Cooling systems for the SMART GRID

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October 17, 2013

Topics to cover

CALMAC's History

Energy Storage Types – Market Impacts

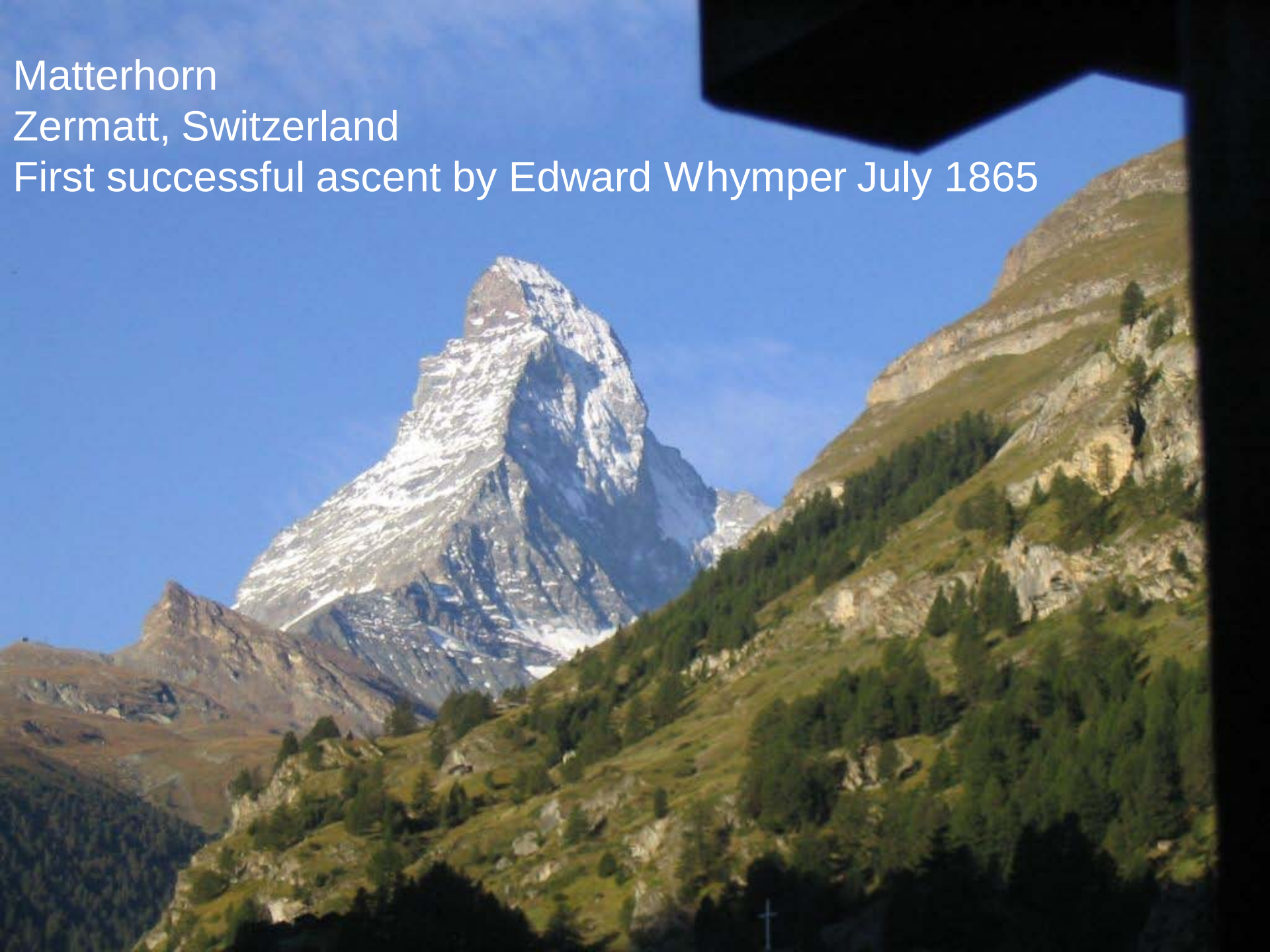
Thermal Storage Market - Past and Future

Electric Grid - Past , Present and Future

Grid Implications of Renewables and Shale

Case Studies


Calvin D. MacCracken
Inventor and Entrepreneur
CALMAC
Sir Frank Whittle Inventor of Jet Engine


Matterhorn
Zermatt, Switzerland
First successful ascent by Edward Whymper July 1865

Matterhorn
Zermatt, Switzerland
Summitted by Mark M MacCracken (with son with guide)

August 19, 2012

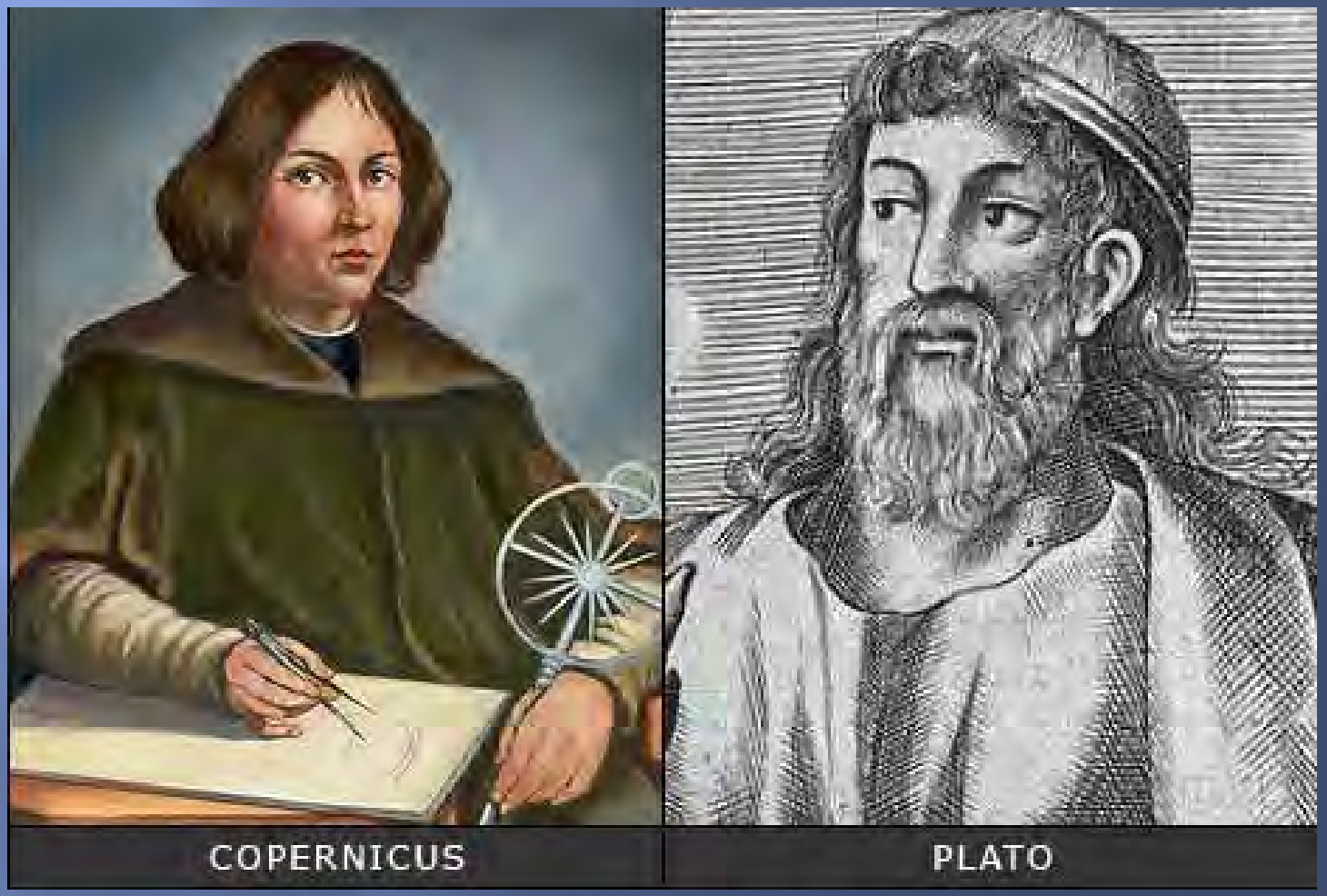
CALMAC

- Founded in 1947 by Calvin D MacCracken
- Developed over 250 products for major others
- Mark M MacCracken Joined in 1976
- First commercial TES project in 1979
- Currently have 4000 projects in 37 countries
- Reduced Peak demand by over 1 GW
- Shift 6GW-hr. daily from On to Off Peak
- 33% of our business is Export and 1% has been to UK (~60MW-hrs reducing peak by ~10MW)

Archibald MacLeish
American writer

The New York Times
25 December 1968

Heretics ???



Ferdinand de Magellan

According to repeated nationwide surveys,

More Doctors Smoke CAMELS than any other cigarette!

Doctors in every branch of medicine were asked, "What cigarette do you smoke?" The brand named most was Camel!

You'll enjoy Camels for the same reasons so many doctors enjoy them. Camels have cool, cool *mildness*, puff after puff, and a *flavor* unmatched by any other cigarette.

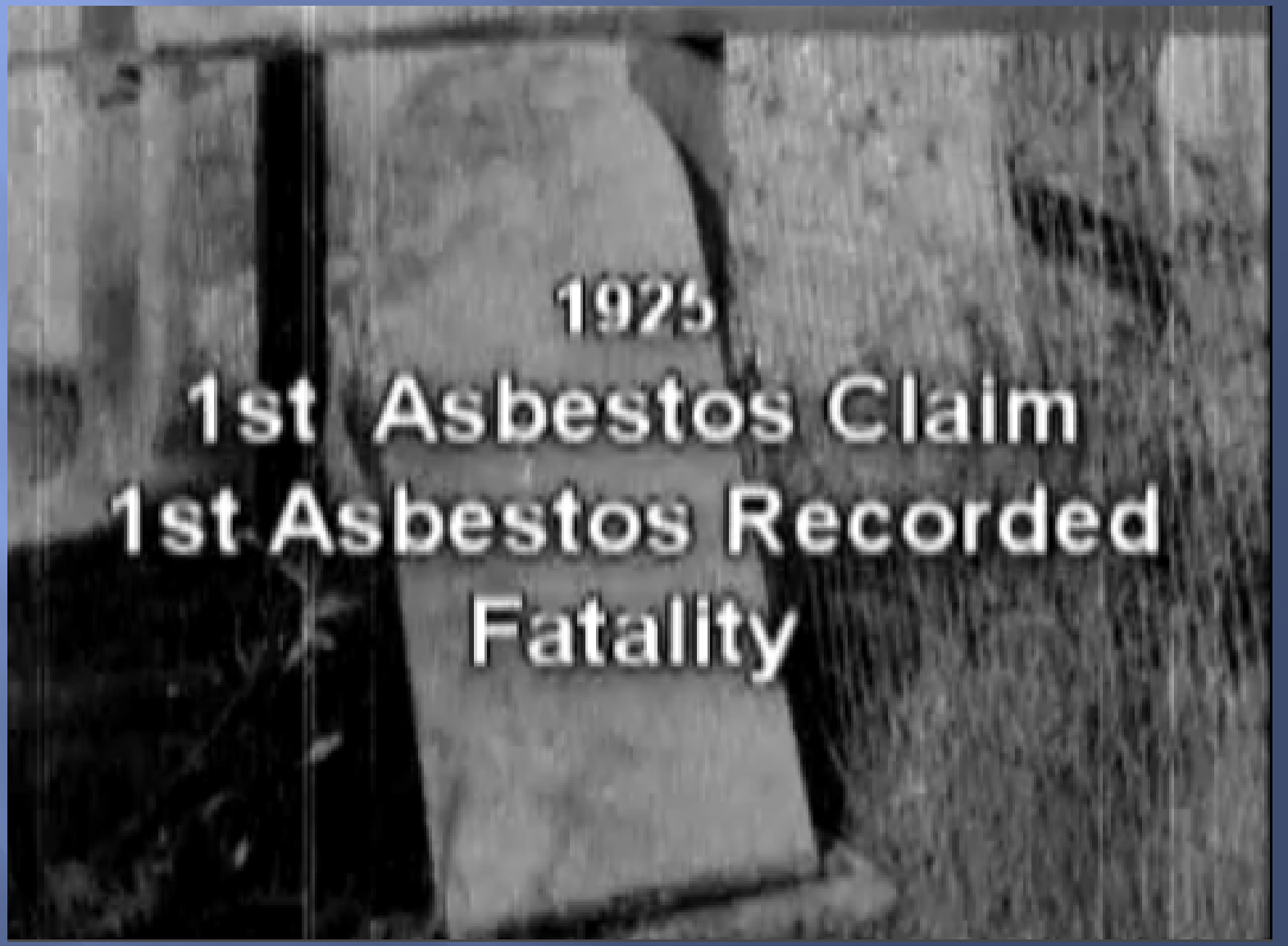
Make this sensible test: Smoke only Camels for 30 days and see how well Camels please your taste, how well they suit your throat as your steady smoke. You'll see how enjoyable a cigarette can be!

THE DOCTORS' CHOICE IS AMERICA'S CHOICE!

For 30 days, test Camels in your "T-Zone" (T for Throat, T for Taste).

CALMAC 60 Years of INNOVATION


Marlboro
EUR 38,50
Marlboro
Marlboro Red
EUR 38,50
Marlboro
FLIP-TOP BOX
Smoking kills
Marlboro
Smoking may reduce the blood flow and causes impotence
Marlboro
Smoking seriously harms you and others around you
Marlboro
Smoking may reduce the blood flow and causes impotence
Marlboro
EUR 38,50
Marlboro
EUR 38,50
Smoking clogs the arteries and
Marlboro
Smoking clogs the arteries and


1925
1st Asbestos Claim
1st Asbestos Recorded
Fatality

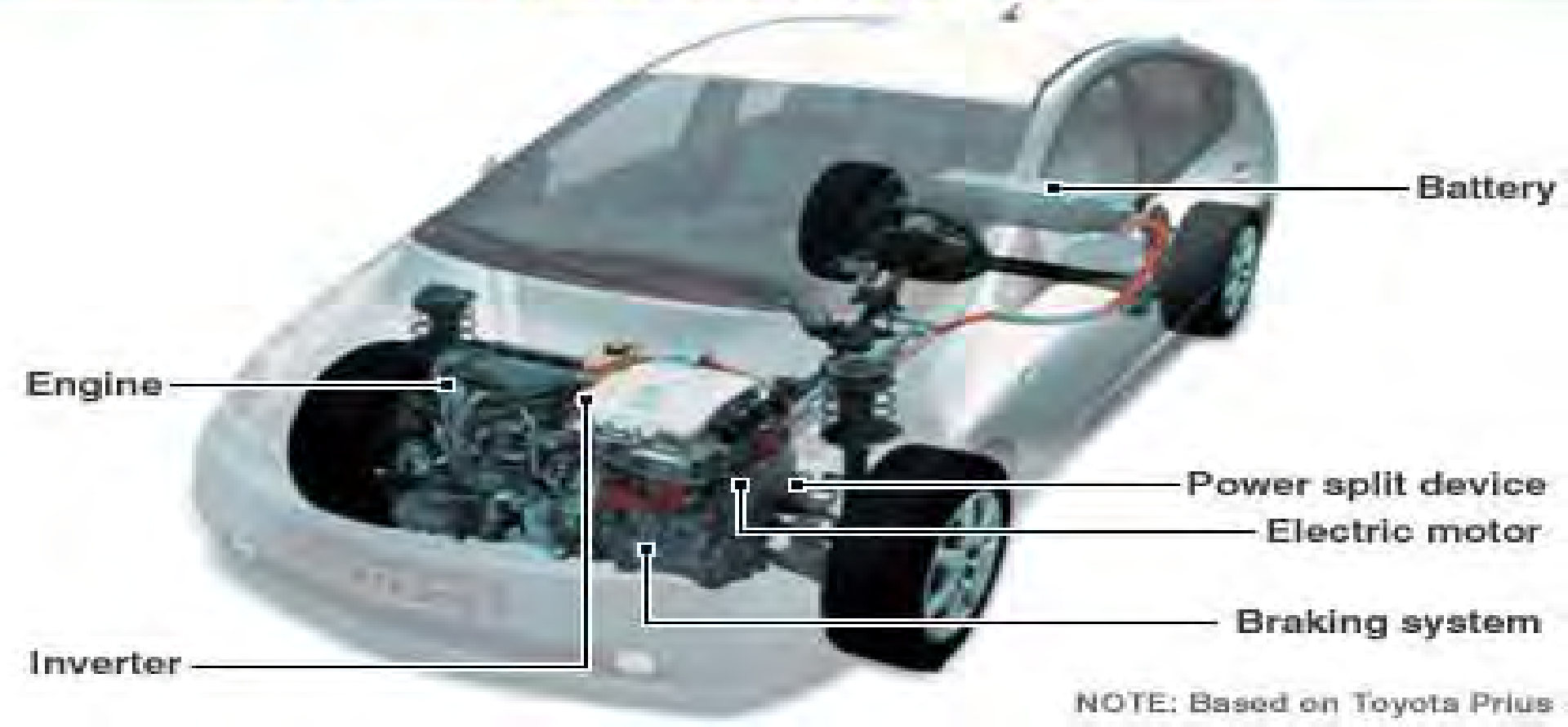

We Are Creating the Changes;
It Is Our Earth--
It is Our Responsibility to Both
Slow the Rate of Change and
Prepare Society to Deal With
the Changes that Are Coming!!
Warming will create a new look for the Arctic


CALMAC
VOLT

KEY COMPONENTS OF A HYBRID CAR

Many hybrid cars cut fuel consumption by combining a petrol engine with additional power sources - such as battery power

- Electric motor in use throughout
- Petrol engine used
- Battery power used
- Battery recharging



