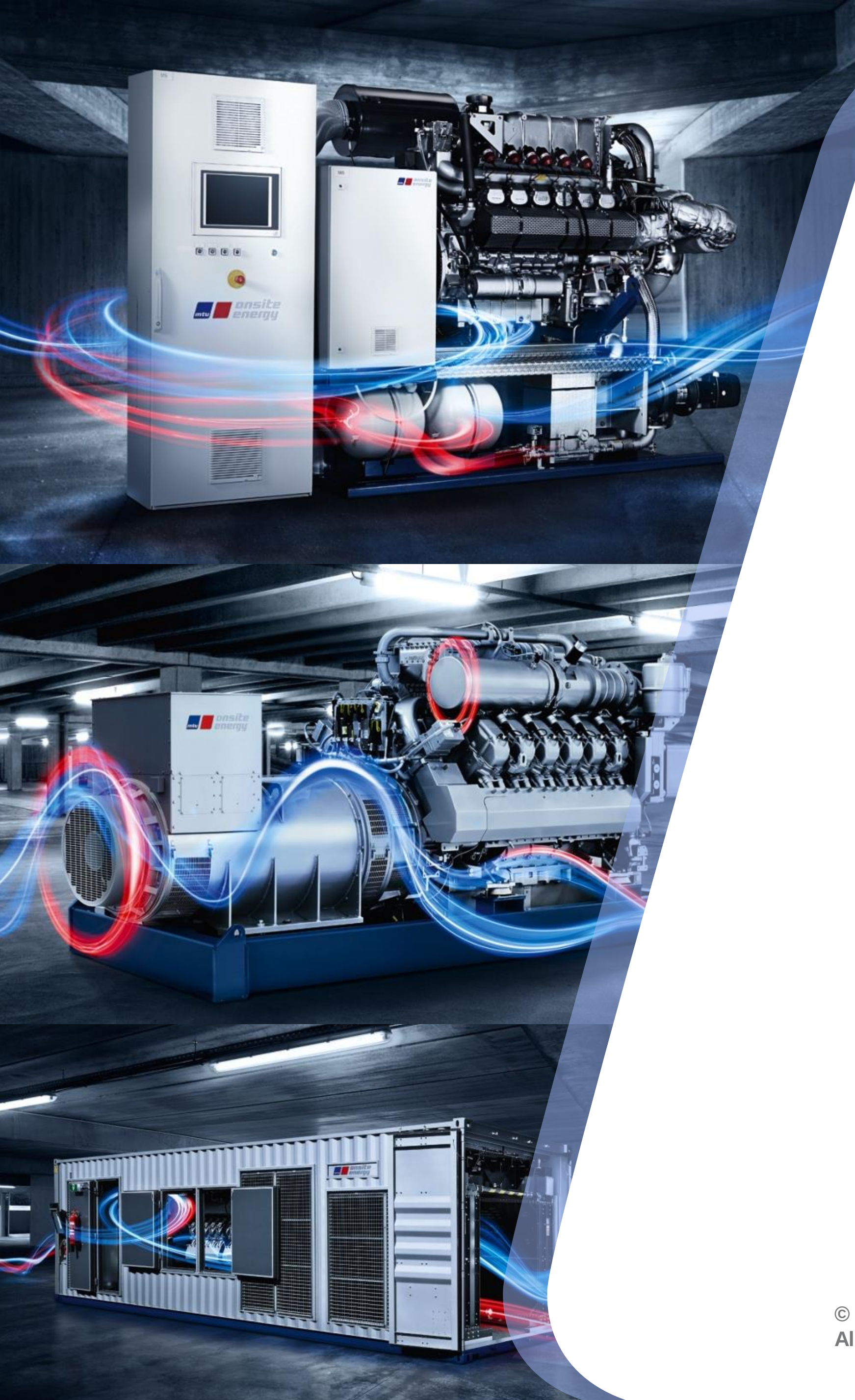


ROLLS-ROYCE POWER SYSTEMS & MTU ONSITE ENERGY

Hybrid Microgrids with Reciprocating Engine Generator Sets

Christian Mueller
Sr. Sales Engineer - Gas Power Systems
MTU Onsite Energy Corp.

