Department of Energy - Technical Targets

PORTABLE POWER (*DRAFT* Targets):

			2005	2007	2010
Consumer Electronics (subWatt - 20/50W)		Specific Power (W/kg)	30W/kg		100W/kg
		Power Density (W/L)	30W/L		100W/L
		Energy Density (Wh/L)	500Wh/L		1,000Wh/L
		Cost ($/W)	$5/W		$3/W
		Lifetime (hrs)	1,000 hrs		5,000 hrs
Power Electronics (20W - 5kW)	Low Power (20W-50W)	Energy Density (Wh/kg)		600Wh/kg	
		Efficiency		25% for consumers 50% for military	
		Lifetime (hrs)		1,000 hrs at full power	
		Cost ($/W)		$400/W for 20W uses - $1,000/W for 50W uses	
	High Power Applications (1kW-5kW)	Power Density, Specific Power, Efficiency		Values are set at 2/3 the PNGV technical targets for transportation	
		Lifetime (hrs)		1,500-2,000 hrs for commercial 5,000 hrs for industrial	
		Cost ($/kW)		$1/W	
Fuels & Fuels Packaging	Consumer Electronics (subWatt - 20/50Watts)	*Energy Density*: -System -Fuel Processor		 400Wh/kg, 500Wh/L 65-75% of the system	
		Cost: -Initial cost of fueling system -Recurring/ Refueling Cost		 $2/Wh $0.30/Wh	
		Lifetime (hrs)		2,000 hrs (2 yrs)	
	Power Electronics (20W-5kW)	*Energy Density*: -System		.1kW/kg, .1kW/L	
		Cost: - Initial cost of fueling system		$400/W	
		Lifetime (hrs)		5,000 hrs	

TRANSPORTATION:

Table 1. DOE Technical Targets for 50-kWe (net) Integrated Fuel Cell Power Systems Operating on Tier 2 Gasoline Containing 30 ppm Sulfur, Average
(includes fuel processor, fuel cell stack, and auxiliaries; excludes gasoline tank and vehicle traction electronics; all targets require simultaneous achievement)

Characteristic	Units	Calendar Year		
		2001 Status	2005	2010
Energy efficiency[a] @ 25% of peak power	%	34	40	45
Energy efficiency @ peak power	%	31	33	35
Power density	W/L	140	250	325
Specific power	W/kg	140	250	325
Cost[b]	$/kW	300	125	45
Transient response (time from 10 to 90% power)	sec	15	5	1
Cold start-up time to peak power @ –20°C ambient temperature @ +20°C ambient temperature	 min min	 TBD <10	 2 1	 1 <0.5
Survivability[c]	°C	TBD	–30	–40
Emissions[d]		<Tier 2 Bin 5[e]		
Durability[f]	hours	1000[g]	2000[h]	5000[i]

[a] Ratio of dc output energy to the lower heating value of the input fuel (gasoline).

[b] Includes projected cost advantage of high-volume production (500,000 units per year) and includes cost for assembling/integrating the fuel cell system and fuel processor.

[c] Achieve performance targets at 8-hour cold-soak at temperature.

[d] Emissions levels will comply with emissions regulations projected to be in place when the technology is available for market introduction.

[e] 0.07 NO_x g/mile and 0.01 PM g/mile.

[f] Performance targets must be achieved at the end of the durability time period.

[g] Continuous operation.

[h] Includes thermal cycling.

[i] Includes thermal and realistic drive cycles.

