



## Pacific Region CHP Application Center How Can We Help You?

**Vince McDonell**

**Co-Director, Pacific Region CHP Application Center  
Associate Director, Advanced Power & Energy Program, UC Irvine**

[www.chpcenterpr.org](http://www.chpcenterpr.org)

*CWEA Specialty Workshop  
Whittier, CA  
5 June 2007*

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## Outline

- **What is PRAC and what do we do**
- **What is CHP and why you should care**
- **CHP for water treatment applications**
- **Next steps you can take**

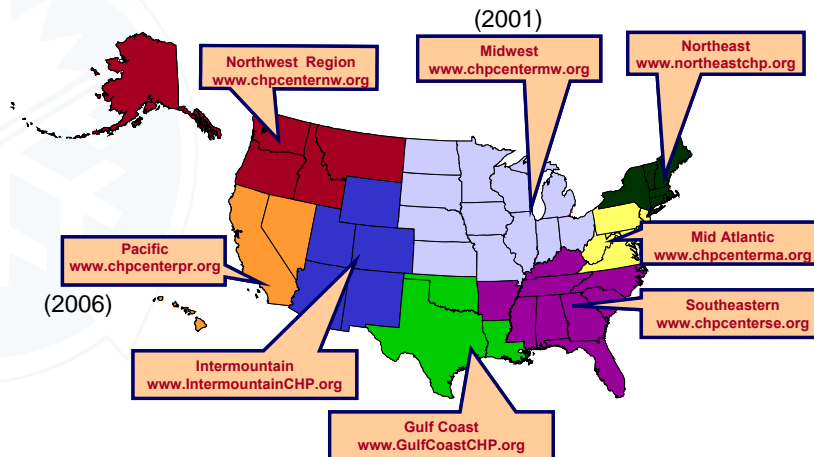
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PACIFIC REGION  
COMBINED HEAT & POWER  
APPLICATION CENTER

## CHP Application Center Mission

The regional application centers will promote combined heating and power (CHP) technology and practices, serve as a central repository and clearinghouse of CHP information, and identify and help implement regional CHP projects.



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COMBINED HEAT & POWER  
APPLICATION CENTER

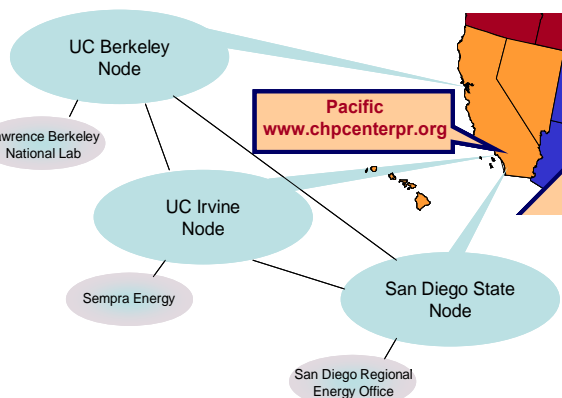
## Pacific Region CHP Application Center (PRAC)

### Partnerships



[www.chpcenterpr.org](http://www.chpcenterpr.org)

UC Berkeley—Tim Lipman, 510 642 4501  
UC Irvine—Vince McDonell, 949 824 5950 x121  
SDSU—Asfaw Beyene, 619 594 6207



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## PRAC Structure

- **Partnership:**
  - University of California - Berkeley
    - Energy and Resources Group (ERG)
    - Lipman, Kammen, Farrell
    - With: Lawrence Berkeley National Lab (Marnay)
  - University of California - Irvine
    - Advanced Power and Energy Program (APEP)
    - McDonnell, Samuelsen, Brouwer
    - With: Sempra Energy (Berokoff, Ruiz)
  - San Diego State University
    - Industrial Assessment Center (IAC)
    - Beyene
    - With: San Diego Regional Energy Office (Stillings)



## PRAC Advisory Board

Michael Batham Sacramento Municipal Utility District	Chris Marnay Berkeley Lab
David Berokoff Sempra Energy Utilities	Charlie Senning The Gas Company
Kevin Best Real Energy	Irene Stillings San Diego Regional Energy Office
Keith Davidson DE Solutions, Inc.	Eric Wong Cummins Power Generation
Neil Dimmick Nevada State Office of Energy	Keith Yoshida The Gas Company



## PRAC Activities

- **Specializations**

- Low-Emission Technologies
  - Low-emission engine and exhaust treatment systems
  - Fuel cell systems
  - Solar thermal systems
  - Other low-emission systems to meet ARB '07 DG standards
- Cooling Technologies
  - Absorption cooling systems
  - Solar activated cooling systems
- PRAC Network: “Clean and Cool”



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## PRAC Activities

- **Outreach--Technical**

- CHP Roadmap Workshop and outcomes
  - CADER conference in 1/04, results posted 6/04
  - Follow-on being planned
- University facility managers -- working group
- Workshops conducted
  - Waste-heat to power Feb 05, Feb 06
  - CHP for Dairy, WWTP, Sept 06, Apr 07
  - CHP for Universities, Sept 06
- Workshops Coming up
  - “CHP 101”, Sept 07, Downey CA
  - Waste Heat to Power, Sept 07, Houston, TX

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## PRAC Activities

- **10 project “case study” profiles completed**
  - Hotel microturbine
  - Brewery fuel cell
  - Wastewater treatment microturbine
  - Casino reciprocating engine
  - Office building microturbine
  - Office building reciprocating engine
  - Pharmaceutical laboratory reciprocating engine
  - Dairy reciprocating engine
  - Winery microturbine
  - Jail fuel cell
- **Examples available here and on website**

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## PRAC Activities

- **Project Assistance**

Site	Assessment	Report	CHP Recommended?
CA UC campus	Complete	Final	Yes
Hawaii hotel	Complete	Draft	Yes
Hawaii hotel	Complete	Draft	Yes
CA ethanol plant	Complete	?	?
CA bakery	Complete	Final (?)	Yes
CA Contra Costa Cty. building	Complete	?	?
CA Contra Costa Cty. building	Complete	?	?
CA laboratory	Complete	In progress	?
CA manuf. facility	Complete	In progress	?

