Cogeneration + Microgrid + Anaerobic Digestion
=
Efficiency + Reliability + Sustainability

Presentation to NJWEA Annual Conference

Bally's Atlantic City

Shoreline Energy Advisors, LLC

May 9, 2017

Key Definitions and Concepts

- Energy
- Measuring Energy – BTU's
- First Law of Thermodynamics
- Energy Conversion
- Useful Energy
- Waste Energy
- Energy Efficiency
- Electricity Flow through a Conductor

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What is Energy?

- Energy is a property or characteristic (or trait or aspect?) of matter that makes things happen, or, in the case of stored or potential energy, has the "potential" to make things happen.
- By "happen", we mean to make things move or change condition- Examples of changes in condition are:
  - Changes in shape, volume, and chemical composition (results of a chemical reaction)
  - Changes in pressure, temperature, and density, called a "change of state" in thermodynamics
  - Phase changes, such as changing from solid to liquid, or liquid to vapor, or back the other way, are also examples of condition changes

How is Energy Measured?

- Today, in international circles, Joule is the “official” measure of energy but here in the U.S. we may be more familiar with **British Thermal Units or, BTU’s for short.**
- 1055 Joules = 1 BTU
- One BTU is the amount of energy required to change the temperature of one pound of water (up or down), one degree Fahrenheit

In dealing with Natural Gas, you may hear the following metrics:

- One cubic foot of pipeline quality natural gas is usually assumed to have 1,000 BTU's (actual measure is closer to 1026 BTU's)
- A therm of natural gas = 100,000 BTU's
- A CCF of gas is 100 cubic feet of pipeline quality natural gas (or approximately 100,000 BTU's)
- A dekatherm of natural gas = 1,000,000 BTU's and is often abbreviated MMBTU
- Not all cubic feet of natural gas (methane) are the same when it comes to energy content:
  - Landfill gas has less BTU's per cubic foot than natural gas from a pipeline (more like 500 BTU/cubic foot)
  - Digester gas has 600 BTU/cubic foot (it can vary)

First Law of Thermodynamics

- *"Energy is neither created or destroyed, it can only change in form"*

- One might ask: "How can that be, when I burn oil in my boiler, sooner or later I run out of oil"

- The answer is that it wasn't destroyed, or used up, it just changed in form, which brings us to our next concept:

  – ***Energy Conversion***

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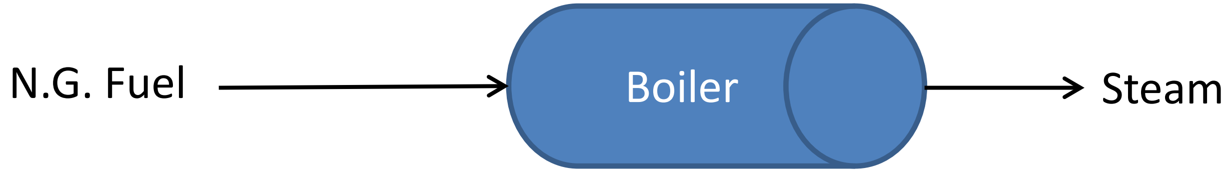
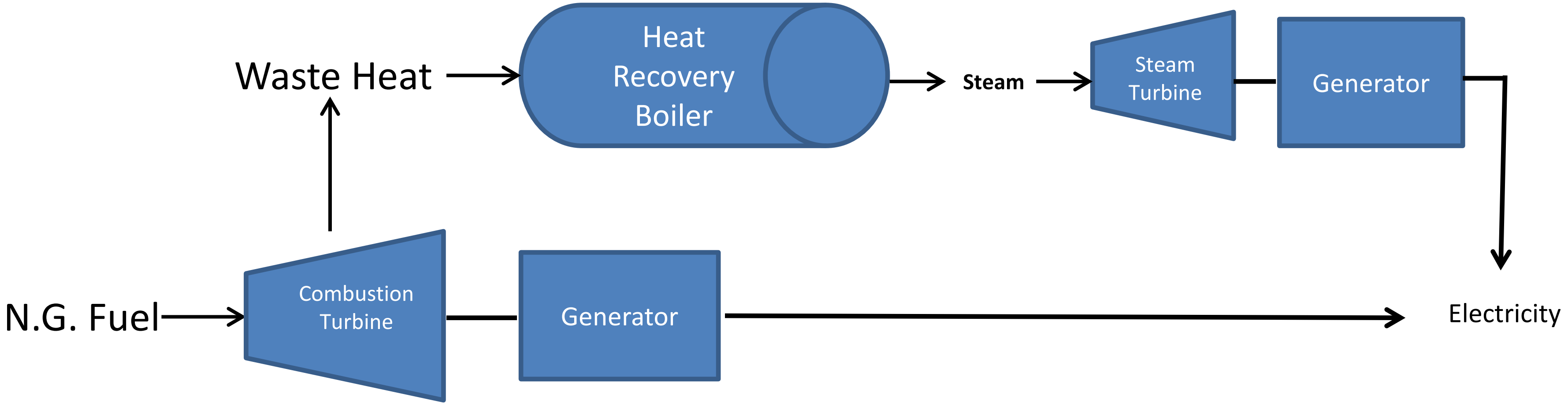
Energy Conversion - refers to a change in energy from one form to another by means of natural or induced processes

1. Traditional Boiler (***Gas converted to Steam***):



2. Natural Gas Combined Cycle Power Generation ***(Gas converted to Electricity):***



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Useful Energy versus Waste Energy

- When Energy is converted from one form to another by means of a conversion process (boil, burn, freeze, light, sound, mechanical work, etc.) some of the converted energy is useful and some of it is wasteful
  - Useful energy is "post-conversion" energy in the form that was the desired objective of the conversion process (eg: hot water from a boiler)
  - Waste energy is "post-conversion" energy in the form that was not the desired objective of the conversion process (eg: waste heat up the boiler stack)
- Energy Output from a conversion activity =

  Useful Energy + Waste Energy =

  Energy Input to a conversion activity

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Energy Efficiency

$$\frac{\text{Useful Energy out of a Conversion Process}}{\text{Energy into a Conversion Process}} = \text{Energy Efficiency}$$

Example:

$$\frac{\text{80,000 BTU's of Hot Water out of a Boiler}}{\text{100,000 BTU's of Natural Gas fuel into a Boiler}} = \text{80\% Energy Efficiency}$$

