady-stage power degradation of 2% per 1,000 hours, better than the DOE target of 4% per 1,000 hours.



- System availabilities averaging 97%, better than the 90% DOE target across the board.
- Projected system costs ranging from \$724 to \$775 per kilowatt, which eclipsed the DOE intermediate target (based on an annual production of 250 megawatts) and moves the technology toward achieving the \$400 per kilowatt target for commercial applications.

(See [5] http://www.fossil.energy.gov/news/techlines/2007/07039-SECA_Concludes_Phase_I.html)

2.2.6 Other demonstration programs

There are many demonstration programmes that have been undertaken, or are still continuing, for stationary fuel cells in the U.S. and Canada. These include the work of specific utilities or local agencies (e.g. King County Fuel Cell Demonstration Project, California Air Quality Resource Board, Delaware County Electric Cooperative Residential Fuel Cell Demonstration, etc); Long Island Power Authority Clean Energy Initiative; New York State Energy Research & Development Authority Hydrogen Initiative and Fuel Cell Demonstration Programme. These are too numerous to review separately as they have all at some level contributed to the continuing development and deployment of stationary fuel cells, however the activities in New York State are of considerable significance in their own right and represent key milestones in stationary activities. This includes:

- **New York Power Authority (NYPA)** [6] installed the world's first commercial fuel cell in 1997 to run on anaerobic waste gas created at a wastewater treatment plant (used primarily methane and carbon dioxide by-product gas from sewage treatment, avoiding flaring, generating 1.6 million kWh pa for just 70kg of emissions).
- NYPA installed 21 other PAFC and MCFC grid parallel or grid independent stationary fuel cells in the State providing 2.9MW of capacity. Locations included 8 other waste water treatment plant, hospitals, the Police Station in Central Park, New York University, and the New York Aquarium in Brooklyn; making NYPA the national leader in stationary fuel cells.
- **Long Island Power Authority (LIPA)** [7]: In 2004, LIPA began the first State backed Residential Fuel Cell Demonstration Project based on 5kW fuel cells at multiple residential homes providing CHP to demonstrate the ability to supply critical electric and thermal loads within each residence (and supplemental power or as primary power if the grid goes down). This was extended in 2005, with a set of Residential and Remote Sites projects (e.g. in 2005, back-up power at West Babylon substation to run DC power for the battery based UPS located in the Control Room to ensure continued DC power to the substation switches and prevent loss of electricity to all customers fed by the substation).
- LIPA tested multiple small fuel cell systems (during 2000-2002) then in 2004 created the first fuel cell powered substation, using 75 x 5kW (Plug Power) units (utilising natural gas as the fuel source)



- Between 2001 and 2005 LIPA installed 3,759 MWh of fuel cell resources, which accounted for 264 MWh of electric generation (see Figure 4 below)

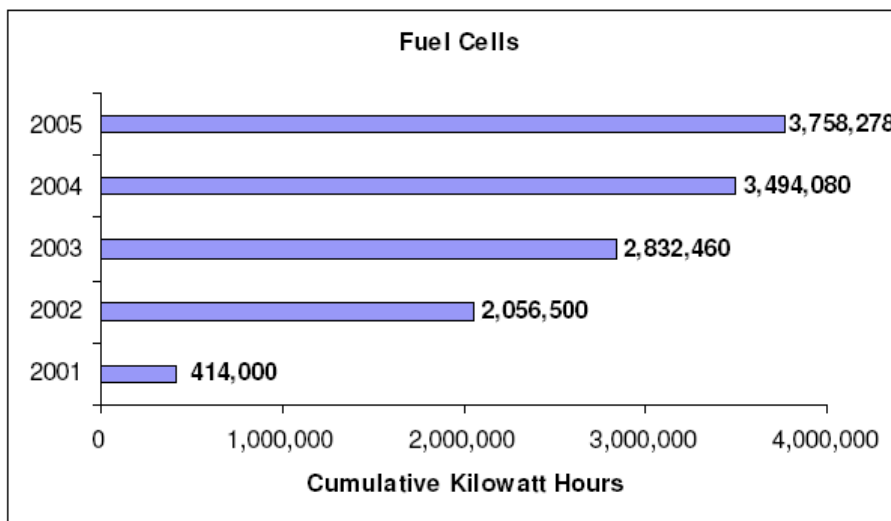


Figure 4: Stationary Fuel Cells (PEM) installed by Long Island Power Authority 2001-2004



