CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

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**

CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

Solar® Turbines
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Solar Turbines Incorporated Combustion Turbine Applications in Combined Heat & Power

By Chris Lyons

Manager, Power Generation Group

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A Caterpillar Company

Solar Turbomachinery Systems

Over 15,000 Units Installed Worldwide

Over 2.0 Billion Operating Hours

Over 8000 Generator Packages

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What Is DG/CHP?

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."

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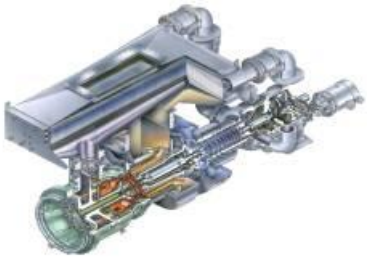
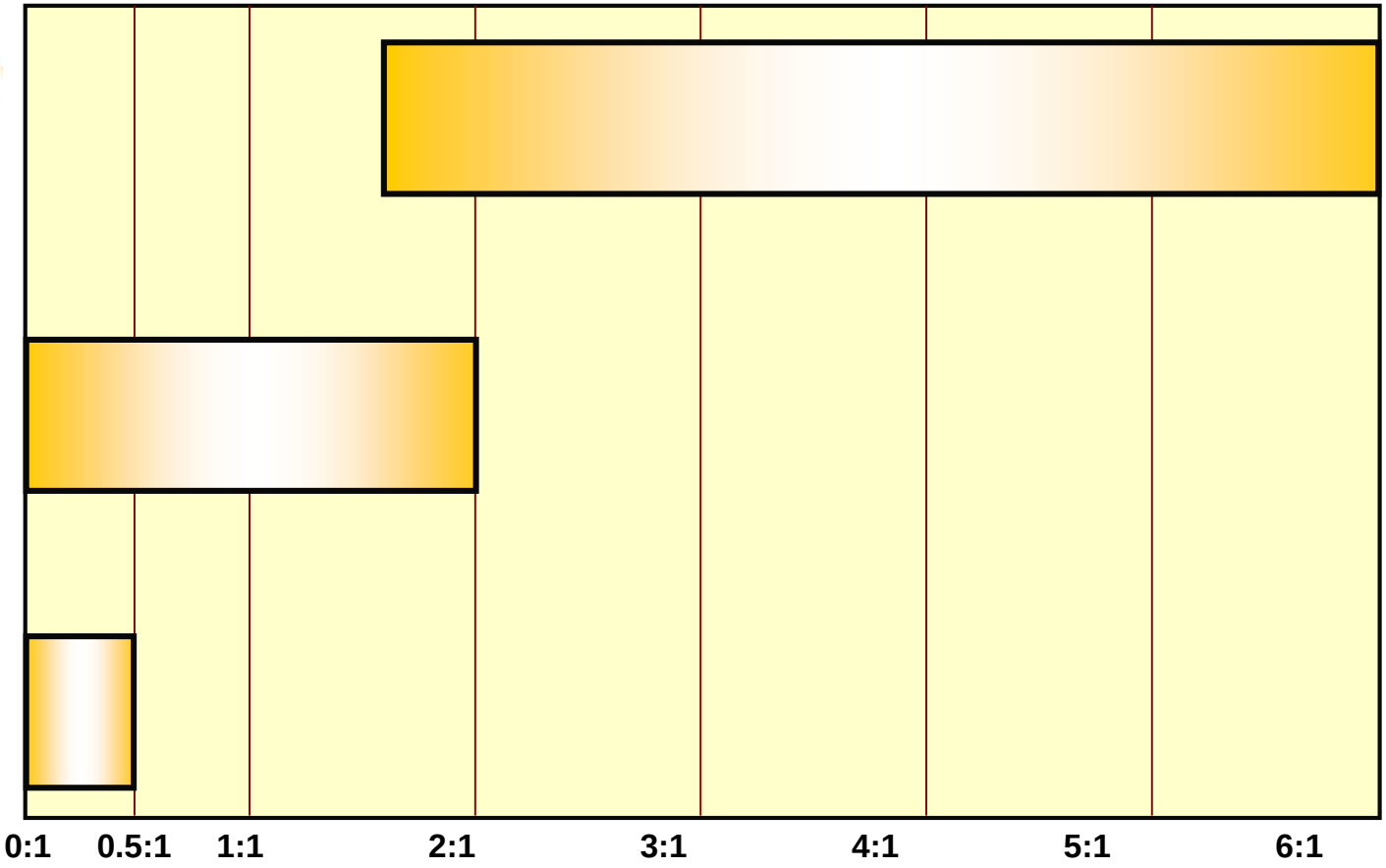
Thermal Matching is Key for CHP





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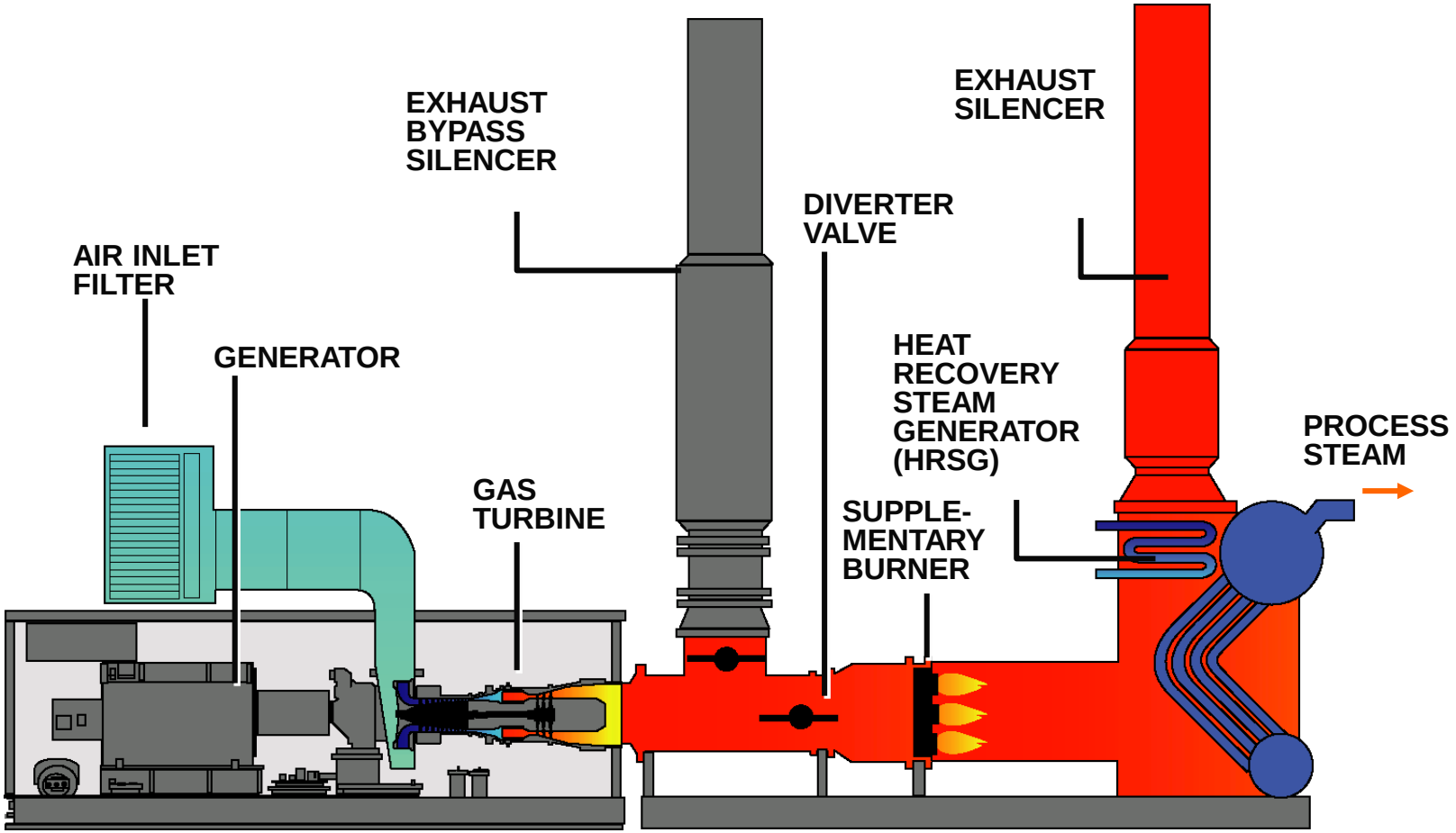
Typical Combustion Turbine CHP



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Industries using CHP

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Industries using CHP

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Typical Hospital Applications

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Typical University Applications