A Rolls Royce Power Systems Company

AGENDA

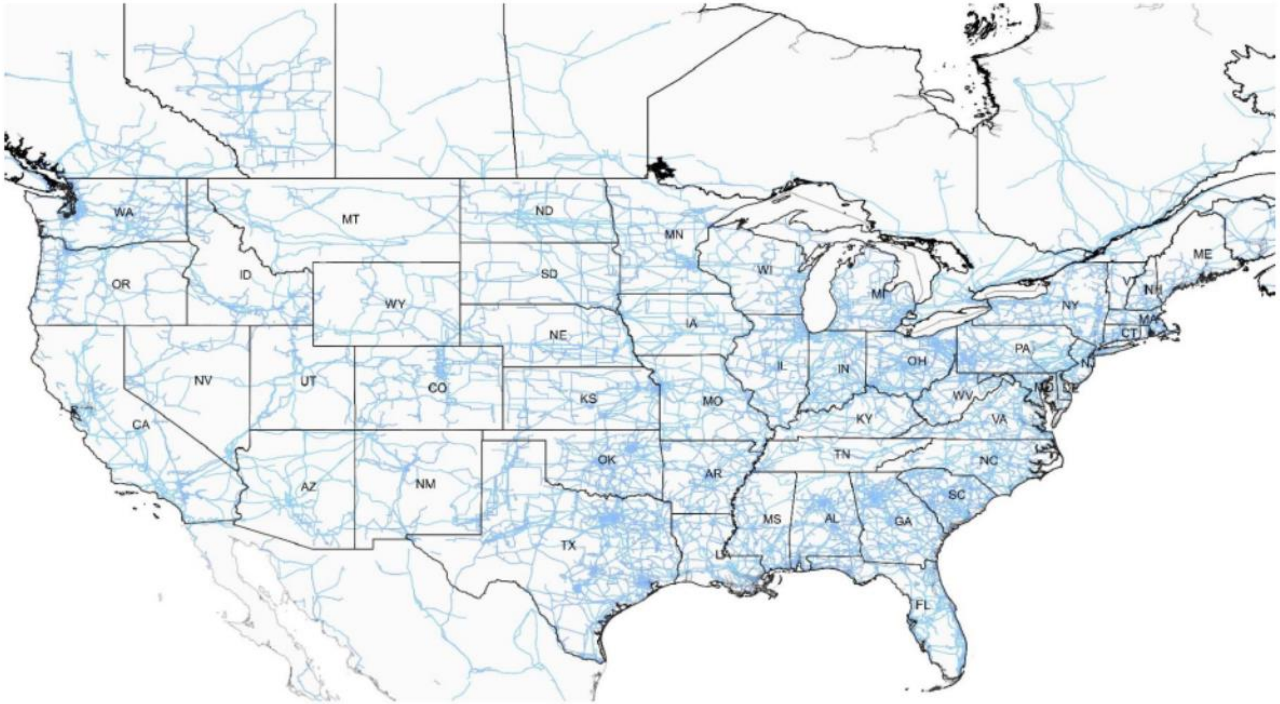
01. The case for Microgrids

02. Microgrid Features

03. Case Studies

THE CASE FOR MICROGRIDS
DEMAND RESPONSE GRID SUPPORT / MUNICIPAL

US transmission infrastructure asset map



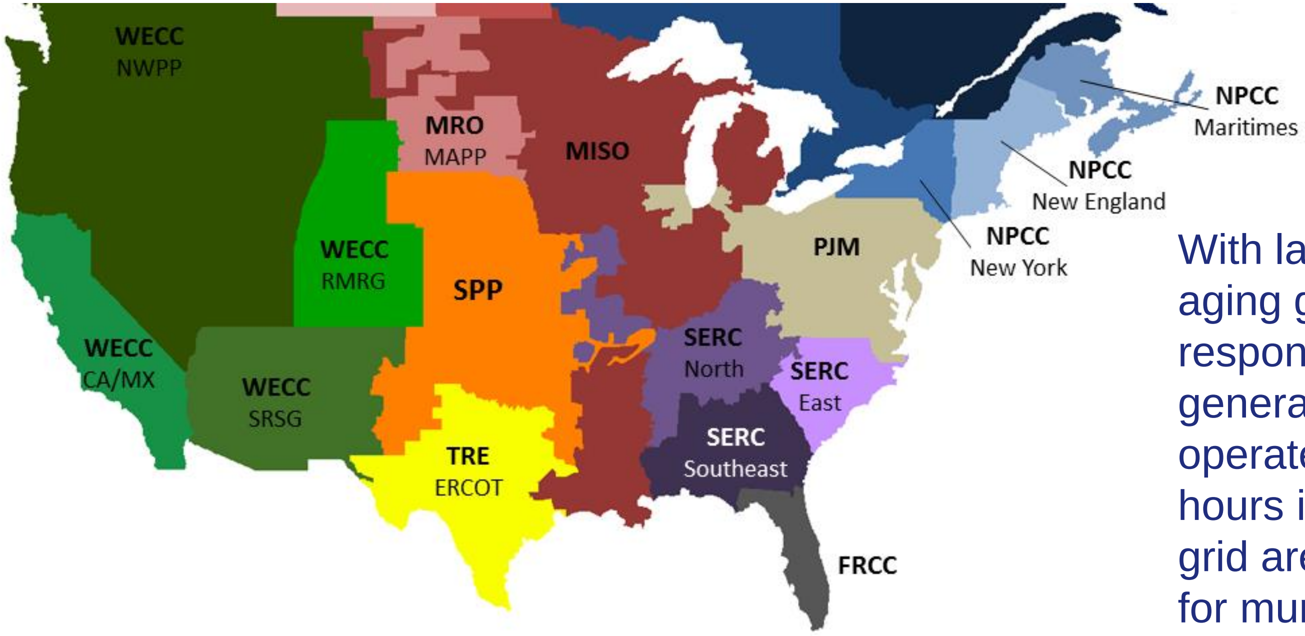
The aging US transmission system has seen increasing investment in recent years and may continue to be a major area of spending.

For example, the transmission lines of AEP, the largest transmission owner in the US, have an average age of 52 years. AEP estimates that it would need to invest $2.5bn per year simply to maintain the current asset age profile of the over 40,000 miles of transmission lines under its ownership.

THE CASE FOR MICROGRIDS
DEMAND RESPONSE GRID SUPPORT / MUNICIPAL

Winter Peak Load (Megawatts)				
				ERCOT
Period	MISO	PJM	SPP	TRE
2010 / 2011	86,728	115,535	41,226	**57,315**
2011 / 2012	86,844	122,563	39,220	**50,100**
2012 / 2013	74,430	122,566	34,916	**46,909**
2013 / 2014	109,400	140,510	39,168	**57,256**

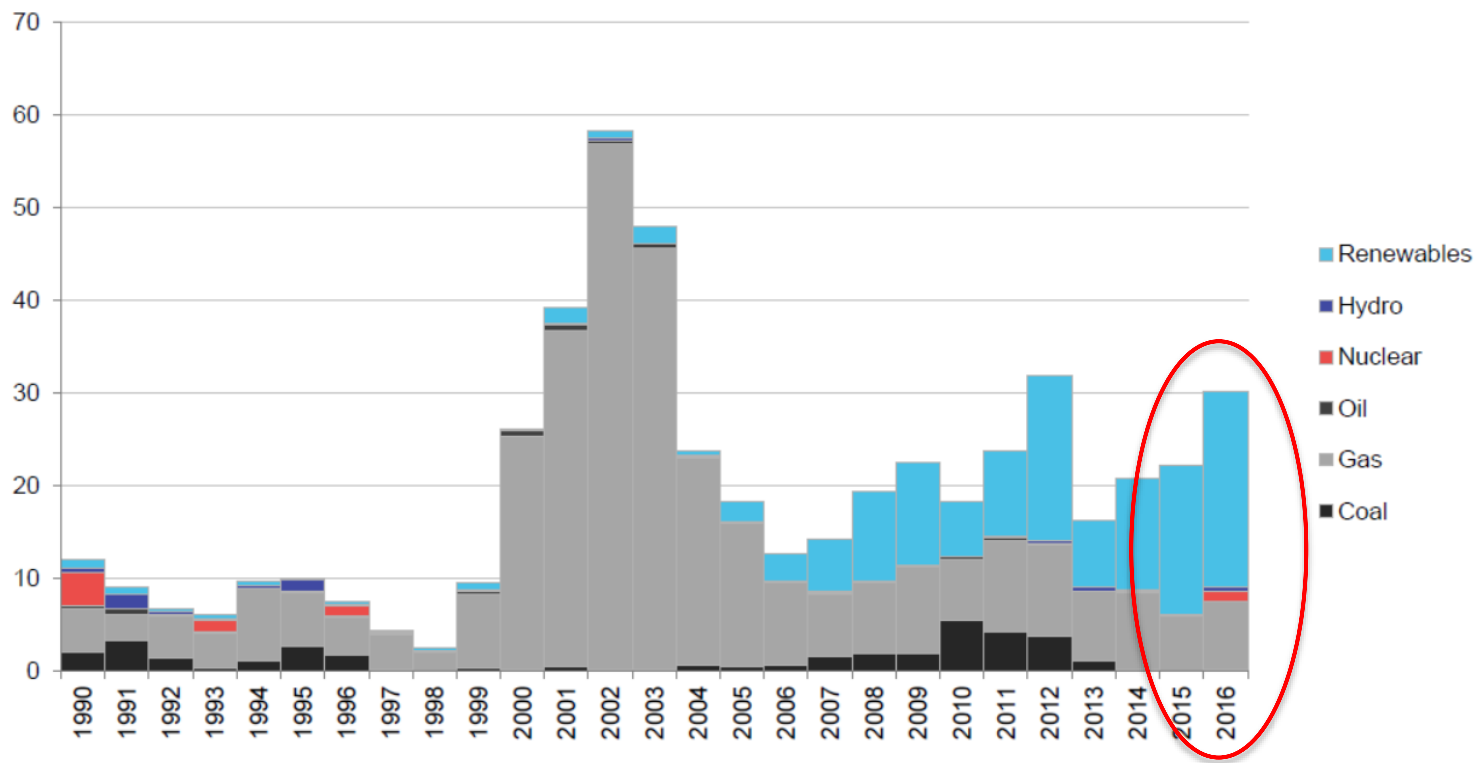
Summer Peak Load (Megawatts)				
				ERCOT
Period	MISO	PJM	SPP	TRE
2010	108,346	136,465	53,077	**65,776**
2011	102,819	158,043	55,817	**68,416**
2012	96,769	154,339	50,246	**66,548**
2013	121,124	157,509	47,647	**67,245**



