RESILIENT POWER

A project of Clean Energy Group

Hydrogen and Fuel Cells for Resiliency: Microgrids for Grid Power

June 16, 2016

Clean Energy Group
Innovation in Finance, Technology & Policy

Northeast Electrochemical energy storage Cluster

Housekeeping

All participants are in "Listen-Only" mode. Select "Use Mic & Speakers" to avoid toll charges and use your computer's VOIP capabilities. Or select "Use Telephone" and enter your PIN onto your phone key pad.

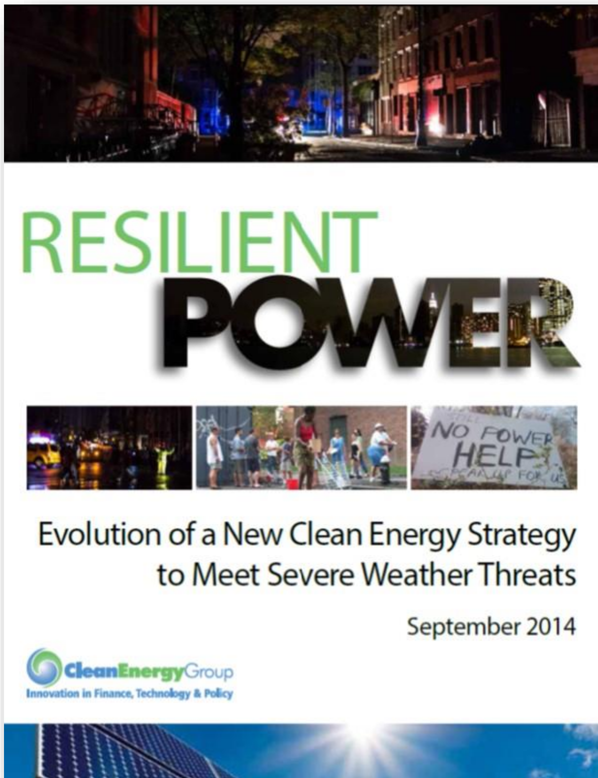
Submit your questions at any time by typing in the Question Box and hitting Send.

This webinar is being recorded.

You will find a recording of this webinar, as well as previous Resilient Power Project webinars, online at:

www.resilient-power.org

Who We Are



www.cleanegroup.org

www.resilient-power.org

CleanEnergyGroup
Innovation in Finance, Technology & Policy

Meridian Institute
Connecting People to Solve Problems

CleanEnergy States Alliance

THE JPB FOUNDATION

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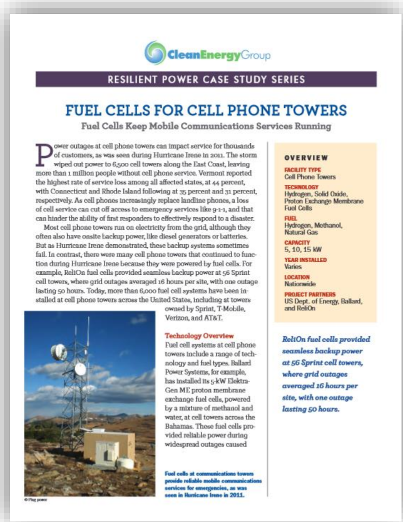
Cummings Foundation

THE KRESGE FOUNDATION

SURDNA FOUNDATION
Fostering sustainable communities in the United States

Resilient Power Project

- Increase public/private investment in clean, resilient power systems
- Engage city officials to develop resilient power policies/programs
- Protect low-income and vulnerable communities
- Focus on affordable housing and critical public facilities
- Advocate for state and federal supportive policies and programs
- Technical assistance for pre-development costs to help agencies/project developers get deals done
- See www.resilient-power.org for reports, newsletters, webinars, and more.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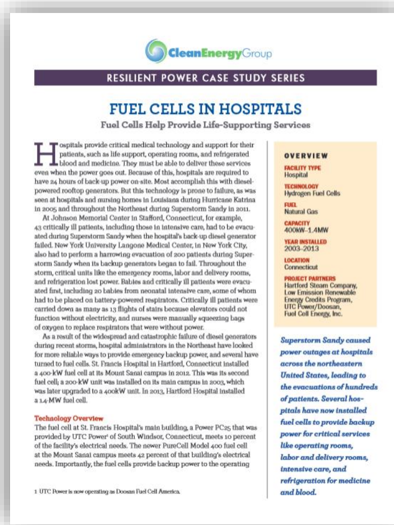
RESILIENT POWER CASE STUDY SERIES

FUEL CELLS FOR CELL PHONE TOWERS

Fuel Cells Keep Mobile Communications Services Running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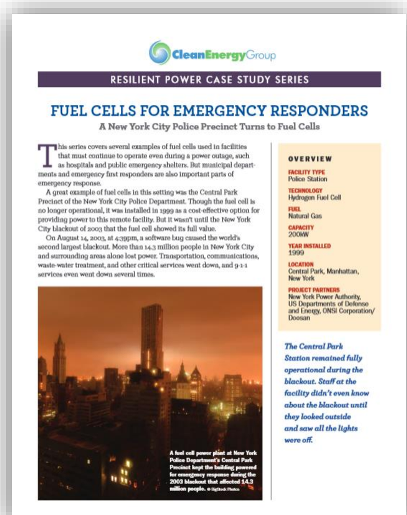
FUEL CELLS IN HOSPITALS

Fuel Cells Help Provide Life-Supporting Services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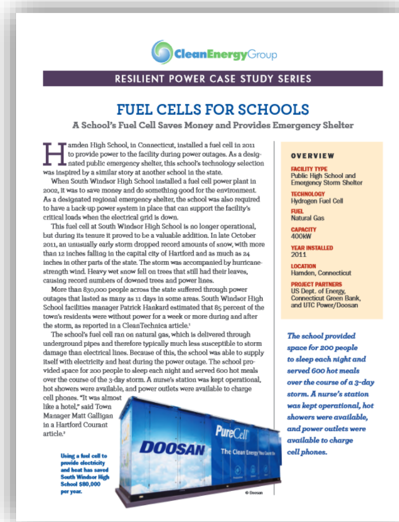
FUEL CELLS FOR EMERGENCY RESPONDERS

A New York City Police Precinct Turns to Fuel Cells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FUEL CELLS FOR SCHOOLS

A School's Fuel Cell Saves Money and Provides Emergency Shelter

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Resilient Power Project

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RESILIENT POWER PROJECT

To reduce impacts and dangers of power outages in communities now and in the future, the Resilient Power Project works to provide technology and policy solutions to address three challenges: Community Resiliency, Climate Adaptation, and Climate Mitigation.