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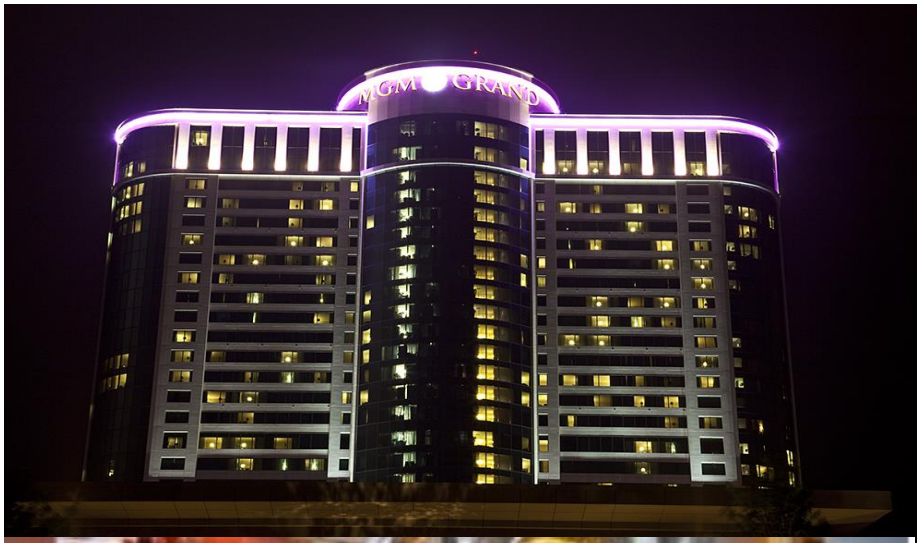
Commercial CHP is Growing



Power, steam, hot water and chilled water

Unfired Heat Recovery Steam Application

City of Russell 14 MW CHP Project at Ethanol Plant in Kansas

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CHP with Supplemental Firing

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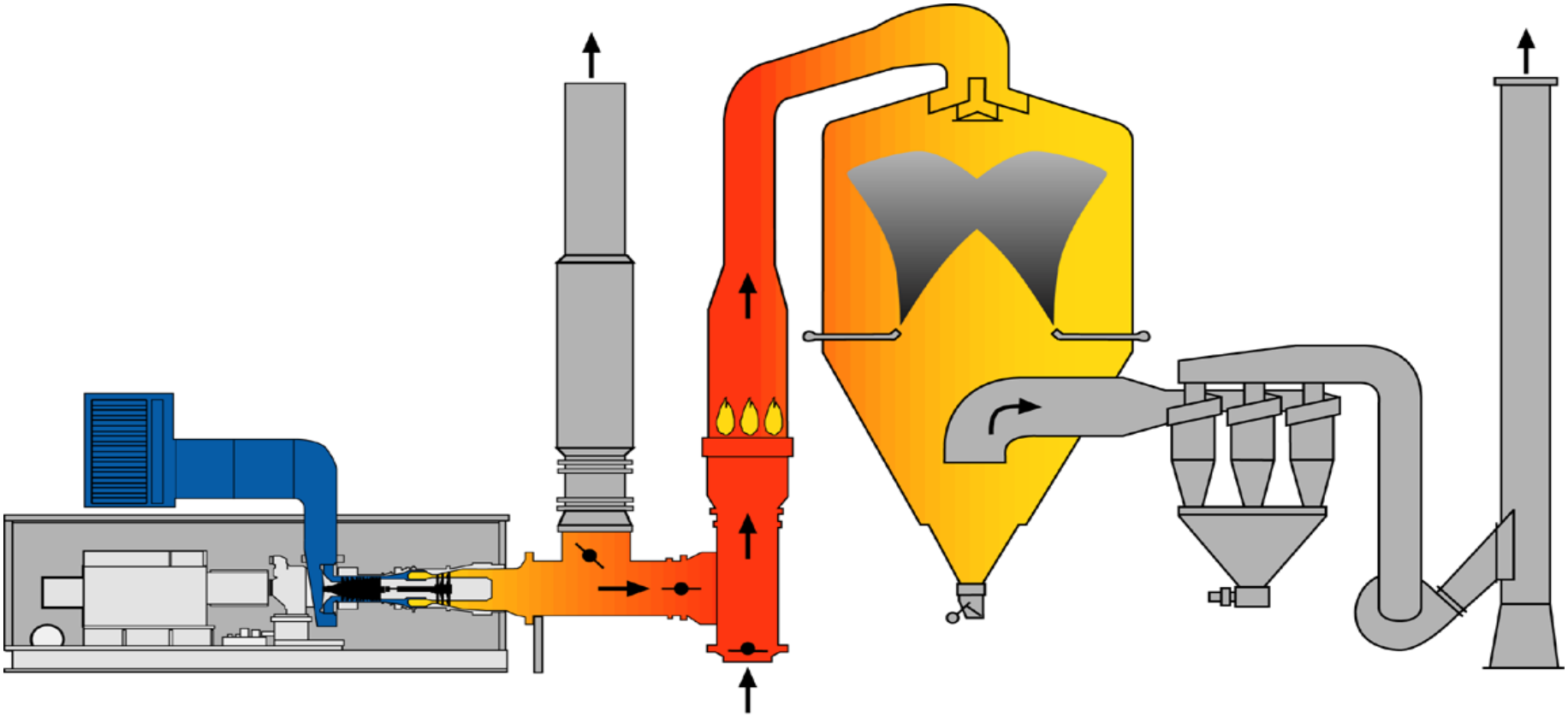
Drying Application Using Turbine Exhaust Heat



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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

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CHP is also for Chilled Water

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Alternative Fuels also Possible

- Coke Oven Gas
- Refinery Gas
- Landfill and Digester Gas
- Coal Bed and Coal Mine Methane
- Synthetic Gas
- Gasified Biomass

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LFG CHP SYSTEM

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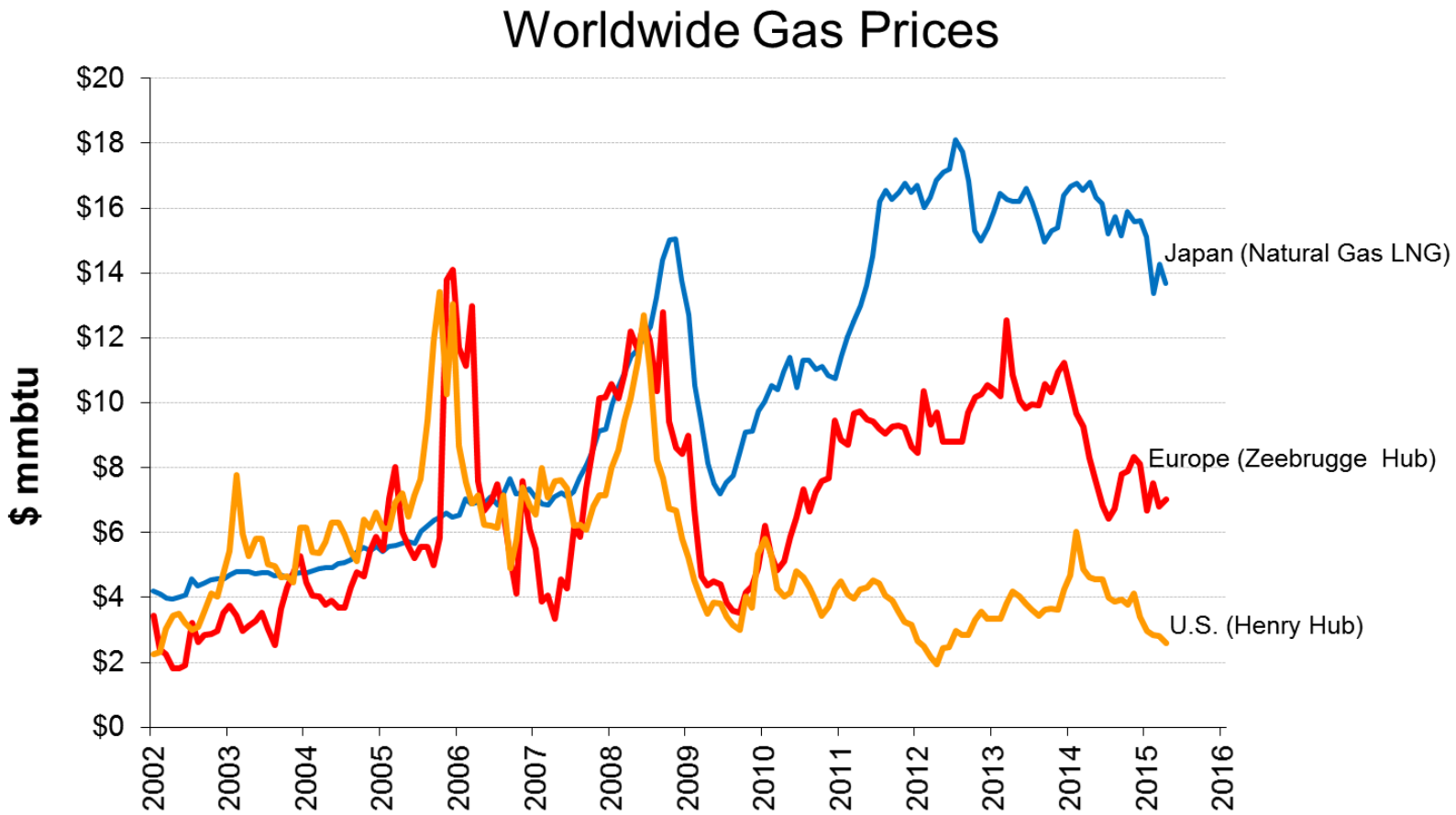
Gasified MSW Project