Night & Day operation



75 PEM Systems Connected to the Grid



Figure 5: Fuel Cell (PEM) power plant - connected to the grid at LIPA's West Babylon substation



2.3 Stationary Fuel Cell Demonstration Activities - Japan

Japan is a formidable developer of fuel cell technologies for stationary applications. The Japanese government has been a firm supporter of fuel cells for CO₂ emission reduction, as a contribution to energy security and as a reinforcement of industrial competitiveness. Via the Ministry of Economy, Trade and Industry (METI) [8], the New Energy and Industrial Technology Development Organisation (NEDO) [9] and other agencies a formal roadmap has been prepared and implemented for both technology and infrastructure development, demonstration and accelerated introduction of systems to achieve full scale commercialisation in 2030 (see: Roadmap Committee of FC Technology Development, NEDO, 2006, <http://www.fcdic.com/eng/news/200606.html>).

Fuji Electric developed large stationary fuel cells based on PAFC technology [10] and delivered the first demonstration units in the early 1990's, leading to commercial type system being installed from 1998, utilising city gas and biogas fuels, operated at a variety of sites (hospitals, water treatment, office blocks, etc).

This represented approximately 10MW of generating capacity installed between 1998 and 2005, most achieving over 40,000 hours of operation (and some over 50,000 hours of operation) in their demonstration period. Fuji Electric is continuing development of the technology and is now shipping PAFC systems with a service life of at least 60,000 hours.

MCFC systems have been developed and demonstrated by IHI between 1999 and 2005 while Marubeni Corporation has imported and installed UTC 250kW MCFC systems.

The most significant attention for stationary applications though has gone to PEM fuel cells for home use, which with regards to Japanese lifestyle requirements, often do not exceed 1 kW. Town gas, LPG, LNG and kerosene have been used as fuel sources. More recently, attention is being given to SOFC development for 1-5kW domestic scale systems.



Demonstration of Residential PEFC Systems for Market Creation

Stationary Use

Introduction of 480 Residential PEFC Systems in FY2005

NEDO activity

NEDO commenced a large-scale residential PEFC system demonstrative research project in FY2005 that is expected to have a significant CO₂ reduction effect. The objective of this project is not only to promote the commercialization of residential PEFC systems, but also to acquire extensive real-world operating data in order to identify technical issues, such as those related to durability or reliability, and to feed this information back into future R&D activities.

Features

In FY2005, 480 1kW stationary PEFC systems were installed through the New Energy Foundation, in order to acquire operating data. Approximately 700 additional systems will be installed in FY2006.



Gas supplier: Tokyo Gas Co., Ltd.
Equipment manufacturer: Matsushita Electric Industrial Co., Ltd.

Oil supplier: Nippon Oil Corporation
Equipment manufacturer: Sanyo Electric Co., Ltd.

Figure 6: NEDO residential demonstration program

The NEDO demonstration programme for residential fuel cells commenced in 2005 (see Figure 6). The programme had a budget of some \$23 million to be disbursed as a subsidy across the deployment of 480 1kW stationary PEM systems.

Seven local firms were designated as formal participants in the programme for supply, installation and monitoring (see: www.nedo.go.jp/english/index.html):

- Tokyo Gas
- Osaka Gas
- Nippon Oil Corporation
- Japan Energy Corporation
- Idemitsu Kosan Co
- Kyushu Oil Co
- Yaiyo Oil Co

An overview of the field results is given in figure 7, showing power generation and usage efficiencies and heat recovery and heat utilisation efficiencies across 175 phase 1 sites (compared with the best results of the top few sites).

