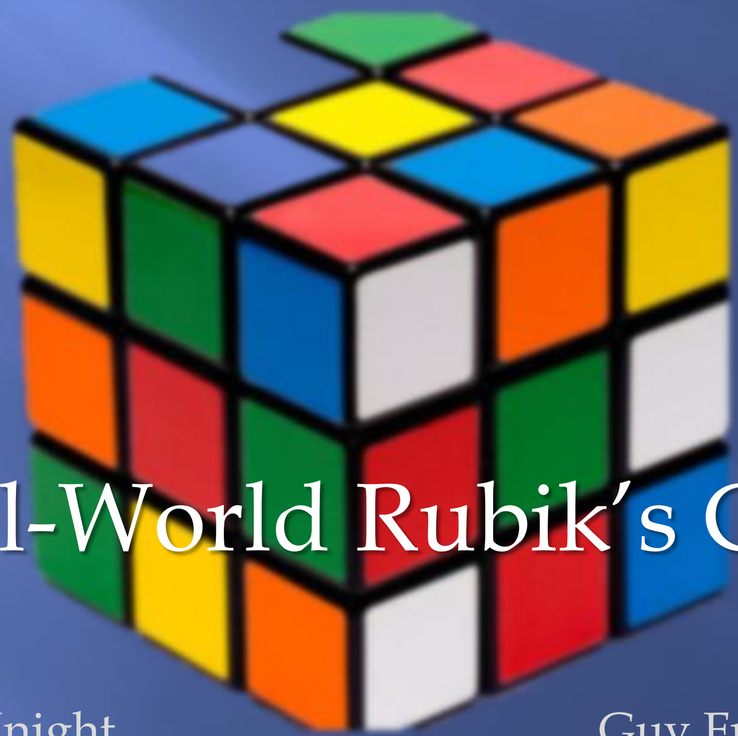
INTEGRATING THERMAL ENERGY STORAGE DISTRICT CHILLED WATER AND COMBINED HEAT & POWER



A Real-World Rubik's Cube

James C. Knight
Director – Energy & Utilities
Bucknell University

Guy Frankenfield, P.E.
Energy Business Unit Leader
DN Tanks

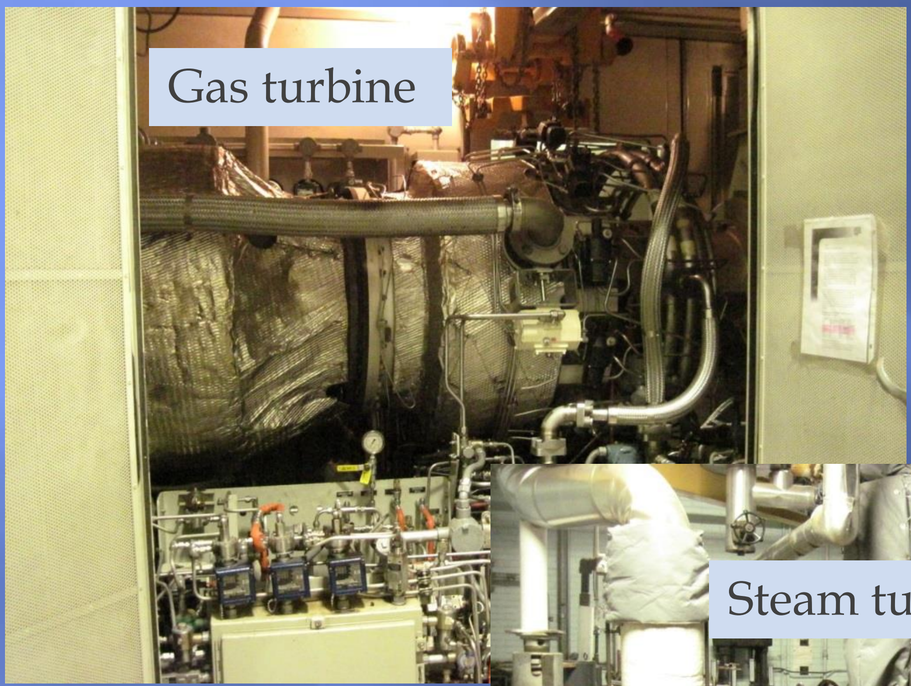
Bucknell University Facts

- Bucknell is a medium sized, private university located in Lewisburg, Pennsylvania.
- Founded in 1846.
- Known for liberal arts, engineering, and management curricula.
- Student population of 3,300 - 90%+ live on campus.
- Faculty and staff of over 1,000.
- Campus of 450 acres with 175 buildings totaling 2.9 million gross square feet.

Utility Infrastructure

- Combined cycle CHP plant, including 4.8 MW gas turbine, 70,000 lb/hr HRSG (25,000 lb/hr unfired), 1.2 MW steam turbine generator.
- Central chiller plant with three 800 ton variable frequency electric centrifugal chillers. Variable flow primary based on campus load.
- Distributed steam absorption chillers provide approximately 800 tons cooling capacity.
- Steam distribution to 88% of campus.
- CHW distribution to 69% of campus.
- CHP plant supplies 94% of campus electricity.