Table 2. DOE Technical Targets for Fuel Cell Stack Systems Operating on Hydrogen-Containing Fuel from A Fuel Processor (Gasoline Reformate) in 50-kWe (net) Fuel Cell Systems

(includes thermal, water, and air management; excludes fuel processing/delivery systems; all targets must be achieved simultaneously)

Characteristic	Units	Calendar Year		
		2001 Status	2005	2010
Power density[a,b]	W/L	200	400	550
Specific power	W/kg	200	400	550
Efficiency[c] @ 25% of peak power	%	45	50	55
Efficiency[c] @ peak power	%	40	42	44
Precious metal loading[d]	g/peak kW	2.0	0.6	0.2
Cost[e]	$/kW	200	100	35
Durability[f]	hours	1000[g]	>2000[h]	>5000[i]
Transient response (time for 10% to 90% of peak power)	sec	3	2	1
Cold start-up time to peak power				
@ –20°C ambient temperature	min	2	1	0.5
@ +20°C ambient temperature	min	1	0.5	0.25
Survivability[j]	°C	–20	–30	–40
CO tolerance[k]				
steady state (with 2% maximum air bleed)	ppm	50	500	500
transient	ppm	100	500	1000

[a] Power refers to net power (i.e., stack power minus auxiliary power requirements).

[b] Volume is "box" volume, including dead space, and is defined as the water-displaced volume times 1.5 (packaging factor). Power density includes ancillaries (sensors, controllers, electronics, radiator, compressor, expander, and air, thermal and water management) for stand-alone operation.

[c] Ratio of output DC energy to lower heating value of hydrogen-rich fuel stream (includes converter for 300 V bus); ratio of peak power to 25% of peak power efficiencies unchanged, assuming continued proportional reduction in stack efficiency at higher current and proportional increase in compressor efficiency at higher flow rates.

[d] Equivalent total precious metal loading (anode + cathode): 0.1 mg/cm^2 by 2010 at peak power. Precious metal target based on cost target of <$3/kW precious metals in MEA [@$450/troy ounce ($15/g), < 0.2 g/kW]).

[e] High-volume production: 500,000 units per year.

[f] Performance targets must be achieved at the conclusion of the durability period; durability includes tolerance to CO, H_2S, and NH_3 impurities (see Table III.D-3).

[g] Continuous operation (pertains to full power spectrum).

[h] Includes thermal cycling.

[i] Includes thermal and realistic driving cycles.

[j] Performance targets must be achieved at the end of 8-hour cold-soak at temperature.

[k] CO tolerance requirements assume capability of fuel processor to reduce CO. Targets for the stack CO tolerance are subject to trade-offs between reducing CO in the fuel processor and enhancing CO tolerance in the stack. It is assumed that H_2S is removed in the fuel processor.

Table 3. DOE Technical Targets for Fuel Processors[a] to Generate Hydrogen-Containing Fuel Gas from Tier 2 Gasoline Containing 30 ppm Sulfur, Average, for 50-kWe (net) Fuel Cell Systems
(excludes fuel storage; includes controls, shift reactors, CO cleanup, heat exchangers; all targets must be achieved simultaneously)

Characteristic	Units	Calendar Year: 2001 Status[b]	2005	2010
Energy efficiency[c]	%	78	78	80
Power density	W/L	500	700	800
Specific power	W/kg	450	700	800
Cost[d]	$/kW	85	25	10
Cold start-up time to maximum power				
@ –20°C ambient temperature	min	TBD	2.0	1.0
@ +20°C ambient temperature	min	<10	<1	<0.5
Transient response (time for 10% to 90% power)	sec	15	5	1
Emissions[e]		<Tier 2 Bin 5	<Tier 2 Bin 5	<Tier 2 Bin 5
Durability[f]	hours	1000[g]	2000[h]	5000[i]
Survivability[j]	°C	TBD	–30	–40
CO content in product stream[k]				
steady state	ppm	10	10	10
transient	ppm	100	100	100
H_2S content in product stream	ppb	<200	<50	<10
NH_3 content in product stream	ppm	<10	<0.5	<0.1

[a] With catalyst system suitable for use in vehicles.

[b] Projected status for system to be delivered in late 2002: 80% efficiency, 900 W/L, 550 W/kg.