- **Level I assessment (1 day, utility bills)**
- **More information available**
  - Flyer
  - Website

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## PRAC Activities

- **Project Assessment**

- Additional Resources (links on website)
  - MW RACs CHP Resource Guide
  - IM RAC's Buyer's Guide
  - ORNL's CHP Assessment Tool
    - [http://www.ornl.gov/sci/engineering\\_science\\_technology/cooling\\_heating\\_power/success\\_analysis\\_BCHP.htm](http://www.ornl.gov/sci/engineering_science_technology/cooling_heating_power/success_analysis_BCHP.htm)
  - EPA/CHP Partnership
    - [http://www.epa.gov/chp/project\\_resources/wastewater.htm](http://www.epa.gov/chp/project_resources/wastewater.htm)

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## PRAC Activities

- **Outreach--Policy**

- California Energy Action Plan
- The Western Governor's Association Efforts (including white paper development) - The Western Governors Association adopted the *Clean and Diversified Energy for the West Policy Resolution 06-10* on June 11, 2006. The final report called *Clean Energy, a Strong Economy and a Healthy Environment* June 2006 included strong CHP support <http://www.westgov.org/wga/meetings/am2006/CDEAC06.pdf> . CHP White Paper is completed at <http://www.westgov.org/wga/initiatives/cdeac/CHP-full.pdf> .
- Tracking current/pending SGIP legislation
  - AB 32 GHG emissions, CHP
  - AB 2778 (SGIP)
  - AB 1613 (Blakeslee): CHP is EE (loading order pref)
  - AB 1064 (Lieber): SGIP for biogas--Combustion Technologies just removed

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## For Further Information

- **Pacific Region CHP Application Center**  
– [www.chpcenterpr.org](http://www.chpcenterpr.org)
  - Tim Lipman - UCB/ERG: (510) 642-4501
  - Vince McDonell - UCI/APEP: (949) 824-5950 x121
  - Asfaw Beyene - SDSU/IAC: (619) 594-7143

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## Outline

- What is PRAC and what do we do
- **What is CHP and why you should care**
- **How has CHP been implemented in water treatment applications**
- **Next steps you can take**

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## CHP Overview

- **DG Technology**
- **CHP**
- **CHP in context of WWT**

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## Engines

- **Compression Ignition (Diesel)**
  - **Spark Ignited (Nat Gas)**
  - **Mature Technology**
  - **500 to 5000 kW typ market**
  - **Installed Cost \$500-1200/kW**
  - **Reasonable Efficiency (40%)**
  - **Emissions\* (untreated Nat Gas)**
    - 50-150 ppm NOx
    - 200-1100 ppm CO
  - **Emissions\* (untreated Diesel)**
    - 5 to 25 times more NOx vs Nat Gas
  - **Relatively High Maintenance (\$0.01-0.04/kWhr)**
  - **Approaching 95% availability**
  - **Primarily Used For Back-up And Remote Power Applications**
  - **DER Applications Emerging (Base and Load Following)**
  - **Fuel Flex to a degree (e.g., BioDiesel, Hydrogen)**
  - **DOE ARES/CEC ARICE Programs**
- \*Clean up can reduce by 90%→95%

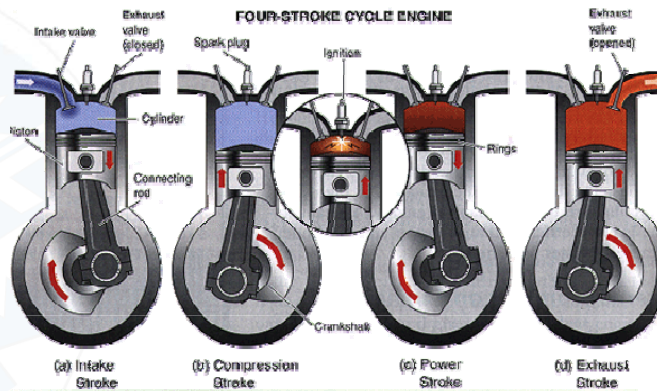


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## Engines

### Basic Process: Spark Ignition



Many moving parts

Lubrication Required

Highly Dynamic Process with Challenging Time Scales

High Emissions of CO, HC, NO<sub>x</sub> reduced substantially with cleanup

Water Management/Fluid Management

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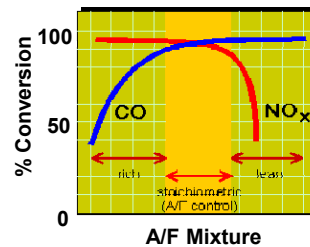


## Engines

### DOE ARES Targets (2010):

#### Barriers & Solutions

- Emissions (currently 150 ppm NO<sub>x</sub>, UHC, 2000+ CO)
  - To get to 10 ppm:
  - 3-way catalysts (NSCR)
    - Limits Exhaust Composition (Need EGR to maintain comparable CO, UHC, NO<sub>x</sub> levels)
  - Lean Burn Strategies
    - SCR (90% eff) being considered
    - Lower Specific Power (more air)
    - HCCI
- Maintenance
  - Improved Manufacturing
  - Improved Materials

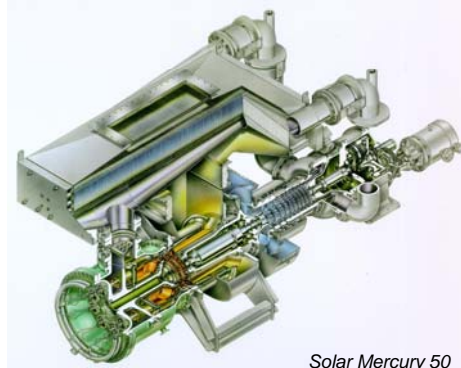


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## Gas Turbines

- **Mature Technology**
- **1 to 50 MW**
- **25 to 40% efficiency**
- **9-25 ppm NOx**
- **Maintenance Cost**
  - \$0.003-0.008/kW-hr
- **Installed Cost \$400-900/kw**
- **Durable**
  - 40,000 hour lifetime
- **Baseload and Peaking Applications Common**
- **Fuel Flex**