With larger peaks and an aging grid quick responding natural gas generators that can operate on unlimted hours in support of the grid are an important tool for municipalities.

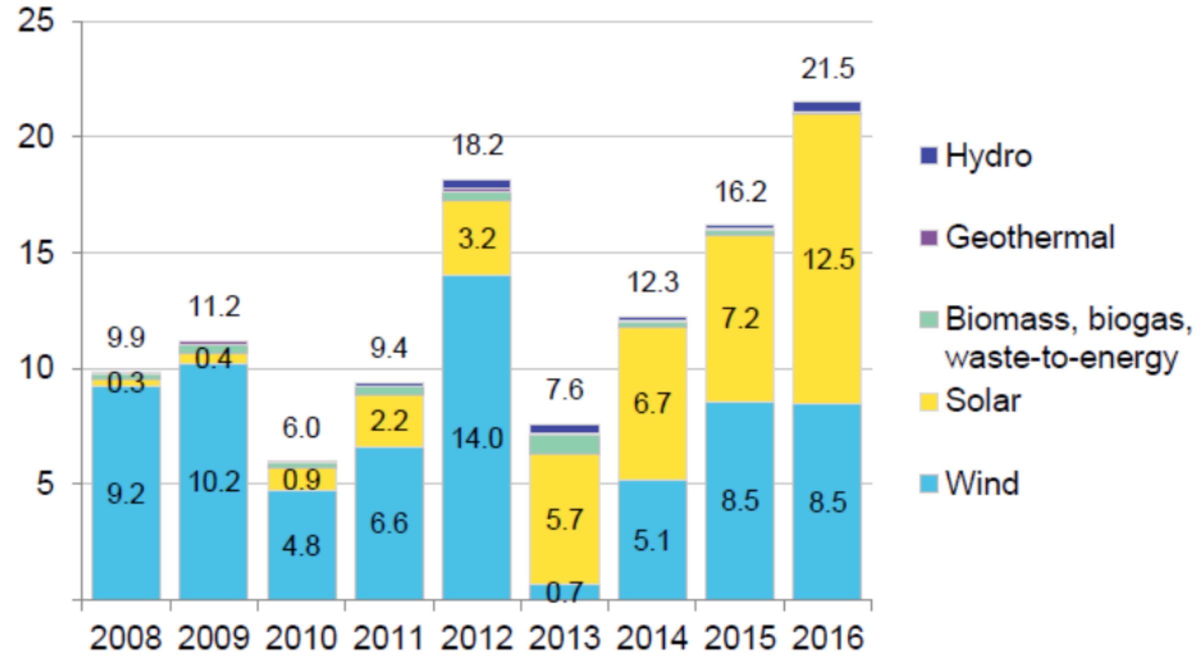
THE CASE FOR MICROGRIDS
DEMAND RESPONSE GRID SUPPORT / MUNICIPAL

Generating Capacity Build by Type (GW)



THE CASE FOR MICROGRIDS
DEMAND RESPONSE GRID SUPPORT / MUNICIPAL

Renewable Capacity Build by Type (GW)



THE CASE FOR MICROGRIDS
DEMAND RESPONSE GRID SUPPORT / MUNICIPAL

Renewables are variable and need to be matched with dispatchable base load assets

Dis-patchable Assets like reciprocating engines.

- Quick starting
- Continuous Run Times (not limited by emissions)
- “Cheap” Fuel
- Ease of installation

Look for the “Duck Curve”

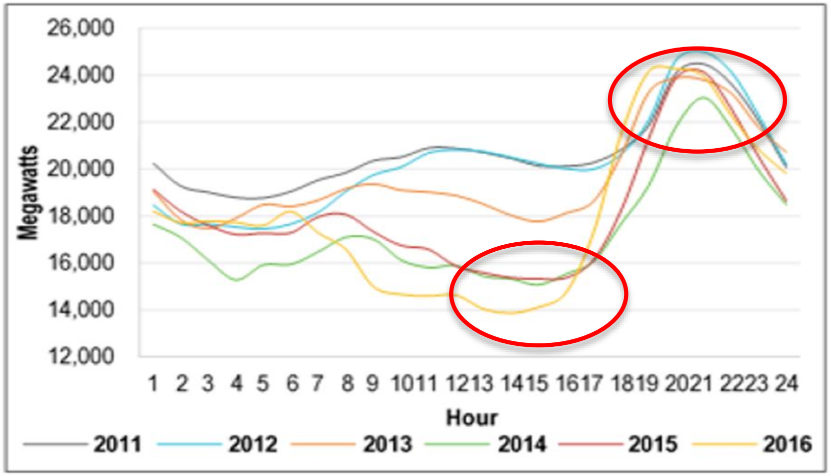
Daytime net load varies greater with more renewable generation asssets