NOTE: Based on Toyota Prius

Storage is Natural

Most common TES System

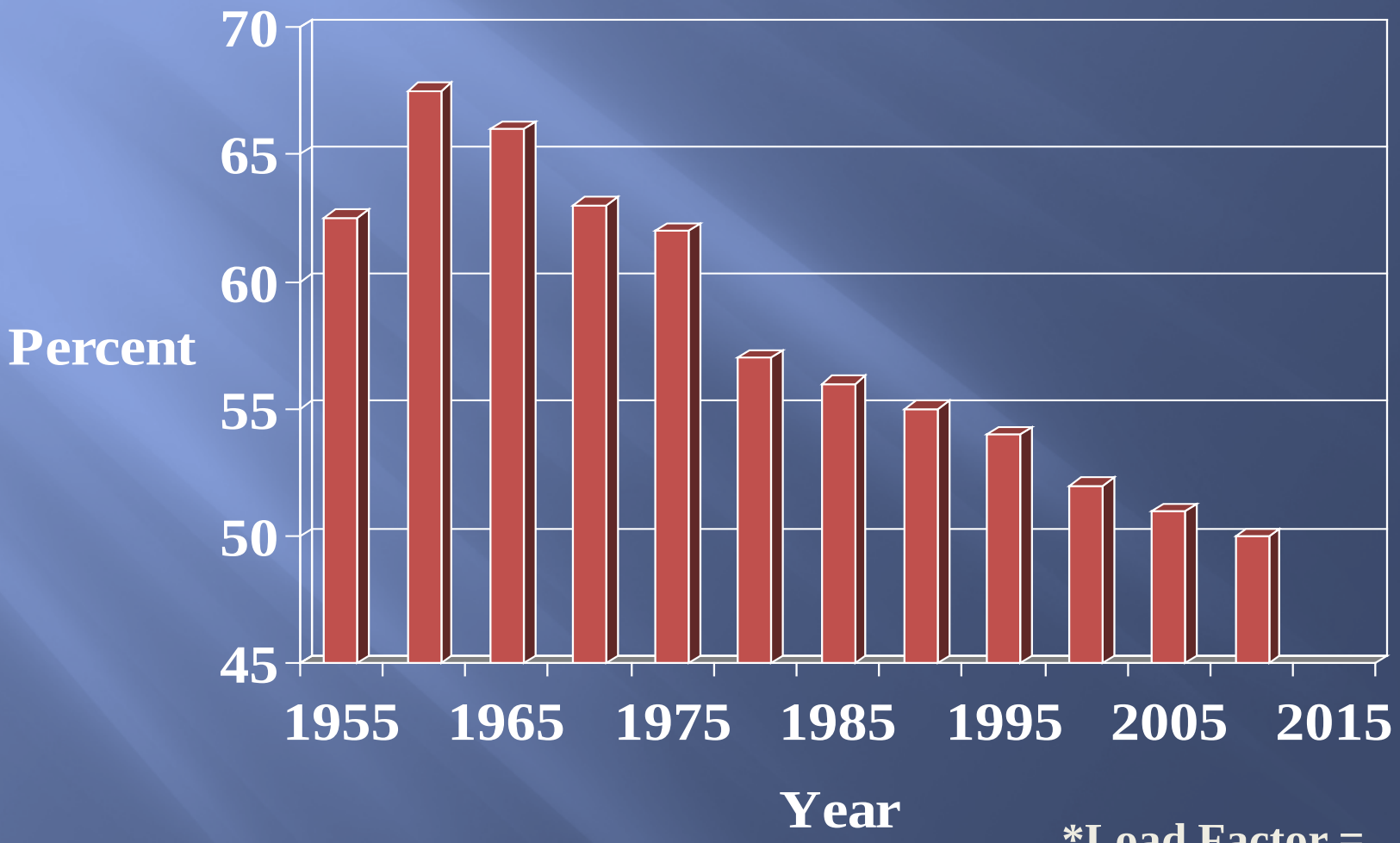
4.5 kW
Heater

Water Heater (Electric)

Assume one low-flow shower
((2.5gpm x 8.33 lb/gal x (110-60))
x 60 minutes/hr / 3,414 Btu/kW =

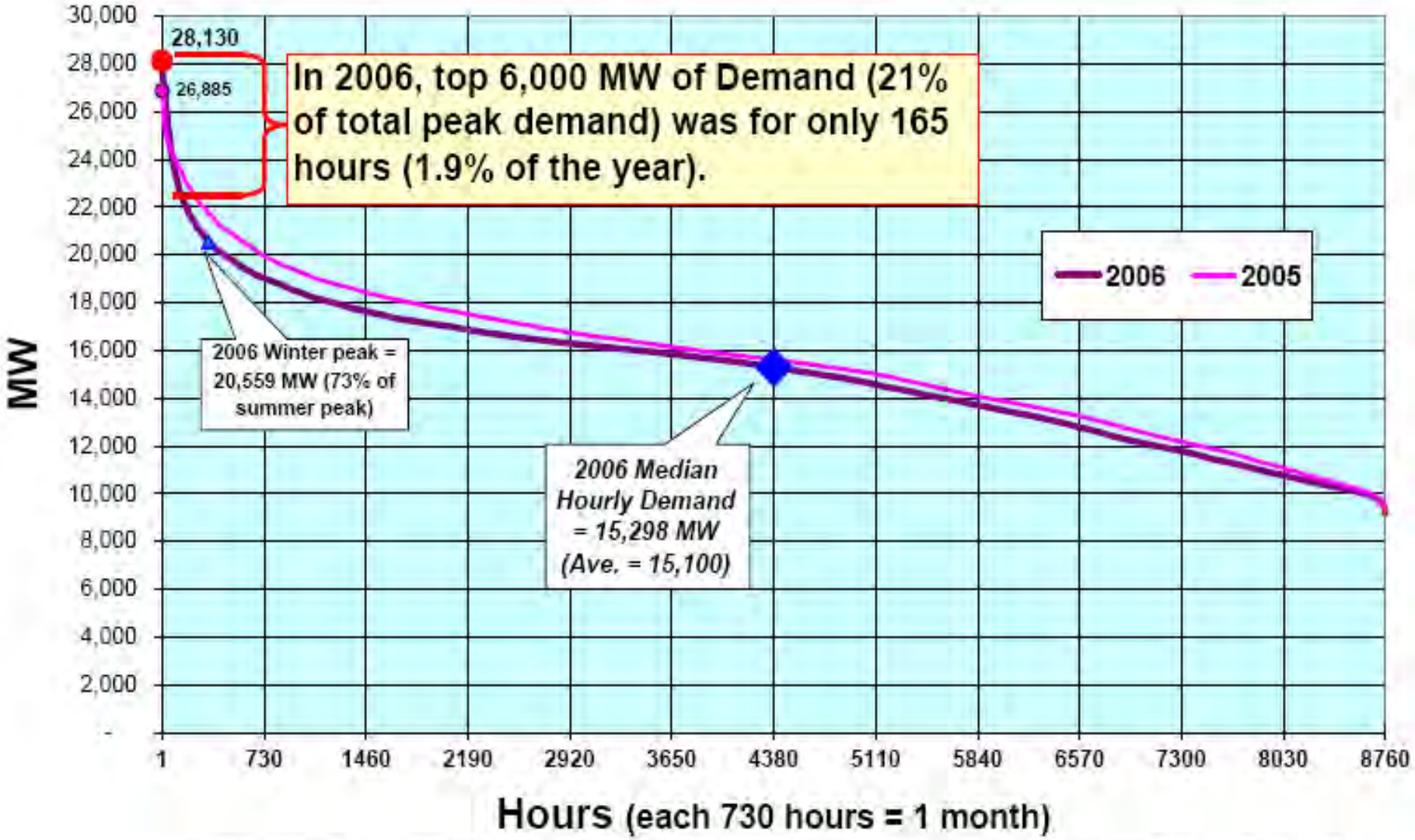
18.3 kW

Utility Load Factors* in the USA

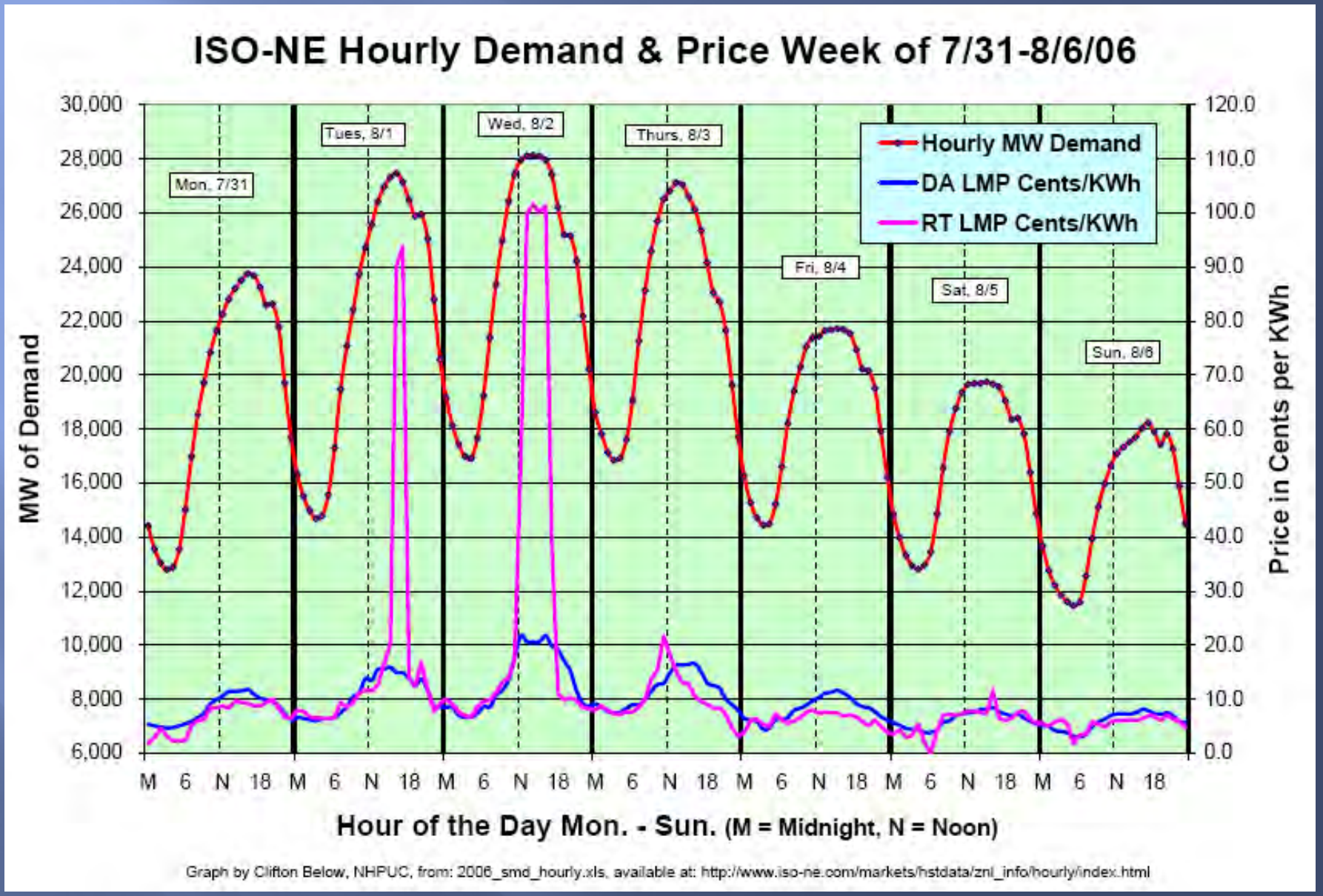


*Load Factor = $\frac{\text{Avg. Load}}{\text{Peak Load}}$

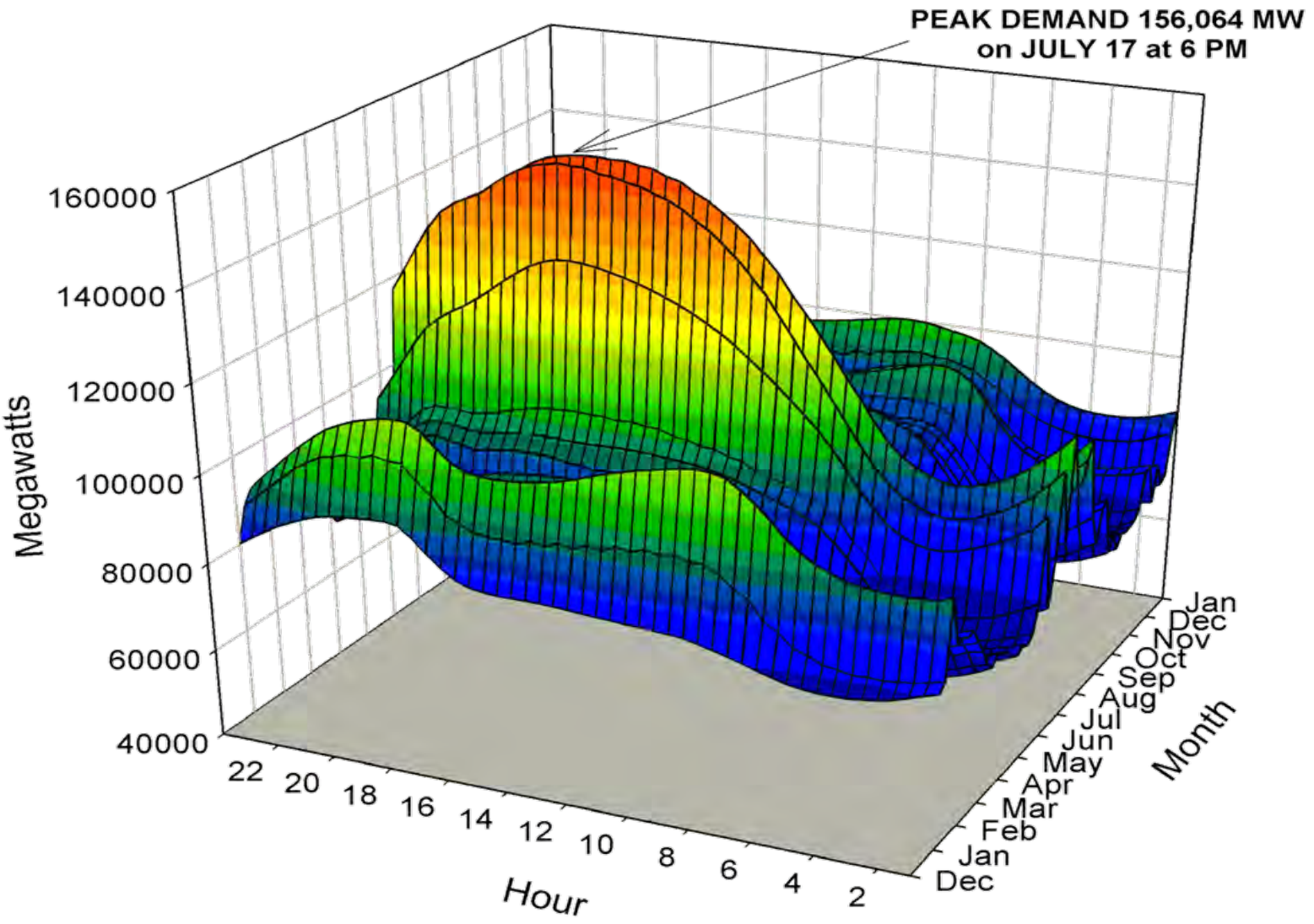
ISO-New England 2005 & 2006 Hourly MW Load Duration Curve

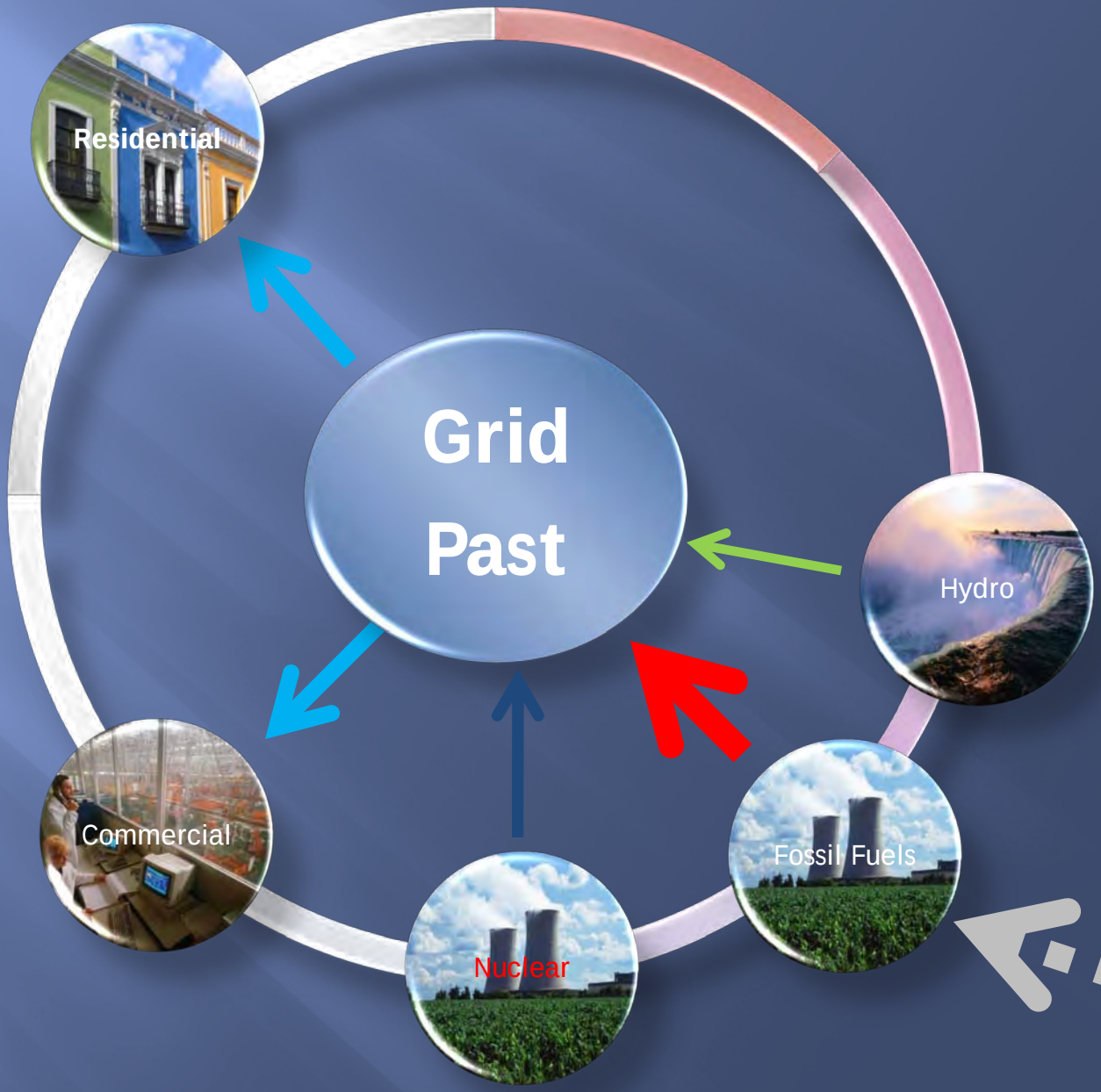


Graph by Clifton Below, NHPUC, from: 2006_smd_hourly.xls and 2005_smd_hourly.xls available at: http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html


ISO-NE Hourly Demand & Price Week of 7/31-8/6/06
MW of Demand
Price in Cents per KWh
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mon, 7/31
Tues, 8/1
Wed, 8/2
Thurs, 8/3
Fri, 8/4
Sat, 8/5
Sun, 8/6
Hourly MW Demand
DA LMP Cents/KWh
RT LMP Cents/KWh
M 6 N 18 M 6 N 18 M 6 N 18 M 6 N 18 M 6 N 18 M 6 N 18 M 6 N 18
Hour of the Day Mon. - Sun. (M = Midnight, N = Noon)
Graph by Clifton Below, NHPUC, from: 2006_smd_hourly.xls, available at: http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html