Overview | Publications | Webinars | Blog | Newsletters | FAQs | Project Map | Featured Installations

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A Project of Clean Energy Group

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Project Manager
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With the Resilient Power Project, Clean Energy Group and Meridian Institute are working to accelerate market development of clean energy technologies for resilient power applications that serve low-income communities and vulnerable populations during disasters and power disruptions, and to address climate adaptation and mitigation goals through expansion of reliable renewable energy deployment. To reduce impacts and dangers of power outages in communities now and in the future, the Resilient Power Project works to provide technology and policy solutions to address three challenges facing the country: Community Resiliency, Climate Adaptation, and Climate Mitigation.

Clean Energy Group's role in this process is to help inform, coordinate, and support federal, state, and local officials, policy makers and developers with the goal of deploying resilient power projects in communities across the country. In addition to providing program guidance to policy makers and limited technical assistance funding

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Sierra Club
@sierraclub
#Fracking's Costs Fall Disproportionately on the Poor and Minorities in South Texas bit.ly/24aU4Fn (by @BrianBienkowski)

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Northeast Electrochemical Energy Storage Cluster (NEESC)

NEESC is a network of industry, academic, government and non-governmental leaders working together to help businesses provide energy storage solutions.

Northeast Electrochemical energy storage Cluster

www.neesc.org

Today's Guest Speakers

- **Robert Rose**, Vice President, A-Z Corp
- **Ben Toby**, Vice President of Sales, FuelCell Energy

Hydrogen & Fuel Cells for Resiliency: Microgrids for Grid Power

June 16, 2016

Ben Toby
FuelCell Energy, Inc.

Robert Rose
A/Z Corporation

Ultra-Clean | Efficient | Reliable Power

Microgrids

- Interconnected Loads
- Distributed Generation
  - Fuel Cell
  - Reciprocating Engine
  - Gas Turbine
  - Micro-Turbine
  - Renewables
    - PV
    - Wind
    - Energy Storage
- Defined Electrical Boundaries
- Single Controllable Entity

Microgrid Considerations

Define Overall Objective(s)

- Critical Facility
- Existing infrastructure
- Financial Options
- Technical Requirements
  - Electrical Distribution
  - Thermal Distribution
  - Fuel Source

Daegu, South Korea, 11.2 MW

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Why Fuel Cells?

- Energy Cost Savings
- Reliable, Grid Independent
- Clean, Quiet & Efficient
- Fuel Flexible
- Permitting and Siting Ease

Hartford Hospital, 1.4 MW

Central CT State University, 1.4 MW

Power Source	Efficiency (%LHV)	NOx (lb/MWh)	SOx (lb/MWh)	PM^{10} (lb/MWh)	CO_2 (lb/MWh)
Average U.S. Grid	33%	3.43	7.9	0.19	1,408
Average U.S. Fossil Fuel Plant	36%	5.06	11.6	0.27	2,031
DFC® Fuel Cell on Nat Gas	**47%**	**0.01**	**0.0001**	**0.00002**	**940**
DFC® Fuel Cell on Nat Gas (CHP)	**80%**	**0.006**	**0.00006**	**0.00001**	**550**
DFC® Fuel Cell on Biogas (CHP)	**80%**	**0.006**	**0.00006**	**0.00001**	**0**

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

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FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

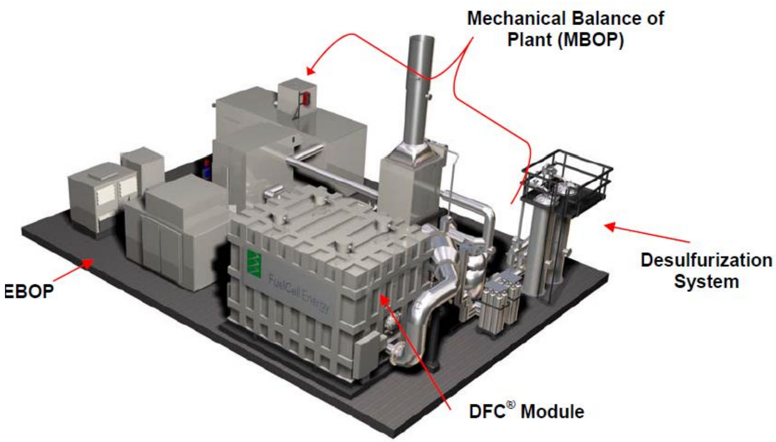
DFC®1500 Fuel Cell Power Plant

The DFC®1500 stationary fuel cell power plant from FuelCell Energy provides high-quality, Ultra-Clean electrical power with 47% efficiency, and high quality exhaust heat suitable for hot water, steam, or absorption chilling applications, around the clock. Designed for commercial and industrial applications, the system offers easy transport, quiet and reliable operation, and simple site planning and regulatory approval. The DFC1500 is ideal for wastewater treatment plants, manufacturing, food and beverage processing, universities and office campuses.