Larger Percentage of Renewables on the Grid

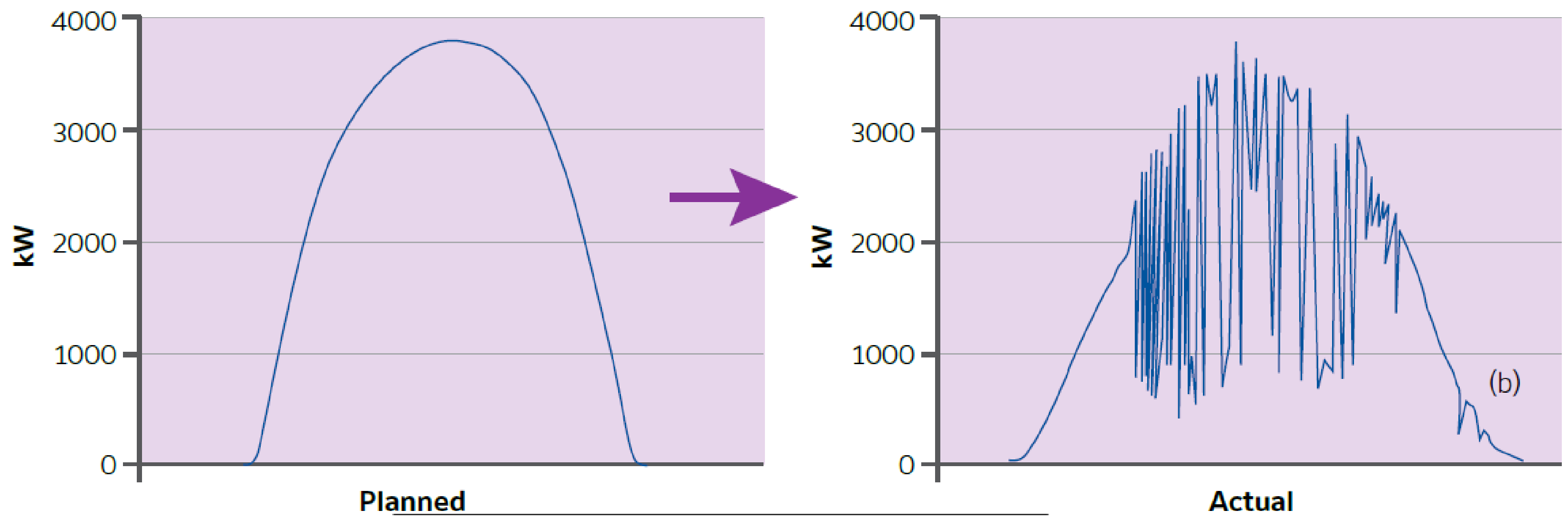
56% of 700GW of Regional Capacity Growth will be through Renewable Generation with a variable capacity factor

Wind and Solar have a capacity factor between 25% and 40%

Figure 2: Lowest March Daytime Net Load, 2011–2016



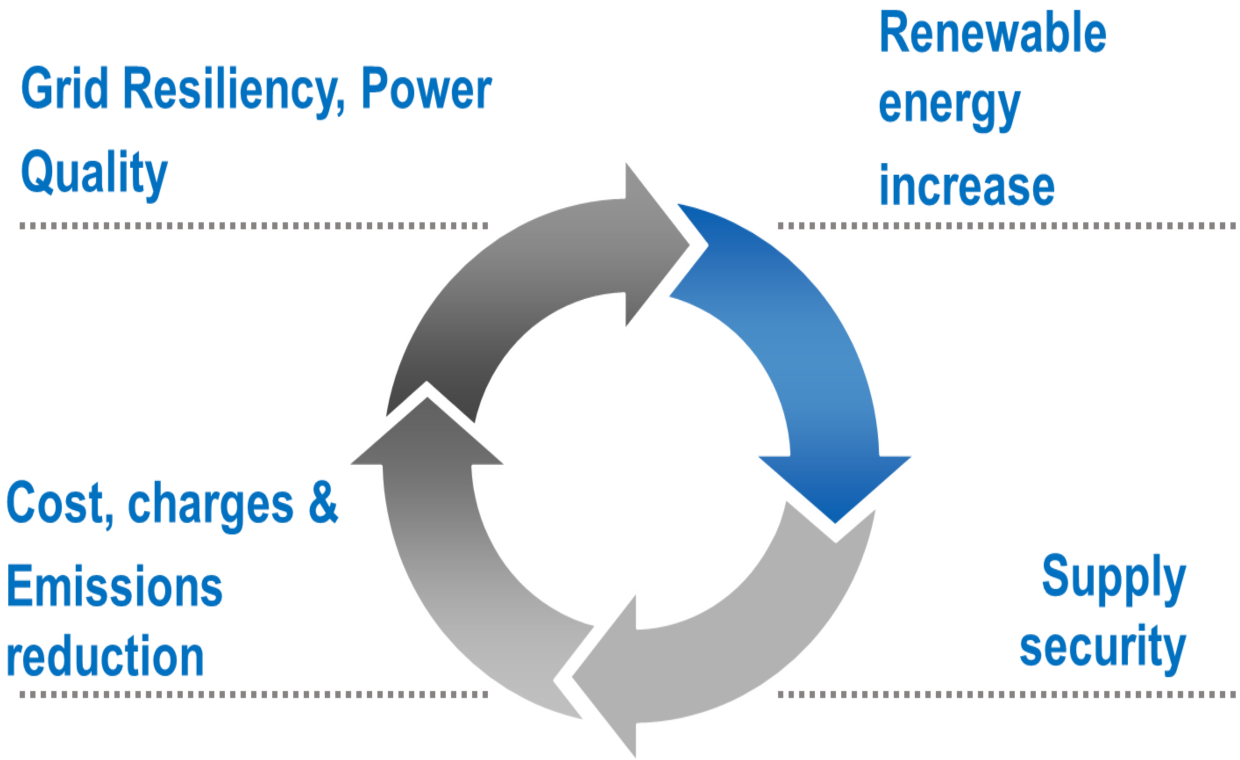
THE CASE FOR MICROGRIDS
DEMAND RESPONSE GRID SUPPORT / MUNICIPAL



The above diagram demonstrated the planned and actual power output from a 4.6MW solar array over a day. The planned smooth ramp up and ramp down are in contrast to the actual output. An area "depending" on this power will need other assets to supply power on short notice repeatedly over an undetermined amount of time.

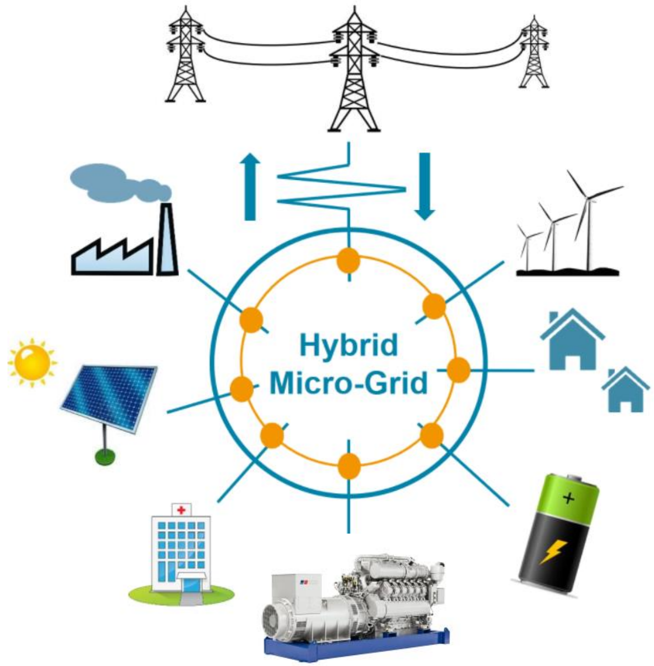
AGENDA

MICROGRID
MARKET DRIVERS



MICROGRID
DEFINITION AND TYPICAL FEATURES

Typical Set-up of a Microgrid



Definition of a Microgrid

- Multiple power generation assets
- Including Renewable generation and/or
- Energy storage
- Local demand centers
- Dynamically controlled
- With or without access to the main grid
- *Every micro-grid is different!*

