Webinar

What is CHP?
Technologies and Applications
Webinar Overview

- **Welcome and Introduction**
  - Neeharika Naik-Dhungel, U.S. EPA CHP Partnership Program

- **Combustion Turbines and CHP**
  - Chris Lyons, Solar Turbines, Manager, Power Generation

- **Microturbines and CHP**
  - Marc Rouse, Capstone Turbines, Director of Sales - America

- **Fuel Cells and CHP**
  - Anthony Leo, Fuel Cell Energy, Vice President, Applications and Advanced Technology Development

- **Catalog of CHP Technologies**
  - Anne Hampson, Senior Manager, ICF International

- **Questions and Answers Session**
Solar Turbines Incorporated
Combustion Turbine
Applications in
Combined Heat & Power

By Chris Lyons
Manager, Power Generation Group
Solar Turbomachinery Systems

Over 15,000 Units Installed Worldwide
Over 2.0 Billion Operating Hours
Over 8000 Generator Packages
Combined Heat & Power or Cogeneration

“Simultaneous Production of Two Useful Forms of Energy from Same Source”

Distributed Generation
Global Definition

“... Any Modular Technology that is Sited throughout a Utility’s Service Area to Lower the Cost of Service or Improve System Quality.”
Thermal Matching is Key for CHP

Heat – to – Power Ratio

0:1  0.5:1  1:1  2:1  3:1  4:1  5:1  6:1
Typical Combustion Turbine CHP

- AIR INLET FILTER
- GENERATOR
- GAS TURBINE
- EXHAUST BYPASS SILENCER
- DIVERTER VALVE
- HEAT RECOVERY STEAM GENERATOR (HRSG)
- SUPPLEMENTARY BURNER
- EXHAUST SILENCER
- PROCESS STEAM
Industries using CHP

- Food Processing
- Pharmaceutical
- Pulp and Paper
- Manufacturing
Industries using CHP

- Refinery / Oil
- Hospitals
- Universities
- Utilities
Commercial CHP is Growing

Power, steam, hot water and chilled water
City of Russell 14 MW CHP Project at Ethanol Plant in Kansas
CHP with Supplemental Firing
Drying Application Using Turbine Exhaust Heat

Caterpillar Confidential: Green
Waste Heat Recovery for Drying Applications

- 4-MW CHP
- Heat Used for Slurry Drying of Ceramic Tile

- 5-MW CHP
- Heat Used to Dry Gypsum for Wall Board Production
CHP is also for Chilled Water
Alternative Fuels also Possible

- Coke Oven Gas
- Refinery Gas
- Landfill and Digester Gas
- Coal Bed and Coal Mine Methane
- Synthetic Gas
- Gasified Biomass
Gasified MSW Project
USA Has a Good Supply of NG

Worldwide Gas Prices

- Japan (Natural Gas LNG)
- Europe (Zeebrugge Hub)
- U.S. (Henry Hub)
Future Spark Spreads Look Favorable for 
NG fueled CHP

Source = US DOE Energy Information Administration
Can You Depend on the Grid?
What will the grid of the future look like?

Caterpillar Confidential:  Green

Source: http://sustainability.ucsd.edu/_images/Solar-sky-tracker.png
## Solar’s Turbine Product Line

### SATURN®
- Saturn 20: 1,210 kW
- Saturn 60: 5,500 kW
- Saturn 70: 7,520 kW

### CENTAUR®
- Centaur 40: 3,515 kW
- Centaur 50: 4,600 kW
- Mars 90: 9,450 kW
- Mars 100: 10,690 kW

### MERCURY™
- Mercury 50: 4,600 kW
- Mars 90: 9,450 kW
- Mars 100: 10,690 kW

### TITAN™
- Titan 130: 15,000 kW
- Titan 250: 22,000 kW
## GENERATOR SET PERFORMANCE

ISO Performance: 59°F (15°C); Sea Level; No Inlet and Exhaust Losses.
Specific Site Performance: 102 mm (4 inches) Inlet, 254 mm (10 inches) Exhaust Losses; Saturated Steam @ 10.3 Bar (150 psig)

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>POWER MWe</th>
<th>HEAT RATE Btu/kW-hr</th>
<th>EXHAUST TEMP °F</th>
<th>EXHAUST FLOW lb/hr</th>
<th>SITE SPECIFIC POWER– Thousand lbs/hr</th>
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<td>STRENGTHENED FUELS</td>
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Service Support Network