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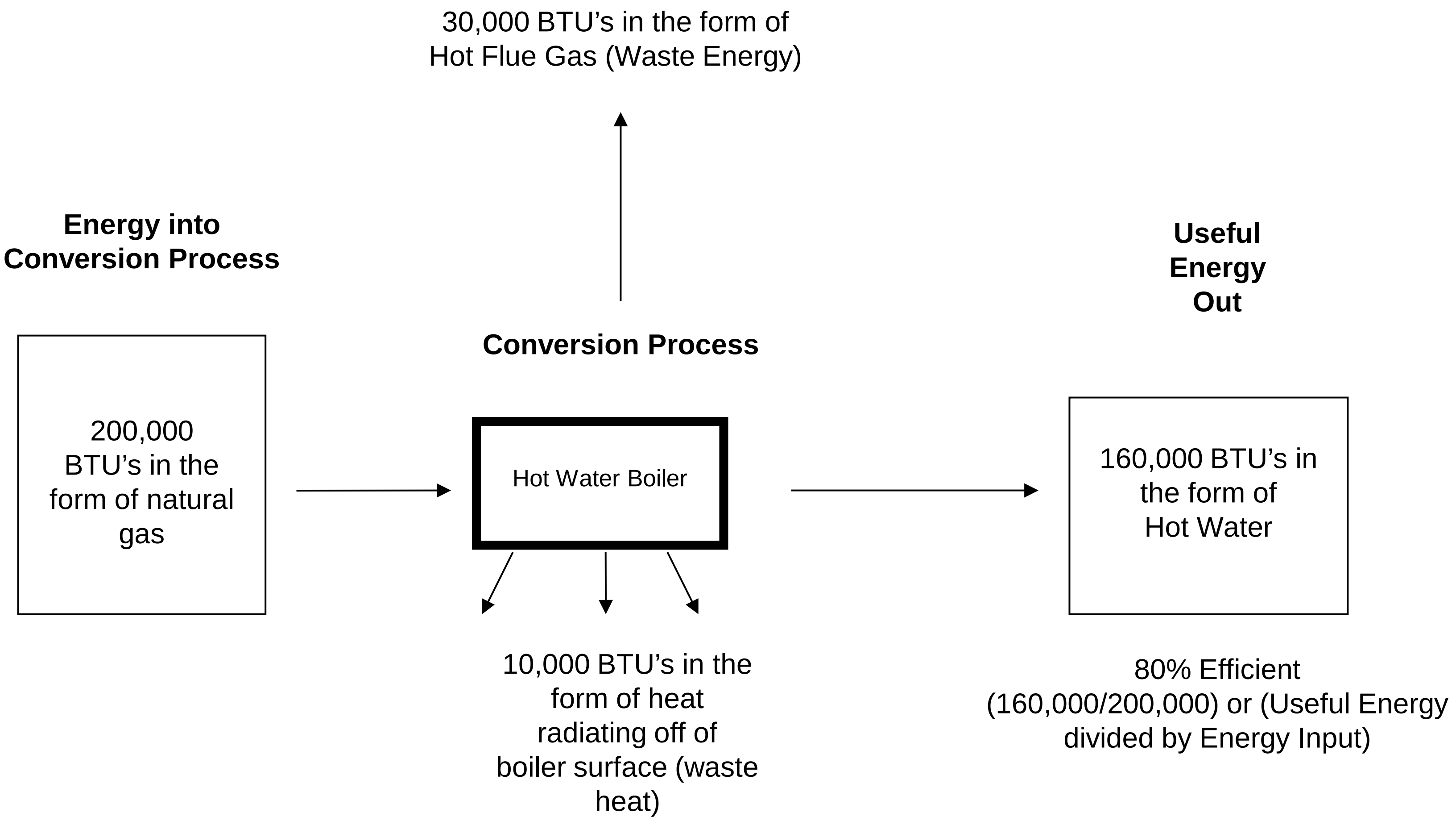
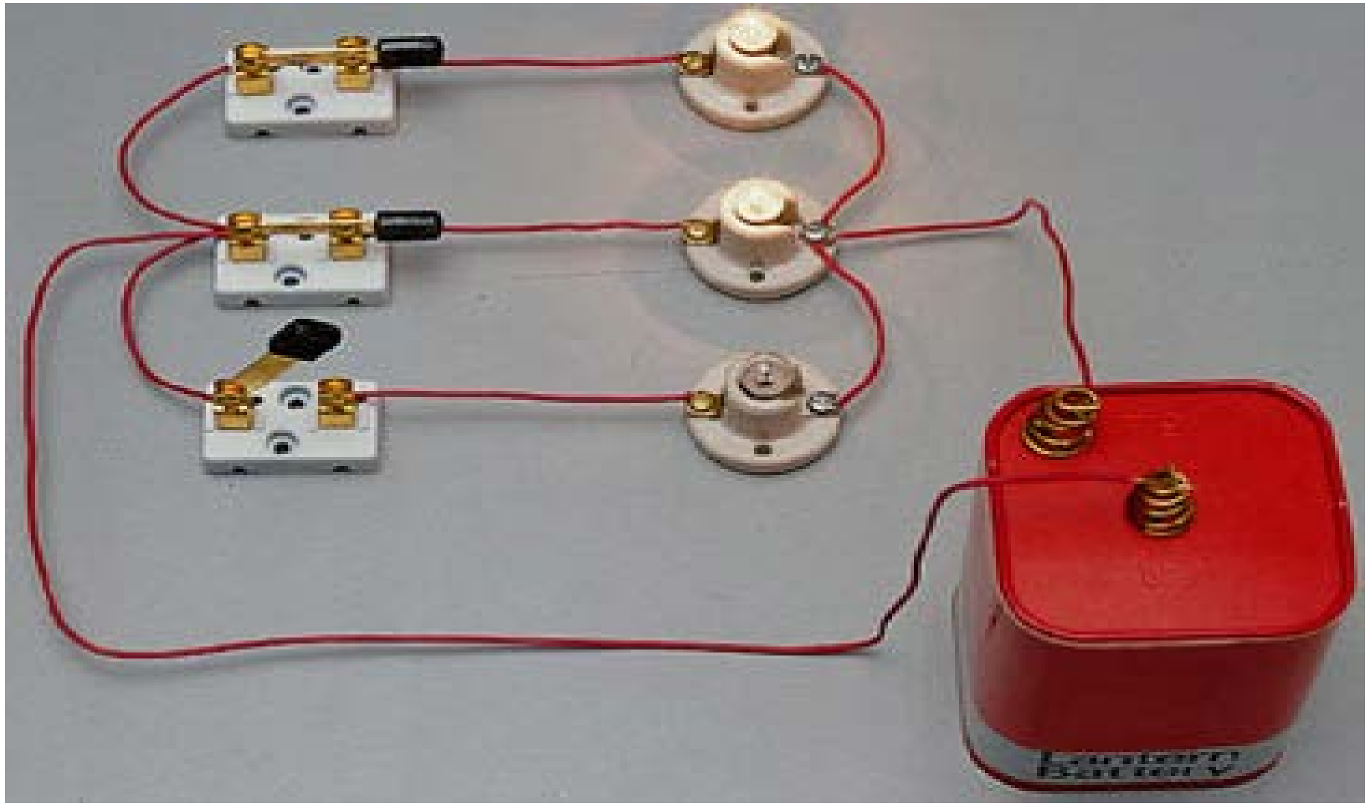
Energy Conversion in a Hot Water Boiler and a Simple Energy Balance