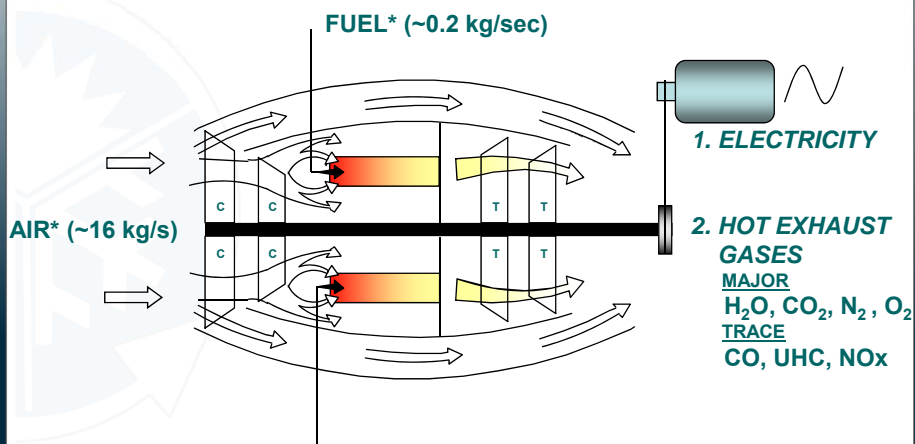
Solar Mercury 50

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## Gas Turbines

### Basic Process: Gas Turbine



\* ~4 MW STATIONARY GTE

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## “Microturbine” Generators

- **<100 kW**
  - Larger Units Appearing Today
- **Installed Cost\*\*\***
  - \$800 to \$2000/kW
- **Emissions**
  - <9 to 25+ ppm NOx
- **O&M Costs\*\*\***
  - \$0.003 to 0.015/kWhr
- **Efficiency 25-30%**
  - Fuel to Electricity
- **70dB @ 10m\*\*\***
- **Design Life 5+ years\*\*\***
  - Insufficient Data
  - Capstone 330s approaching 30,000 hours (>half way!)
  - Fuel Compressor?
- **Baseload, Peaking, Backup?,**
- **Fuel Flexible (gas, liquid, landfill, anaerobic digester, ...)**
- **Active Commercial Interest**



\*\*\*work in progress

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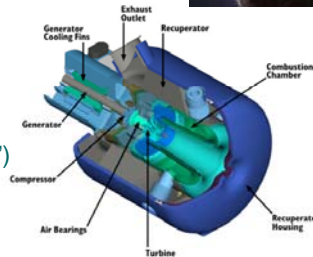
## “Microturbine” Generators

### Commercialization Issues

- Cost
  - Economy of Scale
  - New Engines Larger
  - Materials
  - Packaging/Integration
- Efficiency
  - PR/Recuperation
  - Materials
  - Hybridize
  - CHP
- Emissions (“CARB 2007”)
  - Low PR
  - Turndown
  - Acoustics



Capstone C-200

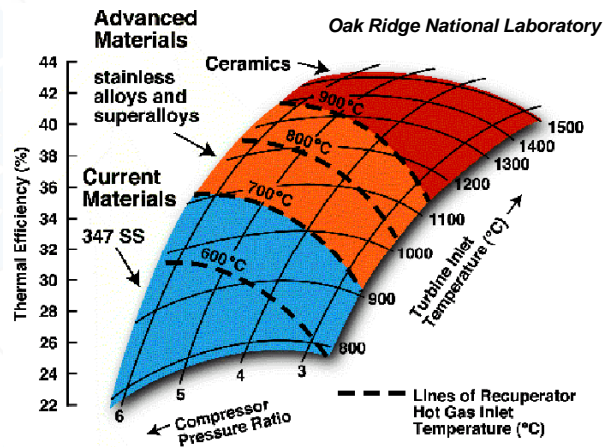


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# “Microturbine” Generators

## Barriers to Efficiency



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# Fuel Cells

- <1500 kW\*
  - Larger Units Planned
- Installed Cost
  - \$4,500 to \$30,000/kW
  - Insufficient Data
- Emissions
  - ~0
- O&M Costs
  - Warranty Issue Now
- Efficiency 30-60%
  - Fuel to Electricity
- Quiet
- Design Life 5+ years
  - Insufficient Data
  - Few Commercial Products
- Baseload or Load Following Depending on Cell Type



\*UTC Fuel Cells, Plug Power, Fuel Cell Energy offer Commercial Products today

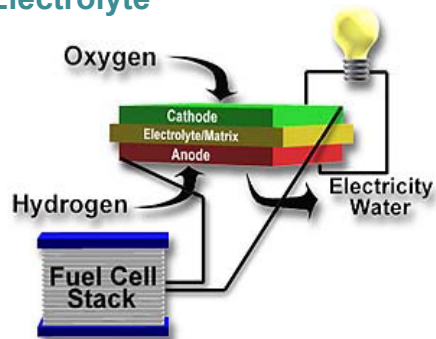
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## Fuel Cells

### Basic Process: Fuel Cell

- “Continuous Battery”
- Fuel And Oxidant (Air) Supplied to separate chambers - Never Needs Charging
- Ionic Transport Through Electrolyte
- Reverse Hydrolysis

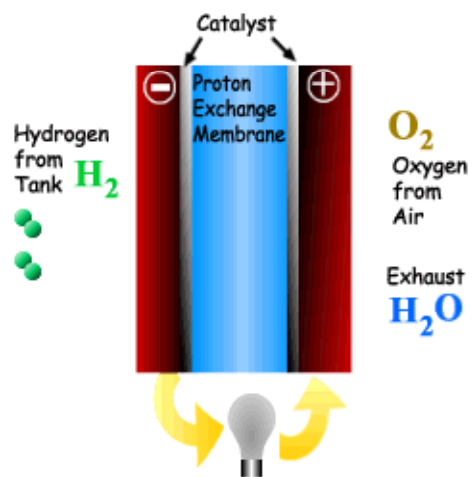


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## Fuel Cells

### Basic Process: Fuel Cell



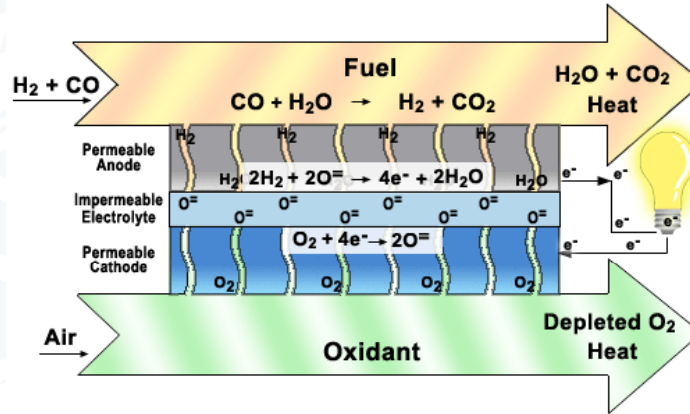
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## Fuel Cells

