DOE Hydrogen and Fuel Cells Program Record	
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Title: Medium-scale CHP Fuel Cell System Targets	
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Item:

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

Table 1. Technical Targets[a]: 100 kW–3 MW Combined Heat and Power and Distributed Generation Fuel Cell Systems Operating on Natural Gas[b]

	2010 Status[c]	2015 Target	2020 Target
Electrical efficiency at rated power[d]	42-47%	45%	>50%[e]
CHP energy efficiency[f]	70-90%	87.5%	90%
Equipment cost, natural gas	$2,500-4,500/kW[g]	$2300/kW[h]	$1000/kW[h]
Installed cost, natural gas	$3,500-5,500/kW[g]	$3000/kW[h]	$1500/kW[h]
Equipment cost, biogas	$4,500-6,500/kW[g]	$3200/kW[h]	$1400/kW[h]
Installed cost, biogas	$6,000-8,000/kW[g]	$4100/kW[h]	$2100/kW[h]
Number of planned/unplanned outages over lifetime	50	50	40
Operating lifetime[i]	40,000-80,000 h	50,000 h	80,000 h
System availability[j]	95%	98%	99%

[a] Targets are for a complete system, including fuel processor, power electronics, stack, and ancillaries.
[b] Pipeline natural gas delivered at typical residential distribution line pressures.
[c] Status varies by technology. Reported status represents PAFC and MCFC technology.
[d] Ratio of regulated AC net output energy to the lower heating value (LHV) of the input fuel
[e] Higher electrical efficiencies (e.g. 60% using SOFC) are preferred for non-CHP applications.
[f] 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.
[g] Cost at current production volume (~30 MW per year).
[h] Includes projected cost advantage of high-volume production (100 MW per year).
[i] Time until >10% 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:

Status

The Office of Energy Efficiency and Renewable Energy (EERE) and the Office of Fossil Energy jointly sponsored a workshop on molten carbonate fuel cells (MCFCs) and phosphoric acid fuel cells (PAFCs) in conjunction with the 2009 Fuel Cell Seminar and Exposition [1]. As a follow-on to this workshop, the National Renewable Energy Laboratory prepared a technical overview and gap analysis report on MCFCs and PAFCs [2], hereafter referred to as "the gap analysis." The gap analysis, prepared using input from FuelCell Energy and UTC Power, documented current status and identified research and development needs for MCFC and PAFC technology.

According to the gap analysis, the installed cost of FuelCell Energy's 1.4 MW combined heat and power (CHP) system operating on pipeline natural gas "averages about $4,200/kW, broken down as approximately $2,400/kW for the fuel cell module, $1,100 for the balance-of-plant (BOP), and $700/kW for conditioning, installation, and commissioning." These costs vary with system capacity, with installed cost ranging from $3,500/kW for a 2.8 MW CHP system to $5,500/kW for a 300 kW system [2]. Operation using lower-purity fuels introduces increased costs for fuel cleanup. When operated at a wastewater treatment plant or landfill, the average cost of FuelCell Energy's 1.4 MW CHP system increases to $7,200/kW [2].

The gap analysis identified an installed cost of $4,375/kW for a 400 kW PAFC CHP system operated on natural gas, based on a feasibility study performed for the National Renewable Energy Laboratory (NREL) by Engineering, Procurements & Construction, LLC of Lakewood, Colorado. According to information provided by UTC Power for the gap analysis, the major cost components of the system are the fuel cell stack, the fuel processing system, the power conditioning system, and the system balance of plant [2]. Platinum-based catalyst accounts for 4–6% of the system installed cost [3]. As with MCFCs, gas cleanup costs would be higher for operation of PAFCs on biogas.

While cost varies with fuel cell technology and system capacity, values of $4,500/kW for 100 kW–3 MW fuel cell CHP systems operating on natural gas, and $7,000/kW for systems operating on biogas, were selected to represent average installed cost status values in 2010. Based on further discussion with stakeholders, corresponding equipment cost status values of $3,500/kW and $5,500/kW were selected for systems operation on natural gas and biogas, respectively.

The electrical efficiency of state-of-the-art stationary fuel cell systems operating on natural gas is typically between 40% and 50% on an LHV basis, depending on the technology. For instance, molten carbonate fuel cells, such as FuelCell Energy's 1.4 MW DFC 1500, can achieve 47% electrical efficiency [1,4]. The 400kW UTC PureCell 400 Phosphoric Acid Fuel Cell system is capable of 40%–42% electrical efficiency [1,5].

Utilization of byproduct heat allows fuel cell CHP systems to achieve high CHP efficiencies, with 2010 status typically between 70% and 90% on an LHV basis. For instance, the DFC 1500 can achieve CHP efficiency as high as 84% when heat is delivered at 50°C, and as high as 69% at 120°C [4]. The PureCell 400 can achieve 90% CHP efficiency when heat is delivered at 60°C [5].

Long stack and system lifetime is critical to achieve a favorable LCOE. The standard FuelCell Energy 10-year maintenance contract includes one stack replacement at 5 years (stack lifetime status ~40,000 hours) [1]. The PureCell 400 system lifetime is expected to be 20 years with a stack replacement after 10 years (~80,000 hours) [5].