Support for More than 15,000 Combustion Turbines

- 14 Repair and Overhaul Centers
- 16 Parts Facilities
- 41 Service Offices (~850 Field Personnel)
Service Product Portfolio

Comprehensive Suite of Service Products
Extensive Experience That Will Benefit Your Power Generation Needs
Combined Heat and Power
Microturbines
Capstone Turbine Corporation

- Founded 1988 – Commercial launch in 1998
- Public Company on NASDAQ: CPST
- World Leader in Microturbines
- Headquarters and manufacturing plants in California
- Sales and/or service centers in China, Mexico, Singapore, South America, the United Kingdom, and the United States
- Over 95 Distribution Partners
- Over 9,000 units shipped worldwide with more than 60 million operating hours
What Is CHP?

• An Integrated Heating Cooling and Electric Power System
• Located Onsite or Near a Building/Facility
• Supplies a Portion of the Total Electric Load
• Recovers the Waste Heat from Generating Electricity to Provide the Facility with:
  – Space Heating/Hot Water/Steam
  – Space Cooling
  – Dehumidification
  – Heat for Processes (such as sterilization or cooking)
How does it save?

• **Combined Heat and Power (CHP) Saves Money by Increasing Efficiency**

To create the same power output, traditional sources use more fuel and have much higher emissions.
# Typical CHP Paybacks

<table>
<thead>
<tr>
<th></th>
<th>Population</th>
<th>Avg. Comm. Electric Rate</th>
<th>Payback with incentives</th>
<th>Payback without incentives</th>
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<tbody>
<tr>
<td>North Dakota</td>
<td>723,323</td>
<td>$0.086</td>
<td>4.5</td>
<td>7.5</td>
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<tr>
<td>South Dakota</td>
<td>844,877</td>
<td>$0.086</td>
<td>4.5</td>
<td>7.5</td>
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<tr>
<td>Minnesota</td>
<td>5,420,380</td>
<td>$0.094</td>
<td>3.9</td>
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<td>Wisconsin</td>
<td>5,742,713</td>
<td>$0.109</td>
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<td>Illinois</td>
<td>12,882,135</td>
<td>$0.079</td>
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<td>Indiana</td>
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<td>$0.097</td>
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<td>Michigan</td>
<td>9,895,622</td>
<td>$0.111</td>
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<td>Massachusetts</td>
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<td>$0.139</td>
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<td>Rhode Island</td>
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<td>$0.110</td>
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<td>6.0</td>
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<td>New Hampshire</td>
<td>1,323,459</td>
<td>$0.134</td>
<td>2.8</td>
<td>4.3</td>
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<td>Vermont</td>
<td>626,630</td>
<td>$0.150</td>
<td>2.4</td>
<td>3.6</td>
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<tr>
<td>Maine</td>
<td>1,328,302</td>
<td>$0.113</td>
<td>3.6</td>
<td>5.8</td>
</tr>
</tbody>
</table>
Why Microturbines?

• **CHP can be simple, modular, small, quiet**
Integrated CHP Solution

Heat Recovery Module (HRM)
**Environmental Benefits**

*CHP can fit with your environmental goals*

<table>
<thead>
<tr>
<th>Category</th>
<th>Reduction vs Traditional (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse Gas (CO2)</td>
<td>28%</td>
</tr>
<tr>
<td>Criteria Pollutants (NOx)</td>
<td>94%</td>
</tr>
<tr>
<td>Energy (Fuel in MMBTU/year)</td>
<td>29%</td>
</tr>
<tr>
<td>Equivalent Cars Removed (2)</td>
<td>575</td>
</tr>
</tbody>
</table>

(1) Based on 50% Heating/50% Cooling. Capstone MT heat recovery uses double effect absorption chiller for cooling. Traditional assumes average US Power Plant (Source: EPA) for electricity, electric chiller with COP of 3, and 80% efficient boiler.

(2) Assumes 1MW project operating 8,500 hours per year. US EPA data for “equivalent” car emissions and fuel consumption.
Back-up Power

- CHP can provide backup power

Ennergy
How Natural Gas Kept Some Spots Bright and Warm as Sandy Blasted New York City
By ANDREW C. REVKIN NOVEMBER 5, 2012 6:11 PM
Why Microturbines?

