

COMMERCIALLY AVAILABLE FUEL CYCLE TECHNOLOGIES

- **F - Fully satisfies all conditions:**

- Conventional Crude Oil Extraction
- Conventional Natural Gas
- Conventional Coal

- **MC - Most Conditions satisfied:**

- Enhanced Crude Oil Extraction – Thermal
- Nuclear Fission – Fuel Processing
- Petroleum Coke
- Municipal Solid Wastes
- Wind (Farms)

COMMERCIALY AVAILABLE FUEL CYCLE TECHNOLOGIES (2)

- **LC – Least Conditions satisfied:**

- Enhanced Crude Oil Extraction - Chemical
- Enhanced Crude Oil Extraction – Gas Displacement
- Nuclear Fission – Decommissioning
- Liquid Petroleum Gas (LPG)
- Liquid Natural Gas (LNG)
- Tar Sands
- Coal Gasification
- Ethanol
- Methanol (from Natural Gas)

COMMERCIALY AVAILABLE FUEL CYCLE TECHNOLOGIES (3)

- **LC – Least Conditions satisfied (*continuation*):**
 - Hydrothermal - Vapor & Liquid Dominated
 - Biomass Fuel
 - Solar Resource (PV, Thermal Electric)

COST OF COMMERCIALY AVAILABLE FUELS

US Energy Prices					
	Fuel Cycle Technology	1996	2000	2001	2002
	Electricity, Residential (cents/kWh)		8.23	8.58	8.54
F	Conventional Crude Oil Extraction (\$/bbl)		27.72	24.65	24.66
	Heavy Fuel Oil (\$/metric ton)	126.1			
	At retail (\$/bbl)		25.34	23.85	23.15
	At electric utility (\$/million Btu)		4.26	3.90	3.73
	Diesel Oil, at retail (\$/gallon)		1.49	1.45	1.42
	Heating Oil, at retail (\$/gallon)		1.31	1.31	1.25
	Heating Oil, wholesale (\$/gallon)		0.89	0.83	0.79
	Conventional Natural Gas				
	At wellhead (\$/1,000 cubic feet)		3.61	4.23	2.65
	At electric utility (\$/million Btu)		4.33	4.69	3.29
	At residential (\$/1,000 cubic feet)		7.71	9.30	7.38
	Conventional Coal				
	At electric utility (\$/million Btu)		1.20	1.24	1.23
	MC	Enhanced Crude Oil Extraction – Thermal			
Nuclear Fission – Fuel Processing					
Petroleum Coke					
Municipal Solid Wastes					
Wind (Farms)					
LC	Enhanced Crude Oil Extraction - Chemical				
	Enhanced Crude Oil Extraction – Gas Displacement				
	Nuclear Fission – Decommissioning				
	Liquid Petroleum Gas (LPG)				
	Liquid Natural Gas (LNG)				
	Tar Sands				
	Coal Gasification				
	Ethanol				
	Methanol (from Natural Gas)				
	Hydrothermal - Vapor & Liquid Dominated				
	Biomass Fuel				
	Solar Resource (PV, Thermal Electric, Thermal)				

FUEL CYCLE TECHNOLOGIES

Primary Energy Source	Commercially Available (F, MC, LC)	Not Yet Commercially Available (Near Term)	Not Yet Commercially Available (Long Term, Indeterminate)
1.1 Conventional Fuels:			
1.1.1 Oil	Conventional Oil Ext. (F) Enhanced Oil Extraction: Thermal (MC) Chemical (LC) Gas Displacement (LC)		
1.1.2 Natural Gas	Natural Gas (F)		
1.1.3 Coal	Conventional Coal (F)		
1.1.4 Nuclear Fission	Fuel Processing (MC) Decommissioning (LC)		Waste Disposal (LT)
1.1.5 Liquid Petroleum Gas (LPG)	LPG (LC)		
1.1.6 Liquid Natural Gas (LNG)	LNG (LC)		
1.1.7 Petroleum Coke (“Coke”)	Petroleum Coke (MC)		

FUEL CYCLE TECHNOLOGIES (2)

