Thermal Energy Storage

New Mexico State University

Presented by:

Pat Chavez, Director of utilities and Plant Operations, New Mexico State University

Doug Stingelin, P.E., Director of Mechanical Engineering, GLHN A/E , Inc.

TODAY'S PRESENTATION

- Primer – Cool Thermal Energy Storage (CTES)
- Why CTES for NMSU?
- NMSU CTES Infrastructure
- CTES Performance after 7 years and Adjusting to Change
- Future for CTES at NMSU

CTES Primer

Presentation Terminology:

- Electrical ENERGY – measured in Kilowatt Hours (kWh)
- Electrical POWER/DEMAND – measured in Kilowatts (kW)
- Demand charges billed monthly - often based on peak value per time frame (ex. Highest avg. over 30 minutes)

EL PASO ELECTRIC COMPANY
SIXTH REVISED RATE NO. 26
CANCELLING FIFTH REVISED RATE NO. 26

STATE UNIVERSITY SERVICE RATE

NEW MEXICO
PUBLIC REGULATION
COMMISSION
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2009 DEC 17 PM 4 58

Page 1 of 2

APPLICABILITY:

This rate is available to any public college or university's main campus for lighting, power and heating service. The Customer and the Company will determine whether a Customer qualifies for this rate. A Customer qualifies for this rate if the expected monthly demand will exceed 9,000 kilowatts (kW). All service will be taken at one point of delivery designated by the Company and at one of the Company's standard types of service. A contract may be required in order to take service under this rate.

TERRITORY:

Areas served by the Company in Dona Ana, Sierra, Otero and Luna Counties.

TYPE OF SERVICE:

The type of service available will be determined by the Company and will be three phase at a standard Company approved voltage.

MONTHLY RATE:

Customer Charge

$25.00 per customer

Demand Charge	Per Billing kW
	$7.60

Energy Charge	Per kWh
On-Peak	$0.24212
Off-Peak	$0.04860

On-Peak Period shall be from 12:00 P.M. to 6:00 P.M, Mountain Daylight Time, Monday through Friday, for months of June through September.

Off-Peak Period shall be all other hours of the week not covered in the On-Peak Period.

Advice Notice No. 213

Signature/Title
David G. Carpenter
Senior Vice President-Chief Financial Officer

CTES Primer

Presentation Terminology:

- Utility Rates $
- Demand and Energy Charges
- Time-of-Use (TOU)
- Real-Time-Power (RTP)

MONTHLY RATES:

Customer Charge (per meter per month)	$135.00

Demand and Energy Charges	Summer (June through September)	Winter (October through May)
Demand Charge per Billing kW	$16.71	$8.85
Energy Charge per kWh: On-Peak	$0.09124	-------
Energy Charge per kWh: Off Peak	$0.00428	$0.00428

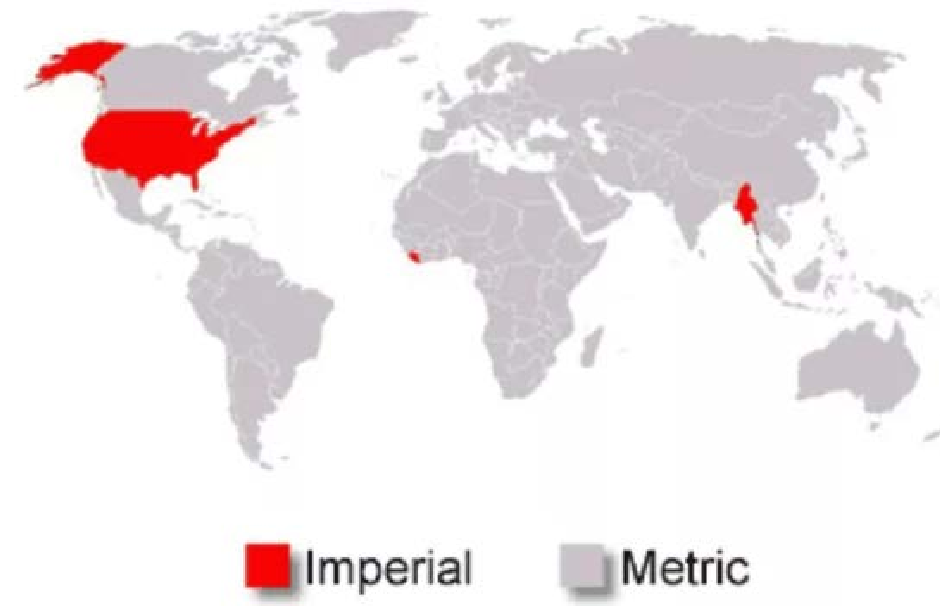
The On-Peak Period shall be from 12:00 P.M. to 6:00 P.M, Mountain Daylight Time, Monday through Friday, for the months of June through September.

The Off-Peak Period shall be all other hours of the week not covered in the On-Peak Period.

CTES Primer

Presentation Terminology:

- Imperial Units (Metric/SI)
- Cooling Capacity or Demand TonR (kW)
- Cooling Energy/Storage Capacity TonHr (kWh)



CTES Primer

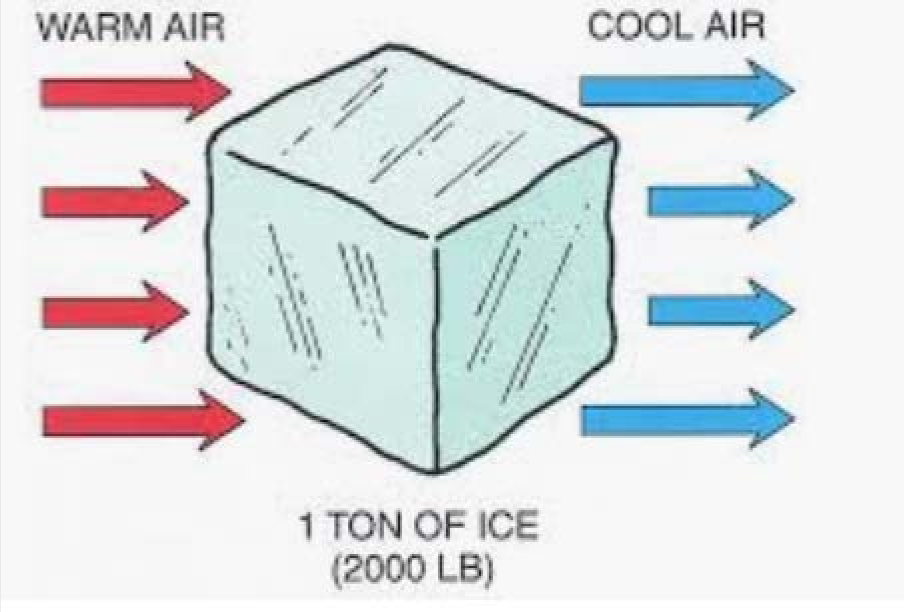
Presentation Terminology:

- British Thermal Unit (Btu) = energy to raise 1LB of Water 1°F
- 1 kWh =3412 Btu
- Sensible Heat ~ energy needed for raising or lower temperature
- Latent Heat ~ energy needed to create phase change (ice to water, water to steam)
- 1LB ICE to 1 LB Water = 144 Btu

CTES Primer

Presentation Terminology:

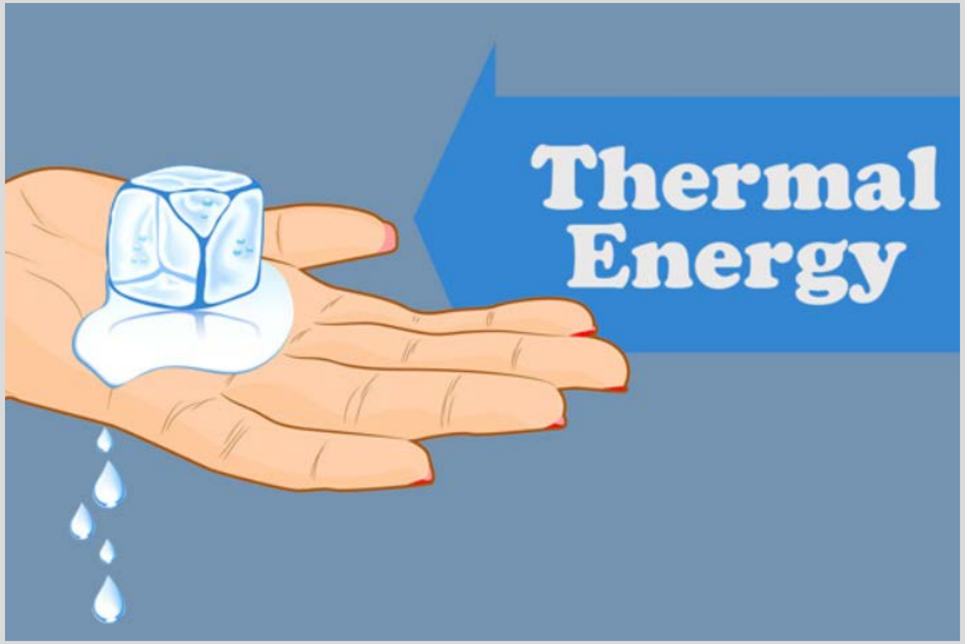
- TonR - the rate of heat transfer that results in the freezing (*or melting) of 1 ton (2,000 lb; 907 kg) of pure ice at 32 °F (0 °C) in 24 hours.
- A refrigeration ton is approximately equivalent to 12,000 BTU/h or 3.5 kW.



$$\dot{Q} = \frac{\left(144\,\frac{\text{Btu}}{\text{lbm}}\right)}{(1\ \text{day})\left|\frac{24\ \text{hr}}{\text{day}}\right.}\left[(2000\ \text{lbf})\left(\frac{32.174\,\frac{\text{lbm-ft}}{\text{lbf-s}^2}}{32.174\,\frac{\text{ft}}{\text{s}^2}}\right)\right] = 12{,}000\,\frac{\text{Btu}}{\text{hr}}$$

CTES Primer

- Thermal Energy Storage (TES) systems store thermal capacity as sensible or latent heat
- Can be hot or cold
- Cool storage (‘C’TES) mediums are usually water or ice respectively
- CTES primarily designed to reduce plant electric utility costs



CTES Primer

- Air-Conditioning has had a large impact on the way utility companies operates their power plants
- Most utility company prime movers are for summer peaking – 35% of US summer peak is do to air-conditioning
- Electric Utility – Production Efficiency is not the main issue anymore – Predictable Demand Is

CTES Primer

- Utility Company Strategy: Modify User Behavior by creating rates that penalize high demand during peak demand hours and reward power use during off-peak (‘Time of Use’ TOU Rates or ‘Real-Time Price’ RTP rates)
- CTES became exceptionally popular in 1980s driven by electrical demand-side management (DSM) programs which provided capital incentives

CTES Primer

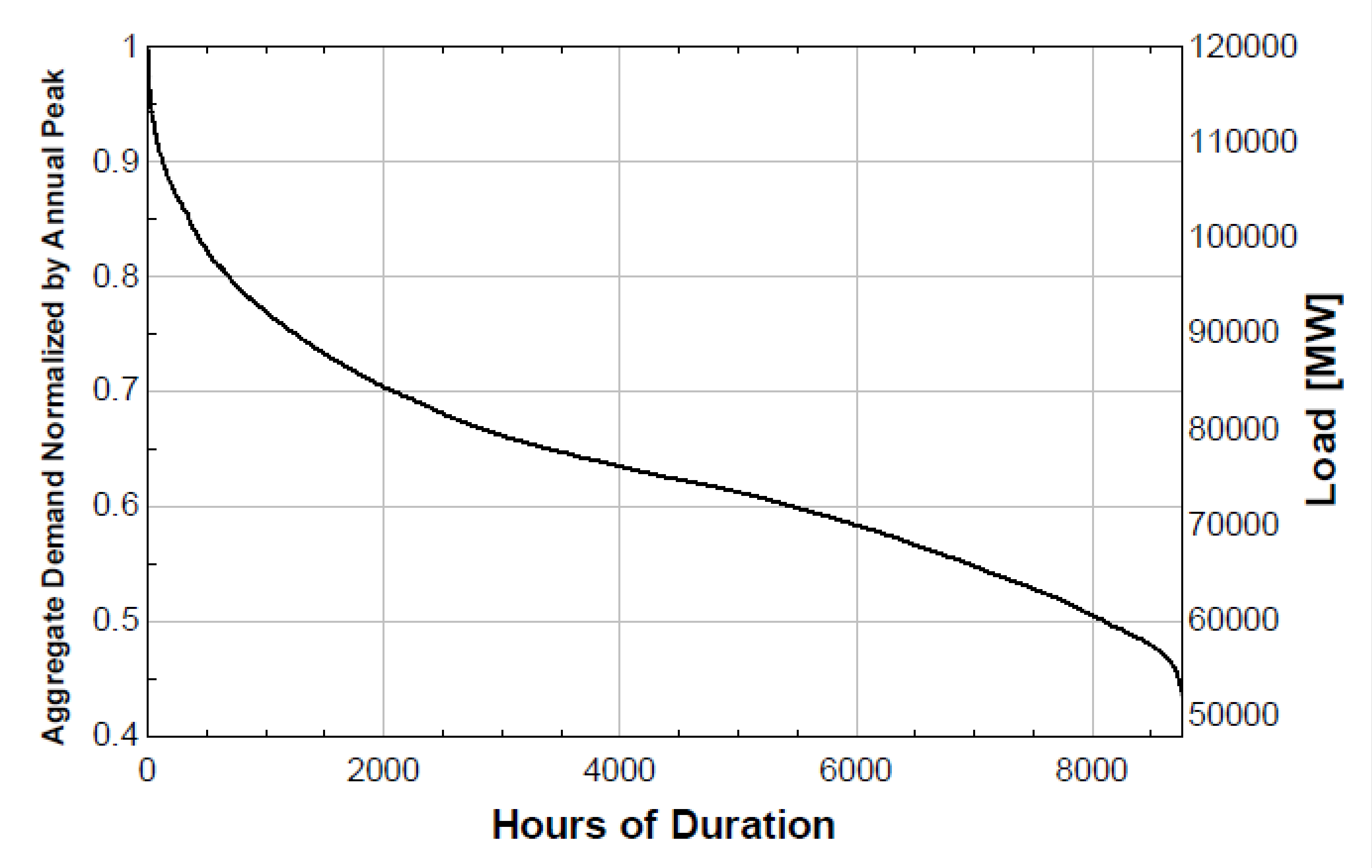
- TOU rates permits cost saving through load shedding
- Early CTES encouraged by offering Capital Incentives to users
- CTES for cooling applications fostered to fruition with chilled water and ice storage systems

CTES Primer

- Fast forward to 2019 – CTES is still very popular
- TOU and RTP electric rates still a driver
- Future – CTES is an option to capture Intermittent power production from renewable energy (solar, wind) and deploy when needed