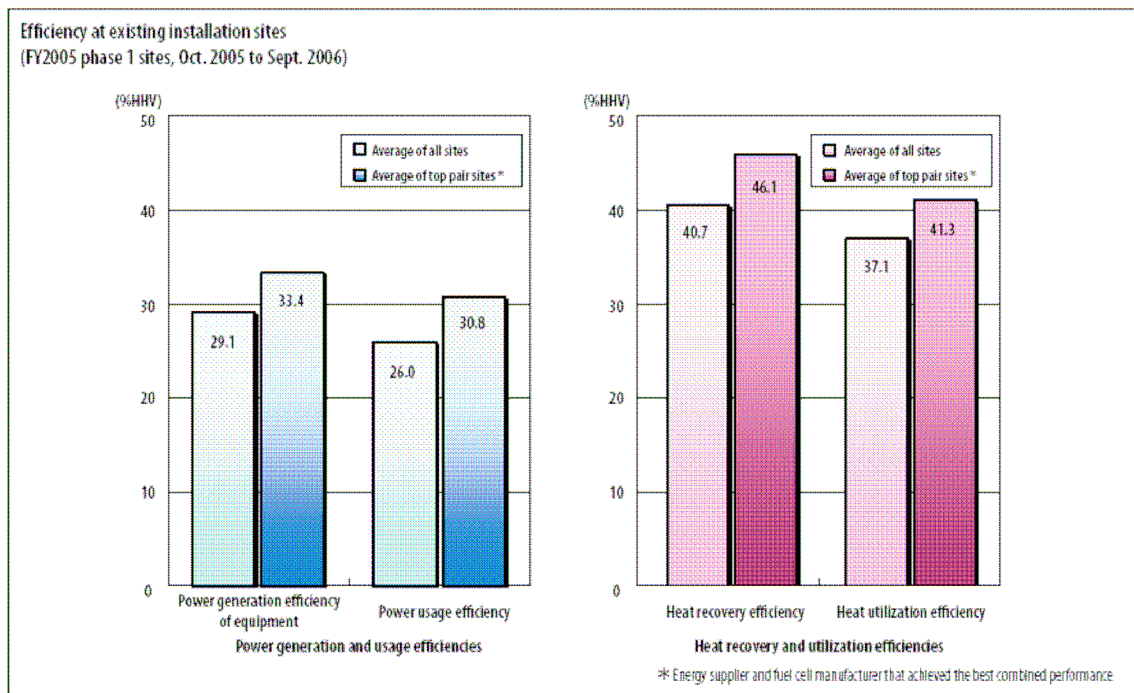


Figure 7: Overview of results from the NEDO residential fuel cell demonstration program

In April 2007 NEDO increased the total number of residential fuel cell systems to 930 sets. The fuel source mix was consolidated on just town gas (for 355 systems), LPG (for 424 systems) and kerosene (151 systems).

Installations are to be at individual dwellings (houses rather than apartments) in a mix of locations with the continuing objective of obtaining real life practical usage information at the household level for both the fuel cell and fuel reformation systems.



3. Results & Lessons Learned

As indicated earlier, the amount of publicly available data for stationary applications is limited or, at best, very 'patchy'. This, correspondingly, hampers the ability to draw firm conclusions. At a general level the review indicates that there has been significant progress across all technologies; that there have been relatively few outright programme failures; and no substantive accidents / fatalities. Even though there are still no internationally adopted codes and standards for the installation and operation of stationary fuel cell and hydrogen systems, all of the reviewed programmes and projects found a local resolution to codes and standards requirements for site identification, preparation and then installation and operation. In the clear majority of cases, the environmental benefits of the demonstrated fuel cell systems were positive at the point of use.