Typical Applications

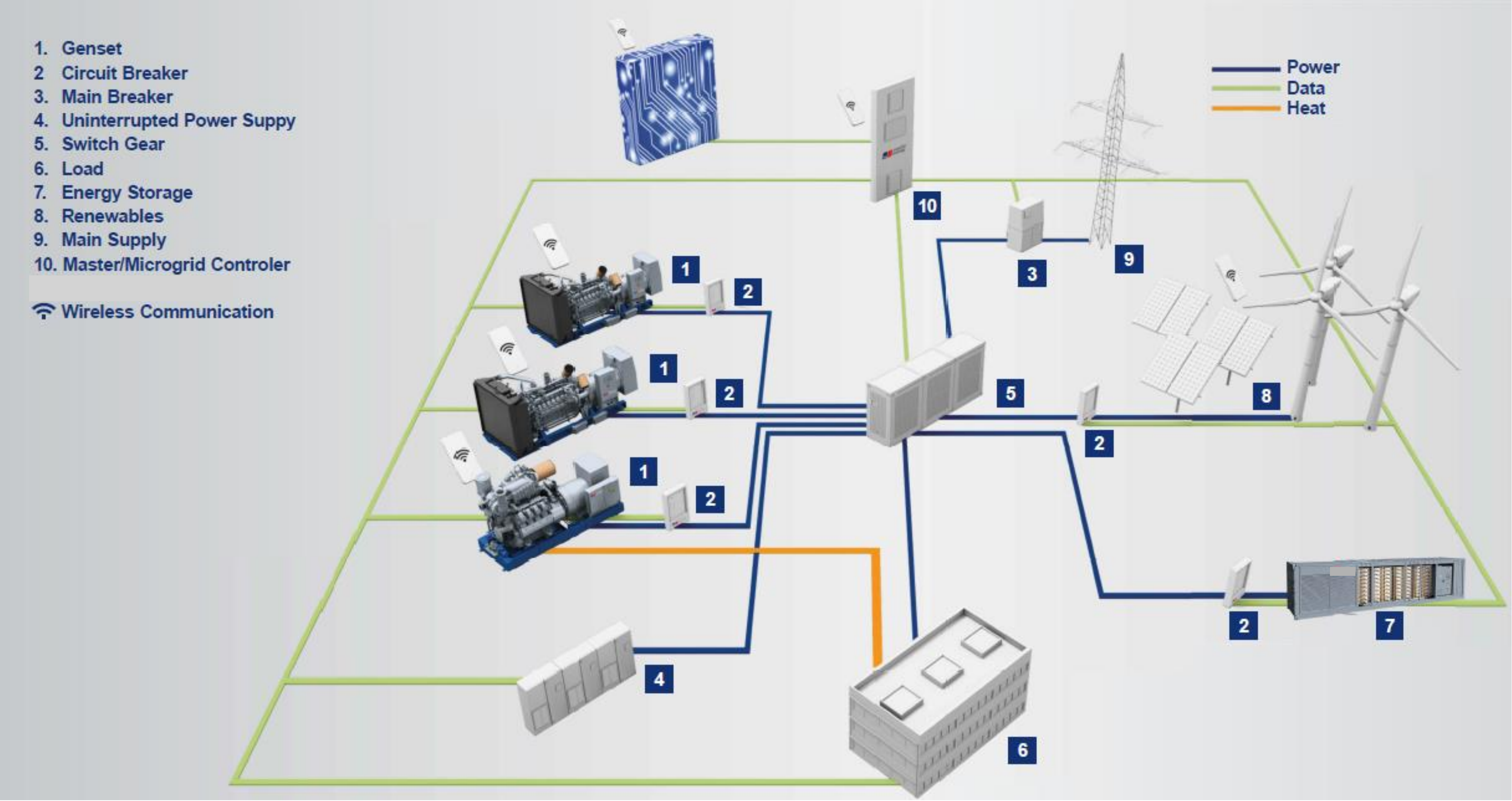
Remote Areas

Utilities/ IPPs

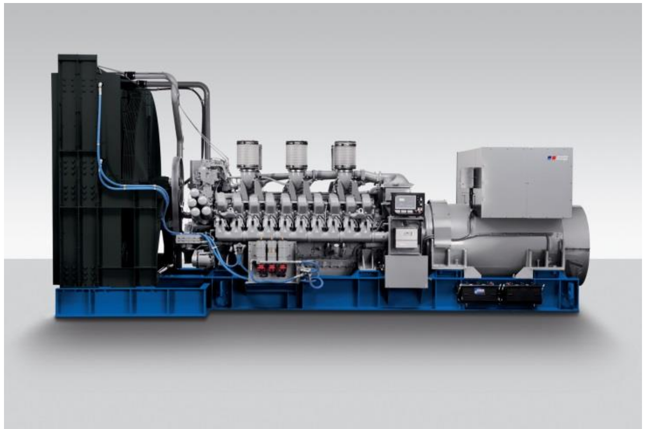
Big Industry

Rural Electrification

MICROGRID
INTEGRATED POWER GENERATION SOLUTION

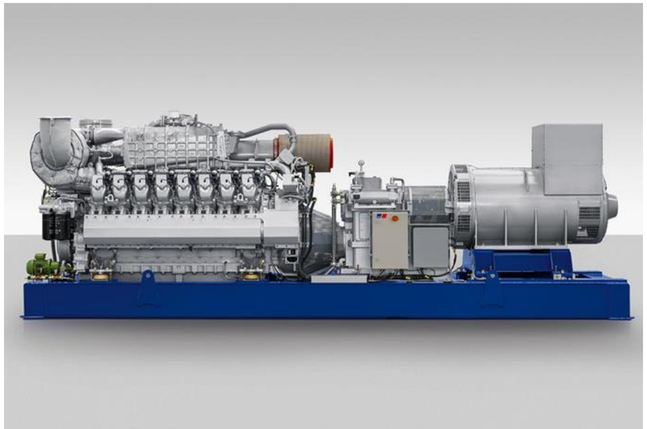


MICROGRID
GENERATOR USAGE



Diesel Generator Sets

+ Fast start-up
+ High load acceptance
+ Very good transient response
+ Low-load operation of ~20% possible
+/- Fuel storage
- Higher emissions, require after treatment
- Higher Fuel Cost



Gas Generator Sets & CHP

+ High fuel efficiency
+ CHP option
+ Low fuel cost
+ Low emissions
+/- Part load operation ~35% possible
- Slower start-up and limited transient response
- Costly fuel storage (if needed)