USA Has a Good Supply of NG



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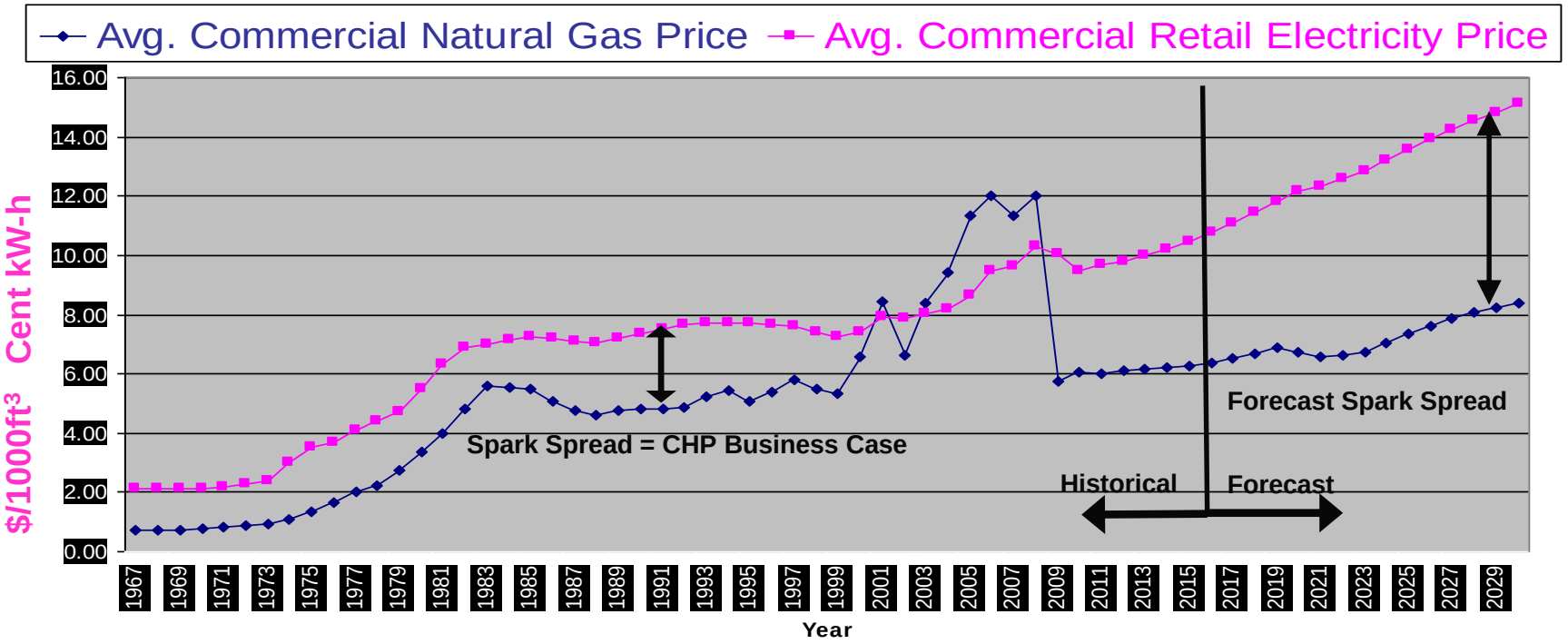
Future Spark Spreads Look Favorable for NG fueled CHP



Source = US DOE Energy Information Administration

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Can You Depend on the Grid?

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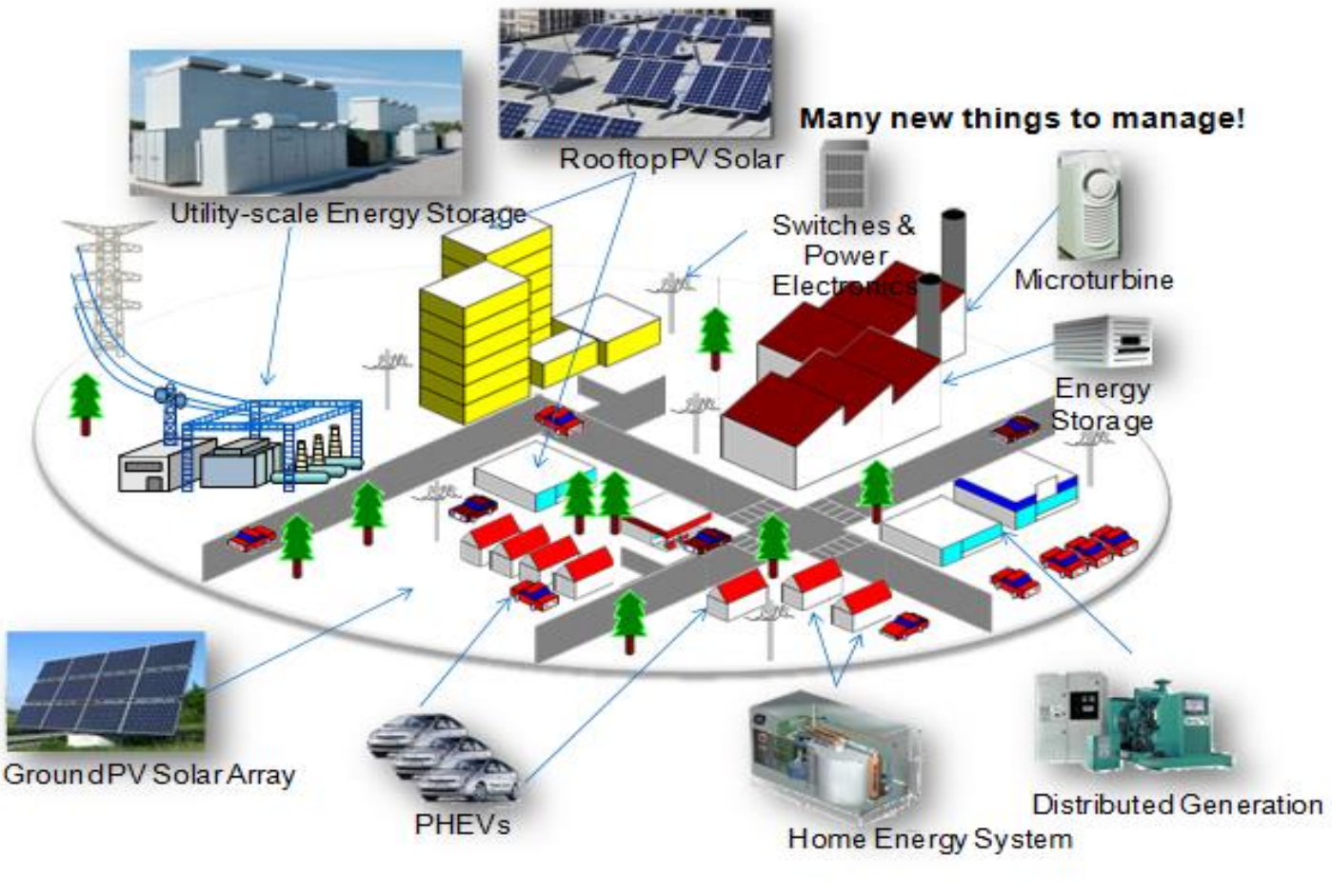
What will the grid of the future look like?