CHP Plant



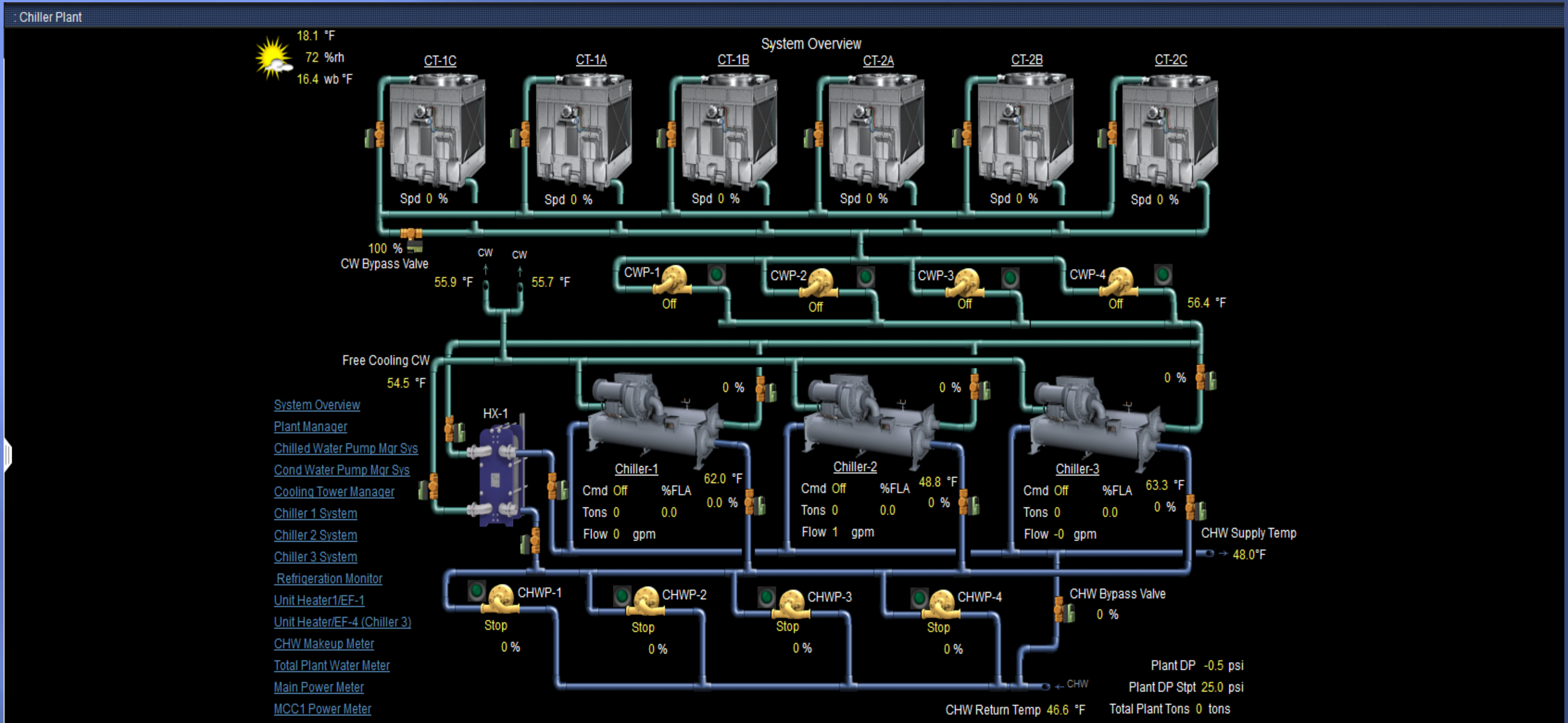
Bucknell has operated a combined-cycle CHP plant since 1998.

Bucknell
UNIVERSITY

Utility Operations

- Gas turbine generator operates at full capacity except occasional off-peak hours.
- Steam turbine generator output follows campus steam load.
- Excess generation is sold to the local utility at spot market rates.
- Gas turbine output is reduced to track campus load if power prices fall below incremental generation cost.
- Absorption chillers provide base (unfired) steam load from late spring through early fall.
- Power is purchased from the utility to meet peak loads in excess of generating capacity.

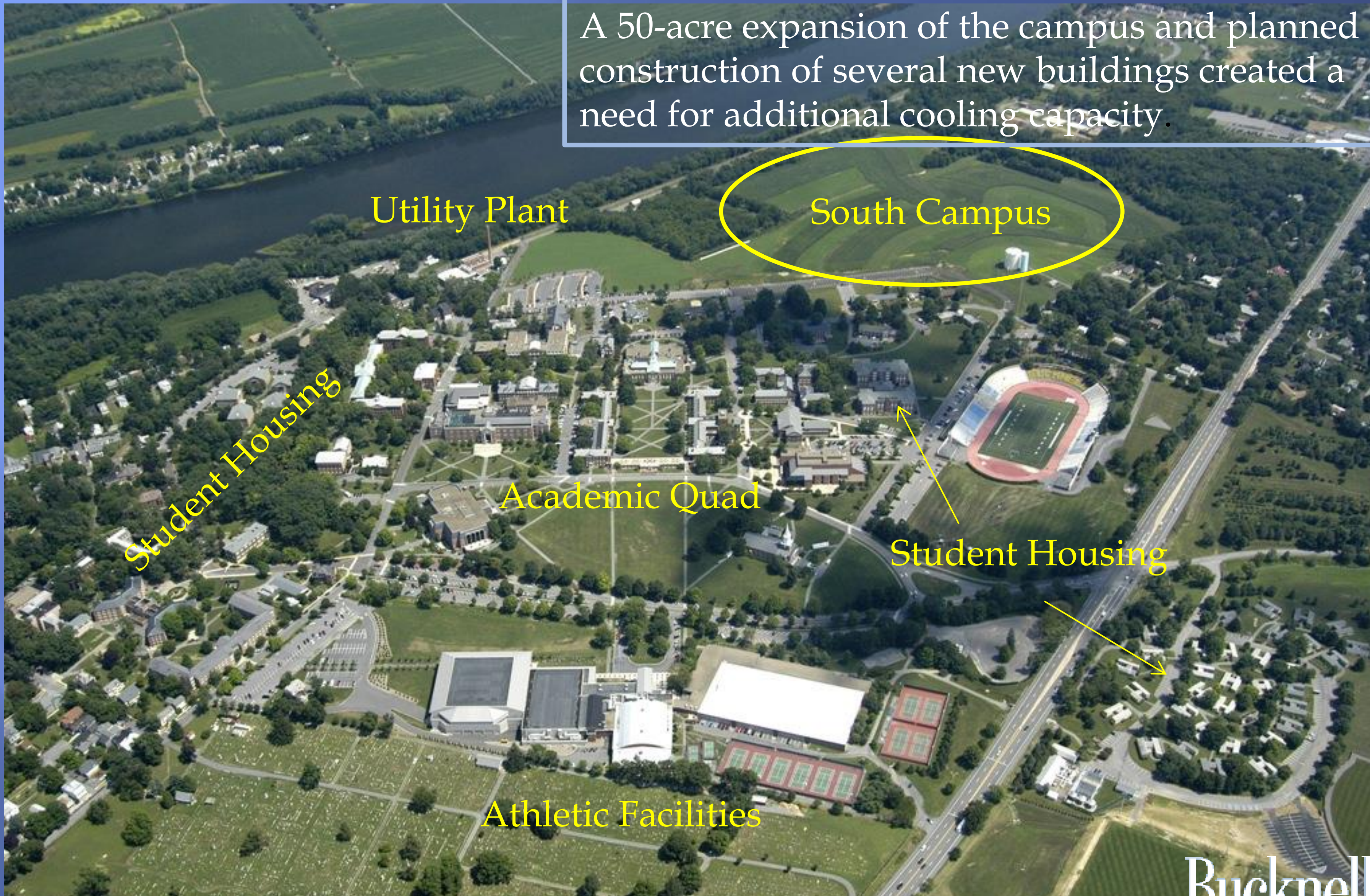
Chiller Plant



Central chiller plant constructed in 2001 and expanded with addition of third chiller in 2007.