### Basic Process: Fuel Cell

#### Solid Oxide Fuel Cell



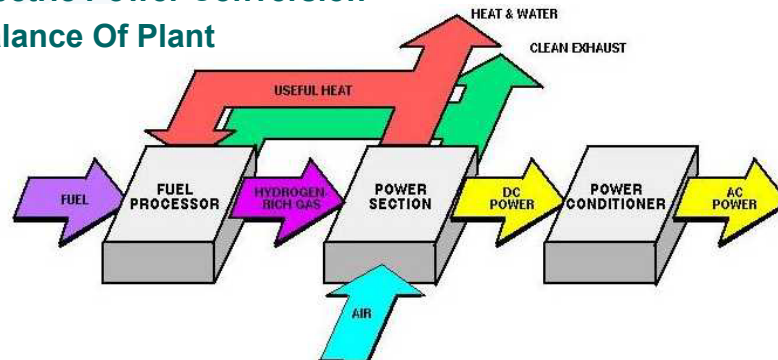
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## Fuel Cells

### Basic Process: Fuel Cell

- Fuel Cell Stack
- Fuel Processing
- Electric Power Conversion
- Balance Of Plant



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## Fuel Cells

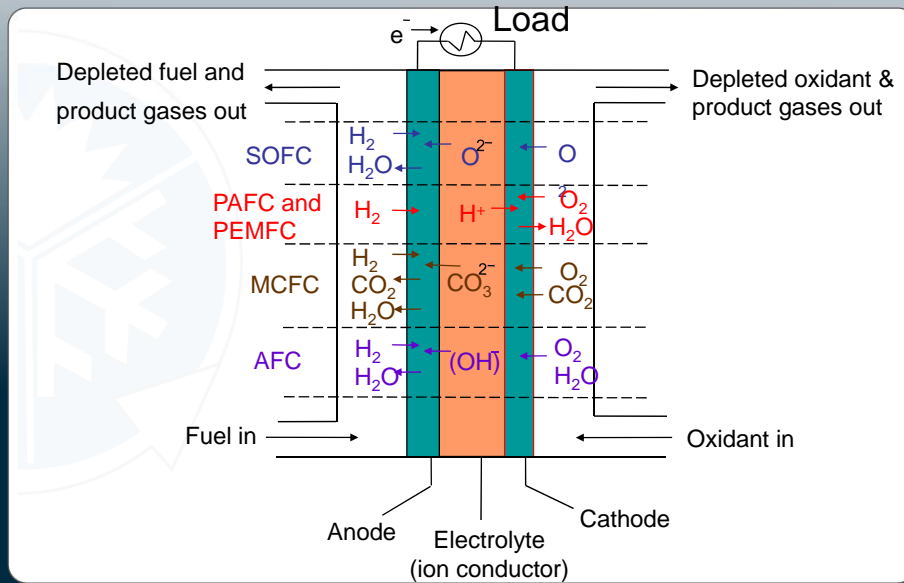
- Various types of Fuel Cell technology
- Characterized by electrolyte material

	PAFC	MCFC	SOFC	PEMFC	AFC
Electrolyte	H <sub>3</sub> PO <sub>4</sub>	Molten Carbonate Salt	Ceramic (YSZ)	Sulfonic-acid Polymer (Nafion™)	KOH/H <sub>2</sub> O
Operating Temperature	~ 200°C	~ 650°C	800-1000°C	~ 80°C	60-80°C
Fuels	H <sub>2</sub> /Reformate	H <sub>2</sub> /CO/Reformate	H <sub>2</sub> /CO/CH <sub>4</sub> /Reformate	H <sub>2</sub> /Reformate	H <sub>2</sub>
Reforming	External	External/Internal	External/Internal	External	
Oxidant	O <sub>2</sub> /Air	CO <sub>2</sub> /O <sub>2</sub> /Air	O <sub>2</sub> /Air	O <sub>2</sub> /Air	O <sub>2</sub> /Air
Electrical Efficiency (LHV)	36-45%	45-55%	50-60%	32-40%	50-60%

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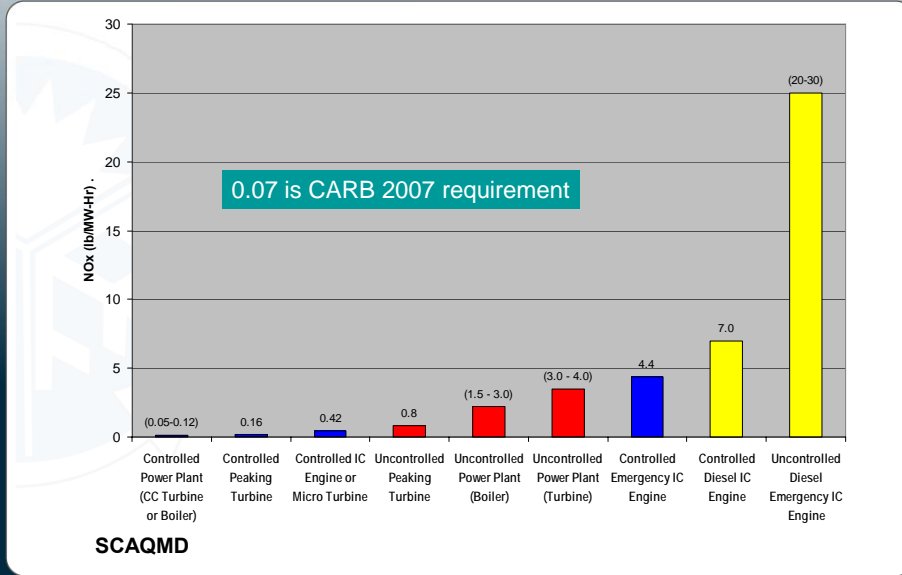
## Fuel Cells