Electricity flows on a Conductor (e.g. wire)

- A stream of moving electrons is called an electrical current and they take the path of least resistance, flowing from areas of higher charge to an areas of lower charge
- A good analogy is water flowing in a pipe
  - Water pressure moves water from an area of high concentration to an area of lower concentration
  - Electrical Voltage is analogous to Water Pressure
- As with water whose flow can be turned on and turned off with valves, electrical current can flow or be interrupted through the use of switches which open or close the path of electrical flow

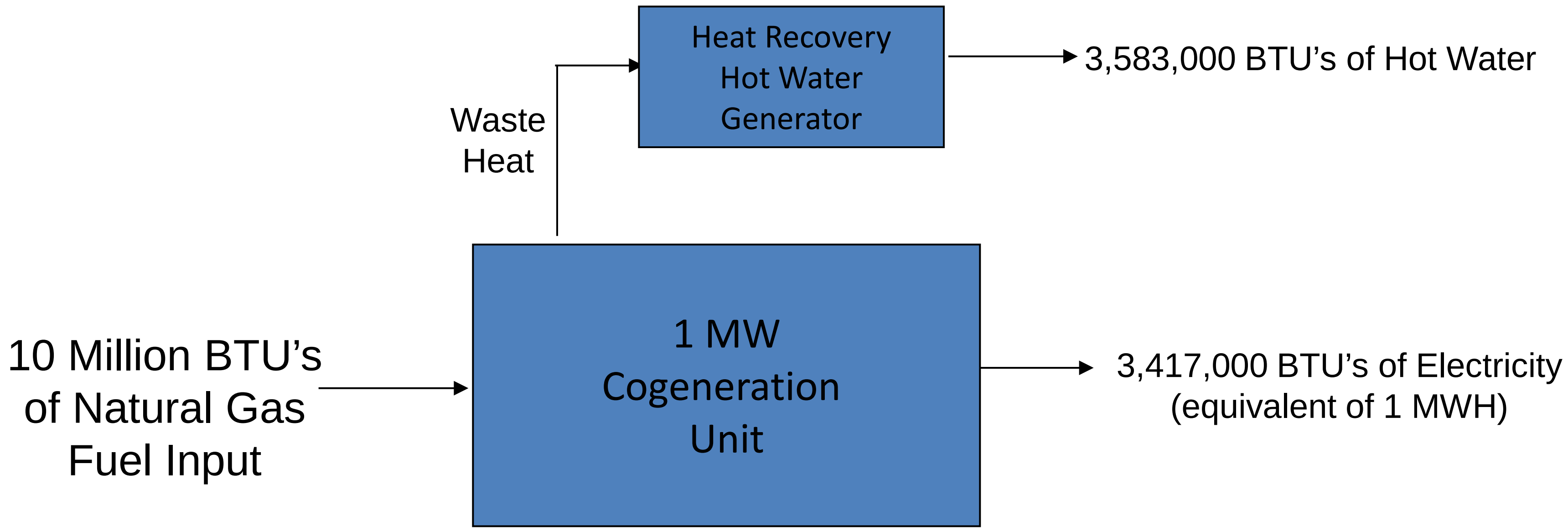
Electricity Flows and is Converted to Light but Flow is Controlled with Switches



Cogeneration
A High Potential Conservation Option

- Cogeneration is the simultaneous production of two or more forms of useful energy from one fuel source
- Example:
  - Burn natural gas (one fuel source) in a reciprocating engine to turn a shaft connected to a generator to produce electricity (useful energy form #1)
  - Waste heat from combustion of gas is routed to a heat recovery hot water or steam generator and is used to make hot water or steam (useful energy form #2)
  - Coupled with an absorption chiller, the waste heat from the combustion of fuel can also feed the absorption chiller to make chilled water
- Benefits of cogeneration:
  - You get steam or hot water without having to burn additional gas or fuel oil in a conventional boiler, and;
  - You get chilled water without feeding electricity to an electric chiller
- Conversion efficiency of energy input is much higher since you are getting multiple forms of useful energy from one fuel source

The Cogeneration Option-One Hour of Operation (this example assumes 70% efficiency)



3,583,000 BTU's of Hot Water
<u>Plus: 3,417,000 BTU's of Electricity</u>
7,000,000 BTU's of Useful Energy Produced
<u>Divided by: 10,000,000 BTU's of Energy Input</u>
= 70% Efficiency

What is a Micro Grid?

Microgrid Definition

- A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in grid-connected or island-mode.