Primary Energy Source	Commercially Available (F, MC, LC)	Not Yet Commercially Available (Near Term)	Not Yet Commercially Available (Long Term, Indeterminate)
1.2 Alternative Fuels:			
1.2.1 Oil Shale			Oil Shale (LT)
1.2.2 Tar Sands	Tar Sands (LC)		
1.2.3 Nuclear Fusion			Nuclear Fusion (LT)
1.2.4 Coal	Coal Gasification (LC)	Direct Liquefaction (NT) Indirect Liquefaction (NT) Pyrolysis (NT)	
1.2.5 Ethanol	Ethanol (LC)		
1.2.6 Methanol (from Natural Gas)	Methanol (LC)		
1.2.7 Hydrogen			Hydrogen (LT)

FUEL CYCLE TECHNOLOGIES (3)

Primary Energy Source	Commercially Available (F, MC, LC)	Not Yet Commercially Available (Near Term)	Not Yet Commercially Available (Long Term, Indeterminate)
1.3 Renewable Fuels:			
1.3.1 Geothermal	Hydrothermal (LC)	Hot Dry Rock (NT)	Magma (LT)
1.3.2 Biomass Fuel	Biomass Fuel (LC)		
1.3.3 Municipal Solid Wastes (MWS)	MSW (MC)		
1.3.4 Solar Resource	Solar (LC)		
1.3.5 Wind	Wind (MC)		
LEGEND:	F = Fully MC = Most Conditions LC = limited conditions	NT = Near Term (≤ 20 years)	LT = Long Term (20 – 50 years) I = Indeterminate
Source:	1996 Energy Technology Status Report California Energy Commission		

COMMERCIALY AVAILABLE POWER GENERATION TECHNOLOGIES

- **F - Fully satisfies all conditions:**

- *Oil & Gas* Simple Cycle Gas Turbine (GT)
- *Oil & Gas* Conventional Combined Cycle (CC)

- **MC – Most Conditions satisfied:**

- *Oil & Gas* Small-Scale Turbines
- *Coal* Conventional Steam Boiler
- *Coal* Atmospheric Fluidized Bed Combustion (AFBC)
- *Nuclear Fission* Boiling Water Reactor (BWR)
- *Nuclear Fission* Pressurized Water Reactor (PWR)
- *Geothermal* Vapor Dominated

COMMERCIALLY AVAILABLE POWER GENERATION TECHNOLOGIES (2)

- **MC – Most Conditions satisfied (*continuation*):**
 - *Geothermal* Liquid Dominated Brine pH Modification
 - *Geothermal* Liquid Dominated Binary Cycle
 - *Hydroelectric* Conventional Hydro
 - *Hydroelectric* Hydro Uprating
 - *Municipal Solid Waste* Mass Burn
 - *Municipal Solid Waste* Landfill Gas Recovery
 - *Cogeneration* GT Heat Recovery
 - *Cogeneration* GT with Combined Cycle
 - *Cogeneration* Reciprocating (Piston) Engines

COMMERCIALY AVAILABLE POWER GENERATION TECHNOLOGIES (3)

- **MC – Most Conditions satisfied (*continuation*):**

- *Cogeneration* Bottoming Cycle Low Pressure ST
- *Wind* Utility-Scale Applications (Wind Farms)
- *Storage* Conventional Pumped Hydro

- **LC – Least Conditions satisfied:**

- *Oil & Gas* Conventional Rankine
- *Oil & Gas* Supercritical Rankine
- *Oil & Gas* Kalina Combined Cycle
- *Oil & Gas* Steam Recuperated GT
- *Geothermal* Liquid Dominated Flashed Steam
- *Geothermal* Liquid Dominated Topping Cycle Biphase

COMMERCIALLY AVAILABLE POWER GENERATION TECHNOLOGIES (4)

- **LC – Least Conditions satisfied (*continuation*):**
 - *Geothermal* Liquid Dominated Bottoming Cycle Biphase
 - *Hydroelectric* Hydro Retrofit
 - *Biomass* Direct Combustion
 - *Biomass* Gasification
 - *Biomass* Anaerobic Fermentation
 - *Municipal Solid Waste* RDF Spreader-Stoker
 - *Municipal Solid Waste* RDF Fluidized Bed Boiler
 - *Cogeneration* Topping Cycle Back-Pressure ST
 - *Cogeneration* Topping Cycle Extraction ST
 - *Cogeneration* Bottoming Cycle Organic Rankine Engines