- Low operating and maintenance costs
- Proven technology
- High reliability >98%
- Low total cost of owners
- Low emissions
- Low noise
Case Study: Kaiser Vacaville

- Medical Center Combined Heat and Power
  - 12 Capstone C65 to generate 750 kW
  - Commissioned 2009

- Facility Quick Facts
  - 580,000 sq. ft.
  - Facility average load 1MW
  - Electricity offsets base load, heat offsets boiler

- Benefits
  - NOx emissions reduced by 72 tons a year
  - CO2 emissions reduced by 1,741 tons per year
  - Payback 2.5 years

Annual Energy Bill savings $450,000 / year
Contact Info

Capstone Turbine Corporation
818.734.5463
www.capstoneturbine.com

To find a local Capstone Distributor
www.capstoneturbine.com/company/dist/
Fuel Cell Technologies and Applications for Combined Heat and Power
FuelCell Energy Facilities

**MW-class distributed generation solutions**
- Grid support and on-site CHP power generation
- Carbonate solution commercialized / Commercializing Solid Oxide
- ~650 employees on 3 continents / ~$180 million annual revenue in 2014
- POSCO Energy Fuel Cell Division: ~225 employees / ~$300 million annual revenue
  - > 3.6 billion kWh produced

**Office Locations**
- R&D and Service
- ~275 employees
- Headquarters in Danbury, CT USA

**Manufacturing**
- ~325 employees USA
- ~15 employees Germany
- S. Korea via partner

**Global Installations**
- 50 sites / customers in 9 countries
  - > 300 MW installed/backlog

NASDAQ: FCEL  www.fuelcellenergy.com
Why Fuel Cells?

- Power without combustion
  - Higher efficiency, low CO₂
  - Very low emissions (PM, SOx, NOx)
- Fewer moving parts
  - Low Noise
  - High Availability
- Available for use with commercial fuels
  - Natural gas
  - Biogas
- Commercially available in distributed generation sizes appropriate for micro grids
  - 100’s kW to Multi-MW
- Waste heat for on-site CHP applications
- Reactive power capabilities of inverter based power output
MCFC-Based Direct FuelCell

• Electrochemical conversion of fuel
• Optimal Operating Temperature
  – Uses commonly available materials
  – No noble metal catalysts
  – Negligible NOx
  – High temperature waste heat for CHP

• Internal Reforming
  – Natural gas or biogas converted to hydrogen inside fuel cell stack
  – High efficiency since stack waste heat drives hydrogen production
  – Enhanced cooling

Direct FuelCell®, or DFC® refers to the fact that fuel is sent directly to the fuel cell stack, without an external reformation step
Fuel Cell Configuration

- ANODE
- MATRIX
- CATHODE
- BIPOLAR PLATE
- FUEL
- OXIDANT
Scalable Solutions

1.4 MW DFC1500®
- Utilizes one module
- Adequate to power 1,400 homes

2.8 MW DFC3000®
- Utilizes two modules
- Adequate to power 2,800 homes

59MW fuel cell park

Individual fuel cell & 350 kW fuel cell stack

Four-Stack Module 1.4 megawatts

Completed module 1.4 megawatts

Completed module 1.4 megawatts
**DFC System**

- Fuel and Water are treated to remove contaminants (e.g. sulfur), mixed, heated to stack temperature and sent to anodes
- Fuel and water react in anode chambers to produce hydrogen
- Anodes consume 70% of hydrogen in power generation
- Residual 30% hydrogen used in catalytic oxidizer to pre-heat air
- Heated air is cathode gas
- Cathode exit gas is 600 – 650 C, cooled to 370 C after fuel/water preheat
- 370 C exhaust used for cogeneration heat recovery
Powerplant Subsystems

- Mechanical Balance of Plant (MBOP)
- Exhaust Stack
- Fuel Treatment - Desulfurizer
- DFC Stack Module A
- Inverter
- DFC Stack Module B
- Blower, Heater, Preconverter
- Switchgear
- Water Treatment and Control Panel
- Electrical Balance of Plant (EBOP)
- FuelCell Energy
  Ultra-Clean, Efficient, Reliable Power
## Two Types of Applications

### On-site Power *(Behind the Meter)*

**Typical Project sizes 1.4 – 11.2 MW**

- **Affordable & Clean energy**
  - High efficiency drives savings
  - CHP reduces costs and improves customer’s carbon footprint
  - Virtual lack of pollutants benefits public health
- **Supports energy security** *(micro-grid)*

### Electric Grid Support

**Typical Project Sizes 5.6 – 60 MW**

- **Cost effective baseload power**
  - when/where needed *(i.e. next to existing sub-stations)*
  - Avoids transmission cost and permitting / reduces congestion
- **Enhances grid resiliency**
- **Supports economic development & renewable portfolio standards**
## High Efficiency & Low Emissions

