DOE Hydrogen and Fuel Cells Program Record	
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Title: Micro CHP Fuel Cell System Targets	
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Item:

Performance, cost, and durability targets for residential combined heat and power (CHP) fuel cell systems operating on natural gas are presented in Table 1.

Table 1. Technical Targets: 1–10 kW_e Residential Combined Heat and Power and Distributed Generation Fuel Cell Systems Operating on Natural Gas[a]

	2011 Status	2015	2020
Electrical efficiency at rated power[b]	34-40%	42.5%	>45%[c]
CHP energy efficiency[d]	80-90%	87.5%	90%
Equipment cost[e], 2 kW_{avg}[f] system	NA	\$1,200/kW_{avg}	\$1,000/kW_{avg}
Equipment cost, 5 kW_{avg} system	\$2,300-4000/kW[g]	\$1,700/kW_{avg}	\$1,500/kW_{avg}
Equipment cost, 10 kW_{avg} system	NA	\$1,900/kW_{avg}	\$1,700/kW_{avg}
Transient response (10-90% rated power)	5 min	3 min	2 min
Start-up time from 20°C ambient temperature	<30 min	30 min	20 min
Degradation with cycling[h]	<2%/1,000 h	0.5%/1,000 h	0.3%/1,000 h
Operating lifetime[i]	12,000 h	40,000 h	60,000 h
System availability[j]	97%	98%	99%

[a] Pipeline natural gas delivered at typical residential distribution line pressures.
[b] Regulated AC net/LHV of fuel.
[c] Higher electrical efficiencies (e.g. 60% using SOFC) are preferred for non-CHP applications.
[d] Ratio of regulated AC net output energy plus recovered thermal energy to the LHV of the input fuel. For inclusion in CHP energy efficiency calculation, heat must be available at a temperature sufficiently high to be useful in space and water heating applications. Provision of heat at 80°C or higher is recommended.
[e] Complete system, including all necessary components to convert natural gas to electricity suitable for grid connection, and heat exchangers and other equipment for heat rejection to conventional water heater, and/or hydronic or forced air heating system. Includes all applicable tax and markup. Based on projection to high-volume production (50,000 units per year).
[f] kW_{avg} is the average output (AC) electric power delivered over the life of system while unit is running.
[g] Strategic Analysis, Inc. preliminary 2011 cost assessment of stationary PEM system, range represents manufacturing volumes of 100 to 50,000 units per year.
[h] Durability testing should include effects of transient operation, startup, and shutdown.
[i] Time until >20% net power degradation.
[j] Percentage of time the system is available for operation under realistic operating conditions and load profile. Unavailable time includes time for scheduled maintenance.

Supporting Information:

On May 28, 2009, DOE issued a request for information (RFI), DE-FOA-0000111, soliciting comments from stakeholders and the research community on proposed technical targets for residential CHP fuel cells systems and APU fuel cell systems. The targets proposed in the RFI, as detailed in Table 2, were generated at a pre-RFI workshop organized by DOE on June 12, 2008 in Arlington, Virginia, and were further revised through interactions with the research community prior to release of the RFI.

Table 2. Proposed performance, durability, and cost targets for fuel cell systems for residential CHP using natural gas from the 2009 RFI.

	Estimated 2008 Status	2012	2015	2020
Power output	1 - 10 kW	1 - 10 kW	1 - 10 kW	1 - 10 kW
Energy efficiency at rated power[1]	~38% DC	42.5% DC	42.5% AC	47.5% AC
CHP energy efficiency	> 75%	80%	85%	90%
Cost[2]	~ $750/kW	$550/kW	$500/kW	$350/kW
Transient response (10 - 90% rated power)		< 1 min	20 s	5 s
Start-up time from 20°C ambient	720 min	240 min	60 min	30 min
Average steady-state degradation	< 2%/1000 h	1%/1000 h	0.5%/1000 h	0.25%/1000 h
Transient power degradation	< 1%	0.50%	0.25%	0.10%
Operating lifetime	~5900 h	16,650 h[3]	24,975 h[4]	49,950 h[5]
System availability	97.00%	97.5%	> 97.5%	> 97.5%

[1] DC net/LHV or AC net/LHV. 2015 and 2020 targets include DC-AC conversion efficiencies.
[2] Factory cost defined at 50,000 unit production (250 MW in 5-kW modules).
[3] Approximate hours in 2 yrs of operation at 95% availability.
[4] Approximate hours in 3 yrs of operation at 95% availability.
[5] Approximate hours in 6 yrs of operation at 95% availability.