Bucknell Campus 2010

A 50-acre expansion of the campus and planned construction of several new buildings created a need for additional cooling capacity.



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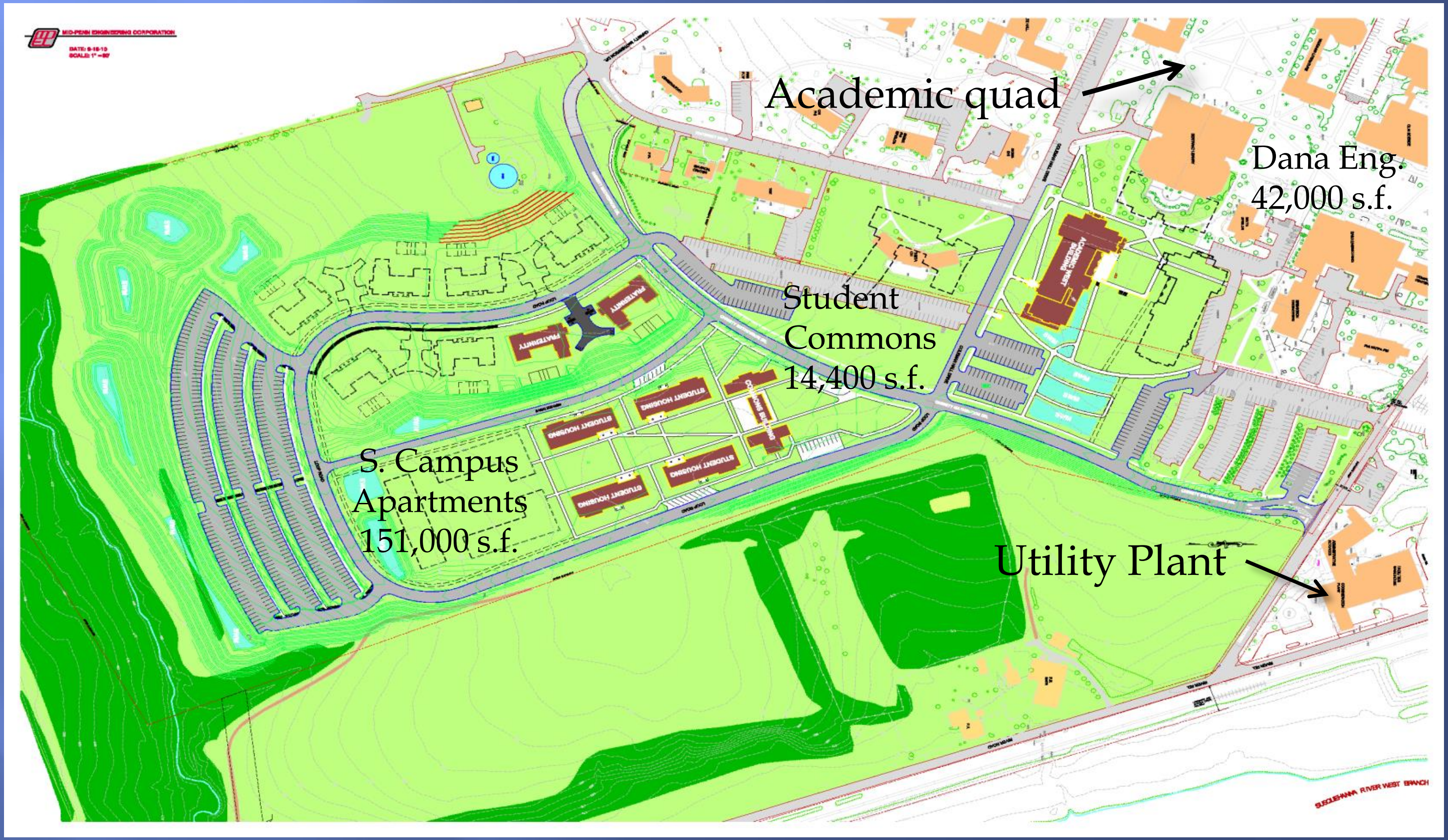
South Campus Expansion