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## Comparisons: Emissions



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## Comparisons: Emissions

TABLE 1: NOx & EFFICIENCY LEVELS FOR DG POWER/FUEL SOURCES

	EFFICIENCY (HHV)	TYPICAL CAPACITY(kW)	NOx (lb/MW-hr)
Solid Oxide Fuel Cell	42%	25	0.01
Phosphoric Acid Fuel Cell	37%	200	0.03
Natural Gas Lean Burn IC Engine	36%	1,000	2.2
3-Catalyst NG Rich Burn IC Engine	29%	1,000	0.5
Uncontrolled Diesel IC Engine	38%	1,000	21.8
SCR Controlled Diesel Engine	29%	1,000	4.7
Microturbine	25%	25	0.44
Small Natural Gas Turbine	27%	4,600	1.15
Medium Natural Gas Turbine	30%	12,900	0.61
Large Natural Gas Combined Cycle	51%	500,000	0.06
Large Natural Gas Turbine	31%	70,140	0.59
ATS Simple Cycle Gas Turbine	35%	4,200	0.32
Average Coal Boiler (1998)	33%	300,000	5.6

Bluestein

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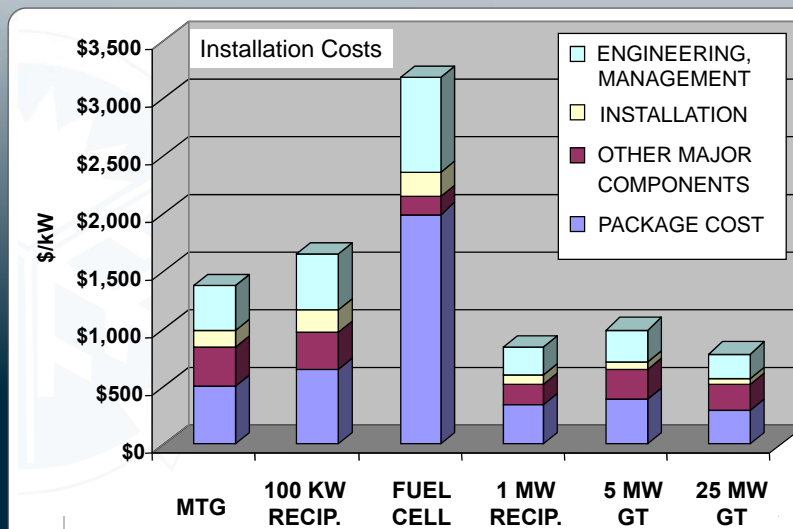
## Comparison: Emissions

- **Fuel Cell approaches wind, solar**
- **Most Advanced MTGs and IC Engines are Comparable**
  - New Regulations are in place
    - National 0.5-0.47 lb/MWh to 0.07 after Jan 09
    - California 0.5 lb/MWh to 0.07 after Jan 07
- **State of the Art Combined Cycle Central Station is Clean**
- **Typical Aged Power Plant is relatively awful!**
- **Uncontrolled Diesel (typical backup power today) is awful!**
- **DOE/EPA Technology Characterization Documents**
  - <http://www.epa.gov/chp/>
  - MTGs, IC Engines

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## Comparison: Economics



Source: Davidson, On-Site Energy, PowerGen '99

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## Comparison: Economics

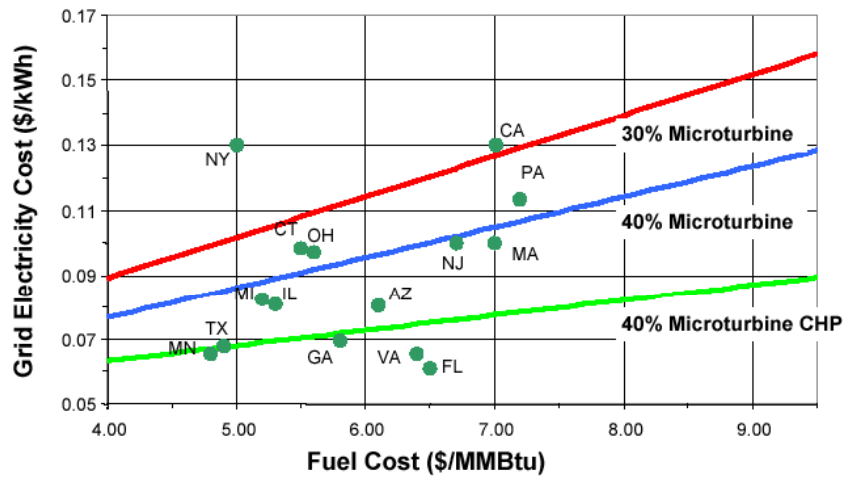
- **O&M Costs**
  - Systems are not maintenance free
    - <1¢ - 10¢ per kw-hr of electric power generated have been seen
    - Some correlation with installation/design
    - Newer DG technology: insufficient data
- **Availability and economics**
  - Availability can be significant factor in overall economics
    - 90+% availability is not unreasonable need and is achievable
    - Significant economic impact for down time in peak periods
      - Demand charges \$35/kw/month. Even 15 min down time can have severe impact on monthly utility savings.
    - Ownership and vested interest on part of customer has great impact on system reliability
- **Risk Mitigation Option**
  - ESCO (Energy Services Company) to operate and maintain equipment for purchase of power and heat at reduced costs.
    - A topic for separate discussion.