MICROGRID
CONTROL SYSTEMS

Genset Master Controller

- Complete island mode and grid failure control logic of multi-unit power plants
- Black start with fast paralleling of multiple gensets
- Scalable architecture for small, medium and complex solutions
- Control of all gensets, breakers with trends analysis and display of relevant values and Remote Systems
- Efficient Power Management with i.e. load sharing and load demand swap, power export control, advanced load shedding, standard utility and industrial interfaces

Microgrid Controller

- Dispatches power generation resources according to priority strategy
  1. Renewables
  2. Batteries
  3. Generator Sets (Gas/Diesel)

AGENDA

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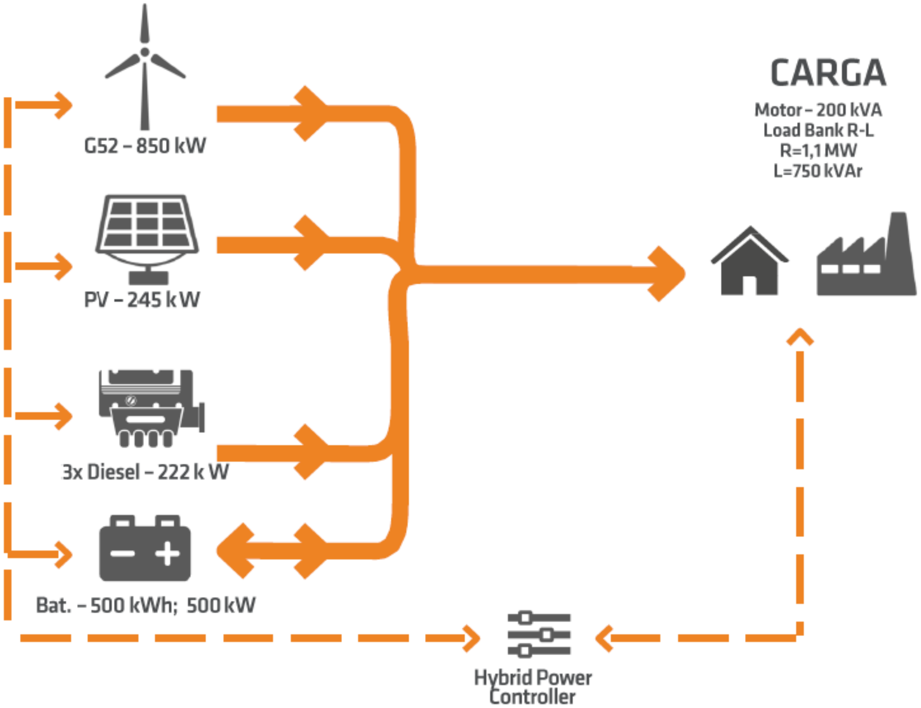
MICROGRID CASE STUDIES
RENEWABLE ENERGY MICROGRID



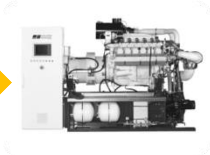
- Located near Zaragoza, Spain
- Launched in May 2016
- Serving for development and testing of Microgrid solution
- 3x MTU S1600 gensets

MICROGRID CASE STUDIES
RENEWABLE ENERGY MICROGRID

Features

- Maximize usage of wind and solar generation
- Excess power is used to charge the batteries
- Batteries provide power when there is not enough renewable power generation
- Only when renewables and batteries cannot cover the demand, gensets will be used in the power generation mix
- Microgrid controller manages optimized dispatch of batteries and gensets
- Adaptive load bank to simulate resistive and inductive load profiles

MICROGRID CASE STUDIES
OFFICE BUILDING MICROGRID



248kW CHP

765kW Solar

400kW Gas Genset

900kW Diesel Genset

MTU 248kW CHP

MICROGRID CASE STUDIES
OFFICE BUILDING MICROGRID

Features

- Maximize usage of solar generation
- 248kW CHP base loads, but will reduce output if solar generation + CHP generation higher than building demand to give solar priority
- CHP thermal usage for building heating and cooling (chillers)
- Gas Genset (non-CHP) for peak loads
- Diesel Genset for Backup power
- Electric vehicle (EV) charging stations
- Microgrid controller manages optimized dispatch of generation resources

MICROGRID CASE STUDIES
DEMAND RESPONSE / CHP FOR INDUSTRIAL PLANT

Midwestern bottling plant with high thermal and electrical usage with six days a week and three shifts operations.

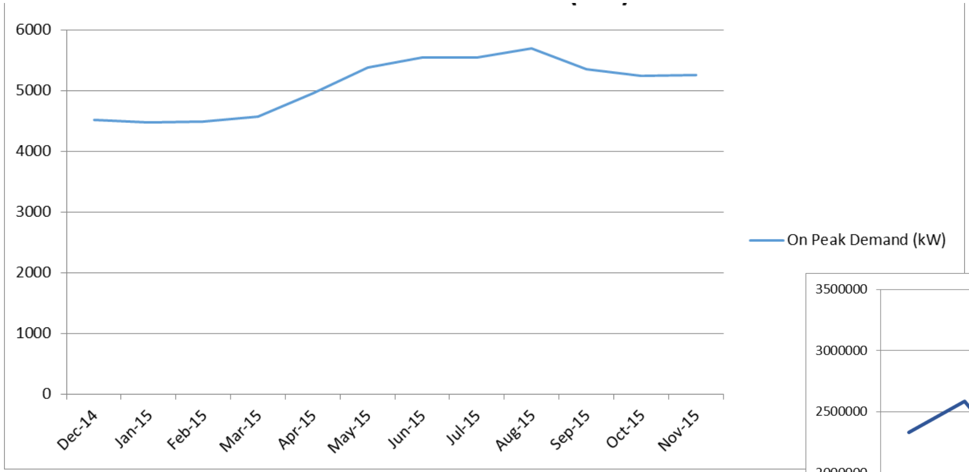
Good potential fit for distributed generation projects.

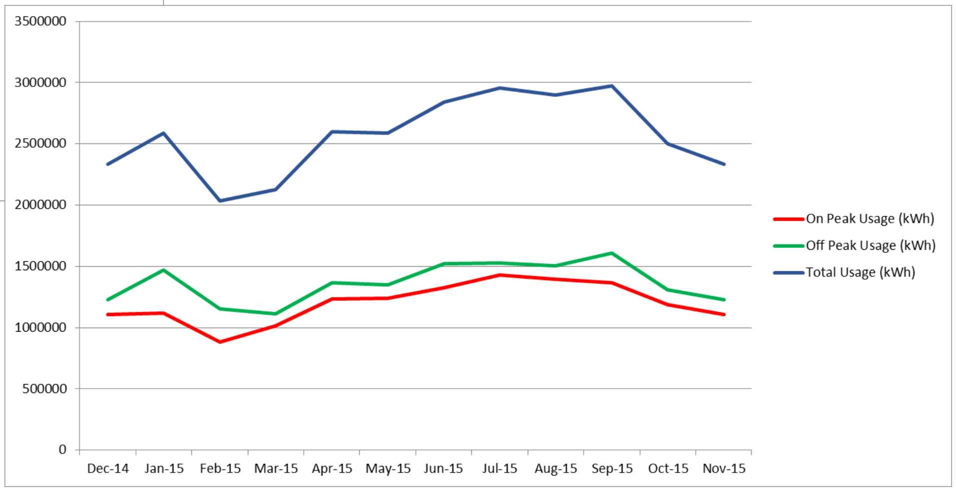
Look at an option for a 1MW natural gas generator to manage peak loads or an option for base load 3.5MW CHP project with heat recovery for steam to be used at the facility.