[c] Fuel processor efficiency = total fuel cell system efficiency/fuel cell stack system efficiency, where total fuel cell system efficiency accounts for thermal integration. For purposes of testing fuel-processor-only systems, the efficiency can be estimated by measuring the derated heating value efficiency (lower heating value of H_2 × 0.95/ lower heating value of the fuel in) where the derating factor represents parasitic system power losses attributable to the fuel processor.

[d] High-volume production: 500,000 units per year.

[e] 0.07 g/mile NOx and 0.01 g/mile PM (particulate matter).

[f] Time between catalyst and major component replacement; performance targets must be achieved at the end of the durability period.

[g] Continuous operation.

[h] Includes thermal cycling.

[i] Includes thermal and realistic driving cycles.

[j] Performance targets must be achieved at the end of an 8-hour cold-soak at specified temperature.

[k] Dependent on stack development (CO tolerance) progress.

Table 4. DOE Technical Targets for 50-kW (net) Integrated Fuel Cell Power Systems Operating on Direct Hydrogen[a]
(all targets must be achieved simultaneously)

Characteristic	Units	Calendar Year		
		2001 Status	2005	2010
Energy efficiency[b] @ 25% of peak power	%	59	60	60
Energy efficiency @ peak power	%	50	50	50
Power density				
excluding H_2 storage	W/L	400	500	650
including H_2 storage	W/L	TBD	150	220
Specific power				
excluding H_2 storage	W/kg	400	500	650
including H_2 storage	W/kg	TBD	250	325
Cost[c] (including H_2 storage)	$/kW	200	125	45
Transient response (time from 10% to 90% power)	sec	3	2	1
Cold start-up time to maximum power				
@ –20ºC ambient temperature	sec	120	60	30
@ +20ºC ambient temperature	sec	60	30	15
Emissions		Zero	Zero	Zero
Durability[d]	hours	1000	2000[e]	5000[f]
Survivability[g]	°C	-20	–30	–40

[a] Targets are based on hydrogen storage targets (Table III.D-5) in an aerodynamic 2500-lb vehicle.

[b] Ratio of dc output energy to the lower heating value of the input fuel (hydrogen).

[c] Includes projected cost advantage of high-volume production (500,000 units per year).

[d] Performance targets must be achieved at the end of the durability time period.

[e] Includes thermal cycling.

[f] Includes thermal and realistic driving cycles.

[g] Achieve performance targets after 8-hour cold-soak at temperature.

Table -5. DOE Technical Targets for On-Board Hydrogen Storage[a,b]

Characteristic	Units	Target	2001 Status	
			Physical Storage[c]	Chemical Storage[d]
Storage capacity[e]	wt%	6	5.2	3.4
Recoverable usable amount[f]	%	90	99.7	>90
Energy density[g]	Wh/L[h]	1100	620	1300
Specific energy[i]	Wh/kg[h]	2000	1745	1080
Cost[j]	$/kWh	5	50[k]	18[l]
Cycle life	cycles	500	>500	20-50
Operating temperature[m]	°C	–40 to +50°C	–40 to +50°C	20 to 50°C
Start-up time to full flow @ +20°C @ –20°C	 sec sec	 15 30	 <1 TBD	 <15 TBD
Refueling time	min	<5	10	TBD
Hydrogen loss	scc/hour/L	<1.0	<1.0	<1.0

[a] Based on lower heating value of hydrogen; includes both physical and chemical methods of hydrogen storage; enables greater than 300-mile range, based on an aerodynamic, 2500-lb vehicle.

[b] R&D carried out in collaboration with DOE Hydrogen Program.

[c] Based on 5,000 psi tanks; 10,000 psi tanks have been built and tested, but not yet certified.

[d] Projected from laboratory-scale (100 g) test beds and proposed system designs.

[e] Weight percent H_2 is the weight of H_2 divided by the weight of (H_2 + tank).

[f] Recoverable stored hydrogen, e.g., in a 100-kg H_2 storage system containing 6 kg of stored hydrogen, at least 5.4 kg of useful hydrogen must be recoverable.