Gross Power Output	
Power @ Plant Rating	1,400 kW
Standard Output AC voltage	480 V
Standard Frequency	60 Hz
Optional Output AC Voltages	By Request
Optional Output Frequency	50 Hz
Efficiency	
LHV	47 +/- 2 %

Available Heat	
Exhaust Temperature	700 +/- 50 °F
Exhaust Flow	18,300 lb/h
Allowable Backpressure	5 iwc
Heat Energy Available for Recovery	
(to 250 °F)	2,216,000 Btu/h
(to 120 °F)	3,730,000 Btu/h

Pollutant Emissions	
NOx	0.01 lb/MWh
SOx	0.0001 lb/MWh
PM10	0.00002 lb/MWh
Greenhouse Gas Emissions	
CO_2	980 lb/MWh
CO_2 (with waste heat recovery)	520-680 lb/MWh



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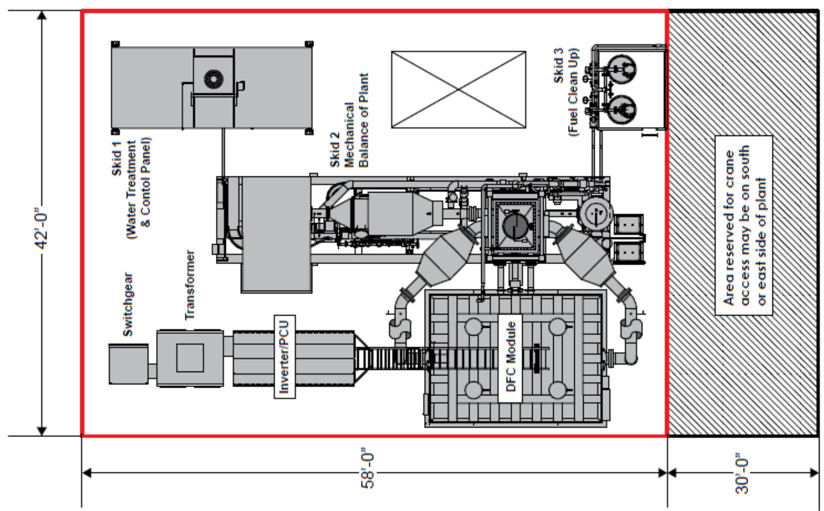

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FuelCell Energy
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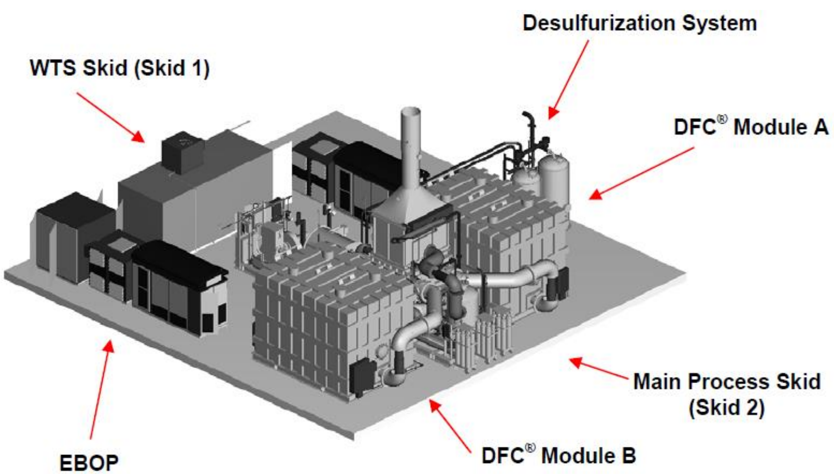
DFC® 3000 Fuel Cell Power Plant

FuelCell Energy's DFC3000™ system is the largest of the Direct FuelCell® (DFC®) power plant fleet, capable of providing high-quality baseload power with 47% electric power generation efficiency around-the-clock. Scalable for Multi-Megawatt Fuel Cell Parks, the system is especially suitable for applications with larger load requirements such as universities, manufacturing facilities, wastewater treatment plants, and utility/grid support.

Gross Power Output	
Power @ Plant Rating	2,800 kW
Standard Output AC voltage	13,800 V
Standard Frequency	60 Hz
Optional Output AC Voltages	By Request
Optional Output Frequency	50 Hz
Efficiency	
LHV	47 +/- 2 %

Available Heat	
Exhaust Temperature	700 +/- 50 °F
Exhaust Flow	36,600 lb/h
Allowable Backpressure	5 iwc
Heat Energy Available for Recovery	
(to 250 °F)	4,433,000 Btu/h
(to 120 °F)	7,460,000 Btu/h

Pollutant Emissions	
NOx	0.01 lb/MWh
SOx	0.0001 lb/MWh
PM10	0.00002 lb/MWh
Greenhouse Gas Emissions	
CO_2	980 lb/MWh
CO_2 (with waste heat recovery)	520-680 lb/MWh



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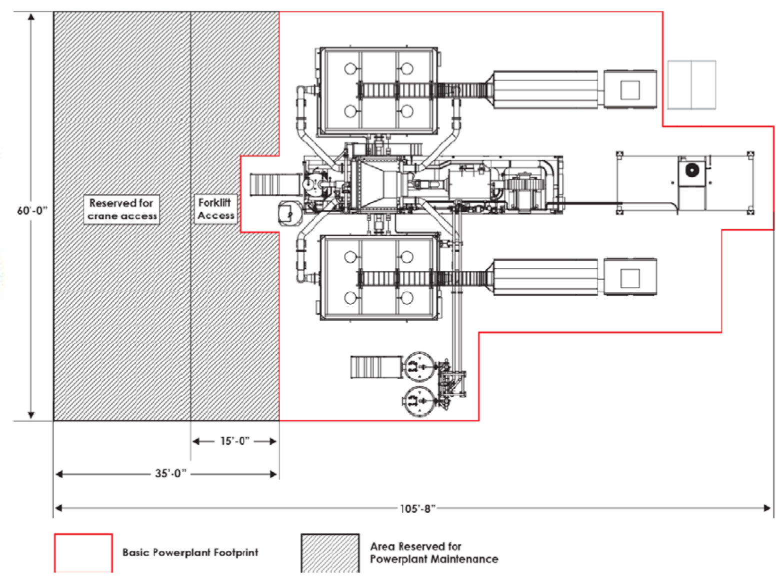