CTES Primer

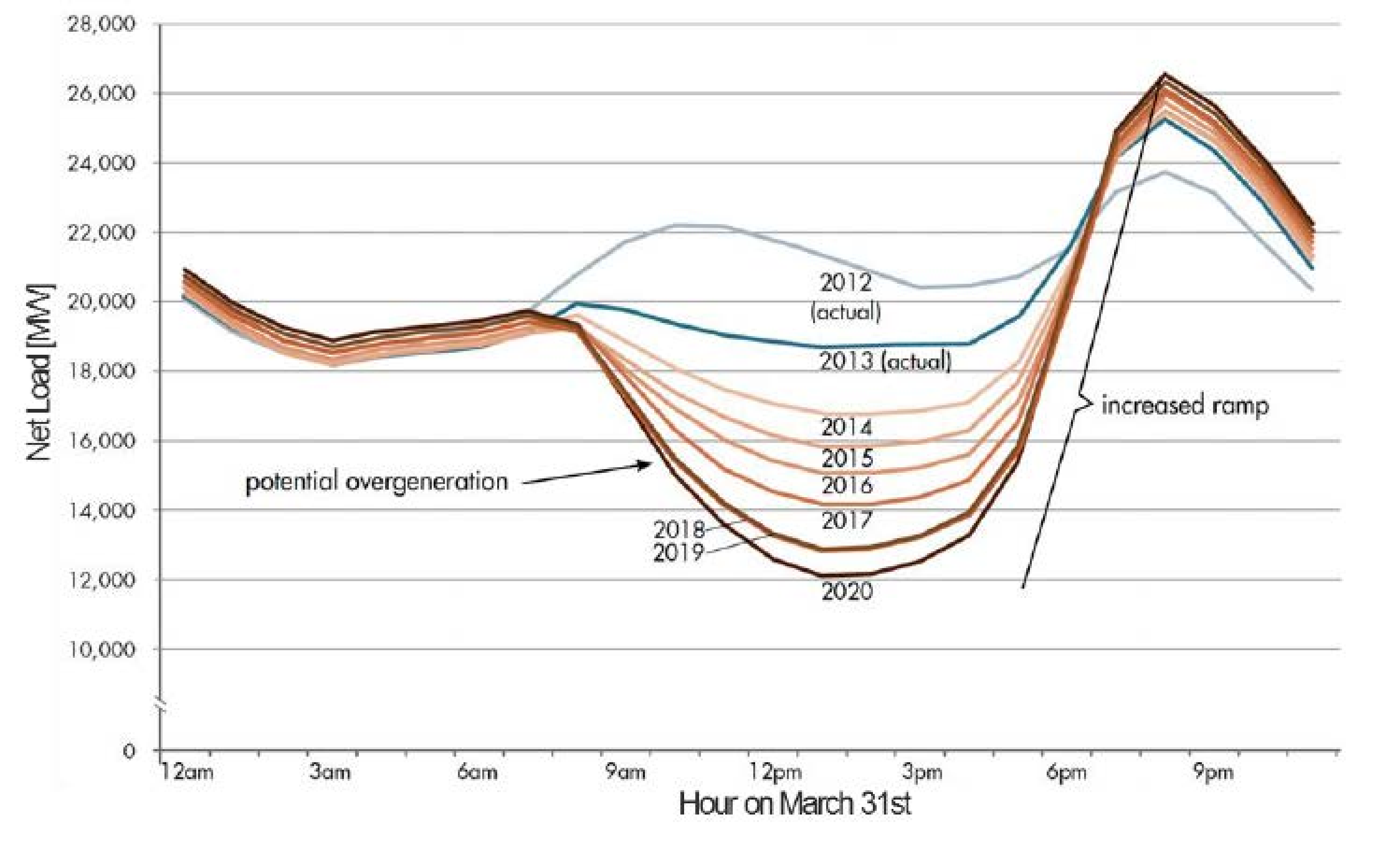
- Most utilities experience 80-100% peak power for less than 8% of all operating hours



Aggregate Load Duration Curve (Miso 2016)

CTES Primer

- Traditional power generation favors slow changing demand – rapid response to dynamic changes in demand is difficult to manage (‘grid dynamics’, ‘ramp rates’, ‘over generation’)
- Photovoltaic (PV) Power production is the largest disrupter
- Peak diurnal PV power occurs at Noon
- Utility grid summer peak power is ~ 4PM



CAISO net load ‘Duck Curve’

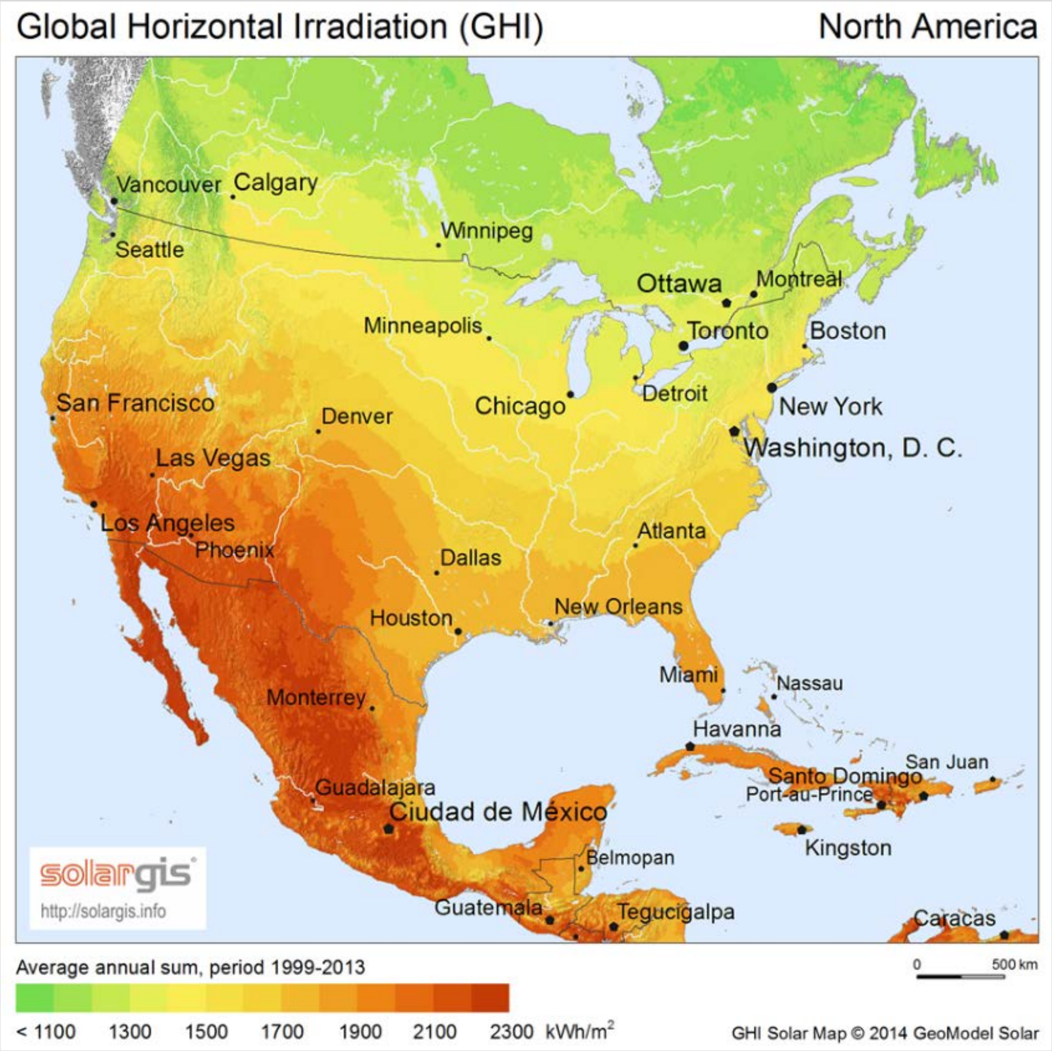
CTES Primer

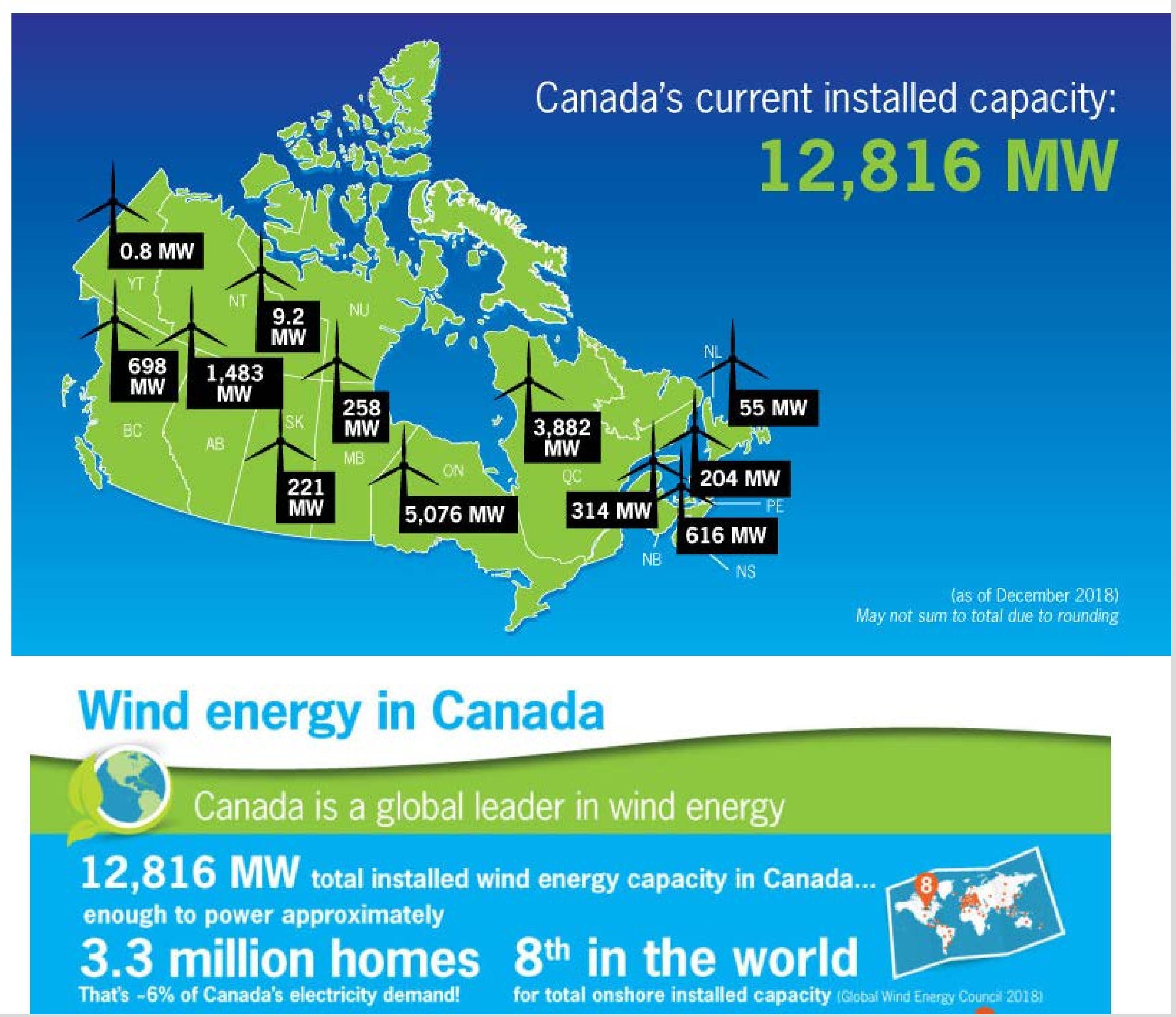
- Utility company’s are looking for approaches to reduce or shift electricity demands that can also benefit both facility owners
- CTES can bridge mismatches between intermittent renewable generation and utility aggregate demand for electricity

CTES Primer

- Look for more incentives in the future
- Widespread CTES will assist utilities in reaching their renewable penetration targets.
- Ever growing Legislation to increase deployment of renewable energy will lead to greater mismatches in demand
- Also the desire to have 'Net-Zero' buildings is on the rise

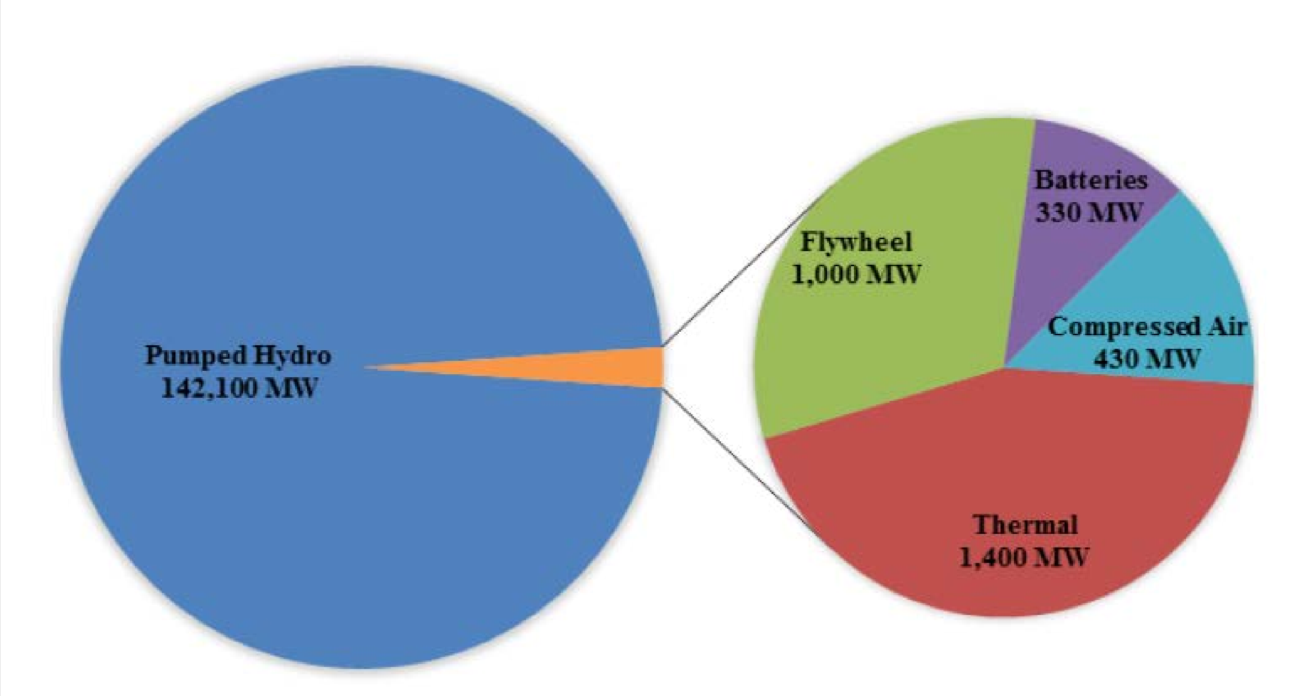
CTES Primer


Global Horizontal Irradiation (GHI)
North America
Vancouver
Calgary
Seattle
Winnipeg
Ottawa
Montreal
Minneapolis
Toronto
Boston
San Francisco
Denver
Chicago
Detroit
New York
Washington, D. C.
Las Vegas
Los Angeles
Phoenix
Dallas
Atlanta
Houston
New Orleans
Miami
Nassau
Monterrey
Havanna
San Juan
Santo Domingo
Port-au-Prince
Guadalajara
Ciudad de México
Kingston
Belmopan
Guatemala
Tegucigalpa
Caracas
solargis
http://solargis.info
Average annual sum, period 1999-2013
0 500 km
< 1100 1300 1500 1700 1900 2100 2300 kWh/m²
GHI Solar Map © 2014 GeoModel Solar


Canada's current installed capacity:
12,816 MW
0.8 MW
YT
NT
9.2 MW
NU
698 MW
1,483 MW
258 MW
NL
55 MW
3,882 MW
BC
AB
SK
MB
221 MW
ON
5,076 MW
QC
314 MW
204 MW
PE
616 MW
NB
NS
(as of December 2018)
May not sum to total due to rounding
Wind energy in Canada
Canada is a global leader in wind energy
12,816 MW total installed wind energy capacity in Canada...
enough to power approximately
3.3 million homes
That's ~6% of Canada's electricity demand!
8th in the world
for total onshore installed capacity (Global Wind Energy Council 2018)

CTES Primer

- Energy Storage can be used to effectively bridge mismatches between renewable energy production and aggregate utility demand
- Energy Storage Technologies: CTES, Battery, Deep Cavern Compressed Air, Pumped Hydroelectric



Global installed energy storage by type CESA 2014

CTES Primer

- Non-Storage Cooling Plant
  - Direct-Coupling of Load Production
  - Load Profile and Plant Output Identical

- CTES Plant
  - Uncouple Production of Cooling Capacity from Demand for Capacity
  - CTES does not change integrated cooling load – it redistributes it.

