MERITS OF MICROGRIDS

CASE STUDIES FROM MID-ATLANTIC STATES

DR. NANDINI MOULI

ESAI LLC

CAMPUS ENERGY 2018 CONFERENCE

BALTIMORE, MARCH 2018

AGENDA

- Why microgrids?
- Trends in microgrid development
- Why reciprocating engines and turbines for microgrids?
- Case studies of Mid-Atlantic States Projects
- Typical challenges of CHP-RE-DER Challenges
  - Microgrid as a solution – modeling outcome
- Conclusion

NEED FOR MICROGRIDS- NATURAL/HUMAN DISASTERS

NATURAL SOURCE OF DIASTER:

CAUSE	LOCATION	AFFECTED	DURATION
Hurricane Sandy (2012)	17 States	8.5 Million People	2-7 Days
Hurricane Irma (2017)	Puerto Rico/Florida	Islands/Kennedy – OPF	10 Days
Wildfires (2017)	California	10 Thousand People	Few hours- Days
Line Flashing & Tree Grounding	West Coast	7.5 Million People	6 Hours

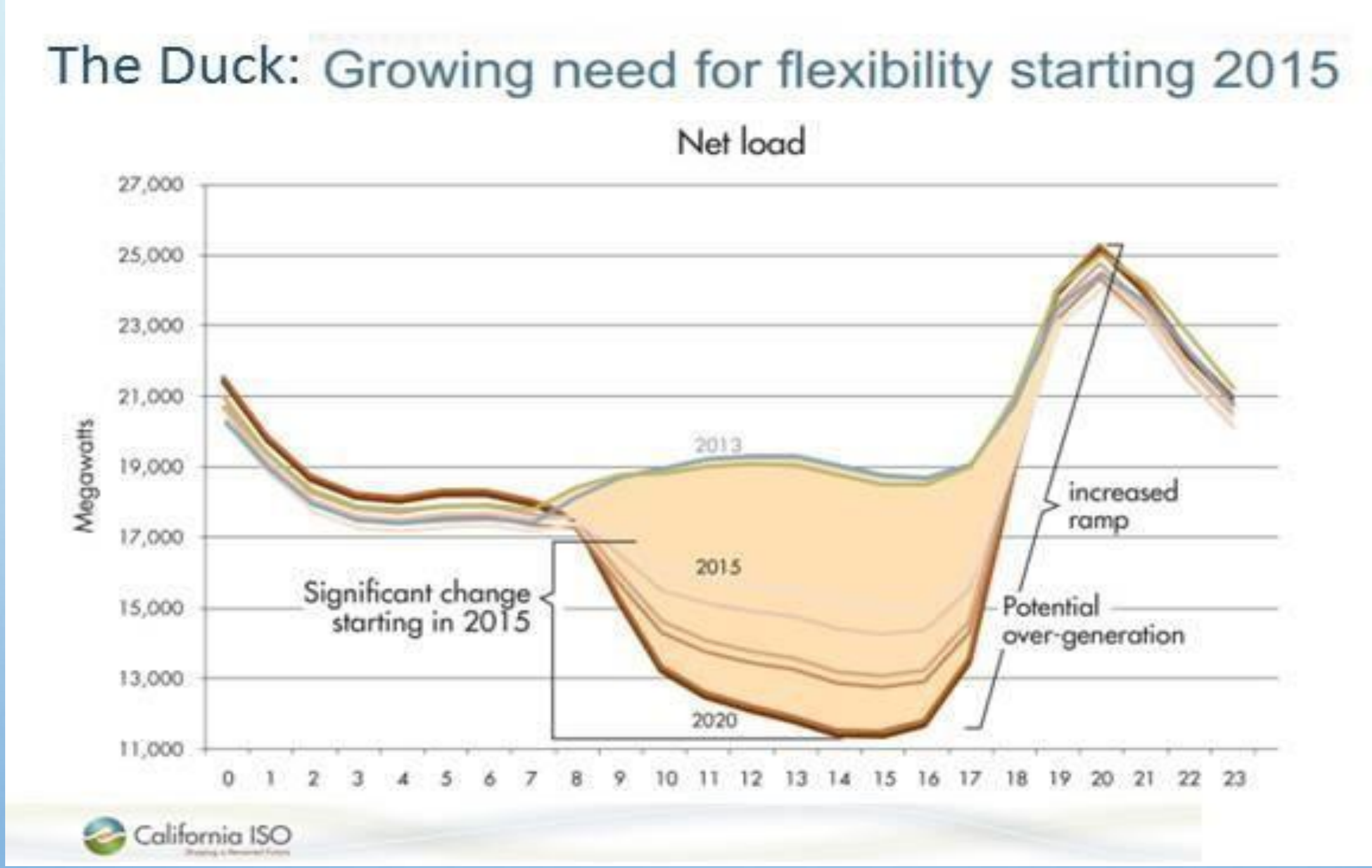
HUMAN SOURCE OF DIASTER:

CAUSE	LOCATION	AFFECTED	DURATION
Software Bug & Poor Load Shed	Northeast/ Canada (2016)	45 Million People	2-7 Days
Hot Weather + Technician Error During Maint.	California/ Arizona (2017)	2.7 Million People	12 Hours