Cost/Benefit Analysis

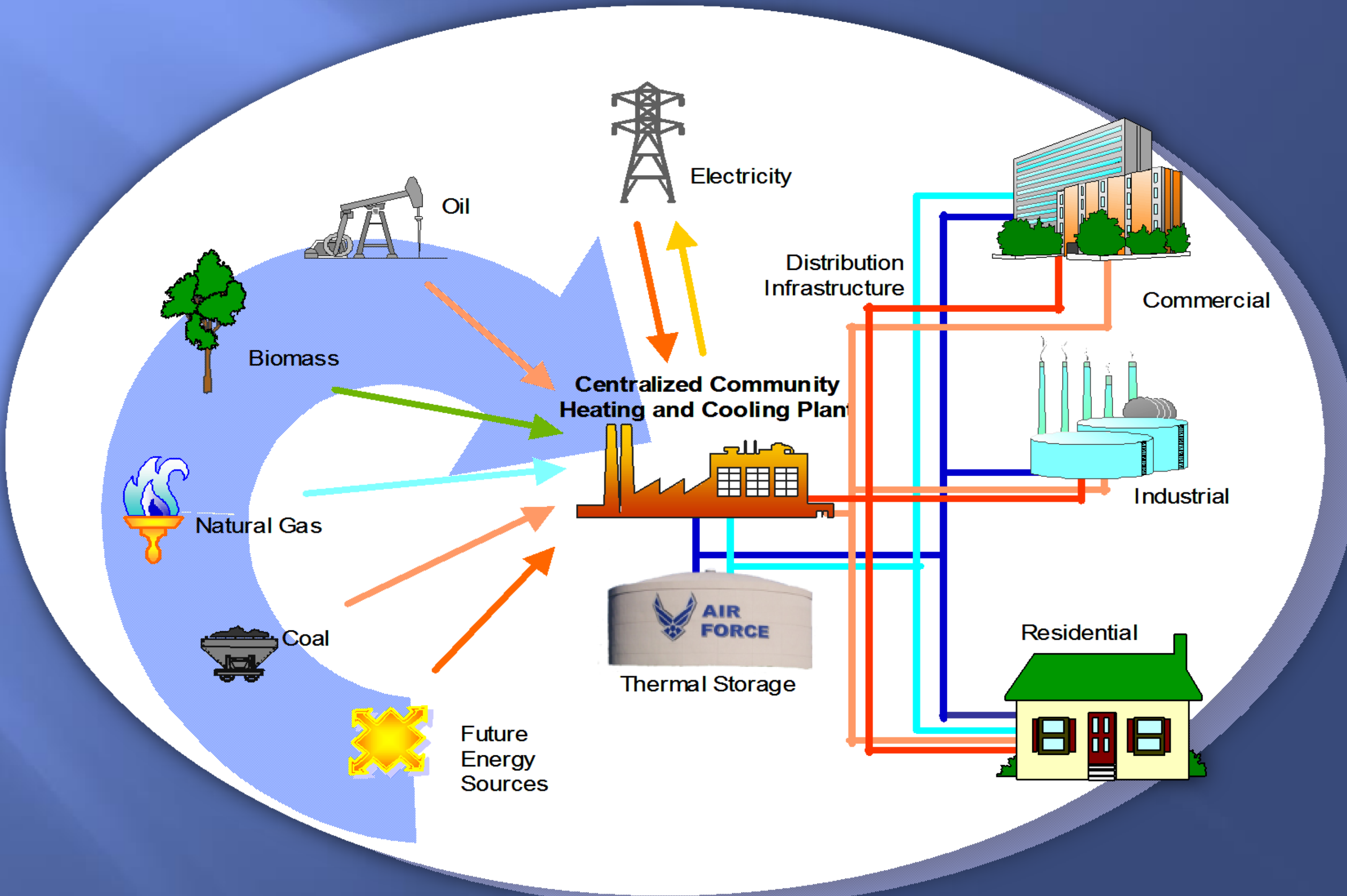
Chilled Water Option	Estimated construction cost	Annual energy cost	Life cycle operating cost
Water-cooled screw chiller	$1,910,000	$50,000	$1,343,519
Water-cooled centrifugal chiller	$1,830,000	$44,000	$1,182,296
Air cooled screw chiller	$1,730,000	$60,000	$1,612,222
Thermal storage tank	$1,880,000	-$23,000	-$618,019

Bucknell considered several chiller options:

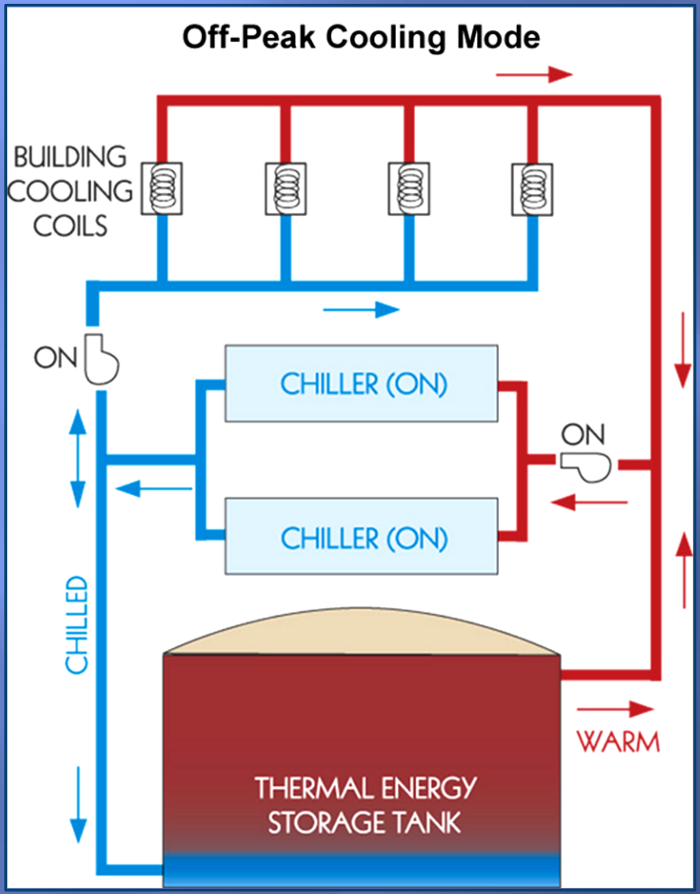
- water-cooled centrifugal,
- steam absorption,
- air-cooled, and
- thermal energy storage (no new chiller)

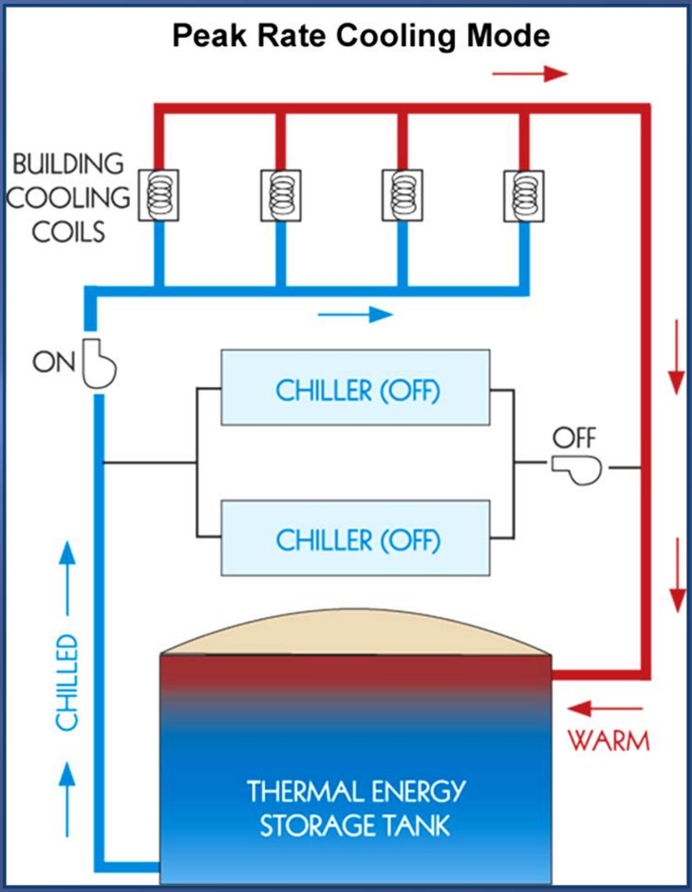
Thermal energy storage provided the necessary capacity at comparable or lower capital costs and far lower operating costs than the other options