Key Attributes

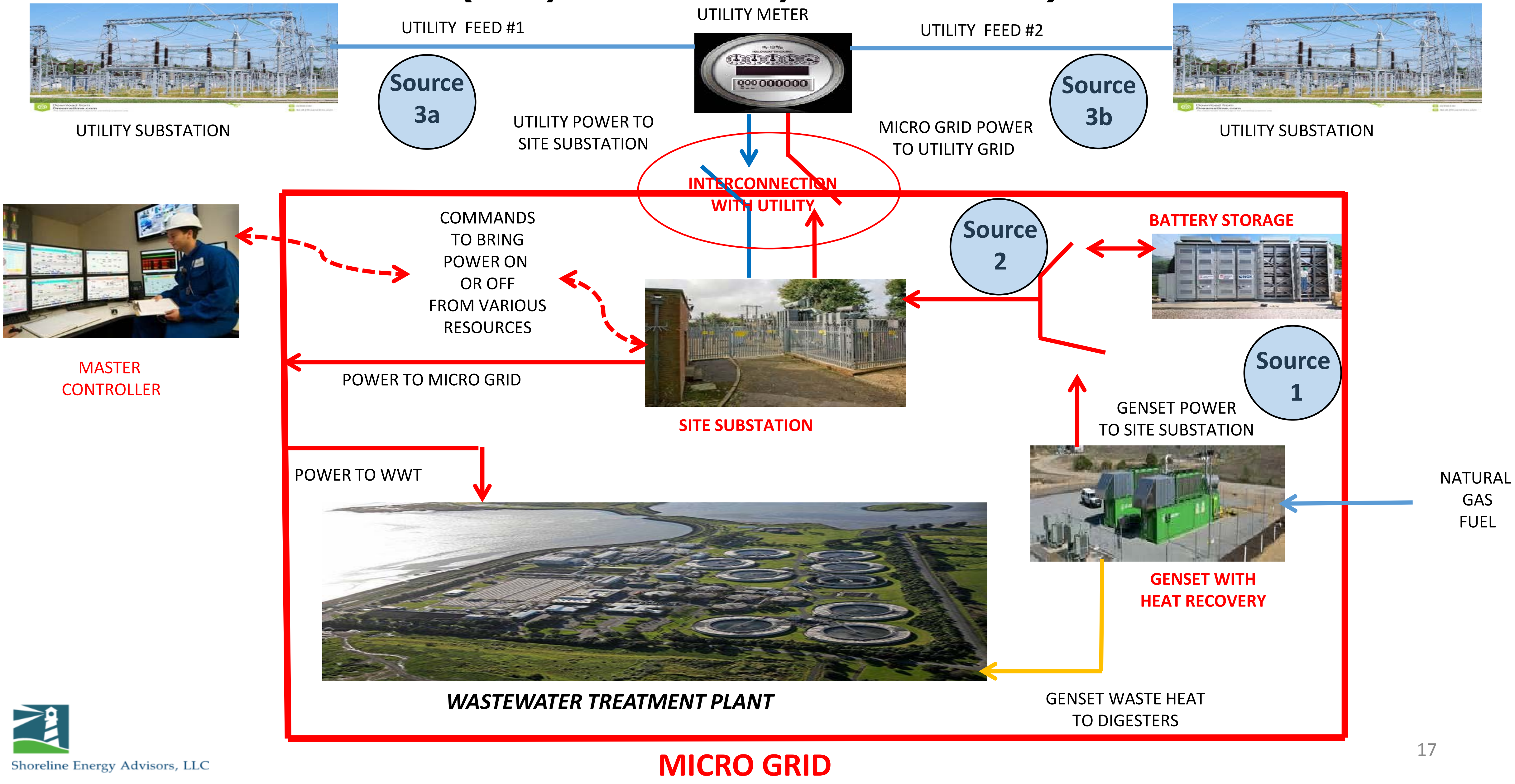
- Grouping interconnected loads and distributed energy resources
- Can operate in island mode or grid-connected
- Can connect and disconnect from the grid
- Acts as a single controllable entity to the grid

Source: US DOE, OE

Some More Definitions…

- Nano Grid - One building or facility:
  - A generator and distribution system that service only one building or facility, interconnected with and capable of importing or exporting power to or from the larger utility grid
  - Example: A cogeneration system at a sewer treatment plant that can also accept service from the local utility but can disconnect from it too
- Micro Grid- Several buildings or facilities:
  - A group of buildings with their own generation and distribution infrastructure that can connect or disconnect from the local utility grid
  - Example: A City Hall building and a Police Headquarters building that have a generator in the basement of City Hall and wires and circuitry across the street to Police HQ that can operate in sync or isolated from the local utility grid
- Mini Grid- Several Micro Grids:
  - One or more Micro Grids interconnected with each other that have their own generation and distribution infrastructure that can connect or disconnect from each other and from the local utility grid
  - Example: A city has two micro grids, one serving City Hall and Police Headquarters and one serving the local High School and a Hospital. Each micro grid can operate independently or can be interconnected with the other micro grid and / or the local utility grid

Simple Schematic for a Nano Grid
(Only one facility shown here)



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A Micro Grid is a Different Form of Distributed Generation with Unique Objectives from other forms of Self-Generation you may be familiar with

- **Distributed Generation** - Generation of power at or near the point of use, perhaps with several generating units interconnected to each other. May or may not have cogeneration capability. Solar Photovoltaics are an example of Distributed Generation but not cogeneration.
- **Cogeneration Plant** – Central Energy Plant that generates two or more forms of useful energy from the combustion of one fuel source (e.g. electricity and hot water, electricity and steam, etc.)
- **Grid Support Generation Assets** - Sales of ancillary services to Independent System Operators like PJM
    - Frequency regulation
    - Black start
    - Peak Capacity
- **Emergency Generation** – Back up power in the event of a loss of power from the grid during short periods of time (hours or perhaps a few days). Diesel Emergency Generators are very common, often required by code for public buildings or critical facilities and most are familiar with them.
- **Micro Grid** – Power generation and distribution system that services the critical peak load of a specific facility or group of buildings in total, with the capability to isolate and run independent of the grid for extended periods of time (weeks or months)

Characteristics of Different Types of Generation

Form of Generation	Run Characteristics	Project Usually Sized to:	Ability to Isolate from Grid	Economic Drivers
Cogeneration	Base load, round the clock	Thermal Base Load	Sometimes, usually not	Favorable electro/thermal balance, High Utilization, Efficiency, Lower energy costs
Distributed Generation	Base load, round the clock	Electric Base Load	Sometimes, usually not	Reliability, Lower Distribution Costs
Ancillary Services	Peak times or Emergency Situations when the market requires	Dependent upon Service being offered to Independent System Operator	No	Revenue Generation through ability to respond to "Outlier" Events of variable Intensity and duration when the grid needs assistance/support
Back Up Generation	Emergency Situations when needed	Peak Critical Electrical Load	Yes	Safety and Loss of Production Capability
Micro Grid	Base and peak loads, round the clock	Peak Electrical Loads	Yes	Reliability, Availability, High Utilization

