A Matrix for Distributed Energy Resource Technologies

A complex series of developments in distributed energy is taking place. The matrix which follows gives an overall view of the primary types of distributed energy and storage systems as they relate to development status, operational characteristics, maintenance, siting, environment, performance, and power quality.

This information has been provided by the CADER (California Alliance for Distributed Energy Resources) Technology Characterization Committee. CADER and the subcommittee make no claim or warranty regarding the accuracy or validity of the data contained in this matrix.

As the new millennium approaches, the electric industry is preparing for a fundamental shift in the way power is produced. The next century will feature smaller generating units in a range of sizes to accommodate homes, restaurants, shopping malls, industrial plants, as well as strategic use on distribution and transmission systems.

This matrix reviews the range of technologies already available, including turbines, reciprocating engines, renewables (solar, wind and biomass) and storage systems. Advanced and emerging technologies—such as fuel cells and microturbines—are expected to join the roster in the next 2-5 years.

These generating technologies, combined with storage systems, efficiency technology and load management, are referred to as "Distributed Energy Resources" (DER). Together these new strategies promise greater energy efficiency, lower prices, higher quality of service, and a cleaner environment.

Electric utilities and consumers will have greater choices than ever before. Government initiatives on both the federal and state level are gearing up to change the rules to allow "Plug and Play" generation sets. These issues include: interconnection rules with electric utilities, rates and tariffs for backup and standby services, air quality regulations and permitting and building codes.

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	DEVELOPMENT STATUS		OPERATION								
	Current Status (Dev, Demo, Comm) Compatible	Year Commercial Fuel	Rated Full Load Not Capacity (kWe)	Rated Minimum Load (%FL)	Usable Thermal Output (Btu/kWh)	Usable Thermal Temperature (F)	Operator?	Dispatchable?	Practical Load Duty (Bass, Interim., Peak)	Fuel(s)	Specifications
GENERATION											
Reciprocating UCs											
Diesel	Comm		50-5,000	50	3,400	185-900	No	Yes	B,I,P	Diesel	>2.0 psig
Otto (Spark Ignition)	Comm		50-6,000	50	1.000-5,000	316-500	No	Yes	B,I,P	Biogas Natural Gas Propane	1.0-45 psig
Gas Turbines											
Micro-Turbines	Dev/Demo	1997-1999	25-250	0-50	4,000-15,480	400-635	No	Yes	B,I,P	Nat. Gas. Diesel. Propane. Multi fuel	3-100 psig
Small Gas Turbines	Dev/Comm.	1999	500-10,000	5-50	3,400-12,000	500-1,100	No	Yes	B,I,P	Nat. Gas Distillate, Biogas	140-500 psig

CADER Technology Characterization Subcommittee (*Continued*)

	DEVELOPMENT STATUS		OPERATION								
	Current Status (Dev, Demo, Comm) Compatible	Year Commercial Fuel	Rated Full Load Not Capacity (kWe)	Rated Minimum Load (%FL)	Usable Thermal Output (Btu/kWh)	Usable Thermal Temperature (F)	Operator?	Dispatch able?	Practical Load Duty (Bass, Interim., Peak)	Fuel(s)	Specifications
Fuel Cells											
Molten Carbonate	Demo	2000-2003	250-2,850	25-30	1.400-1,800	170-710	No	Yes	B,I	Nat. Gas	15-45 psig
Phosphoric Acid	Demo/Comm	1998	200	0	3,500-3,750	140-250	No	Yes	B,I	Nat Gas Propane	15-5 psi
Proton Exchange Membrane	Dev/Demo	1998-2000	3-250	0-33	2,000-3,250	135-165	No	Yes	B,I,P	Nat. Gas Propane, Butane, Diesel	gas pipeline press
Hybrid Solid Oxide	Dev/Demo	2001-2003	225-2,240	25	540-1.100	350-420	No	Yes	B,I	Nat. Gas	None Reported
Solar Electric											
Photovoltaics	Dev/Demo/Comm		10-10,000	0	0	0	No	No	P	Solar	
Dish Stirling	Dev/Demo	1999	5-25	0-10	6,800	150	No	Yes (when fossiled fueled)	B,I,P	Solar. Fossil Fuels	>300 W/m^2
Wind Turbines											
<50 kW	Comm		0.85-50	1	0	0	No	No	P (w/storage)	Wind	>8 MPH Wind
>50 kW	Comm		50-1,000	1	0	0	No	No	I	Wind	>10 MPH Wind