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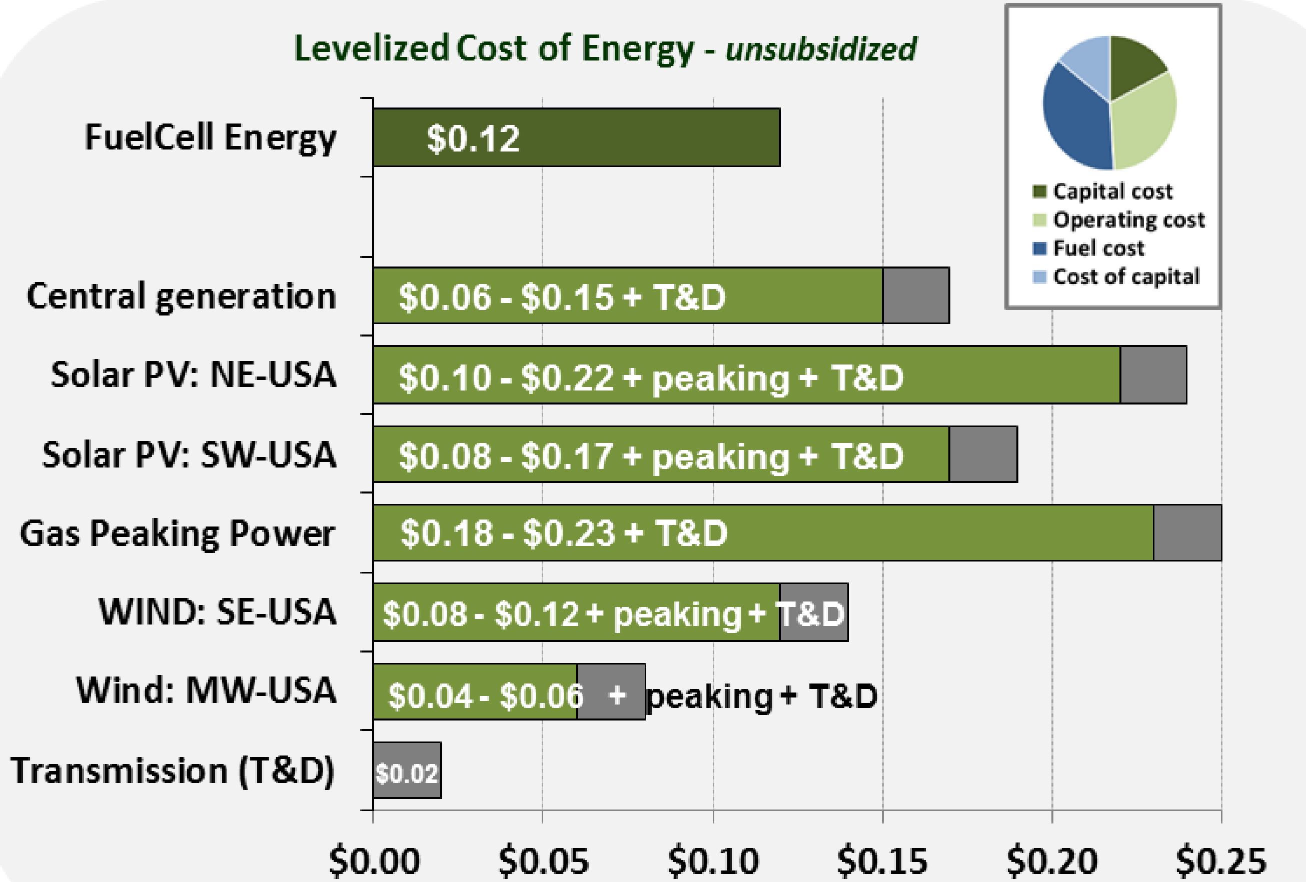
Direct FuelCell® Power Plant

Key
Fuel cell module
Mechanical Balance of Plant (MBOP)
Electrical Balance of Plant (EBOP)

Levelized Cost of Electricity



Based on $4.50 mm/Btu gas cost; Each $2/mmBtu change equates to one penny for FCE LCOE
Source: Company estimates, Lazard LCOE v. 8.0, EIA, Oak Ridge National Lab

Renewable Energy Credits (RECs), Federal Investment Tax Credit (ITC) and Heat Use enable LCOE ~ $0.09/kWh

Grid-Independent Capability

Fuel cells provide dependable, clean electricity and heat for microgrids, either alone or in parallel with other generation sources

Grid Connected mode

In normal operation the fuel cell synchronizes to local utility grid and offsets part or all of the load demand of the facility, reducing power needed from the utility

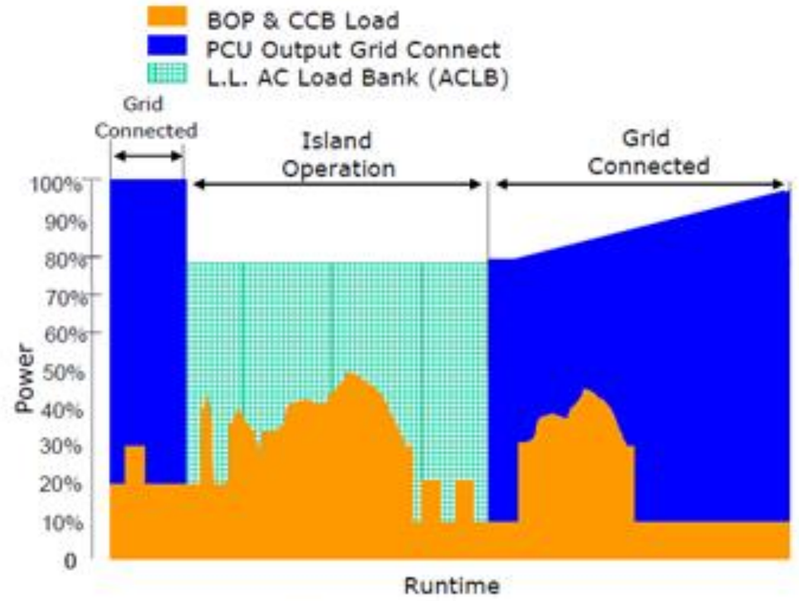
Microgrid mode

After a grid outage, facility loads see a brief interruption, and are then reconnected in a controlled manner to the fuel cell and other on-site sources