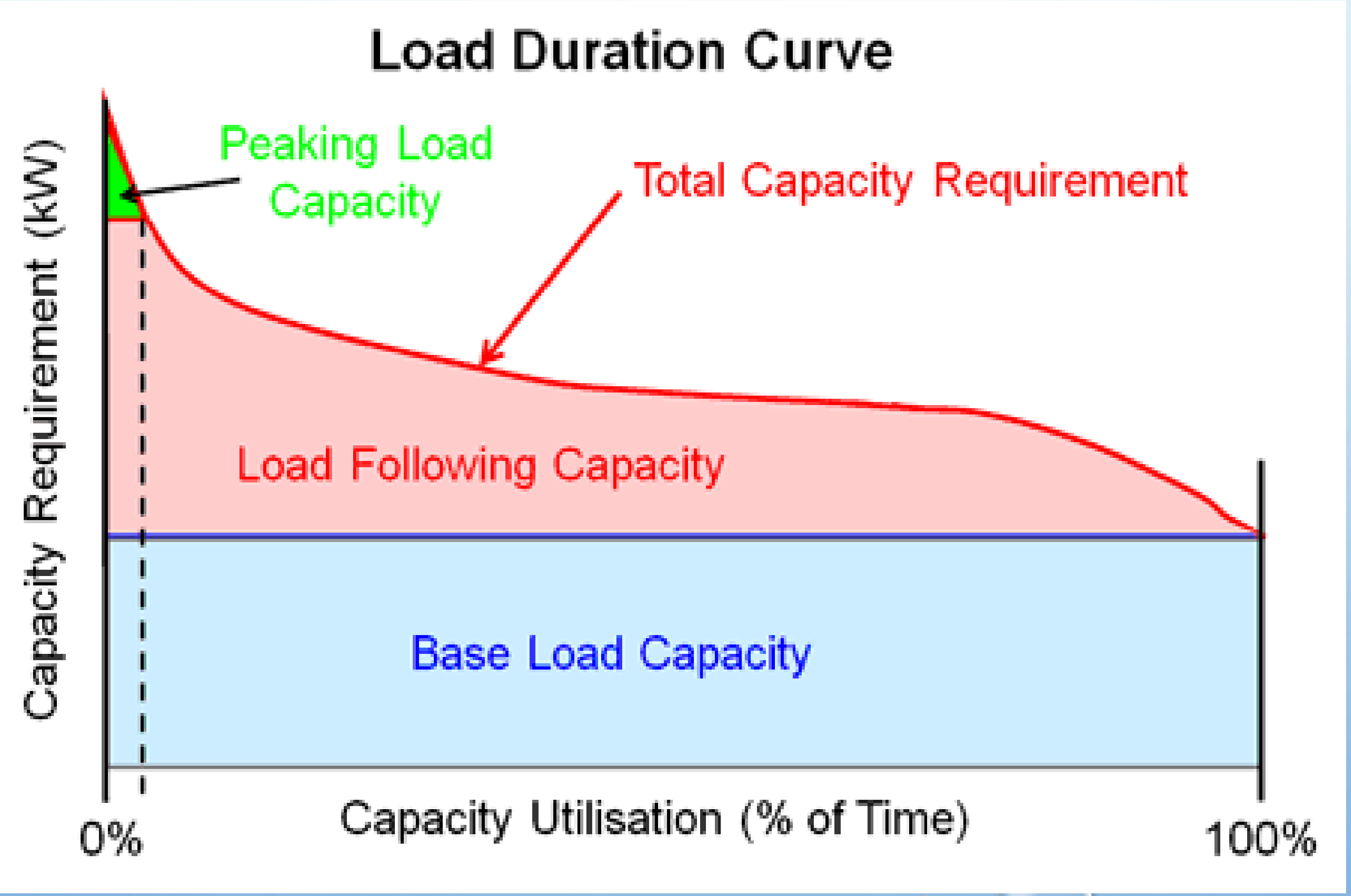
TRENDS IN MICROGRID DEVELOPMENT

- Decentralization of energy production, desire for decarbonization and rise of digital assets have changed the dynamics of energy generation.
- High Renewable energy penetration is increasing
  - ❑ Low operational expenses
  - ❑ Environmentally preferable
- Inherent variability makes them difficult to use as the sole source of power
  - ❑ R&D efforts focused on overcoming this, using more inverter-based resources
- The "Anchor" resource is a proven solution
  - ❑ Allows a certain penetration ratio of alternative energy (10-30%) with minimal engineering
  - ❑ CHP technologies make good anchor resources
  - ❑ Variable loads, variable load banks
- High speed Control is required

GROWING NEED FOR FLEXIBILITY

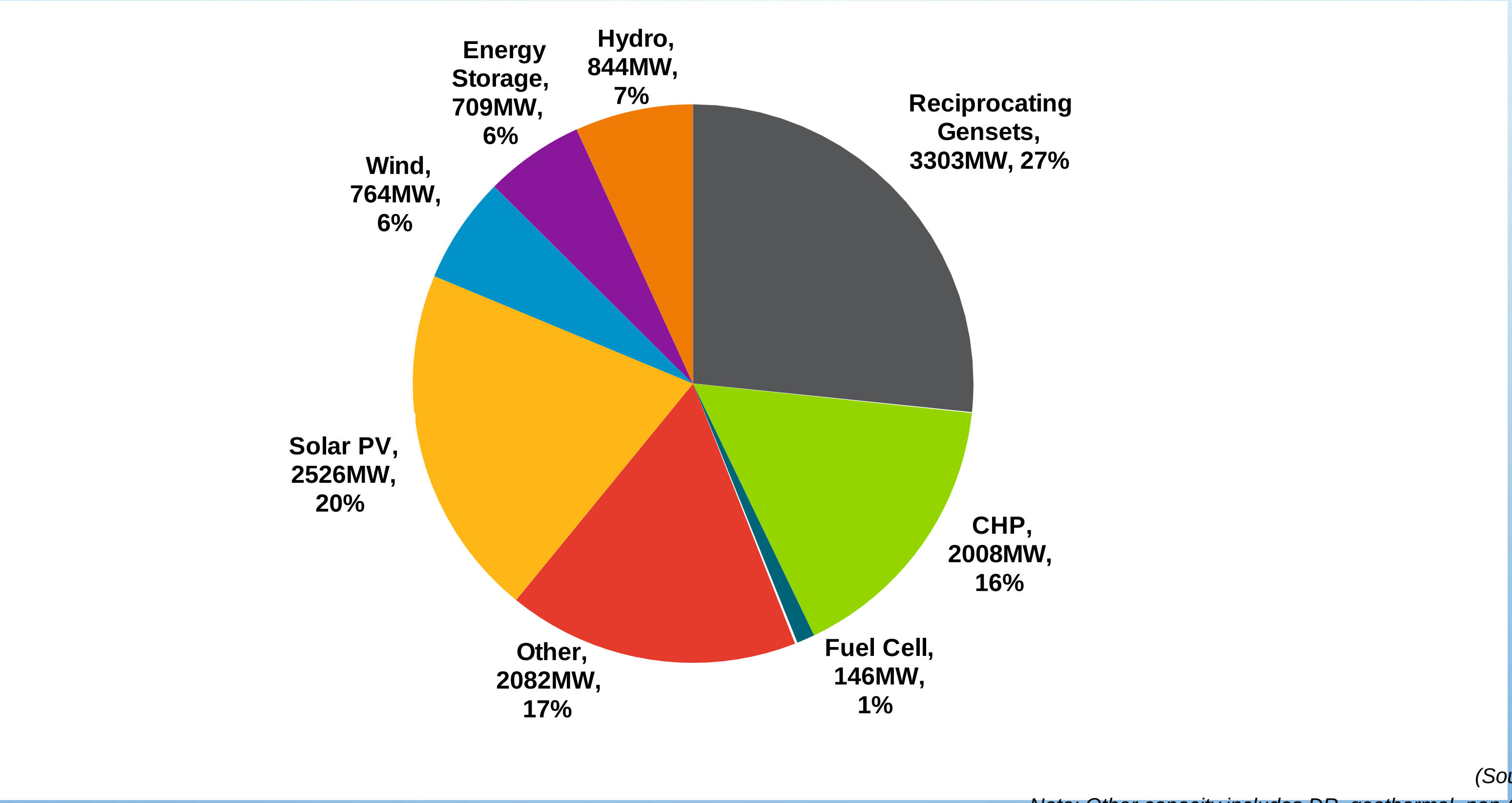


CHANGING PLANNING PARADIGM



TECHNOLOGY TREND: 1) FOSSIL FUELED DG REPRESENTS NEARLY HALF OF GLOBAL MICROGRID CAPACITY

Planned and Operational Microgrid Power Capacity by Technology, World Markets: 2Q 2018



(Source: Navigant Research)