Stakeholders submitted recommendations to DOE in response to the RFI. Revisions to the proposed targets were made using information provided in the RFI responses, as well as information obtained in subsequent discussions with stakeholders. Where target values were changed from those proposed in the RFI, explanation of the basis for the change is included below. The targets were designed with the intention that 2020 target values represent levels at which fuel cell CHP systems would be competitive with grid electricity and conventional heat generation in regions with climate and energy prices favorable to CHP. Commercialization in some markets may be possible at 2015 target values.

Electrical Efficiency at Rated Power

RFI responses indicated that electrical efficiency status and targets should be based on regulated AC power. The 2011 status of 34-40% reflects status from various sources, including input from the pre-RFI workshop (34%, based on an assumption of 90% efficient DC-AC inversion), responses to the RFI (around 35%), and public information reported by manufacturers (including 40% reported by Acumentrics [1], ClearEdge [2], and Panasonic [3]).

RFI recommendations for a long-term electrical efficiency target ranged from 40% to 50%. Based on these recommendations, as well as input from the pre-RFI workshop, a 2020 target of 45% was established. The selected value represents a slight reduction from the original proposed target of 47.5%, since it was determined that a target higher than 45% is not needed to compete with conventional technology. Furthermore, an excessively high target may lead to inordinate emphasis on electrical efficiency R&D, at the expense of R&D needed to address other barriers. A 2015 target of 42.5% was established as an interim target on a path toward the 2020 target.

CHP Energy Efficiency
The 2011 status of 80-90% CHP efficiency (LHV) is based on input from the RFI (80-85%) and public information from manufacturers (85% reported by Acumentrics [1], and 90% reported by ClearEdge [2] and Panasonic [3]). Reported status numbers do not necessarily conform to the DOE specification of heat available at 80°C; for instance, ENE Farm product specifications indicate that hot water is available at approximately 60°C [4], while ClearEdge specifies heat availability at 65°C [2].

Input from the RFI indicated that the proposed 2020 target of 90% CHP efficiency is appropriate. However, the 2015 target was increased to 87.5%, which is a more appropriate interim target given current status.

Cost Status
In 2011, Strategic Analysis, Inc. (SA) conducted a cost analysis for 5 kW low-temperature PEMFC CHP systems, yielding a preliminary projected status ranging from ~$2,300/kW for manufacturing at a volume of 50,000 units per year to ~$4,000/kW at a volume of 100 units per year [5]. The cost status determined by SA represents a hypothetical status for low-temperature PEMFCs, since U.S. manufacturers are not currently producing fuel cell micro CHP systems at high volume. Other cost estimates include $729/kW for a 3-10 kW tubular SOFC system [1], though this cost does not include all system components.

The suggested price of ENE-Farm systems supplied by Tokyo Gas and Panasonic is ¥2.76 million for a 750 W system [6], corresponding to approximately $36,000/kW. Several factors prevent the ENE-Farm number from being directly comparable with the DOE cost status:

- The ENE-Farm number is a suggested price, which may include profit, overhead, and various other markups; it also includes tax
- ENE-Farm rated power is lower (750 W, vs. 5 kW in the DOE status)
- Actual ENE-Farm manufacturing volume is lower than in the DOE projections (expected sales of 5,000 750 W units/year vs. 50,000 5 kW units/year)
- ENE-Farm units contain component technologies that were developed several years ago, and have since been integrated into complete systems and validated through field testing; in contrast, the DOE status represents the current laboratory-scale state-of-the-art, but significant work remains for system integration and validation

- The value of the yen vs. the dollar is near a historic high, making the cost of Japanese products relatively high

Cost Targets
Fuel cell CHP systems have the potential to significantly reduce the use of grid electricity in residential installations, providing cost savings to homeowners. Cost targets are based on the assumption that fuel cell CHP systems will be adopted because of these utility cost savings; other advantages, including reliability and low GHG emissions, are not factored into the cost targets, though they may represent additional incentives to homeowners.