TES with Chilled Water District Cooling Systems



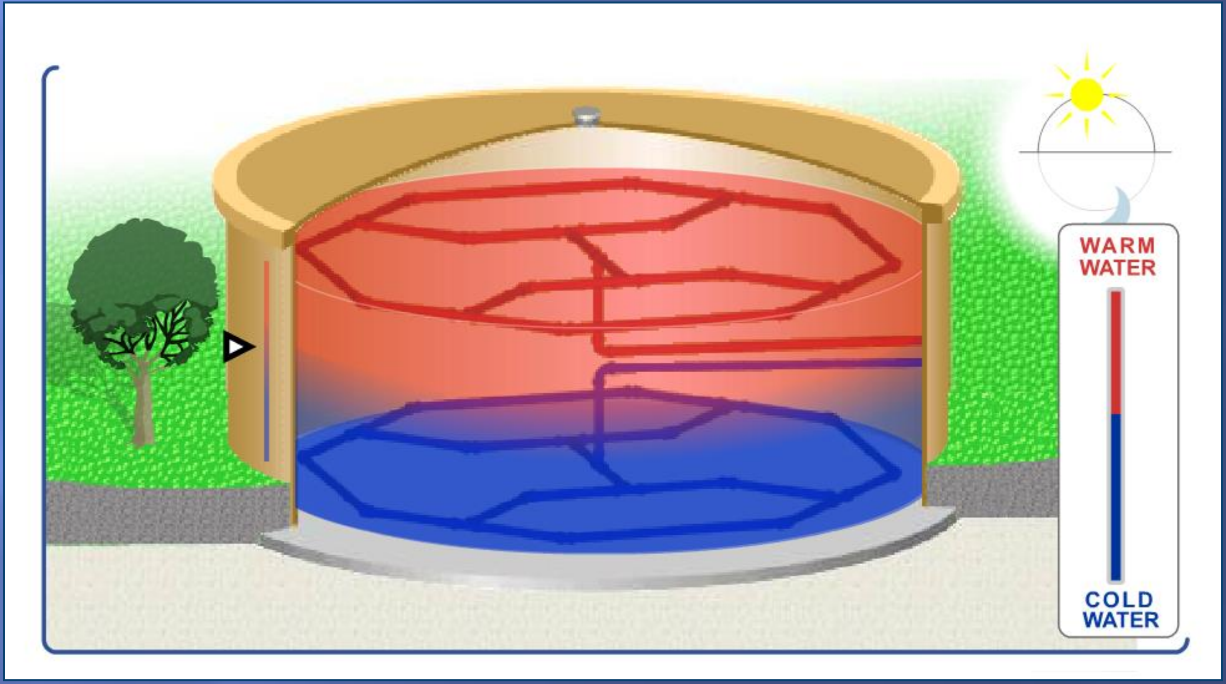
Chilled Water TES Concept





Stratified Chilled Water

Maximize the chilled water ΔT
to minimize the tank size



Information Required to Size the TES Tank:

- Useable TES capacity (ton-hrs)
- Chilled water ΔT (°F)
- Maximum chilled water flow rate (gpm)

Bucknell University's TES Tank

- Design Parameters
  - 6,500 ton-hrs – useable TES capacity
  - 2,340 gpm CHW flow rate
  - 2% max. heat gain in 24 hrs