CADER Technology Characterization Subcommittee (*Continued*)

	DEVELOPMENT STATUS				OPERATION						
	Current Status (Dev, Demo, Comm) Compatible	Year Commercial Fuel	Rated Full Load Not Capacity (kWe)	Rated Minimum Load (%FL)	Usable Thermal Output (Btu/kWh)	Usable Thermal Temperature (F)	Operator?	Dispatch able?	Practical Load Duty (Bass, Interim., Peak)	Fuel(s)	Specifications
STORAGE											
Batteries	Dev/Demo/Comm	1997-2000	100-20,000					Yes	B,I,P	Electricity	N/A
Flywheels	Dev/Demo/Comm	1997-2000	10-3,000	0-10	0	0	No	Yes	P	Electricity	N/A

	MAINTENANCE				SITING & ENVIRONMENTAL							
	Cold Start-Up Time (minutes)	Annual Maintenance Hours (hrs/yr)	Time Before Intervention (opr hrs)	Time Between Overhauls (opr hrs)	Power Plant Size			Infrastructure Needs				
					Footprint (sqft/kW)	Volume (cuft/kW	Weight (lb/kW)	Water Service	Waste Water Service	Fuel Delivery	Maint. Access	Telecom-munications,
GENERATION												
Reciprocating VCs												
Diesel	0.167	20-250	1,500-2,000	25,000-30,000	22			Engine Coolant	No	Yes	Yes	Optional
Otto (Spark Ignition)	0.017-0.167	20-250	280.1,000	24,000-60,000	.22-31	3-6	22-65	Engine Coolant	No	Yes	Yes	Optional
Gas Turbines												
Micro-Turbines	0.5-1.0	1-20	750-10,000	5,000-40,000	0.15-1.5	0.6-4.0	2.6-37	None Reported	None Reported	Yes	Yes	Optional
Small Gas Turbines	1.0-100	50-700	4,000-8,000	30,000-50,000	02-61	.30-1.06	7-26	None Reported	None Reported	Yes	Yes	Optional

CADER Technology Characterization Subcommittee (*Continued*)

	MAINTENANCE				SITING & ENVIRONMENTAL							
	Cold Start-Up Time (minutes)	Annual Maintenance Hours (hrs/yr)	Time Before Intervention (opr hrs)	Time Between Overhauls (opr hrs)	Power Plant Size			Infrastructure Needs				
					Footprint (sqft/kW)	Volume (cuft/kW	Weight (lb/kW)	Water Service	Waste Water Service	Fuel Delivery	Maint. Access	Telecom-munications,
Fuel cells												
Molten Carbonate	1,200-2,400	120	720	40,000	1-4	8-40	120-240	Yes or Can Be Self Sufficient	Yes or No	Yes	Yes	Optional
Phosphoric Acid	180	50-55	2,200-8,760	40,000	4	40	200	None Reported	None Reported	Yes	Yes	Yes
Proton Exchange Membrane	60	4	8,700	8,700-40,000	0.6-3	4.7-9	100-300	Possible	None Reported	Yes	Yes	Optional
Hybrid Solid Oxide	2 (see note)	40	8,000	40,000	1.1-1.2	18-20		None Reported	None Reported	Yes	Yes	Optional
Solar Electric												
Photovoltaics	0				538			None	None	No	Yes	Optional
Dish Stirling	3-5	6-10	8,000	30,000	160-269		600	None	None	No	Yes	No
Wind Turbines												
<50 kW	.08-16	0.25	30,000	200,000	15-9.0	9-24	330-720	None	None	No	Yes	No
>50 kW	0.16-0.5	40	4,000	130,000	0.24-110		250	None	None	No	Yes	Optional
STORAGE												
Batteries	0-.004	120-150	8,700		1-7		124-186	None	None	Yes (Electricity)	Yes	Optional