[g] Based on 5 kg hydrogen for >300 mile range at 10,000 psia (volume of stored hydrogen is 135 L). Allowing for 10% containment volume, system volume is 150 L.

[h] Watts thermal.

[i] Specific energy is the lower heating value of H_2 contained, divided by the weight of (H_2 + tank).

[j] Based on high-volume production of 500,000 units per year.

[k] Based on individual tanks.

[l] Projected hydride material cost only; based on 100–200 kg alanate production.

[m] Hydrogen storage system must provide hydrogen to the fuel cell at these ambient temperatures.

Table 6. DRAFT DOE Technical Targets for Off-Board Hydrogen Production and Dispensing Infrastructure (based on higher heating value) – not reviewed by Fuel Cell Tech Team

Component	Characteristic	Units	2001 Status	2005[a]	2010
Reforming	Cost[b]	\$/kWh H_2	0.027[c]	0.026	0.025
	GHGs[d]	g/km	0	0	0
	Energy Efficiency	%(HHV)	75–80[e]	80–82	85
Purification	Cost[b]	\$/kWh H_2	0.005[f]	0.004	0.004
	GHGs[d]	g/km	108	100	91
	Energy Efficiency	%(HHV)	75–90[g]	82–90	90
Compression	Cost[b]	\$/kWh H_2	0.007[h]	0.005	0.004[i]
	GHGs	g/km	10	8.5	7
	Energy Efficiency	%(HHV)	80–90[j]	82–92	85–93
Storage & Dispensing	Cost[b]	\$/kWh H_2	0.009[k]	0.008	0.007
	GHGs	g/km	0	0	0
	Energy Efficiency	%(HHV)	100[l]	100	100

[a] 2005 targets taken to be halfway between current status and 2010 targets. The 2005 targets represent a 1.5X vehicle in terms of fuel efficiency and a 2.1X vehicle in terms of GHGs. The 2010 targets represent a 2.0X vehicle in terms of fuel efficiency and a 2.3X vehicle in terms of GHGs.

[b] Cost based on a hydrogen fueling station serving 300 cars per day (~10,000 std m^3 per day). Assumes 3 employees at \$50,000/year. Annual capital charge, mark-up (profit, marketing, etc.), and maintenance assumed to be 15%, 25%, and 10% of total capital cost, respectively.

[c] Based on Arthur D. Little (ADL) bottoms-up cost analysis of a partial oxidation reformer and balance-of-plant at production volumes of 100 units per year. Natural gas and electricity demand based on ADL experience. Assumes a natural gas price of \$0.011/kWh and an electricity price of \$0.05/kWh.

[d] The reformer exhaust goes directly into the purification process, where the GHGs are separated from hydrogen and emitted.

[e] Assuming a steam methane reformer operating at 5–20 atm.

[f] Based on the low end of vendor quotes for a small-scale pressure-swing adsorption (PSA) system.

[g] Assuming a small-scale PSA system operating at reformer outlet pressure.

[h] Based on a 4-stage compressor with intercooling and a cooling tower. Maximum outlet pressure assumed to be 400 atm. Compressor assumed to be 20% more expensive than comparable natural gas compressors. Assumes an electricity price of \$0.05/kWh.

[i] Assuming low-pressure (50 atm) hydrogen storage (e.g., hydrides). Compressor electricity demand would be about half that at high pressure (400 atm). Assumes compressor capital costs would also be reduced in half due to simplicity of design (less intercooling, no cooling tower, etc.).

[j] Based on a 4-stage intercooled compressor with an exit pressure of 400 atm. Assumes a U.S. average power generation efficiency of 30%, and compressor adiabatic efficiency of 65–75%.

[k] Based on high-pressure (400 atm) gas storage. Estimated from multiple vendors of comparable compressed natural gas equipment.

[l] Assuming high-pressure gas storage with no leaks during storage or dispensing.