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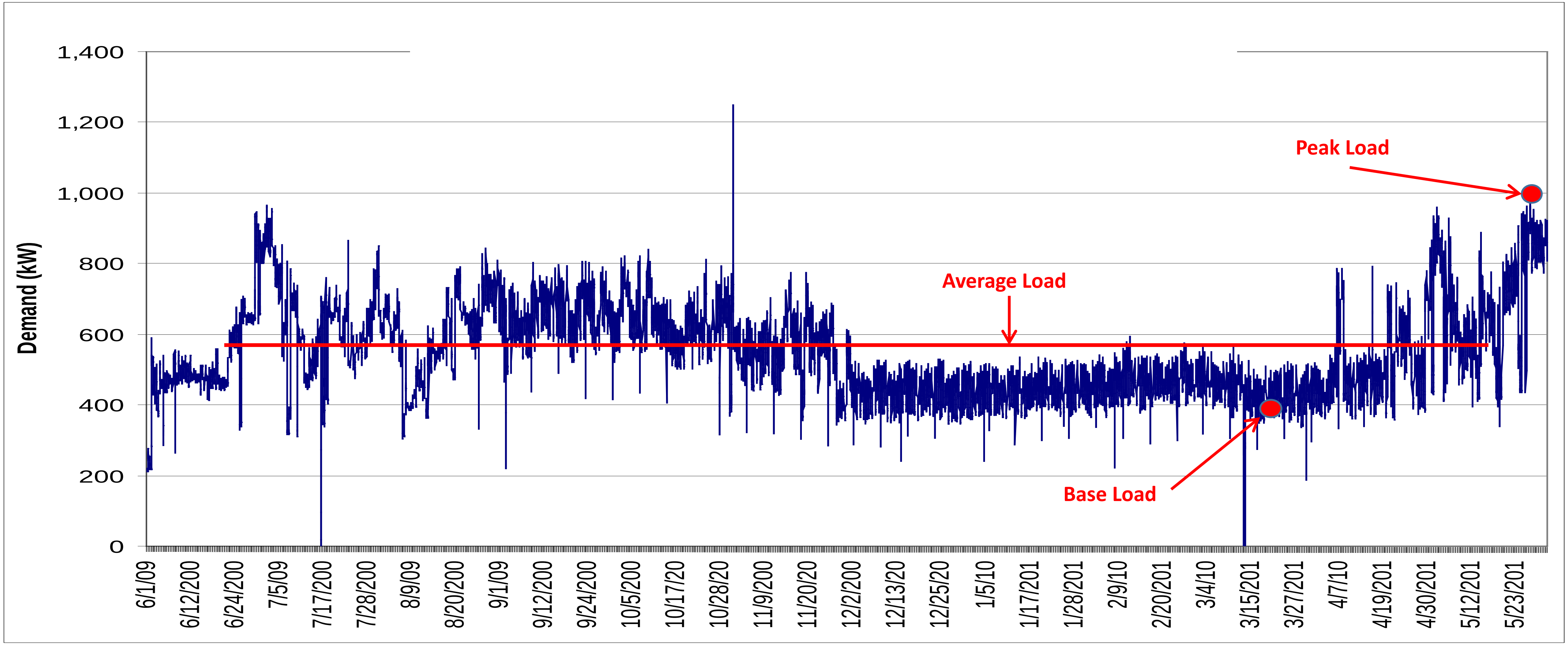
Illustration of Electrical Loads

Demand refers to the Generating Capacity needed to service electrical load in the building



Peak Load = 980 KW
Average Load = 580 KW
Base Load = 400 KW

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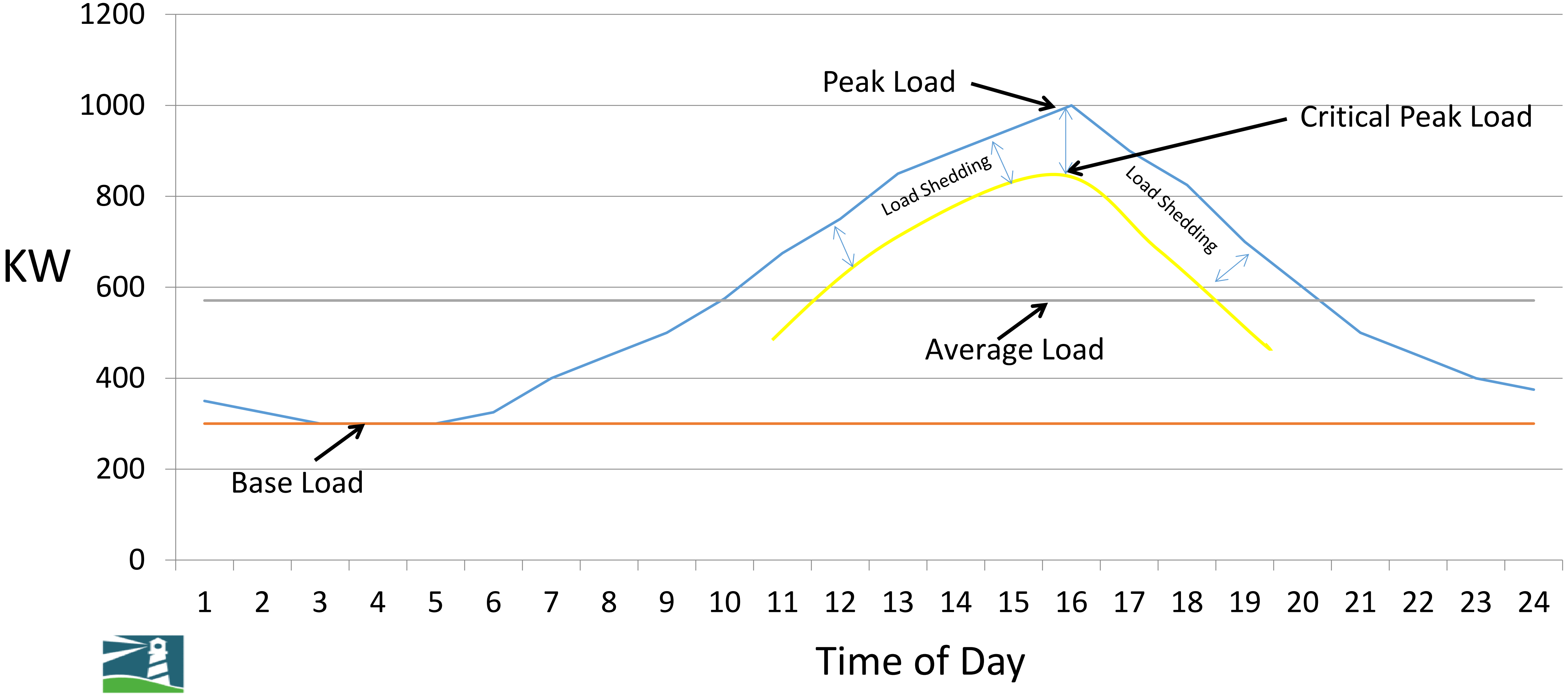
Illustration of Load Curves
KW of Demand by Hour for a Given Day
Critical Peak Load is Peak Load after Shedding Non-Critical Loads