CTES Primer

- Consequences of Using CTES
  - Smaller Refrigeration Plant (Usually)
  - Lower Electric Costs (Almost always)
  - Energy Savings (Almost never)
  - Greater Operational Flexibility
  - Helping to smooth out grid-dynamics – reduce use of ‘dirty’ peaking plants

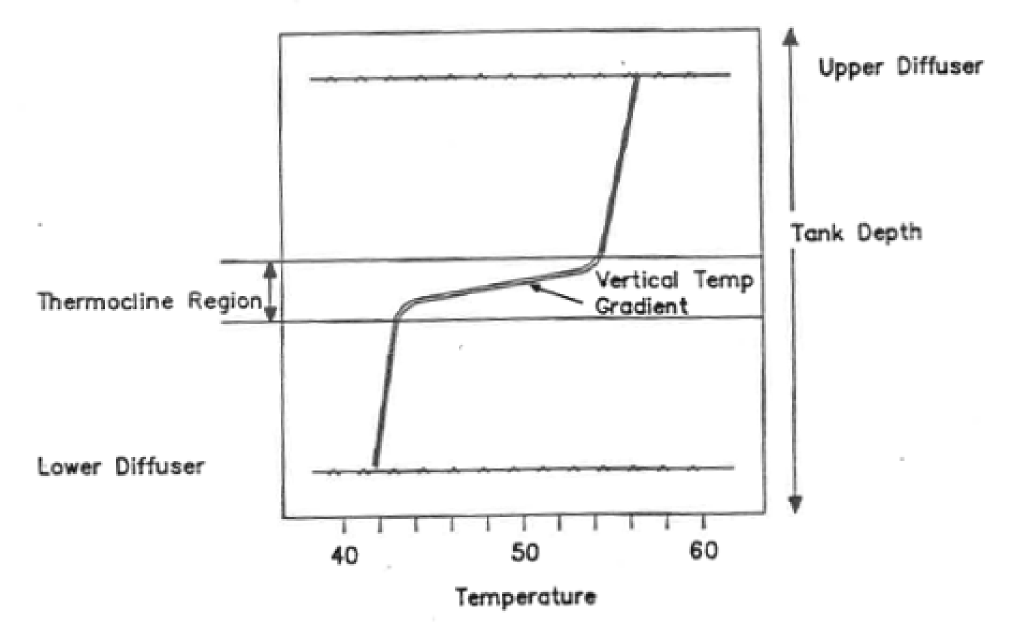
CTES Primer

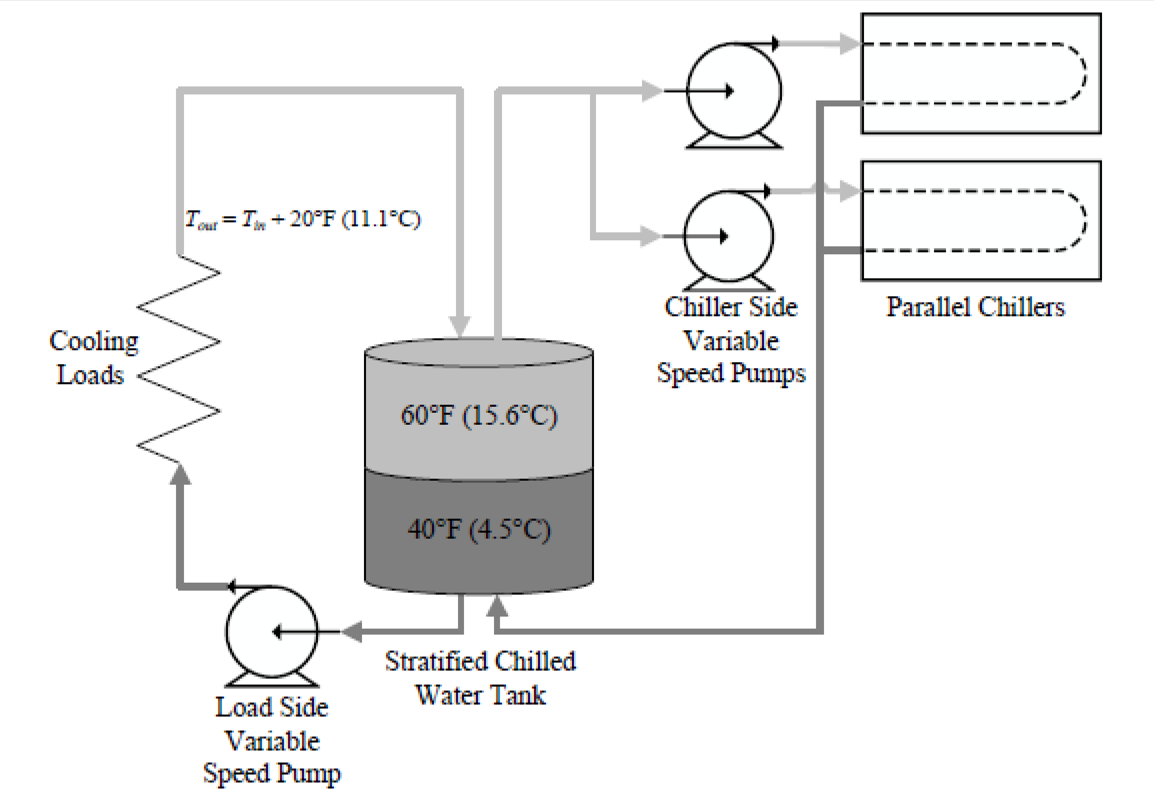
- Sensible CTES Media - Water
  - Density 62.4 lb/FT^3
  - Specific Heat 1 Btu/Lb°F
  - Stratified Chilled Water Tank – 85%-90% Usable capacity
  - Steel or Concrete Tank
  - 11-21 FT^3/TonHr (practical storage density)
  - 80-150 Gallons/TonHr

University of Wyoming – Rendering of New Chilled Water Plant with CTES

CTES Primer

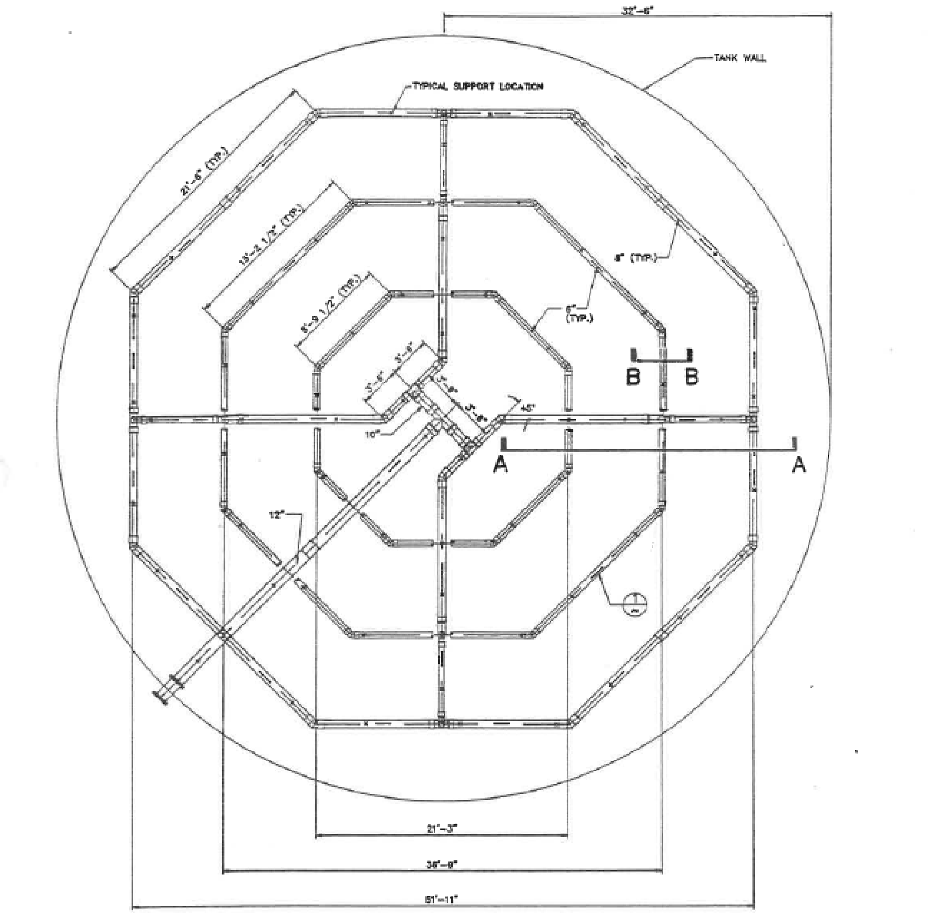
- Sensible CTES Media - Water
  - Supply Temps 40-50°F
  - Delta Ts 14-20°F





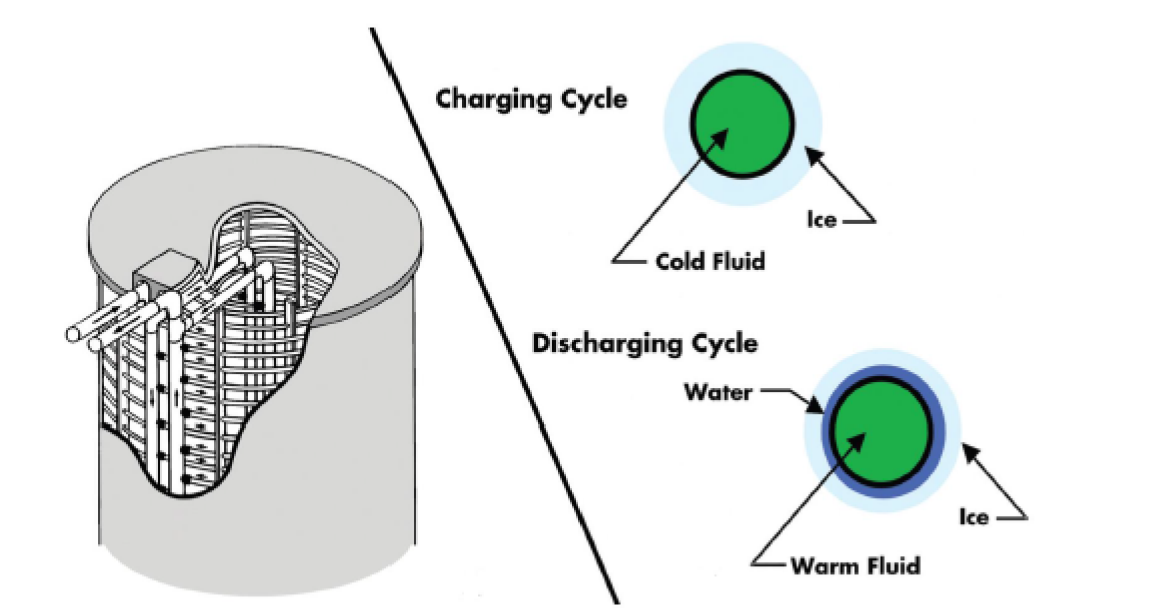
Stratified Chilled Water CTES Schematic – ASHRAE 1607-RP March 2017

CTES Primer


32'-6"
TANK WALL
TYPICAL SUPPORT LOCATION
21'-6" (TYP.)
15'-2 1/2" (TYP.)
8" (TYP.)
6" (TYP.)
B
B
A
A
45°
10"
12"
21'-3"
36'-9"
51'-11"

CTES Primer

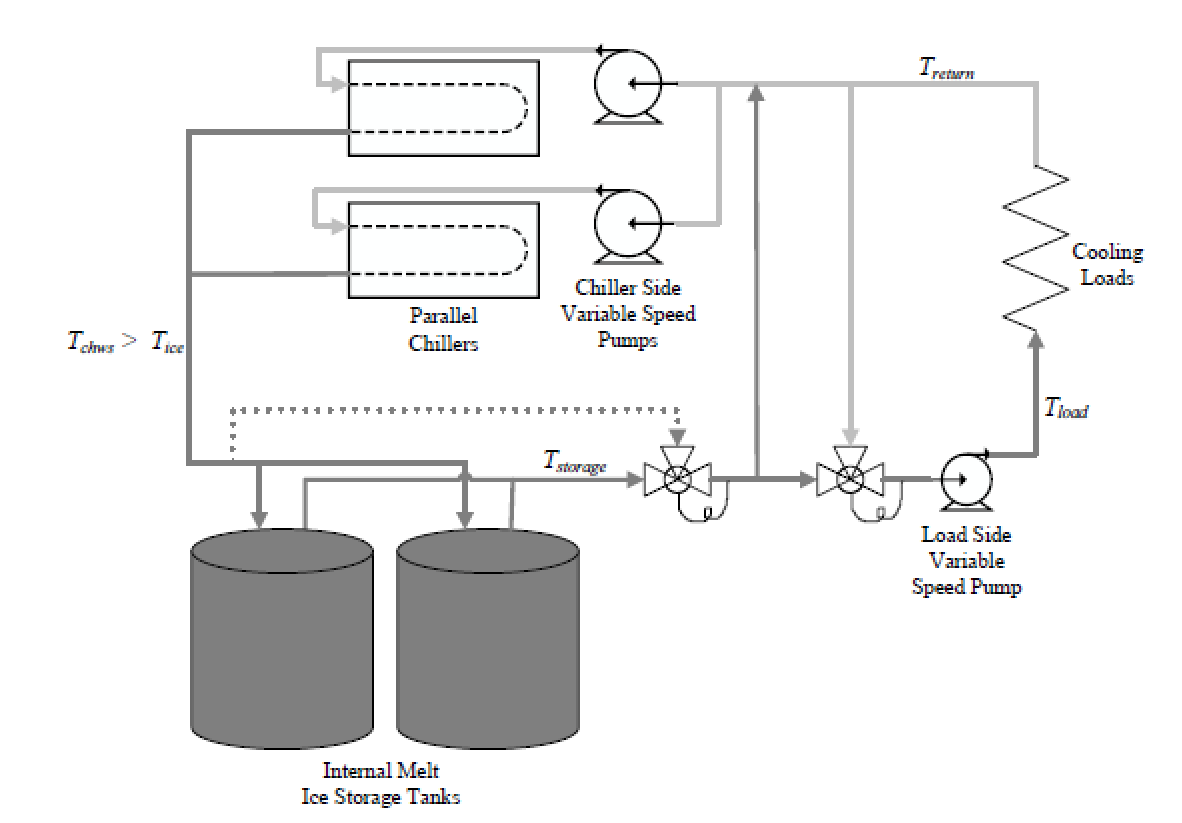
- Latent CTES Media - Ice
  - Density 62.4 lb/FT^3
  - Latent Heat of formation 144 Btu/Lb
  - Modular Ice Tank – Internal Melt "Ice-on-Coil"
  - 2.4-3.3 FT^3/TonHr (practical storage density)
  - 18-25 Gallons/TonHr



ICE CTES tank cutaway with charging and discharging cycle detail – (EPRI 2008)

CTES Primer

- Latent CTES Media - Ice
  - Charging Temps 22-26°F
  - Discharging Temps 36-39°F
  - Charging Energy .85-1.2 kW/Ton
  - Cost