Critical Supply mode

Upon grid outage, disconnects from the grid and enters standby mode. Seamless backup power available to hard-wired customer critical loads up to 85% of fuel cell output

Load Leveler operation profile: microgrid established in ~30 seconds



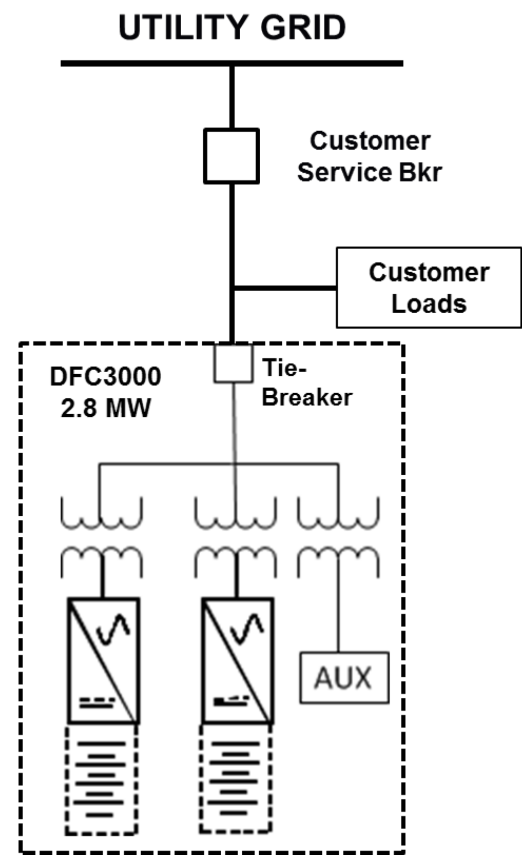
Schematic of the Load Leveler in Operation

Grid Connected

Grid Connected Mode

Powerplant synchronizes to local utility grid and reduces local power demand or exports power to grid. Grid must meet stringent requirements for voltage and frequency or powerplant will disconnect and go into grid independent mode

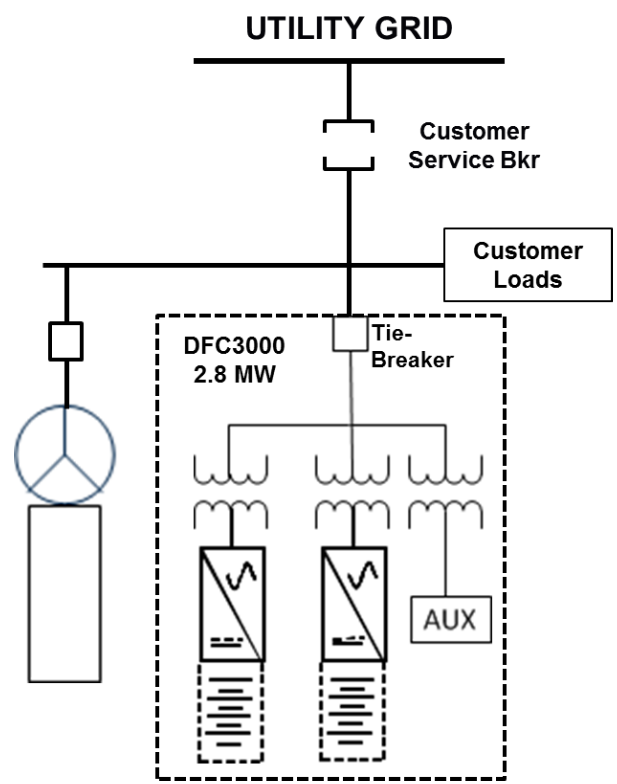
- Baseload, Full Power Production
- Current Control Mode
- Match & Follow Grid Voltage
- UL-1741 Anti-Islanding Detection
  - Abnormal Volt. & Freq.
  - Active anti-islanding algorithm



Micro-Grid

Micro-Grid Mode

Powerplant synchronizes to microgrid either as a baseload current source, reducing output from local power generation systems, or as a load following voltage source in parallel with other local generators or as a stand-alone generator



Current Source Micro-Grid Mode

- Gen set connects to bus at rated voltage and freq
- DFC syncs with gen set and connects to bus with wider V&F relay settings and active anti-islanding disabled.

Voltage Source Micro-Grid Mode

- Multiple fuel cells or fuel cell / gen set combination.
- No master sync setting, units synchronize autonomously
- Compliant with CERTS philosophy