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Micro Grids
Changing Paradigms in the Marketplace

- In the past, micro grid development was driven by the dire economic circumstances certain facilities ("Premium Power" Users) would find themselves in if they had no power (e.g.: Banks, credit card companies and brokerage houses where momentary lapse of power would cost millions in lost revenues)
- Today, micro grid development is increasingly being driven by government sponsored programs to support critical public facilities
  - Generally serve critical facilities dependent on electric power, providing continuous service for extended periods of time (e.g. Hospitals, Emergency Shelters, Public Safety, Transit, Suppliers of Necessities such as Food Stores, Gas Stations, etc.)
  - Programs specify that power must be available at any time of year in quantities sufficient to service the load at that time

Unique Challenges of Micro Grid Initiatives

- Need to provide capacity to service load at any time of year-build to peak (or even n+1) not to base load
- Many “critical” facilities are not typical cogeneration candidates so thermal production from traditional self-generation of power is largely wasted
- Public agencies (where many of these micro grids are being developed) like the “insurance” aspect but don’t want to pay the “premiums”
- Public/Private Partnerships bring another set of challenges when investor’s objectives are considered
- Utilities are being brought along but drag their feet and introduce hurdles whenever they feel their business may be adversely affected (loss of revenue, safety of workers, future threat to their “franchise” and regulated rate of return world, etc.
- Multiple critical parties in the development team all have their own objectives and never correlate with the host site’s need for reasonably priced reliability

NJ BPU's Town Center Micro Grid Pilot Program

- NJ BPU recently submitted proposals from developers, engineers, consultants and government entities for grant money to study the feasibility of developing a micro grid that will serve critical public buildings with electric power, being interconnected with, but capable of isolating from, the local electric grid in the event of an extended power outage
- Program was spurred by recent occurrence of severe outages due to Sandy, early snow storms and similar events that left NJ residents and critical facilities without power for extended periods of time
- Program has a budget of $1 million and it is anticipated that up to 10 grants for individual studies will be awarded with a $200,000 cap on each study
- Applicant must be a public entity (town, county, authority, etc.) but in most instances proposals were developed by third parties for the government entity (consultants/engineers/developers)
- Government Entity has ***no financial responsibility*** or obligation for the development of proposals if a third party is developing it for them and has no obligation to the third party consultants
- Government Entitiy has ***no obligation to follow through*** with the development of a proposed micro grid even if they are selected for an award and a study is completed
- Program is intended to provide BPU with context and background to identify operational, ownership, regulatory and economic issues and to determine if further subsidized investment is merited in order to bring micro grids to fruition
- Not well defined in terms of what they are looking for. Presumably they will select sites based on their projected ability to be built and to be technically and economically viable

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NJ BPU's Office of Clean Energy Microgrid Pilot

- 13 applications received for a portion of $1MM pilot study funding
  - Towns: Montclair, Atlantic City, Paterson, Trenton, Woodbridge, Highland Park, Neptune, Galloway and Hoboken
  - Improvement Authorities: Camden County, Hudson County
  - WWT Authority: Cape May, Middletown?
- Oversubscribed for available $1MM funding, OCED asked for Final and Best Offers
- Decision should be forthcoming in early June
- Selected pilot studies that appear feasible will be eligible for 2nd phase of program which will fund actual development

Micro Grid Program Requirements for Connecticut DEEP Program

- $20MM in grants available for projects which meet certain criteria
- Must serve two or more physically separated critical facilities for all loads (not just those currently served by Emergency Generation)
- Generation can't be more than 25% diesel
- Must operate for a minimum of 7,000 hours annually
- Need to follow critical facility load
- Capacity must exceed island mode peak load by 20%
- Must have black start capability
- Must withstand a Category 1 hurricane
- Must have a 2-4 week fuel supply on hand
- Can't be located in a flood plane

What qualifies as a Critical Facility under current CT DEEP Micro Grid Program?

- Hospital
- Police Station
- Fire Station
- Water treatment plant
- Sewage treatment plant
- Public Shelter
- Correctional facility
- Municipal Center
- Telecommunications equipment
- Gas Station
- Pharmacy
- Grocery Store
- Etc.