Note: Other capacity includes DR, geothermal, non-CHP turbines, and others

TECHNOLOGY TREND: PROPERTIES CRITICAL FOR MICROGRID

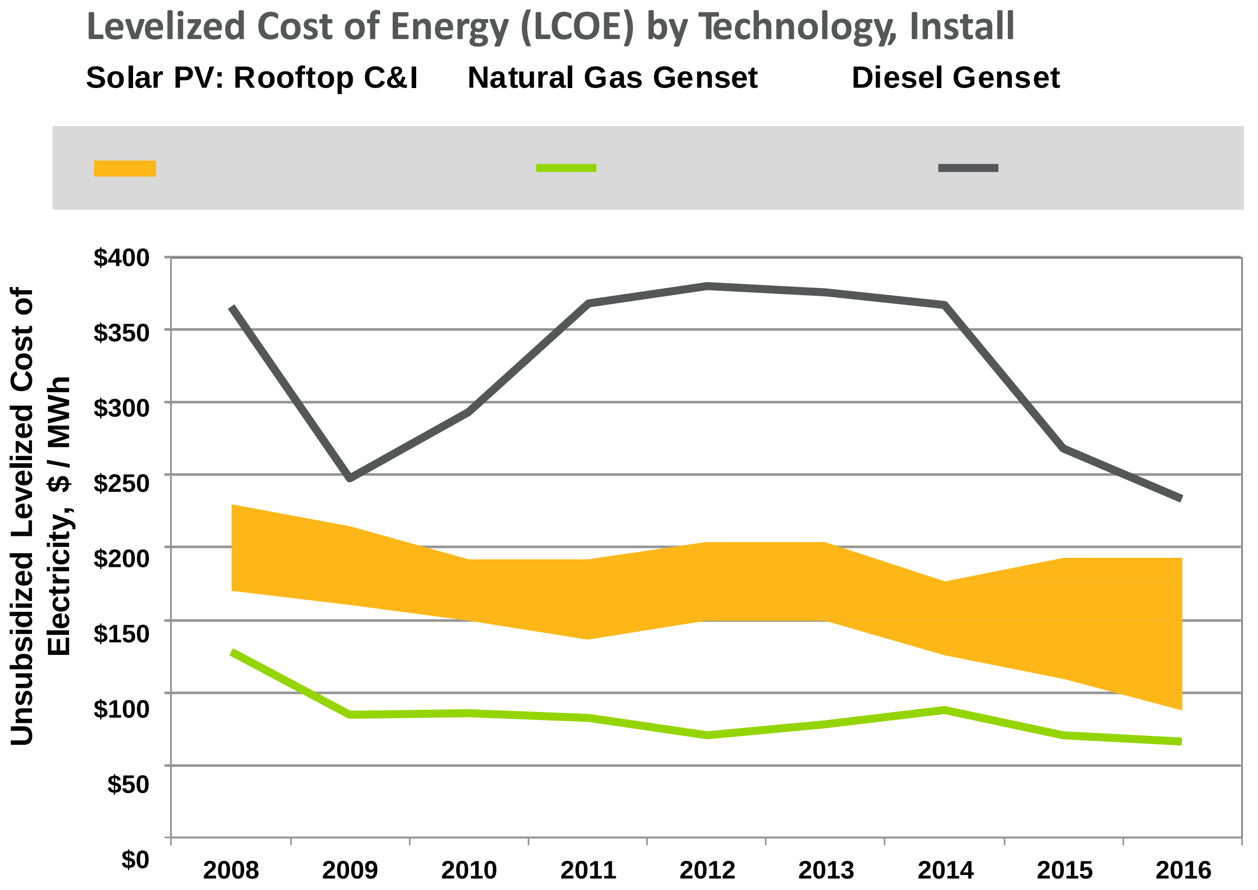
GENERATOR TECHNOLOGIES IN MICROGRID APPLICATIONS

CHP and Other Technologies

Technology	Electrical Output	Emissions	Load Following Ability	Technology Maturity	Desirable Traits for Microgrid Ancghor Resource
Natural Gas Reciprocating Engines	Synchronous	MEDIUM	MEDIUM	HIGH	1) Dispatchability
Fuel Cell	Inverter	LOW	LOW TO MEDIUM	MEDIUM TO HIGH	2) Inertia/"stiffness"
Microturbine	Inverter	LOW	MEDIUM TO HIGH	MEDIUM TO HIGH	3) Quick response
Gas Turbine	Synchronous	LOW	MEDIUM TO HIGH	HIGH	4) Medium To High Technology Maturity
Diesel Reciprocating Engine	Synchronous	HIGH	HIGH	HIGH	5) Medium to Low Emissions
Battery Energy Storage	Inverter	ZERO	HIGH	MEDIUM	
Solar PV	Inverter	ZERO	LOW	HIGH	
Wind Turbine	Inverter	ZERO	LOW	HIGH	

TECHNOLOGY TREND: 2) SOLAR PV FALLING IN PRICE

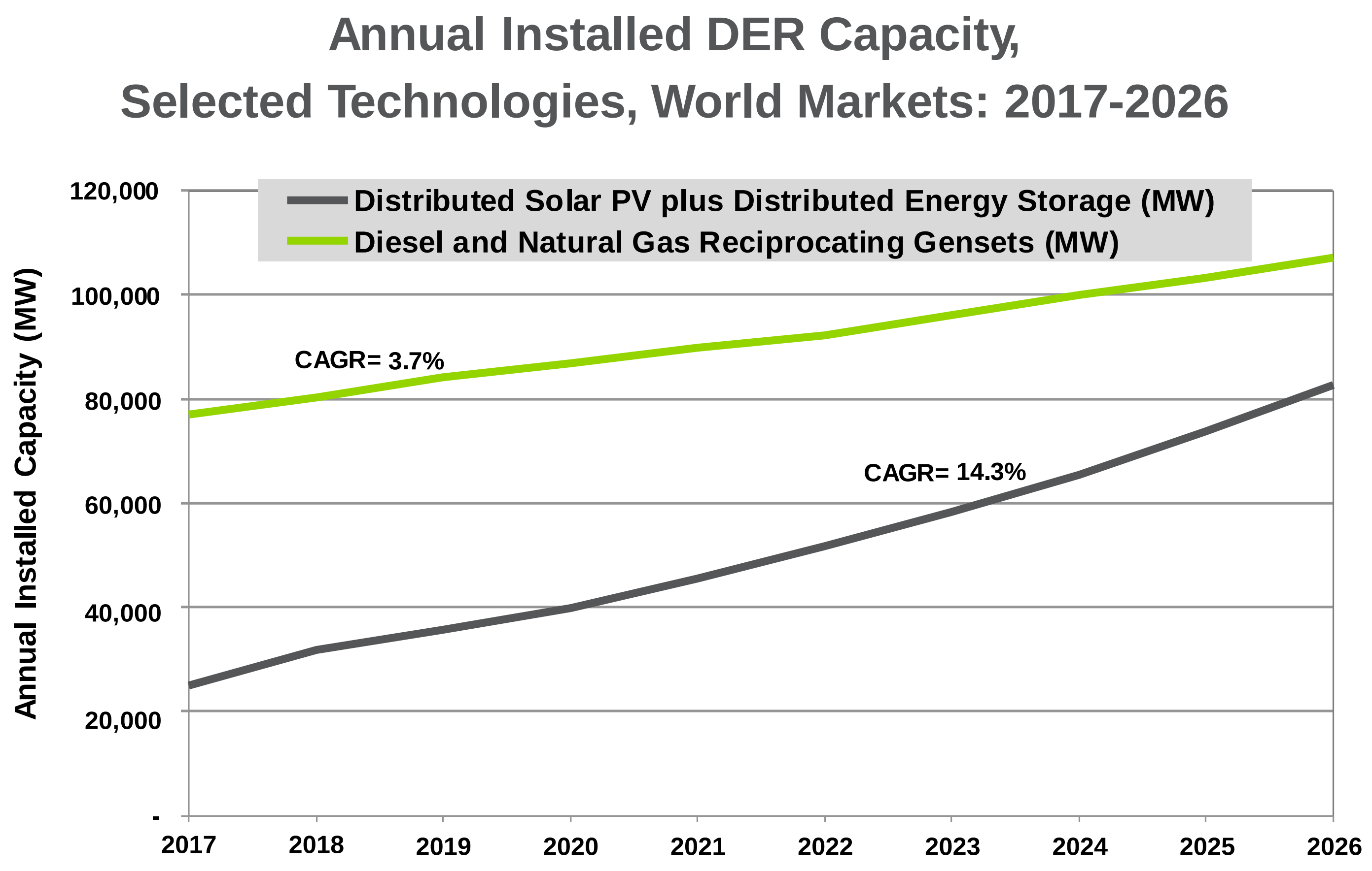
INCREASINGLY COMPETITIVE WITH FOSSIL-FUELED DG



(Sources: Navigant Research, Energy Information Administration, Lazard)

Genset LCOE based on same-year installation and 20-year life and 2.5% cost of fuel escalation. Diesel based on average US retail Ultra Low Sulfur Diesel prices; natural gas based on average price paid by US industrial users.

TECHNOLOGY TREND: 3) DERS CATCHING UP WITH GENSETS FAST



(Source: Navigant ReSearch)

FOSSIL FUELED "PRIME MOVERS": A CLOSER LOOK

`	Diesel Reciprocating Engine	Natural Gas Reciprocating Engine	Gas Turbine	Fuel Cell	Microturbine
Share of Total Global Microgrid Capacity, 2Q17	25%	3%	17%	1%	<1%
Typical Installed Cost/kW	$500-$900	$700-$1,200	$800-$1,400	$4,000-$9,000	$2,500-$4,000
Load Following Ability	Best	OK	OK	Poor	OK
Emissions	High	Medium	Low	V. Low	Low
Outlook	(↔) Low cost, versatile, trusted, but emissions & fuel costs a major drag	(↑↑) Cheap, modular, efficient; growing availability of NG is key	(↑) Well suited for larger applications with access to high-pressure NG	(↑) High cost + inflexibility curb demand; remains longer-term threat	(↑) High cost a challenge vs alternatives; CHP applications attractive

WHY NATURAL GAS RECIPROCATING ENGINE?