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<tr>
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<th>Efficiency % LHV</th>
<th>CO2 (lb/MWh)</th>
<th>NOX (lb/MWh)</th>
<th>SOX (lb/MWh)</th>
<th>PM-10 (lb/MWh)</th>
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<tbody>
<tr>
<td>Average US Grid</td>
<td>33%</td>
<td>1,408</td>
<td>3.43</td>
<td>7.9</td>
<td>0.19</td>
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<tr>
<td>Average US Fossil Fuel Plant</td>
<td>36%</td>
<td>2,031</td>
<td>5.06</td>
<td>11.6</td>
<td>0.27</td>
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<tr>
<td>DFC Fuel Cell on Nat Gas 47% efficiency</td>
<td>47%</td>
<td>940</td>
<td>0.01</td>
<td>0.00001</td>
<td>.00002</td>
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<tr>
<td>DFC Fuel Cell on Nat Gas CHP 80% efficiency</td>
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<td>DFC Fuel Cell on Biogas CHP 80% efficiency</td>
<td>80%</td>
<td>0</td>
<td>0.006</td>
<td>0.00006</td>
<td>.00001</td>
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</tbody>
</table>

Source for non-DFC data: “Model Regulations For The Output Of Specified Air Emissions From Smaller-scale Electric Generation Resources Model Rule and Supporting Documentation”, October 15, 2002; The Regulatory Assistance Project report to NREL
1. On Site CHP
2. District heating
3. Convert to additional electricity
Combined Heat & Power Example

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

2800 kW Power

Fuel Input 5957 kW

DFC Powerplant

3.458 MMBtu/h
High Grade Use

- Hot water (345 gpm from 230°F to 250°F)
- Or Steam (2,630 lb/h @ 75 psig)
- Or Absorption Cooling (380 tons)

64% total thermal efficiency

5.404 MMBtu/h
Low Grade Heat Use

- Hot water 360 gpm from 60°F to 90°F

90% total thermal efficiency

700 °F Exhaust

350 °F Exhaust

Unused heat

100 °F Exhaust
Typical Steam Gen Application

1.2MW Pepperidge Farms, Connecticut
Steam generation and incinerator pre-heat for commercial bakery
2.8MW at Inland Empire Utilities Agency water treatment plant

• Renewable baseload power consumed at water treatment facility
• Heat supplied to digesters to maintain sludge temperature for gas production
• > 10 tons per year NOX reduction compared to engines
59MW Fuel Cell CHP System

- 21 DFC3000® power plants
  - Only ~ 5.2 acres for 59 MW
- Supplying electric grid and district heating system
- Constructed in only 14 months
- Adequate to power ~ 140,000 S. Korean homes

Project developed by POSCO, Korea Hydro Nuclear Power Co. (KHNP) and Samchully Gas Co in Hwaseong, South Korea
University CHP Installation

- High efficiency drives savings
- CHP for heating and absorption chilling
- Ultra-clean emission profile supports sustainability goals
- Micro-grid enhances energy security
- Private capital providing public benefits

“CCSU’s power costs will be reduced annually by more than $100,000 -- a savings for both the university and Connecticut taxpayers.”

Jack Miller, President, Central Connecticut State University
• Electricity sold to Hartford Hospital
• Heat sold to Hartford Hospital and supplied to district heating system owned by Hartford Steam
• Component of Micro-grid

“The ability of the fuel cell power plant to produce both electricity and steam from the same unit of fuel supports the attractive economics of this installation.”
Derek Rudd
President
Hartford Steam Company
Microgrid CHP Applications

Microgrid features are standard plant operating modes which can be deployed in any project.

- Parallel operation with other generators when utility service unavailable
- Customer facilities, behind-the-meter applications
- Interruptible and Seamless Applications
- CERTS compatible

DFC Microgrid examples:

Central CT State University
  • Gensets & 1.4MW fuel cell

San Jose Water Treatment Plant
  • Gensets & 1.4MW fuel cell

University of Bridgeport
  • Gensets & 1.4MW fuel cell

UC San Diego
  • Gensets & 2.8MW biogas fuel cell
• Fuel cell benefits in CHP applications:
  – High electrical efficiency
  – High quality waste heat
  – Multiple waste heat applications
  – High total thermal efficiency
  – Very low emissions
  – Low noise
Thank You!