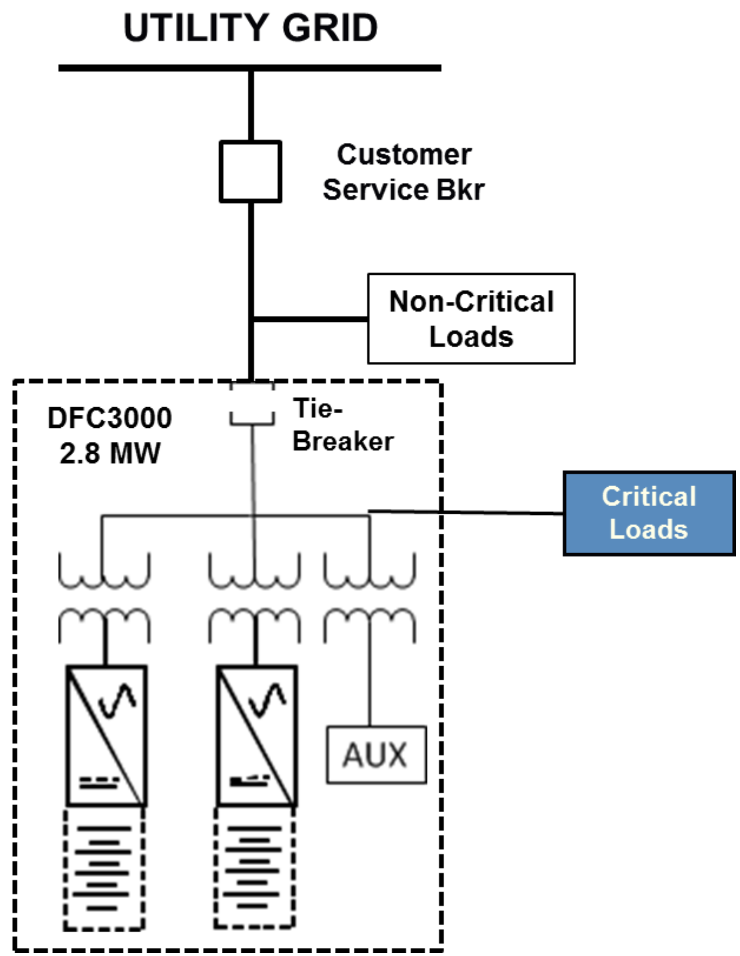
Critical Supply

Critical Supply Mode

Powerplant is not connected to grid, generates its own frequency signal. Supports powerplant parasitic loads in standby mode, and can support local critical loads

Upon detection of abnormal Voltage & Frequency:

- Tie Breaker Opens
- Switch to Voltage Control Mode
- Parasitic and Critical loads recovered <4 cycles



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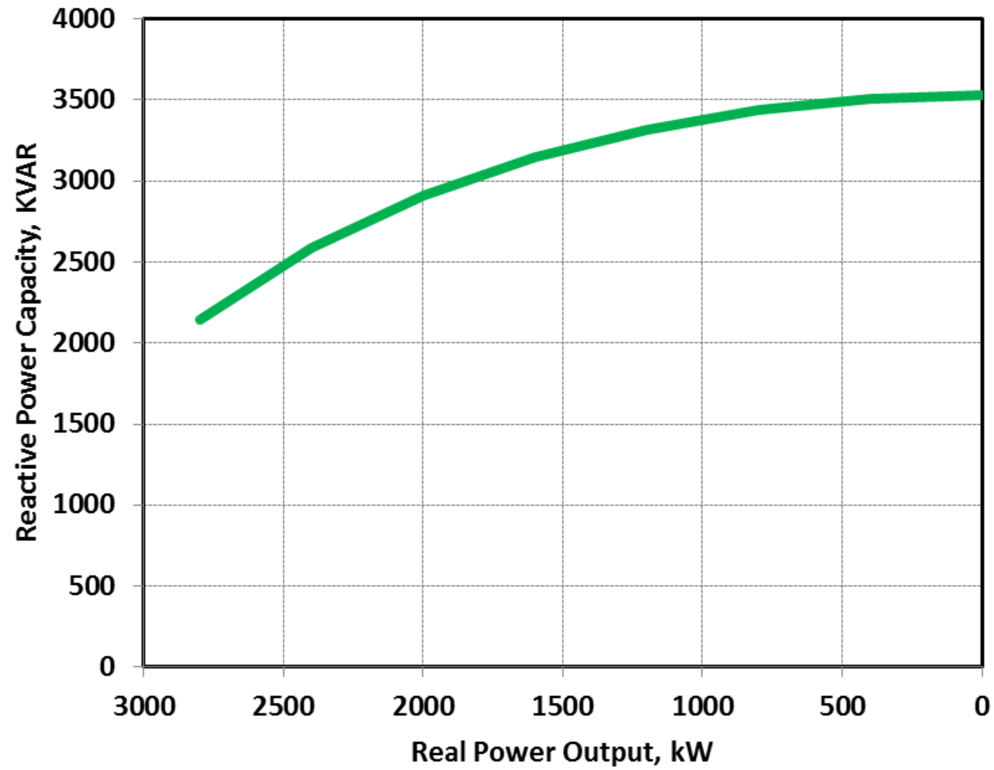
Reactive Power Capabilities

By supplying reactive current locally, less KVA is needed from the local utility or micro grid system.

- Frees up capacity in the local grid or micro-grid.
- Reduces total electric system losses
- Fast and precise power factor correction



All DFC plants are capable of generating rated output from better than (-) 0.9 to (+) 0.9 pf

- 2.8 MW System can provide more than 2 MVAR @ 2800kW, with higher reactive capabilities at lower kW output

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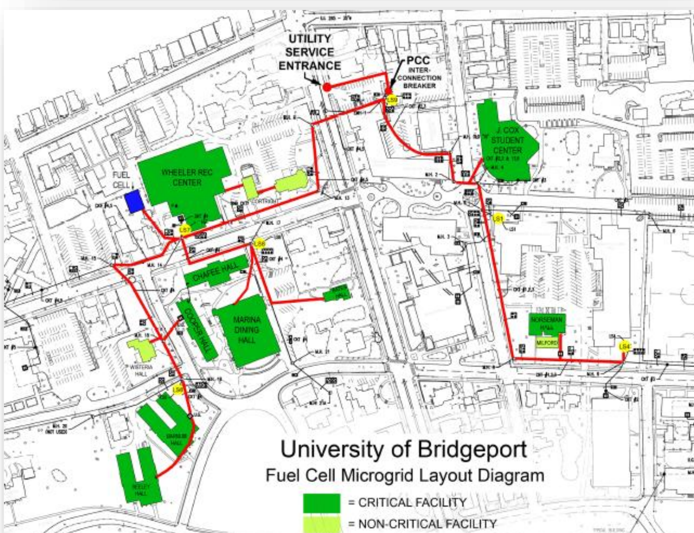
University of Bridgeport



Project Overview

- 1.4 MW combined heat & power fuel cell power plant
- Supplies 80% of campus power needs
- Waste heat converted to hot water and supplied to three locations on campus

Benefits

- ~20% cost savings during normal operations
- In a grid outage, power to critical facilities – shelter, security, dining
- Renewable Energy Research Lab – "practice what we teach"
- Emissions reductions:
  7,000 tons CO2, 64 tons SOx, 28 tons NOx