CADER Technology Characterization Subcommittee (*Continued*)

	DEVELOPMENT STATUS		OPERATION								
	Current Status (Dev, Demo, Comm) Compatible	Year Commercial Fuel	Rated Full Load Not Capacity (kWe)	Rated Minimum Load (%FL)	Usable Thermal Output (Btu/kWh)	Usable Thermal Temperature (F)	Operator?	Dispatchable?	Practical Load Duty (Bass, Interim., Peak)	Fuel(s)	Specifications
Flywheels	0-40	0-2	8,700-18,000	10,000-175,000	.013-.830	0.5-6.0	1.3-17	None	None	Yes (Electricity)	Yes	Optional

SITING & ENVIRONMENTAL

	Air Emission Controls	Air Emissions (lb/kWh, unless indicated otherwise)						Noise (dB @ 7 ft)	Water Consumption (Gal./kWh)	Waste Water Production (Gal./kWh)	Hazardous Materials	Other Hazards
		CO	CO	NOx	SOx	UHC	PM10					
GENERATION												
Reciprocating I/Cs												
Diesel	None Reported			.022-.025				60-85 dB @ 23 ft	Nearly Zero Reported	Zero Reported	None Reported	None Reported
Otto (Spark Ignition)	None Reported, SCR	0.473-0.525	0.004-0.006	0.0015-0.037	0.0	0.0009	0.0002	100 @ 3.3 R	Nearly Zero Reported	Zero Reported	None Reported	None Reported
Gas Turbines												
Micro-Turbines	None Reported. Catalytic		3-50 ppm	3-50 ppm	Negligible	3-9 ppm	Negl.	<60 dB @ 33 ft <60 dB @ 10 ft	Zero Reported	Zero Reported	None Reported	Batteries
Small Gas Turbines	None Reported, Water/Steam injection, SCR, OLN Comb.		<15-50 ppm	.007-.009 <9 ppm	Negl.	<15-25 ppm	Negl.	60-85 @ 23 ft 85 dB @ 3 ft	Zero Reported	Zero Reported	None Reported	None Reported

CADER Technology Characterization Subcommittee (*Continued*)

SITING & ENVIRONMENTAL

	Air Emission Controls	Air Emissions (lb/kWh, unless indicated otherwise)						Noise (dB @ 7 ft)	Water Consumption (Gal./kWh)	Waste Water Production (Gal./kWh)	Hazardous Materials	Other Hazards
		CO	CO	NOx	SOx	UHC	PM10					
Fuel Cells												
Molten Carbonate	None Reported	0.785-0.9	0.00001	<0.000002	<0.000003	Negl.	Negl.	60 dB @ 30 ft dB @ 100 ft	0-0.125	0-0.044	None Reported	None Reported
Phosphoric Acid	None Reported	1.13	0.000023	0	0.000016	0	0.0000004	0	62 dB @ 30 ft	Zero Reported	Zero Reported	None Reported	None Reported
Proton Exchange Membrane	None Reported	1.1-1.5	Negl.	Negl.	0	0	0	50 dB @10 ft 65 dB @ 10 ft	0-0,2	Zero Reported	Batteries	None Reported
Hybrid Solid Oxide	None Reported	0.7	0.0	0.00005- 0.00006	0 0	0	0	60 dB @ 30 ft	Zero Reported	Zero Reported	Spent Desulfur-izer Reagent	None Reported
Solar Electric												
Photovoltaics	None	0	0	0	0	0	0	0	0	0	None	None Reported
Dish Stirling	Low NOx Burner		.02	.02				Negligible	0	0	Hydrogen	None Reported
Wind Turbines												
<50 kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	58-64 @ 100 ft	0	0	Batteries	None Reported
<50 kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	45 dB @ 820 ft	0	0	Hydraulic Fluid	Aviary Hazard