3.1 Large Stationary Projects

The large stationary projects have mainly involved PAFC and MCFC technologies, with fewer examples of SOFC and PEMFC technologies in use. In general:

- Earlier PAFC and MCFC projects (installed in the USA and Europe, and to a lesser extent in Japan) in the mid to late 1990's were proof of technical capability for providing back-up electrical power and thermal capture for boiler heating, space heating, condensate return, etc. and in running grid connected loads.
- The projects also demonstrated the ability to work with a wide diversity of fuels; from natural gas to waste gas and digester gas, and with various liquid fuels.
- Plant fleet availability was relatively low in earlier demonstration periods (pre 2003), at around 65-75%, but has been improving and has reached >90% (particularly for larger MCFC projects in the US and Europe).
- The thermal output is not always well utilised so system efficiencies may not have been as high as achievable (~60% in operation versus ~85% generally available).
- There have been numerous practical issues at the installation and operation stages, such as:
 - Integration with utility networks less than straightforward (special agreements and surveys often required) in US and Europe
 - Matching the operating voltage of the fuel cell with that of the local distribution network was sometimes an unexpected challenge
 - Minor equipment damage during shipping
 - Minor modifications made in the field



- Not all sub-modules ‘plug & play’
- Gas feed quality and quantity needing special attention and monitoring
- Multiple component maintenance requirements (some anticipated, some not)
- Operational simplicity once up and running
- Air quality improvements over conventional systems proven
 - Up to 160 tonnes of CO₂ saved per 1000 hours of operation relative to central generating plant
- No (reported) safety related incidents
- Installed plant size generally increasing – more instances since 2005 of MW scale plant
- Operating lifetimes increasing from around 25,000 hours to near 60,000 hours
- Also, more instances of plant hybridisation: fuel cell system plus gas turbine for higher efficiency and higher heat recovery (this has been noted for MCFC and recent SOFC systems)

3.2 Small Stationary Projects

The small stationary projects have mainly involved PEMFC (around 90% of the installed base by number) and SOFC (around 10% of the installed base by number) technologies. PEMFC demonstration programmes gained momentum from around 2002/3 onwards, SOFC demonstration programmes from around 2005 onwards. In general:

- Earlier PEMFC demonstration projects were mainly in the USA (and to a much lesser extent in Europe).
- This has been eclipsed by Japan, which now has the highest numbers of installed PEMFC systems in demonstration than any other country.
- PEMFC systems have shown proof of technical capability for providing back-up electrical power (for both grid connected and grid independent installations) and remote power; for cogeneration CHP; running as separate individual units and as connected multiple units ‘power plant’.
- In particular, grid parallel inter-connect experience has been shown to be successful (over 1.1 million hours of successful operation in the US National Rural Electric Cooperative Association evaluation of residential fuel cells).
- Use of PEMFC hybrid systems (with a battery array to cover peaks and cut-over period) shown to be technically and financially realistic.



- They have also demonstrated the ability to work with a 'pure' hydrogen feed and, via reformation, a mix of other base fuels: typically natural gas, propane, LPG, methanol, ethanol, kerosene, etc.
- Plant fleet availability can be impressively high, and has reached 90% (US DOD residential PEM demonstration project), but this has not been sustained over long operational periods (> 2 years).
- Relatively low overall electrical efficiency (24% to 30%) – mainly a reflection of PEMFC systems combined with reformation systems; a direct hydrogen fuelled PEMFC can achieve up to 56% overall electrical efficiency
- Average life span of a PEM stack in stationary demonstration reached 4722 hours
- Numerous practical issues at installation and operation stages
 - Installations typically outdoors – no standards or certification route for widespread installation indoors
 - Necessity to provide continuous monitoring of the fuel cell unit to provide immediate awareness of actual or potential problems
 - When used in conjunction with fuel reformation, reformer waste heat is not readily covered (therefore low thermal and low overall electrical efficiency measures)
 - Unexpected component failure (inverters and converters a particular issue in earlier demonstrations) and maintenance requirements
- Air quality improvements (at point of use) over conventional systems proven
- No (reported) safety related incidents
- PEM and SOFC technologies now looking to extend system life (target of 40,000 hours), improve reliability and reduce costs (target 750 Euro/kW)



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