ICE CTES System Schematic – ASHRAE 1607-RP March 2017

CTES Primer

Calmac – Model 'C' Tank and Cutaway

NMSU Satellite Chilled Water Plant – Ice Farm

CTES Primer

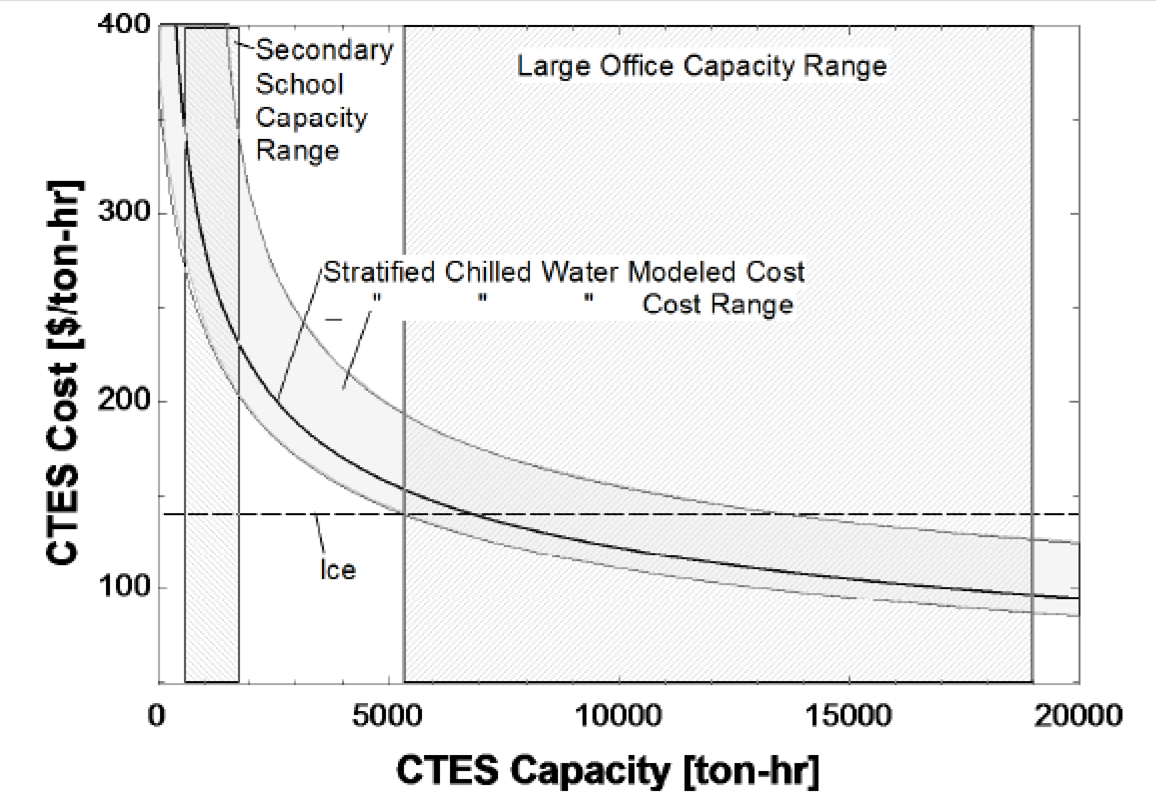
- Other CTES Media (not as practical)
  - Eutectic Salts
  - Depressed Density Glycol/Water Mixtures

CTES Primer

- Water versus Ice
  - Ice is compact - 4.5X to 6X less Volume for equal capacity
  - Water tanks have economy in scale, ice does not
  - Both systems are fairly complex – more O&M than non-storage chilled water systems

CTES Primer

- Water versus Ice
  - Ice is Cost Favorable below ~ 6,500 TonHrs (40 tanks)
  - Above-Ground Stratified Chilled Water Tanks Cost Favorable above 6,500 TonHrs (500,000 Gallons)
  - Breakpoint: 6,500 Ton.Hrs ~$1,000,000 or $150/Ton.Hr or $2/Gallon

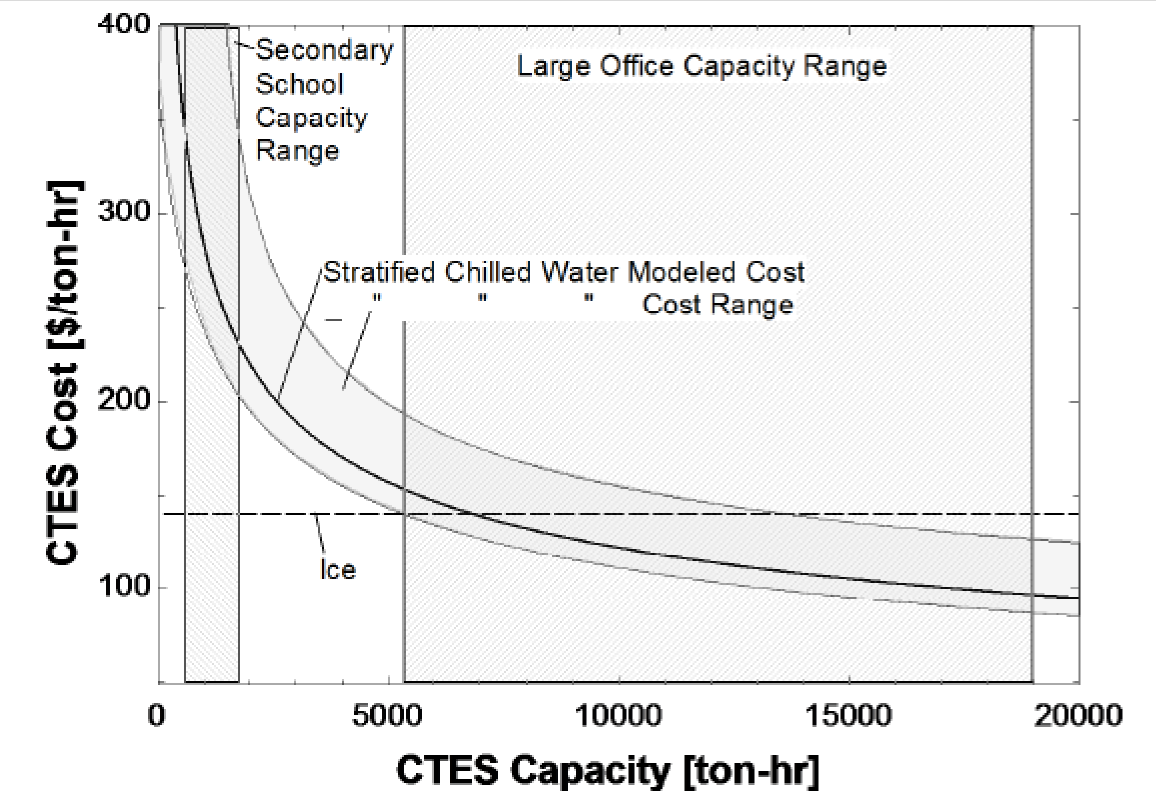


CTES cost data and storage capacity ranges ASHRAE 1607-RP March 2017

CTES Primer

- CTES Rolled-Up Capital Costs in General:
  - $130-$1120/kW
  - $460-$3,900/TonHr

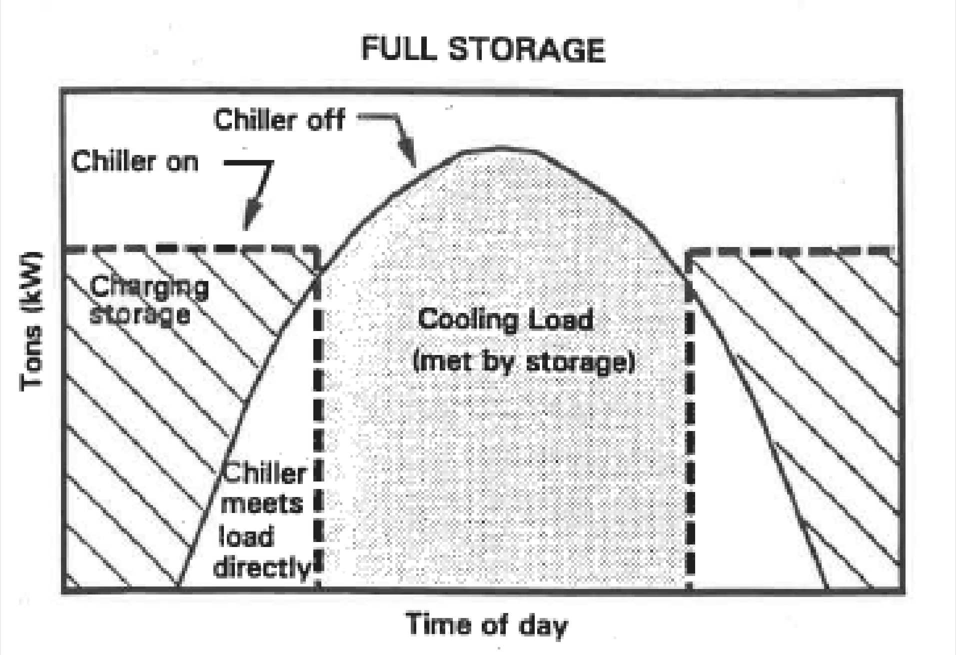
- Several US States offering rebate incentives (CA,FL,NY). More to follow…



CTES cost data and storage capacity ranges ASHRAE 1607-RP March 2017

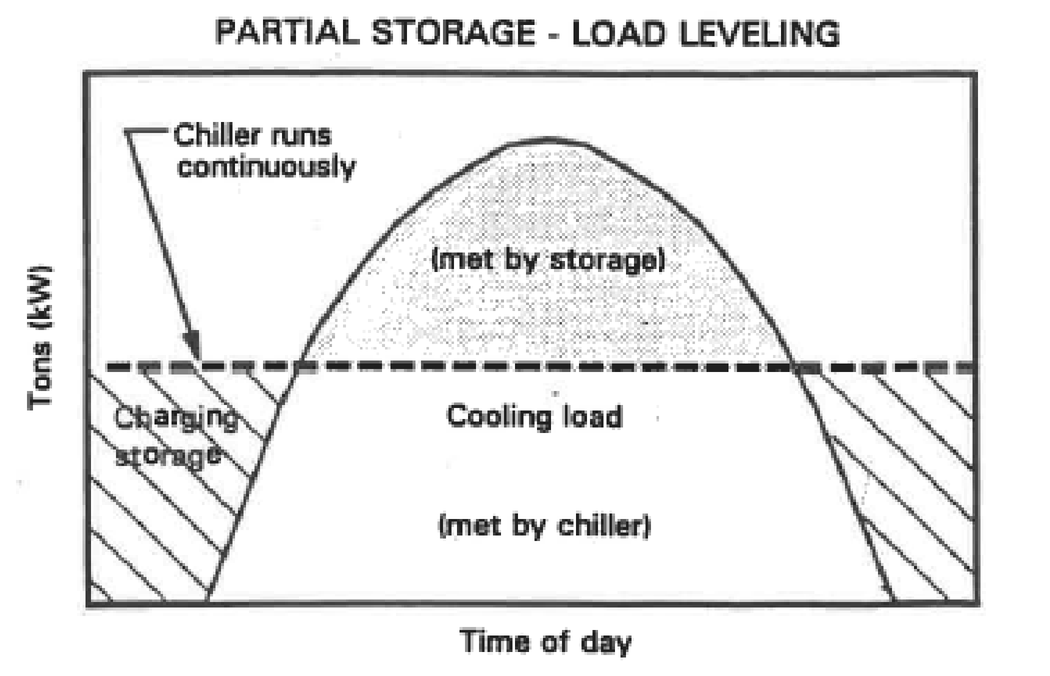
CTES Primer

- Operational Strategies (Ice or Water)
  - Full Storage
    - Largest load shift, largest plant size
    - Best for smaller facilities with high TOU energy rates



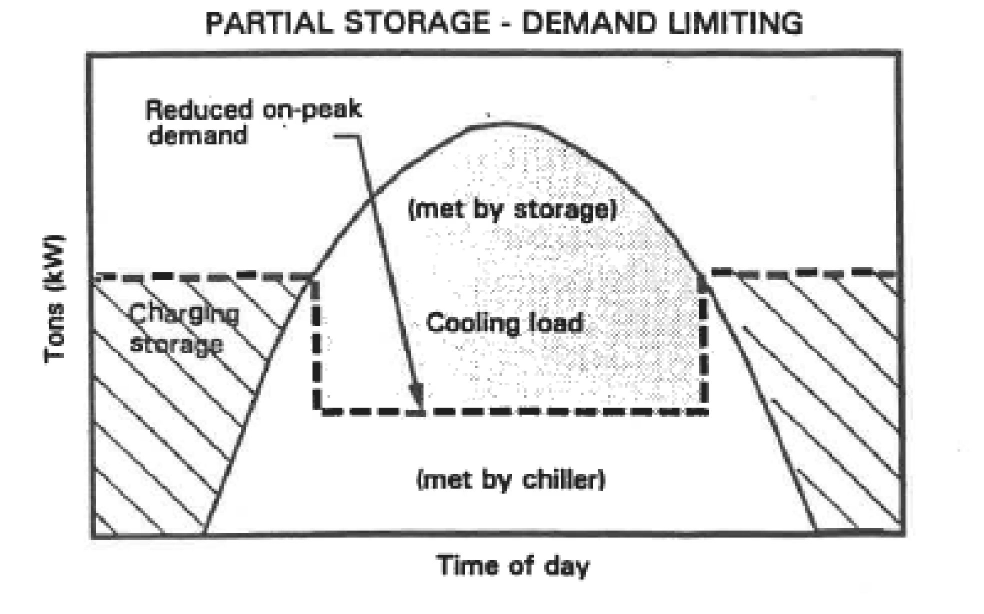
CTES Primer

- Operational Strategies (Ice or Water)
  - Partial Storage / Load Leveling
    - Moderate load shift, smallest plant size
    - Lowest ROI



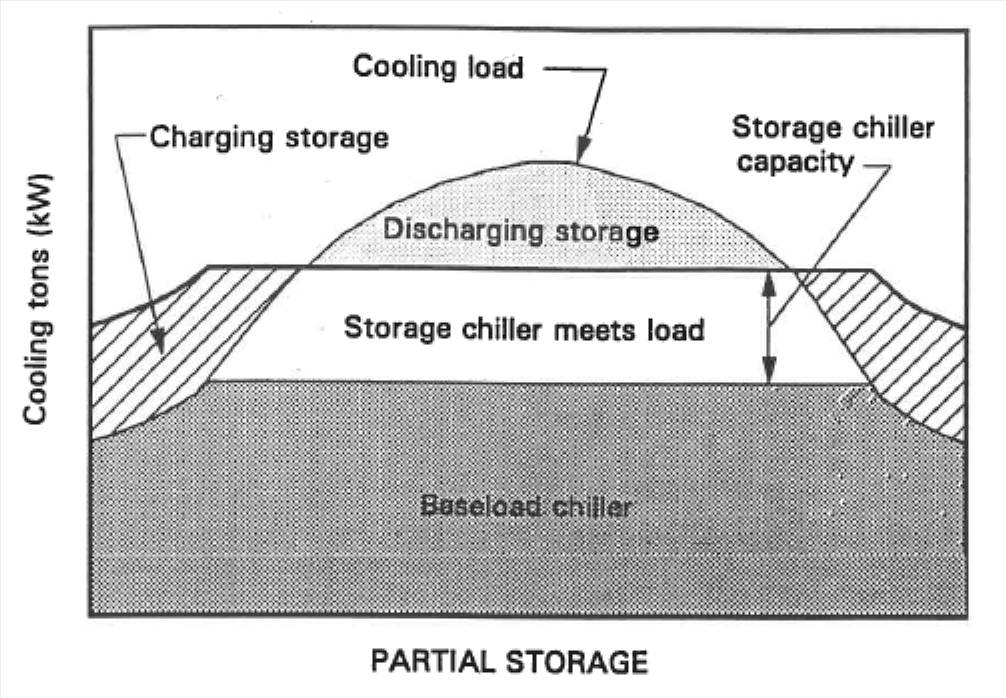
CTES Primer

- Operational Strategies (Ice or Water)
  - Partial Storage / Demand Limiting
    - Similar to load leveling but with more complex control
    - Favorable for high demand and ratcheting demand rates



CTES Primer

- Operational Strategies (Ice or Water)
  - NMSU Partial Storage / Demand Limiting
    - Partial Storage
    - Peak Shaving on top of Baseload

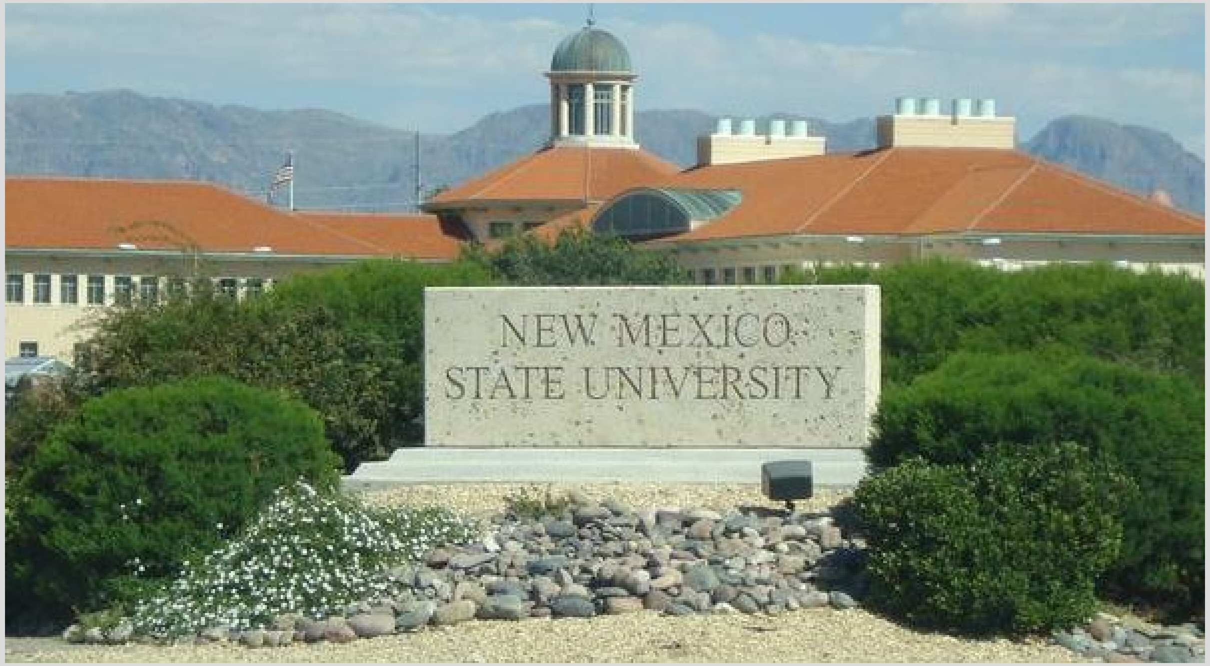


CTES Primer

- Newer Operational Strategies (Ice or Water)
  - 2-Stage CTES Deployment
    - Make Ice at Night to take advantage of TOU (Cost Control)
    - Make more ICE during day with renewable to span into the evening hours when there is high cooling load but no (Renewable Control)
    - Captures Utility cost savings and Increases Penetration of Renewable Energy Generation
    - Works best in our RMA Region

Why CTES for NMSU?