PJM SYSTEM DEMAND
2012



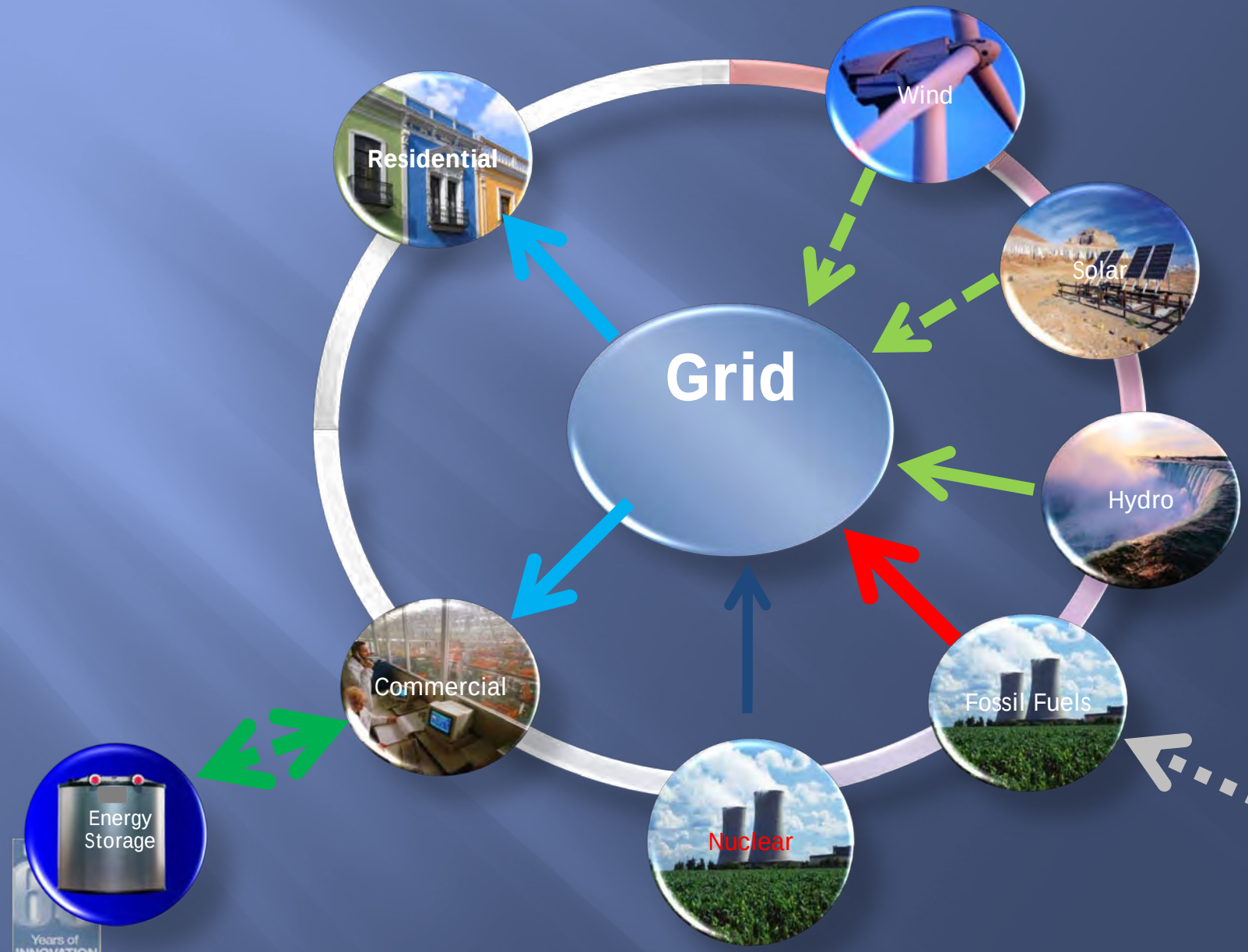

Residential
Grid
Past
Hydro
Commercial
Fossil Fuels
Nuclear

Stored Energy

Energy

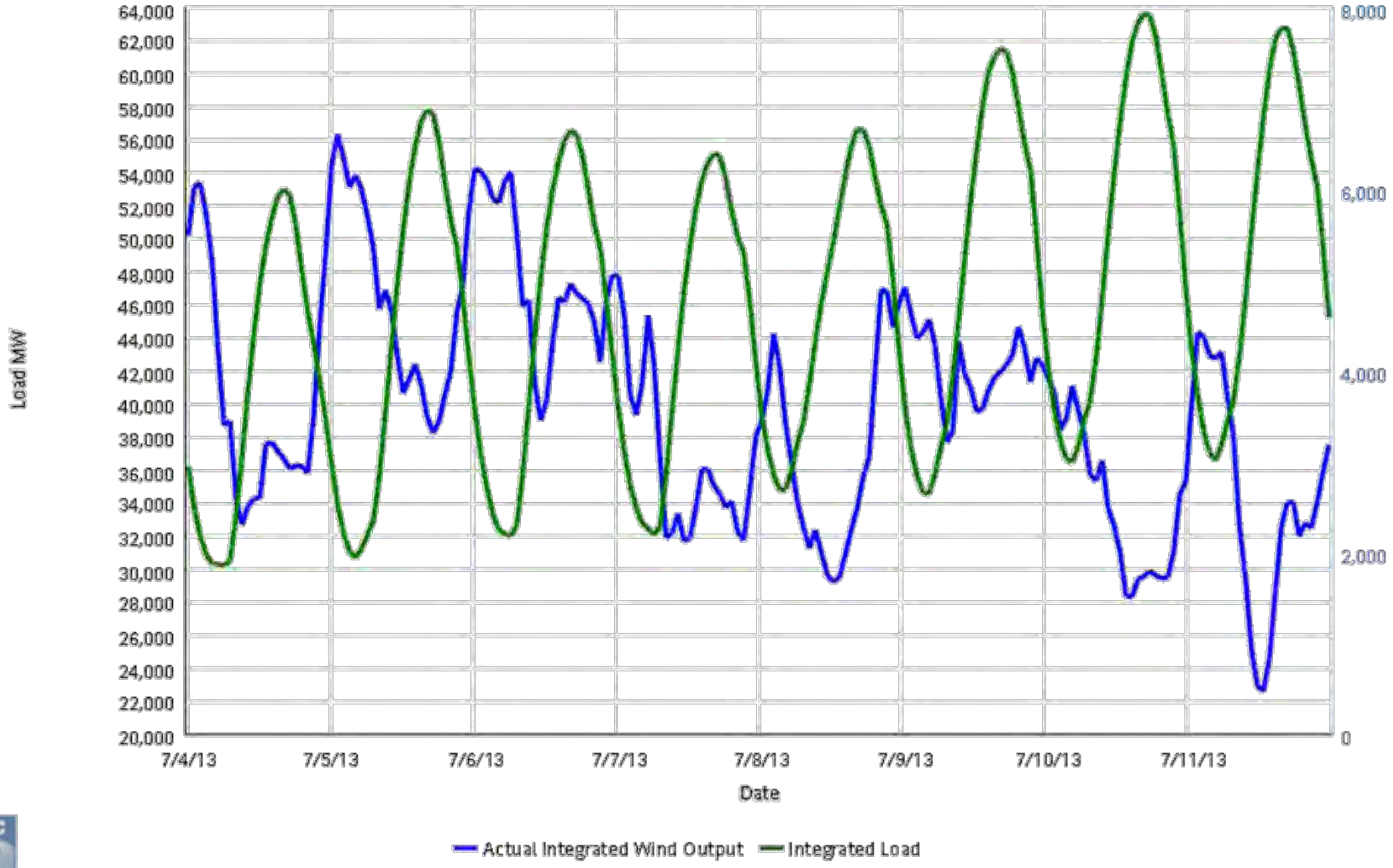
Where is the Storage?