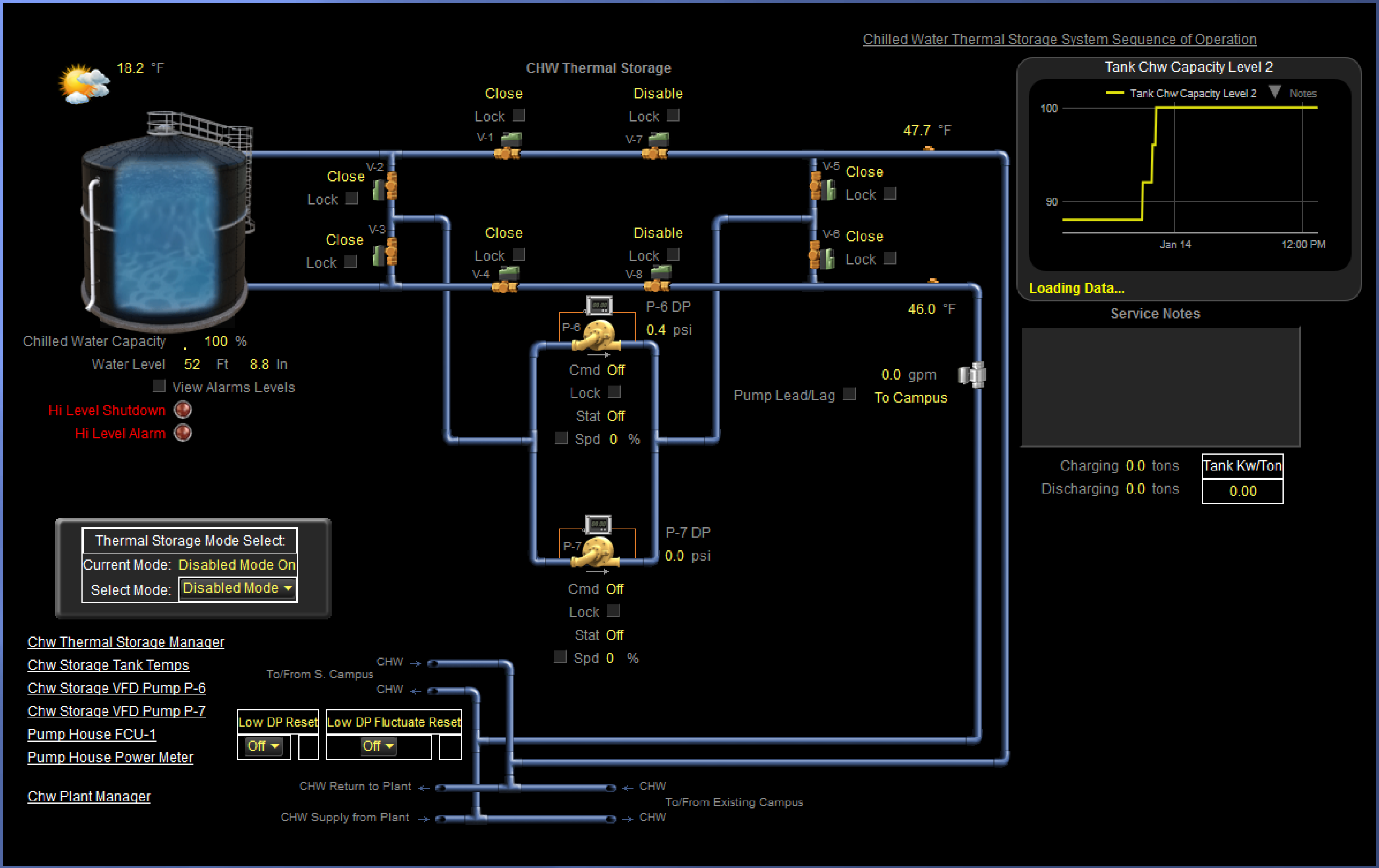
- Tank Details
  - 0.9 Million Gallons
  - 55′ ID x 50′ water depth
  - Sloping hillside construction
  - Differentially buried tank
  - Near the 250 year old heritage tree

TES Tank Construction

Project Design Challenges

- Siting – Construction site sandwiched between a public road, engineering lab, hazmat storage, underground utilities, and heritage oak tree.
- Hydraulic Balance – Integrating atmospheric tank with variable pressure, variable flow distribution system.
- Control Strategy – Avoid competing pressure and flow control between plant and tank systems.
- Operating Criteria – Develop clear operating instructions while optimizing the value of the TES system.

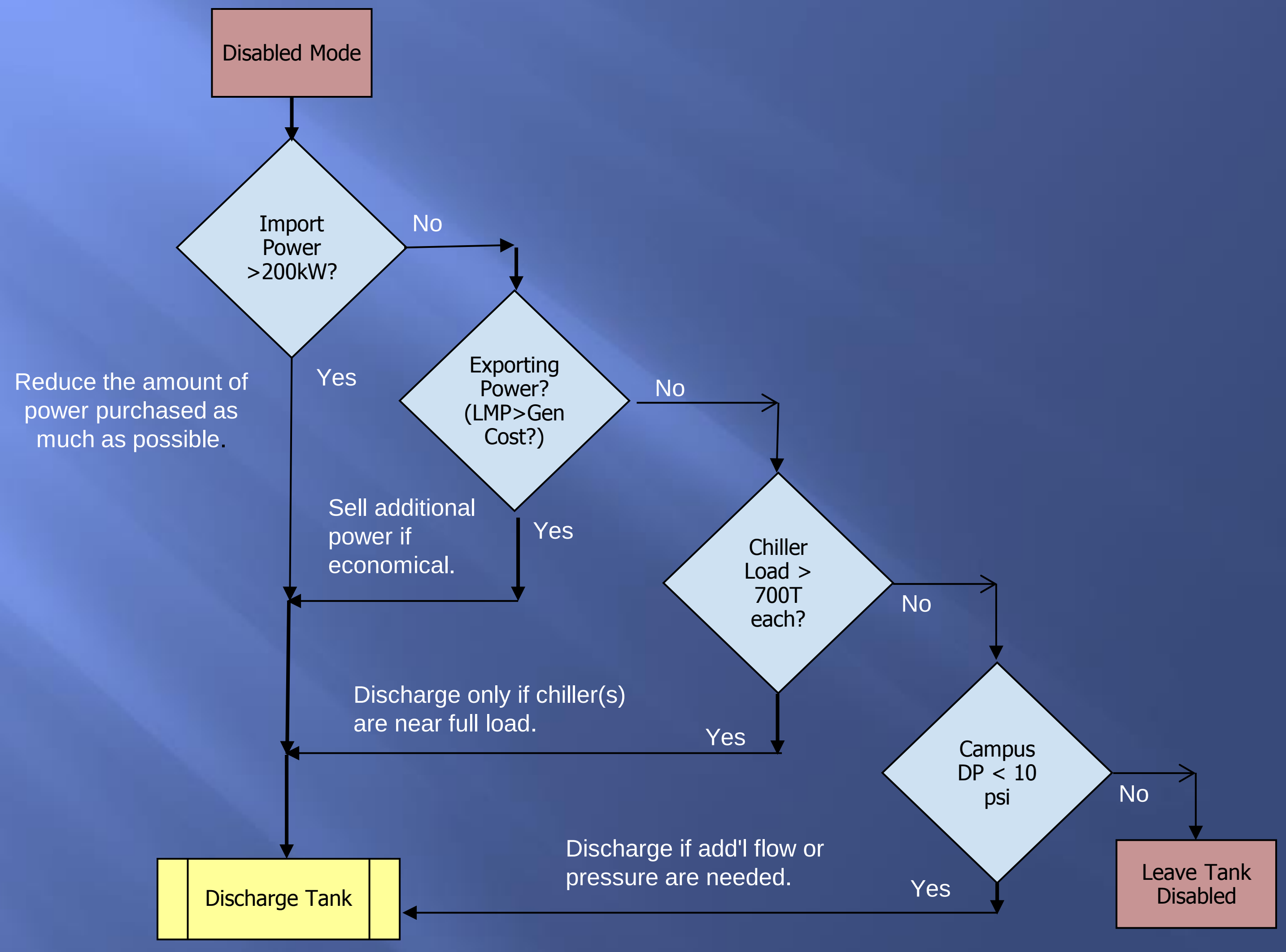
Thermal Energy Storage System



Optimizing System Performance

- The original system design assumed the TES would operate during pre-selected “peak hours” and “peak days” only in the summer months.
- The simple model of discharging the system during peak daytime hours and charging the system overnight did not consider all the variables that affect system operation.
- Because the campus requires some minimal cooling demand year-round, other opportunities arose to cost effectively operate the system.