Status of system availability, or percentage of up time, is 95% [1,4]. The number of planned/unplanned outages metric is related to system availability – scheduled downtime is a result of maintenance, and unscheduled downtime typically arises from a physical event that results in an outage. The status of the number of planned/unplanned outages for the PureCell 400 is currently about 50 over the system lifetime, though the system can tolerate over 100 outages with no impact on lifetime [3].

Targets

In collaboration with stakeholders through the 2009 workshop and subsequent discussion, DOE has established targets as delineated in Table 1. 2020 cost targets were established at values required to achieve a levelized cost of electricity (LCOE) of $0.09/kWh for operation on biogas, and $0.08/kWh for operation on natural gas, values expected to enable limited market entry, based on an Energy Information Administration (EIA) forecast of commercial electricity prices in 2020 [6]. The $0.01/kWh difference in targeted LCOE between biogas and natural gas is due to the existence of low-carbon fuel requirements and renewable portfolio standards, as well as state regulations that promote biogas production and use. Calculation of the expected LCOE was based on:

- 20 year system lifetime with stack replacement at 9.5 years ($360/kWe stack replacement cost)
- Installation cost of $500/kWe for natural gas, and $700/kWe for biogas (does not include capital cost)
- Annual maintenance cost equal to 2% of the equipment cost, and unplanned maintenance cost equal to 1.5% of the installed cost
- Electrical efficiency and CHP efficiency equal to the 2020 target values
- EIA 2020 estimate of natural gas prices
- Cost of displaced stand-alone boiler ($36,000 per MBTU/hour installed cost, $1,100 per MBTU/hour annual maintenance and operation cost), as well as the cost of natural gas that would have been used by the displaced boiler ($9.05 per MBTU), treated as credits to the CHP costs
- Annual standby charges of $40/kWe[1]

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[1] Standby rates are charges levied by utilities when a distributed generation system, such as an on-site CHP system, experiences a scheduled or emergency outage, causing it to rely on power purchased from the grid. These charges are generally composed of two elements: energy charges, in $/kWh, which reflect the actual energy provided to the CHP system; and demand charges, in $/kW, which attempt to recover the costs to the utility of providing capacity to meet the peak demand of the facility using the CHP system. Only demand charges are assumed in this analysis.

The calculation does not include subsidies or incentives of any kind. All costs and financial parameters are in real dollars. The system is assumed to be financed with 60% equity capital and 40% debt. The interest rate on the debt is 8.5% and the equity rate of return is 8.5%, corresponding to an after-tax discount rate of 6.5%, calculated as the debt-equity-weighted after-tax cost of capital. The after-tax discount rate is consistent with discount rates commonly used to calculate the levelized cost of electricity for power plants and for net present value analyses [7,8]. The depreciation schedule is 7 years based on the Modified Accelerated Cost Recovery System (MACRS), and the combined federal and state income tax rate is 39% for the purpose of estimating the actual cost of debt servicing and effect of depreciation.

The 2015 cost targets were established at values on track to meet the 2020 targets, using a similar methodology. The LCOE values corresponding to the 2015 cost targets are $0.13/kWh for biogas and $0.12/kWh for natural gas. Significant differences in the cost calculations include:

- Two stack replacements are required, at 5.5 and 14 years ($900/kWe and $430/kWe for first and second stack replacements, respectively)
- Installation cost of $700/kWe for natural gas and $900/kWe for biogas (does not include capital cost)
- Electrical efficiency and CHP efficiency equal to the 2015 target values
- EIA 2015 estimate of natural gas prices

The 2020 electrical efficiency target of 50% (LHV) represents a value that would allow distributed generation to provide a significant improvement over the efficiency of the electrical grid. The target is expected to be readily achievable for MCFC and SOFC systems, but achievement may be difficult for PAFC and PEMFC systems. The 2015 target of 45% electrical efficiency was selected as an interim target on a path toward meeting the 2020 target.

High CHP efficiency is a major advantage of distributed fuel cell CHP systems over conventional alternatives, but increased costs result in diminishing returns as CHP efficiency increases. Based on workshop feedback and direct discussions with stakeholders [1], the 2015 and 2020 CHP efficiency targets of 87.5% and 90%, respectively, were selected as values that would balance the need for high energy savings with the need to reduce costs.

Long system lifetime is required to compete with conventional technology, such as boilers, which have lifetimes exceeding 20 years. The 2020 target lifetime of 80,000 hours was selected because achievement of this lifetime would enable operation of a fuel cell CHP system for 20 years with only a single stack replacement. Since stack replacement represents a significant cost, achievement of long stack lifetime is required to minimize system lifecycle cost. The 2015 lifetime target of 50,000 hours represents a value at which two stack replacements would be required during the 20 year system life.

Likewise, system availability and the number of planned/unplanned outages also must compete with conventional technology. Therefore, a 2020 system availability target of 99% was selected, with an interim target of 98% in 2015. 2015 and 2020 targets of 50 and 40 outages over system lifetime, respectively, were selected as values that are consistent with the system availability targets, and would be acceptable to customers.

While achievement of some of the individual targets has already been demonstrated, concurrent achievement of all targets remains a challenge. In the case of PAFCs, while UTC Power has already demonstrated stack lifetime similar to the target value, significant R&D will be required to decrease cost and increase electrical efficiency without decreasing lifetime. Similarly, in the case of MCFCs, FuelCell Energy has demonstrated electrical efficiency close to the target value, but significant R&D will be required to improve cost and durability without decreasing efficiency.

References

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