LAST DEFENSE TO KEEP THE POWER FLOWING24/7 Operation

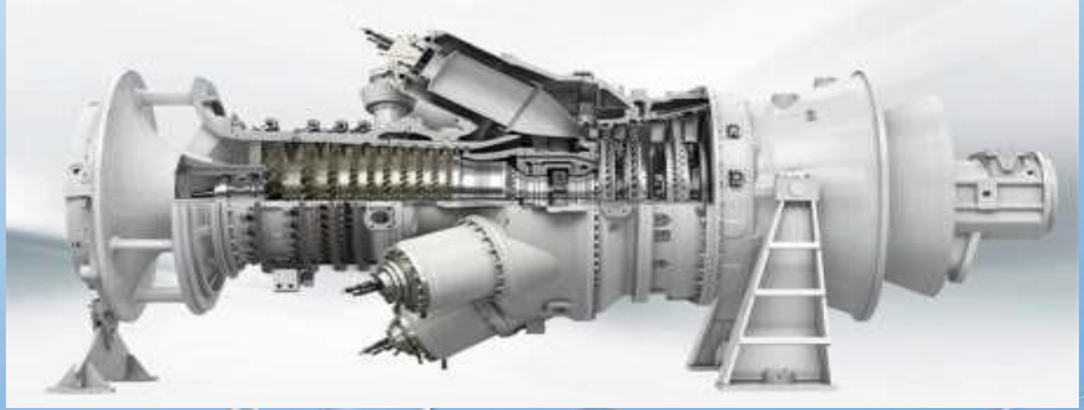
- Electrical efficiencies up to 45%
- High sound power levels
- Does not take on load as fast as diesel generator
- High availability (98%)
- NG lines underground
- Are modular and easy to site
- Fuel Flexibility
- operate at high altitudes and in ambient temperatures
- Approx. Cost $2,800/kW as part of a CHP

Three- 2.5 MW Caterpillar Gen-sets

NATURAL GAS TURBINES

- 24/7 Operation
- Power output reduction as inlet air temperature increases
- 24-42% electrical efficiency depending on size
- Lower O&M costs relative to recip. engines.
- Approx. Cost $3,000/kW as part of CHP system

Typical Gas Turbine Setup



7.9 MW SGT-300 – Courtesy of Siemens

Natural Gas MicroTurbines

- Does not require a building enclosure
- Low sound power levels and emissions
- Low O&M costs
- Low electrical efficiency (22-33%)
- Significant power output loss at ambient temp. above 73F
- Approx. Cost $3,500/kW as part of CHP

200 kW Microturbines-Courtesy of Capstone

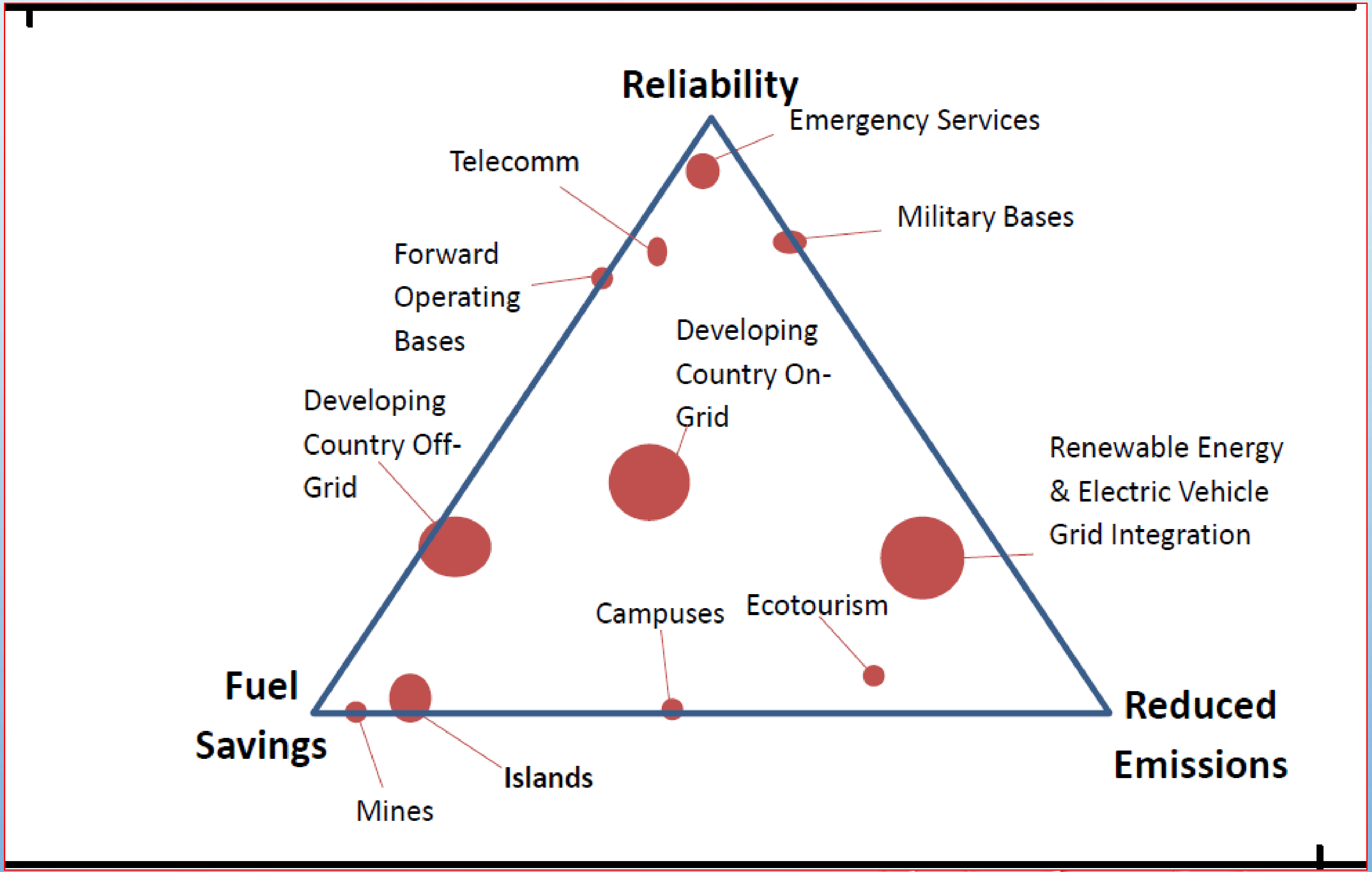
STEAM TURBINES

- 40+% Efficient
- Requires a steam source and steam demand
- Low sound power
- Low O&M cost
- May be combined with gas turbine system
- Low installed cost, approx. $1,100/kW