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## Comparison: Economics

### “Spark Spread”



T. Rosfjord, United Technologies Research Center

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## CHP Overview

- DG Technology
- **CHP**
- **CHP in context of WWT**

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## CHP

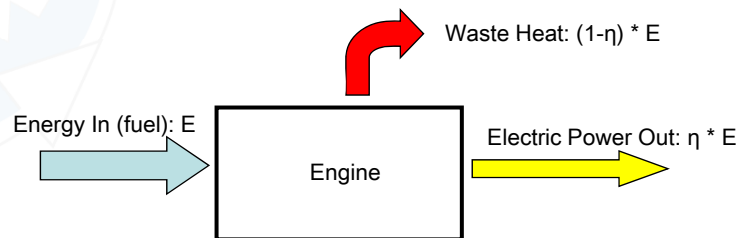
- **What is CHP?**
- **CHP: Combined Heat and Power**
- **C-CHP: Combined Cooling, Heat and Power**
- **Local generation of electric power with some form of prime mover and capture of waste heat to provide some additional beneficial use.**
- **Opportunity to “get more bang for your buck” but getting two or maybe three uses for each unit of energy purchased and consumed on site**

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# CHP

- **Thermodynamic Limitation**
  - Cannot transform energy at 100% efficiency. For all practical systems, there will be always be a loss.
- **Efficiency =  $\eta$  = (useful energy out) / (energy in)**
  - Generation of electricity for fossil energy resources will result in wasted energy.
  - Efficiencies: <10% to approx 50% for simple cycles

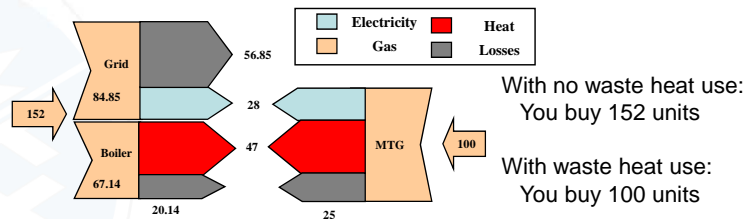


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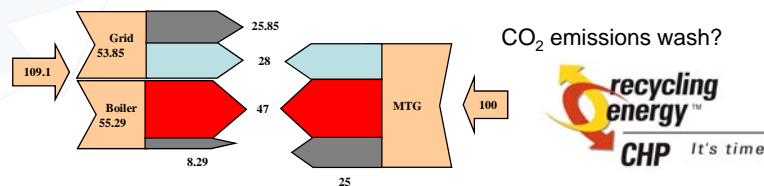


# CHP

- **“Today’s Grid” (33% efficient, 70% boiler)**



- **“Next Generation Grid” (52% efficient, 85% boiler)**



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## CHP

- **Why don't we have CHP at Utility Level?**
  - Quantity of Waste Heat is tremendous
    - Large centralized power plants are approx 35% efficient
    - 500 MW facility → 925 MW of waste heat
  - District Heating is employed in some places
    - Centralized steam heating systems in large cities: e.g. New York, San Francisco
- **Great opportunity for greater efficiency of future city planning for district heating, cooling, and power.**
  - Lower cost, reduced greenhouse gas (CO<sub>2</sub> emissions), reduced pollutant emissions

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## CHP

- **Direct use of exhaust heat:**
  - Process heating/drying (industrial)
    - Example: Higgins Brick (Chino, CA) directly utilizes exhaust from three, 80 kW turbines to preheat air for brick drying to 300+ deg-F
  - Desiccant Dehumidification: Turbine exhaust used to regenerate moisture absorbing material
    - Useful energy reduction scenario for HVAC systems
    - Much energy is used to cool and remove moisture in air.
    - Office, labs, and grocery stores see great benefit

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- **Bottoming Cycles: waste heat → more electricity**
  - Organic Rankine Cycles
    - UTC “Pure Cycle”, Ormat Products
  - Steam driven generators – large qty of high temp heat → large GT
  - Thermoelectric generators
  - Air Cycles – Stirling Cycles

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- **Possibly of most direct interest:**
  - Generate Hot water/steam or other fluid for:
    - Process/Space heating
    - Domestic hot water
      - Hospitals, Hotels, Food services
  - Steam Production
    - Industrial, Hospitals, food services
  - Cooling
    - Thermally activated systems
      - Absorption and Adsorption chillers
      - Steam driven turbine chillers

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### Absorption and Adsorption chillers:

Cooling is highly beneficial to So Cal and Southwest area.

- **Cooling liquid loop based HVAC:**
  - Chillers make cold water to be used in HVAC systems, passing liquid through coils and heat exchanges to cool air.
- **Can be used for deeper refrigeration (freezing)**
  - Lithium Bromide-Water systems: approx 40 deg-F min temp.
  - Ammonia-Water systems: sub-zero minimum temperatures
- **Absorption Chillers offer opportunity for “tri-generation”**
  - Chilled water + hot water
  - Chiller must reject heat it absorbs → can be used for hot water
  - Lower temp/quality vs using heat from generator directly

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### Absorption and Adsorption chillers:

- **Adsorption chillers:**
  - Relatively new concept
  - Water and desiccant-inherently safe
    - Does not use toxic or potentially hazardous materials.
  - Min temp: mid 40's deg-F
  - Utilized on Federal Building in Fresno area

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## CHP Overview

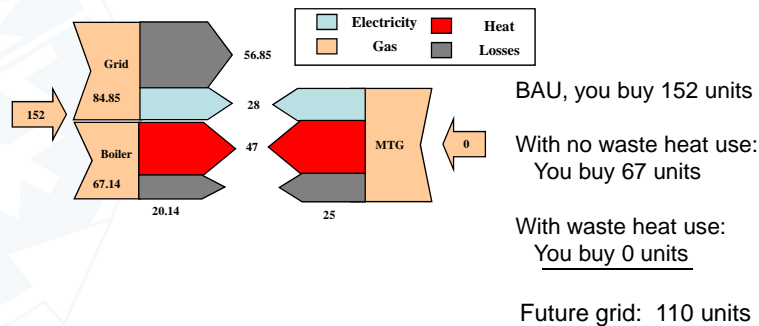
- DG Technology
- CHP
- **CHP in context of WWT**

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## CHP For WWTF

- What if your fuel costs were “zero”??
- **“Today’s Grid” (33% efficient, 70% boiler)**