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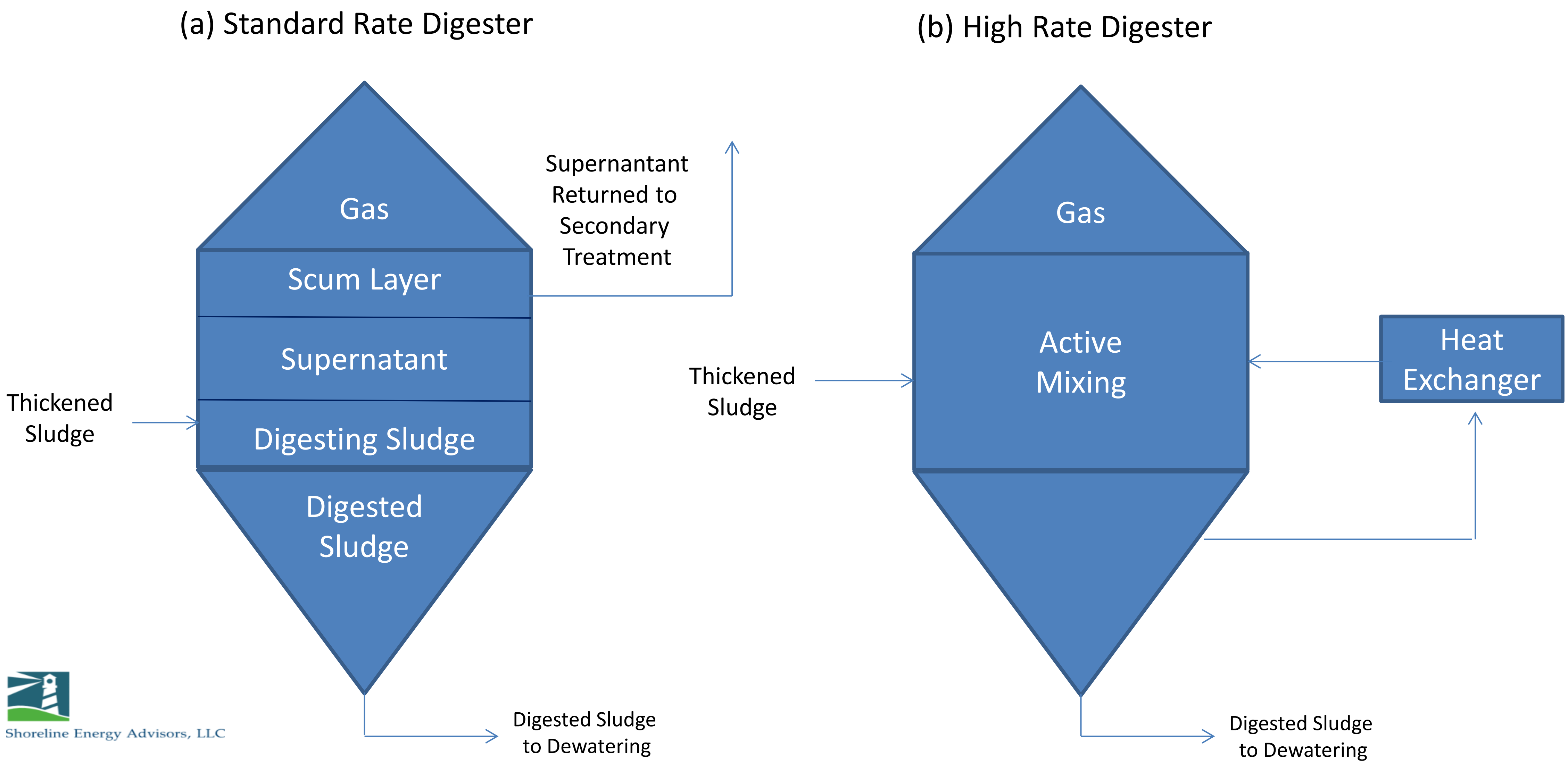
Wastewater Treatment Plants

- **Objective**- Produce an effluent that can be discharged into receiving waterways with no inpact on the environment or human health
- **Treatment** – via a series of opertions in which contaminants are removed using physical, biological and chemical methods
- **By-Product** – Biosolids (sludge)
- **Economics** – Can be improved with different methods of biosolids disposal
- **One Opportunity** – Convert biosolids to energy via Anaerobic Digestion

Anaerobic Sludge Digestion

- Biosolids (primary sludge and waste activated sludge) can be processed in anaerobic digesters where microorganisms stabilize them in the absence of oxygen, reducing the mass, and yielding "biogas"
- Biogas refers to the gas mixture produced by the biological breakdown of organic matter in the absence of oxygen
- Typical digester gas composition is 60% methane and 40% carbon dioxide
- Energy content per cubic foot is approximately 600 BTU's as compared to pipeline natural gas which is approximately 1000 BTU's

Types of Anaerobic Digesters



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A Few NJ "What If's?"

Parameter	Plant A	Plant B	Plant C	Plant D
Design Flow (MGD)	14	12	8.8	8.5
Process	AS	TF	AS	TF
Biosolids (Dry kg/day)	13,919	12.632	9,284	8,948
Biosolids fed to AD @ 5% (GPD)	71,305	64,757	47,488	45,869
Volatile Solids fed to AD (kg/day)	10,432	9,474	6,948	6,711
Number of Digesters	2	2	Existing	Existing
Diameter (feet)	65	65		
Total Volume per Digester (m3)	2,710	2,492		
Active Volume per Digester	2,331	2,115		
Active Volume Ratio	0.86	0.85		
Solid Retention Time (days)	17.3	17.2		
VS Loading	2.24	2.24		
VS destruction (%)	58	58		

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Biogas Production from Digestion of Biosolids and Energy Yield

Parameter	Plant A	Plant B	Plant C	Plant D
Design Flow (MGD)	14	12	8.8	8.5
Biosolids (Dry kg/day)	13,919	12.632	9,284	8,948
Biogas Produced in cubic feet/day (1)	201,662	183,136	134,243	129,663
Biogas Energy Content in MMBTU/year (2)	44,164	40,107	29,399	28,396
Annual Electricity Production per Year in Million of KWH (3)	3.54	3.22	2.36	2.28
Electric Capacity in KW	476	432	317	306
Useful Waste Heat Available in MMBTU/hour (4)	2.02	1.83	1.34	1.30
Heating Requirements (MMBTU/hour)	1.30	1.18	0.88	0.85
Can CHP Useful Waster Heat Supply Process Requirements?	Yes	Yes	Yes	Yes

(1) Using bio-kinetic predictive model
(2) 600 BTU/cubic foot of biogas
(3) 10,600 BTU of fuel per KWH produced (HHV basis)
(4) Useful Heat @ 40% of energy input