COMMERCIALLY AVAILABLE POWER GENERATION TECHNOLOGIES (5)

- **LC – Least Conditions satisfied (*continuation*):**
 - *Cogeneration* Packaged Cogeneration Systems
 - *Solar Thermal Electric* Parabolic Troughs
 - *Solar Photovoltaic* Small-Scale Solar PV Applications
 - *Ocean Energy* Wave Energy (OWC)
 - *Storage* Modular Pumped Hydro
 - *Storage* Compressed Air Energy Storage (CAES)
 - *Storage* Utility Scale Batteries (USB)
 - *Storage* Superconducting Magnetic Energy System (SMES)

COST OF COMMERCIALY AVAILABLE POWER GENERATION TECHNOLOGIES

Commercially Available Power Generation Technologies

	Power Generation Technologies Levelized Cost in Nominal 1996 \$	Baseload 60 - 75 %	Intermediate 20 - 35%	Intermittent Varies	Peaking 0 - 5%
F	<i>Oil & Gas Simple Cycle Gas Turbine (GT)</i>				20.5 - 20.9
	<i>Oil & Gas Conventional Combined Cycle (CC)</i>	5.3 - 6.0	7.2 - 10.1		
MC	<i>Oil & Gas Small-Scale Turbines</i>	5.6 - 7.7			
	<i>Coal Conventional Steam Boiler Rankine Cycle - Subcritical</i>	5.9 - 7.1			
	<i>Supercritical</i>	6.1 - 7.7			
	<i>Coal Atmospheric Fluidized Bed Combustion (AFBC)</i>	6.2 - 7.4			
	<i>Nuclear Fission Boiling Water Reactor (BWR)</i>	11.4 - 15.3			
	<i>Nuclear Fission Pressurized Water Reactor (PWR)</i>	11.7 - 15.6			
	<i>Geothermal Vapor Dominated</i>	6.1 - 10.7			
	<i>Geothermal Liquid Dominated Brine pH Modification</i>	5.3 - 7.2			
	<i>Geothermal Liquid Dominated Binary Cycle</i>	6.1 - 17.5			
	<i>Hydroelectric Conventional Hydro</i>	6.4 - 13.8			
	<i>Municipal Solid Waste Mass Burn</i>	2.7 - 6.0			
	<i>Municipal Solid Waste Landfill Gas Recovery</i>	2.3 - 5.1			
	<i>Wind Utility-Scale Applications (Wind Farms)</i>				7.2 - 8.4
	<i>Storage Conventional Pumped Hydro</i>				19.3 - 22.6
	LC	<i>Oil & Gas Kalina Combined Cycle</i>	5.4 - 8.3		
<i>Oil & Gas Steam Recuperated GT</i>		5.4 - 7.4	7.4 - 13.0		
<i>Geothermal Liquid Dominated Flashed Steam</i>		5.9 - 19.9			
<i>Geothermal Liquid Dominated Topping Cycle Biphase</i>		5.9 - 10.7			
<i>Geothermal Liquid Dominated Bottoming Cycle Biphase</i>		4.9 - 9.4			
<i>Hydroelectric Hydro Retrofit</i>		3.8 - 8.1			
<i>Biomass Direct Combustion</i>		8.6 - 22.4			
<i>Biomass Gasification w/ Engine</i>		10.0 - 16.3			
<i>Biomass Anaerobic Fermentation w/ Engine</i>		11.5 - 20.9			
<i>Municipal Solid Waste RDF Spreader-Stoker</i>		1.6 - 12.1			
<i>Municipal Solid Waste RDF Fluidized Bed Boiler</i>		1.8 - 12.2			
<i>Solar Thermal Electric Parabolic Troughs - 80 MW</i>		10.6 - 12.8	16.2 - 26.0	13.6 - 20.7	
<i>200 MW</i>		9.4 - 11.3	14.0 - 22.2	11.8 - 17.6	
<i>Ocean Energy Wave Energy (OWC)</i>				7.9 - 49.6	
<i>Storage Modular Pumped Hydro</i>				10.9 - 19.3	26.8 - 30.0
<i>Storage Compressed Air Energy Storage (CAES)</i>				8.9 - 9.9	
<i>Storage Utility Scale Batteries (USB)</i>					19.4 - 22.5