Courtesy of Dresser

Case Studies of Microgrid Projects in Mid-Atlantic States

MICROGRIDS AND THEIR VALUE PROPOSITIONS FOR DIFFERENT END-USE SECTORS

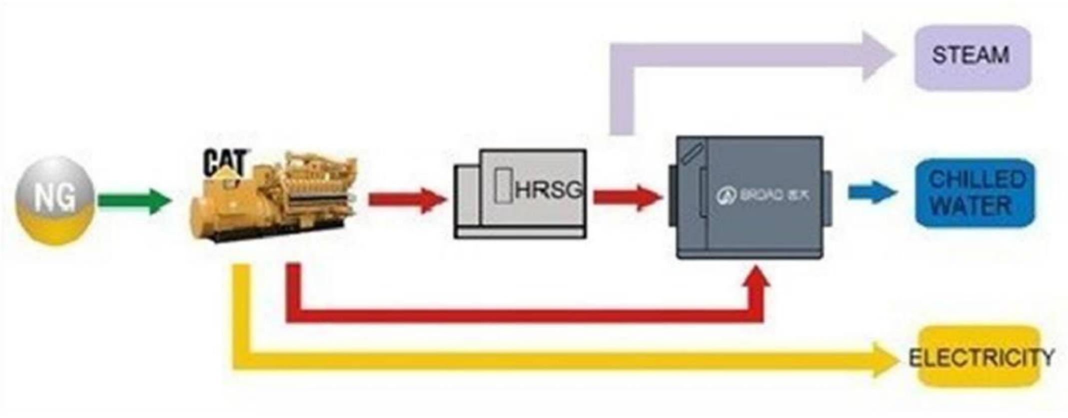


1. UPPER CHESAPEAKE MEDICAL CENTER

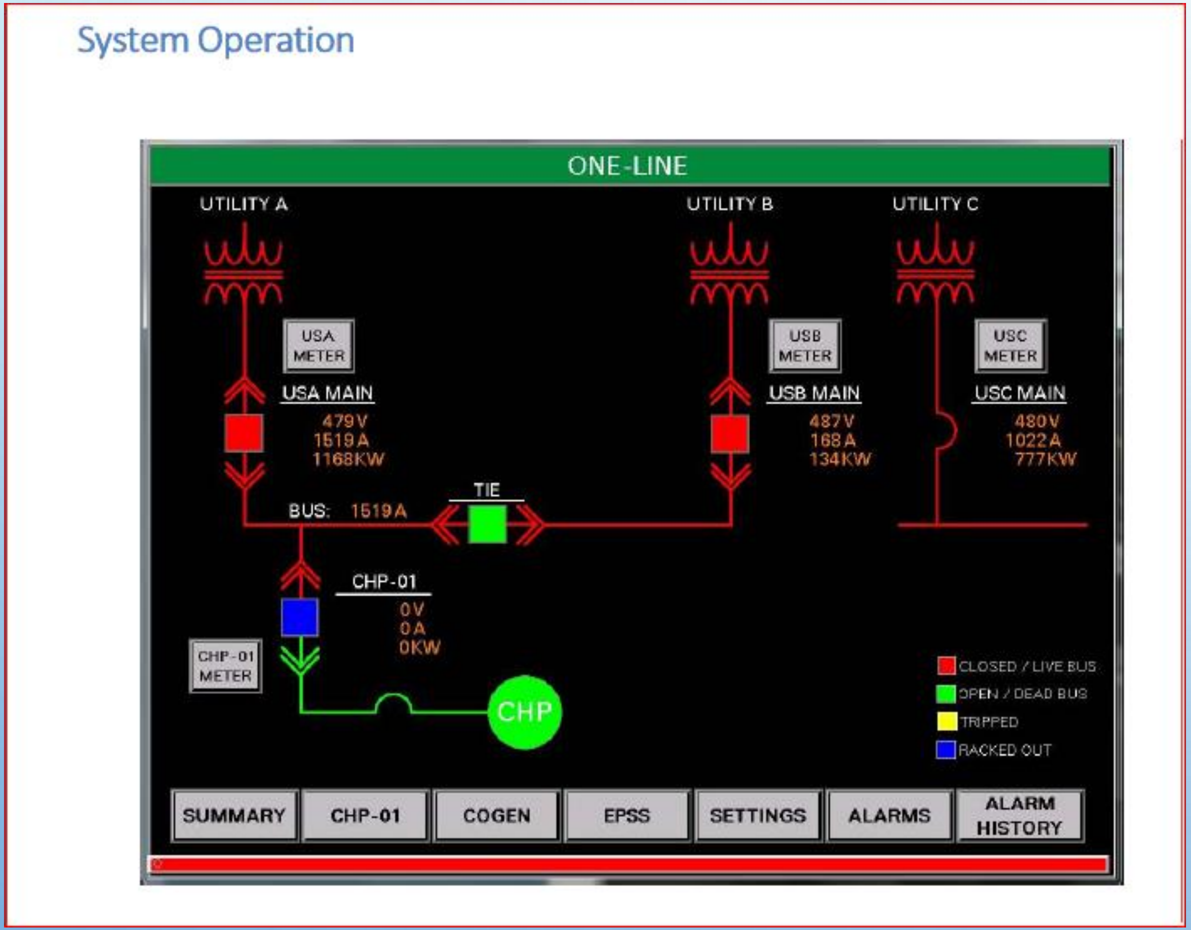
Goal: To have reliability and resilient power

- 2 MW CHP Caterpillar natural gas engine
- Diesel gen-set + Absorption Chiller
- Financed by the end user through PPA financing by Clark Financial Services Group

CHP Process



CHP MICROGRID SYSTEM OPERATION



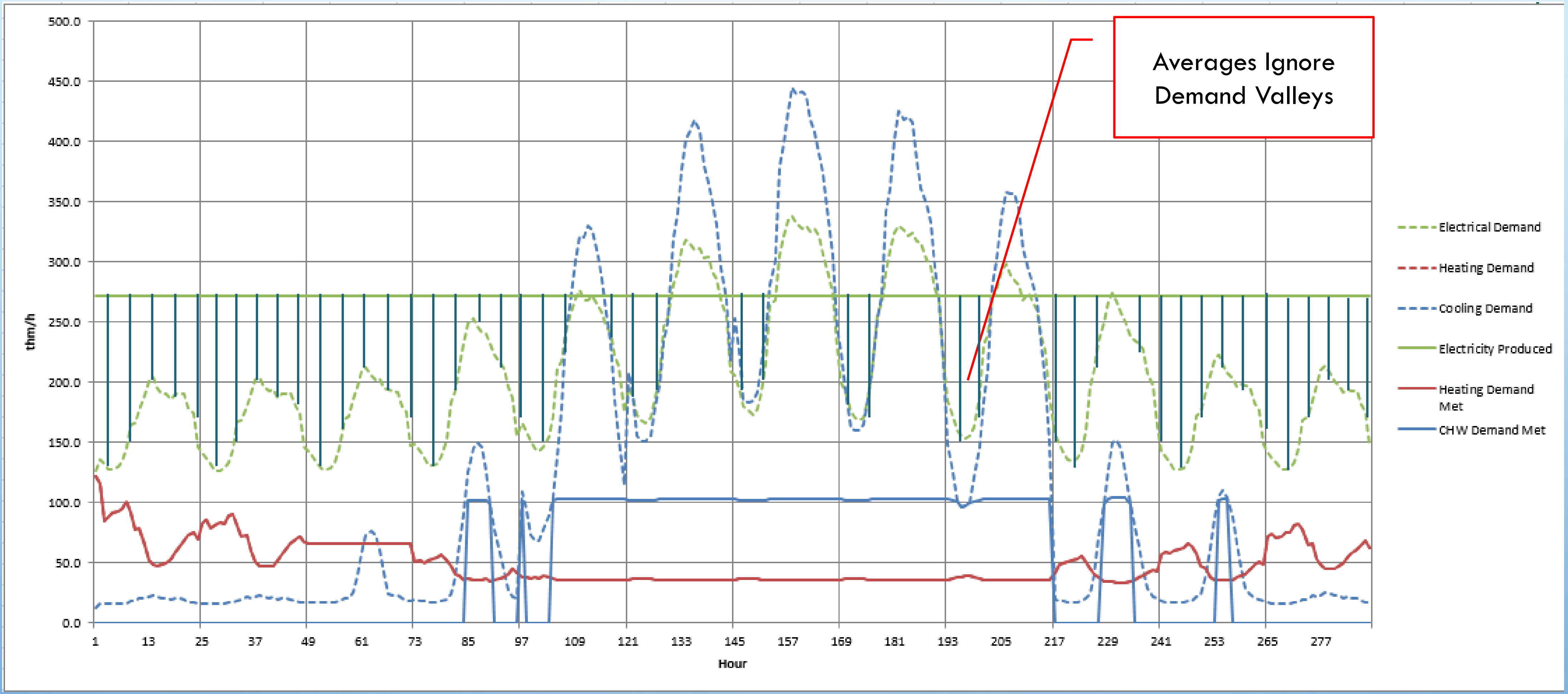
- **100 KW Minimum import requirement**
- **Variable base load**
- **Resiliency for HVAC and other building loads**
- **Additional backup to the code-required diesel during extended utility outages**