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University of Bridgeport

Fuel Cell only

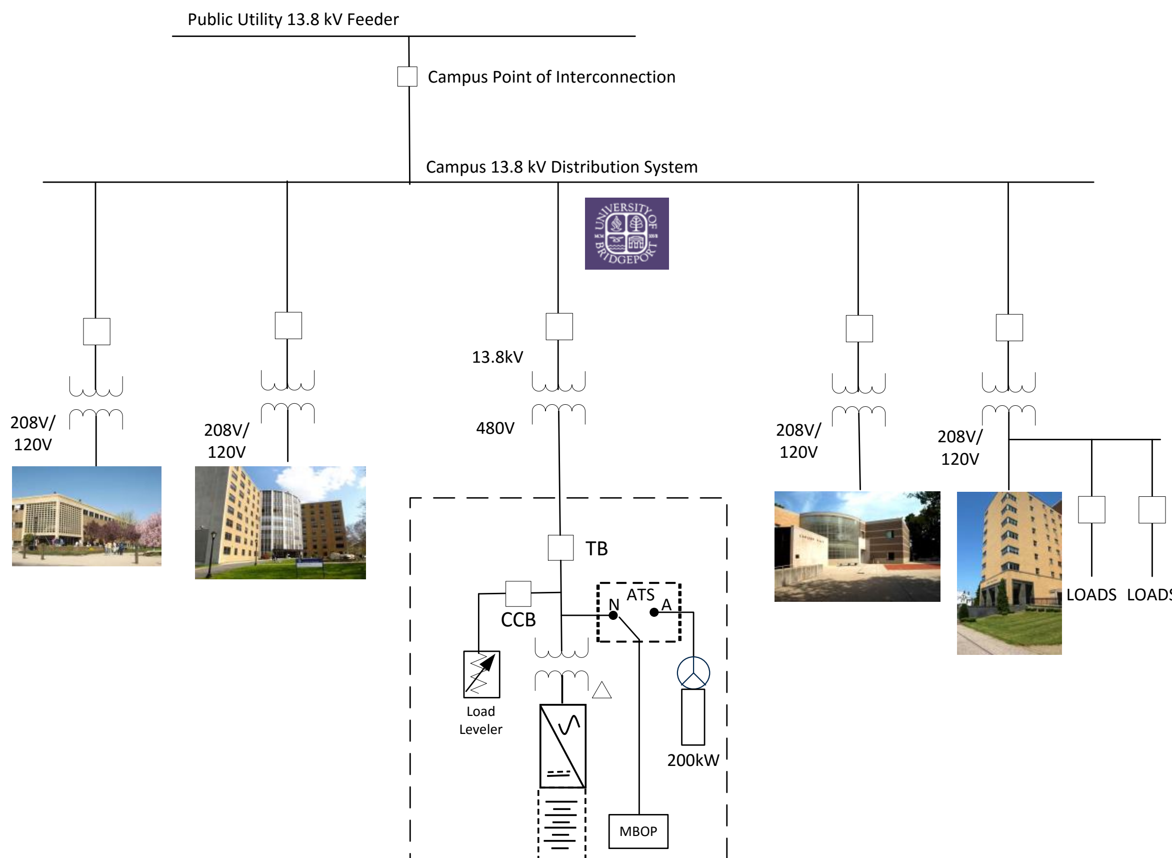
- 1.4 MW Fuel Cell
- Load Follow Capable
- Black-Start Capable

Grid Connected Operation

- Base Load, Net Metering
- Heat to Campus

Microgrid Operation

- "Drop & Pickup"
- Microgrid controller sequences critical facilities
- Inverter follows microgrid load
- Load Leveler maintains fuel cell power constant



DFC1500
1400kW Grid Connected
1200kVA Islanded

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Town of Woodbridge, CT

AMITY
Regional District #5
Bethany-Orange-Woodbridge

Project Overview

- 2.2 MW combined heat & power fuel cell power plant
- Power to UI grid during normal operation
- Supplies 100% of Town microgrid power needs during grid outage
- Heat supplied to Amity High School
- Connecticut Microgrid Program Award

Benefits

- Helps UI achieve its Class I RPS goals
- In a grid outage, power to critical facilities – police, fire, community services
- Savings to Amity High School ~ $100K per year from avoided natural gas
- Enabled upgrade to local gas grid delivery infrastructure

Town of Woodbridge, CT

Fuel Cell only

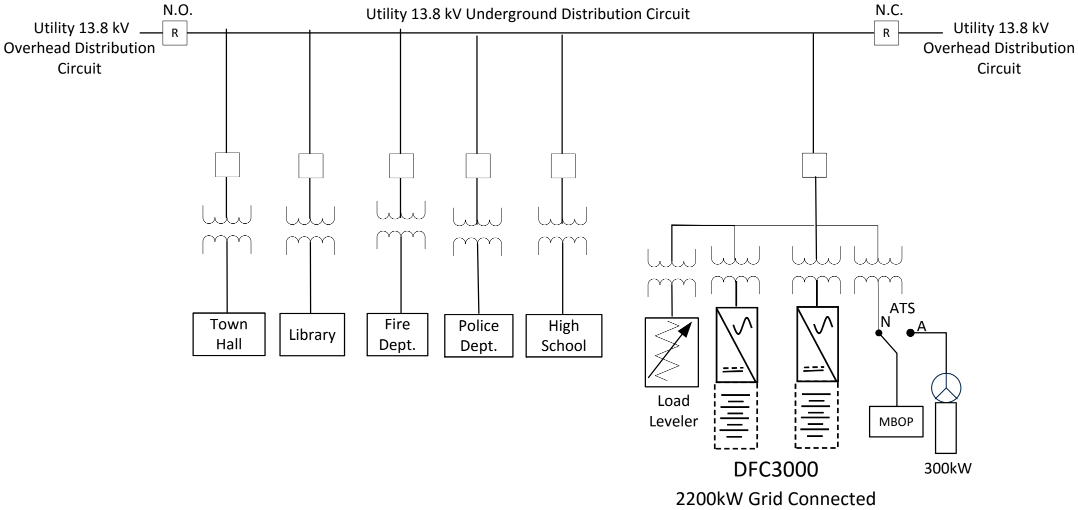
- 2.2 MW Fuel Cell
- Hot water to High School
- Load Follow Capable
- Black-Start Capable