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## CHP For WWTF



### Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities

Prepared by:  
Eastern Research Group, Inc.  
[www.erg.com](http://www.erg.com)  
and  
Energy and Environmental Analysis, Inc.  
[www.eea-inc.com](http://www.eea-inc.com)

Prepared for:  
U.S. Environmental Protection Agency  
Combined Heat and Power Partnership  
[www.epa.gov/chp](http://www.epa.gov/chp)



April 2007

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## CHP For WWTF

### Engineering Rules of Thumb for Considering CHP at a WWTF

- A typical WWTF processes 100 gallons per day of wastewater for every person served.<sup>1</sup>
- Approximately 1.0 cubic foot (ft<sup>3</sup>) of digester gas can be produced by an anaerobic digester per person per day.<sup>2</sup> This volume of gas can provide approximately 2.2 Watts of power generation.<sup>3</sup>
- The heating value of the biogas produced by anaerobic digesters is approximately 600 British thermal units per cubic foot (Btu/ft<sup>3</sup>).<sup>4</sup>
- For each 4.5 MGD processed by a WWTF with anaerobic digestion, the generated biogas can produce approximately 100 kilowatts (kW) of electricity.<sup>5</sup>

<sup>1</sup> Great Lakes-Upper Mississippi Board of State and Provincial Public Health and Environmental Managers, "Recommended Standards for Wastewater Facilities (Ten-State Standards)," 2004.

<sup>2</sup> Metcalf & Eddy, "Wastewater Engineering: Treatment, Disposal, Reuse," 1991.

<sup>3</sup> Assumes the energy content of biogas is 600 Btu/ft<sup>3</sup>, and the power is produced using a 30 percent efficient electric generator.

<sup>4</sup> Metcalf & Eddy, "Wastewater Engineering: Treatment, Disposal, Reuse," 1991.

<sup>5</sup> See section 4.1: Electric and Thermal Generation Potential from CHP Systems.

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## CHP For WWTF

**Table 4: Electric and Thermal Energy Potential with CHP for Typically Sized Digester: Mesophilic**

	No CHP system	Microturbine CHP	Fuel Cell CHP	Internal Combustion Engine CHP
Total POTW Flow (MGD)	9.1	9.1	9.1	9.1
Heat Requirement for Sludge (Btu/day)	5,148,750	5,148,750	5,148,750	5,148,750
Wall Heat Transfer (Btu/day)	541,727	541,727	541,727	541,727
Floor Heat Transfer (Btu/day)	507,869	507,869	507,869	507,869
Roof Heat Transfer (Btu/day)	326,231	326,231	326,231	326,231
Total Digester Heat Load (Btu/day)	6,524,577	6,524,577	6,524,577	6,524,577
<b>Heat Required for Digester Heat Load* (Btu/day)</b>	<b>8,155,721</b>			
Heat Potential of Gas (Btu/day)	54,370,800	54,370,800	54,370,800	54,370,800
% of Gas Used for Digester Heat Load (Btu/day)	15.0%			
<b>Amount of Gas Flared** (Btu/day)</b>	<b>46,215,079</b>			
Electric Efficiency		0.28	0.43	0.30
Power to Heat Ratio		0.61	1.95	0.64
<b>Electric Production (Btu/day)</b>		<b>15,223,824</b>	<b>23,379,444</b>	<b>16,311,240</b>
<b>Electric Production (kW)</b>		<b>186</b>	<b>286</b>	<b>199</b>
<b>Heat Recovery (Btu/day)</b>		<b>24,957,089</b>	<b>11,989,458</b>	<b>25,486,313</b>
<b>Additional Heat Available*** (Btu/day)</b>		<b>18,432,512</b>	<b>5,464,882</b>	<b>18,961,736</b>

Note: Assumes 50 percent summer and 50 percent winter.

\*Assumes 80 percent efficient boiler.

\*\*Assumes no other uses except boiler.

\*\*\*Assumes digester is only heat load.

$T_{\text{process}} = 70-100 \text{ F}$

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## CHP For WWTF

**Table 5: Electric and Thermal Energy Potential with CHP for Typically Sized Digester: Thermophilic**

	No CHP system	Microturbine CHP	Fuel Cell CHP	Internal Combustion Engine CHP
Total POTW Flow (MGD)	9.1	9.1	9.1	9.1
Heat Requirement for Sludge (Btu/day)	11,155,625	11,155,625	11,155,625	11,155,625
Wall Heat Transfer (Btu/day)	490,799	490,799	490,799	490,799
Floor Heat Transfer (Btu/day)	419,334	419,334	419,334	419,334
Roof Heat Transfer (Btu/day)	343,303	343,303	343,303	343,303
Total Digester Heat Load (Btu/day)	12,409,061	12,409,061	12,409,061	12,409,061
<b>Heat Required for Digester Heat Load* (Btu/day)</b>	<b>15,511,327</b>			
Heat Potential of Gas (Btu/day)	54,370,800	54,370,800	54,370,800	54,370,800
% of Gas Used for Digester Heat Load (Btu/day)	28.53%			
<b>Amount of Gas Flared** (Btu/day)</b>	<b>38,859,473</b>			
Electric Efficiency		0.28	0.43	0.30
Power to Heat Ratio		0.61	1.95	0.64
<b>Electric Production (Btu/day)</b>		<b>15,223,824</b>	<b>23,379,444</b>	<b>16,311,240</b>
<b>Electric Production (kW)</b>		<b>186</b>	<b>286</b>	<b>199</b>
<b>Heat Recovery (Btu/day)</b>		<b>24,957,089</b>	<b>11,989,458</b>	<b>25,486,313</b>
<b>Additional Heat Available*** (Btu/day)</b>		<b>12,548,027</b>	<b>-419,603</b>	<b>13,077,251</b>

Note: Assumes 50 percent summer and 50 percent winter.

\*Assumes 80 percent efficient boiler.

\*\*Assumes no other uses except boiler.

\*\*\*Assumes digester is only heat load.