The economic benefits provided by fuel cell CHP systems are sensitive to multiple factors; among these factors, utility prices and climate are among the most significant. Cost targets were established at levels determined to be economically viable in key target markets. These markets were selected because they combine high spark spread (relatively expensive electricity and relatively inexpensive natural gas) with favorable climate (significant space heating requirements during more than six months of the year). The following parameter values were determined to be appropriate in the target markets:

- $0.155/kWh residential grid electricity assumed constant over the life of the system
- $0.06/kWh residential natural gas ($17.60/MMBTU), assumed constant over the life of the system
- Utilization of 2/3 of the recoverable heat

Cost targets were developed under the assumption that fuel cell CHP systems will meet DOE technical targets, including:

- 45% electrical efficiency in 2020 (average over life of system)
- 90% CHP efficiency in 2020 (average over life of system)
- 60,000 hours service life in 2020

Cost targets are based on utility cost savings. Since the analysis assumes fixed electricity and natural gas prices, and since billing is typically assessed on a monthly basis, the accrual of utility cost savings is assumed to occur monthly in equal increments. The monthly utility cost benefit is calculated by subtracting the cost of the natural gas used by the fuel cell system from the sum of the dollar value for heat and electricity generated by the fuel cell system, and dividing by the number of months the system is in service throughout the system lifetime. The dollar value of the produced electricity is calculated based on the cost to purchase the same quantity of electricity from the grid. The dollar value of the heat generated is calculated based on comparison with the cost to generate the same quantity of heat using a natural gas furnace with 90% efficiency (LHV). A factor of two-thirds is applied to account for a limited utilization of recoverable heat in the target markets.

Assuming monthly utility cost savings are reinvested at a 5% annual percentage yield, the present value of the investment is calculated at the end of service assuming a 10% discount rate. This present value is the allowable total cost of the system (excluding natural gas) on a kW-basis, which allows for a 10% rate of return (ROR) on the investment. This analysis is based on the assumption that consumers will ***not*** re-invest utility savings in additional CHP systems, and that a 10% ROR provides a 5 percentage point incentive over the assumed base reinvestment rate of 5%.

The total cost allowance (excluding fuel) calculated in this manner for the CHP system is \$2,447 per kW_{avg}. The kW_{avg} specification here represents the average power the system produces during operation, rather than the rated power of the system. This number was rounded to produce a total cost goal of \$2,400/kW_{avg} in 2020. While this goal was selected to enable competition with the conventional alternative (purchase of power from the electrical grid and generation of heat with a furnace or boiler), fuel cell CHP systems meeting this goal would also be competitive with alternative CHP systems. For instance, CHP systems based on reciprocating engines and microturbines have installed costs around \$1,100-2,100/kW and \$2,400-\$3,000/kW [7], respectively, and provide electrical efficiency significantly lower than that of fuel cell systems.

The target-setting analysis assumes that installation costs to the consumer for a 1-10 kW_{avg} system will be \$2,000, regardless of system size, and that maintenance and repair costs will be \$500/kW_{avg} over the life of the system, based on DOE appliance standards for residential heating equipment [8] and an assessment of additional maintenance costs required for CHP systems. Based on these assumptions, the cost of the equipment will have to be \$1,500/kW_{avg} for a 5 kW_{avg} system to achieve the \$2,400/kW_{avg} total cost goal in 2020. Similarly, a 2 kW_{avg} system must have an equipment cost of \$900/kW_{avg} , which was rounded to \$1,000/kW_{avg} for the 2020 target, while a 10 kW system must have an equipment cost of \$1,700/kW_{avg} to meet the 2020 total cost goal.