Grid Today


Wind
Residential
Solar
Grid
Hydro
Commercial
Fossil Fuels
Energy Storage
Nuclear

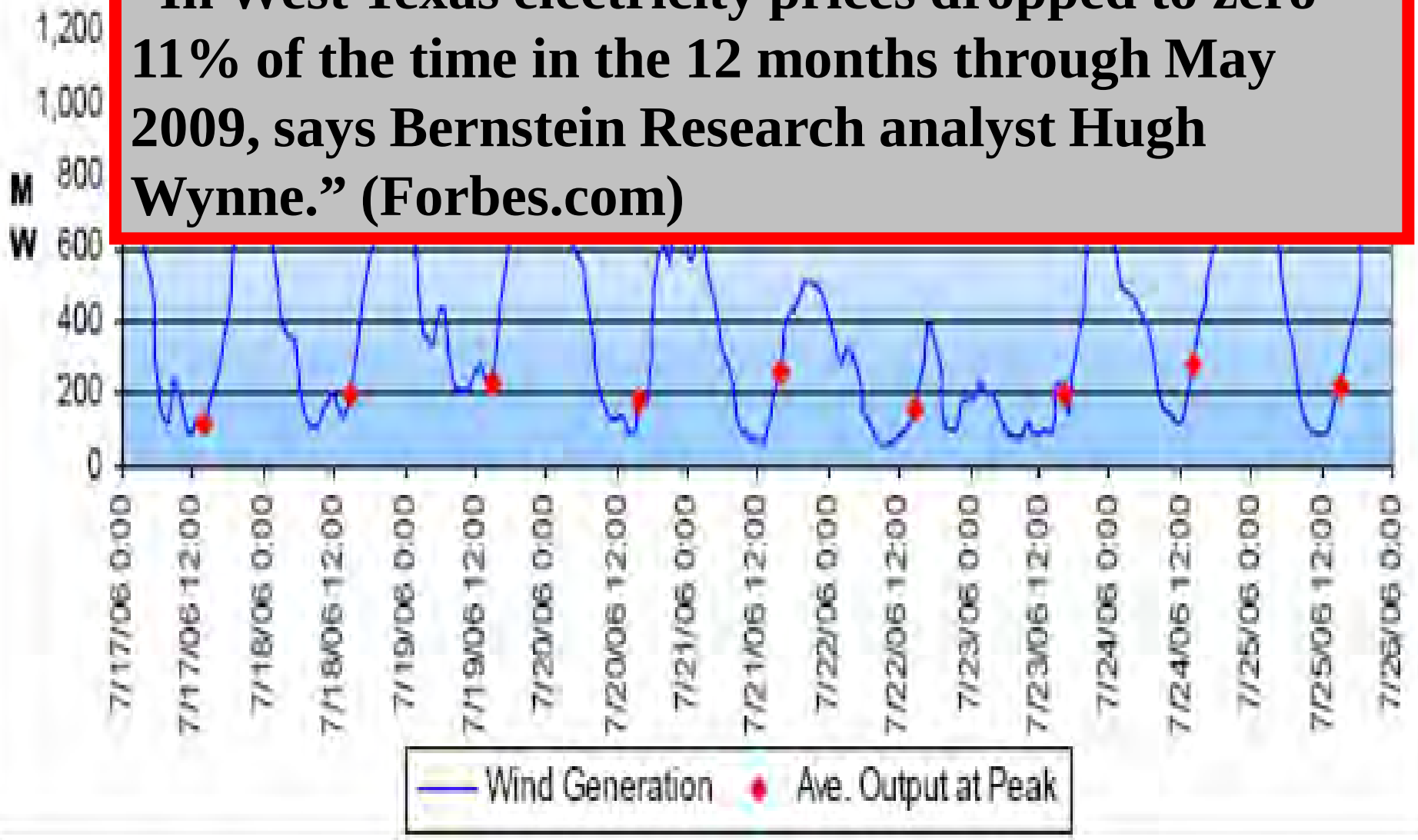
ERCOT Load vs. Actual Wind Output

07/04/2013 - 07/11/2013

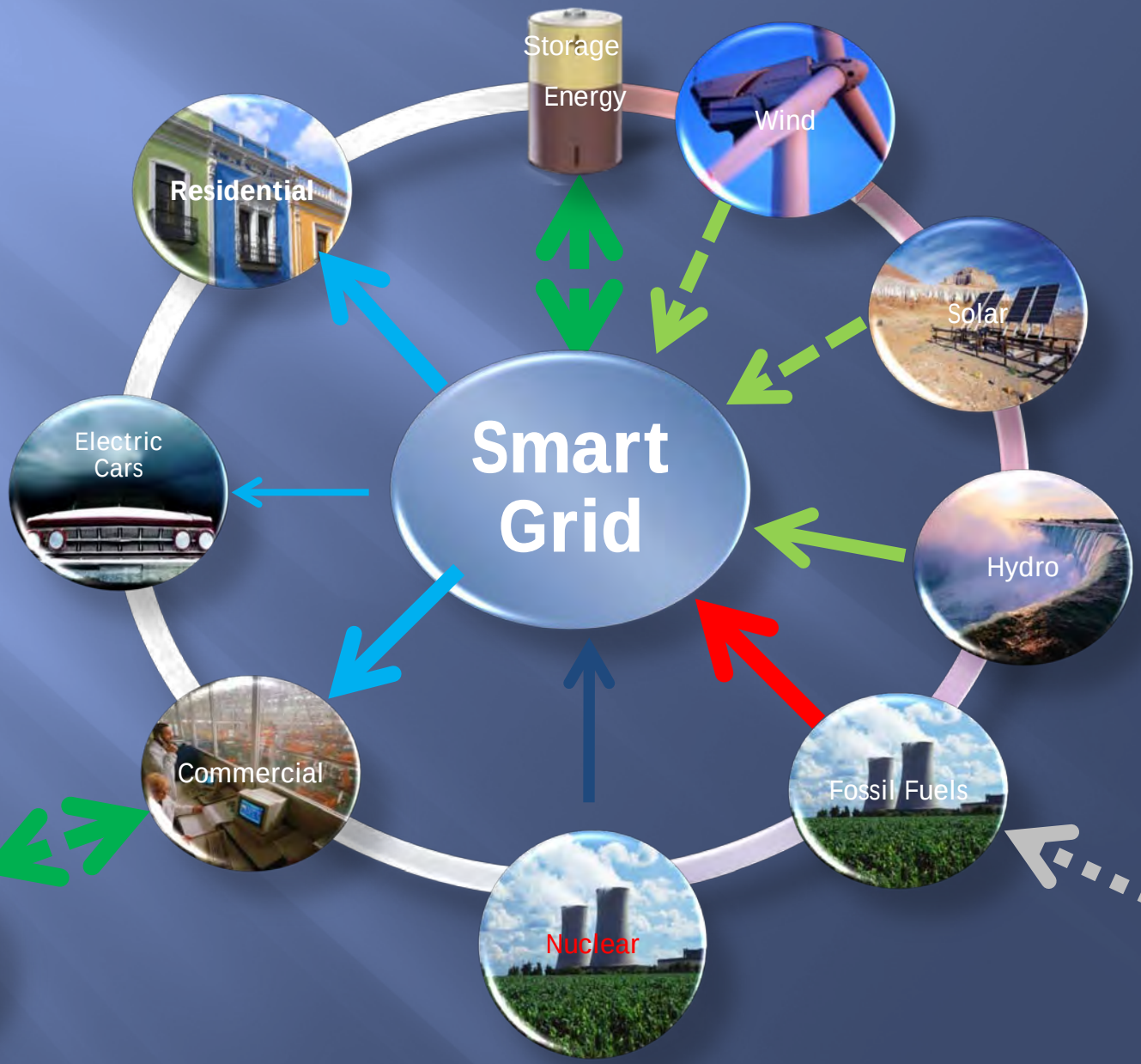


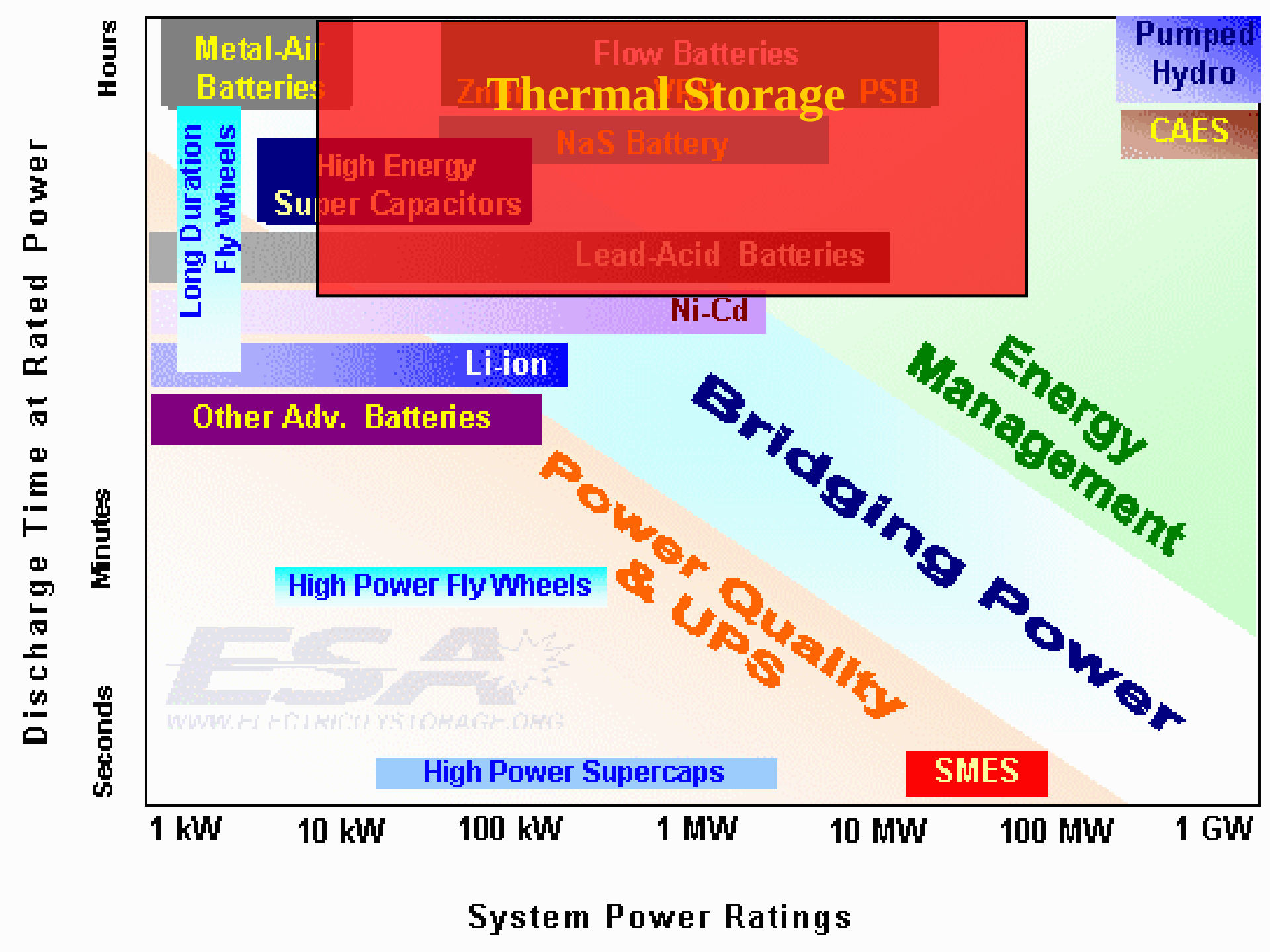
Wind Generation and Output at Peak

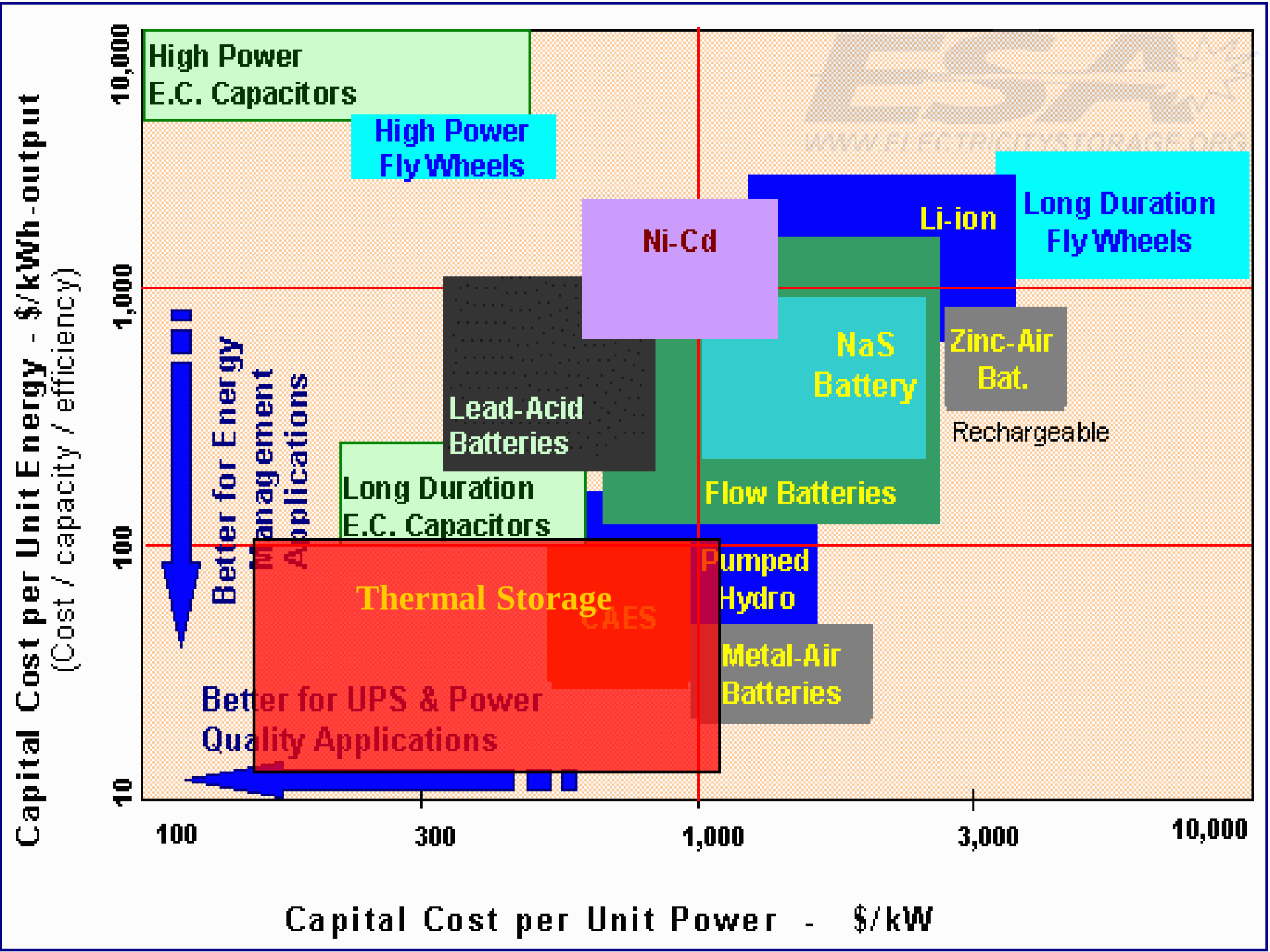
"In West Texas electricity prices dropped to zero 11% of the time in the 12 months through May 2009, says Bernstein Research analyst Hugh Wynne." (Forbes.com)

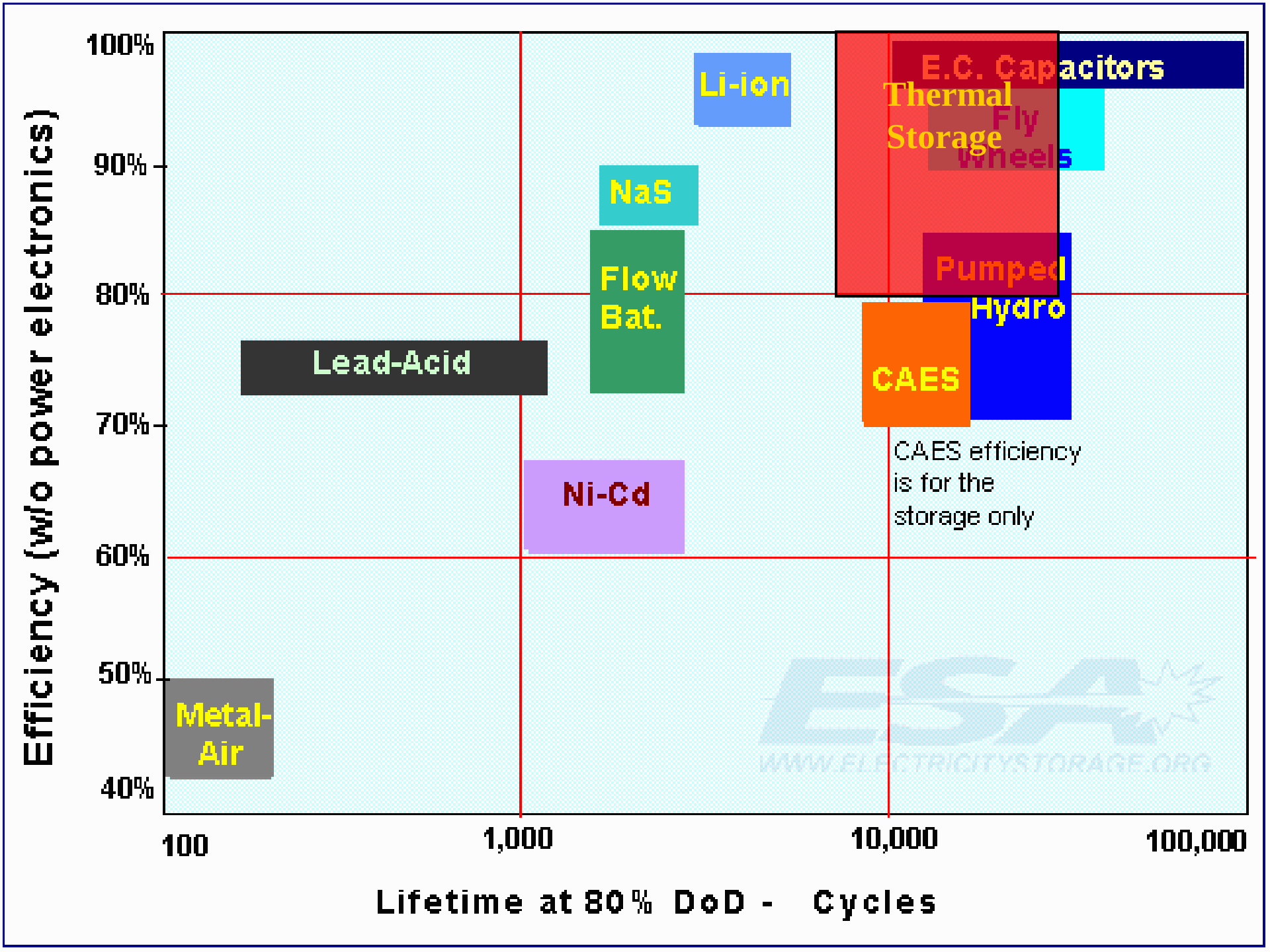


Energy Storage added to Grid



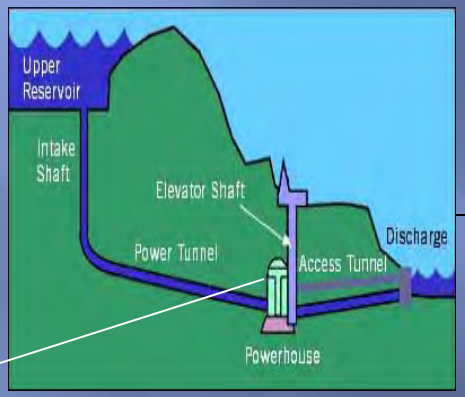

Discharge Time at Rated Power
Hours
Minutes
Seconds
Metal-Air Batteries
Flow Batteries
Zn/Br
VRB
PSB
Thermal Storage
Pumped Hydro
CAES
NaS Battery
Long Duration Fly Wheels
High Energy Super Capacitors
Lead-Acid Batteries
Ni-Cd
Li-ion
Other Adv. Batteries
Energy Management
Bridging Power
Power Quality & UPS
High Power Fly Wheels
High Power Supercaps
SMES
1 kW
10 kW
100 kW
1 MW
10 MW
100 MW
1 GW
System Power Ratings


High Power
E.C. Capacitors
High Power
Fly Wheels
Ni-Cd
Li-ion
Long Duration
Fly Wheels
NaS
Battery
Zinc-Air
Bat.
Rechargeable
Lead-Acid
Batteries
Long Duration
E.C. Capacitors
Flow Batteries
Pumped
Hydro
Thermal Storage
CAES
Metal-Air
Batteries
Better for Energy
Management
Applications
Better for UPS & Power
Quality Applications
10,000
1,000
100
10
100
300
1,000
3,000
10,000
Capital Cost per Unit Energy - $/kWh-output
(Cost / capacity / efficiency)
Capital Cost per Unit Power - $/kW


Efficiency (w/o power electronics)
100%
90%
80%
70%
60%
50%
40%
Li-ion
E.C. Capacitors
Thermal Storage
Fly Wheels
NaS
Flow Bat.
Pumped Hydro
Lead-Acid
CAES
Ni-Cd
Metal-Air
CAES efficiency is for the storage only
100
1,000
10,000
100,000
Lifetime at 80% DoD - Cycles

Understanding End-to-End Cycle Efficiency
Grid Storage vs. Building Energy Storage

Pumped Hydro - 70%



Grid Storage

1.45kWh to create
1 ton-hr of Cooling

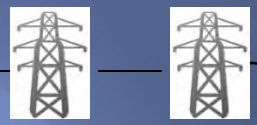
Building Storage

1.07kWh to create
1 ton-hr of Cooling

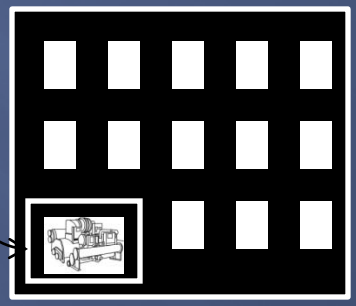
On Peak - Daytime

Transmission 95%

Distribution 93%



0.9 kW/ton

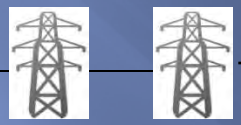


1 ton-hr of Cooling
13,000 Btu's
Source Energy*

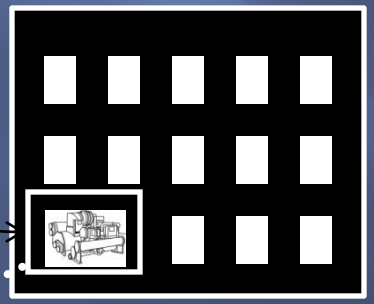
Off Peak - Nighttime

Transmission 97%

Distribution 96%



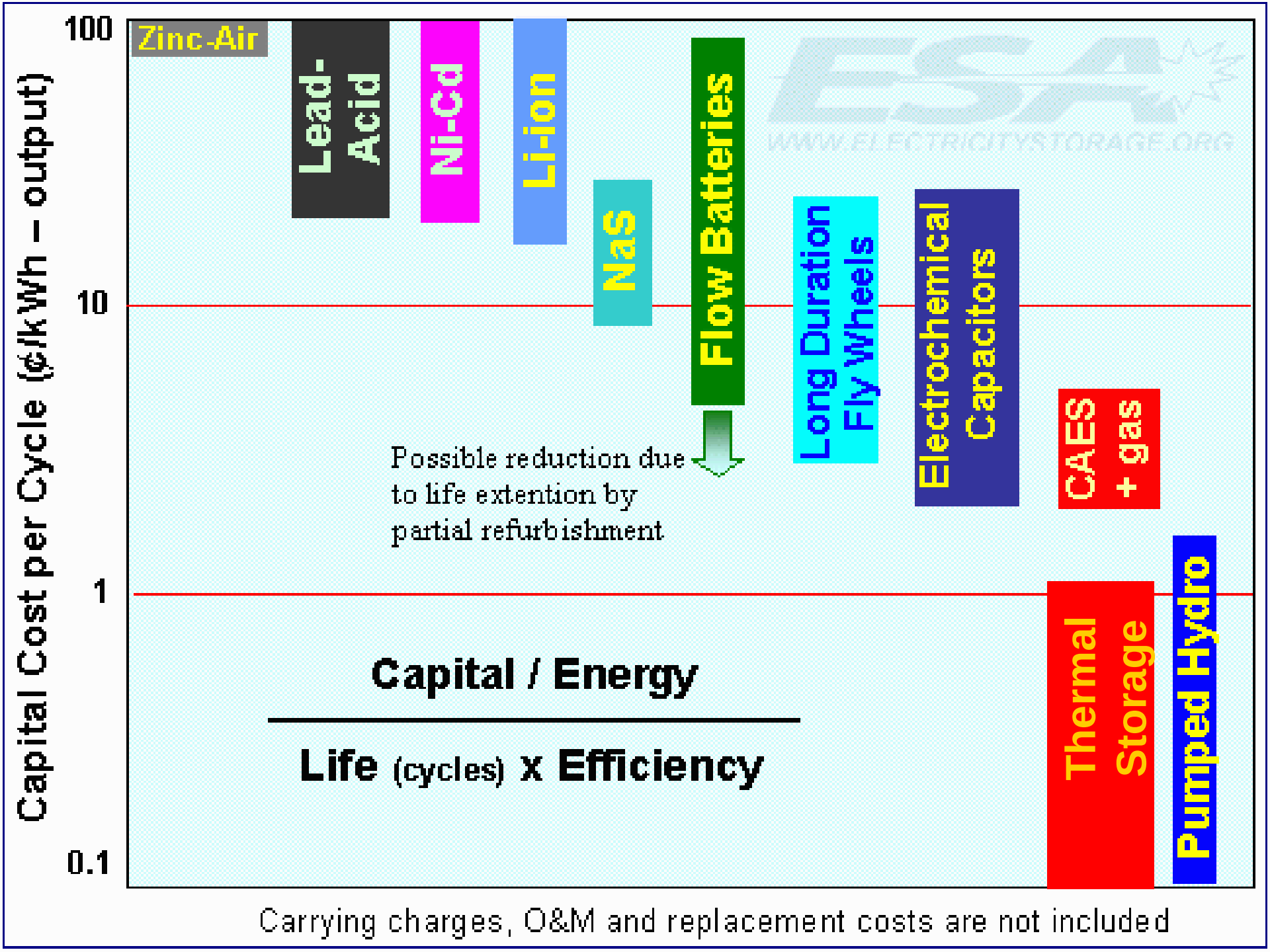
1.0 kW/ton



1 ton-hr of Cooling
9,650 Btu's
Source Energy*

* Fossil Fuel Power Plant Eff.= 38%

CALMAC 60 Years of INNOVATION


100
10
1
0.1
Capital Cost per Cycle (¢/kWh – output)
Zinc-Air
Lead-Acid
Ni-Cd
Li-ion
NaS
Flow Batteries
Long Duration Fly Wheels
Electrochemical Capacitors
CAES + gas
Thermal Storage
Pumped Hydro
Possible reduction due to life extention by partial refurbishment
Capital / Energy
Life (cycles) x Efficiency
Carrying charges, O&M and replacement costs are not included

Economical, Social and Environmental Benefits of Energy Storage are real.

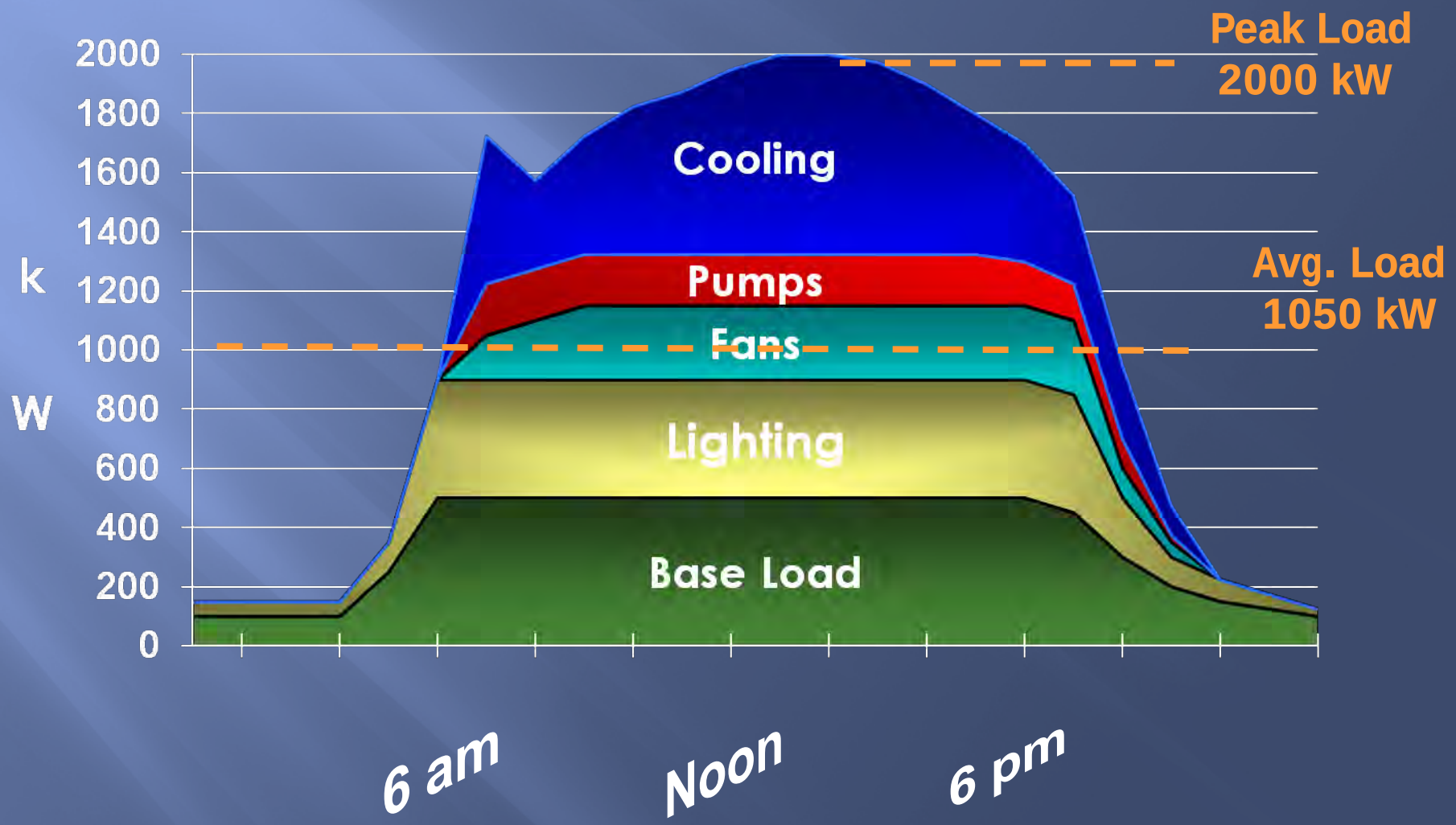
Page 293

USA Total Generation Capacity
1 Trillion Watts

Technology	Cost
	$/W
Gas Turbine	0.70-1.00
Combined Cycle Plant	2.00-4.00
New Coal Plant	3.00-5.00
Clean Coal Plant	>4.00
Nuclear	4.00-8.00
Wind	1.50-2.50
PV (30% Cap Factor -15% Peak Red)	6.50
Building Thermal Storage	0.5-1.0