CADER Technology Characterization Subcommittee (*Continued*)

SITING & ENVIRONMENTAL

	Air Emission Controls	Air Emissions (lb/kWh, unless indicated otherwise)						Noise (dB @ 7 ft)	Water Consumption (Gal./kWh)	Waste Water Production (Gal./kWh)	Hazardous Materials	Other Hazards
		CO	CO	NOx	SOx	UHC	PM10					
STORAGE												
Batteries	N/A			See Note					0	0	Low Risk VRLA	None Batteries
Flywheels	N/A			See Note				0-68 dB @ 3 ft	0	0	None	high energy rotor

	PERFORMANCE				**ECONOMICS**							
	Net Electric Heat Rate (HHV Btu/kWh)			Expected Availability	Typical Forced Outage Rate	Load Ramp Rate (kW/min)	Capital Cost ($/kW)	Installation	Fixed O&M	Variable Non-Fuel ($/kWh)	Power Plant
	Full Load (100% FL)	Reduced Load (75% FL)	Mid-Load (50%FL)								
GENERATION											
Reciprocating I/Cs											
Diesel	7,900-9,500		9,158-10,989	90	1		200-250	50-100		005	30
Otto (Spark Ignition)	9,300-11,800	9,600-11,000	10,200-11,400	97-98	1	250-1,000	200-800	50-100	1.6-11.4	0,007-0.011	25-35
Gas Turbines											

CADER Technology Characterization Subcommittee (*Continued*)

	PERFORMANCE				ECONOMICS							
	Net Electric Heat Rate (HHV Btu/kWh) Full Load (100% FL)	Reduced Load (75% FL)	Mid-Load (50%FL)	Expected Availability	Typical Forced Outage Rate	Load Ramp Rate (kW/min)	Capital Cost ($/kW)	Installation	Fixed O&M	Variable Non-Fuel ($/kWh)	Power Plant
Micro-Turbines	10,300-16,484	11,300-17,000	12,200-25,043	92-98+	1-5	25-250	250-1,250	35-150		0.002-0.10	5-20+
Small Gas Turbines	8,400-16,000	9,000-11,000	9,850-12,200	90-98	1-3		300-870	50-120		002-008	20-50
Fuel Cells											
Molten Carbonate	6,545-7,580	6.270-8.040	6,100-9,090	>95%	<5%	7-285	815-1,900	100-435	70	003	30-35
Phosphoric Acid	9,450	9,450	9,450	97.7	1.2	80kW instan-taneous step load change increase while operating grid independent	3000	450-750		008-010	20
Proton Exchange Membrane	9,492-9,763	9,235-9,492	8,543-9,492	>95	<1	0.5	4,000	1,000		0.010-0.045	15-25
Hybrid Solid Oxide	5,380-6,120	6,110-6,640	6,240-6,670	94	4		1,150-1.300	180-230	25-50	.002-003	30
Solar Electric											
Photovoltaics	22,780 solar to electric						5,000-10,000			001-004	
Dish Stirling	8,400-16,600	11,000-18,500	16,700-21,500	95			3,800-4,000			.05-025	
Wind Turbines											
<50 kW	N/A	N/A	N/A	95-99	0-1	N/A	2,600-4,600	1,000-4,000			30

CADER Technology Characterization Subcommittee (*Continued*)