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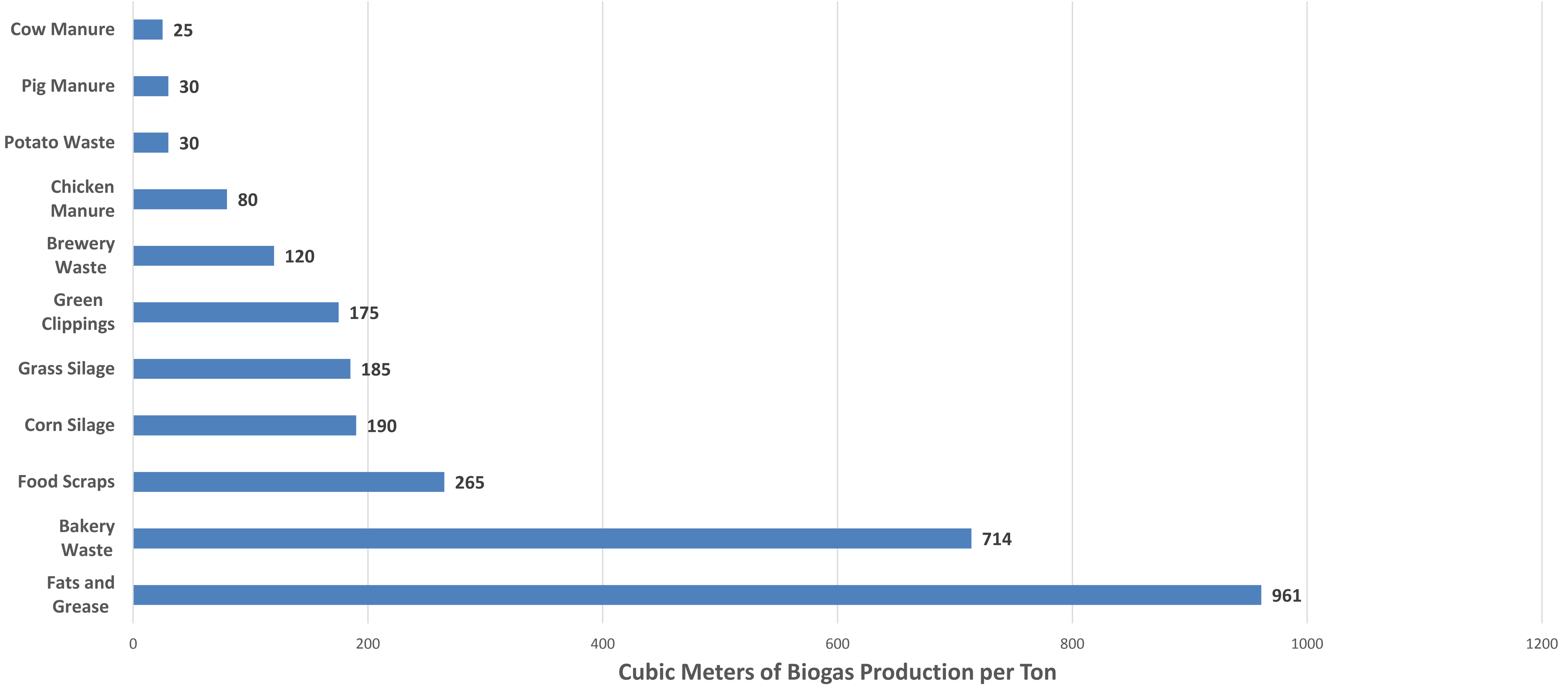
Biogas Yields from Various Organic Materials
Anaerobic Digesters Successfully Treat all these Substances



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Projected Electricity Production with FOG Co-Digestion

	Plant A	Plant B	Plant C	Plant D
Process	AS	TF	AS	TF
Additional Biogas in cubic feet per year	25,584,000	25,584,000	25,584,000	25,584,000
Additional Biogas Energy in MMBTU per year	15,350	15,350	15,350	15,350
Additional Electricity from FOG (MM KWH)	1.23	1.23	1.23	1.23
Electricity from Biosolids (MM KWH)	3.54	3.22	2.36	2.28
Total Electricity Produced (MMKWH)	4.77	4.45	3.59	3.51
Total Electric Capacity (KW)	0.64	0.60	0.48	0.47
Electric Capacity Increase with FOG (KW)	34.8%	38.3%	52.2%	54.1%

Assumes two (2) deliveries per weekday from a 6,000 delivery truck
(10 truckloads per week or 60,000 gallons of FOG per week)

Estimated Capital Expenditures to Add or Expand Digester and CHP Plant

	Plant A	Plant B	Plant C	Plant D
CHP Plant Size (KW)	750	700	500	500
Est Cost of CHP Plant (1)	$3,000,000	$2,800,000	$2,000,000	$2,000,000
Est Cost of Anaerobic Digester Plant (2)	$7,000,000	$7,000,000	$150,000	$150,000
Capital before Incentives	$10,000,000	$9,800,000	$2,150,000	$2,150,000
Less: Estimated Incentive	$1,200,000	$1,120,000	$800,000	$800,000
Net Capital Expenditure	$8,800,000	$8,680,000	$1,350,000	$1,350,000

(1) Assumes $4,000 per KW of capacity installed
(2) Based on Engineering Economics six-tenth power law

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Cogeneration and Anaerobic Digestion Projects Assumptions in Financial Analysis

- Cash flow projections based on current wastewater flow rates
- Electricity rate of $0.10 per kwh being saved with CHP production
- Tipping fee of $0.12 per gallon
- CHP O&M cost of $0.02 per kwh
- FOG Processing O&M cost of $0.02 per gallon
- Anaerobic Digester O&M cost of $0.04 per kg dry solids day
- Sludge Disposal Costs $340 per dry ton

Financial Analysis

	Plant A	Plant B	Plant C	Plant D
Design Flow (MGD)	14	12	8.8	8.5
Actual Flow (MGD)	10.5	10.9	5.21	4.99
Biosolids Fee (DT/Year)	3,808	4,188	2,001	1,916
# of Weekday FOG Deliveries	3	3	2	2
FOG Volume (MM Gallons per year)	4.68	4.68	3.12	3.12
Electricity Production (Million KWH per year)	4.52	4.78	2.62	2.56
Size of Cogeneration Plant in KW	750	700	500	500
Digested Waste Sludge (DT per year)	1,914	2,094	1,000	958
Gross Revenues (Electricity & Tipping Fees)	$1,013,600	$1,039,208	$636,798	$630,890
Plus: Sludge Disposal Cost Avoidance	$647,331	$711,889	N/A	N/A
Less: Annual O&M Costs for CHP, Digester & FOG Operation	$336,313	$356,649	$194,904	$190,336
Equals: Annual Incremental Net Revenues or Savings after O&M	$1,324,618	$1,396,594	$441,894	$440,554
Net Capital Expenditures after Incentives	$8,800,000	$8,680,000	$1,350,000	$1,350,000
Simple Payback in Years	6.6	6.2	3.1	3.1

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Worth a look?

Cogeneration = Efficiency + Better Environmental Profile
Microgrid = Resiliency
Anaerobic Digestion = Sustainability

Lots of "moving parts" including:

Utility Cost of Electric
Cost of Natural Gas Supplemental Fuel
Capital Costs
Tax Treatment
Low / No Cost Loan Programs
CHP Incentives
Renewable Energy Credits
Demand Response Revenues from PJM
Tipping Fees
Cost of Acquiring FOG
Biogas yield from Plant Design

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