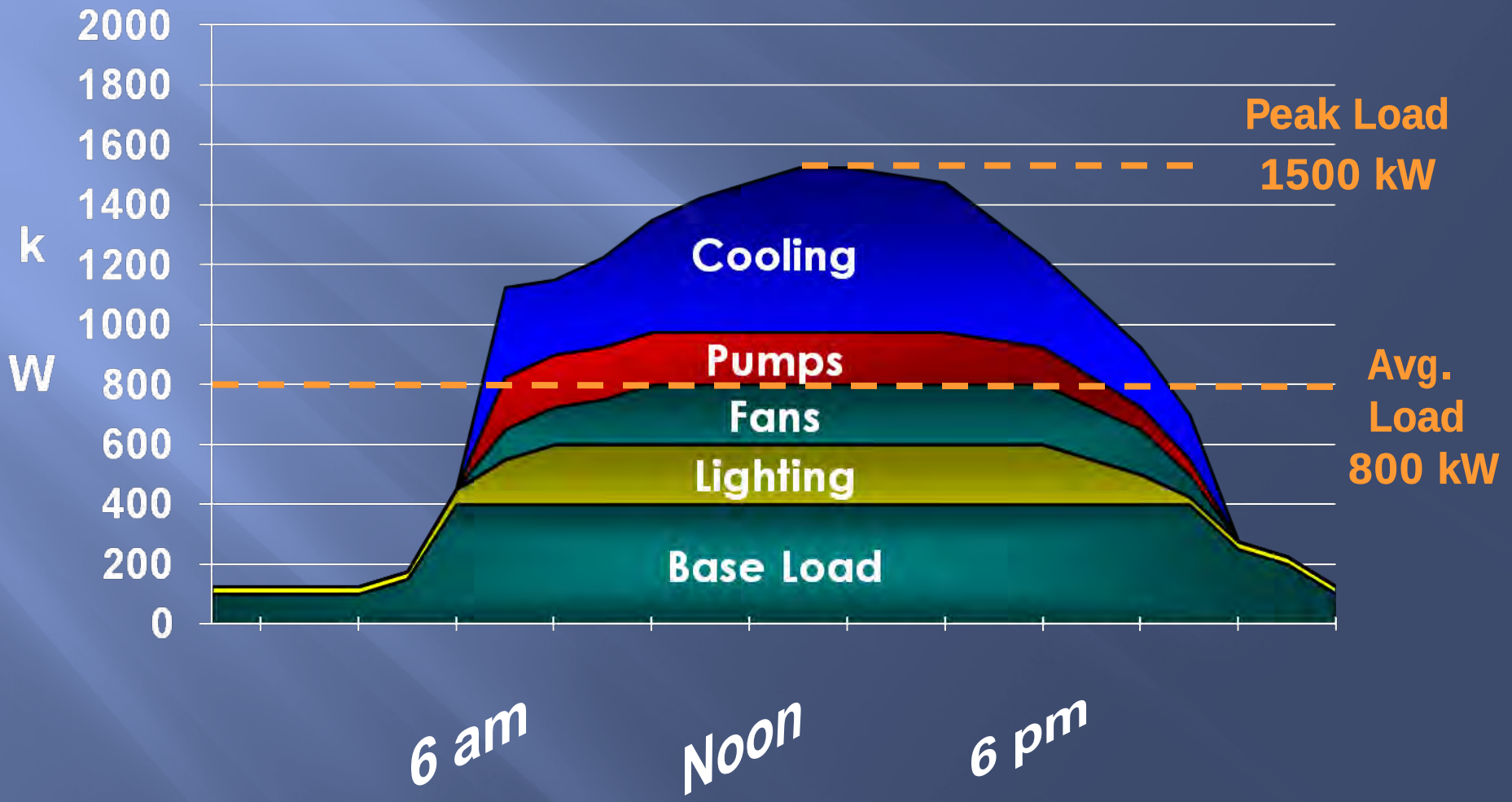
CALMAC 60 Years of INNOVATION

ASHRAE 90.1 Base Building Non-Storage Electrical Profile



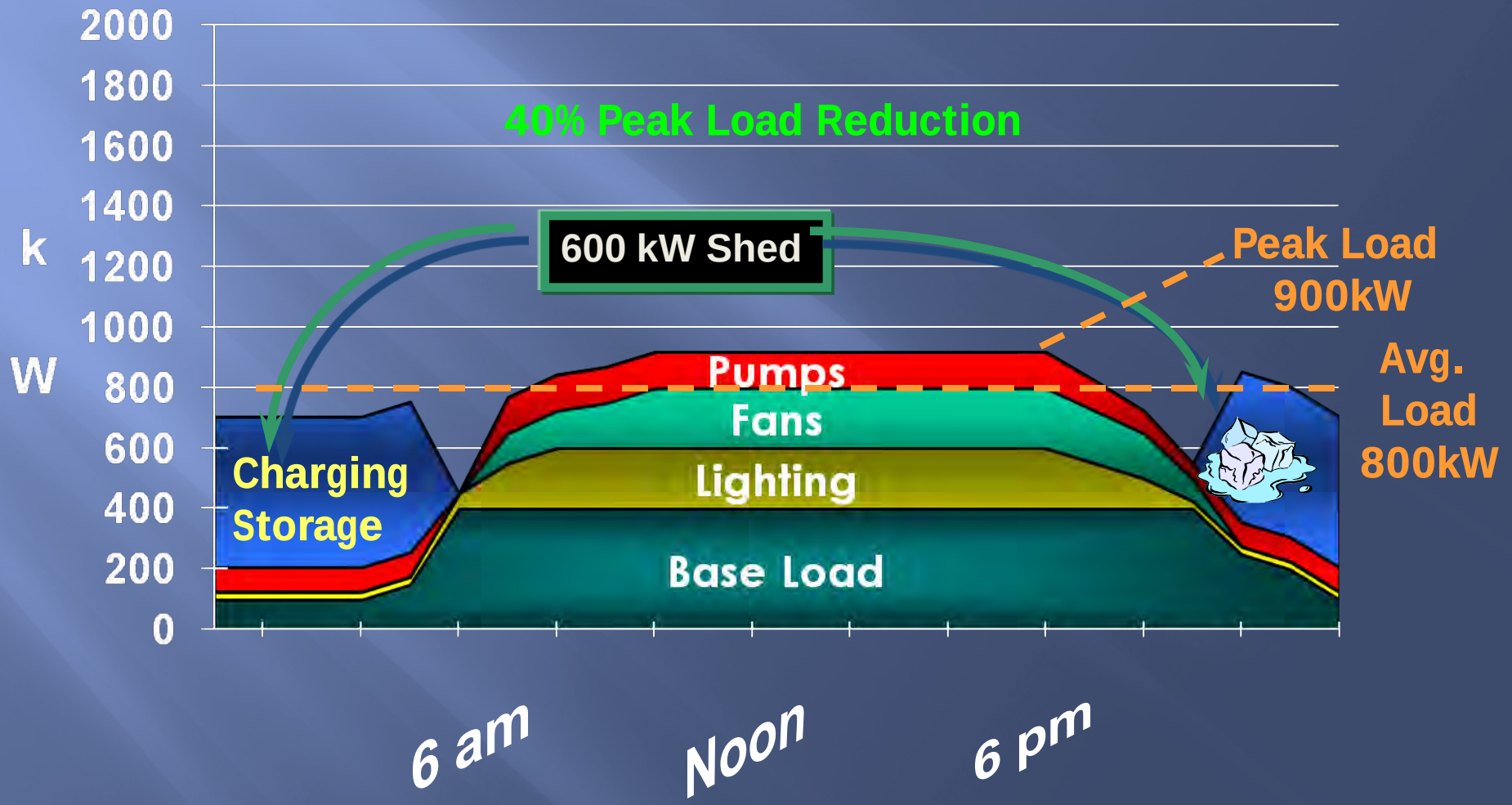
Total kWh = 28,000/day **(Load Factor = 53%)**

30% Better Than ASHRAE 90.1 Non-Storage Electrical Profile



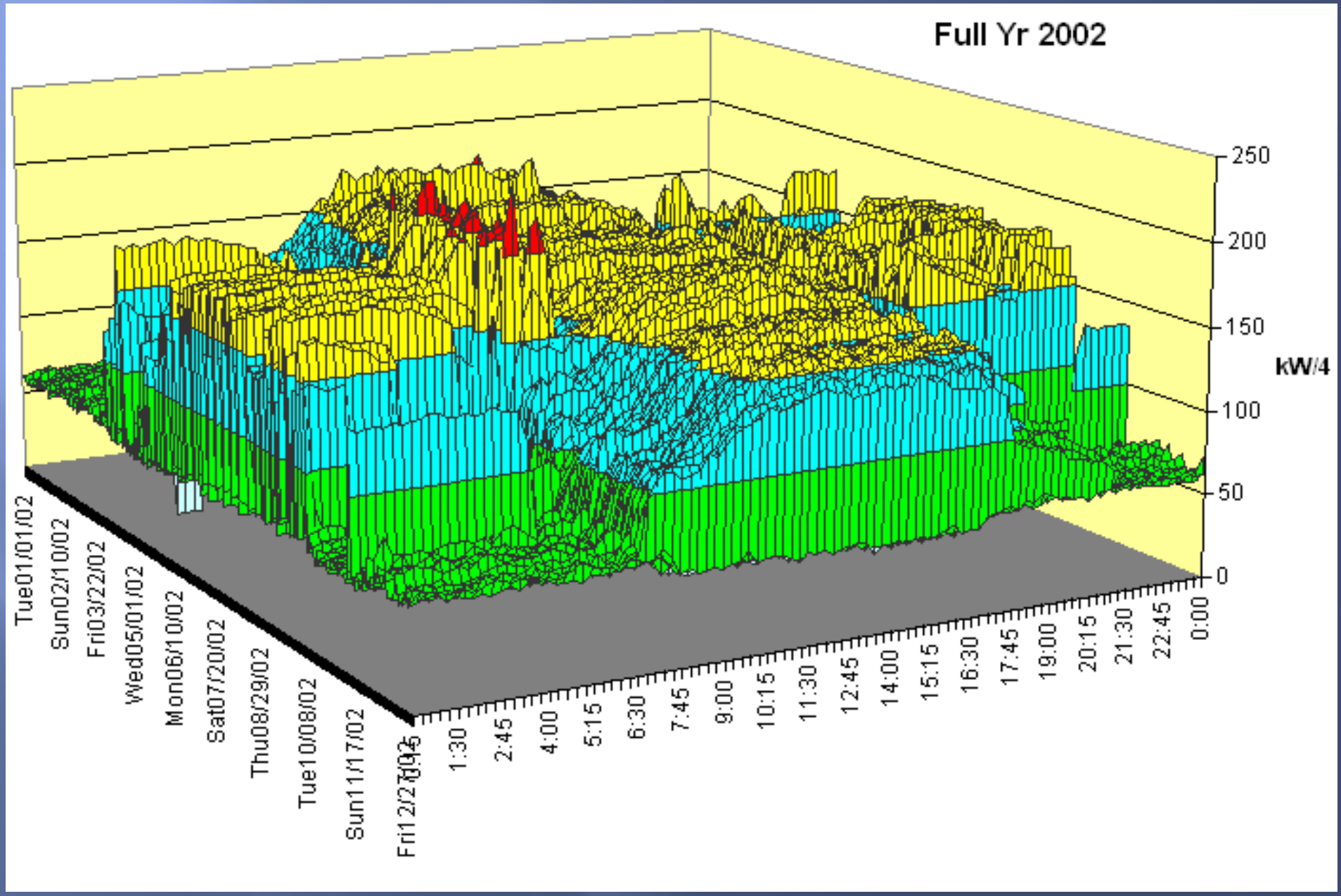
Total kWh = 19,200/day (Load Factor = 53%)

30% Better Than ASHRAE 90.1 with Thermal Energy Storage



Total kWh = 19,200/day (Load Factor = 88%)