Table 7. DOE Technical Targets for Fuel Cell Stack Components

Component	**Target Requirements**
Membranes	Cost: \$5/kW (\$25 meter^2) Stability: <2 mV w/RH 20–100%, <10% swelling H_2 crossover: <1 mA/cm^2 O_2 crossover: <3 mA/cm^2 Area specific resistance: 0.1 ohm cm^2
Electrodes	Cost: \$5/kW CO tolerance: 500 ppm steady state, 1000 ppm transient with 0.2 g Pt/peak kW Durability: 5000 hours Utilization: 85% H_2, 60% O_2
Membrane-Electrode Assemblies	Performance: On hydrogen 400 mA/cm^2 at 0.80V (at rated power), 100 mA/cm^2 at 0.85V (at quarter power) On gasoline reformate 550 mA/cm^2 at 0.75V (at rated power, 30 psig), 125 mA/cm^2 at 0.83V (at quarter power, 9 psig) Cost: \$10/kW
Bipolar Plates	Cost: \$10/kW; <1 kg/kW H_2 permeation rate: $<2\times10^{-6}$ cm^3 sec^{-1} cm^{-2} @ 80 C, 3 atm (equivalent to <0.1 mA/cm^2) Corrosion rate: <16 ì A/cm^2 Resistivity: 0.02 Ù cm^2

Table 8. DOE Technical Targets for Sensors for Automotive Fuel Cell Systems [a]

Sensor	Requirements
Carbon Monoxide	(a) 1–100 ppm reformate pre-stack sensor Operational temperature: <150°C Response time: 0.1–1 sec Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, CO, N_2, H_2O at 1–3 atm total pressure Accuracy: 1–10% full scale (b) 100–1000 ppm CO sensors Operational temperature: 250°C Response time: 0.1–1 sec Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, CO, N_2, H_2O at 1–3 atm total pressure Accuracy: 1–10% full scale (c) 0.1–2% CO sensor 250–800°C Operational temperature: 250–800°C Response time: 0.1–1 sec Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, CO, N_2, H_2O at 1–3 atm total pressure Accuracy: 1–10% full scale
Hydrogen in fuel processor output	Measurement range: 1–100% Operating temperature: 70–150°C Response time: 0.1–1 sec for 90% response to step change Gas environment: 1–3 atm total pressure, 10–30 mol% water, 30–75% total H_2, CO_2, N_2 Accuracy: 1–10% full scale
Hydrogen in ambient air (safety sensor)	Measurement range: 0.1–10% Temperature range: –30 to 80°C Response time: under 1 sec Accuracy: 5% Gas environment: ambient air, 10–98% RH range Lifetime: 5 years Interference resistant (e.g., hydrocarbons)
Sulfur compounds (H_2S, SO_2, organic sulfur)	Operating temperature: up to 400°C Measurement range: 0.05–0.5 ppm Response time: <1 min at 0.05 ppm Gas environment: H_2, CO, CO_2, hydrocarbons, water vapor
Flow rate of fuel processor output	Flow rate range: 30–300 std L/min Temperature: 80°C Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, N_2, H_2O, CO at 1–3 atm total pressure

Ammonia	Operating temperature: 70–150°C Measurement range: 1–10 ppm Selectivity: <1 ppm from matrix gases Lifetime: 5–10 years Response time: seconds Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, N_2, H_2O, CO at 1–3 atm total pressure
Temperature	Operating range: –40 to 150°C Response time: in the –40 to 100°C range <0.5 sec with 1.5% accuracy; in the 100–150°C range, a response time <1 sec with 2% accuracy Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, N_2, H_2O, CO at 1–3 atm total pressure Insensitive to flow velocity
Relative humidity for cathode and anode gas streams	Operating temperature: 30–110°C Relative humidity: 20–100% Accuracy: 1% Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, N_2, H_2O, CO at 1–3 atm
Oxygen in fuel processor and at cathode exit	(a) Oxygen sensors for fuel processor reactor control Operating temperature: 200–800°C Measurement range: 0–20% O_2 Response time: <0.5 sec Accuracy: 2% of full scale Gas environment: high-humidity reformer/partial oxidation gas: H_2 30–75%, CO_2, N_2, H_2O, CO at 1–3 atm (b) Oxygen sensors at the cathode exit Measurement range: 0–50% O_2 Operating temperature: 30–110°C Response time: <0.5 sec Accuracy: 1% of full scale Gas environment: H_2, CO_2, N_2, H_2O at 1–3 atm total pressure
Differential pressure in fuel cell stack	Range: 0–1 psi or (0–10 or 1–3 psi, depending on the design of the fuel cell system) Temperature range: 30–100°C Survivability: –40°C Response time: <1 sec Accuracy: 1% of full scale Size: $\leq$1 in^2, usable in any orientation Other: Withstand and measure liquid and gas phases