- Robust Chilled Water System with Ever-Growing Loads
- Need for redundancy and flexibility in chilled water production
- Highly Favorable TOU rates from El Paso Power



NM STATE

Facilities and Services

Project Development and Engineering

NMSU Chilled Water History

1965 – Central Plant (1) 900 Ton R-11 Centrifugal Chiller installation.

1968 – Central Plant (1) 1500 Ton R-114 Centrifugal Chiller addition.

1975 – Central Plant (1) 1500 Ton R-114 Centrifugal Chiller addition.

1984 – Central Plant 3 Million Gallon Chilled Water Thermal Storage.

1995 – Central Plant (2) 1500 Ton Double Effect LiBr Absorption Chiller addition.

2001 – Central Plant (3) 1500 Ton R-134A Centrifugal Chiller installation. (Replaced ‘65,’68,’75 Chillers)

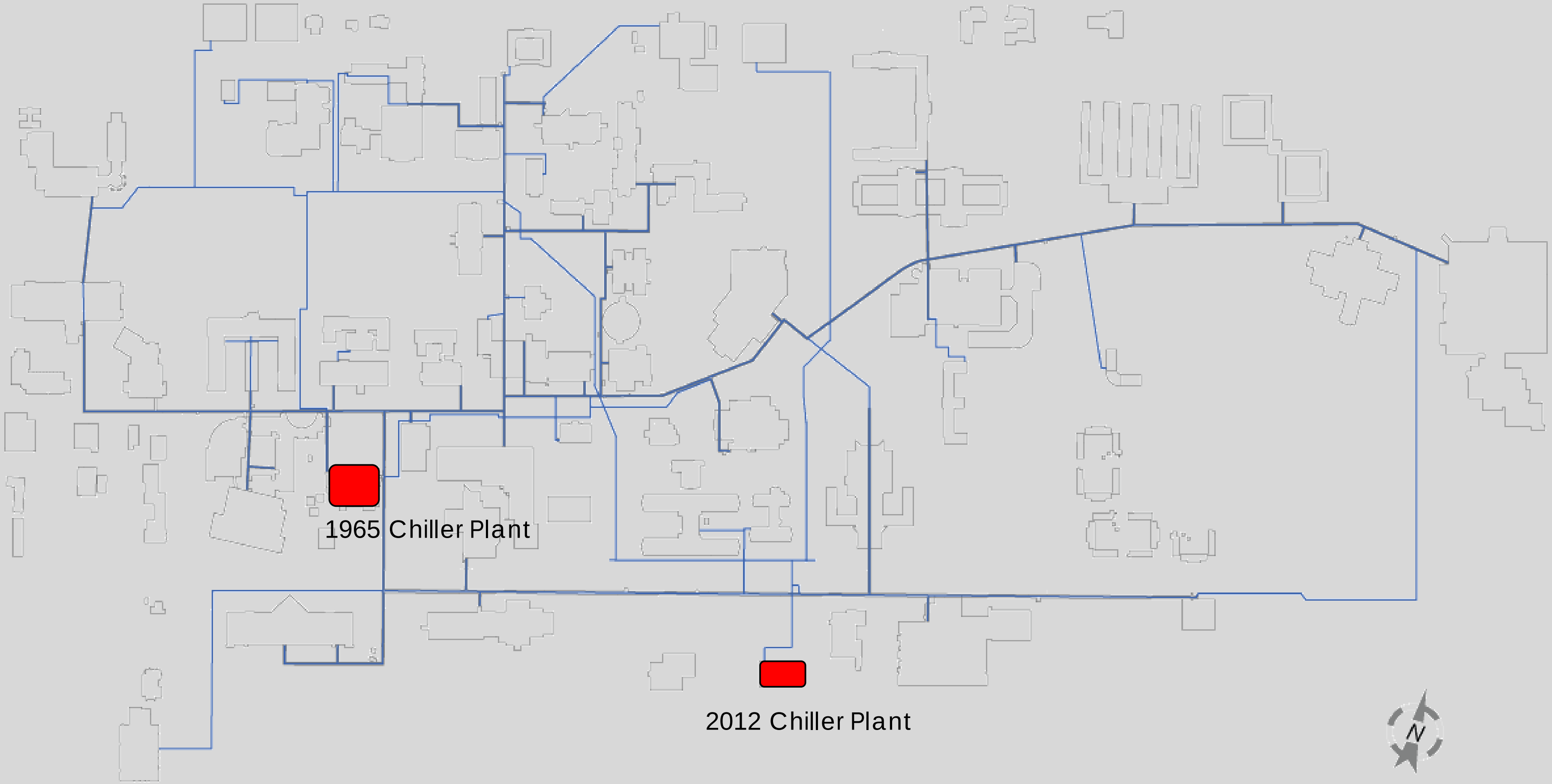
2009 – Updates to Utility Master Plan.

2010 – Chilled Water Distribution Capacity Improvements. (36” Chilled Water Mains)

2012 – Satellite Chiller Plant (1) 2500 Ton, (1) 900 Ton R-123 Centrifugal Chillers with Ice Storage.

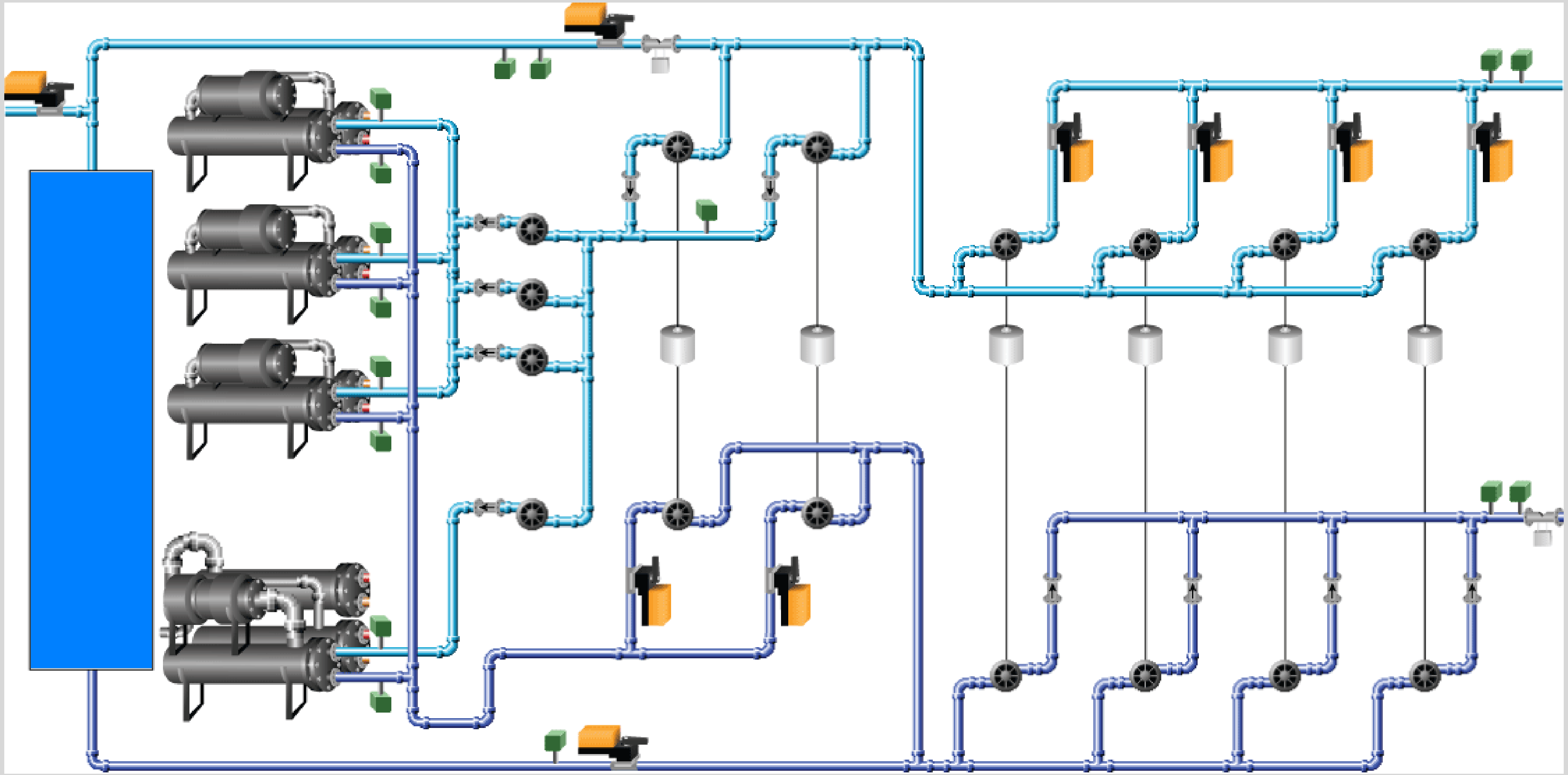
2013 – Central Plant (1) 1100 Ton Steam Driven Centrifugal Chiller. (Replaced 2 Absorption Chillers)