3-D Electric Load Profile -- Full Year



Thermal Storage Tank Ice-on-Coil Internal Melt

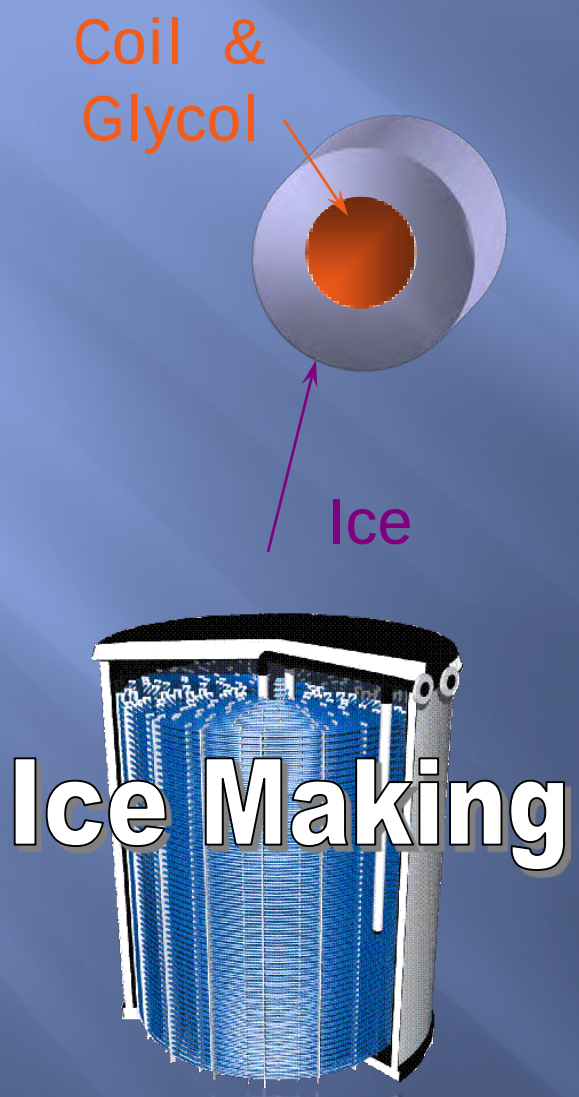
Tank

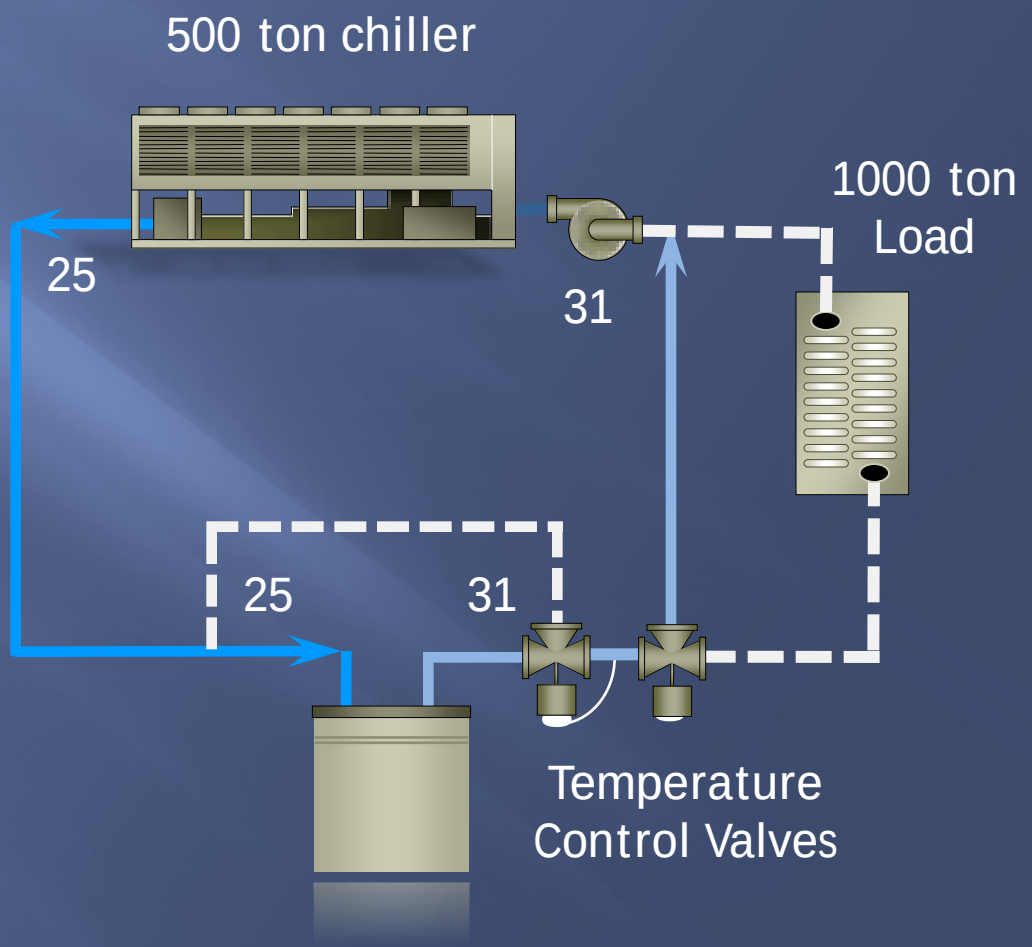
Insulation

Expansion Chamber

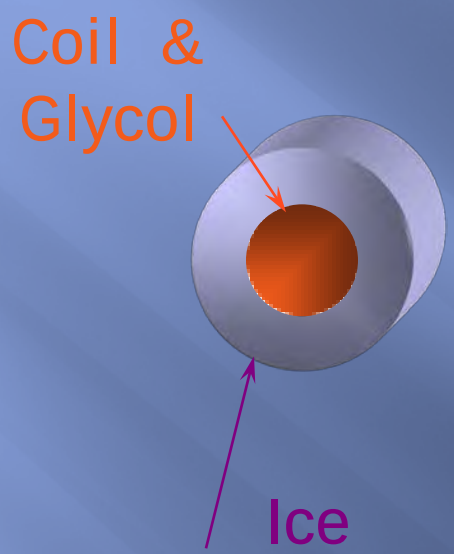
Heat Exchanger

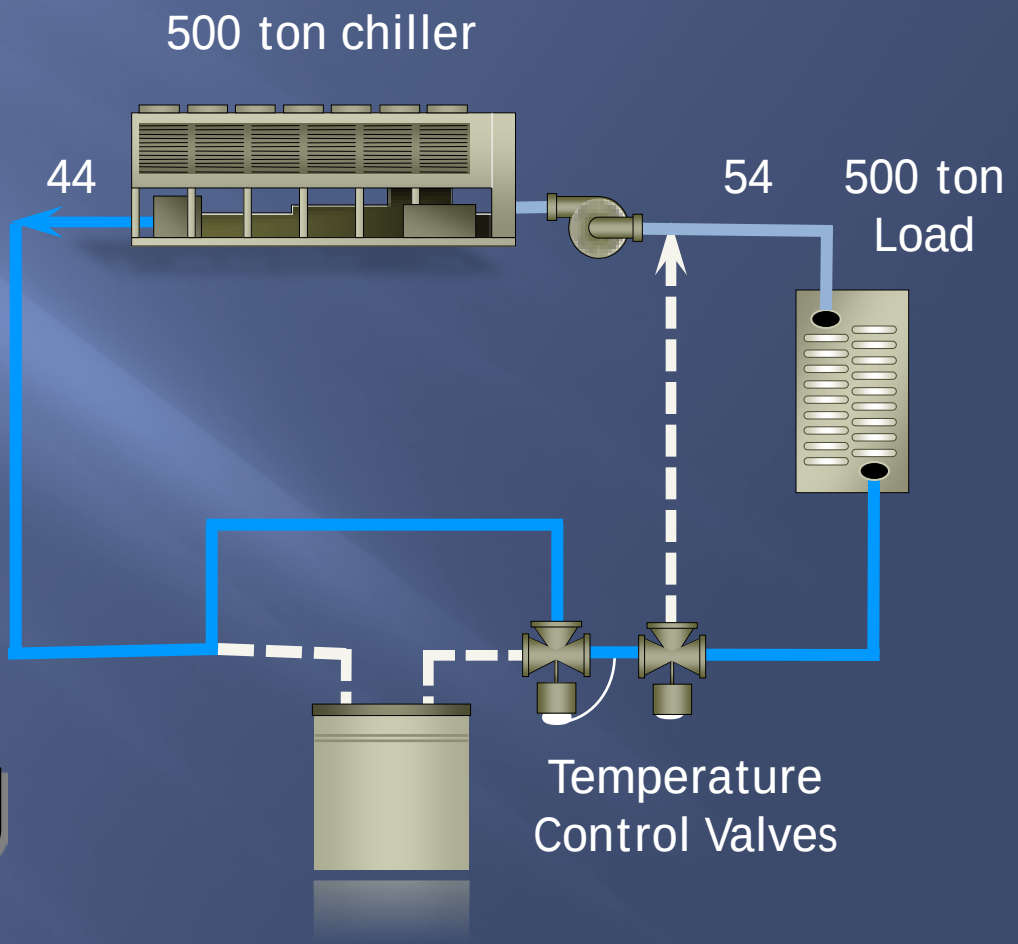
Ice on Coil Internal Melt





Ice on Coil Internal Melt



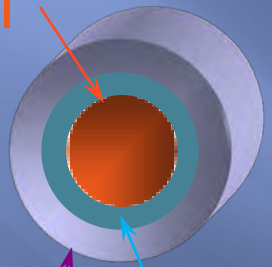


Direct Cooling

Ice on Coil Internal Melt

Coil & Glycol

Centrifugal
Screw
Scroll
Reciprocating

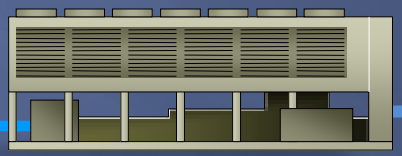


Ice

Melted Ice

Ice Melting & Chilling

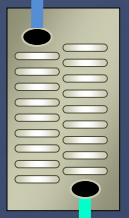
500 ton chiller



52

60

1000 ton Load



52

34-44

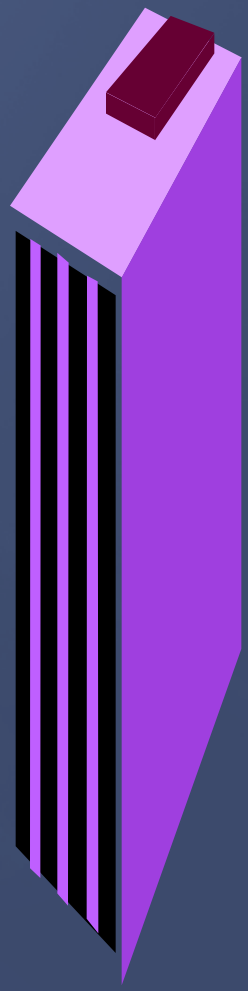
44

Temperature Control Valves

How Much Space for Energy Storage?

Full Storage: 0.70% of cooled floor space

Partial Storage: Ice provides about 33% of a cooling system reducing ice tank floor space to 0.23% of cooled floor space.



1 ton cools 500 ft^2
1 tank provides 20 tons
1 tank cools 10,000 ft^2
1 tank needs 70 ft^2 (60 ft^2)

Would need 25% of roof space on 100 story building!

Same ratio as the water heater in your house

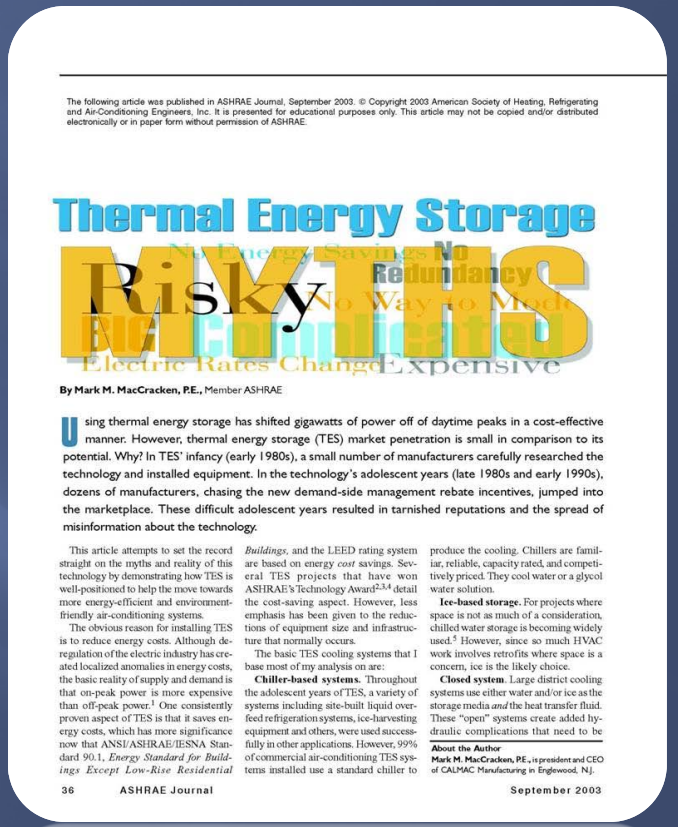
National Air and Space Museum

Washington, DC USA

4,700 Ton Hrs of Storage
On-Peak Chiller – 1122 Tons
On-Peak Ice Contribution – 729 Tons
40% On-Peak Chiller Demand Avoided

Thermal Energy Storage Myths Article
(Ashrae Journal Sept 03)

1. Uncommon
2. Too Much Space
3. Too Complicated
4. Doesn't Save Energy
5. Too Expensive
6. Lack of Redundancy (Risky)
7. Rates Will Change
8. Modeling doesn't Show Results



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Thermal Energy Storage

MYTHS

Risky

Redundancy

Complicated

Expensive

Electric Rates Change

By Mark M. MacCracken, P.E., Member ASHRAE

Using thermal energy storage has shifted gigawatts of power off of daytime peaks in a cost-effective manner. However, thermal energy storage (TES) market penetration is small in comparison to its potential. Why? In TES' infancy (early 1980s), a small number of manufacturers carefully researched the technology and installed equipment. In the technology's adolescent years (late 1980s and early 1990s), dozens of manufacturers, chasing the new demand-side management rebate incentives, jumped into the marketplace. These difficult adolescent years resulted in tarnished reputations and the spread of misinformation about the technology.

This article attempts to set the record straight on the myths and reality of this technology by demonstrating how TES is well-positioned to help the move towards more energy-efficient and environment-friendly air-conditioning systems.

The obvious reason for installing TES is to reduce energy costs. Although deregulation of the electric industry has created localized anomalies in energy costs, the basic reality of supply and demand is that on-peak power is more expensive than off-peak power.[1] One consistently proven aspect of TES is that it saves energy costs, which has more significance now that ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, and the LEED rating system are based on energy *cost* savings. Several TES projects that have won ASHRAE's Technology Award[2,3,4] detail the cost-saving aspect. However, less emphasis has been given to the reductions of equipment size and infrastructure that normally occurs.

The basic TES cooling systems that I base most of my analysis on are:

Chiller-based systems. Throughout the adolescent years of TES, a variety of systems including site-built liquid overfeed refrigeration systems, ice-harvesting equipment and others, were used successfully in other applications. However, 99% of commercial air-conditioning TES systems installed use a standard chiller to produce the cooling. Chillers are familiar, reliable, capacity rated, and competitively priced. They cool water or a glycol water solution.

Ice-based storage. For projects where space is not as much of a consideration, chilled water storage is becoming widely used.[5] However, since so much HVAC work involves retrofits where space is a concern, ice is the likely choice.

Closed system. Large district cooling systems use either water and/or ice as the storage media *and* the heat transfer fluid. These "open" systems create added hydraulic complications that need to be

About the Author

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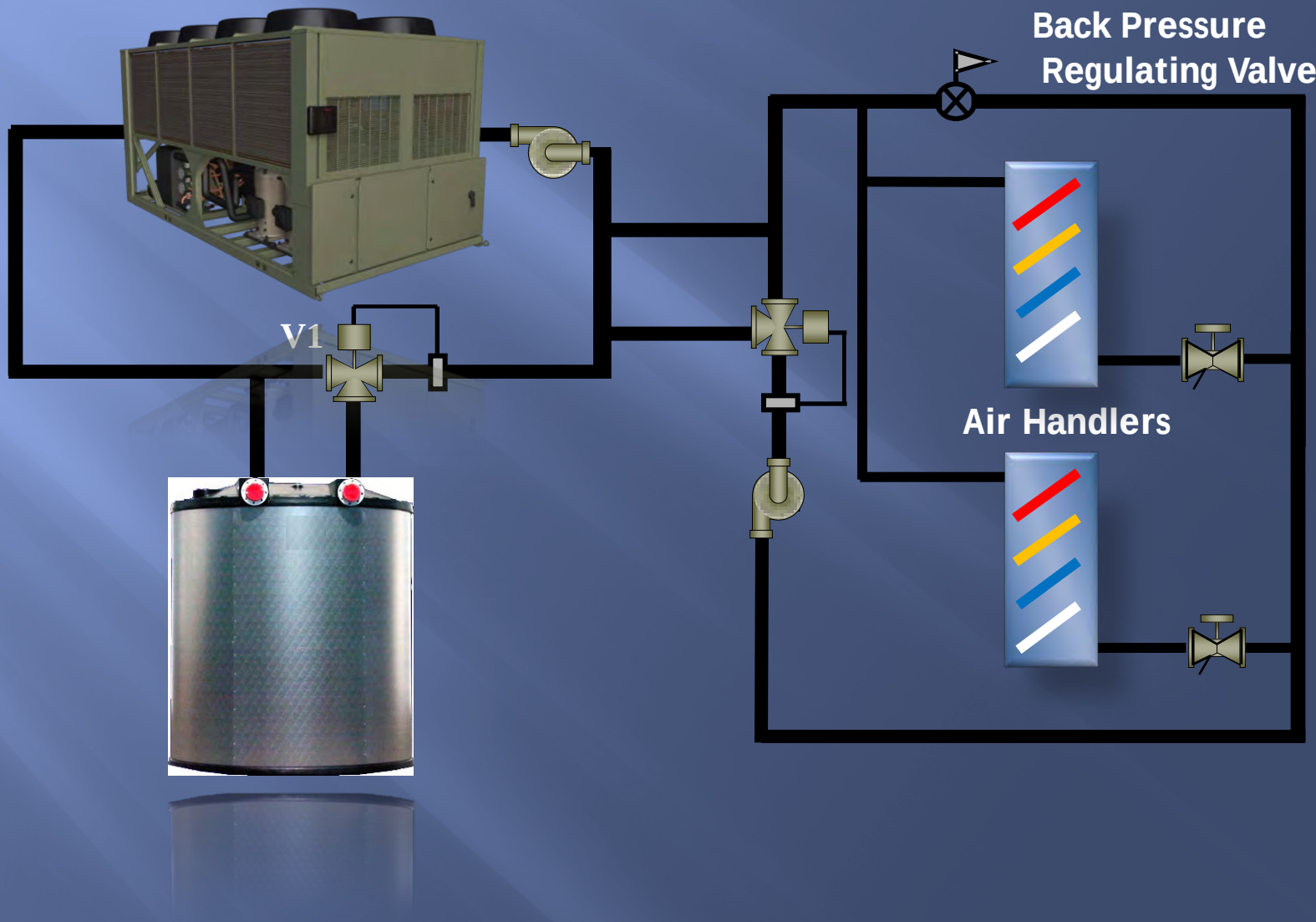
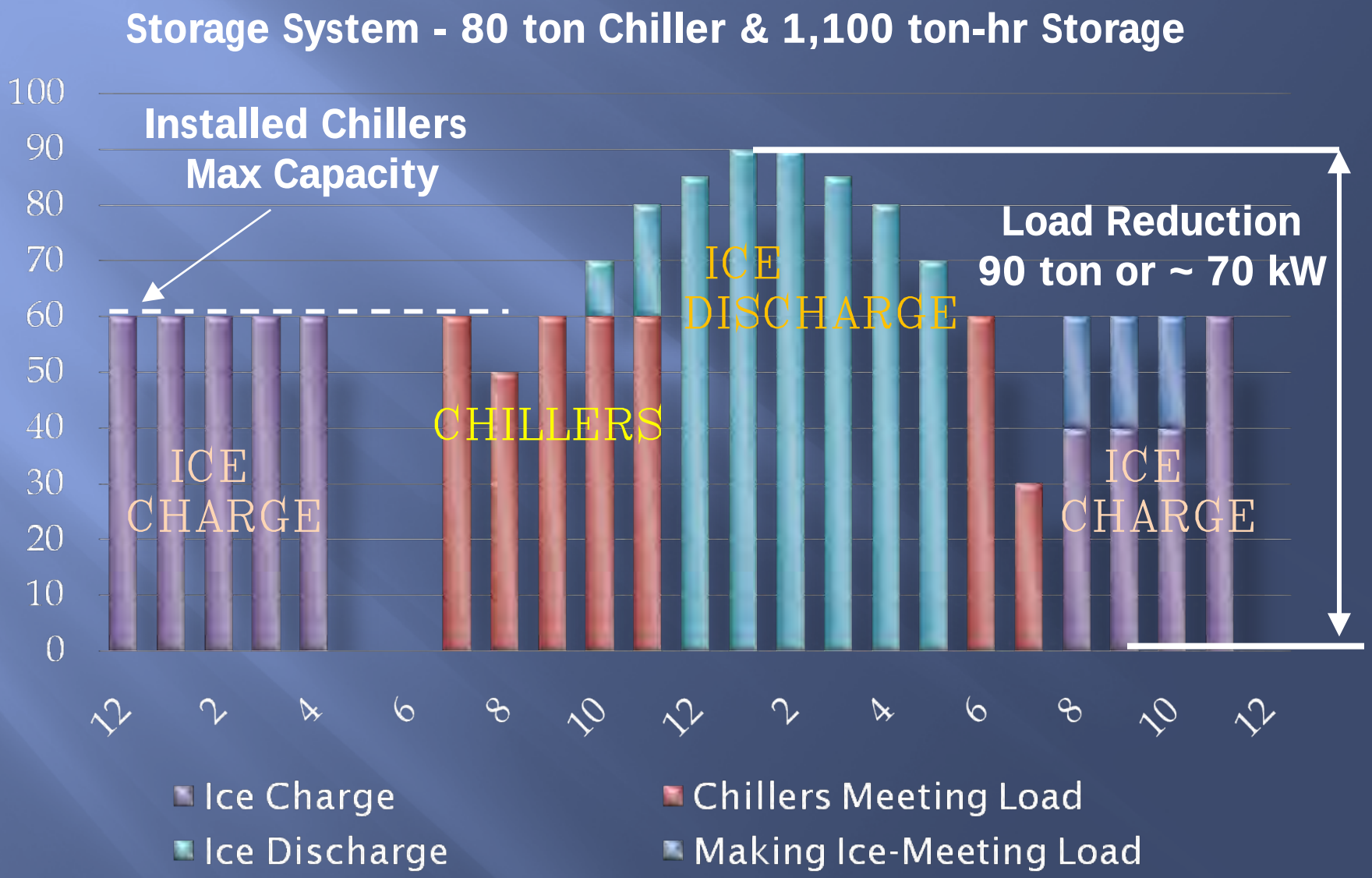
Reality

TES is a Proven Technology that saves Money and Energy

Basic Schematic



Design Day Off-Peak Cooling System



How do you measure “Green”?

One Metric is….

LEED™ Green Building Rating System

LEED™ Credits V3 NC

Certified 40–49 points
Silver 50–59 points
Gold 60–79 points
Platinum 80 points and above

Sustainable Sites:	**26 points**
Water Efficiency:	**10 points**
Energy* & Atmosphere:	**35 points**
Materials & Resources:	**14 points**
Indoor Environment Quality:	**15 points**
Base Points Possible	**100 points**

Innovation & Design:	**6 points**
Regional Priority	**4 points**

***19 Energy Credits are based on ASHRAE 90.1 which is based on Energy COST Reduction**

William & Flora Hewlett Foundation
LEED™ Gold
35% Energy Cost Reduction (5points)

www.usgbc.org

Project Overview

Project Overview

Section

Lighting System

- **Indirect Natural Lightening**
- **Operable Windows with Natural Ventilation**
- **PV for 24 hour lights**
- **Energy Storage Cooling system**

Basic Components

(Calculated 90 ~ 100 ton Peak Load)

80 Ton Evaporative Condensing Chiller

1100 Ton-Hrs of Storage

Real Reasons Energy Storage is Green:

1. It is much more Energy Efficient to create and deliver a kWh of Electricity at night than during the hot of the day.
   - Research from the California Energy Commission on 2 Cal. Utilities Reports 8 to 34% savings in raw fuel when comparing On and Off Peak Operation!
   - Heat Rates for Base Load Plants ~7,800 Btu/kWh vs.
     Peaking Plants ~9,400 to 14,000 Btu/kWh
2. The last power plants to come on during peak hours are normally the dirtiest per kW
   - Ashok Gupta (Director of Energy, NRDC) in NY Times article "Peak Shifting results in lower emissions because some of the plants used to meet demand peaks are among the dirtiest in the city"
   - New CA Report by Greg Kats ***The Costs and Financial Benefits of Green Buildings*** states Peak power in CA is twice as dirty as Off Peak Power.