$T_{\text{process}} = 160 \text{ F}$

Need to purchase fuel

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## CHP For WWTF

**Table 8: Estimated Capital Costs for Three CHP Systems at Wastewater Treatment Facilities**

Capital Cost	CHP System Type					
	126 kW (net) Microturbine		300 kW Fuel Cell		1,060 kW Internal Combustion Engine	
	Cost (\$)	Cost per kW (\$/kW)	Cost (\$)	Cost per kW (\$/kW)	Cost (\$)	Cost per kW (\$/kW)
Gen-Set	\$143,000	\$1,135	\$1,200,000	\$4,000	\$685,000	\$646
Fuel Treatment and Compression	\$202,000	\$1,603	\$194,000	\$647	\$369,000	\$348
Switchgear & Controls	\$19,500	\$155	\$97,600	\$325	\$125,000	\$118
Heat Recovery	\$26,000	\$206	\$23,200	\$77	\$100,000	\$94
<b>Total Equipment Costs</b>	<b>\$390,500</b>	<b>\$3,099</b>	<b>\$1,514,800</b>	<b>\$5,049</b>	<b>\$1,279,000</b>	<b>\$1,207</b>
Consulting and Design	\$23,400	\$186	\$125,000	\$417	\$150,000	\$142
Installation	\$114,400	\$908	\$457,000	\$1,523	\$604,500	\$570
Permits & Inspection	\$9,750	\$77	\$25,000	\$83	\$25,000	\$24
Contingency 5%	\$26,903	\$214	\$106,090	\$354	\$102,925	\$97
<b>Total Project Costs</b>	<b>\$564,953</b>	<b>\$4,484</b>	<b>\$2,227,890</b>	<b>\$7,426</b>	<b>\$2,161,425</b>	<b>\$2,039</b>

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## CHP For WWTF

**Table 9: Net Power Cost Estimates for Three CHP Systems at Wastewater Treatment Facilities**

Cost Element	CHP System Type		
	126 kW (net) Microturbine	300 kW Fuel Cell	1,060 kW Internal Combustion Engine
Maintenance (\$/kWh)	\$0.022	\$0.030	\$0.018
<b>Case 1: CHP thermal replaces biogas-fueled boiler for digester heating and other local use*</b>			
Capital Recovery (\$/kWh)	\$0.043	\$0.072	\$0.020
<b>Unit Power Cost (\$/kWh)</b>	<b>\$0.065</b>	<b>\$0.102</b>	<b>\$0.038</b>
<b>Case 2: Excess thermal energy (above digester needs) replaces natural gas elsewhere on site**</b>			
Digester Heat Needed (Btu/kWh)	2,979	1,840	2,219
Natural Gas Displaced (Btu/kWh)	1,006	(640)	1,953
Thermal Credit (\$/kWh)	\$0.009	No Excess	\$0.017
<b>Net Unit Power Cost (\$/kWh)</b>	<b>\$0.056</b>	<b>\$0.102</b>	<b>\$0.021</b>
<b>Case 3: 100 percent natural gas replacement with CHP thermal energy***</b>			
Natural Gas Displaced (Btu/kWh)	4,980	1,500	5,216
Thermal Credit (\$/kWh)	\$0.035	\$0.011	\$0.037
<b>Net Unit Power Cost (\$/kWh)</b>	<b>\$0.030</b>	<b>\$0.091</b>	<b>\$0.001</b>

\*Assumes: Municipal Capital Recovery Factor of 8.0 percent (5 percent interest rate, 20 years); 95 percent capacity factor.

\*\*Assumes: Digester fuel requirement as a percent of total gas produced = 28.5 percent (consistent with thermophilic average in Table 5); avoided boiler efficiency of 80 percent; avoided boiler fuel cost of \$7.00/MMBtu.

\*\*\*Assumes: Avoided boiler efficiency of 80 percent; avoided boiler fuel cost of \$7.00/MMBtu.

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## Case Study Information- SMWD

- **Chiquita Water Reclamation Plant (4 Capstone 330 MTGs w/ 1 Micogen Heat Exchanger)**
  - Phase 1: 2 MTGs/Micogen (provided by AQMD),, commissioned in December 2001
  - Phase 2: 2 MTGs purchased by SMWD, commissioned in October 2003
- **Open, outdoor space**
  - Noise not an issue
  - Convenient 480V 3ph tie-in
  - Phone installation needed
- **Operation on digester gas**
- **Multipak Operation**
- **Installed Costs**
  - Phase 1: \$114,020
  - Phase 2: \$160,582



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## Case Study Information-- SMWD

- **Waste heat from 2 MTGs provides all necessary heating for digesters.**
  - 2 boilers on-site – 1 is off and the other on stand-by
  - 1 MMBTU/hr exhaust energy utilized
  - Hot water supply/return 145/120F
  - Heat from 2 new MTGs will heat 3<sup>rd</sup> (future) digester and/or dry sludge for transport



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## Case Study Information-- SMWD

- **Experience**

- ~15,000 hours on each of first 2 units, >896,000 kW-hr (5/04)
- First 2 units--90% strict reliability (operating/calendar time), 99% true reliability (through 5/03)
- With 2<sup>nd</sup> Phase--continuous operation 11/03 to 5/04
- Service
  - Typically slow responding
  - Typically slow resolving
- Typical operating cost savings with first 2 units ~\$4,000-\$5,000 per month
- Several delays in finding contractor to install 3<sup>rd</sup> and 4<sup>th</sup> turbines



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## Case Study Information-- SMWD

- **Interconnection**

- Utility is San Diego Gas & Electric (SDG&E)
- Two separate agreements – first took 16 weeks to finalize
- SMWD charged by SDG&E for power generated by MTGs, even when power is used on-site
  - “E-Depart” tariff
  - Approved by CPUC, State Legislature
  - \$300-\$500/month (60-70,000 kWh)
  - CPUC gives grant for same system to mitigate power shortages!



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## Case Study Information-- SMWD

- **Key Lessons Learned**

- Installation costs are very significant in relation to cost of generators themselves
- Robust fuel treatment a must for biogas
  - New installation includes refrigerated dryer and SAG™ filter system
- Integration of heat exchanger with MTGs not trivial

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## Pacific Region CHP Application Center How Can We Help You?

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*CWEA Specialty Workshop*

*Whittier, CA*

*5 June 2007*

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