Main Campus Chilled Water Distribution

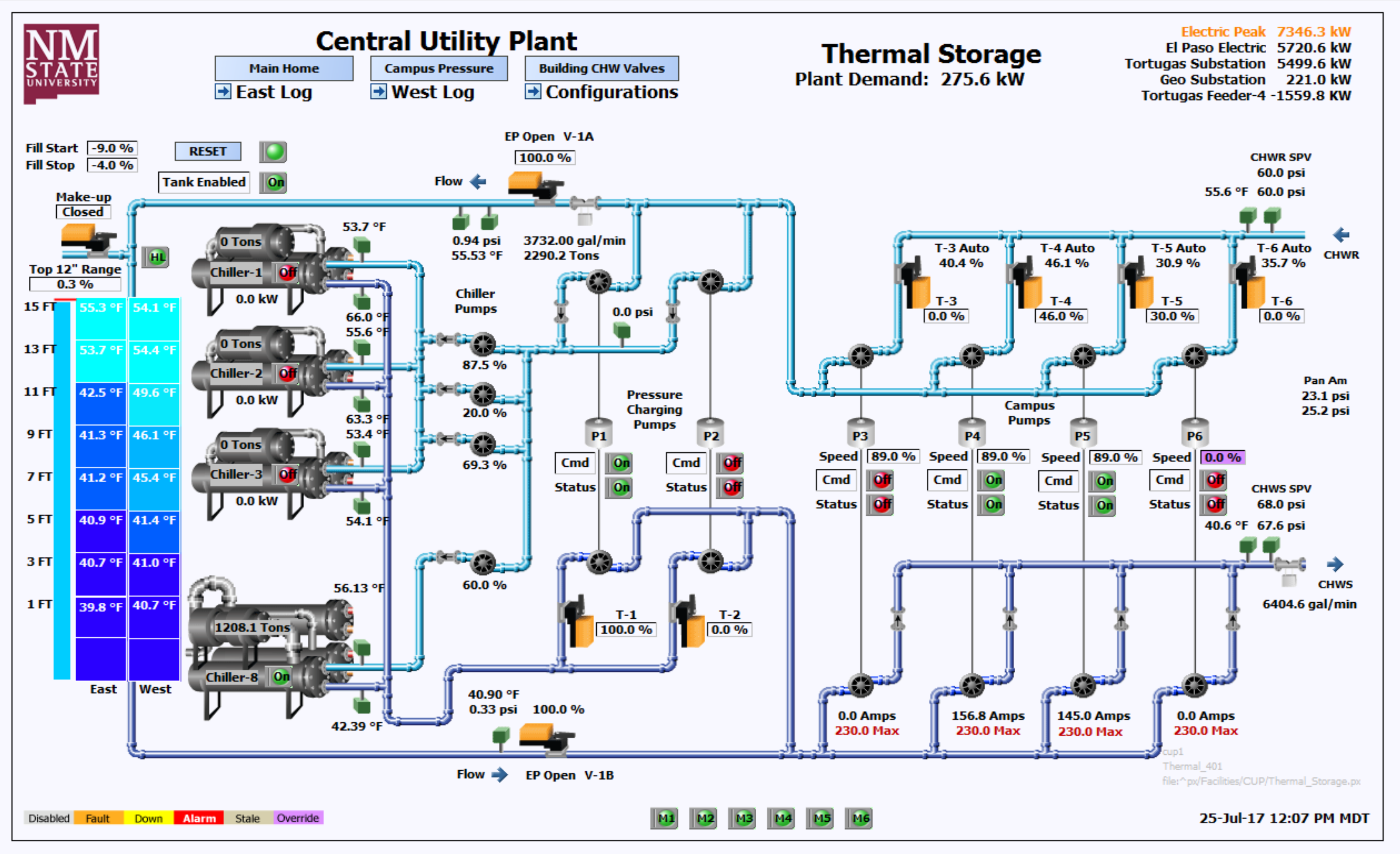


Central Utility Plant and Stratified Chilled Water Storage Site

Central Plant Chilled Water System Overview



Central Plant Chilled Water System Overview



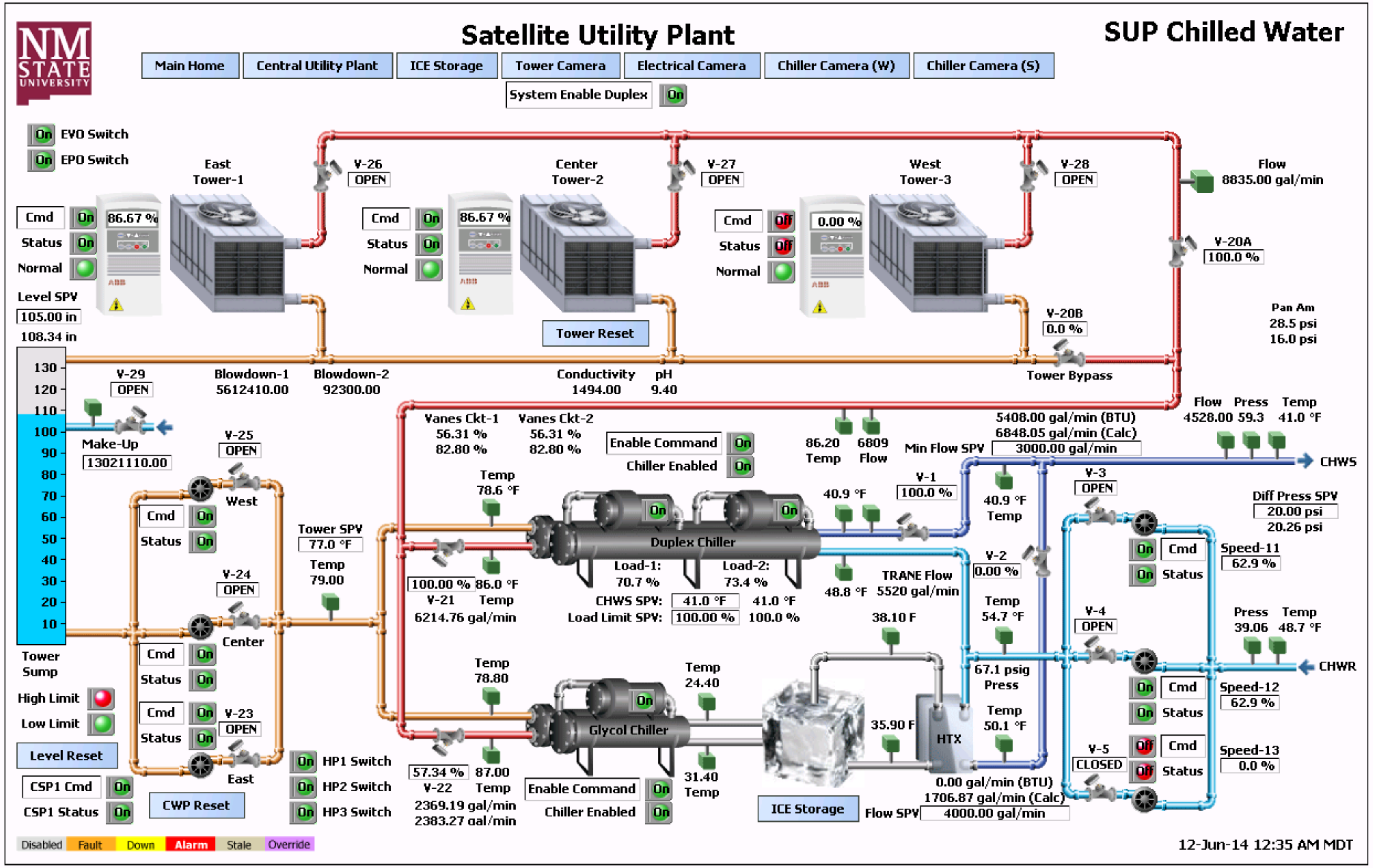
Satellite Chiller Plant & Ice Storage

Satellite Chiller Plant Equipment Overview

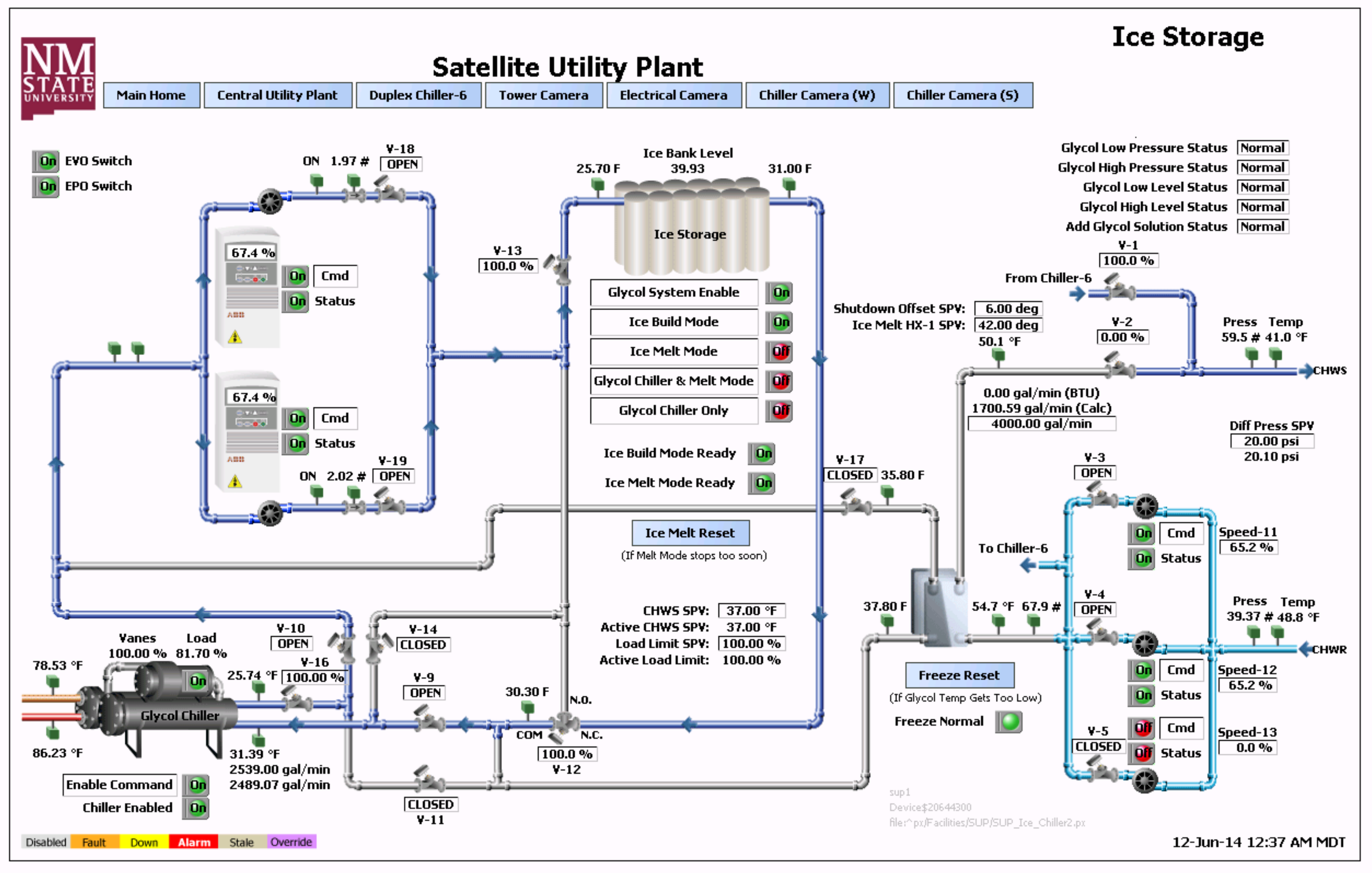
Ice Thermal Storage Site

Ice Thermal Storage Site

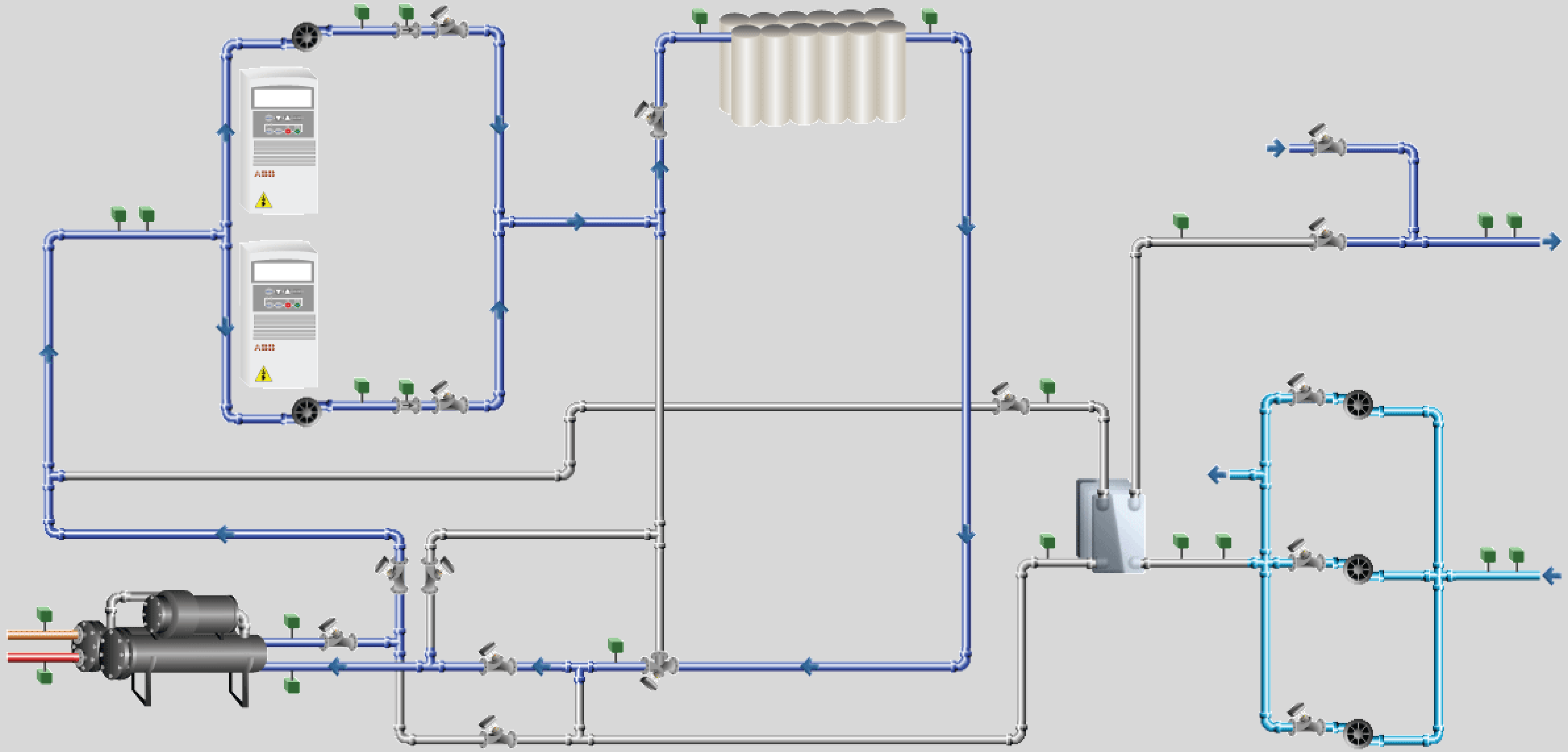
Satellite Chilled Water System Overview



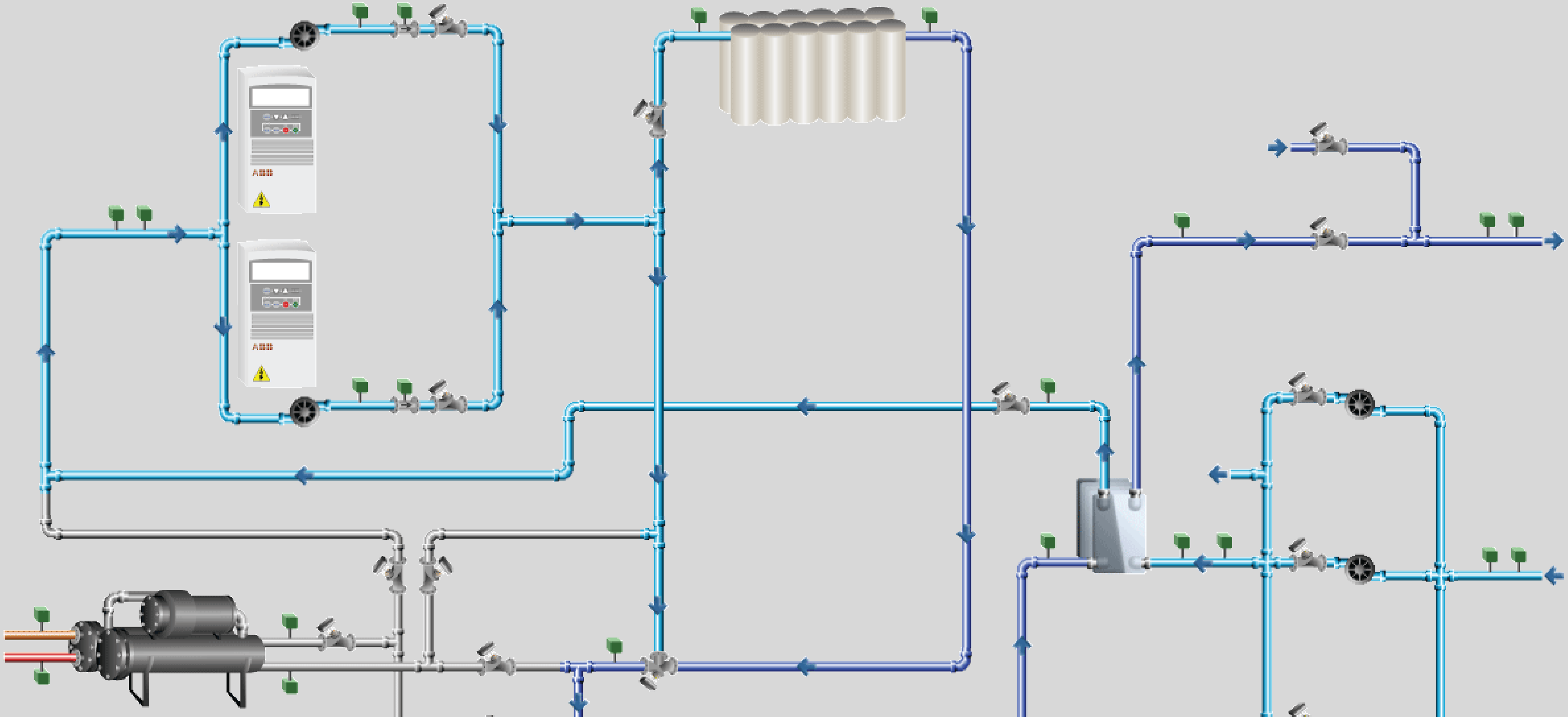
Ice Production Overview



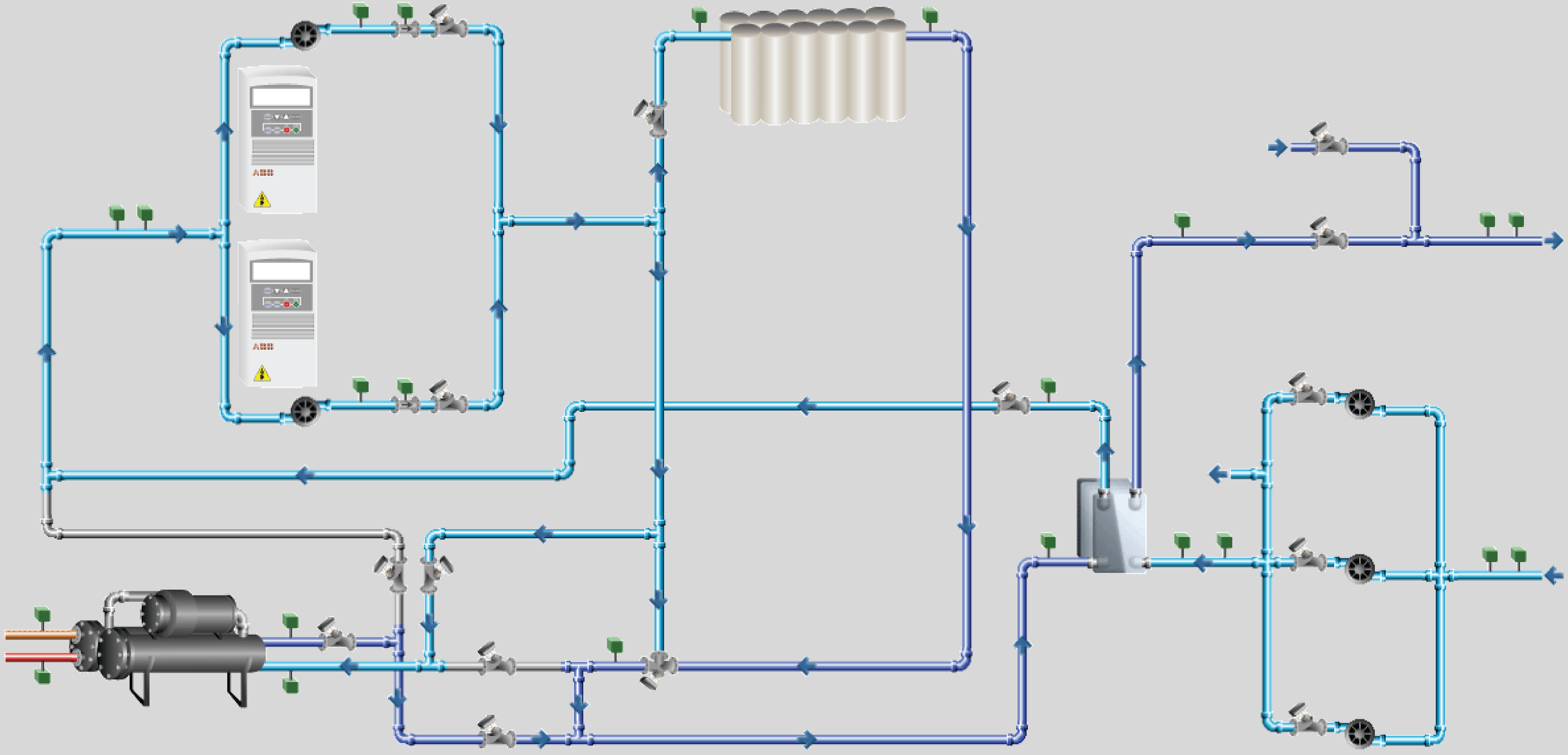
Ice Build Mode



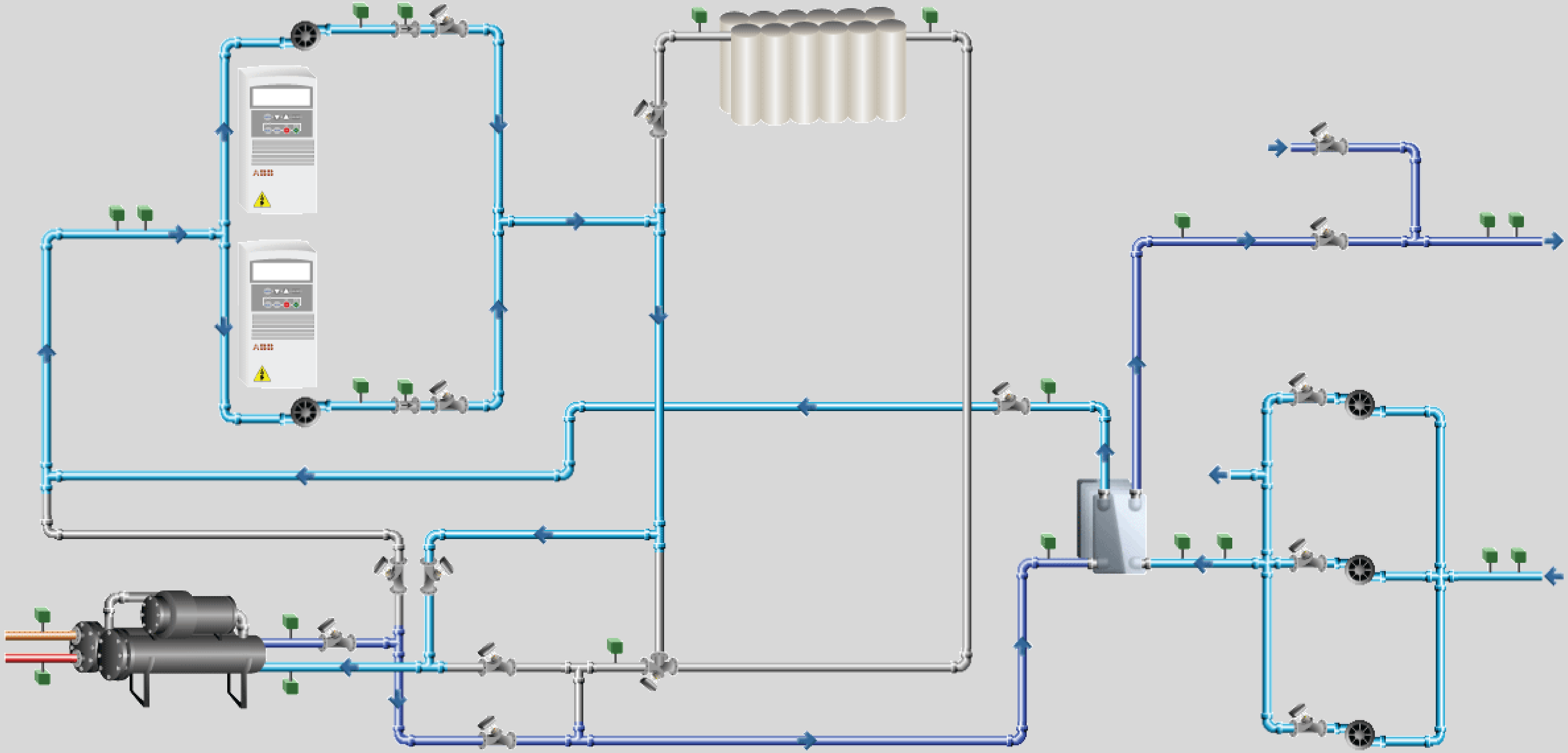
Ice Melt Mode



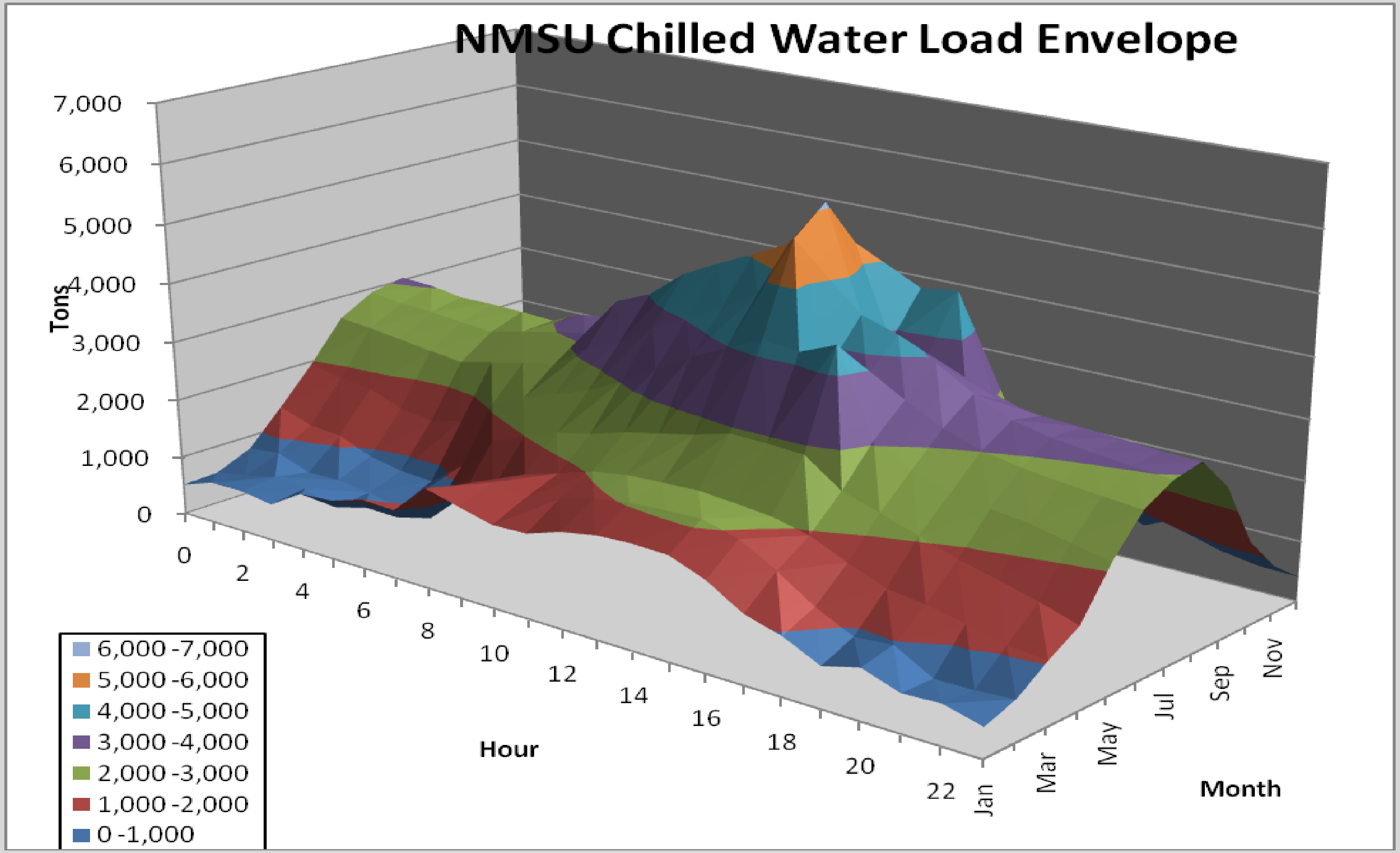
Ice Melt with Chiller Mode



Chiller Only Mode



Campus Chilled Water Demand
(average day/month)



2012 - Electric Utility Rate No. 26

EL PASO ELECTRIC COMPANY
SIXTH REVISED RATE NO. 26
CANCELLING FIFTH REVISED RATE NO. 26

STATE UNIVERSITY SERVICE RATE

NEW MEXICO PUBLIC REGULATION COMMISSION FILED 2009 DEC 17 PM 4 58

Page 1 of 3

APPLICABILITY:

This rate is available to any public college or university's main campus for lighting, power and heating service. The Customer and the Company will determine whether a Customer qualifies for this rate. A Customer qualifies for this rate if the expected monthly demand will exceed 9,000 kilowatts (kW). All service will be taken at one point of delivery designated by the Company and at one of the Company's standard types of service. A contract may be required in order to take service under this rate.

TERRITORY:

Areas served by the Company in Dona Ana, Sierra, Otero and Luna Counties.

TYPE OF SERVICE:

The type of service available will be determined by the Company and will be three phase at a standard Company approved voltage.

MONTHLY RATE:

Customer Charge

$25.00 per customer

Demand Charge	Per Billing kW
	$7.60

Energy Charge	Per kWh
On-Peak	$0.24212
Off-Peak	$0.04860

On-Peak Period shall be from 12:00 P.M. to 6:00 P.M, Mountain Daylight Time, Monday through Friday, for months of June through September.