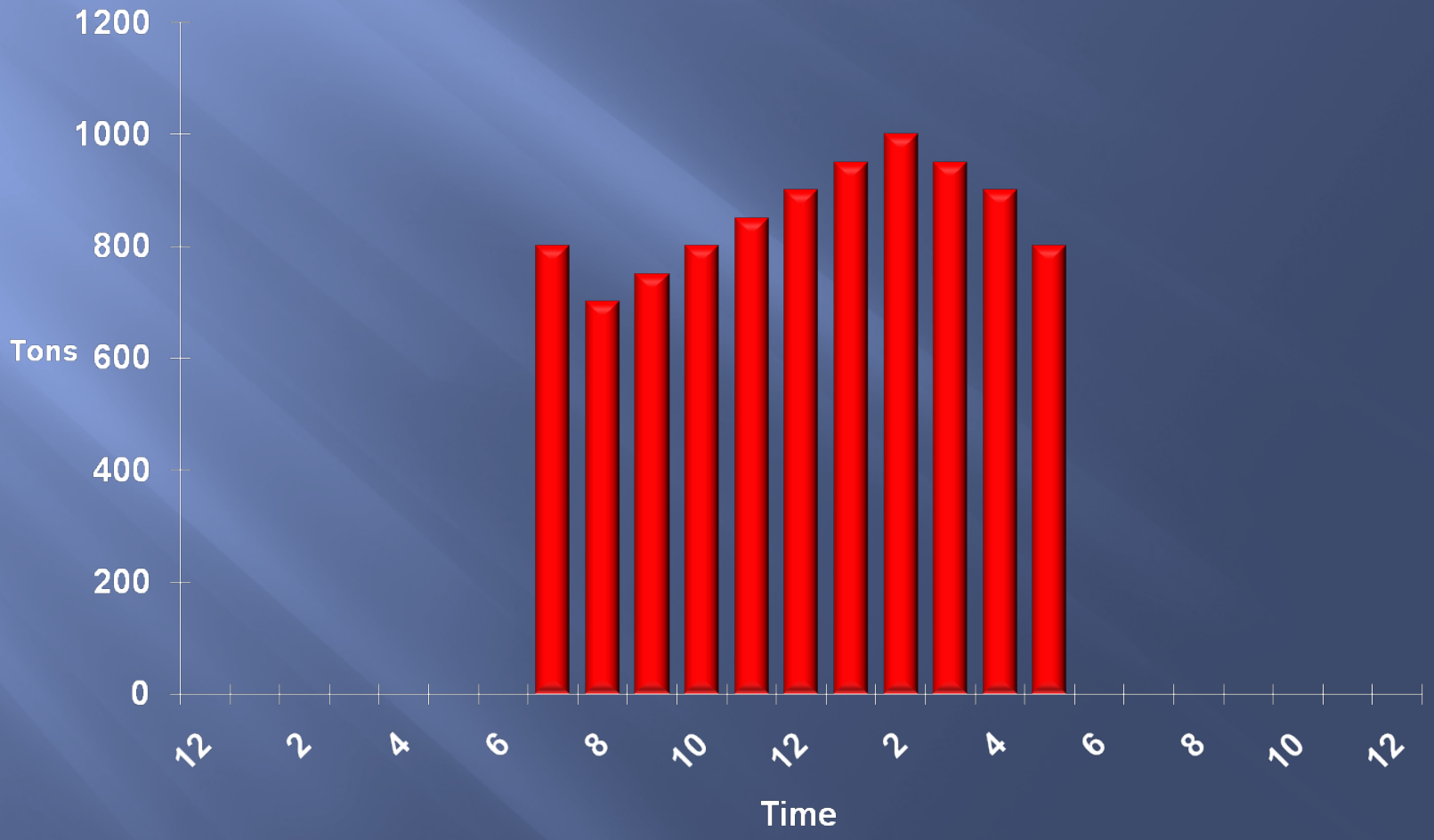
Other "Green" Issues

1. Safety Factors/Redundancy (Over-sizing)

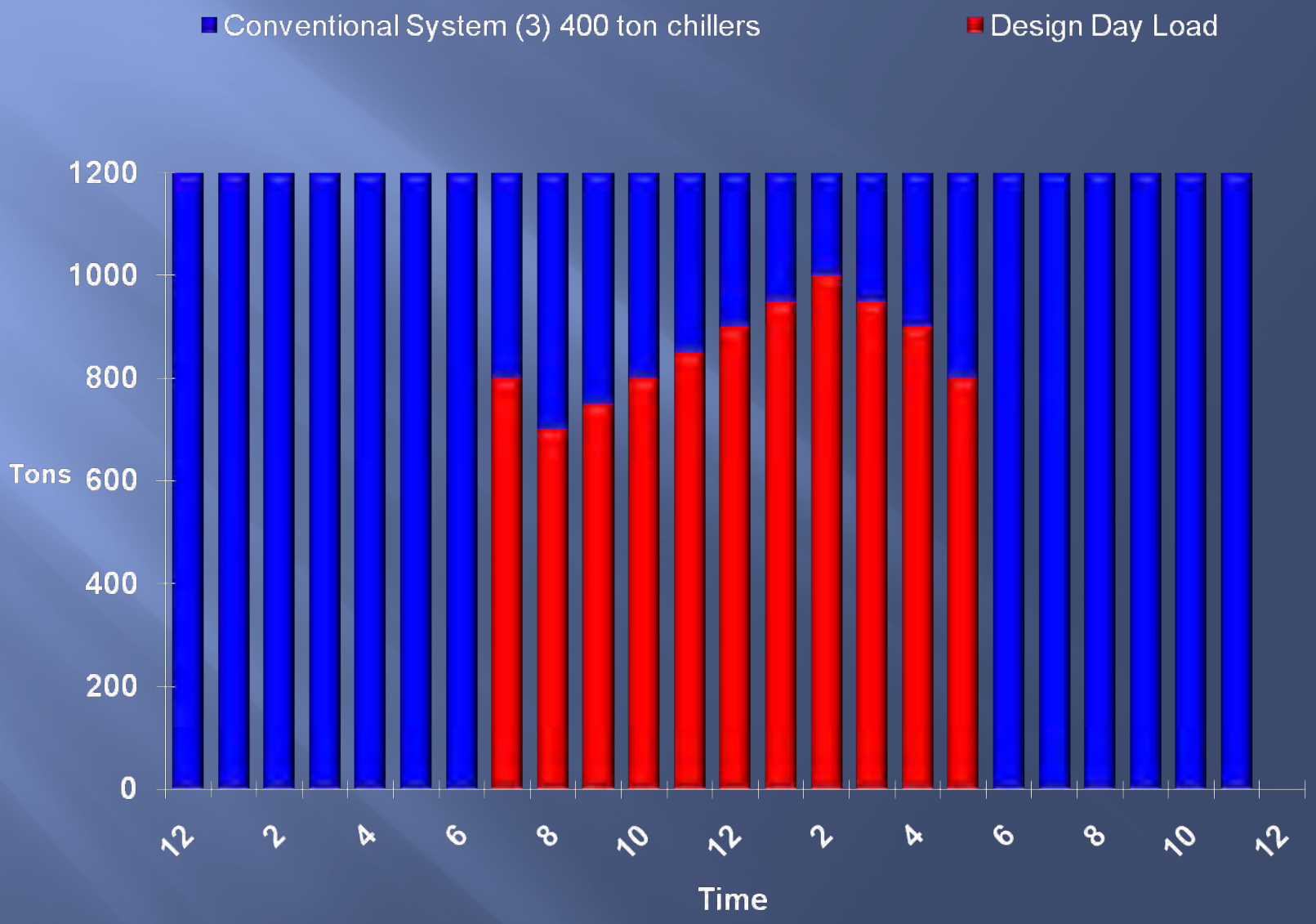
   - Well documented that over-sizing chiller plants creates less efficient real world operation.
   - Engineers have to protect their license