2. MICROGRID – PRIVATE PROJECT

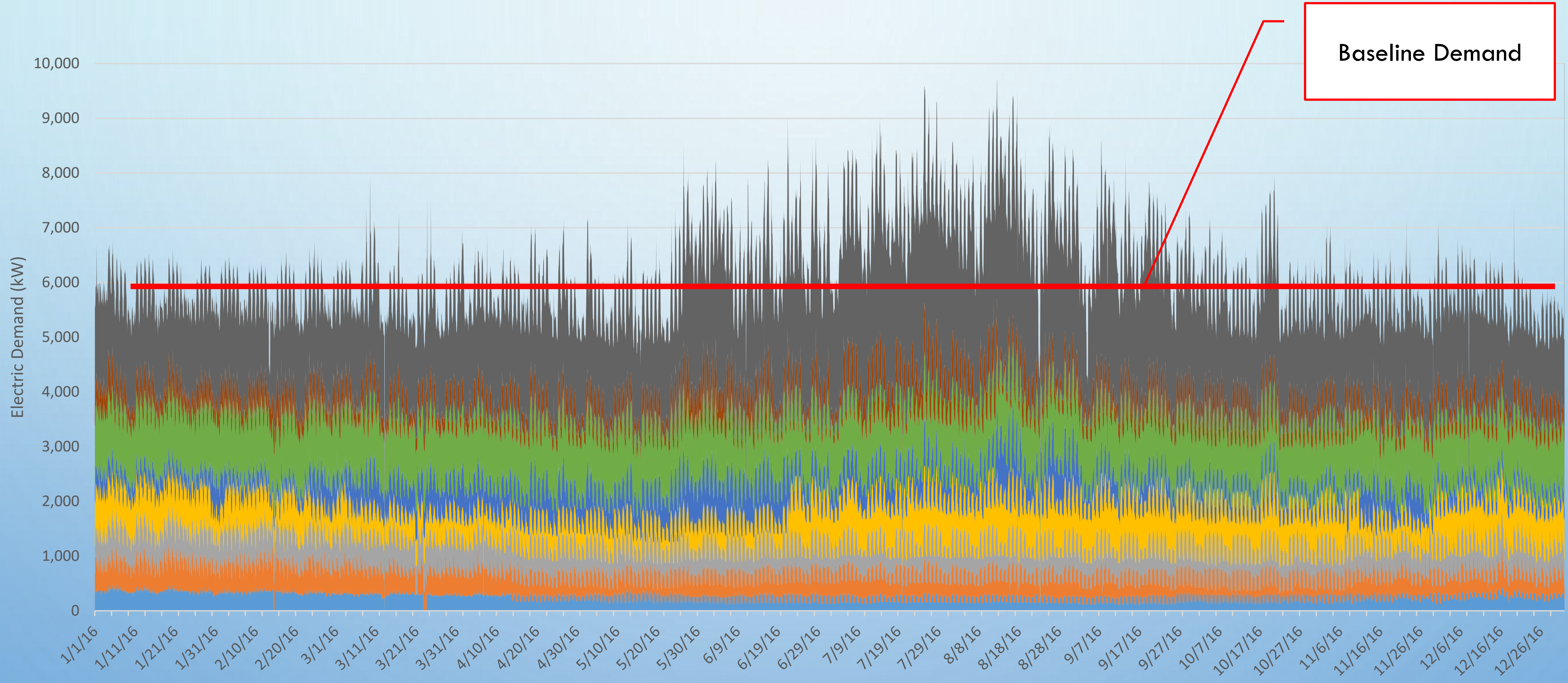
Goal: To have reliability, flexibility, lower cost operation

- Take advantage of new opportunities resulting from campus electrical consolidation project
- Increase power reliability to support entire campus
- Optimize existing CHP by increasing thermal load
- Further reduce carbon footprint
- Further reduce operating Costs
- Increase Chilled Water Capacity

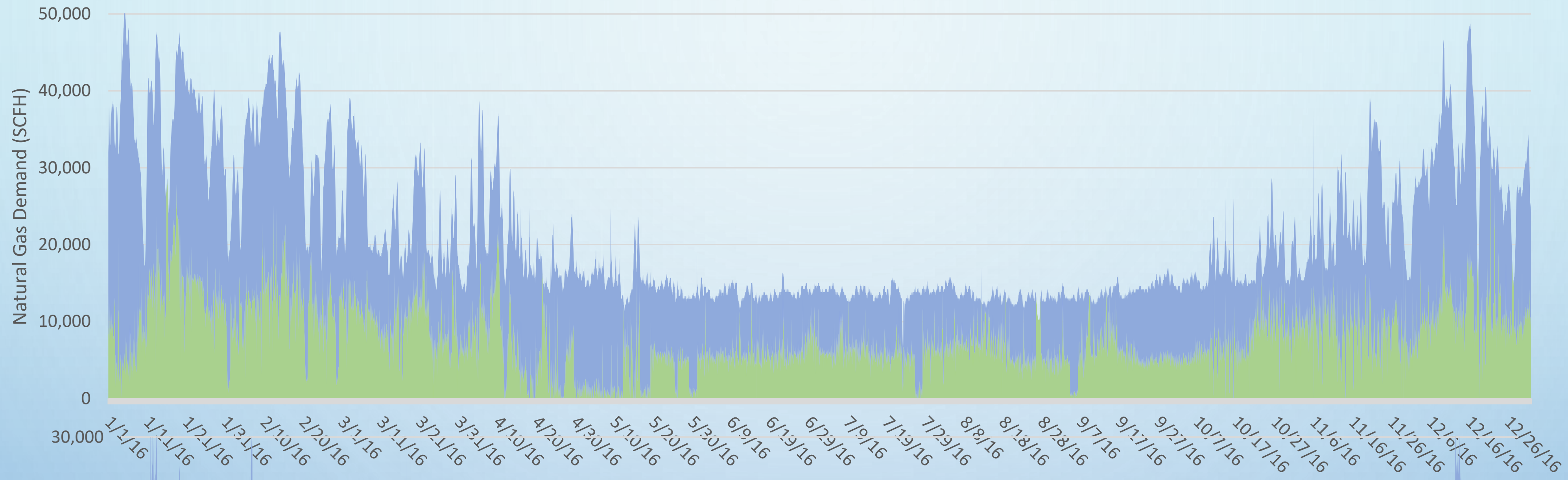
LOAD ANALYSIS – THE IMPORTANCE OF INTERVAL DATA

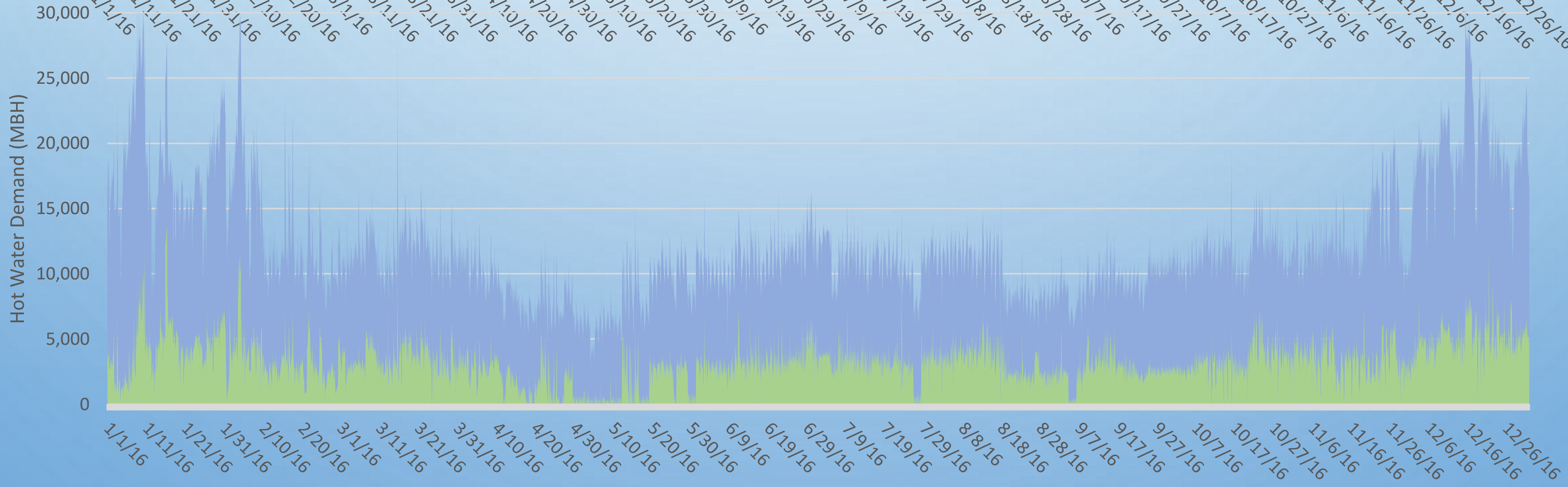


LOAD ANALYSIS – CONSOLIDATED ELECTRICAL LOAD PROFILE

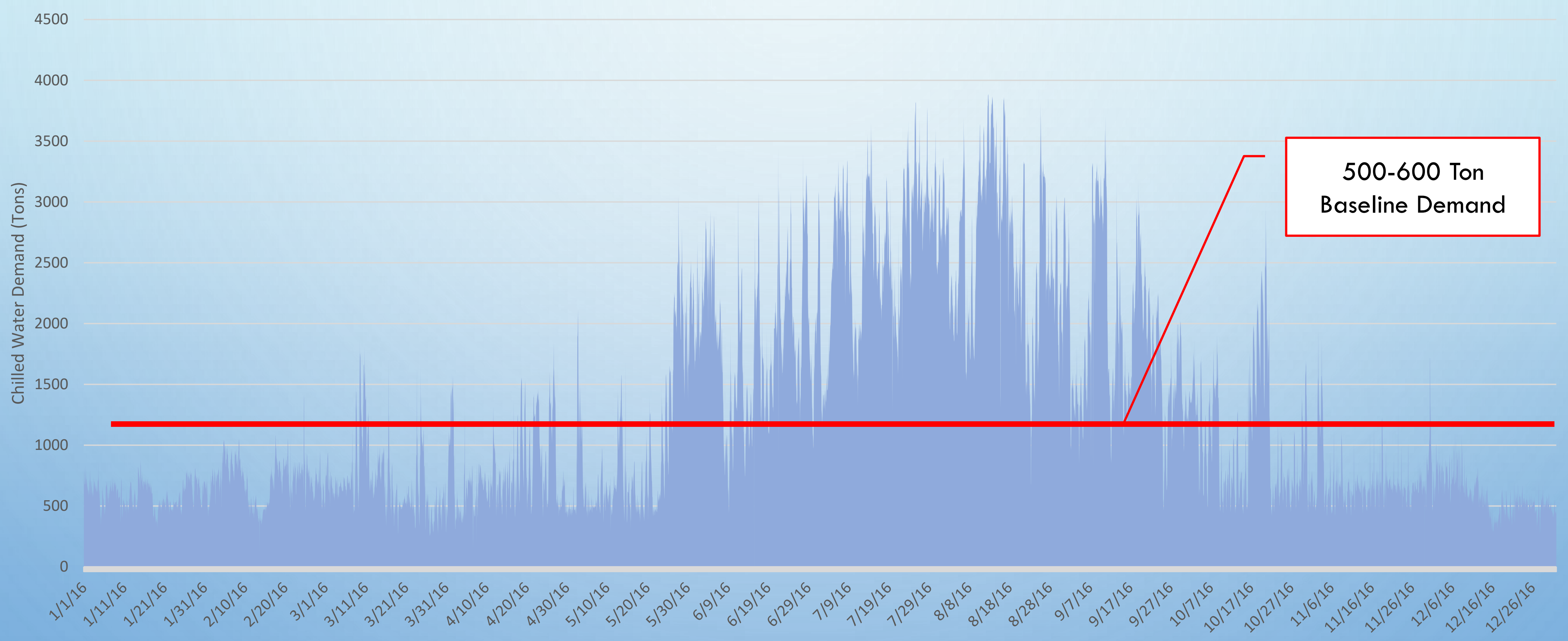


LOAD ANALYSIS – NATURAL GAS & HOT WATER LOAD PROFILES





LOAD ANALYSIS – CHILLED WATER LOAD PROFILES



MICROGRID-CHP AND OTHER COMPONENTS

CHP-6000
2500 KW

CHP-6001
2500 KW

Electrical

Scope
Relocate existing CHP-6000 tie-in
Connect new CHP-6001
Modify PMCS to stage multiple CHP units.

Hot Water Systems

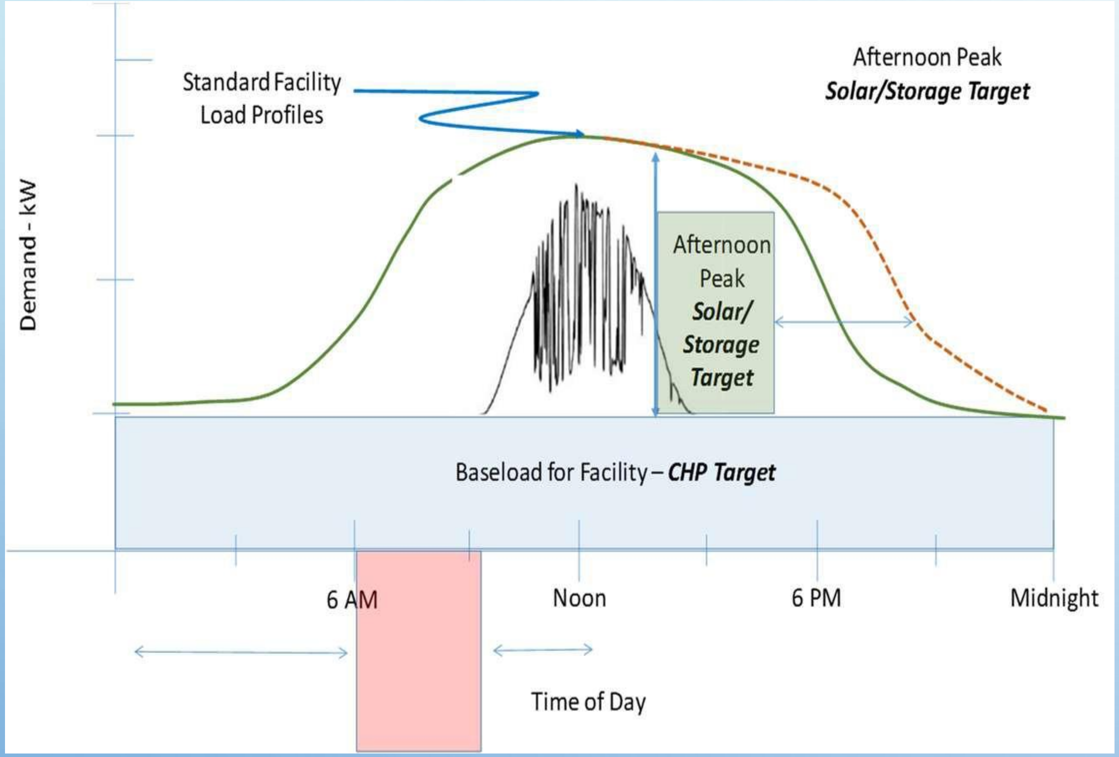
Scope
Extend hot water piping to Area 3 and Area 4.
Add controls to regulate flow to multiple hydronic systems

Steam Systems

Chilled Water Plant

Scope
Extend hot water and steam piping to chiller plant
Chilled water connection
New cooling tower and chiller