Off-Peak Period shall be all other hours of the week not covered in the On-Peak Period.

Advice Notice No. 213

Signature/Title David G. Carpenter

David G. Carpenter
Senior Vice President-Chief Financial Officer

On-Peak period is applicable June through September from 12:00 PM to 6:00 PM.

On-Peak rate equals $.24212 per kWh.

Off-Peak rate equals $.04860 per kWh.

Demand limit set at 9000 kW.

Demand charge equals $7.60 per kW above the 9000 kW.

Current Electric Utility Rate No. 26

EL PASO ELECTRIC COMPANY

SEVENTH REVISED RATE NO. 26
CANCELLING SIXTH REVISED RATE NO. 26

STATE UNIVERSITY SERVICE RATE

Page 1 of 3

APPLICABILITY:

This rate schedule is available to any public college or university's main campus for lighting, power and heating service. The Customer and the Company will determine whether a Customer qualifies for this rate schedule. A Customer qualifies for this rate schedule if the expected monthly demand will exceed 6,000 kilowatts (kW). A contract may be required in order to take service under this rate schedule.

TERRITORY:

Areas served by the Company in Dona Ana, Sierra, Otero and Luna Counties.

TYPE OF SERVICE:

Service available under this rate schedule will be determined by the Company and will be three phase at a standard Company approved voltage. All service will be taken at a single point of delivery designated by the Company.

MONTHLY RATES:

Customer Charge (per meter per month)	$135.00

Demand and Energy Charges	Summer (June through September)	Winter (October through May)
Demand Charge per Billing kW	$16.71	$8.85
Energy Charge per kWh: On-Peak	$0.09124	-------
Energy Charge per kWh: Off Peak	$0.00428	$0.00428

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The Off-Peak Period shall be all other hours of the week not covered in the On-Peak Period.

MONTHLY MINIMUM CHARGE:

The Customer Charge plus applicable Demand Charge plus Tax Adjustment.

Advice Notice No. 239

Signature/Title [signature]
Nathan T. Hirschi
Senior Vice President - CFO

On-Peak period is applicable June through September from 12:00 PM to 6:00 PM.

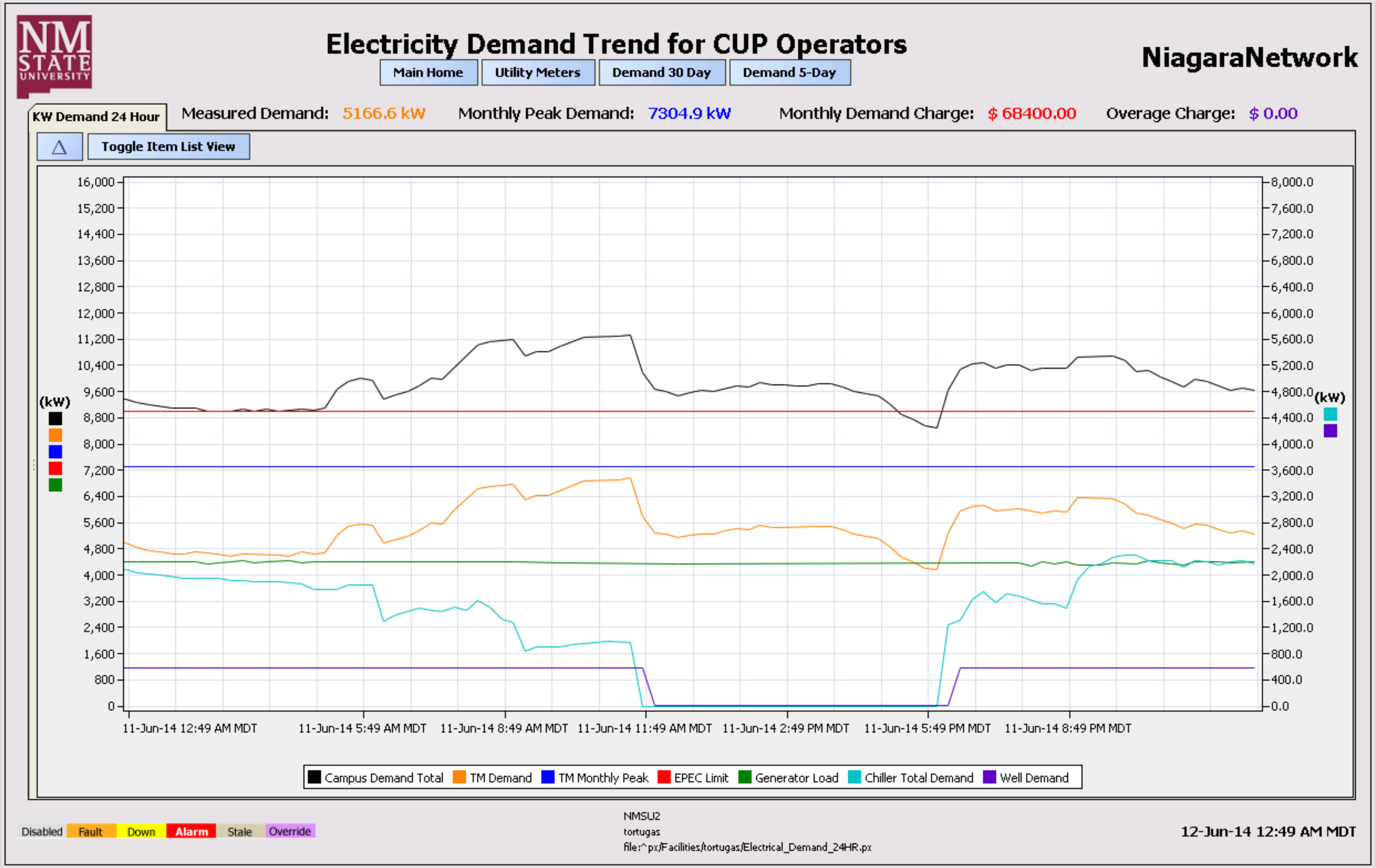
On-Peak rate equals $.09124 per kWh.