Source: http://greenlightnational.com/wp-content/uploads/2013/10/community_microgrid.png

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UCSD Anchored w/ 30 MW CHP

Source: http://sustainability.ucsd.edu/_images/Solar-sky-tracker.png

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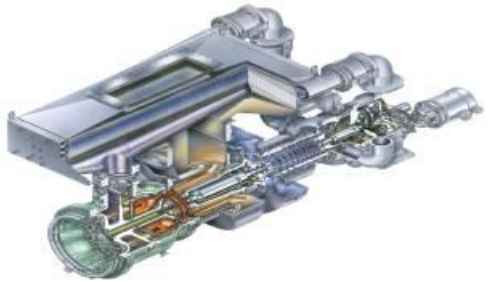
Solar's Turbine Product Line

SATURN ®

Saturn 20	1 210 kW

CENTAUR ®

Centaur 40	3 515 kW
Centaur 50	4 600 kW

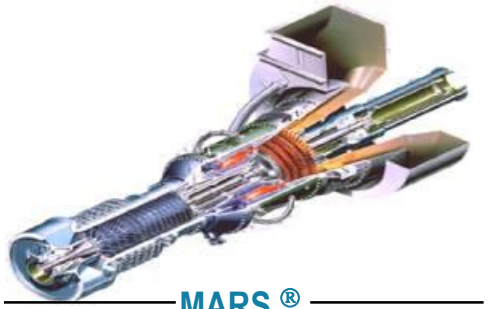


MERCURY ™

Mercury 50	4 600 kW

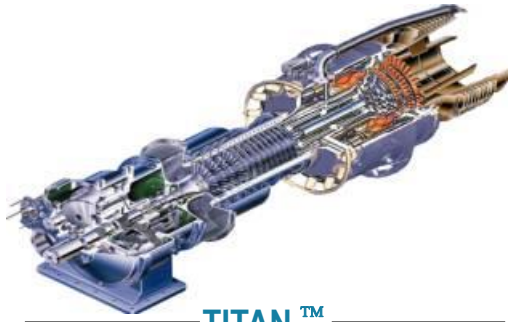
TAURUS ™

Taurus 60	5 500 kW
Taurus 65	6 300 kW
Taurus 70	7 520 kW



MARS ®

Mars 90	9 450 kW
Mars 100	10 690 kW



TITAN ™

Titan 130	15000 kW
Titan 250	22000 kW

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GENERATOR SET PERFORMANCE

PRODUCT	POWER MWe	HEAT RATE Btu/kW-hr	SITE SPECIFIC POWER– Thousand lbs/hr				
			EXHAUST TEMP °F	EXHAUST FLOW lb/hr	STEAM PRODUCTION		
					UNFIRED	FIRED 1600°F	FIRED 2800°F
Saturn 20	1.2	14 025	952	51.5	8.9	18.5	40.0
Centaur 40	3.5	12 240	835	149.6	19.6	53.3	113.2
Centaur 50	4.6	11 630	956	150.3	25.3	53.0	112.4
Mercury 50	4.6	8 863	710	140.4	13.8	49.4	104.4
Taurus 60	5.7	10 860	960	171.3	29.8	62.0	130.5
Taurus 65	6.3	10 373	1032	163.4	32.1	60.5	128.3
Taurus 70	7.5	10 100	914	212.3	34.4	76.1	158.6
Mars 90	9.5	10 710	875	316.2	46.8	113.3	239.5
Mars 100	10.7	10 520	915	329.1	51.8	117.4	248.1
Titan 130	15.0	9 695	932	392.2	64.5	141.4	298.2
Titan 250	21.7	8775	865	541.5	77.5	298	395.0

ISO Performance: 59F (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)

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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)

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Service Product Portfolio

InSight System

Field & Engineering Services

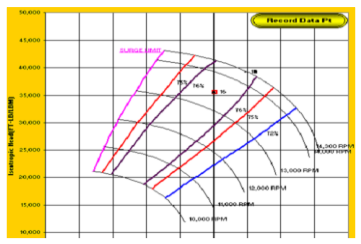
Training

Package Upgrades

CMS

Refurbishment

Comprehensive Suite of Service Products



Softmap

Controls Upgrades

Service Parts

Restaging

Installation Commissioning

Exchange Engines & Overhaul

Global Power Generation Experience

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Chris Lyons
Phone: 1-858-694-6586
Email: clyons@solarturbines.com

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

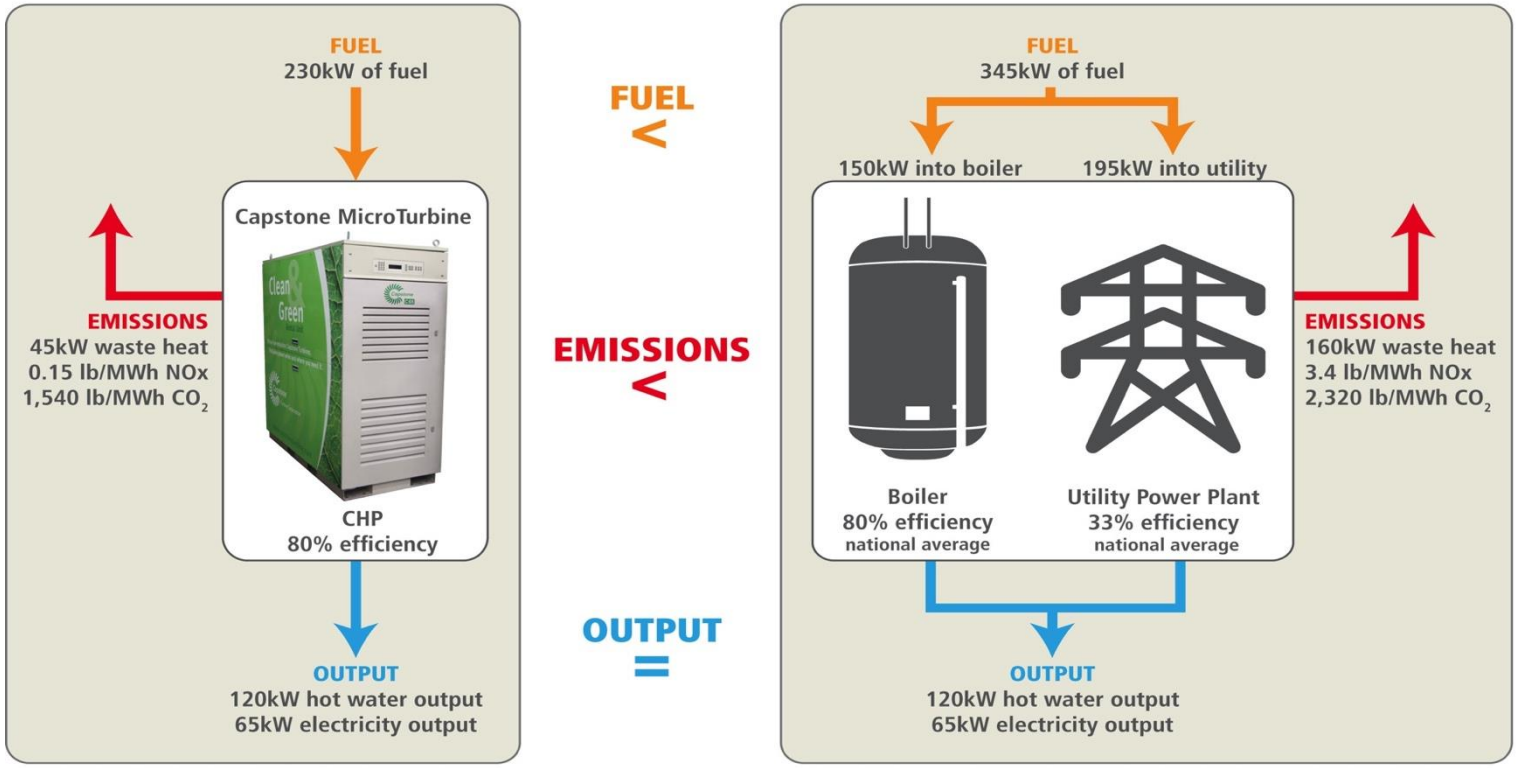
What Is CHP?