TES Operating Guidelines



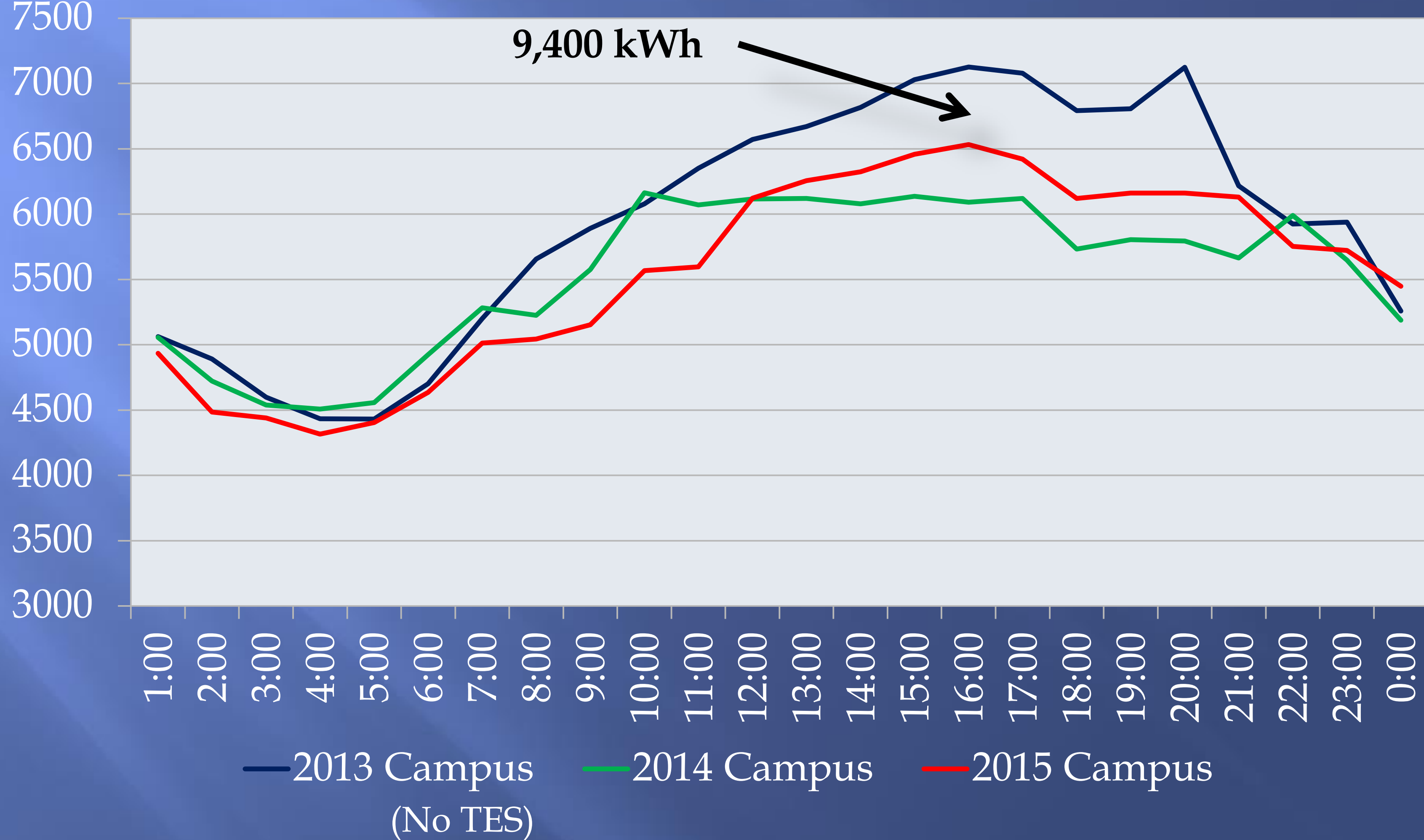
Operational Protocols

- Importing Power – In addition to providing additional peak cooling capacity, the TES system reduces peak power usage (and associated demand charges).
- Exporting Power –When it is cost effective to sell power to the utility company, discharging the TES system increases the generation capacity available to export.
- Chiller(s) Approaching Full Load – If a chiller (or two) is operating over 90% load, discharging the tank avoids or delays starting another chiller.
- Low System DP – If system pressures are low, indicating a need for additional flow and pumps, discharging the tank avoids operating a chiller in an inefficient high flow, low delta-T condition.