[a] Sensors must conform to size, weight, and cost constraints of automotive applications.

Table 9. DOE Technical Targets for Compressor/Expander (C/E) Units for Automotive Fuel Cell Systems[a]

Characteristic	Units	Target
Input power[b] at full flow	kW	4.3
Efficiency at full flow Compressor (at 3.2 pressure ratio)[c] Expander	 % %	 75 90
Efficiency @ 20% of full flow Compressor (at 1.6 pressure ratio)[c] Expander	 % %	 65 80
Volume[d]	L	4
Weight[d]	kg	3
Cost[d,e]	$	200
Turndown ratio		10
Noise	db	<80

[a] Targets are being reviewed as a result of the Compressor Peer Review.

[b] Input power to the controller to power a compressor/expander system producing 76 g/sec (dry) maximum flow. This flow rate roughly corresponds to maximum power for a 50-kW fuel cell system. A 25% flow is 19 g/sec. Expander inlet conditions are assumed to be: 82 g/sec, 150°C, and 2.8 atm (at full flow).

[c] The pressure ratio is allowed to float as a function of load on the fuel cell system (i.e., as a function of the flow through the compressor/expander unit).

[d] Weight, volume, and cost do not include the motor/controller or heat rejection (if required).

[e] Cost target based on a manufacturing volume of 100,000 units per year.

Table 10. DOE Technical Targets for Fuel Processor Catalysts and Reactors (for Reforming Tier II Gasoline Containing 30 ppm Sulfur)[a]

Characteristic	Units	Autothermal Reformer	Sulfur removal	Water-Gas Shift	CO Preferential Oxidation
GHSV[b]	per hour	200,000	50,000	30,000	150,000
Conversion[c]	%	>99.9	>99.95	>90	>99.8
H_2 selectivity[d] (or consumption)	%	>80	<0.1	>99	<0.2
Volume[e]	L/kWe	<0.013	<0.06	<0.1	<0.02
Weight[e]	kg/kWe	<0.015	<0.06	<0.1	<0.03
Durability[f]	hours	5000	5000	5000	5000
Cost	$/kWe	<5	<1	<1	<1

[a] Target values are guidelines for single reactor R&D; system/subsystem targets take precedence.

[b] GHSV (gas hourly space velocity) = the volumetric flow rate of the product gases reduced to 25°C and 1 atm, divided by the bulk volume of the catalyst.

[c] Conversion: (moles of reactant in – moles of reactant out) × 100/(moles of reactant in).

[d] Selectivity: At the autothermal reformer: (moles of H_2 in product) × 100/(moles of H_2 “extractable” from the reformer feed); at the shift reactor: (moles CO converted to H_2) × 100/(total moles of CO converted).

[e] The volume and weight targets include only the catalysts, not the hardware needed to house the catalysts or any heat exchangers.