MICROGRID CASE STUDIES
DEMAND RESPONSE / CHP FOR INDUSTRIAL PLANT

Demand response was initially designed to help utilities and grid operators lower the cost of meeting

large peaks in demands that usually occurred in summer months where peak usage by customers occurred on the hottest summer day.

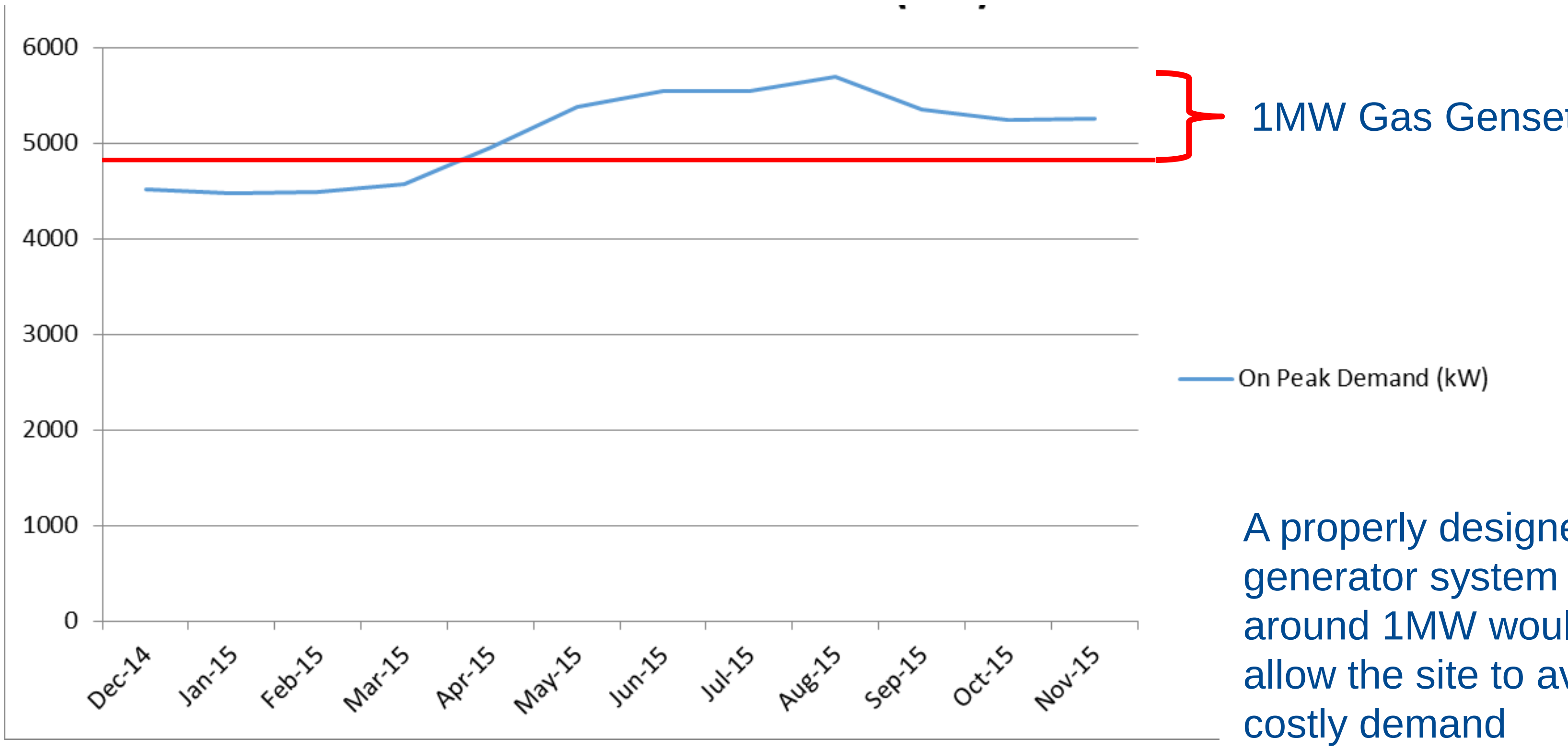




Midwestern industrial facility with peak electrical usage all falling into the summer months of June, July and August. With peak demand at just under 6MW.