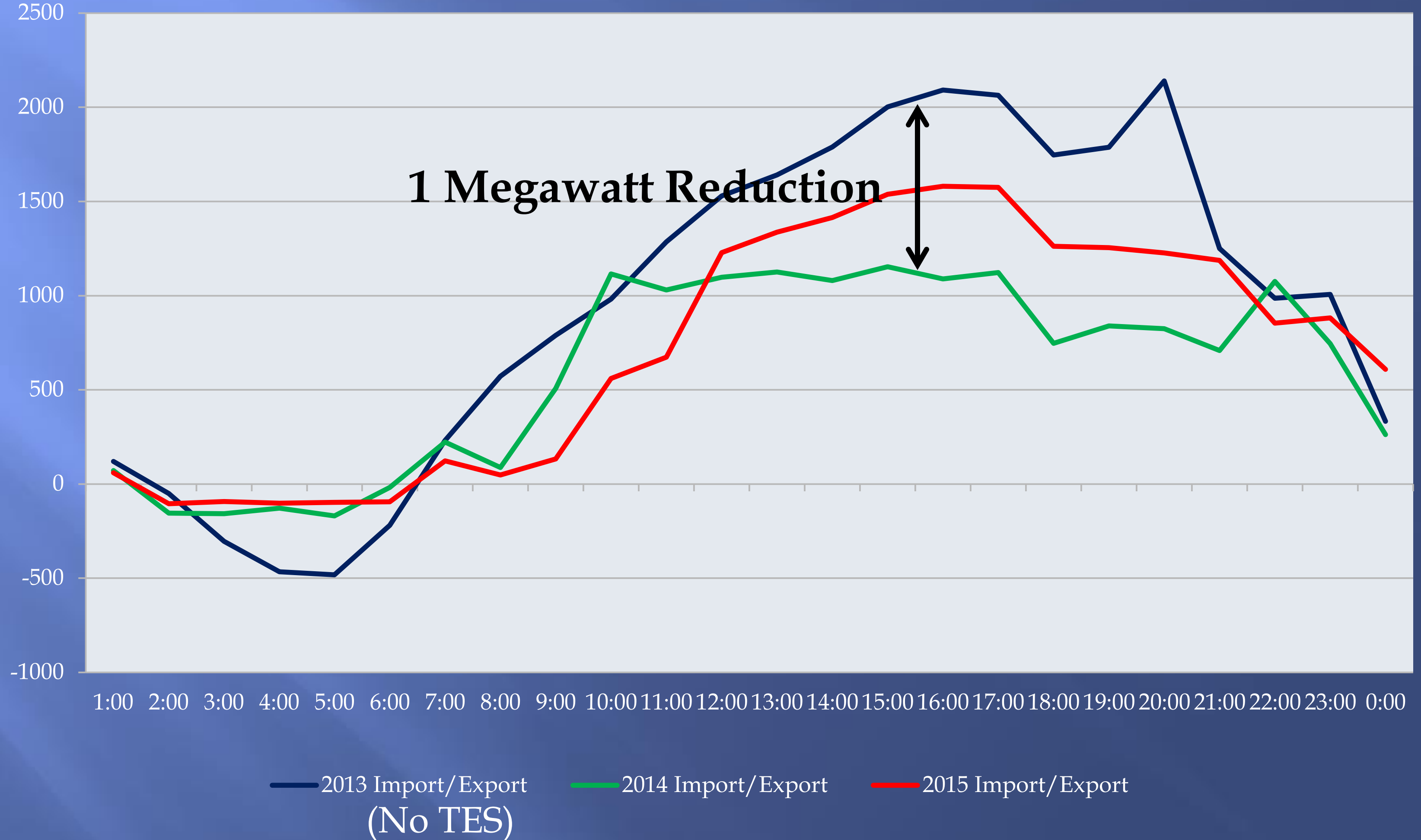
Peak Load and Demand Charges

- Bucknell is billed a demand charge based on the monthly peak electricity usage.
- Shifting cooling load from peak daytime hours to overnight hours reduces peak usage and demand charges.
- Bucknell also is billed, because of the on-site generation, a Reserve Capacity charge based on annual peak usage.
- Reducing peak load reduces both Demand and Reserve Capacity charges.

Thermal Storage Effect on Campus Electricity Load



Utility Demand Savings



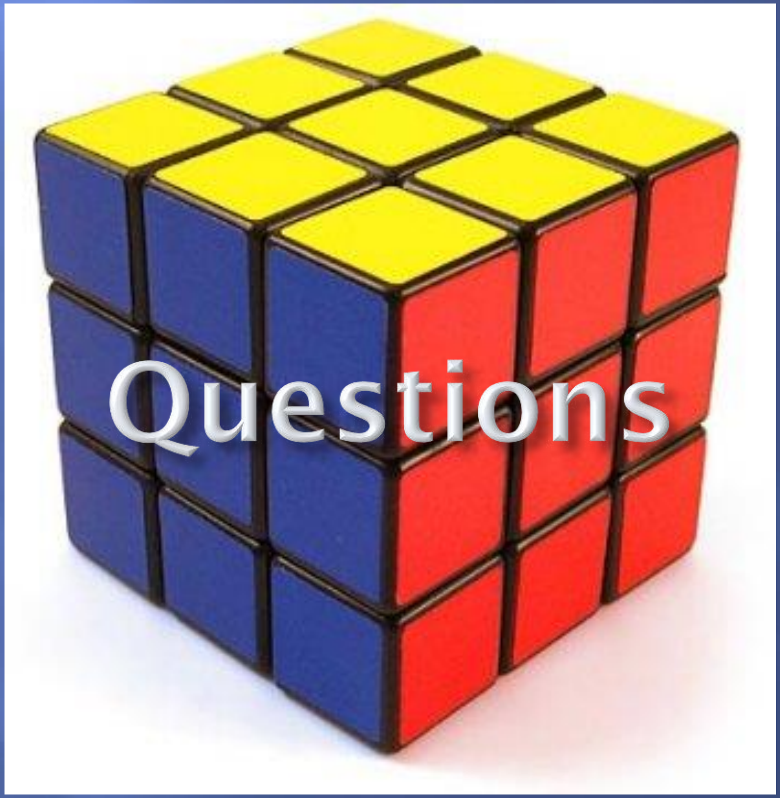
Energy Consumption Savings

	2013	2014		2015	
Jun	124,514	81,021	-35%	53,038	-57%
Jul	140,233	34,967	-75%	91,986	-34%
Aug	170,174	94,572	-44%	202,335	19%
Sep	27,412	16,245	-41%	19,347	-29%
Total	462,333	226,805	-51%	366,706	-21%
Cost Savings		$ 22,564		$ 9,161	
	2013	2014		2015	

2015 included cooling for 207,000 SF of additional space.

Electric Demand Savings

	Campus Demand - kW (non-outage)						
	2013	2014	% Chg	2015	% Chg	2014 Savings	2015 Savings
Jun	980	694	-29.2%	813	-17.0%	$ 801	$ 468
Jul	1,867	1,489	-20.2%	1,199	-35.8%	$ 1,058	$ 1,870
Aug	2,436	959	-60.6%	1,680	-31.0%	$ 4,136	$ 2,117
Sep	2,400	1,410	-41.3%	1,973	-17.8%	$ 2,772	$ 1,196
Total	**7,683**	**4,552**	**-40.8%**	**5,665**	**-26.3%**	**$ 8,767**	**$ 5,650**


Questions