- 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



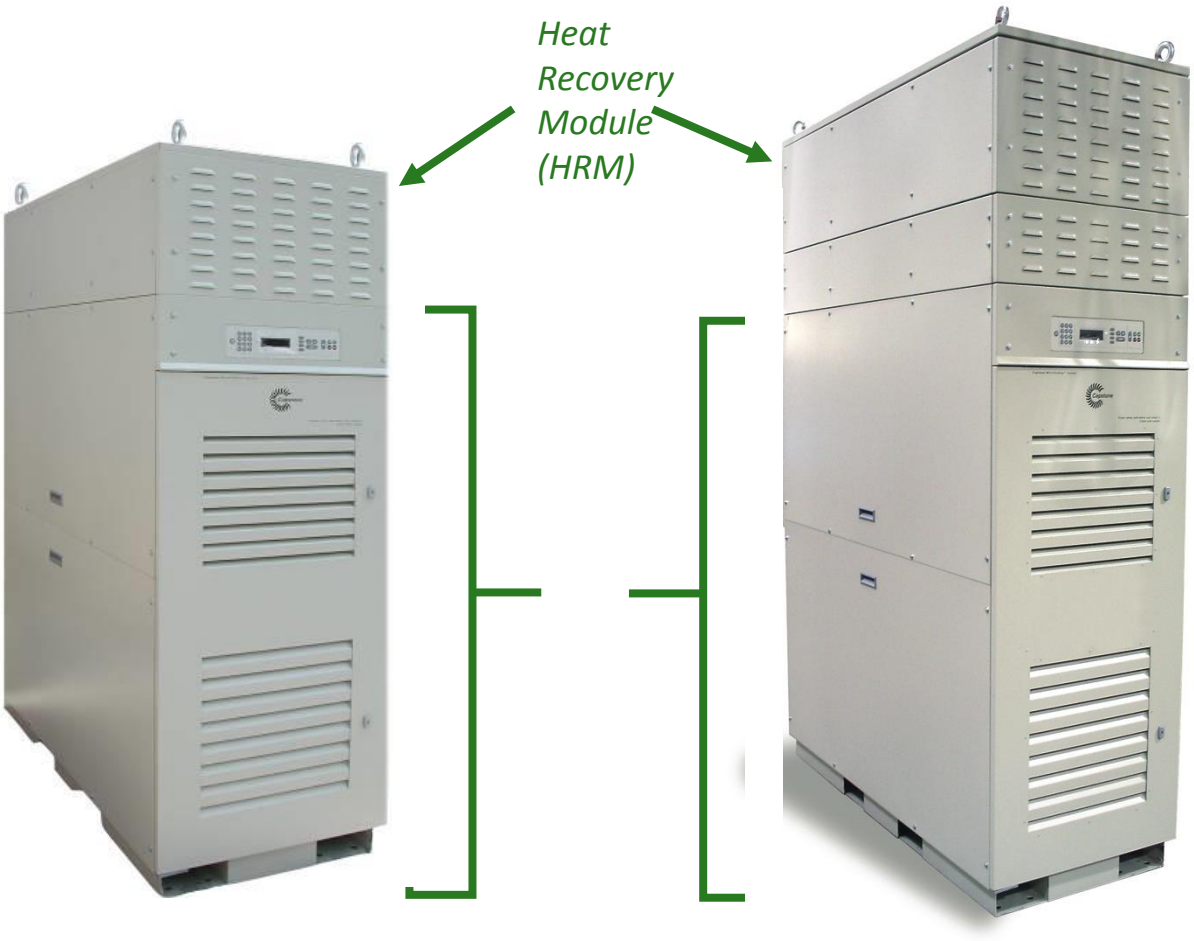
Typical CHP Paybacks

	Population	Avg. Comm. Electric Rate	Payback with incentives	Payback without incentives
North Dakota	723,323	$0.086	4.5	7.5
South Dakota	844,877	$0.086	4.5	7.5
Minnesota	5,420,380	$0.094	3.9	6.3
Wisconsin	5,742,713	$0.109	3.1	4.9
Illinois	12,882,135	$0.079	5.2	8.7
Indiana	6,570,902	$0.097	3.7	5.9
Michigan	9,895,622	$0.111	3.0	4.7
Massachusetts	6,692,824	$0.139	2.7	4.1
Rhode Island	1,051,065	$0.110	3.7	6.0
New Hampshire	1,323,459	$0.134	2.8	4.3
Vermont	626,630	$0.150	2.4	3.6
Maine	1,328,302	$0.113	3.6	5.8

Why Microturbines?

- *CHP can be simple, modular, small, quiet*

Integrated CHP Solution



Environmental Benefits

- *CHP can fit with your environmental goals*

Category	Reduction vs Traditional (1)
Greenhouse Gas (CO2)	28%
Criteria Pollutants (NOx)	94%
Energy (Fuel in MMBTU/year)	29%
Equivalent Cars Removed (2)	575

(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*

The New York Times

ENERGY

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/

Capstone® Turbine Corporation AUTHORIZED DISTRIBUTOR

FuelCell Energy

Ultra-Clean, Efficient, Reliable Power

Fuel Cell Technologies and Applications for Combined Heat and Power

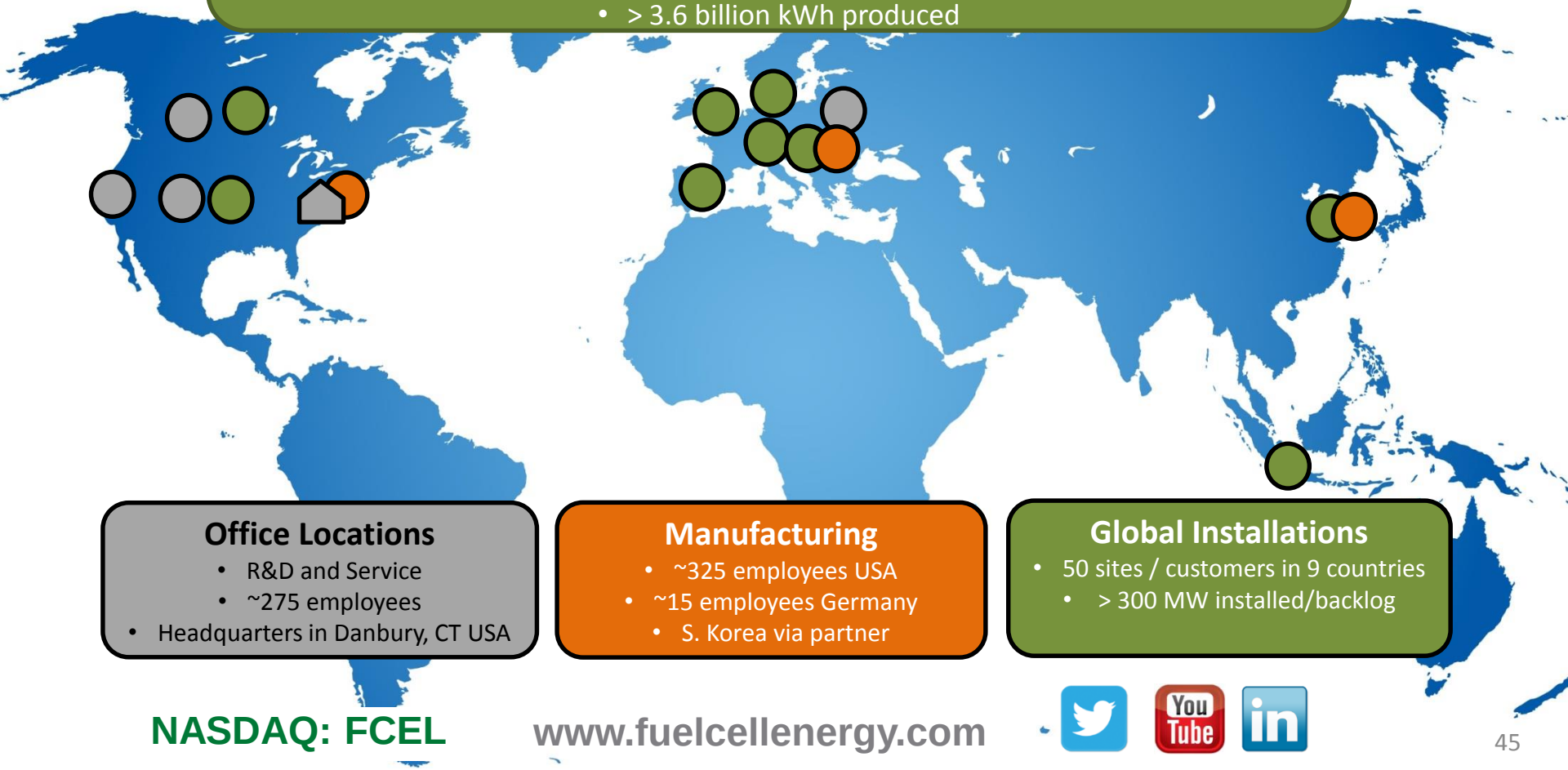
Ultra-Clean | Efficient | Reliable Power

FuelCell Energy
Ultra-Clean, Efficient, Reliable 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

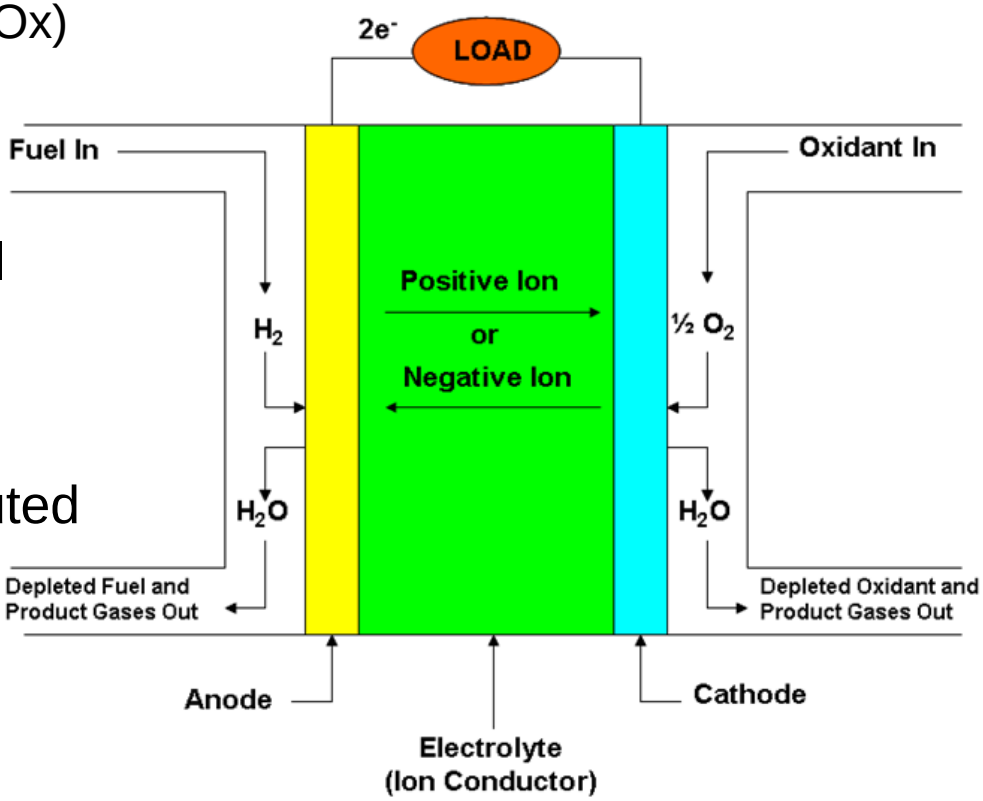
NASDAQ: FCEL

www.fuelcellenergy.com

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Why Fuel Cells?