These cost targets represent values required to enable widespread adoption in target markets, but higher costs may be acceptable in some markets. Justifications for higher costs may include: higher electricity rates, lower natural gas rates, and existing heating appliances with <90% efficiency.

When evaluating specific cases, additional credit may be taken if the installation of a CHP system offsets the cost of installing a conventional system. If a high-efficiency furnace (>90% LHV) is already in place, no extra credit should be taken, but if the CHP system is installed in lieu of a new conventional heating appliance, credit may be taken for offsetting costs of equipment, installation, maintenance, and repairs of the displaced heating appliance.

The 2015 cost targets are established at a level expected to enable market penetration with early adopters and in regions with climate and utility prices favorable for CHP. The relatively small difference between 2015 and 2020 cost targets is due to the lower durability and lower efficiency expected in 2015, both of which have a negative impact on lifecycle cost. Therefore, cost targets must be relatively low in 2015 to achieve an acceptable lifecycle cost.

Transient Response

The time required for a 10-90% power transient varies strongly with technology, with response time generally longer in SOFCs than in PEMFCs. RFI responses indicated that transient response time is a lower priority than other target areas, since the use of grid power, or of hybrid batteries in off-grid applications, can compensate for slow fuel cell response. Status reports from the RFI process indicate that 5 minutes or less is representative of typical transient response time. Based on RFI input, a 2020 target of 2 minutes was selected, with a 2015 interim target of 3 minutes.

Startup Time

Startup time varies widely, but startup in less than 20 minutes has been reported for high temperature SOFC systems [1]. This represents a significant improvement over earlier SOFC systems, which required as long as 12 hours for startup. Based on RFI responses, PEMFC systems are also likely to require 20-30 minutes start-up time, mostly due to the high temperatures required for natural gas reforming. Based on RFI responses, a 2020 target of 20 minutes was selected as a value that would be acceptable to consumers, and that would allow on/off usage during non-winter months.

Degradation with Cycling and Operating Lifetime

Operating lifetime is an important metric for fuel cell CHP systems, since long lifetime is needed to realize expected utility savings and offset high equipment and installation costs. Current status is around 12,000 hours [1]. A 2020 target value of 60,000 operating hours was selected as a value that will be acceptable to consumers, corresponding to a lifetime of around 10 years at 6,000 operating hours per year, or 7 years if operated continuously. Net power degradation of less than 20% over this period is required, corresponding to less than 0.3% degradation per 1,000 hours.

System Availability

System availability is defined as the percentage of time the system is operational. Unavailable time includes time for scheduled maintenance, as well as unscheduled outages. Based on workshop input and RFI responses, current system availability status is around 97%. A 2020 target of 99% availability was selected, based on input indicating that high reliability is a key factor in consumer buying decisions. A 2015 goal of 98% was established as an interim target.

References

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[2] ClearEdge Power website, http://clearedgepower.com/business/products-services/faq

[3] Panasonic household fuel cell (ENE FARM) website, http://panasonic.net/ha/e/FC/doc03_00.html

[4] Kiyoshi Okamura, "Tokyo Gas's Fuel Cell CHP Business for Residential Use," November 9, 2010, http://www.fch-ju.eu/sites/default/files/documents/ga2010/kiyoshi_okamura.pdf

[5] Preliminary analysis provided to DOE by Brian James et al., Strategic Analysis, Inc., 2011.

[6] Tokyo Gas Co. press release, "Tokyo Gas and Panasonic to Launch New Improved 'Ene-Farm' Home Fuel Cell with World-Highest Generation Efficiency at More Affordable Price," February 9, 2011, http://www.tokyo-gas.co.jp/Press_e/20110209-01e.pdf

[7] U.S. Environmental Protection Agency Catalog of CHP Technologies, December, 2008, http://www.epa.gov/chp/basic/catalog.html

[8] U.S. DOE, Residential Furnaces and Boilers Final Rule Technical Support Document, http://www1.eere.energy.gov/buildings/appliance_standards/residential/fb_tsd_0907.html