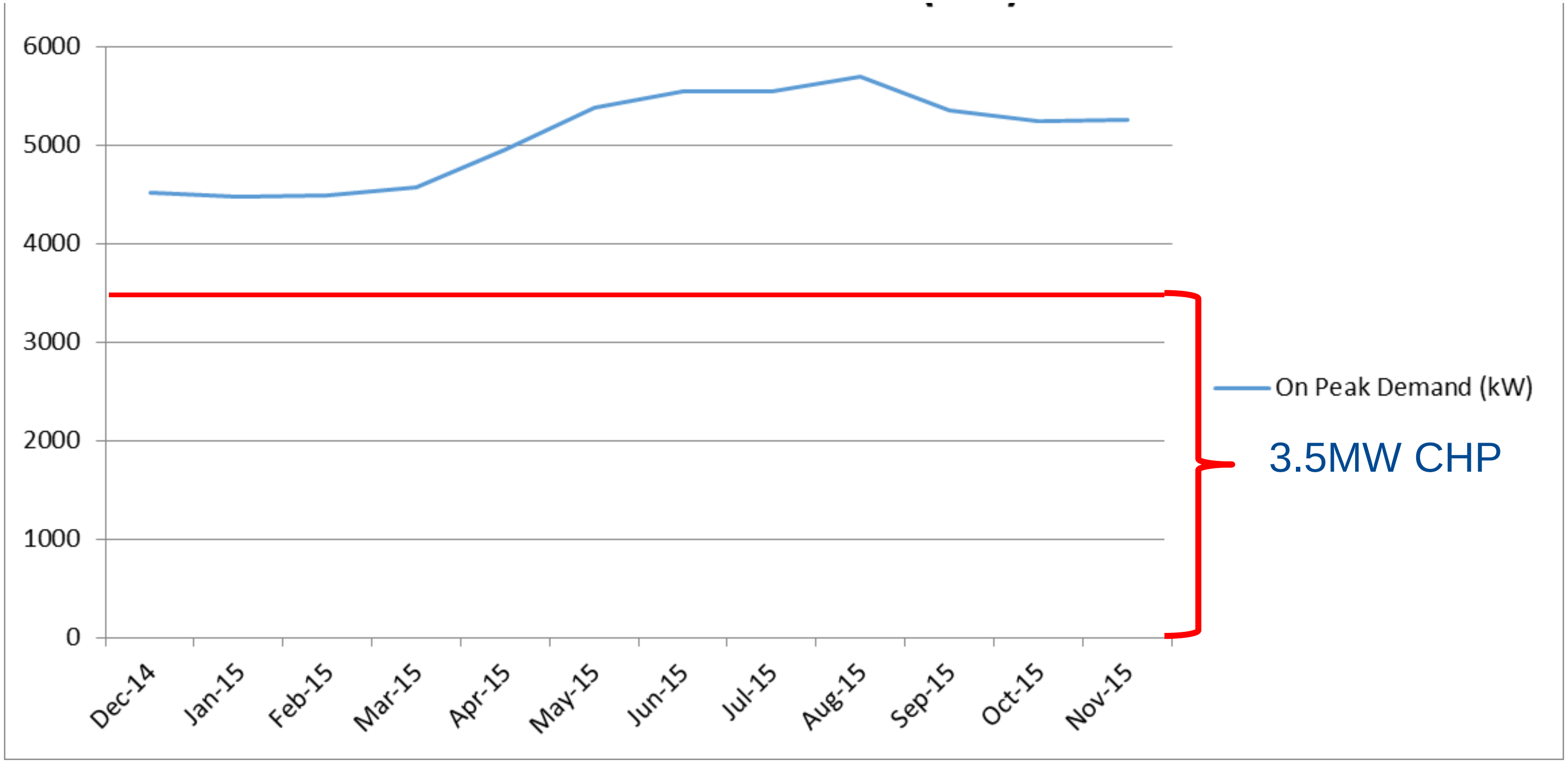
MICROGRID CASE STUDIES

DEMAND RESPONSE / CHP FOR INDUSTRIAL PLANT



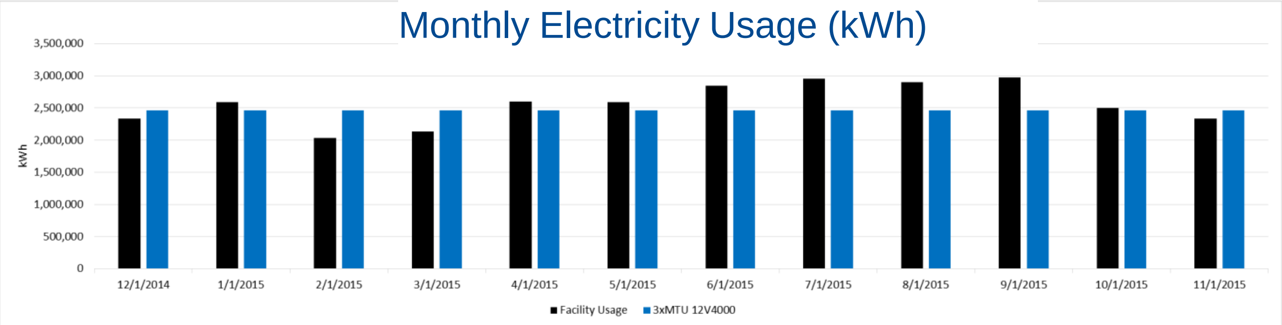
A properly designed generator system of around 1MW would allow the site to avoid costly demand charges from the utility during peak summer usage.

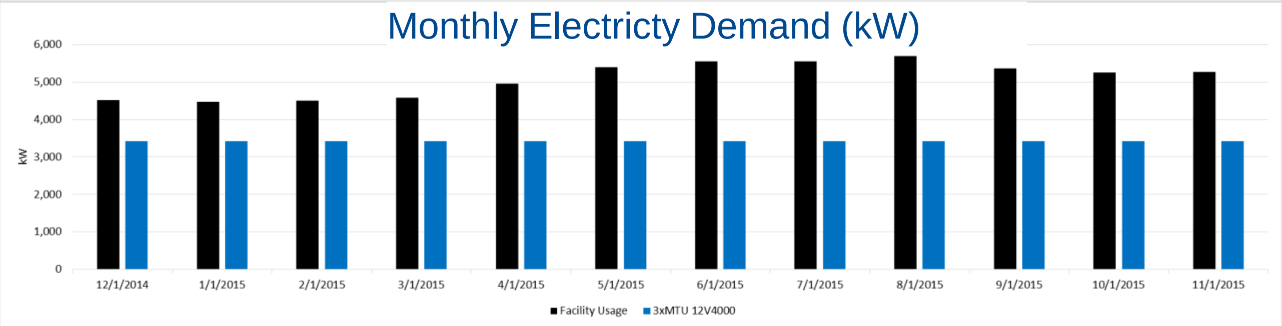
MICROGRID CASE STUDIES
DEMAND RESPONSE / CHP FOR INDUSTRIAL PLANT

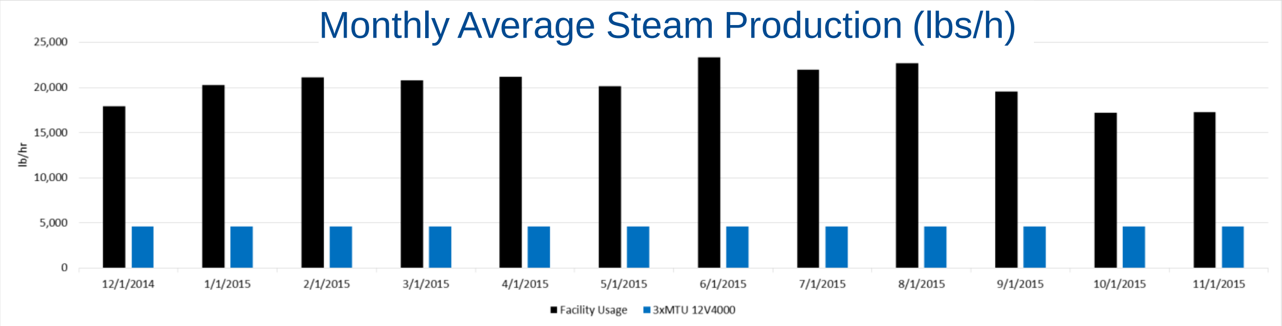


With an electricity rate of approx. $0.10 kWh and a gas price of $4MMBTU a 3.5MW CHP plant would have an ROI between 5 and 7 years.

MICROGRID CASE STUDIES
DEMAND RESPONSE / CHP FOR INDUSTRIAL PLANT







3.5MW CHP system designed for continuous electrical and steam production would reduce electricity purchases by 28M kWh annually for a facility that totaled 31M kWh in 2015.

Steam production by CHP reduces boiler usage by 20%

Thank you for your attention!

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