- Power without combustion
  - Higher efficiency, low CO_2
  - 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



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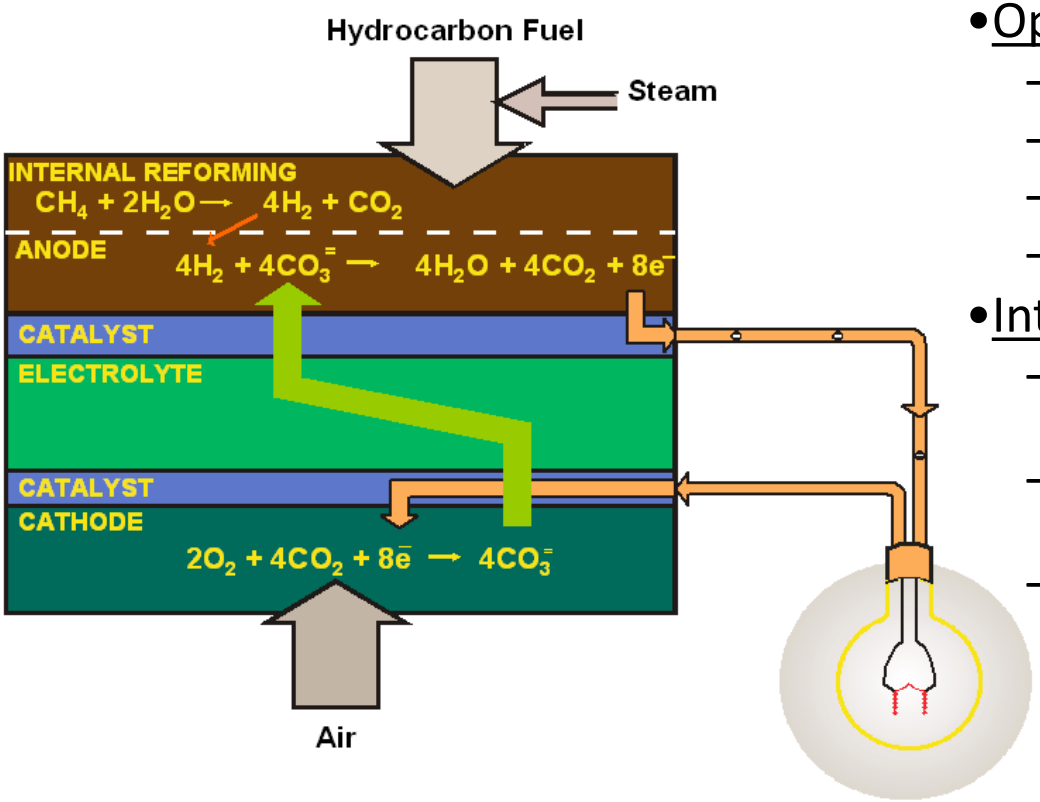
MCFC-Based Direct FuelCell



- 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

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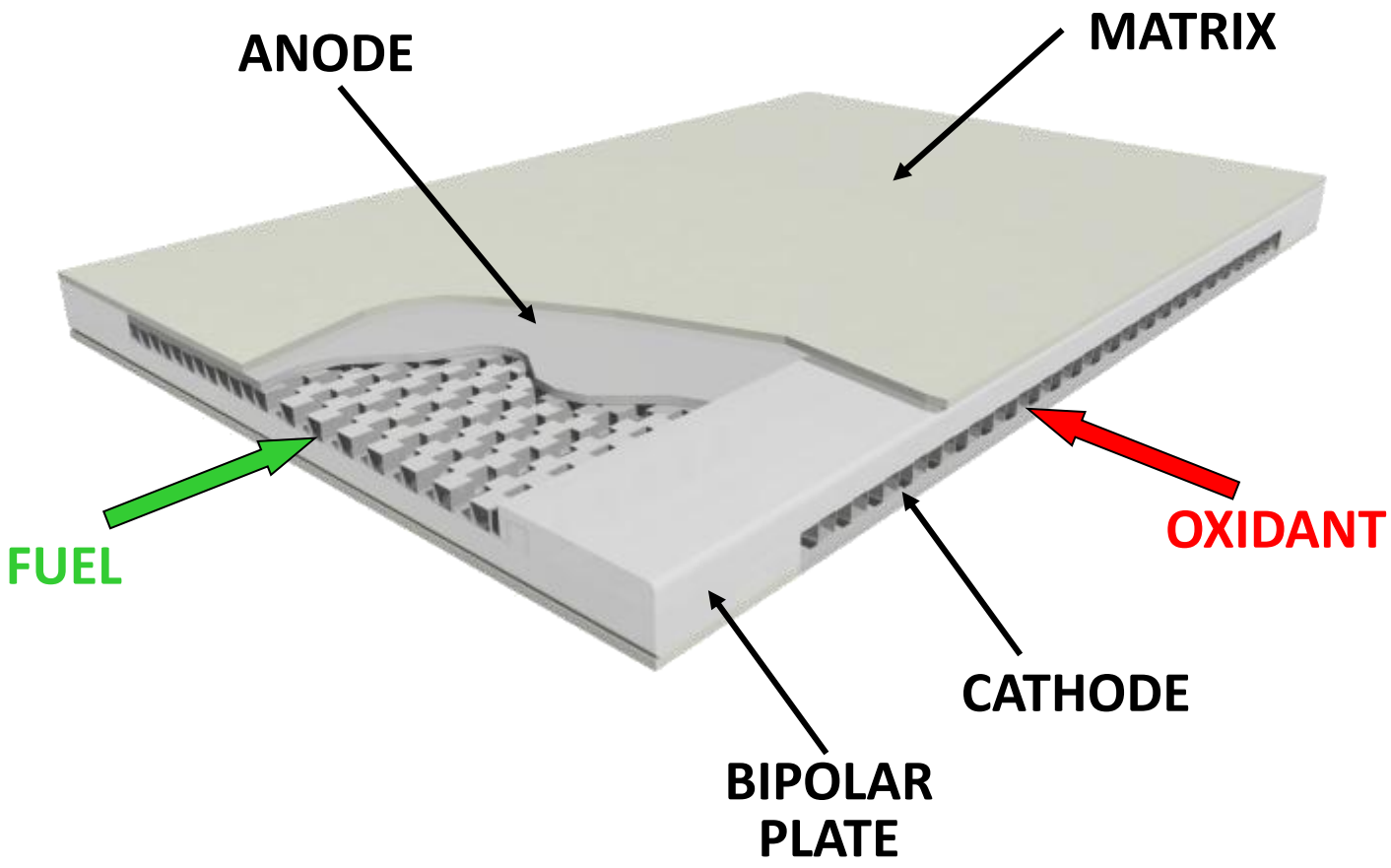
Fuel Cell Configuration



FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Scalable Solutions

Individual fuel cell
&
350 kW fuel cell stack

Four-Stack Module
1.4 megawatts

Completed module
1.4 megawatts

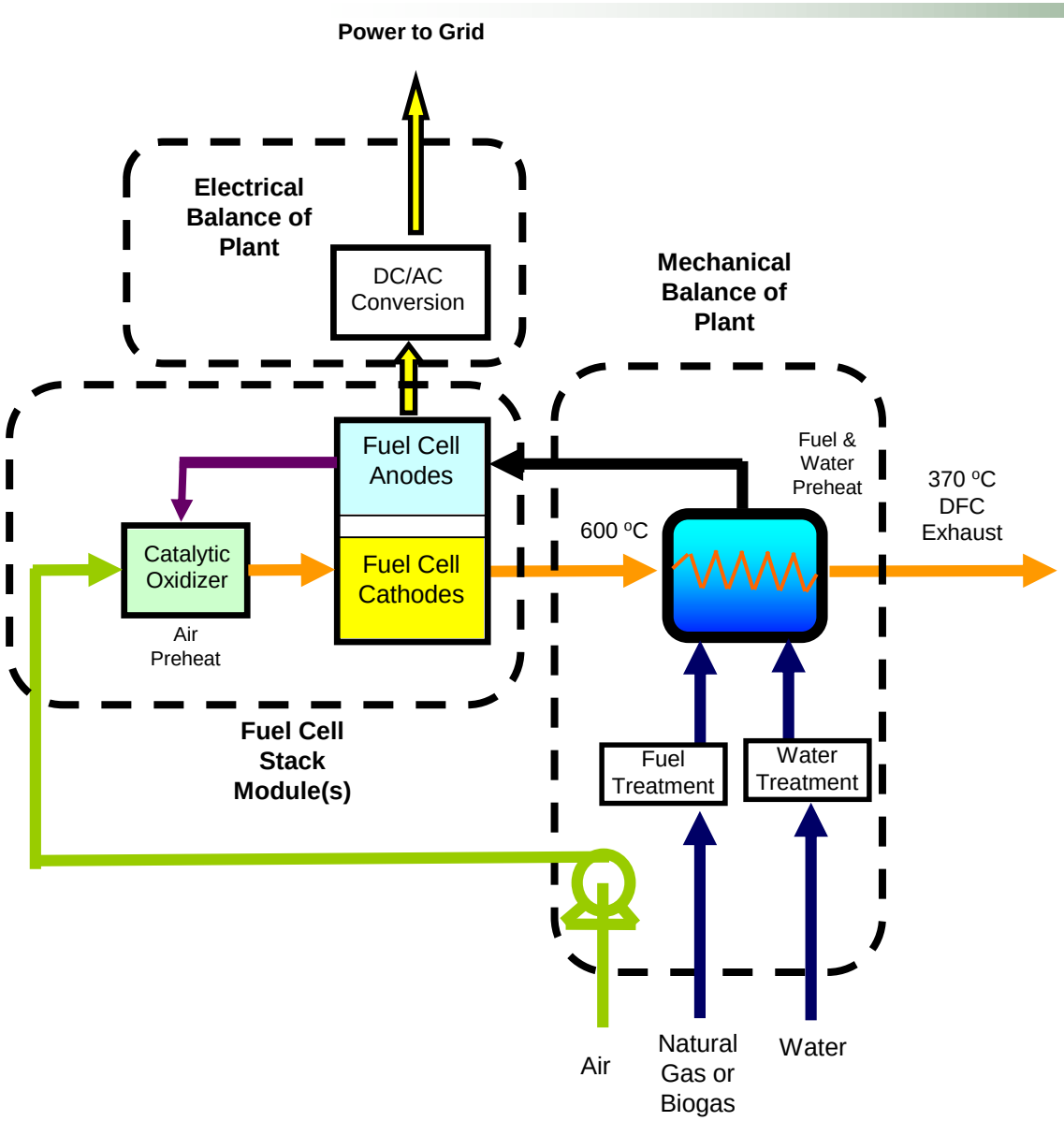
1.4 MW DFC1500®
- *Utilizes one module*
- *Adequate to power 1,400 homes*

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

59MW fuel cell park

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

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

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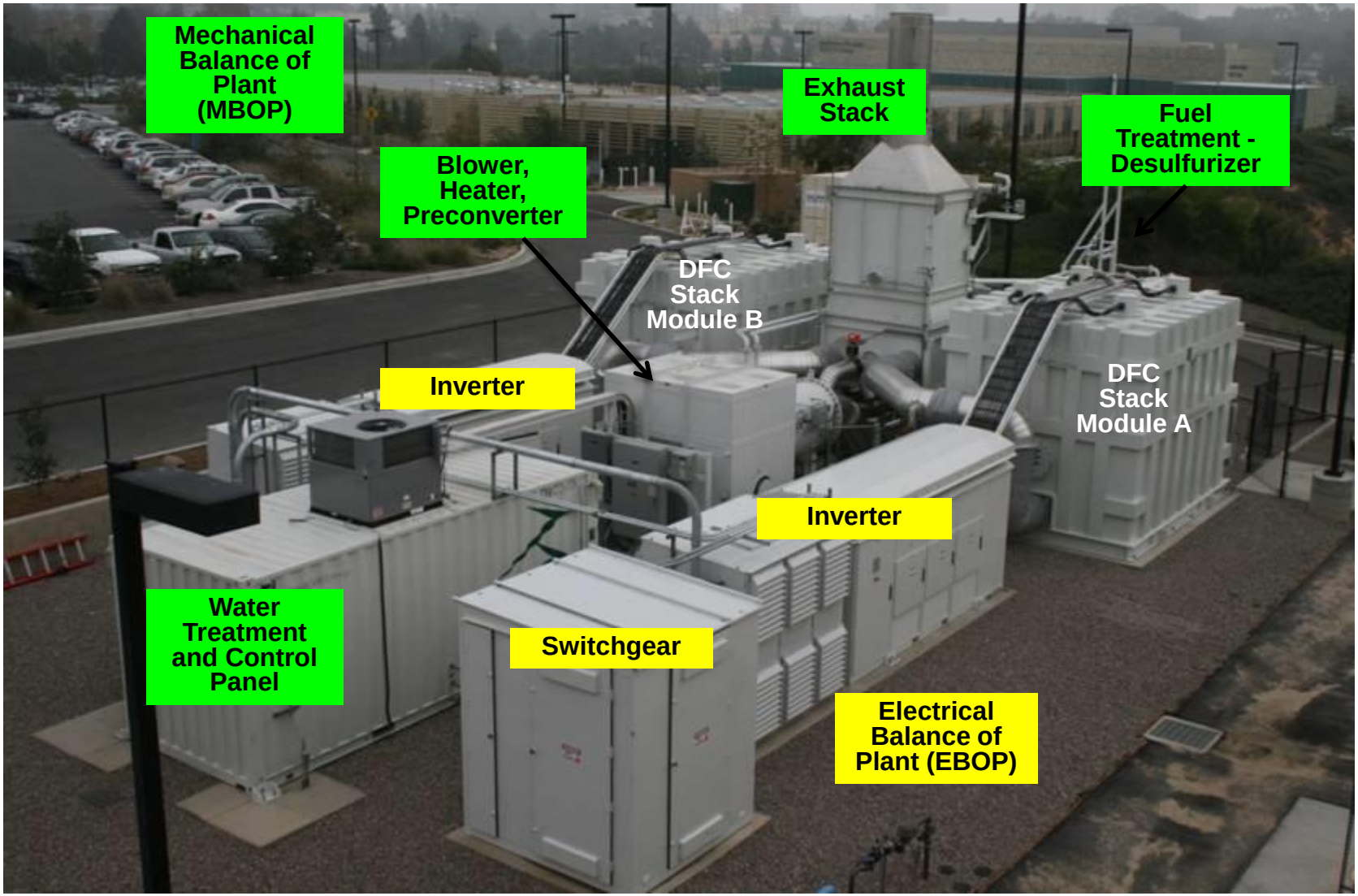
Powerplant Subsystems



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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**

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High Efficiency & Low Emissions

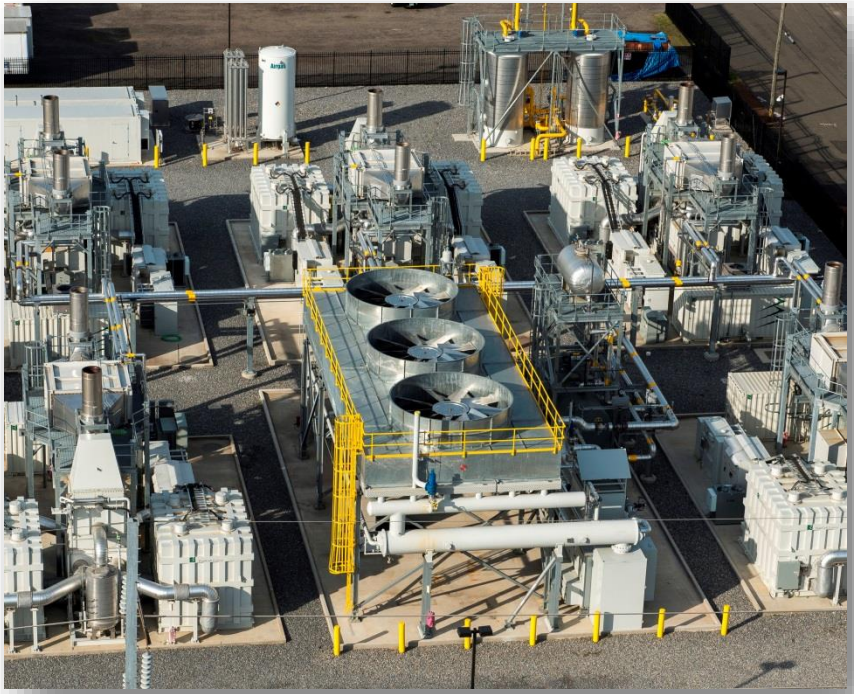
	Efficiency % LHV	CO2 (lb/MWh)	NOX (lb/MWh)	SOX (lb/MWh)	PM-10 (lb/MWh)
Average US Grid	33%	1,408	3.43	7.9	0.19
Average US Fossil Fuel Plant	36%	2,031	5.06	11.6	0.27
DFC Fuel Cell on Nat Gas 47% efficiency	47%	940	0.01	0.0001	.00002
DFC Fuel Cell on Nat Gas CHP 80% efficiency	80%	550	0.006	0.00006	.00001
DFC Fuel Cell on Biogas CHP 80% efficiency	80%	0	0.006	0.00006	.00001