Grid Connected Operation

- Base Load
- Heat to High School

Microgrid Operation

- "Drop & Pickup"
- Microgrid controller sequences critical loads
- Inverter follows microgrid load
- Load Leveler maintains fuel cell power constant



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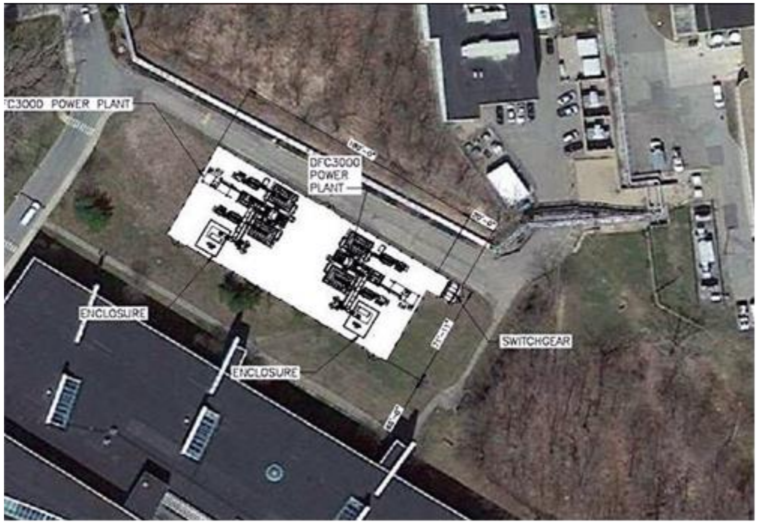
Pfizer R&D Center, Groton CT



Pfizer Groton installation site

5.6 MW fuel cell installation in South Korea

Project Overview

- Grid-connected 5.6 MW fuel cell powered by Natural Gas
- Provides electricity and steam to Pfizer Groton campus
- Seamless grid independent capability
- Private, Critical Facility Microgrid

Benefits

- Closes electrical generation gap with a more reliable source than the commercial grid – makes site independent year round
- PPA structure with no up-front capital cost, delivers energy cost savings to Pfizer
- Enhances site sustainability profile (green energy source)
- Clean profile reduces permitting hurdles

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Pfizer R&D Center, Groton CT

Fuel Cell – Gas Turbine

- 10 MW Gas Turbine
- (2) 2.8 MW Fuel Cells
- Load Follow Capable
- 2 Levels of Seamless Backup.

Grid Connected Operation

- Fuel Cells Base Loaded
- Steam to Campus
- Gas Turbine follows campus load to maintain zero utility import/export.

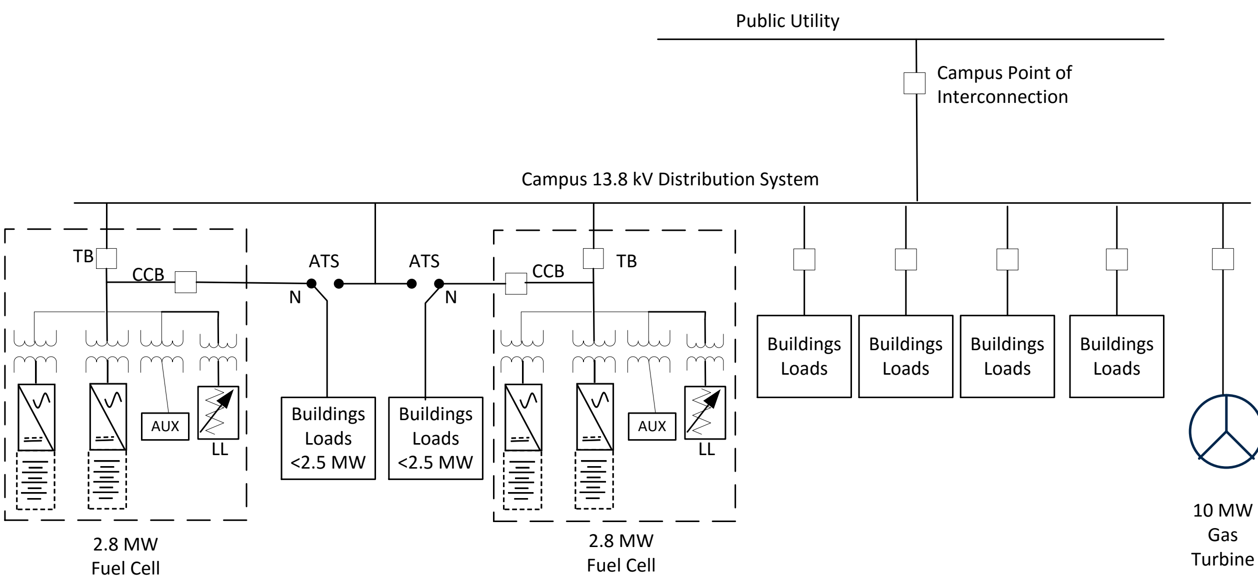
Microgrid Operation

Loss of Utility

- Seamless disconnect from utility
- FC base load
- Turbine Load Following

Loss of Gas Turbine & Utility

- Seamless disconnect from Campus.
- FC maintains critical building loads.



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Summary

- Fuel cell advantages in microgrids:
  - Low emission, quiet distributed generation solution
  - High efficiency, low carbon
  - Reactive power support
  - Energy Cost savings
- Technology proven and gaining acceptance globally
- Complex projects requiring staged development with CHP as the cornerstone
- Clean, Efficient & Financeable

AZ CORP

Thank you

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