[f] Over standard driving cycles

STATIONARY/DISTRIBUTED:

DER & OPT	Fuel-to-Electricity Conversion Rate	Electricity only: 40-50% CHP Applications: 75-80%
	System Life	40,000 hrs
	Cost Target	$1,000-$1,500/kW
Fossil Energy	Efficiency (LHV)	2003: 50-60% 2015: 70-80%
	Cost ($/kW)	2003: $1,000-$1,500/kW 2015: $400/kW

Table 11. DOE Technical Targets for 50-kW (net) Integrated Fuel Cell Power Systems Operating on Direct Hydrogen[a]

Characteristic	Units	Calendar Year		
		2001 Status	2005	2010
Energy efficiency[b] @ 25% of peak power	%	45	50	55
Energy efficiency @ peak power	%	50	50	50
Power density excluding H_2 storage	W/L	400	500	650
Specific power excluding H_2 storage	W/kg	400	500	650
Cost[c] (including H_2 storage)	$/kW	350	250	100
Transient response (time from 10% to 90% power)	sec	3	2	1
Cold start-up time to maximum power @ –20°C ambient temperature @ +20°C ambient temperature	 sec sec	 120 60	 60 30	 30 15
Emissions		Zero	Zero	Zero
Durability[d]	hours	10,000	20,000[e]	50,000
Survivability[f]	°C	-20	–30	–40

[a] Targets are based on hydrogen storage targets (Table III.D-5).

[b] Ratio of dc output energy to the lower heating value of the input fuel (hydrogen).

[c] Includes projected cost advantage of high-volume production (100,000 units per year).

[d] Performance targets must be achieved at the end of the durability time period.

[e] Includes thermal cycling.

[f] Achieve performance targets after 8-hour cold-soak at temperature.

Table 12. DOE Technical Targets for Fuel Processor Catalysts and Reactors

Characteristic	Units	Autothermal Reformer	Water-Gas Shift	CO Preferential Oxidation
GHSV[b]	per hour	150,000	30,000	150,000
Conversion[c]	%	>99.9	>90	>99.8
H_2 selectivity[d] (or consumption)	%	>75	>99	<0.2
Volume[e]	L/kWe	<0.3	<0.2	<0.02
Weight[e]	kg/kWe	<.5	<0.5	<0.03
Durability[f]	hours	5000	5000	5000
Cost	$/kWe	<5	<1	<1

[a] Target values are guidelines for single reactor R&D; system/subsystem targets take precedence.

[b] GHSV (gas hourly space velocity) = the volumetric flow rate of the product gases reduced to 25°C and 1 atm, divided by the bulk volume of the catalyst.

[c] Conversion: (moles of reactant in – moles of reactant out) × 100/(moles of reactant in).

[d] Selectivity: At the autothermal reformer: (moles of H_2 in product) × 100/(moles of H_2 "extractable" from the reformer feed); at the shift reactor: (moles CO converted to H_2) × 100/(total moles of CO converted).

[e] The volume and weight targets include only the catalysts, not the hardware needed to house the catalysts or any heat exchangers.