ELECTRIC GENERATION TECHNOLOGIES

Primary Energy Source	Commercially Available (F, MC, LC)	Not Yet Commercially Available (Near Term)	Not Yet Commercially Available (Long Term, Indeterminate)
2.0 Oil & Gas Combustion	Conv. Rankine (LC) Supercritical Rankine (LC) Simple Cycle GT (F) Conv. CC (F) Kalina CC (LC) Steam Recup. GT (LC) Small-Scale Turbines (MC)	Intercool. SRGT (NT) Chemically Recu. GT (NT) Humid Air GT (NT) Intercool. Reheat CC (NT) Intercool. Aero. GT (NT)	
3.0 Coal	Conv. Steam Boiler (MC) Atm. Fluidized Bed (MC)	Press. Fluidized Bed (NT) IG CC (NT) IG HAT (NT) Direc Coal Comb. (NT) Direct Coal Diesel (NT)	Indirectly Coal CC (I) Magnetohydrodynamics (I)
4.0 Nuclear Fission	PWR (MC) BWR (MC)		HTGR (LT) LMFBR (LT)
5.0 Nuclear Fusion			High Temperature (LT) Cold Fusion (I)
6.0 Geothermal	Vapor-Dominated (MC) Flashed Steam (LC) Geo. Brine ph Mod. (MC) Binary Cycle (MC) Biphase Topping (LC) Biphase Bottoming (LC)	Binary Kalina Cycle (NT)	

ELECTRIC GENERATION TECHNOLOGIES (2)

Primary Energy Source	Commercially Available (FC, MC, LC)	Not Yet Commercially Available (Near Term)	Not Yet Commercially Available (Long Term, Indeterminate)
7.0 Hydroelectric	Conv. Hydro (MC) Hydro Uprating (MC) Hydro Retrofit (LC)		
8.0 Biomass-Fired Plants	Direct Combustion (LC) Gasification (LC) Anaerobic Ferment. (LC)		
9.0 Municipal Solid Waste (MSW)	Mass Burn (MC) RDF Spreader Stoker (LC) Fluidized Bed Boiler (LC) Landfill Gas (MC)	Co-Firing (20% Coal) (NT) Pyrolysis/Thermal Gasification (NT)	
10.0 Cogeneration	GT Heat Recovery (MC) GT with CC (MC) Piston Engine (MC) Back-Press. Top. ST (LC) Extraction Top. ST (LC) Low-Press. Bot. ST (MC) Organic Rankine Bot. (LC) Packaged Cogen. (LC)	Stirling Engines (NT) Fuel Cell Cogen. (NT)	
11.0 Wind	Utility-Scale (MC) <i>Small-Scale Wind Turbines</i>		

ELECTRIC GENERATION TECHNOLOGIES (3)

Primary Energy Source	Commercially Available (F, MC, LC)	Not Yet Commercially Available (Near Term)	Not Yet Commercially Available (Long Term, Indeterminate)
12.0 Solar Thermal Electric	Parabolic Troughs (LC)	Central Receivers (NT) Parabolic Dishes (NT)	Salt Ponds (I)
13.0 Solar Photovoltaic	<i>Small-Scale Solar PVs</i>	Utility-Scale Systems (NT)	
14.0 Ocean Energy Conversion	Wave Energy (LC)	Tidal Energy (NT)	Ocean Thermal Energy Conversion – OTEC (LT)
15.0 Fuel Cells		PAFC (NT) MCFC (NT) SOFC (NT) PEM (NT)	AFC (LT)
16.0 Storage	Conv. Pumped Hydro (MC) Modular Pumped Hydro (LC) CAES (LC) USB (LC) Micro SMES (LC)		