	PERFORMANCE			ECONOMICS							
	Net Electric Heat Rate (HHV Btu/kWh)			Expected Availability	Typical Forced Outage Rate	Load Ramp Rate (kW/min)	Capital Cost ($/kW)	Installation	Fixed O&M	Variable Non-Fuel ($/kWh)	Power Plant
	Full Load (100% FL)	Reduced Load (75% FL)	Mid-Load (50%FL)								
>50kW	N/A	N/A	N/A			N/A	850-1,500	60-175	4.2-70	003-021	20-25
STORAGE											
Batteries	N/A	N/A	N/A	100%	0-0.55%	Nearly Instantaneous to Full Load	620-1,250	200-416	10-42	0076	30
Flywheels	N/A	N/A	N/A	>95%	0	Nearly Instantaneous to Full Load	150-900	30-480	4-5		10-30

	POWER QUALITY				ENERGY STORAGE				OTHER ATTRIBUTES
	Construction Lead Time (months)	Voltage THD (%)	Current THD(%)	Full Load Power Factor	Stored Energy Capacity (kWh)	Discharge/ Charge Efficiency (%)	Stand-By Losses (1% cap/hr)	Time-to-Charge (hrs)	
GENERATION									
Reciprocating VCs									
Diesel	3-12				N/A	N/A	N/A	N/A	
Otto (Spark/Ignition)	8-9	5	5	0.8-1.0	N/A	N/A	N/A	N/A	
Gas Turbines									
Micro-Turbines	0-1	<5%	<5%	0.8-1.0	N/A	N/A	N/A	N/A	Emissions data at 15% O2
Small Gas Turbines	3-16				N/A	N/A	N/A	N/A	Includes Advanced Simple Cycle GT Data Emissions data at 15% O2

CADER Technology Characterization Subcommittee (*Continued*)

	POWER QUALITY				ENERGY STORAGE				OTHER ATTRIBUTES
	Construction Lead Time (months)	Voltage THD (%)	Current THD(%)	Full Load Power Factor	Stored Energy Capacity (kWh)	Discharge/ Charge Efficiency (%)	Stand-By Losses (1% cap/hr)	Time-to-Charge (hrs)	
0									
Fuel Cells									
Molten Carbonate	12-24	<3%	<3%	0.85-1.0 lead or lag	N/A	N/A	N/A	N/A	O&M Site Dependent. Early production units are projected to be available in 2001 at the higher capital cost. Installation does not include the cost of land transformer, switch gear and project development. Fixed O&M includes cost of major overhauls every five years.
Phosphoric Acid	7	<3% balanced linear load		.65 lead or lag	N/A	N/A	N/A	N/A	
Proton Exchange Membrane	1	<5%	<5%	.8 lead or lag	4	40		4	Aggregated data includes small power plant integrated with battery storage.
Hybrid Solid Oxide	3-6	Per IEEE Specs.	Per IEEE Specs.	1.0	N/A	N/A	N/A	N/A	Next generation designs include integration with Brayton cycle turbine, Cold start-up time is for gas turbine, SOFC requires hours for start-up
Solar Electric									
Photovoltaics					N/A	N/A	N/A	N/A	Hybrid design can also use fossil fuels, such as natural gas.
Dish Stirling	1	0.5	05		N/A	N/A	N/A	N/A	
Wind Turbines									
<50 kW	2	0.03	0.05	0.98					Integral storage under development for DG applications
<50 kW	8-12			leading or lagging controller	N/A	N/A	N/A	N/A	

ABOUT CADER

The California Alliance for Distributed Energy Resources (CADER) is dedicated to successfully facilitating a smooth deployment of economic, efficient and environmentally friendly distributed energy resources into the competitive energy market. Members in CADER represent all aspects of the energy industry and are focused on providing objective and much needed information on DER to the government, industry and consumers alike. While CADER's initial focus was on California, it is now broadening its membership to accommodate national coverage and dedicates its efforts to facilitate the DER industry.

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