Source for non-DFC data: "Model Regulations For The Output Of Specified Air Emissions From Smallerscale Electric Generation Resources Model Rule and Supporting Documentation", October 15, 2002; The Regulatory Assistance Project report to NREL

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Uses of Heat

1. On Site CHP
2. District heating
3. Convert to additional electricity



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Ultra-Clean, Efficient, Reliable Power

Combined Heat & Power Example

3.458 MMBtu/h
High Grade Use

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

64% total thermal efficiency

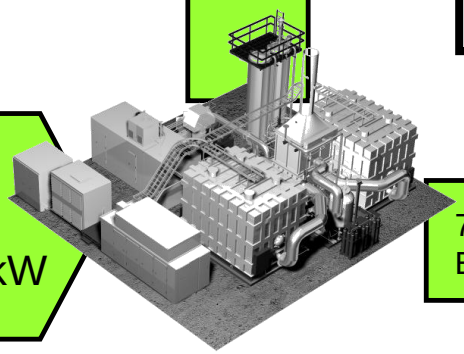
5.404 MMBtu/h
Low Grade Heat Use

Hot water
360 gpm from 60 F to 90 F

90% total thermal efficiency

2800 kW Power

Fuel Input 5957 kW



700 °F Exhaust

350 ° F Exhaust

Unused heat

100 °F Exhaust

DFC Powerplant

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Typical Steam Gen Application

1.2MW Pepperidge Farms, Connecticut

Steam generation and incinerator pre-heat for commercial bakery

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Biogas CHP Application

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

Inland Empire Utilities Agency
A MUNICIPAL WATER DISTRICT

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

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

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

University CHP Installation

"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

- 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

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Hospital CHP Application

*""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

- Electricity sold to Hartford Hospital
- Heat sold to Hartford Hospital and supplied to district heating system owned by Hartford Steam
- Component of Micro-grid

HSC

Hartford Hospital
A Hartford HealthCare Partner

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

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 Micro grid 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

Summary

- 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!

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Bringing it All Together: CHP Technology Overview

Anne Hampson

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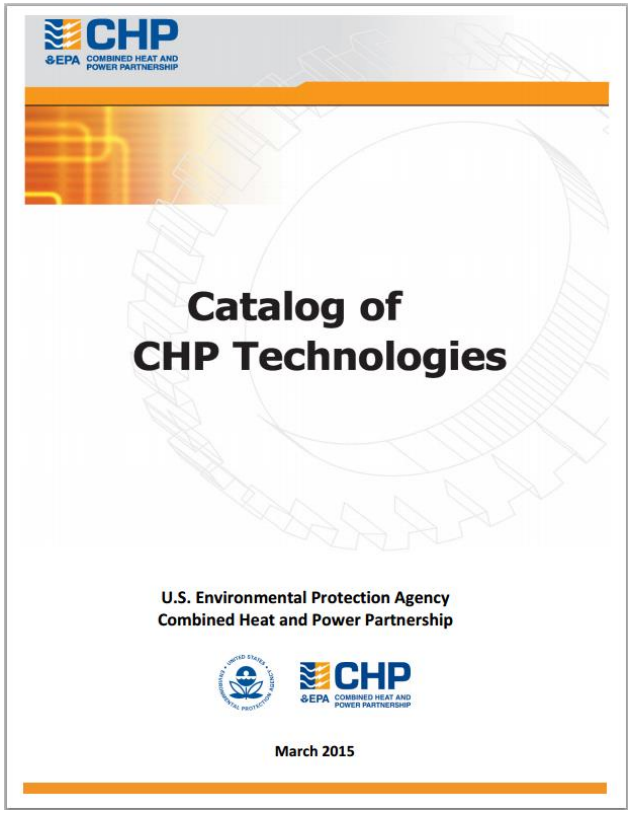
CHP Can Utilize Numerous Prime Movers

- 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.

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

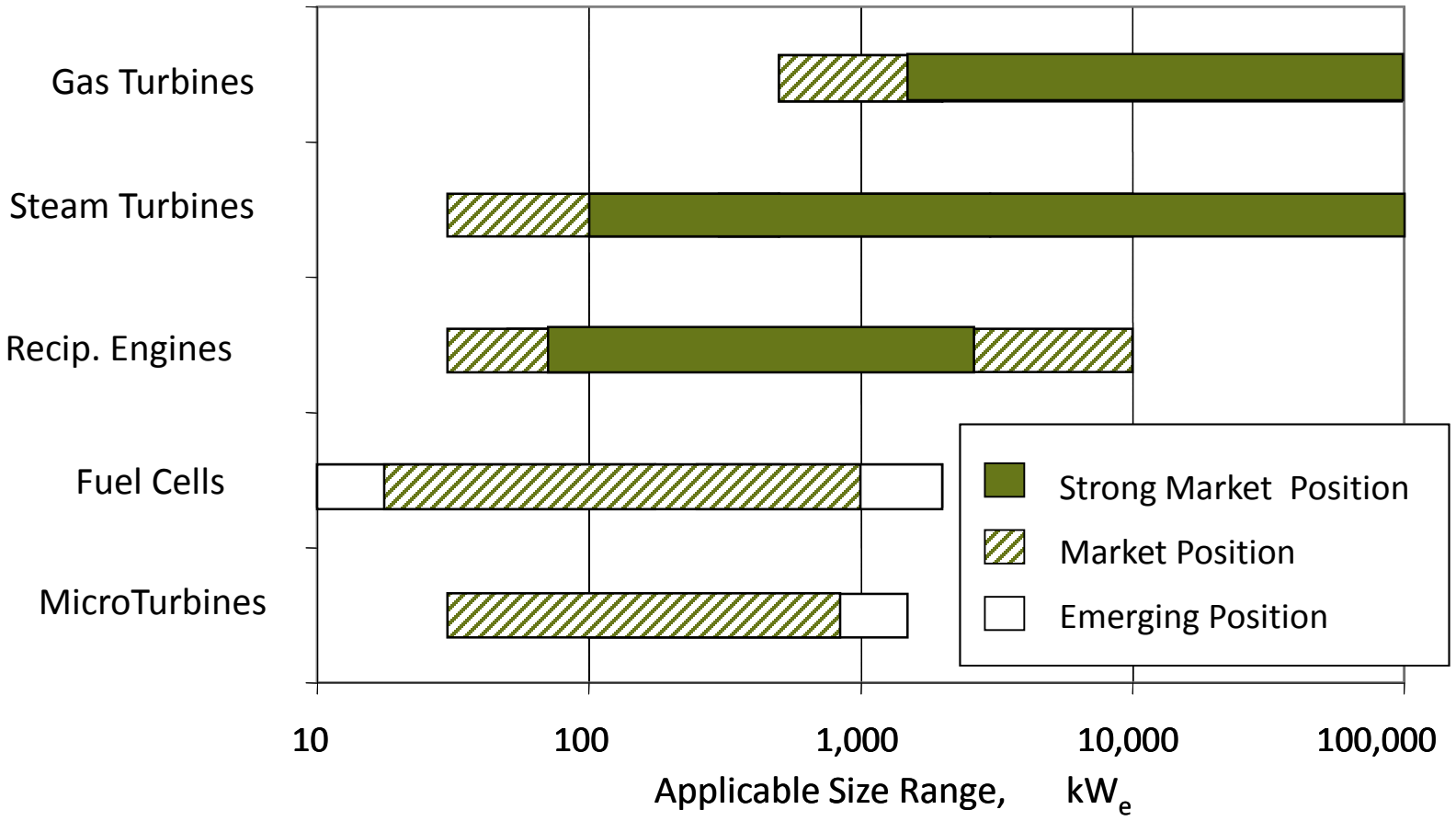
CHP Catalog of Technologies

- 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



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

			Cooling Technologies – Water Consumption (gal/MWh)				
			Open-Loop	Closed-Loop Reservoir	Closed-Loop Cooling Tower	Hybrid Cooling	Air-Cooling
Fuel Technology	Thermal	Coal	300	385 (±115)	480	between	60 (±10)
		Nuclear	400	625 (±225)	720	between	60 (±10)
		Natural Gas Combustion Turbine	negligible	negligible	negligible	negligible	negligible
		Natural Gas Combined-Cycle	100	130† (±20)	180	between	60† (±10)
		Integrated Gasification Combined-Cycle	not used	not used	350† (±100)	between	60† (±10)
		Concentrated Solar Power	not used	not used	840 (±80)	between	80† (±10)
	Non-Thermal	Wind	none	none	none	none	none
		Photovoltaic Solar	none	none	none	none	none

†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

CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP