Energy Production and Distribution At Princeton University

Mid-Atlantic Demand Response Initiative, Fall 2015

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Overview

- Campus Energy Demands
- Energy Plant Equipment
- Combined Heat and Power Production
- Historic & Projected Emissions
- Solar PV
- Plant Economic Dispatch
- Integration with PJM
- “Microgrid” benefits and issues
- Best Practices

Energy Demands at Princeton



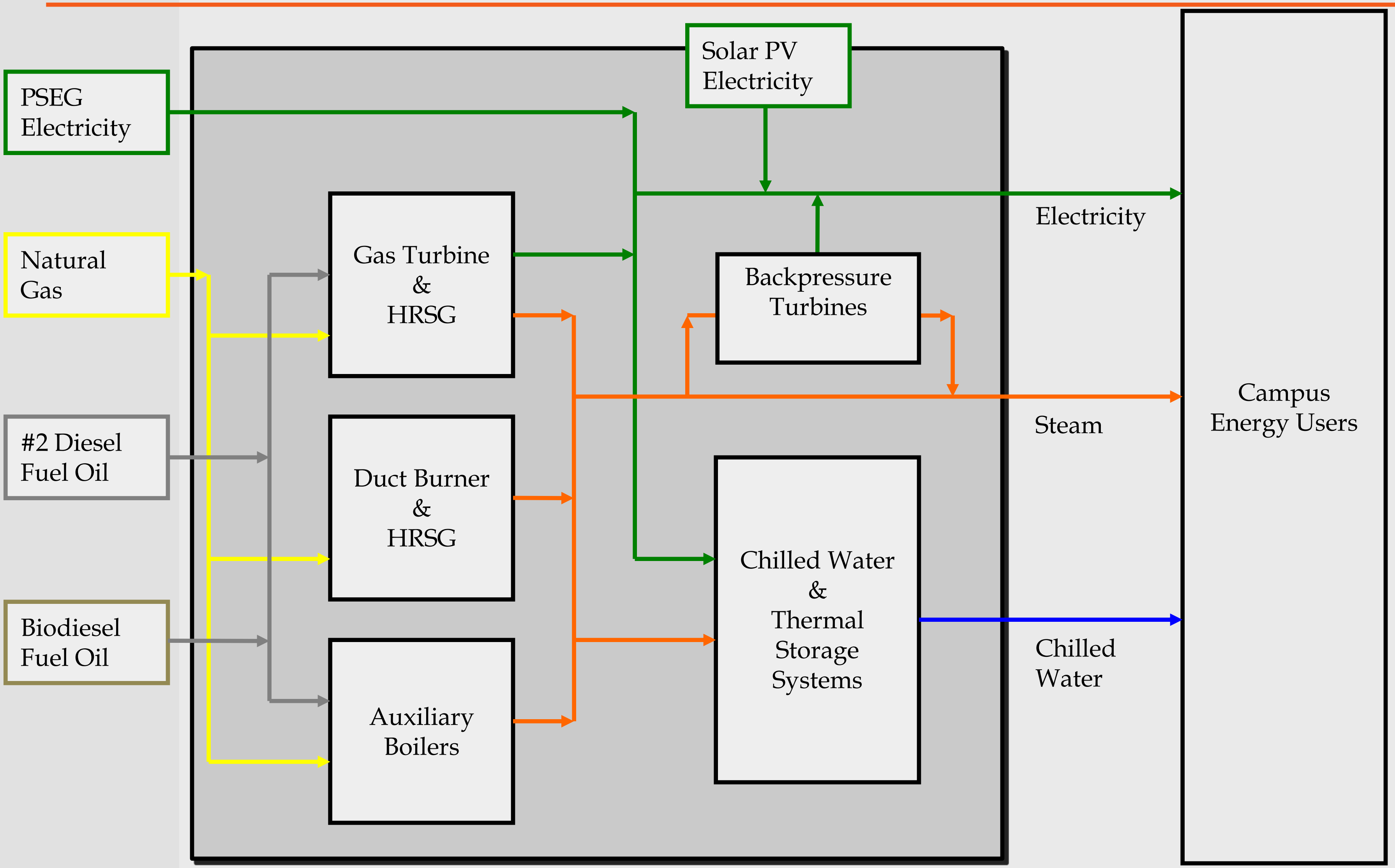

- > 180 Buildings
  - Academic
  - Research
  - Administrative
  - Residential
  - Athletic




Energy Equipment & Peak Demands

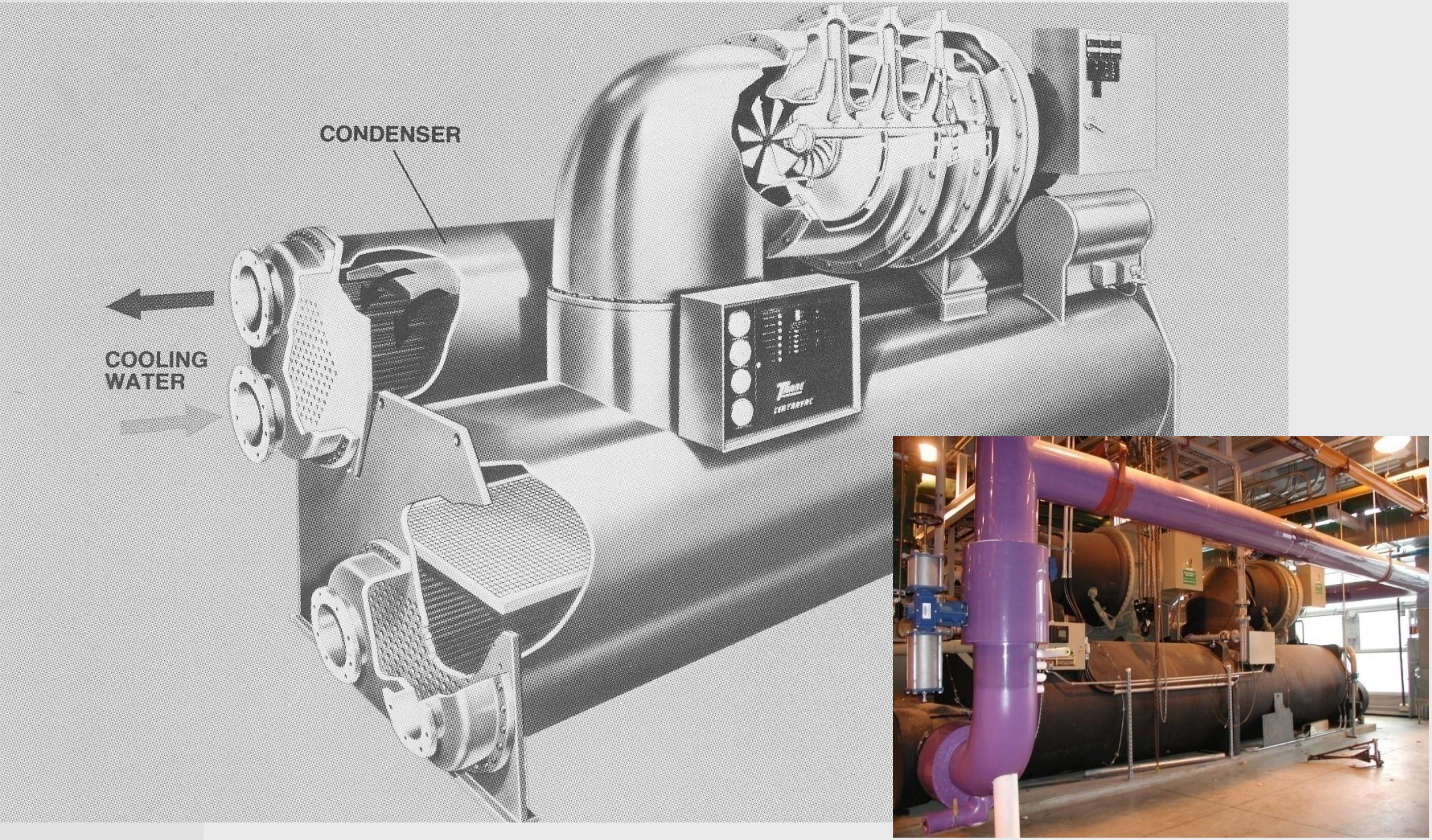
	Rating	Peak Demand
Electricity		
(1) Gas Turbine Generator	15 MW	27 MW
Solar Photovoltaic System	4.5 MW	
Steam Generation		
(1) Heat Recovery Boiler	180,000 #/hr	
(2) Auxiliary Boilers @ 150 ea.	300,000 #/hr	240,000 #/hr
Chilled Water Production		
(3) Steam-Driven Chillers	10,100 Tons	
(5) Electric Chillers	10,700 Tons	15,000 Tons
(1) Thermal Storage Tank	40,000 Ton-hours	
*peak discharge	10,000 tons (peak)	

Plant Energy Balance

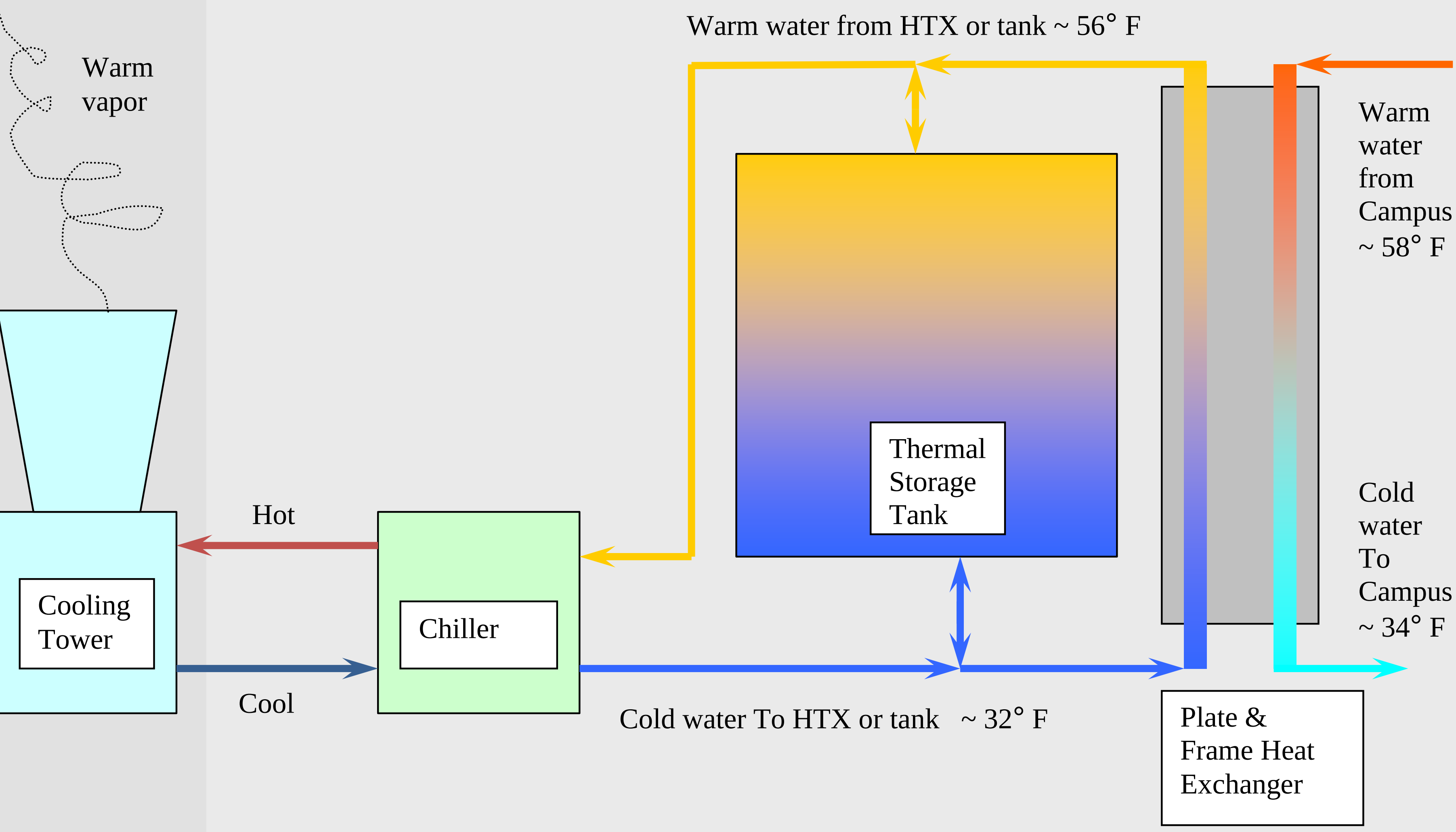


Campus District Energy Systems

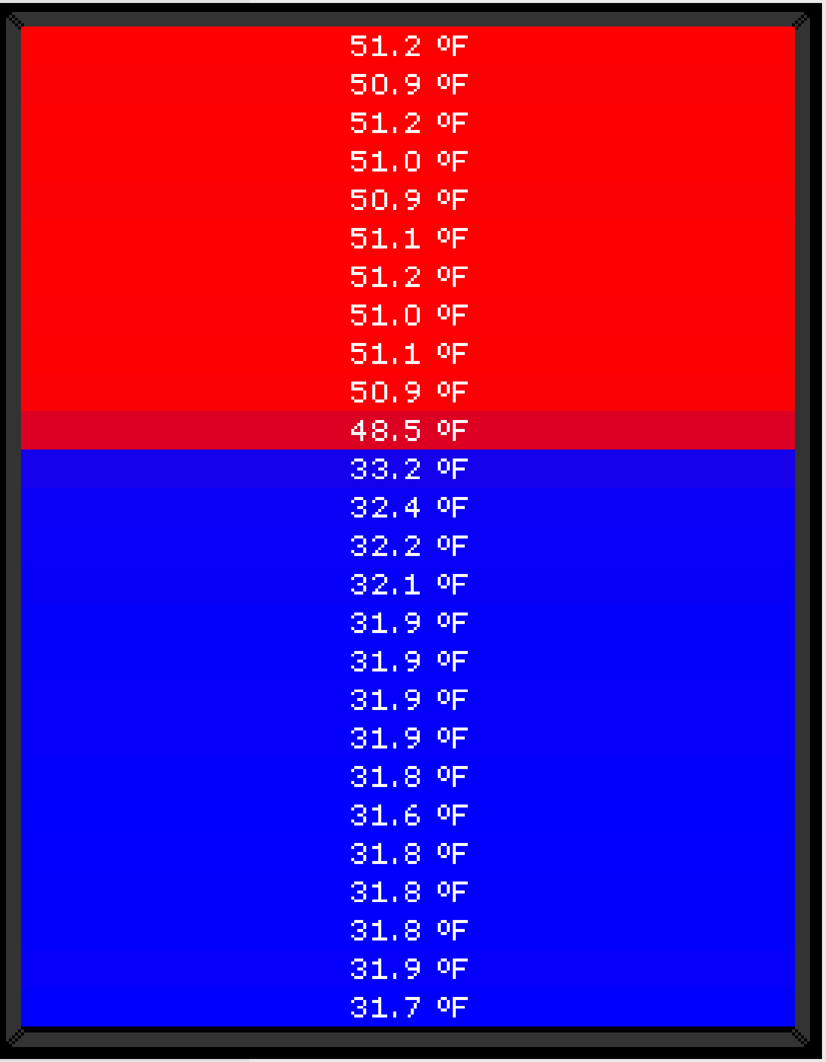
Centrifugal Electric Chiller



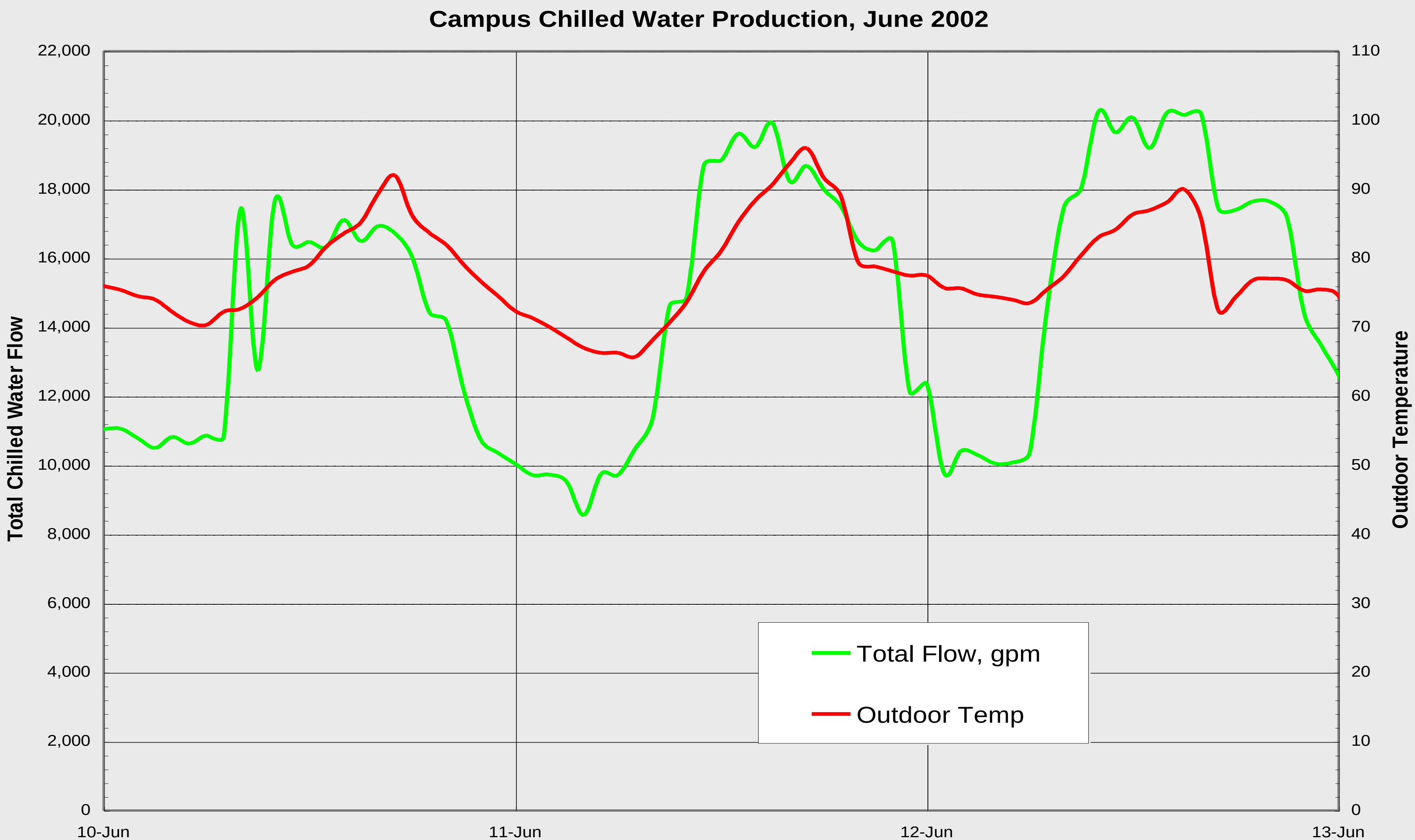
Chilled Water Thermal Storage



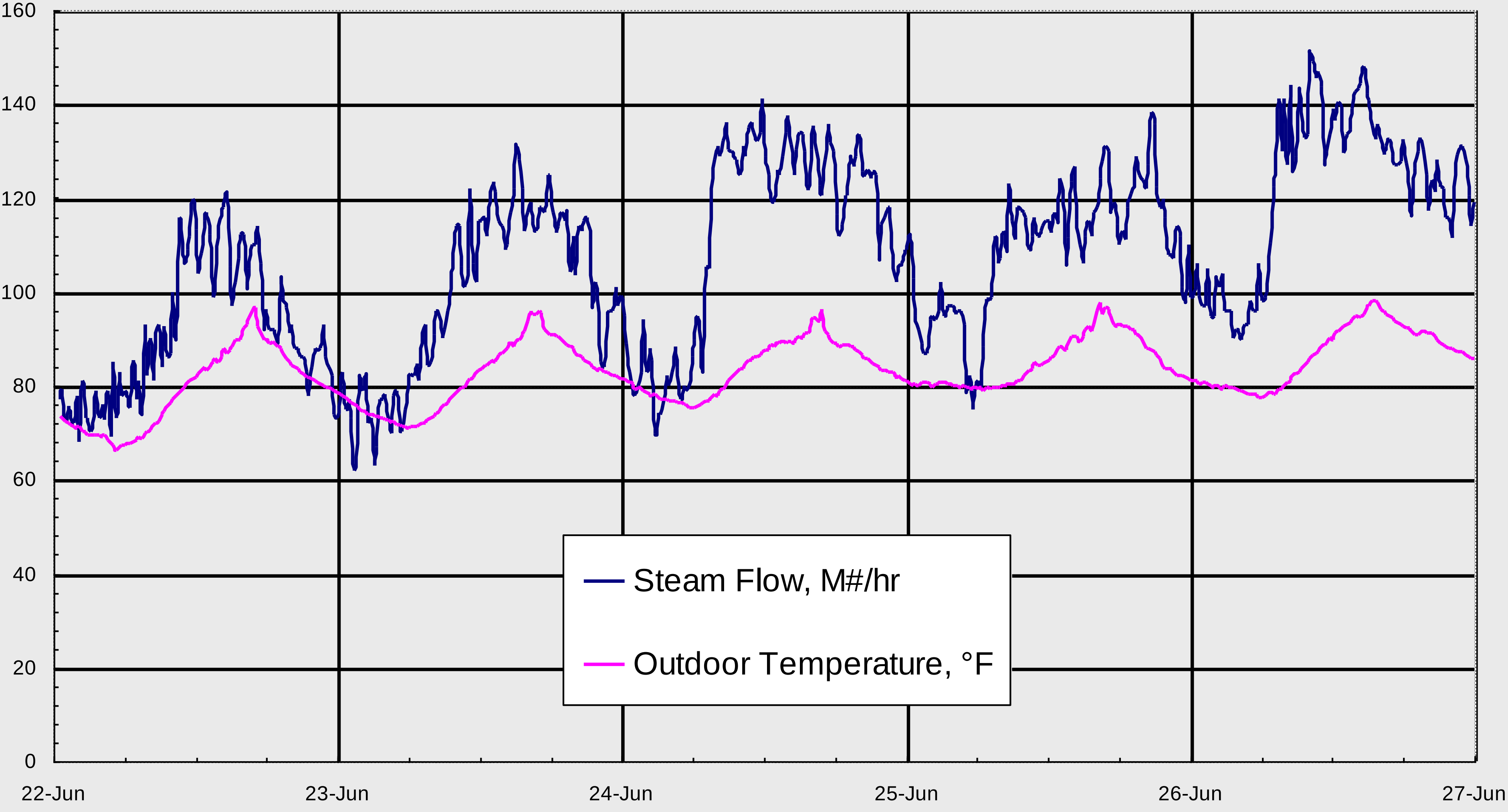
TES Tank Stratification



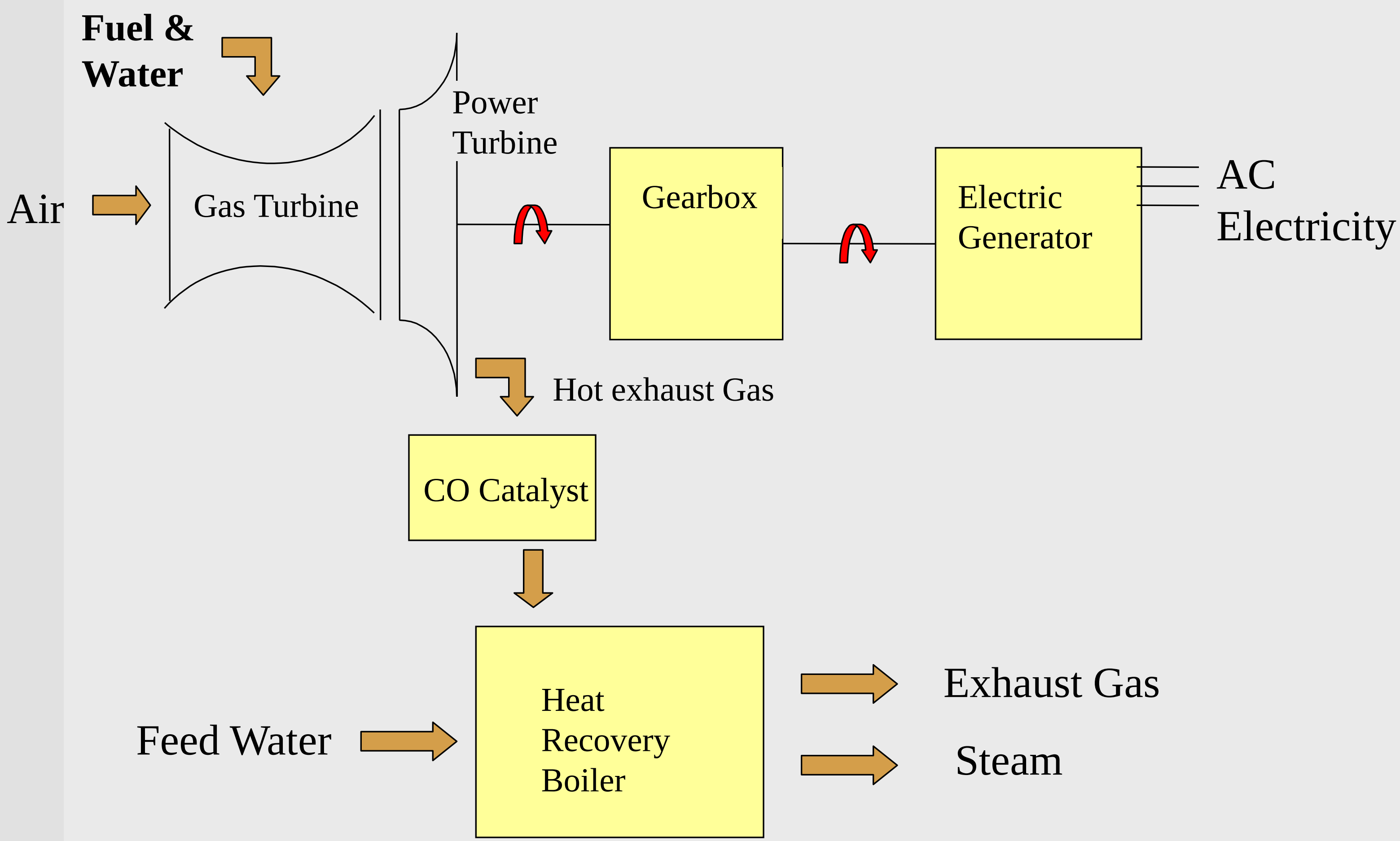
Princeton Chilled Water Use



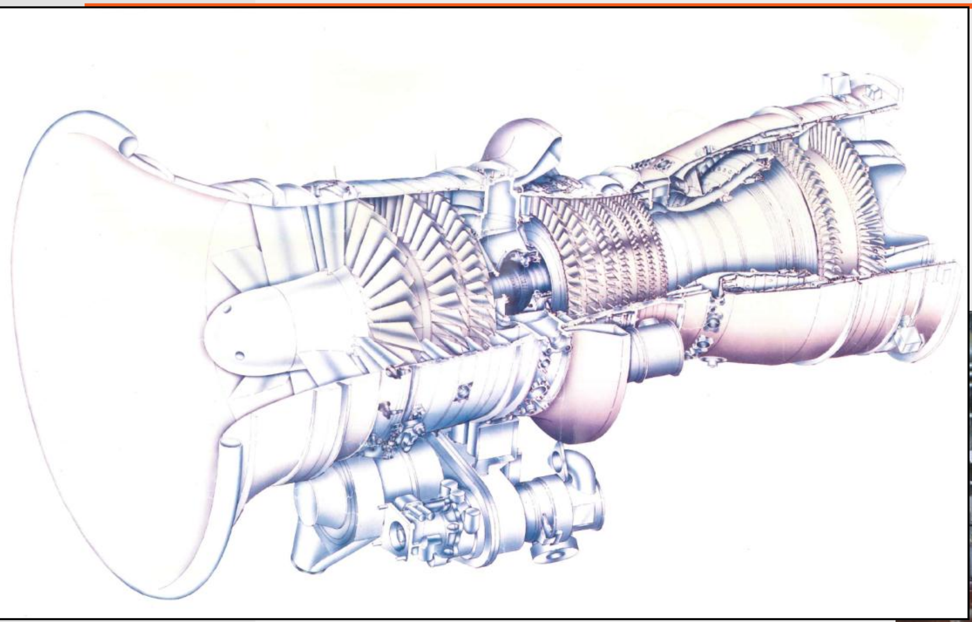
Princeton Summer Steam Use

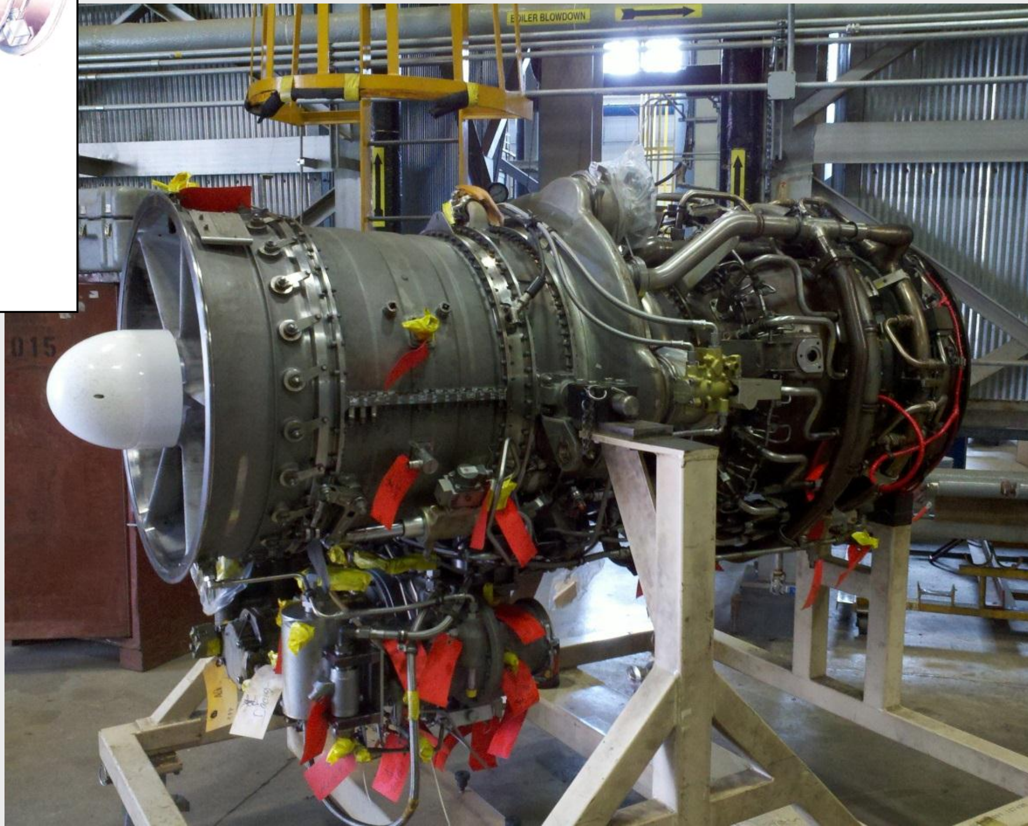


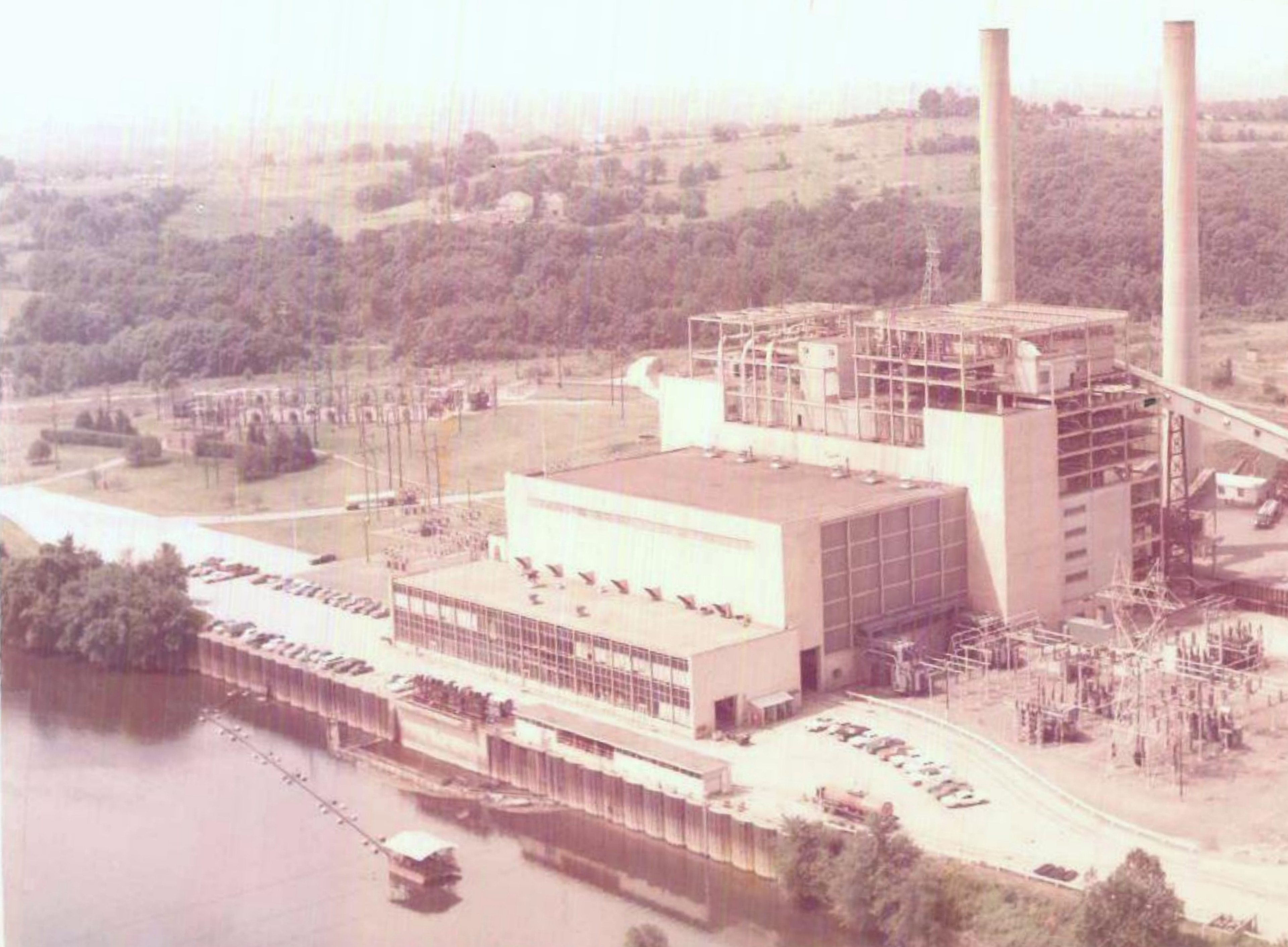
Combined Heat & Power, "Cogeneration"



The GE LM-1600 Gas Turbine

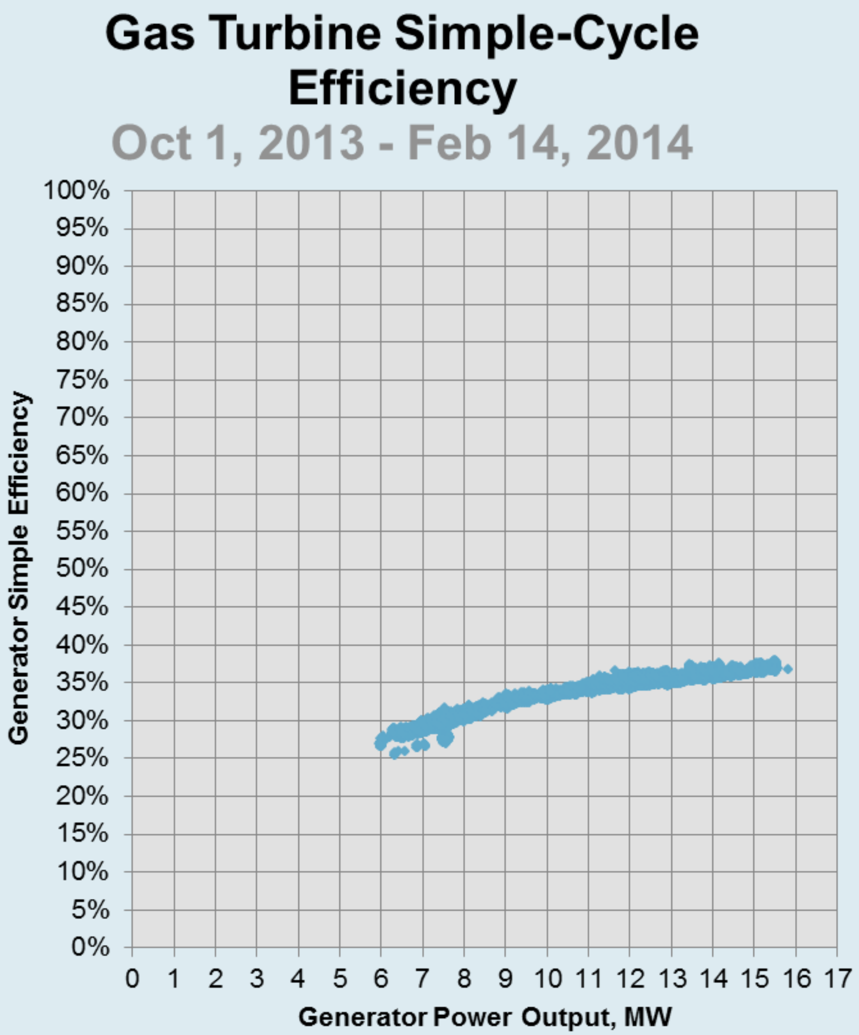


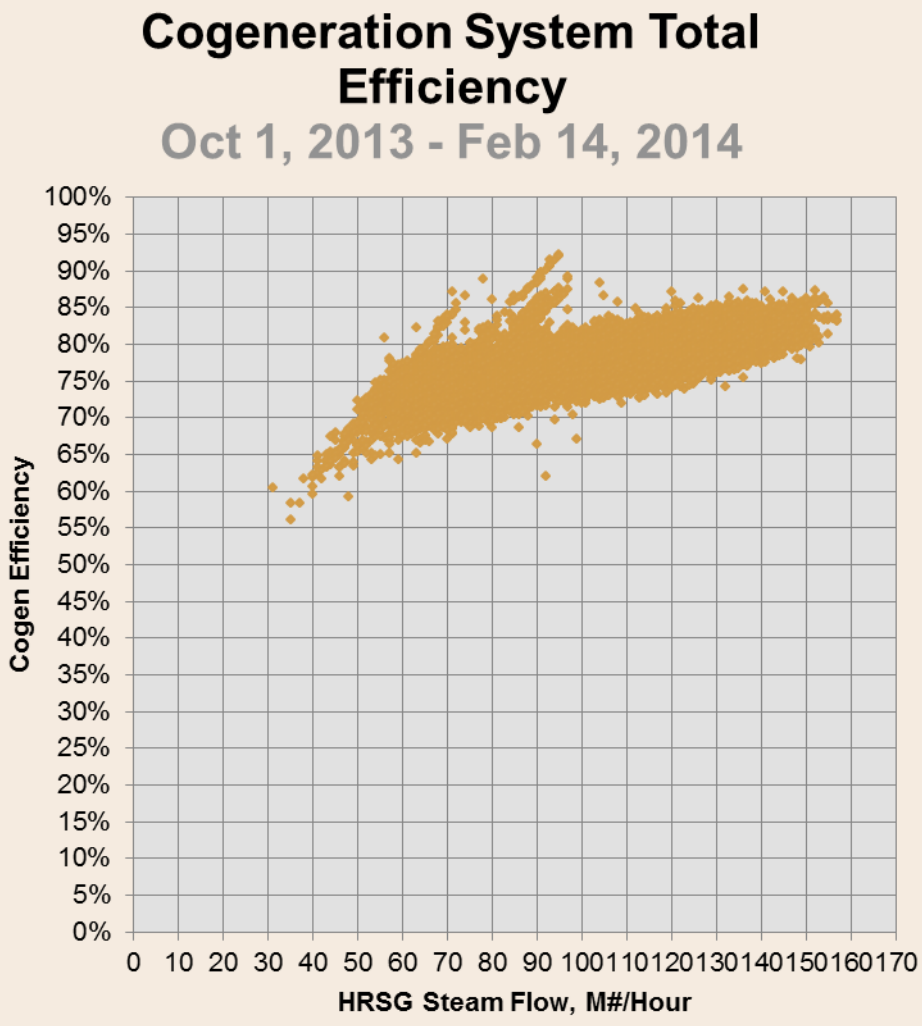




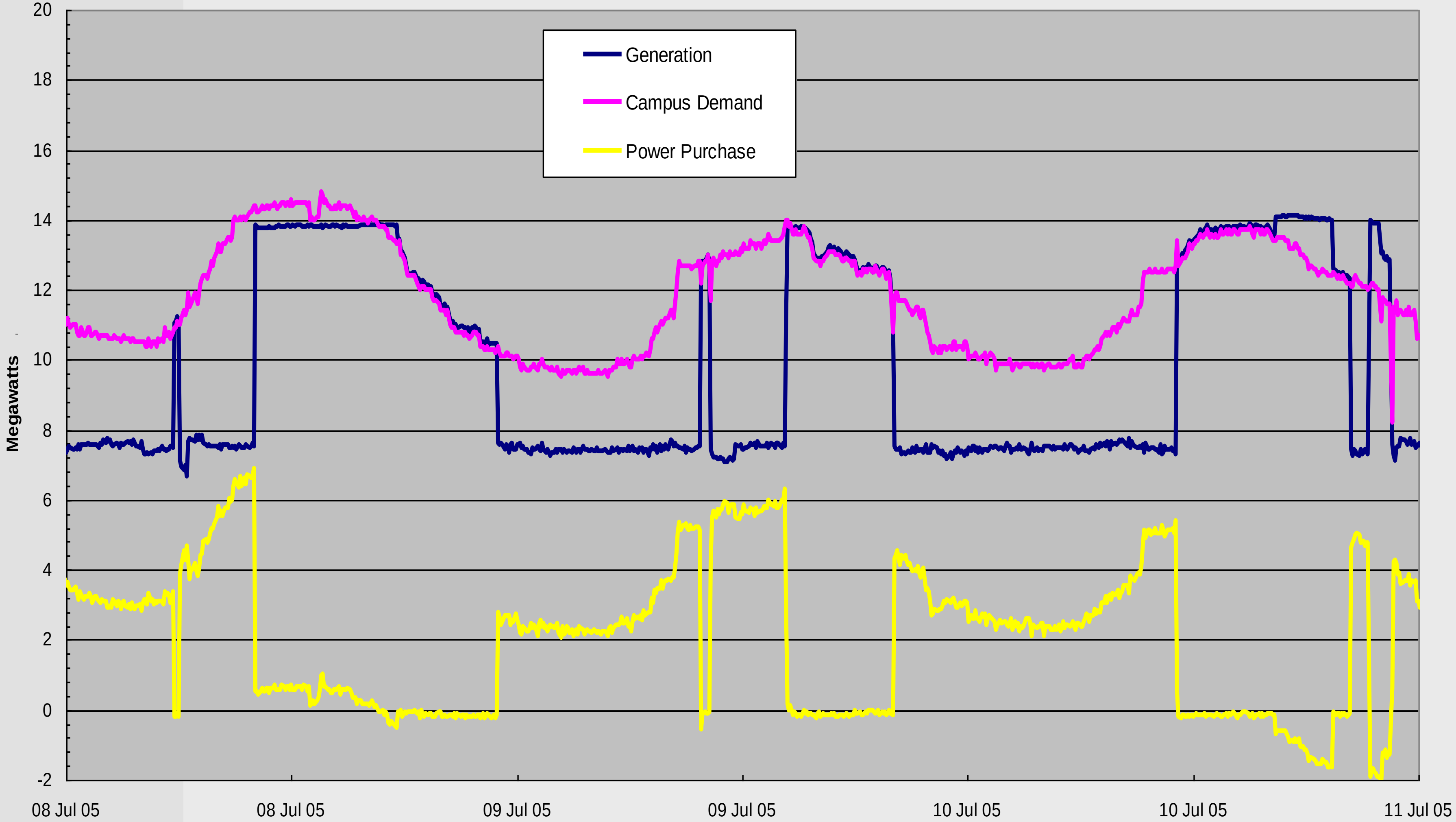
PHILADELPHIA ELECTRIC CO.

How Much More Efficient is Combined Heat & Power?





Princeton Power Demand
With Cogen Dispatch To Minimize Cost

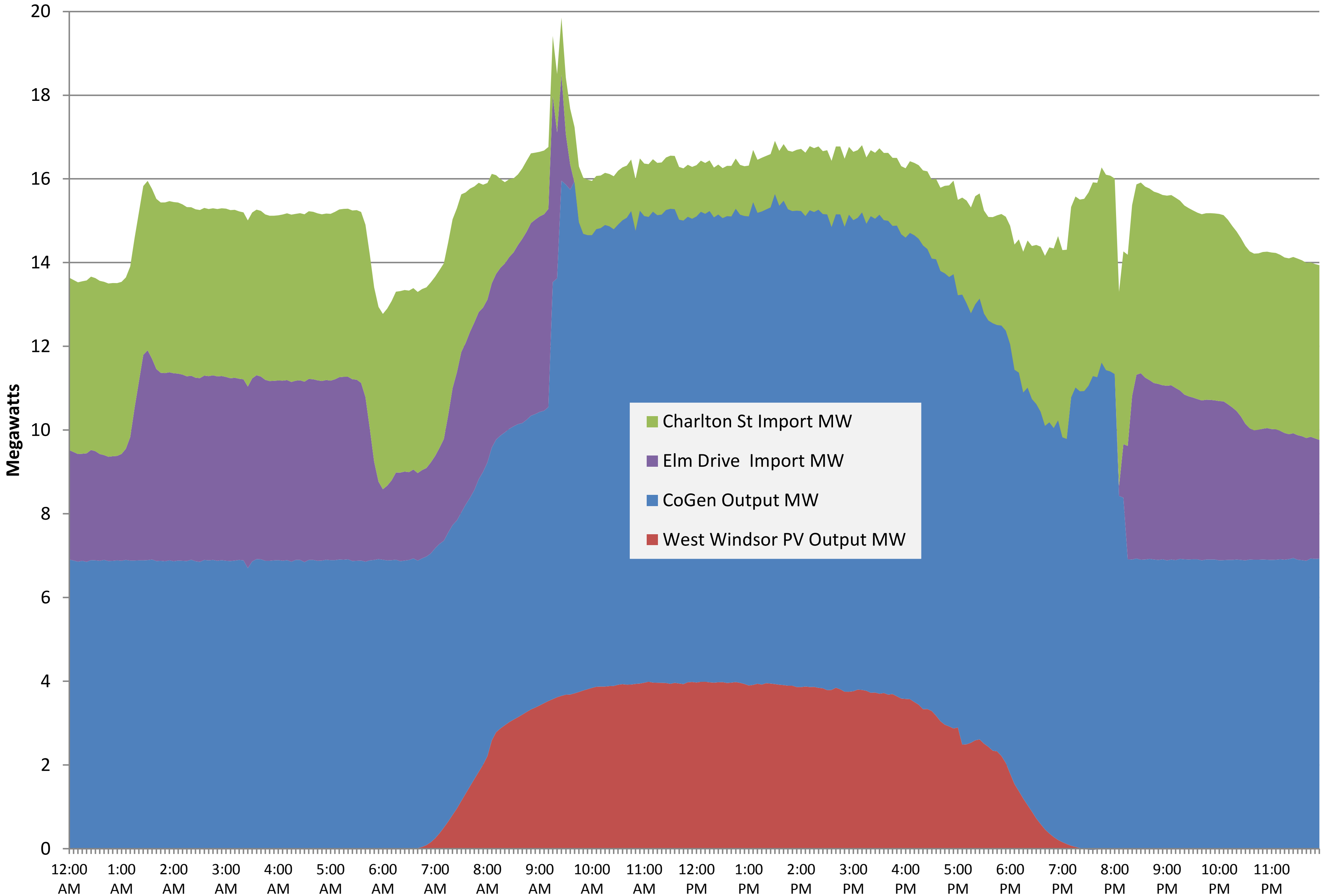


Princeton Solar PV

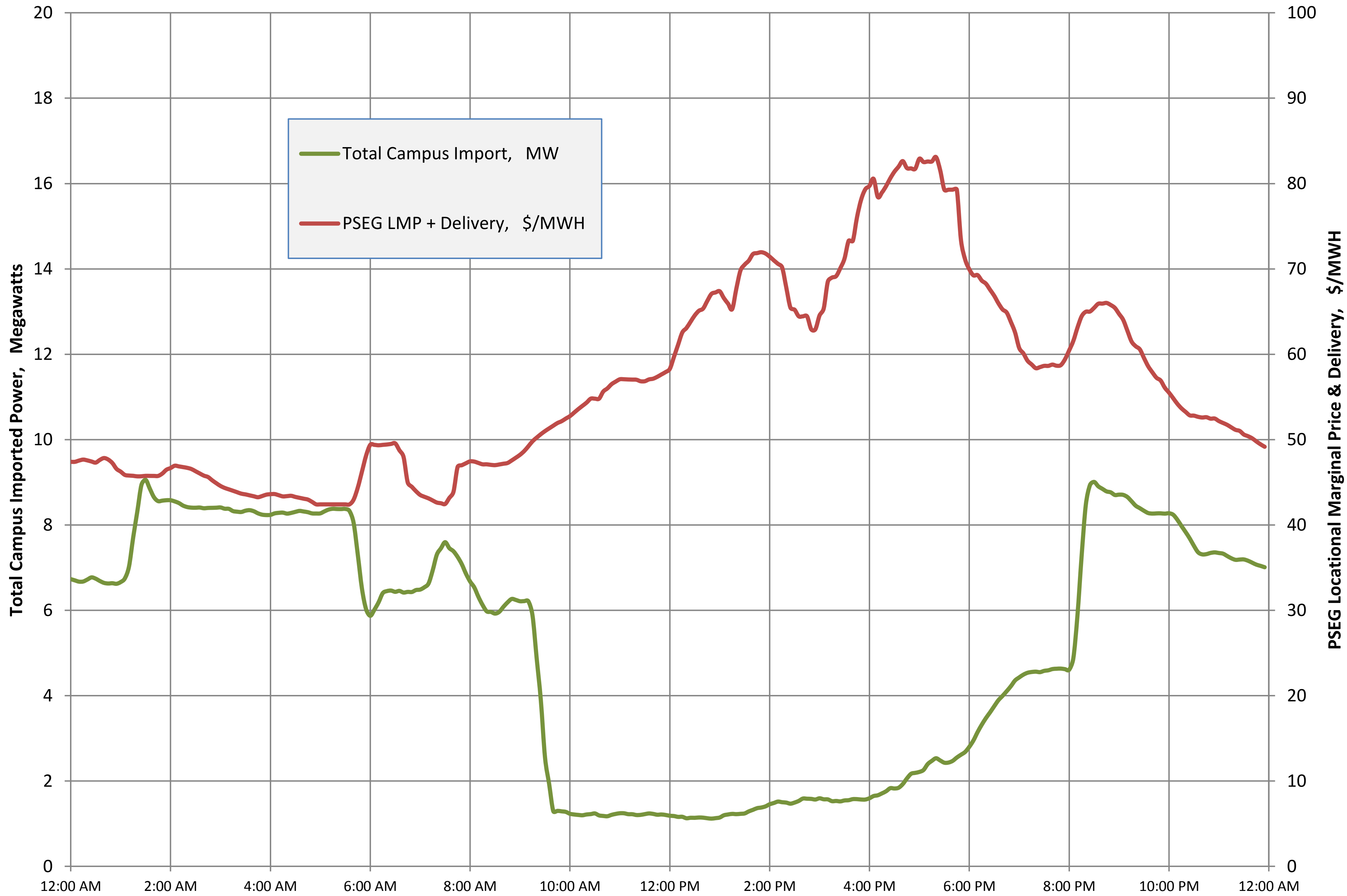
- 5.3 MW DC
- 27 Acres
- Lease equipment
- Own all power and Solar Renewable Energy Credits from day one
- Sell SRECs until system is paid for
- Eventually stop selling SRECs and claim all avoided CO_2


0466
www.AerialPhotosofNJ.com

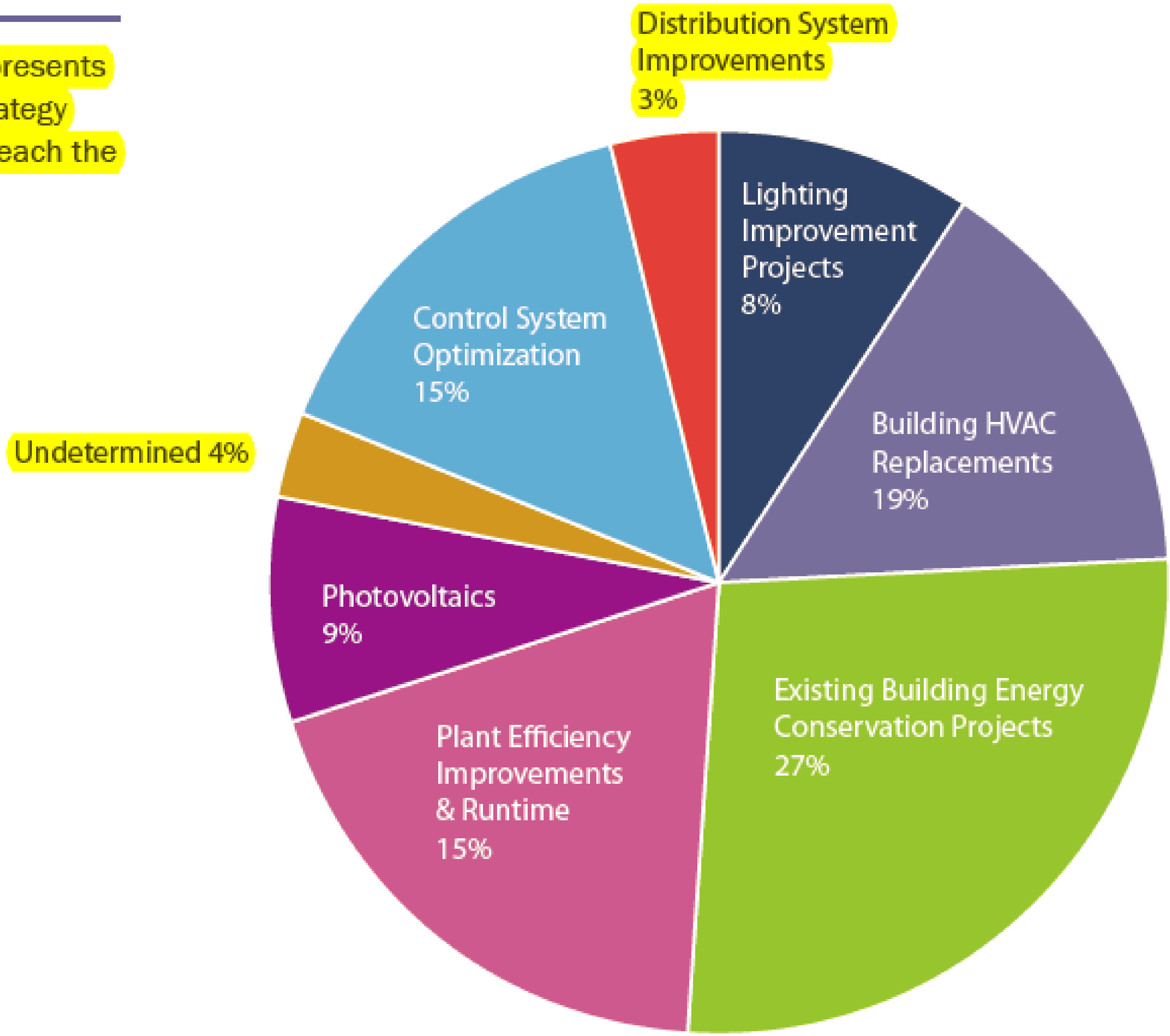
Main Campus Power, Generated & Purchased
During PV System Testing August 30, 2012

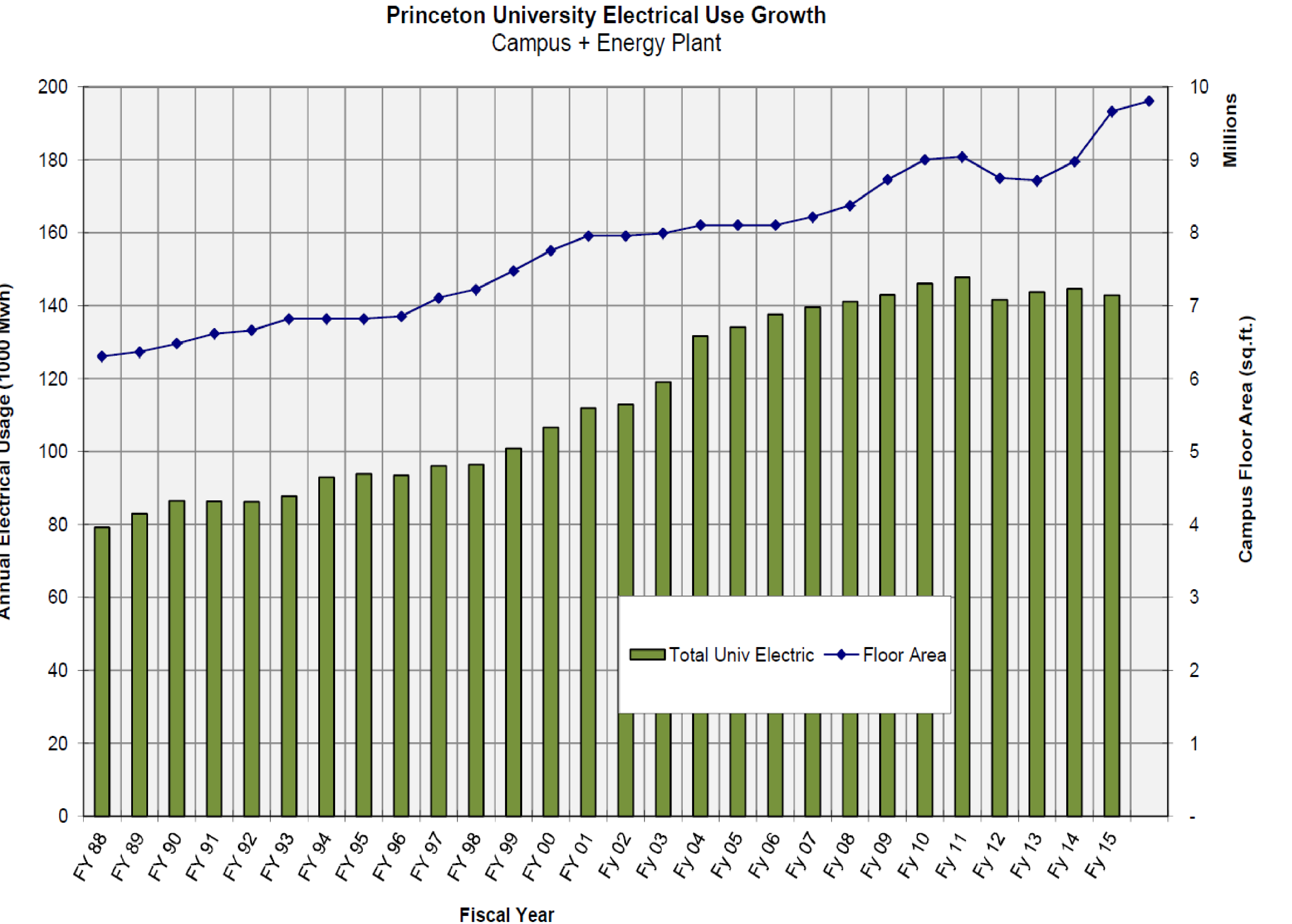


Purchased Power and Power Price
During Solar PV Testing   August 30, 2012



Each pie wedge represents a CO_2 reduction strategy under way to help reach the 2020 goal.





Princeton University Electrical Use Growth
Campus + Energy Plant
Annual Electrical Usage (1000 Mwh)
Campus Floor Area (sq.ft.)
Millions
Fiscal Year
Total Univ Electric
Floor Area
0
20
40
60
80
100
120
140
160
180
200
-
1
2
3
4
5
6
7
8
9
10
FY 88
FY 89
FY 90
FY 91
FY 92
FY 93
FY 94
FY 95
FY 96
FY 97
FY 98
FY 99
FY 00
FY 01
Fy 02
Fy 03
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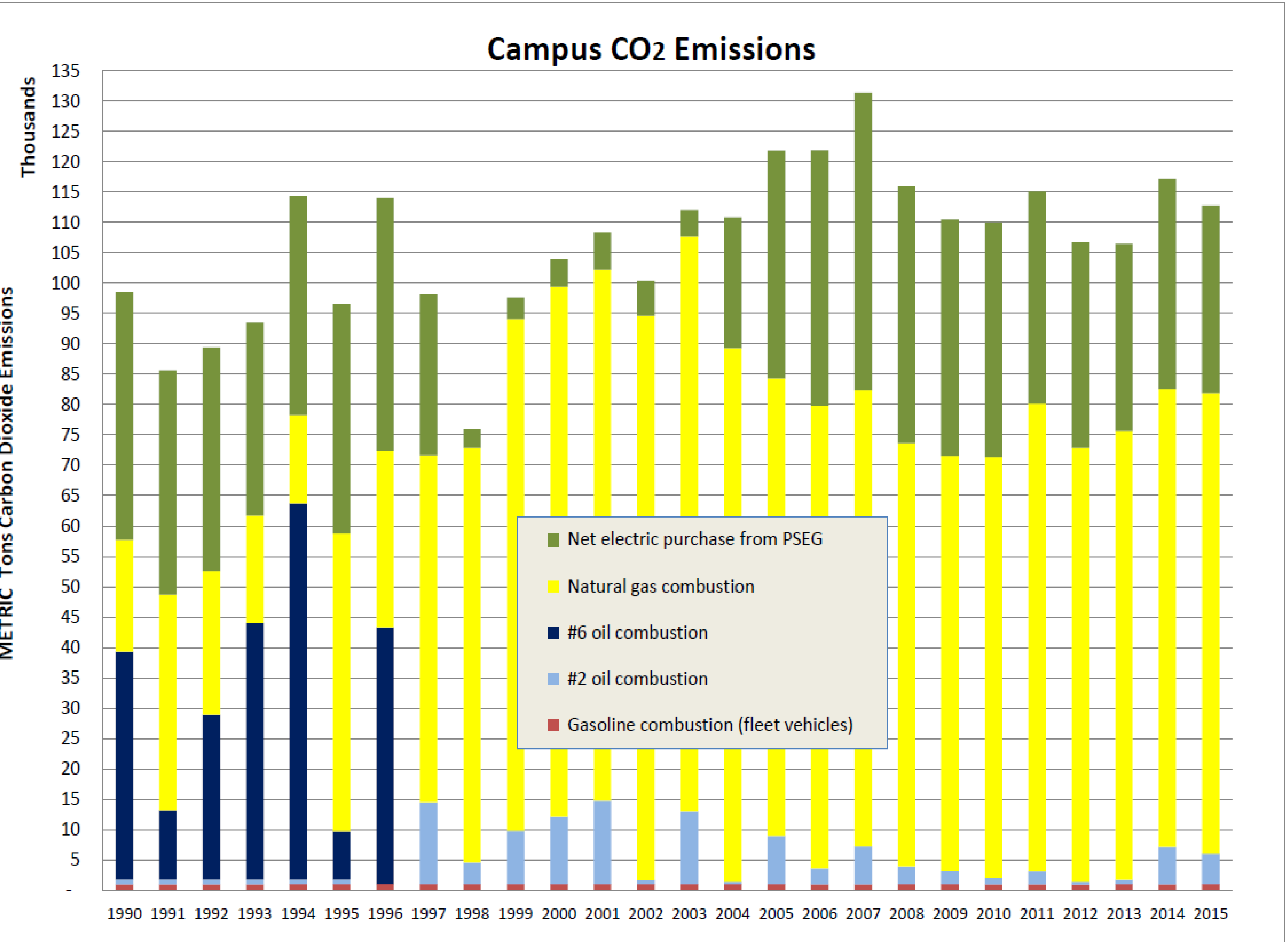
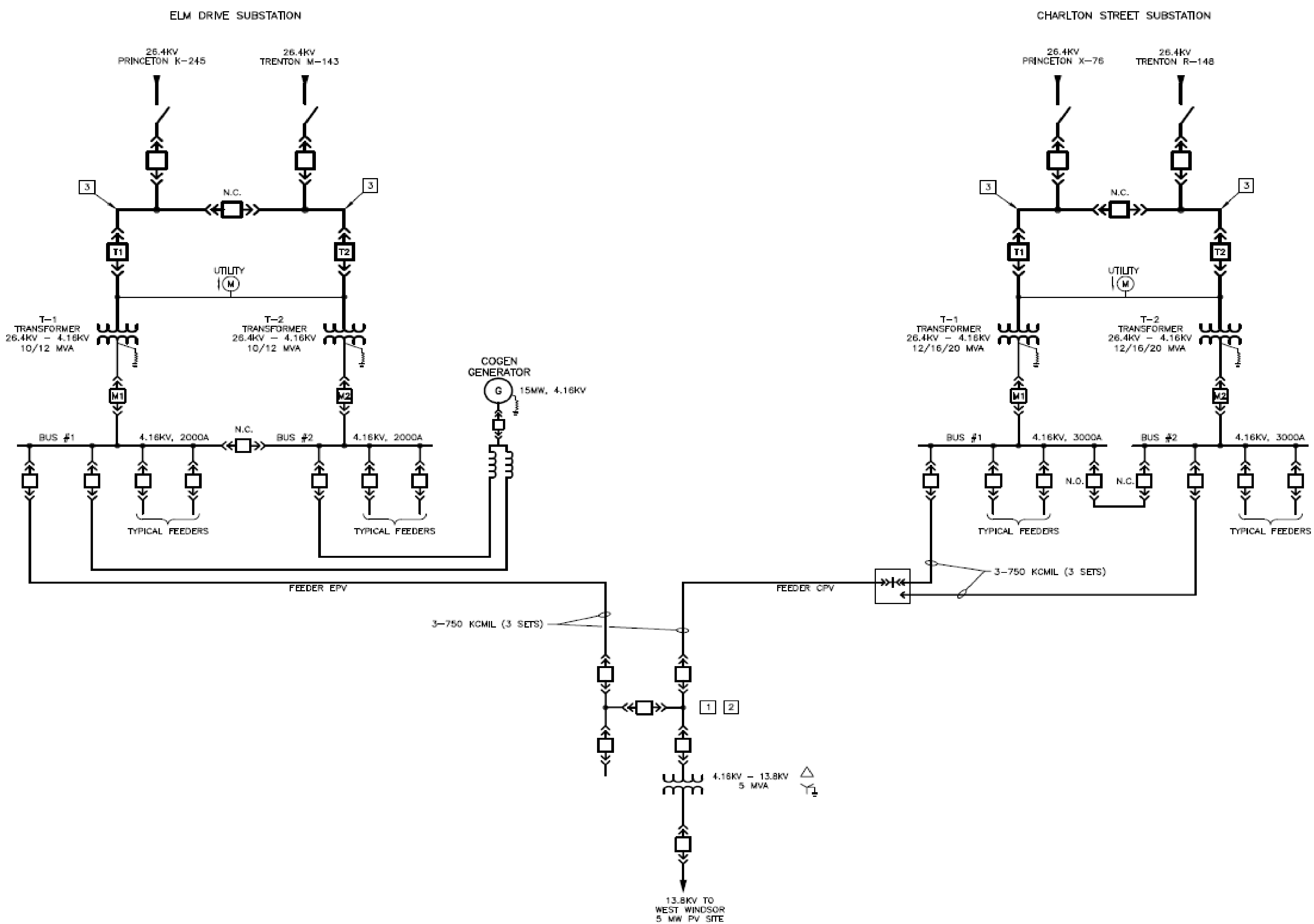
Fy 12
Fy 13
Fy 14
Fy 15

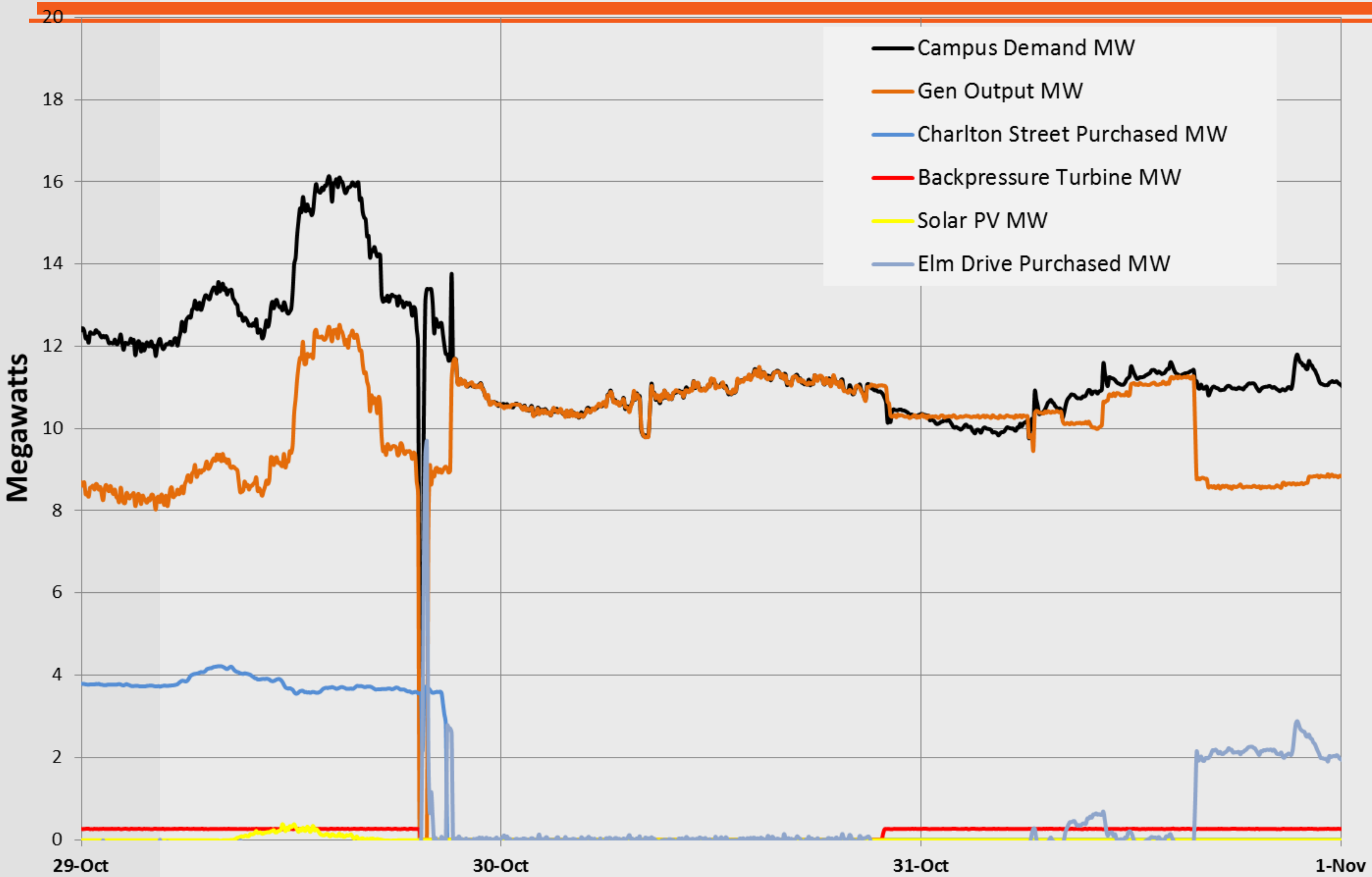


Campus CO2 Emissions
Thousands
METRIC Tons Carbon Dioxide Emissions
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Net electric purchase from PSEG
Natural gas combustion
#6 oil combustion
#2 oil combustion
Gasoline combustion (fleet vehicles)

Princeton Campus One-Line

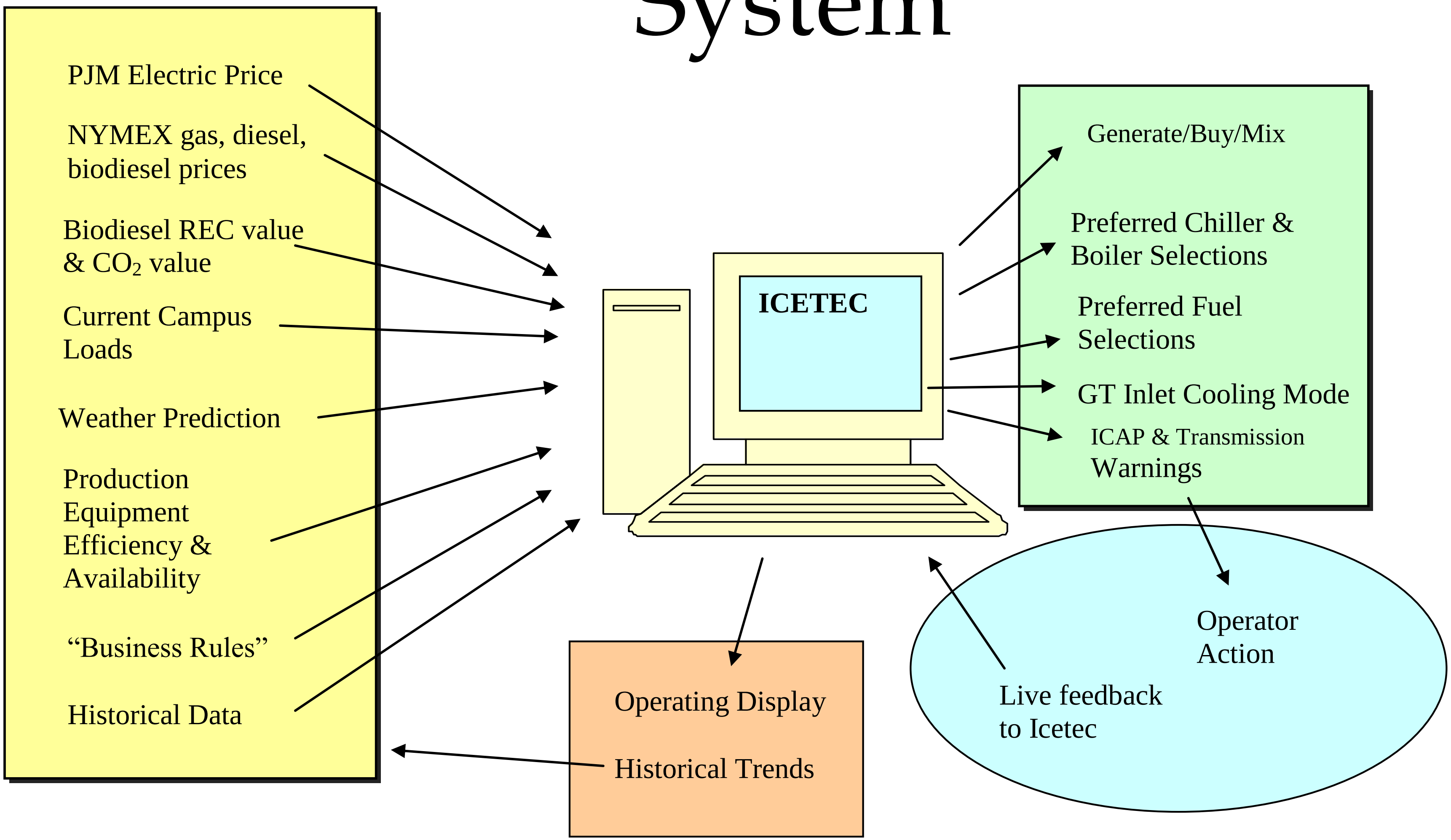


Campus Power During Hurricane Sandy

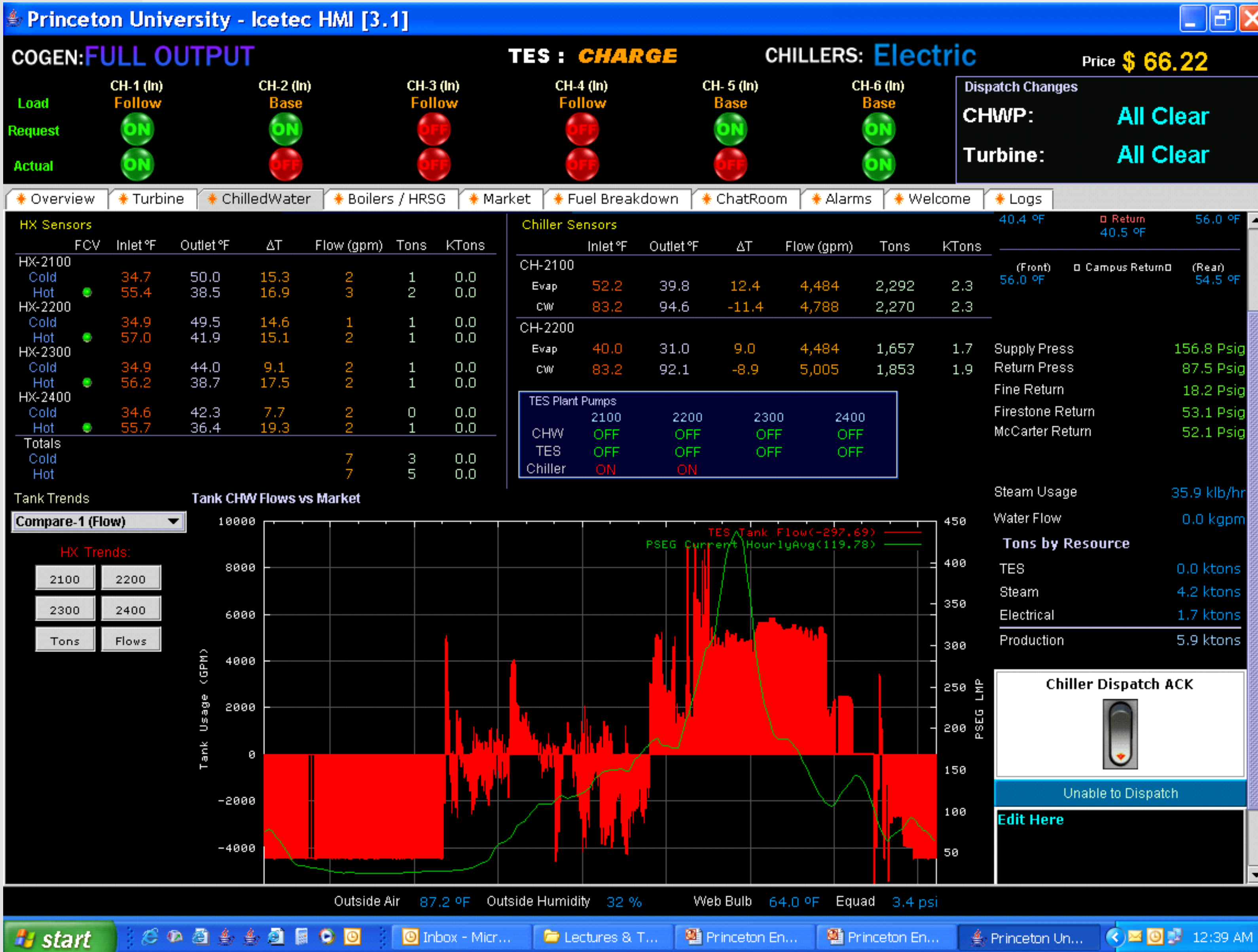


Economic Dispatch and ICETEC SmartGrid System

Princeton Economic Dispatch System



TES Economic Dispatch Screen



Icetec Overview

From Smart Meter to Smart Grid

- Quality metering on all inputs and outputs in system
- Visualize and interact with the data in real-time
- Centralized repository and front end
- Predicative analytics about load, weather, markets
- Solve for optimal interaction with Macrogrid

Distributed Resource Fallacy

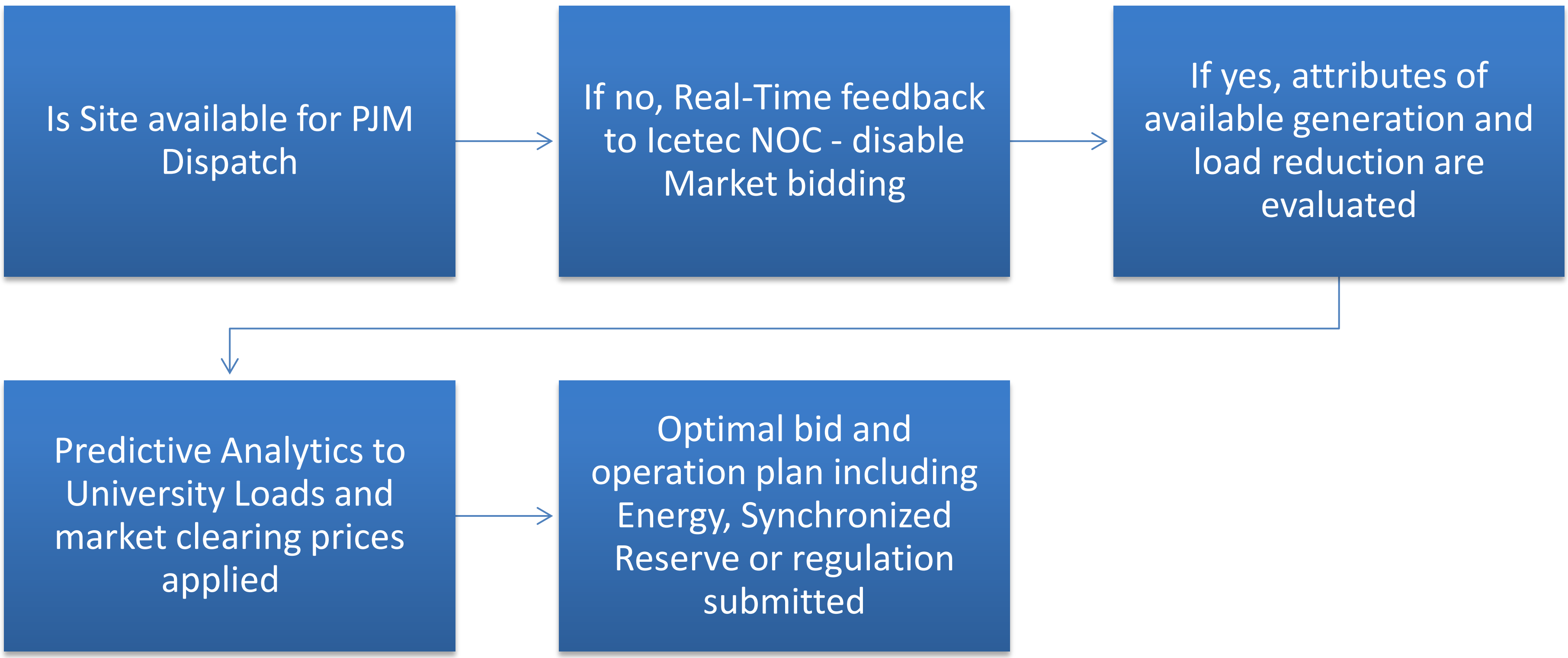
- *Average* retail rate = $.09
- *Average* cost of self generation = $.075
- Conclusion: Run local generation (*on average*) 24/7
- **Best payback occurs** with incentives to integrate DER flexibility into **Hourly Energy Markets**

Rolling Prior 12 Months (PSEG)	
Min Hourly LMP:	-$228/MWh
Frequency of Hours below $10	220
Frequency of Hours below $20	>1,500
Average LMP in lowest 2,000 hours	$14.6 or $.0146/kWH

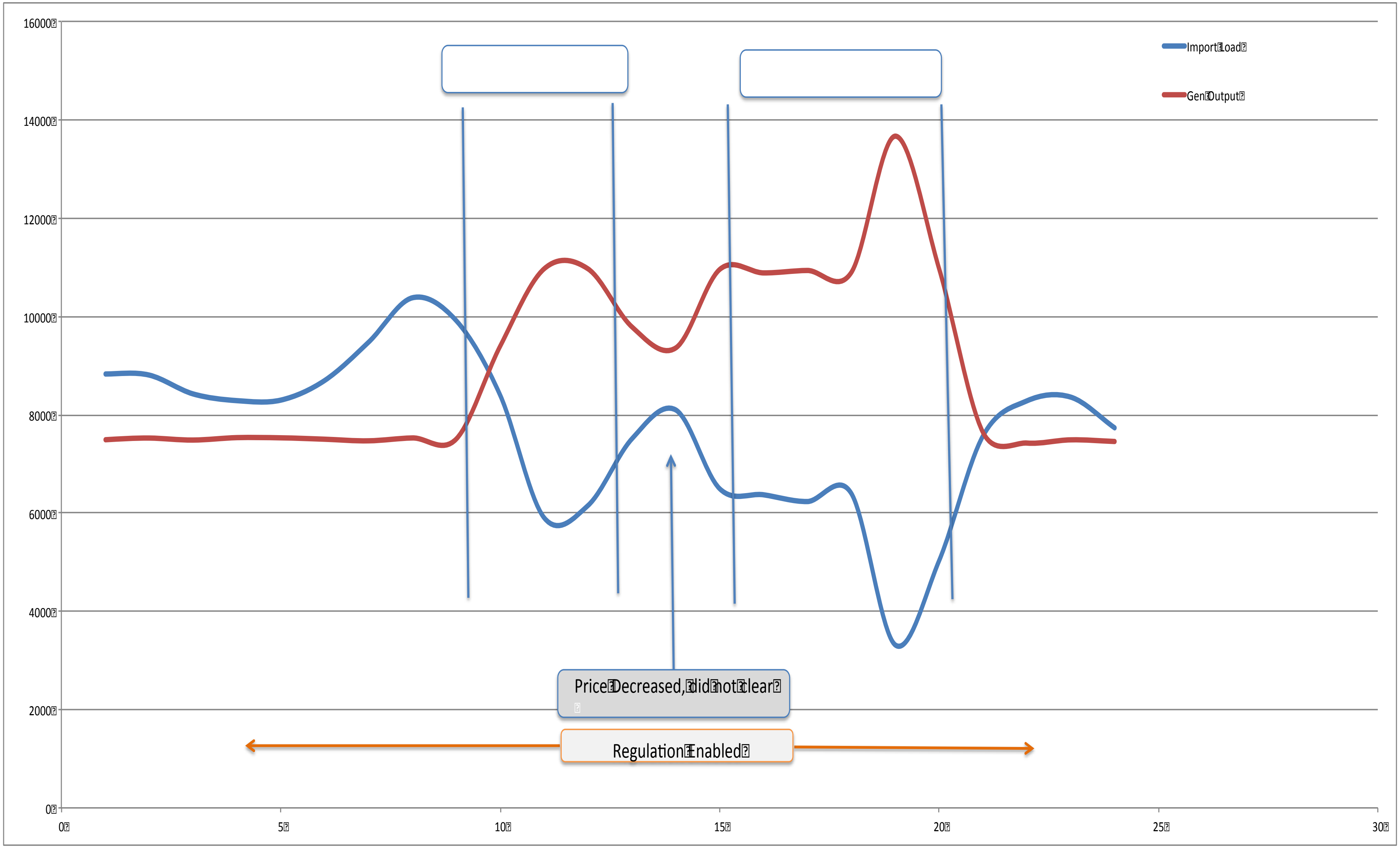
Princeton Participation in PJM

- Princeton currently provides **Energy**, Tier-2 **Sync Reserves** and dynamic **Frequency Regulation (FR)** with the central energy plant

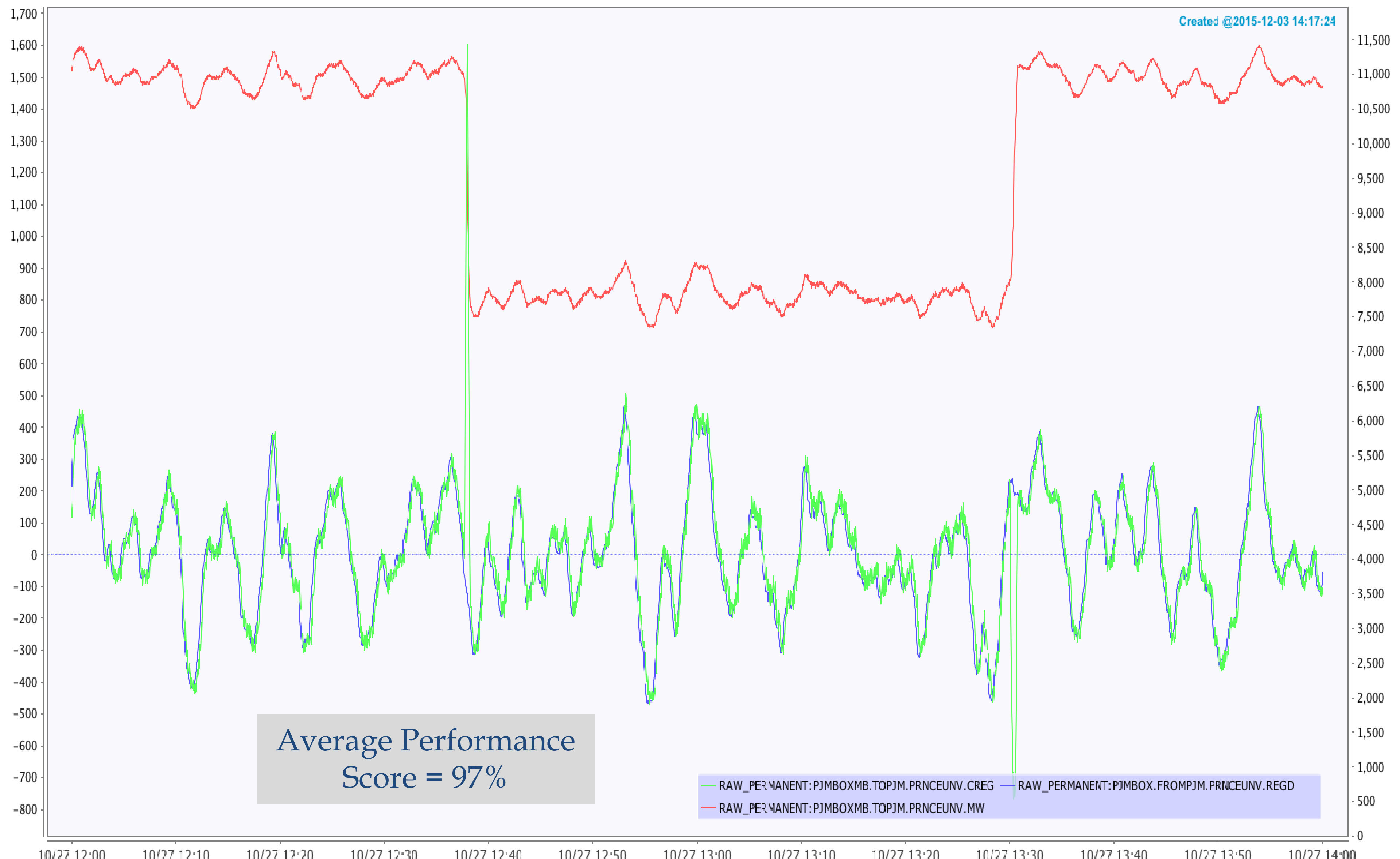
- These are market commitments being evaluated and optimized in every hour based on market analytics, site loads, available assets



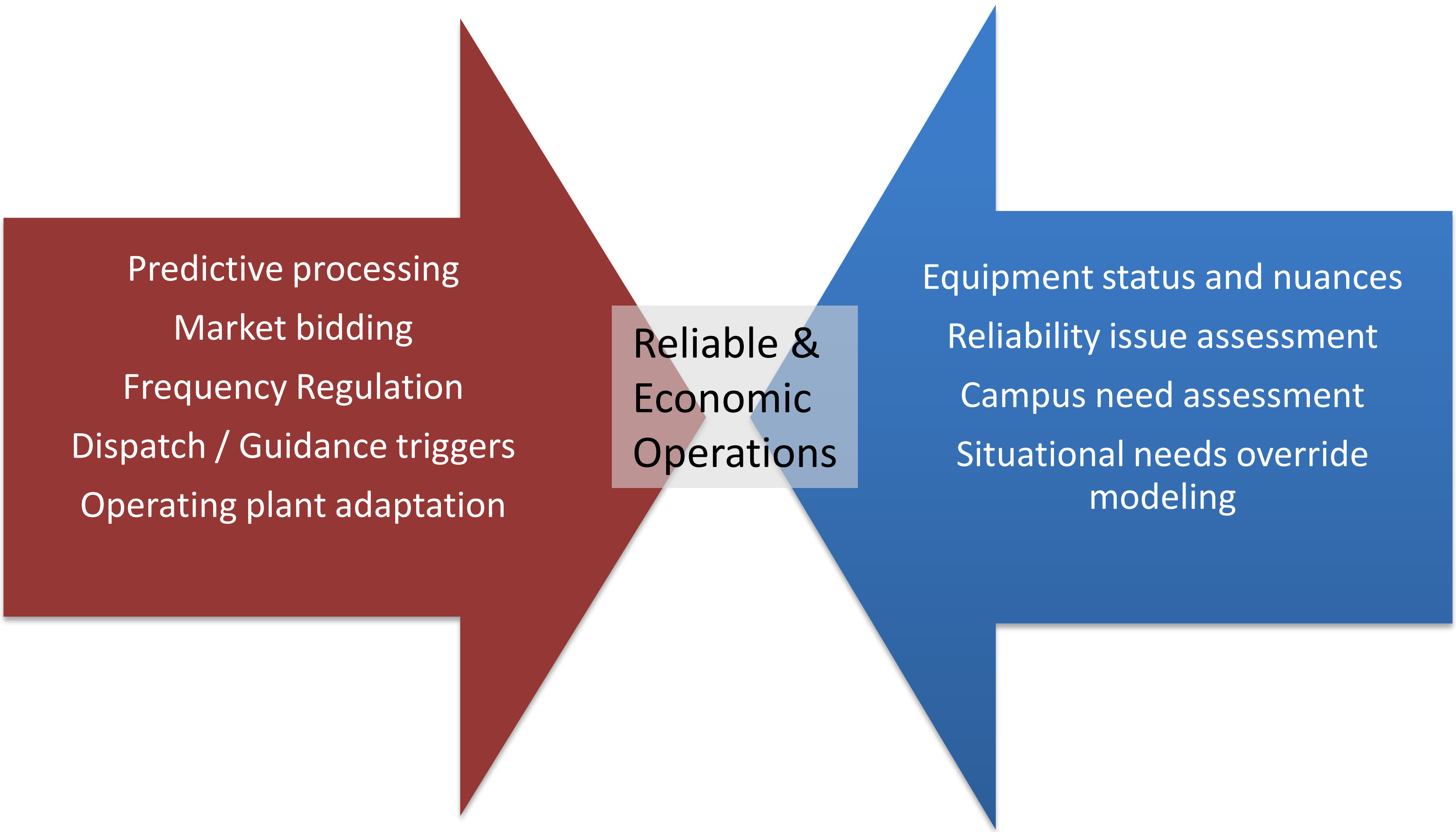
Princeton Participation in PJM



Raw Data – Two Hour Period



Balance between Automation and Oversight



Category	Grid/ Societal Benefits	Recognized by	Details
Grid Service	Energy	PJM pending EPSA appeal	Hourly Market
Grid Service	Capacity	PJM pending EPSA appeal	Annual Market
Grid Service	Fast Start Reserves	PJM	Hourly Market
Grid Service	Frequency Regulation	PJM	Hourly Market
Grid Benefit (High voltage or Low)	Reactive / Var Control, Frequency Response	Not currently recognized by distributed resources	Who best to recognize this service?
Grid Benefit	Fuel Switching/Dual fuel	Not directly recognized	Who best to recognize this service?
Societal/Grid	Resiliency, Source of Refuge	Not directly recognized with recent exceptions	**How** best to recognize this service?
Societal/Grid	CO2 Management, Thermal Efficiencies	Not directly recognized with recent exceptions	**How** best to recognize this service?

With Supreme Court Looming…

- *Important Considerations for states:*
  - Dispatch capable DR is a distinct product with distinguishable values from EE
  - Regardless of jurisdiction or payment issues, one benefit to Order 745 is it created a strong relationship between grid conditions and incentive to respond
  - State or local regulations aimed to affect ratepayer capacity charges must be incorporated into regional planning processes and drafted in a long standing manner

Best Practices / Closing Remarks

Must Do
For Microgrid Reliability

- Distributed base-load generator(s)
- Ability to run isochronous
- Ability to isolate generator-load combinations
  - Skilled, manual, in-person effort, not automatic
- Underground utility distribution
- Black start capability
- Gross load-shed capability

Should Do
For Microgrid Reliability

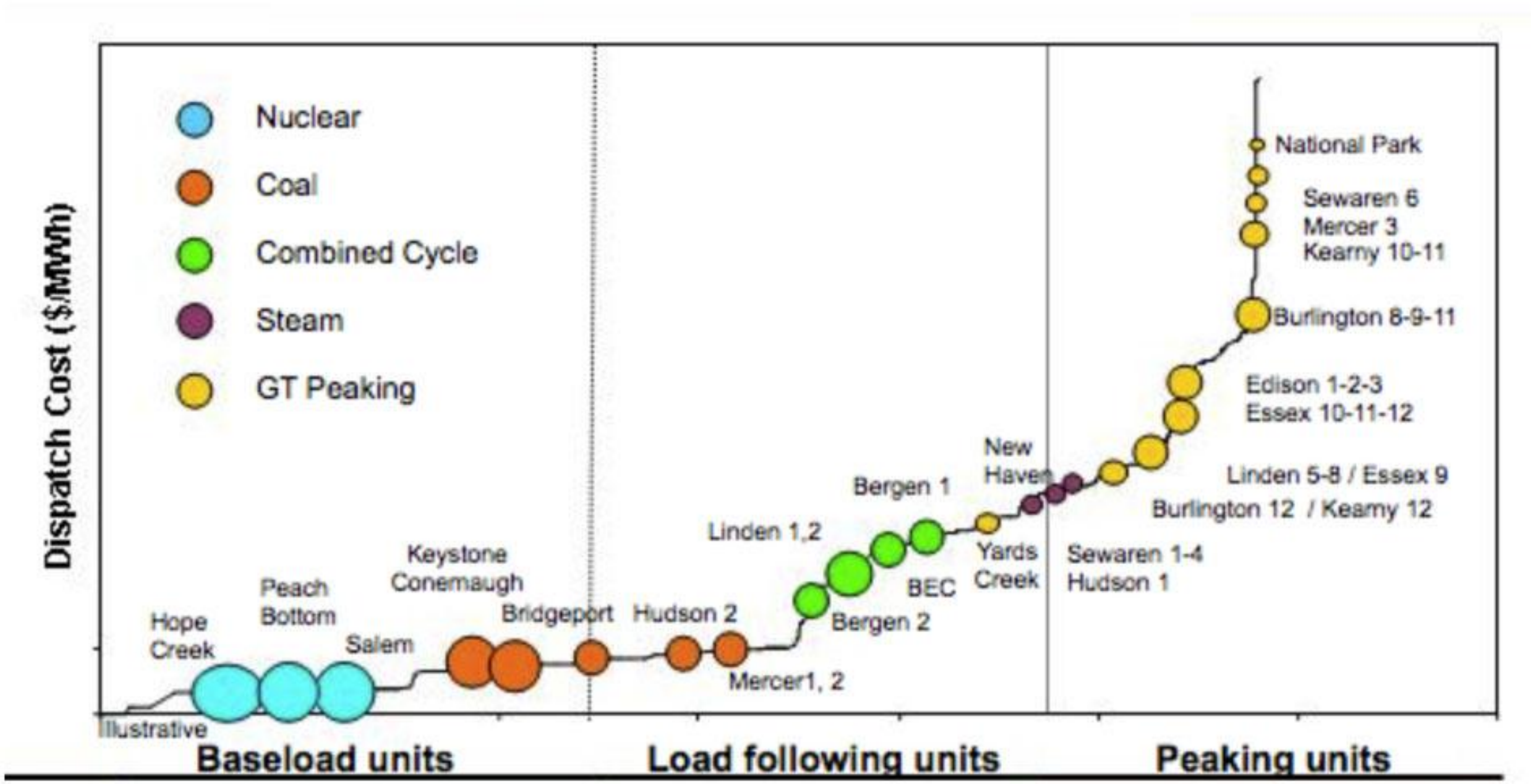
- Fully commission complete systems
- Re-test periodically
- Test using realistic conditions
- Building-level load-shed capability
- Multiple fuel options
- Use emergency response teams periodically
- Plan for human needs

Thank You

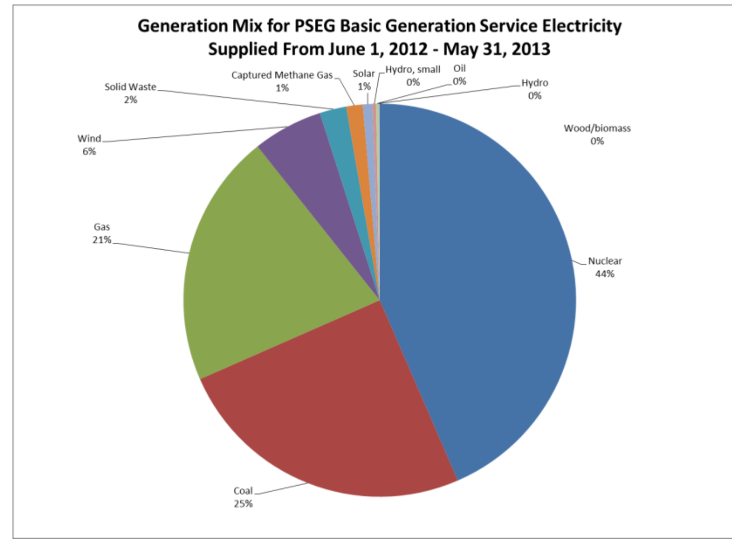
Appendix (or if we have time)

Macro vs Micro Efficiencies

PSEG “Generation Stack”

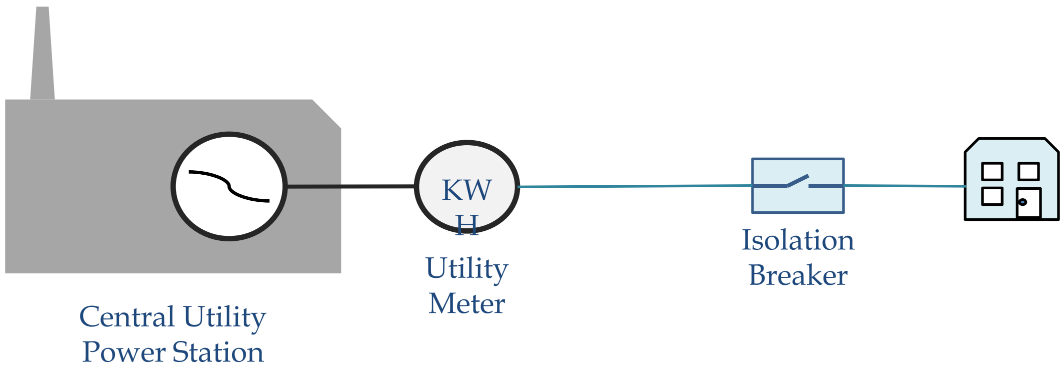


Large Utility Generating Plants Are Far Apart

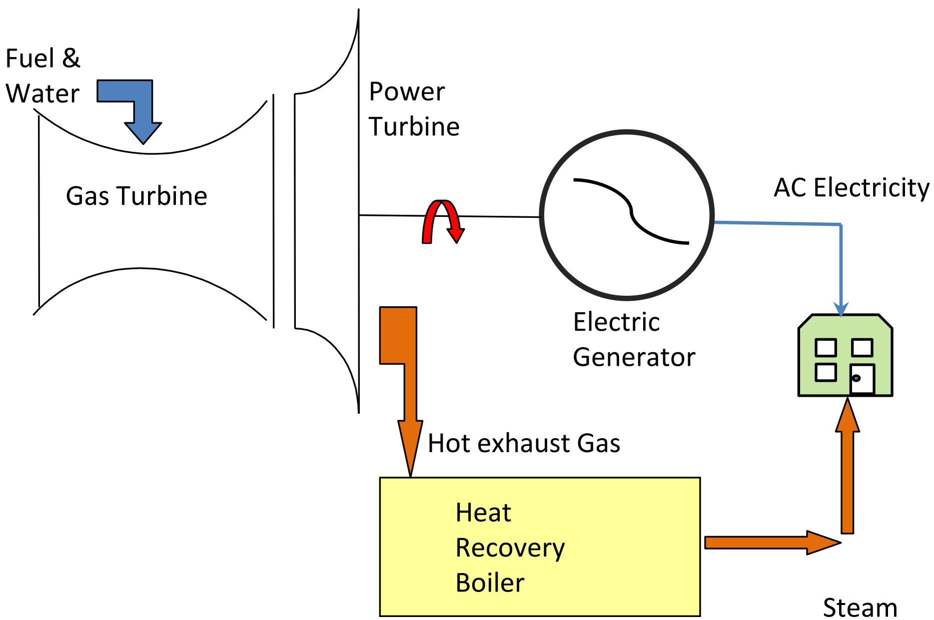


Central Atlantic coal and nuclear plants are shown

Efficient Use Can Beat Efficiency of Scale



25% – 45%
of fuel input →
electricity

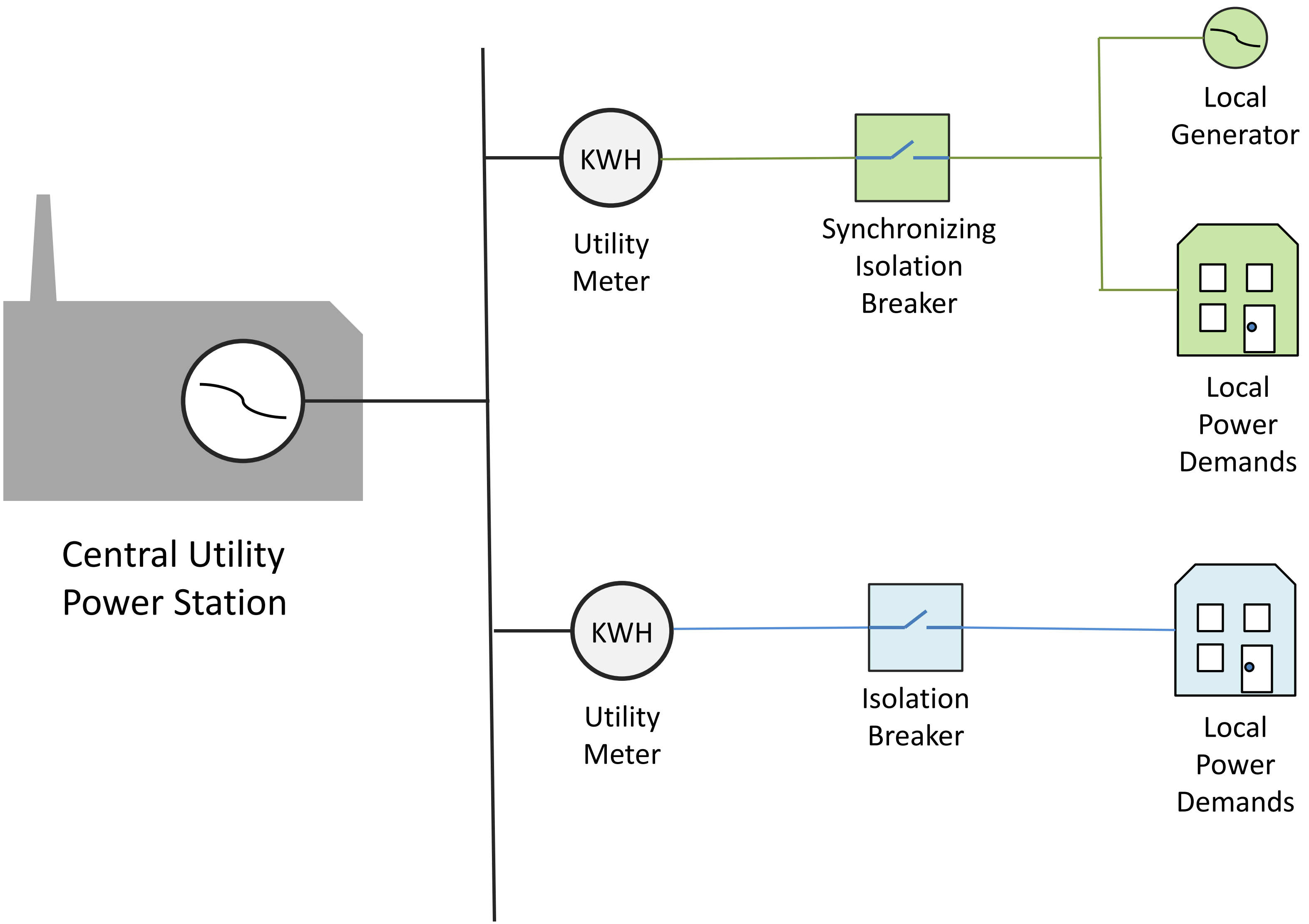


30% - 40%
of fuel input →
electricity

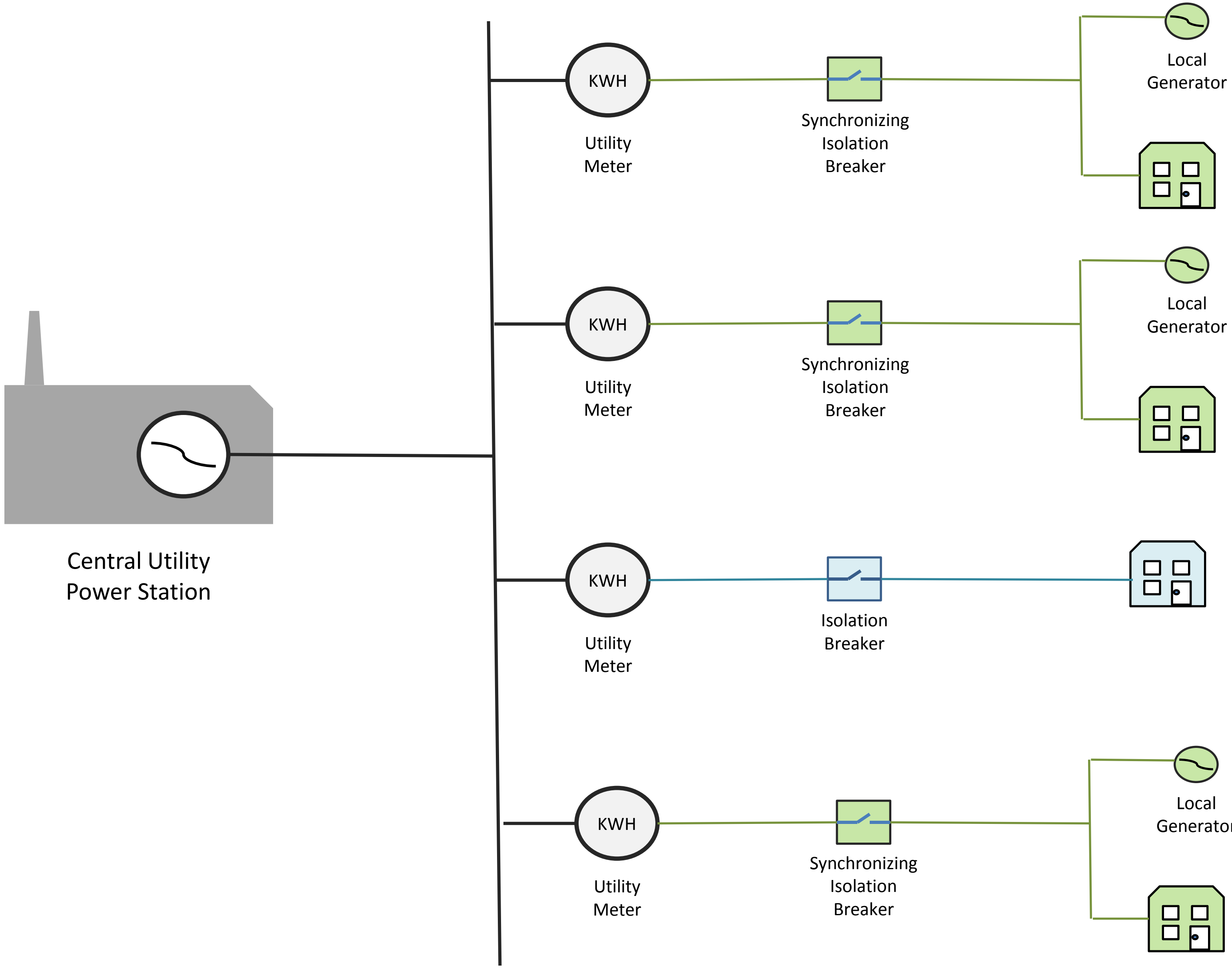
30% - 45%
of fuel input →
thermal energy

Campus Microgrid and Other Models

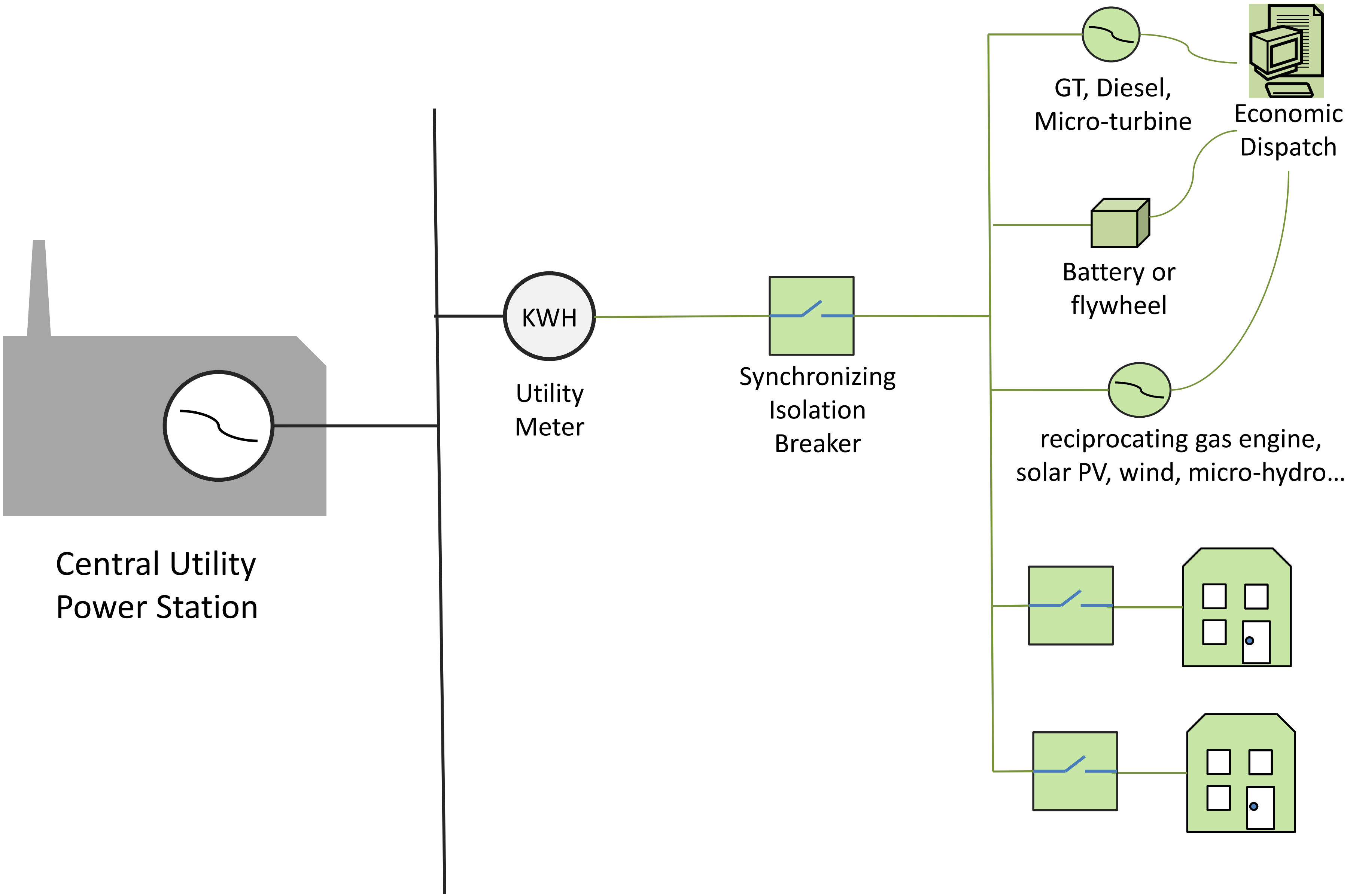
Simple Microgrid Concept



Microgrids Add Reliability



Microgrid Options

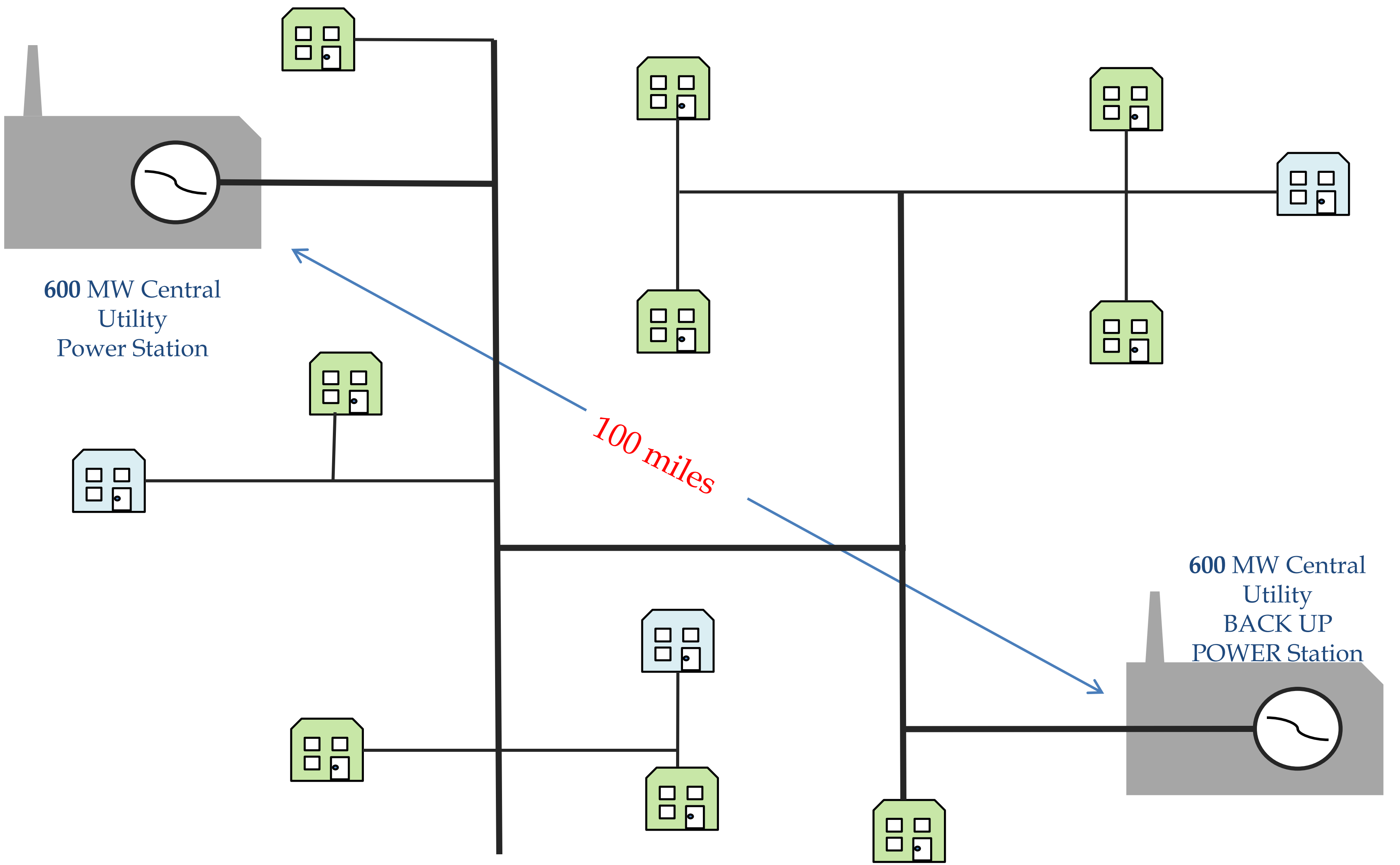


Utility Grid With Simple Redundancy

12 x 50 MW = **600 MW Demand**

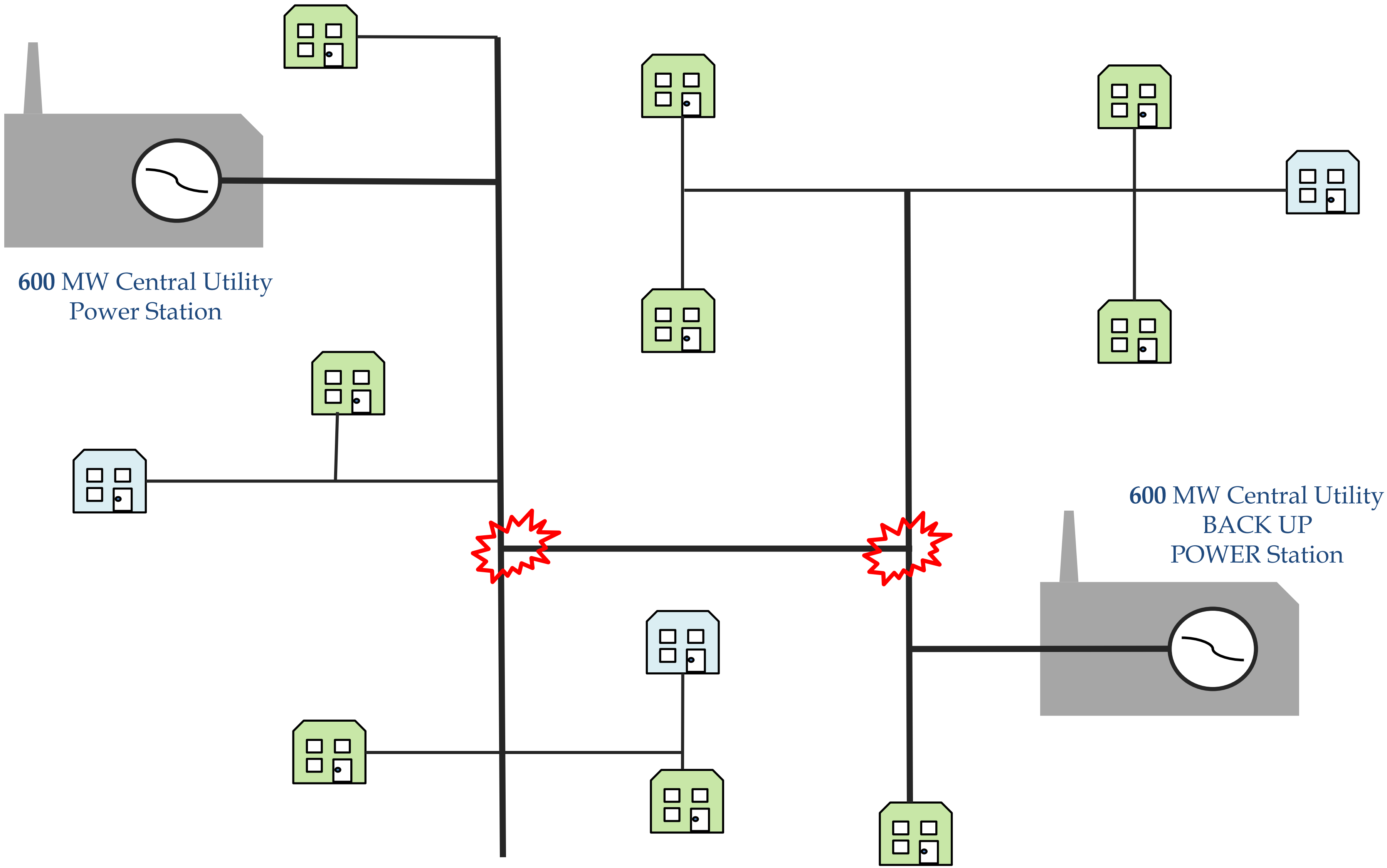
600 MW + 600 MW Back-Up = **1200 MW Installed Generation**

"N-1 Redundancy"



Utility Grid Vulnerability Points

12 x 50 MW = 600 MW Demand, 600 MW + MW Back-Up

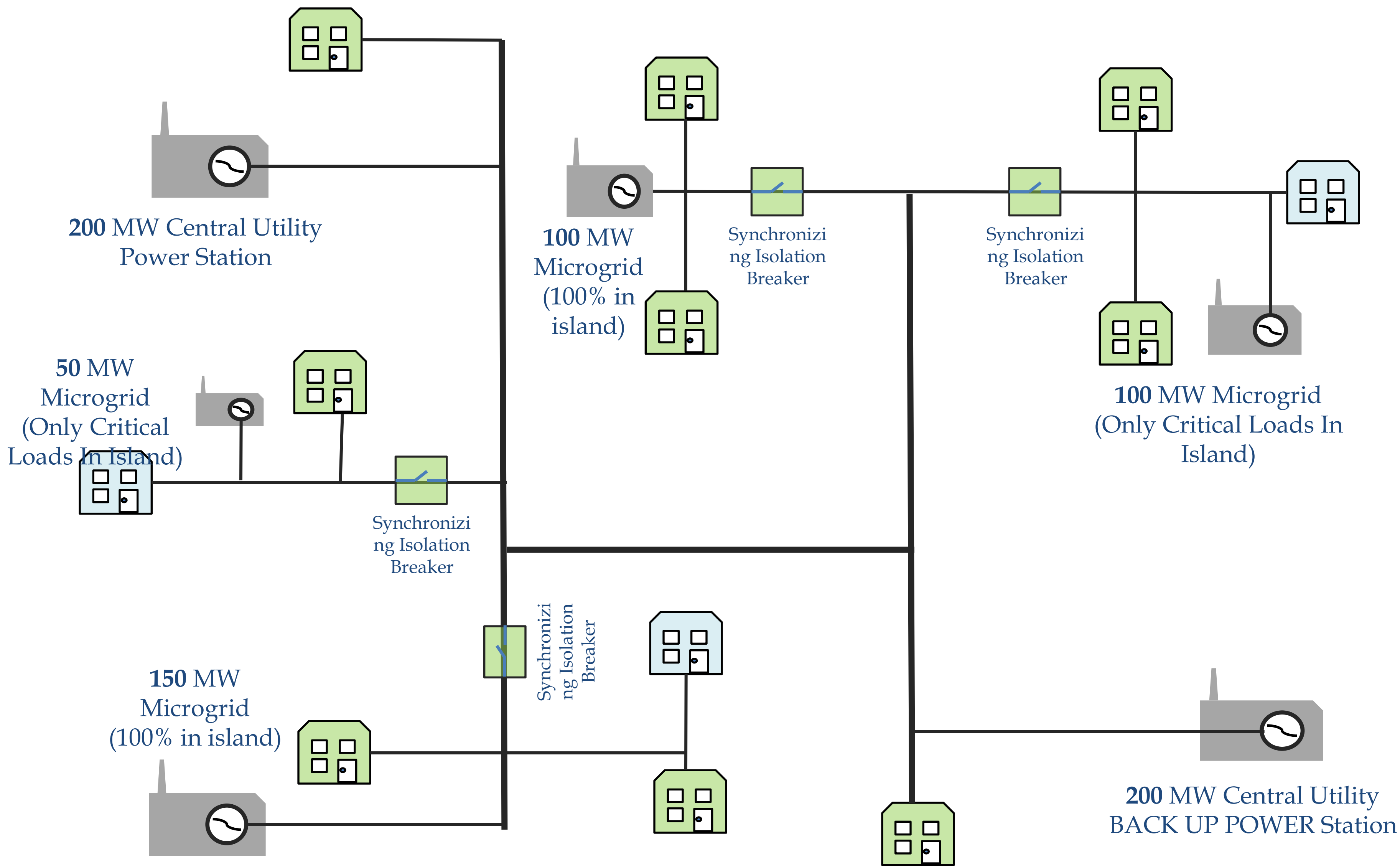


Utility + Distributed Microgrids = Diversity
Increased Resiliency, Less Idle Capacity

12 x 50 MW = **600 MW Demand**

400 MW Utility + 400 MW Microgrids = **800 MW Installed Capacity**

"*Near* N-2 Redundancy" + Reduced *Scale* of Emergencies



Two Zero-Interruption Strategies