[f] Over standard driving cycles

Table I. SECA Industrial Team Minimum Requirements

	PHASE I	PHASE II	PHASE III
POWER RATING (NET)	3kW - 10 kW	3kW - 10 kW	3kW - 10 kW
COST	$800/kW	$600/kW	$400/kW
EFFICIENCY (AC or DC/LHV)	Mobile – 25 to 45%	Mobile – 30 to 50%	Mobile – 30 to 50%
	Stationary – 35 to 55%	Stationary – 40 to 60%	Stationary – 40 to 60%
STEADY STATE TEST @ NORMAL OPERATING CONDITIONS	1500 hours	1500 hours	1500 hours
	80% availability	85% availability	95% availability
	ΔPower ≤ 2% degradation/500 hours at a constant stack voltage.	ΔPower ≤ 1% degradation/500 hours at a constant stack voltage.	ΔPower ≤ 0.1% degradation/500 hours at a constant stack voltage.
TRANSIENT TEST	10 cycles	50 cycles	100 cycles
	ΔPower ≤ 1% degradation after 10 cycles at a constant stack voltage.	ΔPower ≤ 0.5% degradation after 50 cycles at a constant stack voltage.	ΔPower ≤ 0.1% degradation after 100 cycles at a constant stack voltage.
TEST SEQUENCE	1) Steady State Test - 1000 hours 2) Transient Test 3) Steady State Test - 500 hours	1) Steady State Test - 1000 hours 2) Transient Test 3) Steady State Test - 500 hours	1) Steady State Test – 1000 hours 2) Transient Test 3) Steady State Test - 500 hours
FUEL TYPE	For the complete duration of the Steady State and Transient Tests, operate the Prototype on either a commercial commodity, natural gas, gasoline, or diesel fuel (s) or a representative fuel based on respectively methane, iso-octane, or hexadecane corresponding to the proposed primary application (s). If multiple applications using different fuels are proposed split the total test time equally among the different fuel types.	For the complete duration of the Steady State and Transient Tests, operate the Prototype on either a commercial commodity natural gas, gasoline, or diesel fuel (s) corresponding to the proposed primary application (s). Utilize external or internal primary fuel reformation or oxidation. If multiple applications using different fuels are proposed split the total test time equally among the different fuel types.	For the complete duration of the Steady State and Transient Tests, operate the Prototype on either a commercial commodity natural gas, gasoline, or diesel fuel (s) corresponding to the proposed primary application (s). Utilize external or internal primary fuel reformation or oxidation. If multiple applications using different fuels are proposed split the total test time equally among the different fuel types.
MAINTENANCE INTERVALS	Design aspects should not require maintenance at intervals more frequent than 1000 operating hours.	Design aspects should not require maintenance at intervals more frequent than 1000 operating hours.	Design aspects should not require maintenance at intervals more frequent than 1000 operating hours.
DESIGN LIFETIME	≥ 40,000 operating hours for stationary applications and 5,000 hours for transportation applications for military uses.	≥ 40,000 operating hours for stationary applications and 5,000 hours for transportation applications for military uses.	≥ 40,000 operating hours for stationary applications and 5,000 hours for transportation applications for military uses.

Table II, SECA 5kW SOFC System Costs (2)

System Parameters					
	Base Case	Case 1	Case 2	Case 3	Case 4
Fuel	30 ppm sulfur gasoline	30 ppm sulfur gasoline	30 ppm sulfur gasoline	30 ppm sulfur gasoline	0 ppm sulfur diesel
Anode H_2 Utilization	90%	90%	70%	90%	90%
Single Cell Voltage	0.7	0.7	0.7	0.7	0.7
Power Density, W/cm^2	0.3	0.6	0.3	0.6	0.3
Cathode Inlet Air T, ° C	650	500	700	650	650
System Efficiency, %	37	40	26	37	37
System and Component Cost					
Stack					
• Electrode-Electrolyte Assembly	$217.6	$102.7	$253.6	$111.9	$218.4
• Stack balance of components	19.3	16.4	20.2	16.6	19.3
Fuel and Air Preparation					
• POX reformer (+ preheaters)	21.8	21.8	22.7	21.8	21.4
• Cathode Oxidizer (+ preheat & vaporizer	8.5	11.8	9.2	8.5	8.5
• ZnO bed	9.9	9.9	9.9	9.9	n/a
• Anode gas recuperator	12.4	12.1	14.8	12.4	n/a
• Eductor	2.4	2.4	2.4	2.4	2.4
• Secondary cathode air preheater	31.7	n/a	87.7	31.7	26.9
Rotating Equipment					
• Fuel Pump	21.8	21.8	21.8	21.8	21.8
• Air compressor and air filter	54.5	54.5	54.5	54.5	54.5
Balance of System					
• Insulation and channels	10.9	8.8	13.2	7.1	12.2
• Start-up and active cooling blower	15.7	15.7	15.7	15.7	15.7
• Controls and electrical	40.7	40.7	40.7	40.7	40.7
• Piping	17.0	17.0	17.0	17.0	17.0
Labor, indirect and depreciation	43.0	36.2	48.0	43.0	33.4
Total, $/kW	527	372	631	415	492