Contact:
Tony Leo
tleo@fce.com
203-825-6035

On-site Power

Electric Grid Support
Bringing it All Together: CHP Technology Overview

Anne Hampson
ICF International
CHP Can Utilize Numerous Prime Movers

- A prime mover is the equipment that converts fuel to useful work, which is both electricity and heat.
- CHP systems can utilize reciprocating engines, steam turbines, gas turbines, microturbines, and fuel cells as prime movers.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Recip. Engine</th>
<th>Steam Turbine</th>
<th>Gas Turbine</th>
<th>Microturbine</th>
<th>Fuel Cell</th>
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<tbody>
<tr>
<td>Electric efficiency (HHV)</td>
<td>27-41%</td>
<td>5-40+%</td>
<td>24-36%</td>
<td>22-28%</td>
<td>30-63%</td>
</tr>
<tr>
<td>Overall CHP efficiency (HHV)</td>
<td>77-80%</td>
<td>near 80%</td>
<td>66-71%</td>
<td>63-70%</td>
<td>55-80%</td>
</tr>
<tr>
<td>CHP Installed costs ($/kWe)</td>
<td>1,500-2,900</td>
<td>670-1,100</td>
<td>1,200-3,300</td>
<td>2,500-4,300</td>
<td>5,000-6,500</td>
</tr>
<tr>
<td>Non-fuel O&amp;M costs ($/kWhe)</td>
<td>0.009-0.025</td>
<td>0.006 to 0.01</td>
<td>0.009-0.013</td>
<td>0.009-.013</td>
<td>0.032-0.038</td>
</tr>
<tr>
<td>Availability</td>
<td>96-98%</td>
<td>near 100%</td>
<td>93-96%</td>
<td>98-99%</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Start-up time</td>
<td>10 sec</td>
<td>1 hr - 1 day</td>
<td>10 min - 1 hr</td>
<td>60 sec</td>
<td>3 hrs - 2 days</td>
</tr>
</tbody>
</table>
CHP Catalog of Technologies

- The CHP Catalog of Technologies describes the five prime movers in detail.
- For each prime mover, the following is discussed:
  - Applications
  - Technology description
  - Cost and performance
  - Emissions and controls
  - Future developments

http://www.epa.gov/chp/technologies.html
CHP Technologies

Applicable Size Range, kW_e

- Gas Turbines
- Steam Turbines
- Recip. Engines
- Fuel Cells
- MicroTurbines

Strong Market Position
Market Position
Emerging Position
CHP Provides a Reduction in Emissions

- Fuel type is the largest factor influencing the amount of emissions produced.
  - Natural gas produces fewer emissions than oil and coal.

- CHP produces useable electricity and thermal energy for onsite use. This increases the efficiency of the system, which reduces emissions.

- Fuel cells produce the lowest emissions because the power generation does not involve combustion.

- Emissions controls are available for all technology types.
CHP Can Provide a Reduction in Water Consumption

- Steam turbines are the only CHP technology that may consume water.
- CHP systems capture the waste heat from power generation for a useful purpose and therefore no incremental water use is typical even in steam turbine systems.

<table>
<thead>
<tr>
<th>Fuel Technology</th>
<th>Cooling Technologies – Water Consumption (gal/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open-Loop</td>
</tr>
<tr>
<td>Thermal</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>300</td>
</tr>
<tr>
<td>Nuclear</td>
<td>400</td>
</tr>
<tr>
<td>Natural Gas Combustion Turbine</td>
<td>negligible</td>
</tr>
<tr>
<td>Natural Gas Combined-Cycle</td>
<td>100</td>
</tr>
<tr>
<td>Integrated Gasification Combined-Cycle</td>
<td>not used</td>
</tr>
<tr>
<td>Concentrated Solar Power</td>
<td>not used</td>
</tr>
<tr>
<td>Non-Thermal</td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Photovoltaic Solar</td>
</tr>
</tbody>
</table>

*Estimated based on withdrawal and consumption ratios.*
Questions & Contact Information

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Additional Questions?

- EPA CHP Partnership
  - CHP Partnership Help Line
    - chp@epa.gov
    - 703/373-8108
  - CHP Partnership Partners
  - Resources Online (http://epa.gov/chp/)

- DOE CHP Resources
  - AMO CHP Deployment Program
    (http://energy.gov/eere/amo/chp-deployment)
    - CHP Technical Assistance Partnerships (CHP TAPS)
    - CHP Installation Database