Off-Peak rate equals $.00482 per kWh.

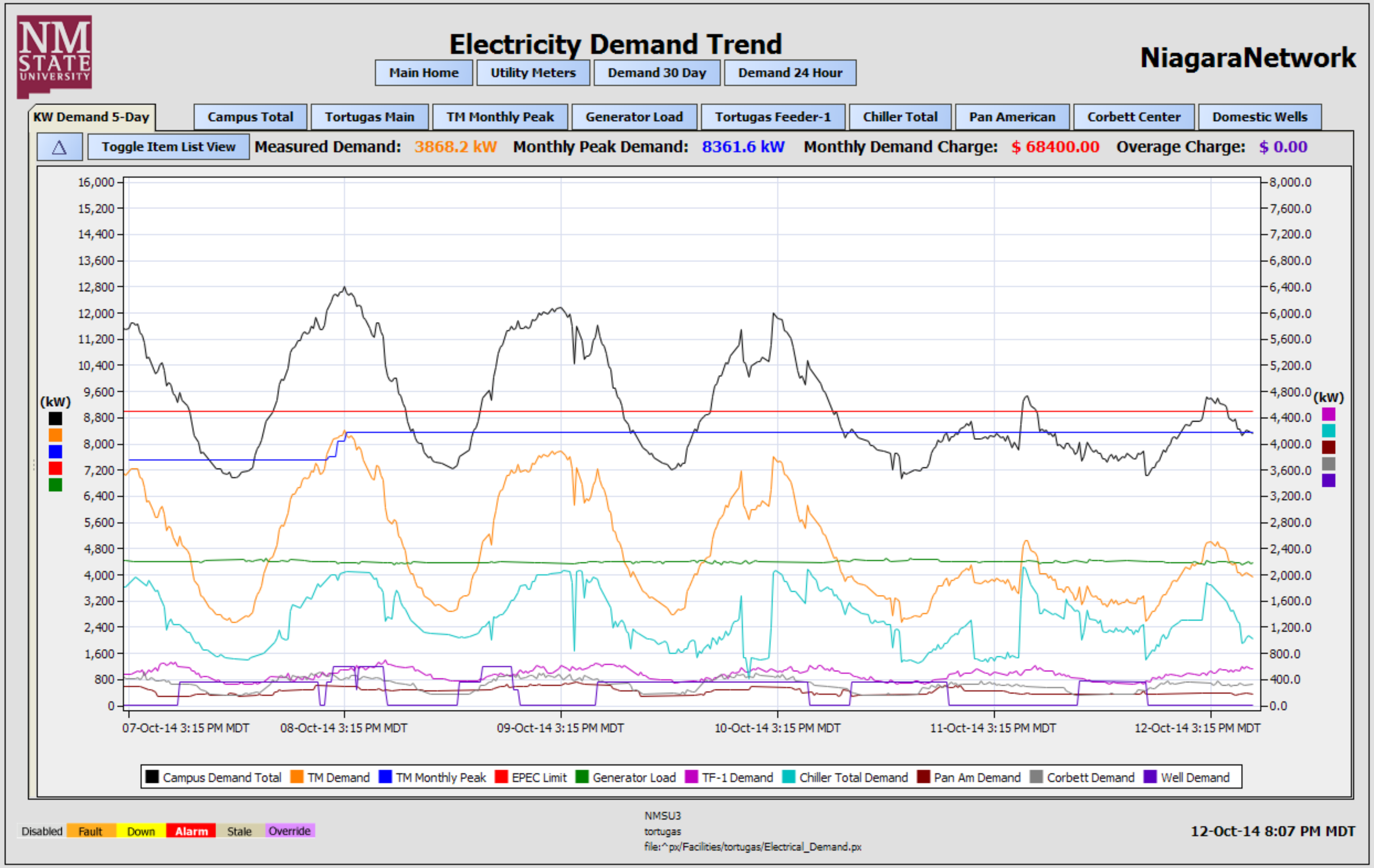
Demand limit set at 6000 kW.

Demand charge equals $16.71 per kW above the 6000 kW.

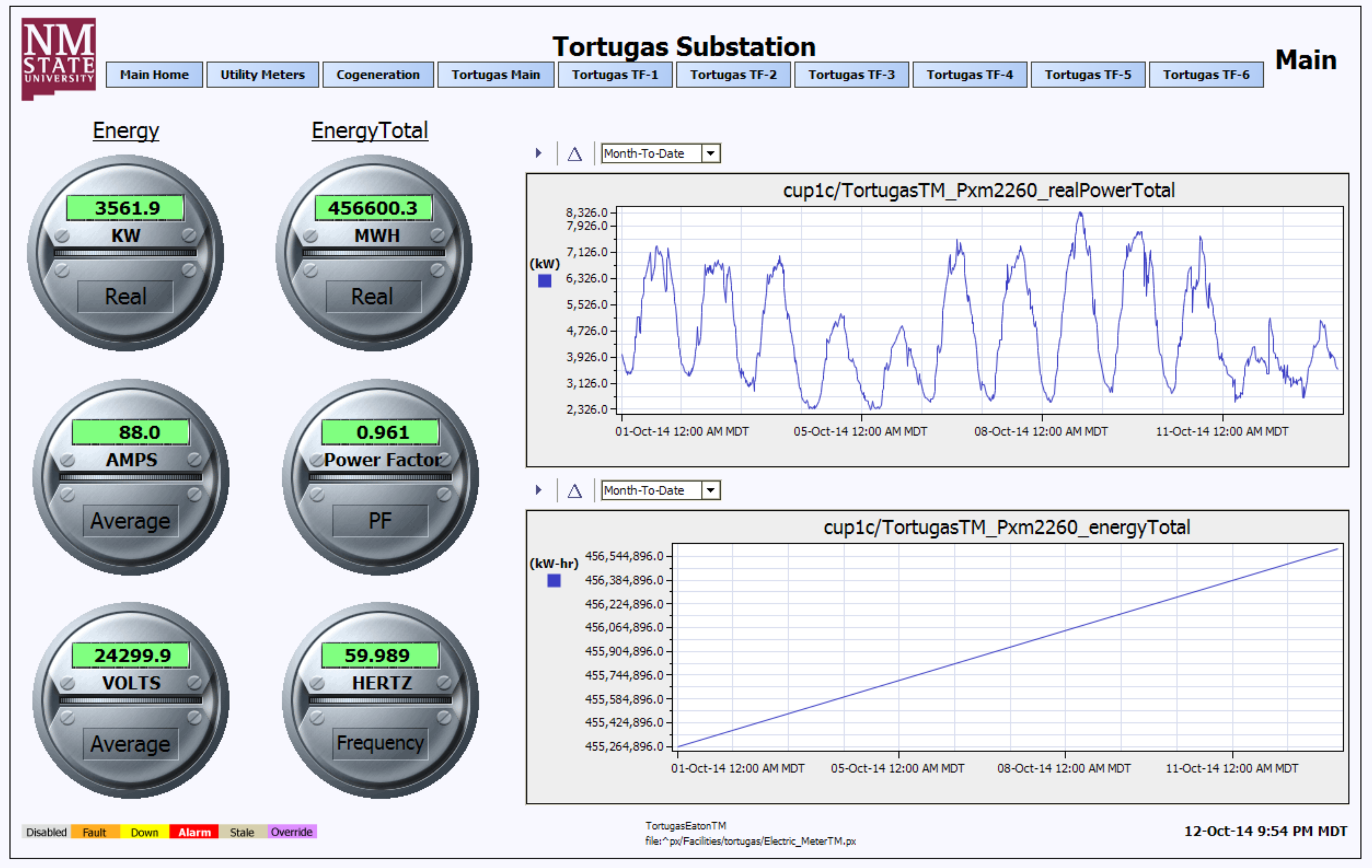
Electrical Demand Overview

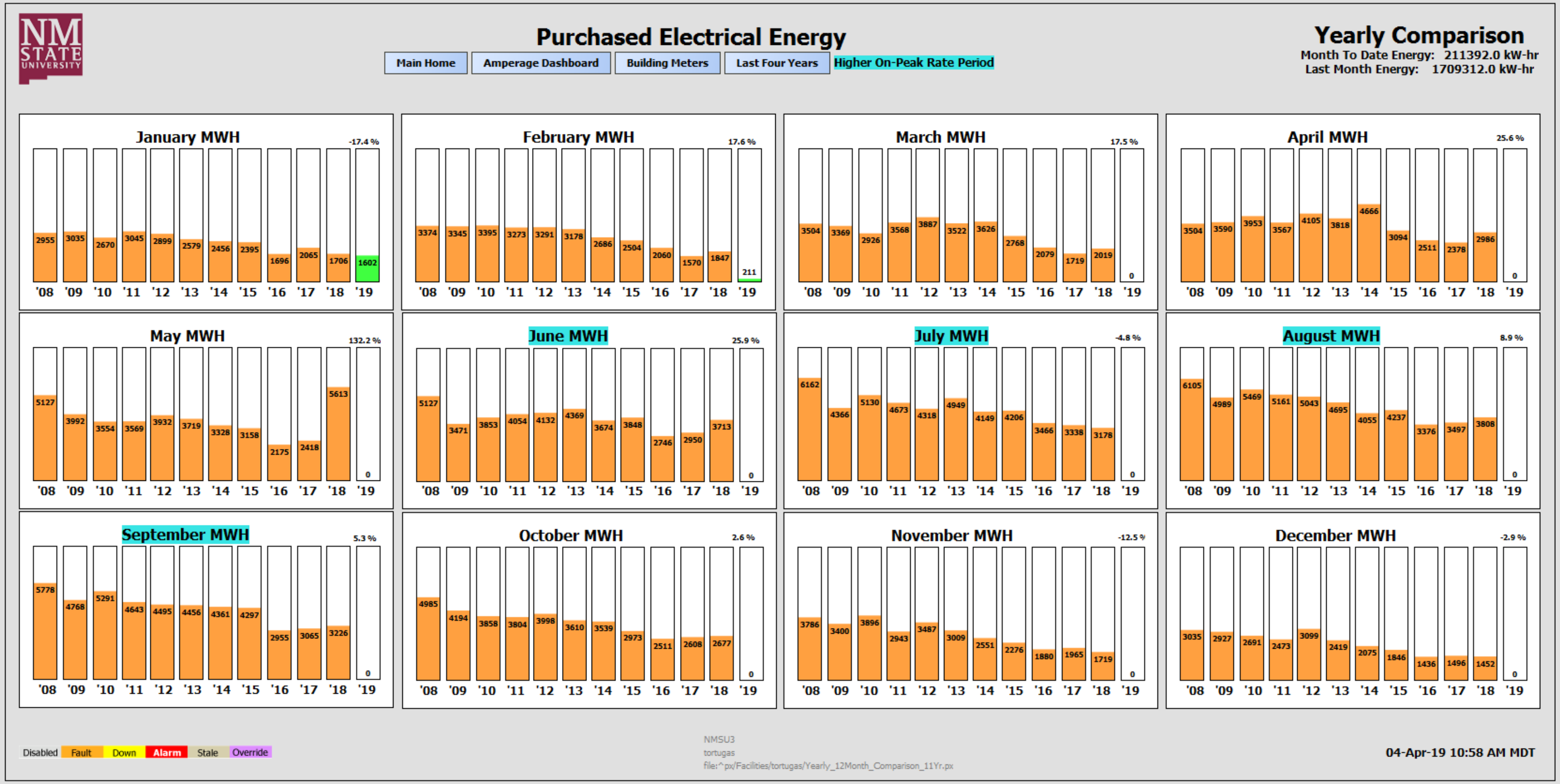


Electrical Demand Detailed Overview



Main Electrical Substation




NM STATE UNIVERSITY
Purchased Electrical Energy
Main Home
Amperage Dashboard
Building Meters
Last Four Years
Higher On-Peak Rate Period
Yearly Comparison
Month To Date Energy: 211392.0 kW-hr
Last Month Energy: 1709312.0 kW-hr
January MWH -17.4 %
2955 3035 2670 3045 2899 2579 2456 2395 1696 2065 1706 1602
February MWH 17.6 %
3374 3345 3395 3273 3291 3178 2686 2504 2060 1570 1847 211
March MWH 17.5 %
3504 3369 2926 3568 3887 3522 3626 2768 2079 1719 2019 0
April MWH 25.6 %
3504 3590 3953 3567 4105 3818 4666 3094 2511 2378 2986 0
May MWH 132.2 %
5127 3992 3554 3569 3932 3719 3328 3158 2175 2418 5613 0
June MWH 25.9 %
5127 3471 3853 4054 4132 4369 3674 3848 2746 2950 3713 0
July MWH -4.8 %
6162 4366 5130 4673 4318 4949 4149 4206 3466 3338 3178 0
August MWH 8.9 %
6105 4989 5469 5161 5043 4695 4055 4237 3376 3497 3808 0
September MWH 5.3 %
5778 4768 5291 4643 4495 4456 4361 4297 2955 3065 3226 0
October MWH 2.6 %
4985 4194 3858 3804 3998 3610 3539 2973 2511 2608 2677 0
November MWH -12.5 %
3786 3400 3896 2943 3487 3009 2551 2276 1880 1965 1719 0
December MWH -2.9 %
3035 2927 2691 2473 3099 2419 2075 1846 1436 1496 1452 0
'08 '09 '10 '11 '12 '13 '14 '15 '16 '17 '18 '19
Disabled Fault Down Alarm Stale Override
NMSU3
tortugas
file:^px/Facilities/tortugas/Yearly_12Month_Comparison_11Yr.px
04-Apr-19 10:58 AM MDT

Benefits of NMSU Chilled Water System Layout

- Additional cooling capacity to keep pace with campus growth.
- Electrical “Off-Peak” thermal storage production capability.
- Chilled Water is produced with higher efficiency refrigeration equipment.
- Centralized utility plant location improves chilled water distribution pressures. This creates a reduction in the electrical energy required to circulate chilled water to the campus buildings.
- The utility plant is a modular design that allows for future equipment expansions.
- The ice producing refrigeration chiller provides operational flexibility due to the fact that this machine can operate as a conventional chiller in an emergency.

CTES Has Been a Success at NMSU

- $1.2 - $1.5 Million Annual Avoided Cost in Utility Bills
- On track for 15 year Payback
- Were able to add sufficient capacity to handle campus cooling load
- CTES provides operational Thermal Capacitor and Battery Effect, Firm Capacity
- Now Have Leverage to Negotiate Utility Rates – NMSU seen at ‘Partner’ rather than ‘Customer’

Where will NMSU Chilled Water System go next?

- Turn NMSU's 'Cool Pool' into Subterranean Ice Farm
  - Discontinue Use of Stratified Thermal Storage Tank
  - Fill Underground Storage Tank with 2-Levels of Ice Tanks
  - Eliminate High Pumping Head associated with 'Open' System
  - Move toward 'Closed' System for simplified O&M

Thank you for your time

Questions or Comments ???

References:

- Bahnfleth and Reindl, 1998, Prospects for Cool Thermal Storage in a Competitive Electric Power Industry, *Journal of Architectural Engineering / March 1998*
- Guideline for Specifying the Thermal Performance of Cool Storage Equipment, *Air-Conditioning and Refrigeration Institute*
- Reindl, Douglas and Contributing Authors, Design and Utilization of Thermal Energy Storage to Increase the Ability of Power Systems to Support Renewable Energy Sources, March 2017, *ASHRAE Research Project Report 1607-RP*