CHALLENGES OF RENEWABLE PENETRATION - A MICRORID SOLUTION

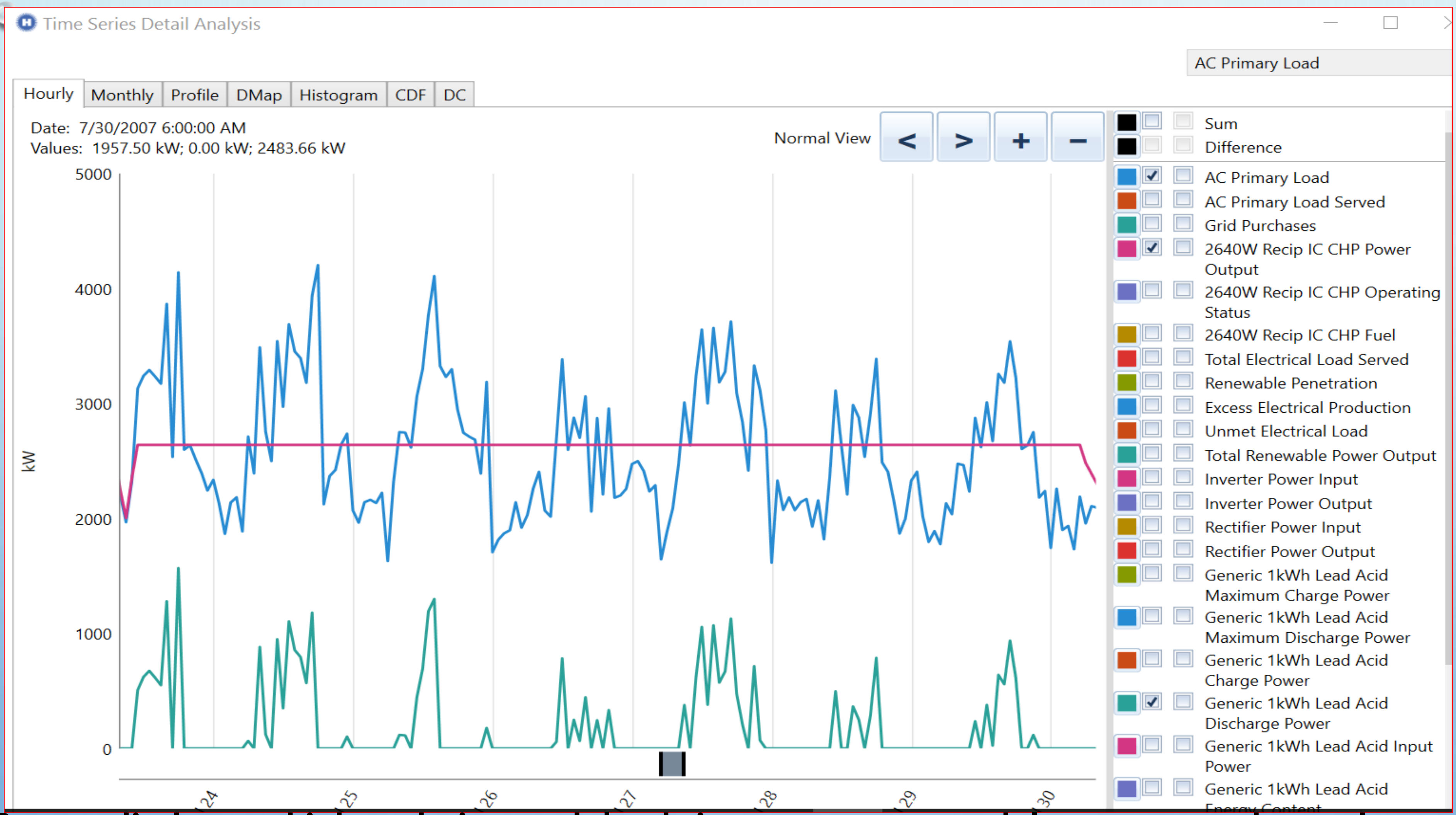


- MICROGRID SOLUTION:
- CHP + STORAGE + SOLAR:
  - CREATING A FIRM, DISAPATCHABLE ASSET TO ADDRESS UTILITY NEEDS AS WELL AS CUSTOMER NEEDS
  - MICROGRID ALLOWS CHP TO BE OPTIMIZED – INCREMENTALLY ADDING ASSETS, SOLAR & STORAGE TO ADDRESS FACILITY PEAK AS WELL AS ADDING FLEXIBILITY TO PARTICIPATE IN GRID SERVICES

MICROGRID – MODELING METHODOLOGY

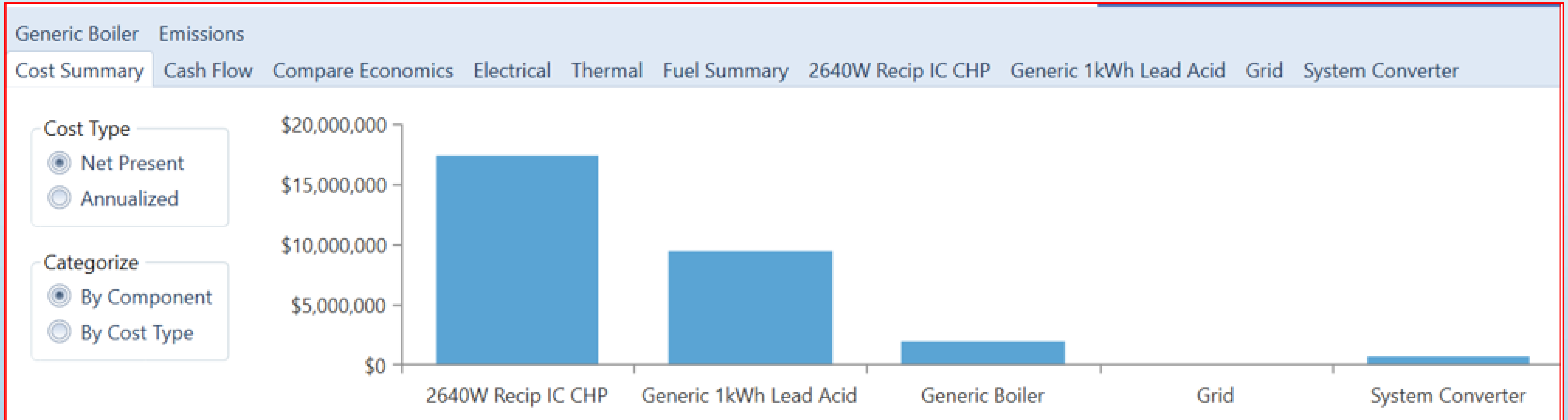
- Modeled a large commercial 2000 kW facility such as a large university campus with grid only as the baseline
- Modeled same with 1) CHP only 2) CHP with battery storage, 3) CHP with solar 4) CHP with battery and solar
- Conclusion:
- For an university campus, CHP microgrid with PV and battery provides additional benefits at a slightly expensive system cost. The resiliency and peak-shaving benefits will overweigh the cost difference.

MICROGRID WITH CHP AND BATTERY – POWER OUTPUT



Battery discharges highest during peak-loads in summer at a much lower cost vs demand charges. Due to this the yearly reserve for the site is reduced and hence the overall yearly electricity bills by 20-25%.

MICROGRID WITH CHP AND BATTERY – NET PRESENT COST



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
2640W Recip IC CHP	$4,752,000.00	$0.00	$3,409,993.28	$9,172,203.07	$0.00	$17,334,196.35
Generic 1kWh Lead Acid	$5,266,500.00	$2,878,284.12	$1,617,805.63	$0.00	($254,124.08)	$9,508,465.67
Generic Boiler	$0.00	$0.00	$0.00	$1,883,369.07	$0.00	$1,883,369.07
Grid	$0.00	$0.00	$20,172.45	$0.00	$0.00	$20,172.45
System Converter	$515,625.00	$126,784.51	$0.00	$0.00	($16,586.95)	$625,822.57
System	$10,534,125.00	$3,005,068.63	$5,047,971.36	$11,055,572.14	($270,711.03)	$29,372,026.11

Conclusion: Net Present Cost for 15 year for the system is $29.3 million from capital costs of CHP and battery. Highest expenses for this comes from fuel for CHP and O&M as in the break-down of expenses in the table.

CONCLUSION: BENEFIT OF MICROGRID VALUE STACKS

Large Commercial, Comparison of Financials with and without Renewable Sources							
System	Type	Net Present cost	Rebates-utility	Grant-State	Federal Tax Credits	Net after financial assistance, $	Comment
100% Grid	Layer 1	20,328,240	None	None	None	20,328,240	Baseline
2640 CHP + 10 kW grid	Layer 2	22,038,060	2,500,000	499,999	475,200	19,038,061	Good Option 1 Vs 100% grid Baseline
2640 kW CHP+806 kW PV+6631 kWh battery	Layer 3	26,207,160	2,500,000	499,999	1,824,888	21,382,273	Good Option 2 Vs 100% grid Baseline
2640 kW CHP + 17555 kWh battery, no grid, no solar	Layer 4	29,372,030	2,500,000	499,999	2,055,150	24,316,881	Good Option 3 Vs 100% grid Baseline
					Nandini Mouli, eSai LLC, 12,11,17		

CONTACT

NANDINI MOULI, PH.D.

PRESIDENT/FOUNDER

ESAI LLC

NANDINI@ESAI.TECHNOLOGY

(443) 691 7664

WWW.ESAI.TECHNOLOGY