- Storage is the Natural solution

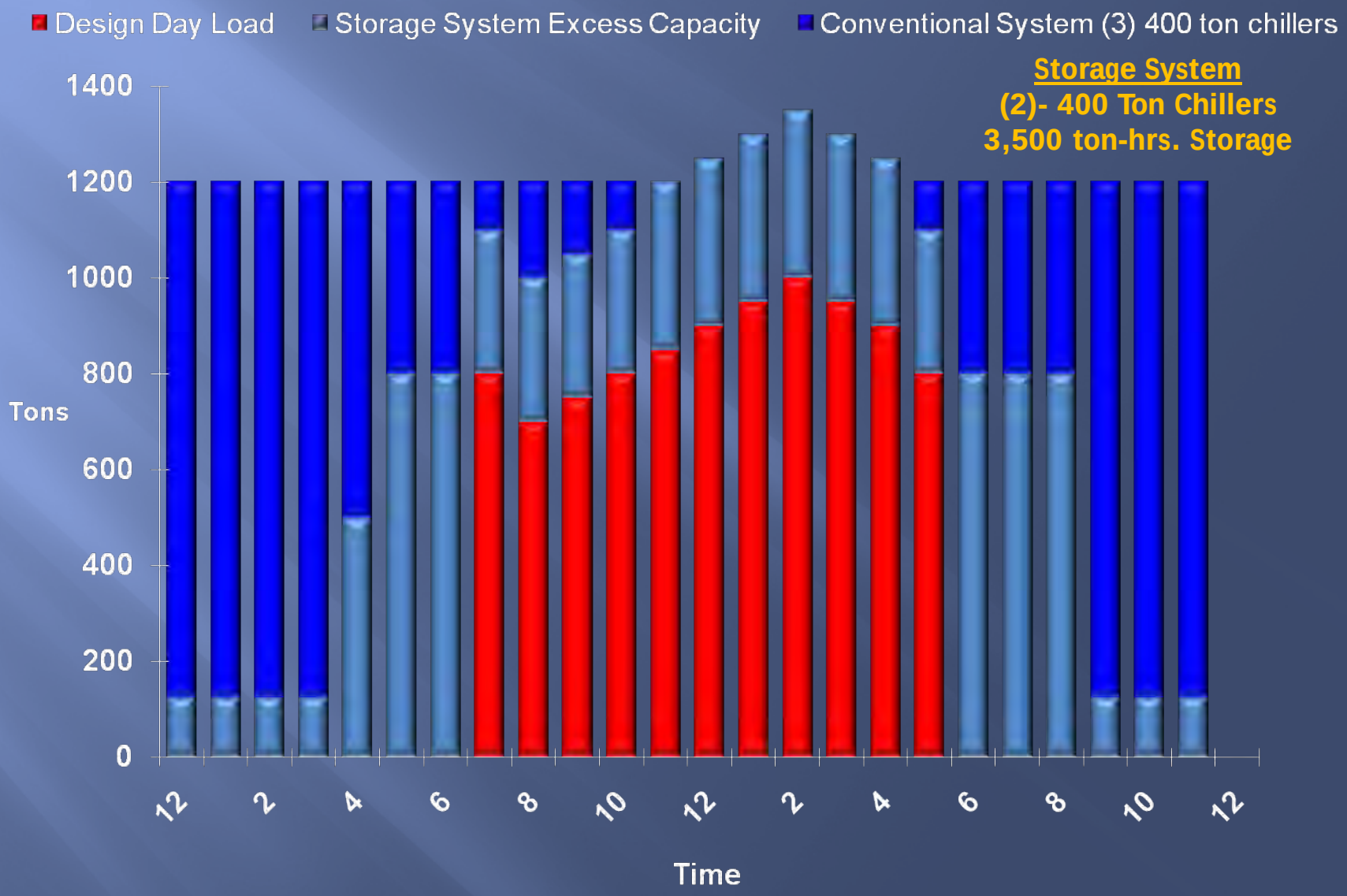
Design Day



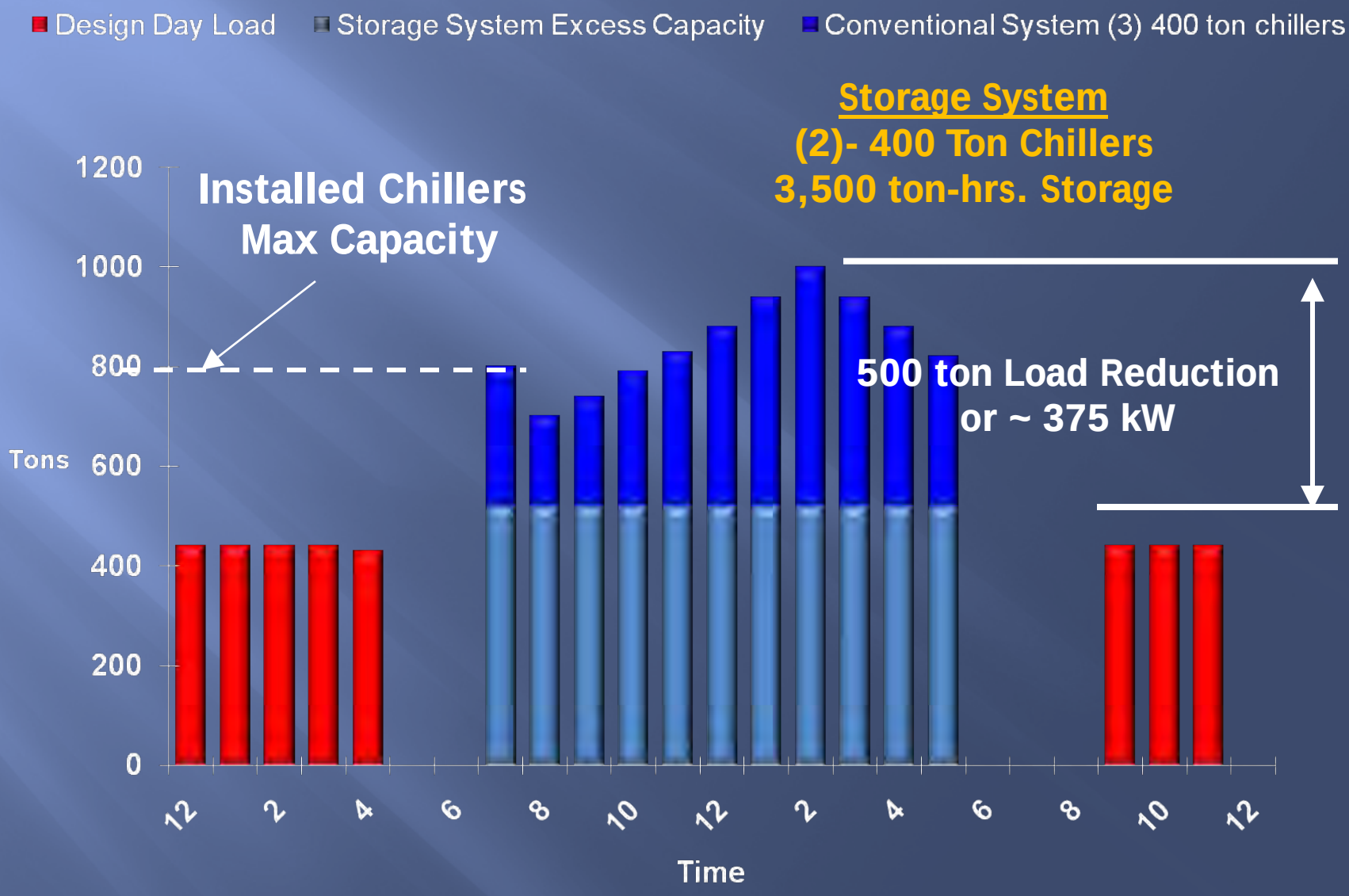
Excess Capacity on Design Day



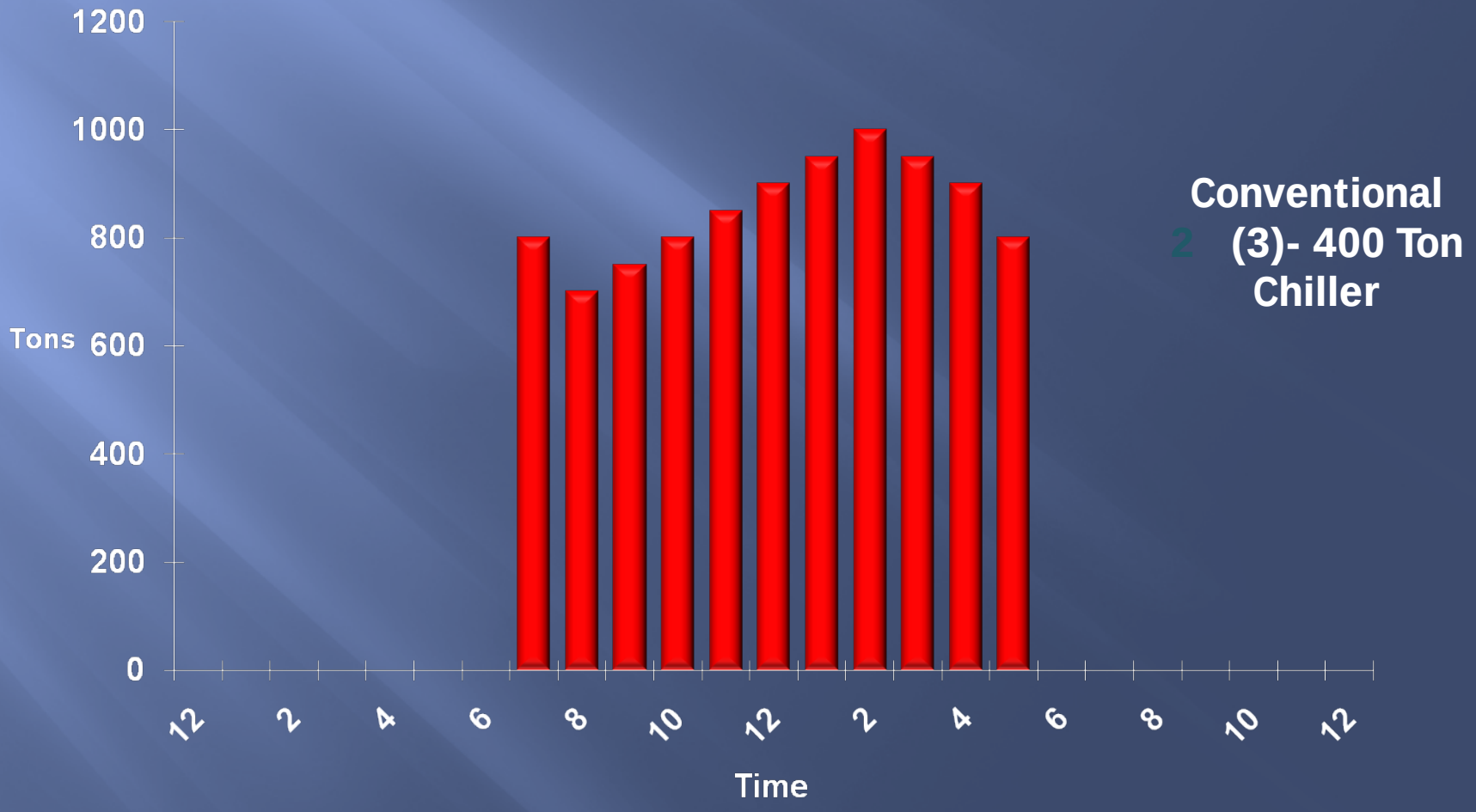
Excess Capacity on Design Day



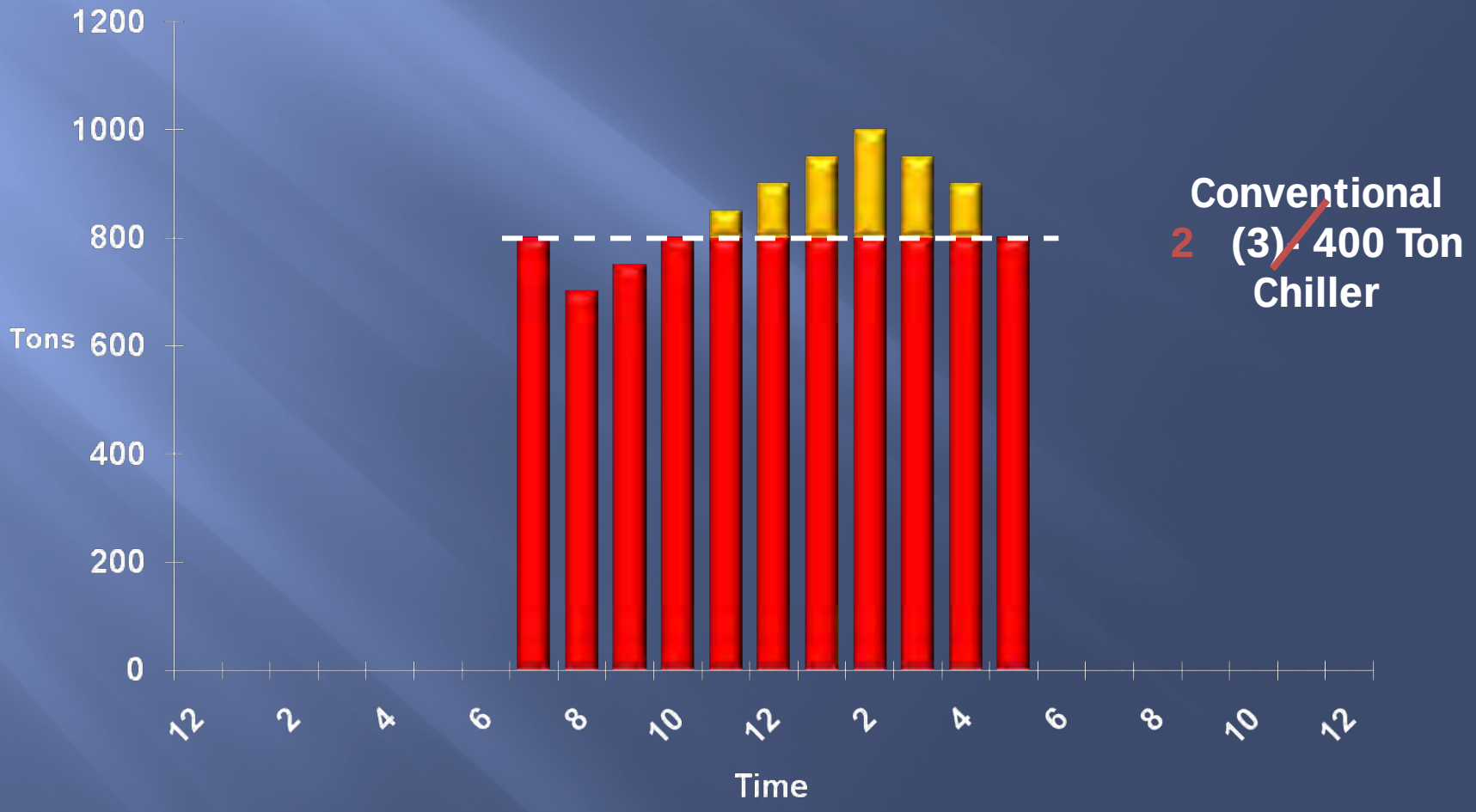
Design Day Operation



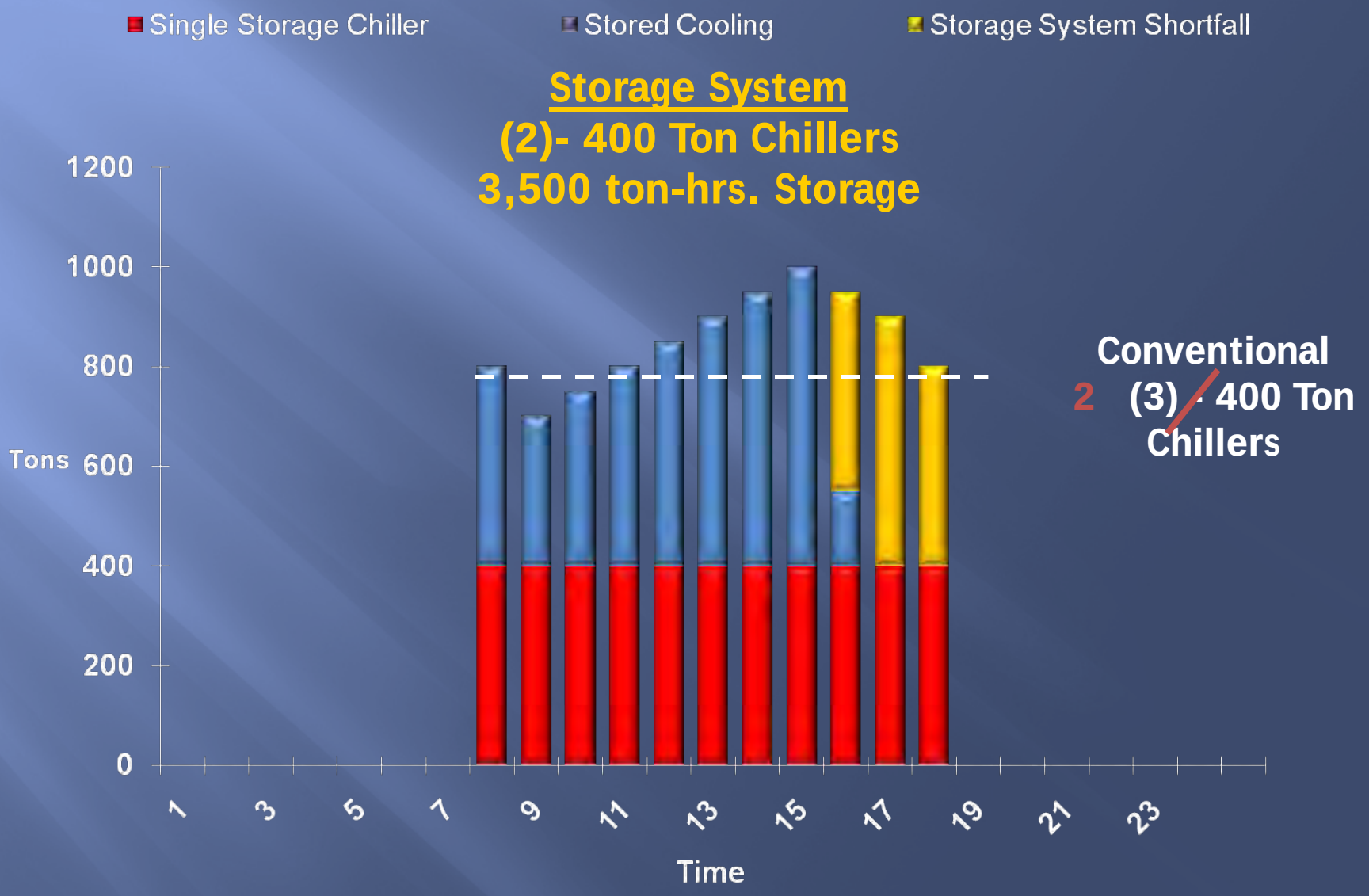
Design Day


1200
1000
800
600
400
200
0
Tons
12
2
4
6
8
10
12
2
4
6
8
10
12
Time
Conventional
(3)- 400 Ton
Chiller

Design Day with Chiller Failure



Design Day with Chiller Failure



Costs of Storage

Standard Chiller Plant Installed?

$1000/ton, $1300/ton, $1600/ton, $1800/ton

Storage Costs installed ~ $100 to $180 per ton-hr

Depending on location, application and design

For each 1 ton of chiller you reduce you need about 8 to 10 ton-hrs of storage.

Costs are about the same

Daytime

£ 1.59/ liter

Nighttime

£0.99 / liter

When Would you Fill-up?

Austin Energy EO 6 Rate

Energy:

Day: 0.034 P/kWh

Night: 0.034 P/kWh

0.105 P/kWh

0.034 P/kWh

Demand: 8.75kW/Month (4 Summer months)

How big an effect is the Demand Charge??

62% less costly at night

Con Edison Rate w/demand

Energy:

Day: 0.07 P/kWh

Night: 0.05 P/kWh

0.18 P/kWh

0.05 P/kWh

Demand: 22.00/kW/Month (4 Summer months)

How big an effect is the Demand Charge??

72% less costly at night

Stable Electric Rates

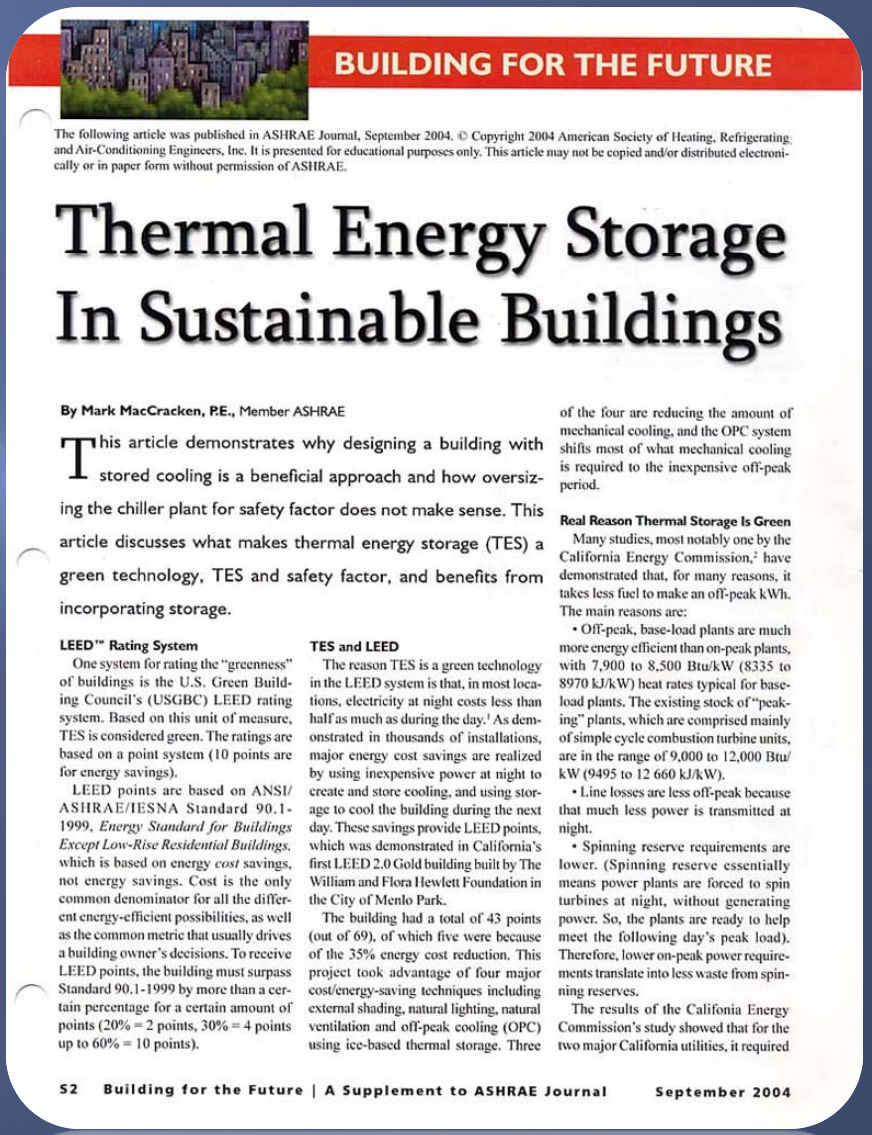
Edison Electric Institute stated that the only form of Energy that has stayed the same cost or gone down in last 30 to 40 years has been

Off-Peak Electricity

Thermal Energy Storage and Sustainable Buildings

Topics:

- LEED
- Why Green
- Safety Factory
- Redundancy
- Back-up Generation



BUILDING FOR THE FUTURE

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Thermal Energy Storage In Sustainable Buildings

By Mark MacCracken, P.E., Member ASHRAE

This article demonstrates why designing a building with stored cooling is a beneficial approach and how oversizing the chiller plant for safety factor does not make sense. This article discusses what makes thermal energy storage (TES) a green technology, TES and safety factor, and benefits from incorporating storage.

LEED™ Rating System

One system for rating the "greenness" of buildings is the U.S. Green Building Council's (USGBC) LEED rating system. Based on this unit of measure, TES is considered green. The ratings are based on a point system (10 points are for energy savings).

LEED points are based on ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, which is based on energy *cost* savings, not energy savings. Cost is the only common denominator for all the different energy-efficient possibilities, as well as the common metric that usually drives a building owner's decisions. To receive LEED points, the building must surpass Standard 90.1-1999 by more than a certain percentage for a certain amount of points (20% = 2 points, 30% = 4 points up to 60% = 10 points).

TES and LEED

The reason TES is a green technology in the LEED system is that, in most locations, electricity at night costs less than half as much as during the day.[1] As demonstrated in thousands of installations, major energy cost savings are realized by using inexpensive power at night to create and store cooling, and using storage to cool the building during the next day. These savings provide LEED points, which was demonstrated in California's first LEED 2.0 Gold building built by The William and Flora Hewlett Foundation in the City of Menlo Park.

The building had a total of 43 points (out of 69), of which five were because of the 35% energy cost reduction. This project took advantage of four major cost/energy-saving techniques including external shading, natural lighting, natural ventilation and off-peak cooling (OPC) using ice-based thermal storage. Three of the four are reducing the amount of mechanical cooling, and the OPC system shifts most of what mechanical cooling is required to the inexpensive off-peak period.

Real Reason Thermal Storage Is Green

Many studies, most notably one by the California Energy Commission,[2] have demonstrated that, for many reasons, it takes less fuel to make an off-peak kWh. The main reasons are:

- Off-peak, base-load plants are much more energy efficient than on-peak plants, with 7,900 to 8,500 Btu/kW (8335 to 8970 kJ/kW) heat rates typical for base-load plants. The existing stock of "peaking" plants, which are comprised mainly of simple cycle combustion turbine units, are in the range of 9,000 to 12,000 Btu/kW (9495 to 12 660 kJ/kW).
- Line losses are less off-peak because that much less power is transmitted at night.
- Spinning reserve requirements are lower. (Spinning reserve essentially means power plants are forced to spin turbines at night, without generating power. So, the plants are ready to help meet the following day's peak load). Therefore, lower on-peak power requirements translate into less waste from spinning reserves.

The results of the Califonia Energy Commission's study showed that for the two major California utilities, it required

(*ASHRAE Journal* Sept 04)

Current Events in Energy Storage

California Sets Terms of Massive Energy Storage Mandate 1.3 GW

DECC - June 2013 Funding that at least £20m will be made available to run a pilot on electricity demand reduction.

The electric utility energy storage market is projected to top $2.5 billion by 2015. Eight technologies will compete .....

Shale Gas?

Durst HQ Retrofit

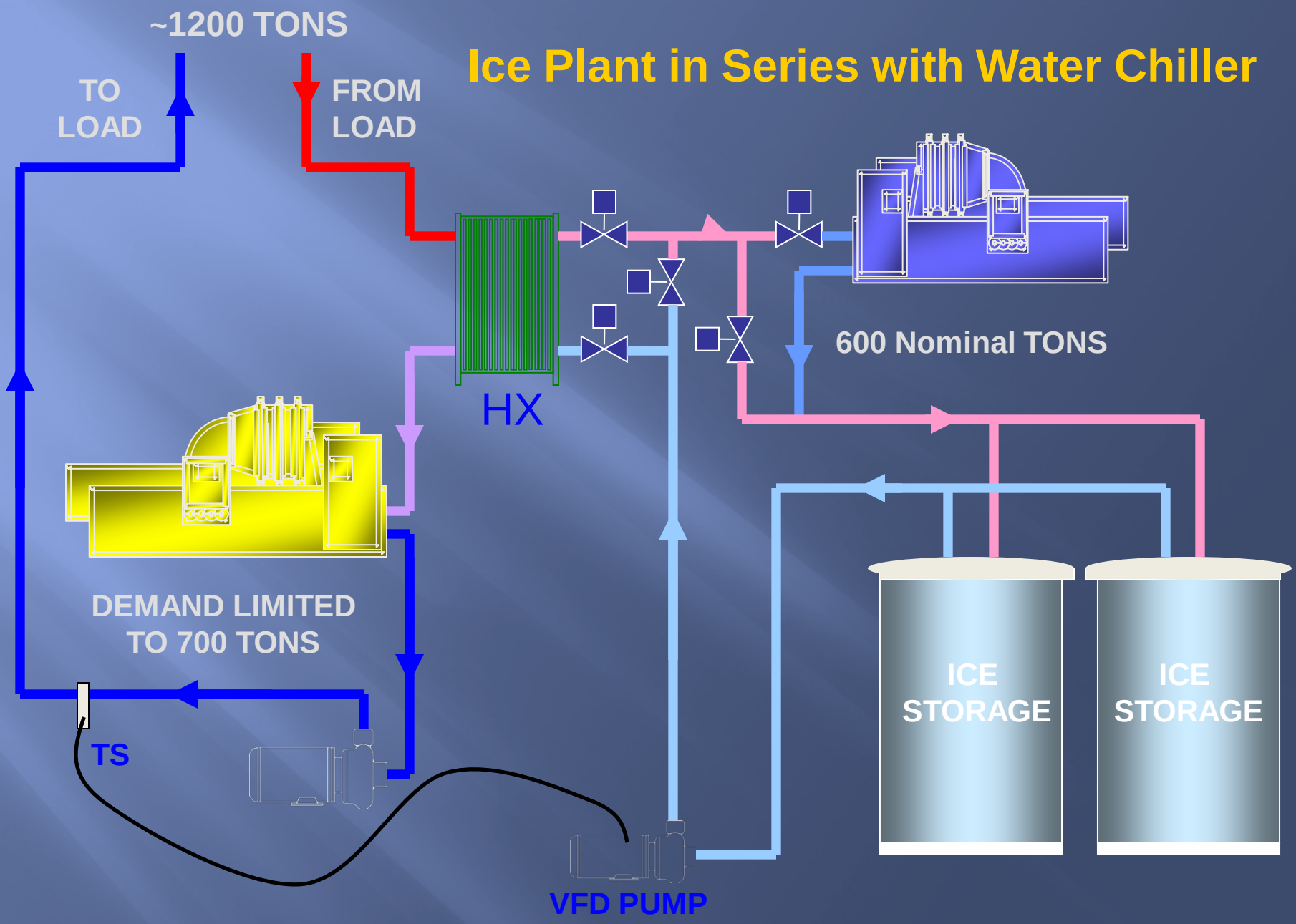
1155 Avenue of the Americas

41 Stories

3400 Ton Hours Storage

Avoids ≈ 700kW out of 3500kW Original Total

Ice Plant in Series with Water Chiller



TIAA CREF

30 Model Tanks

6,500 ton- hrs

On 28th Floor Roof

Credit Suisse

11 Madison Ave., NY, NY

30 Stories, 2.2 Million Ft²

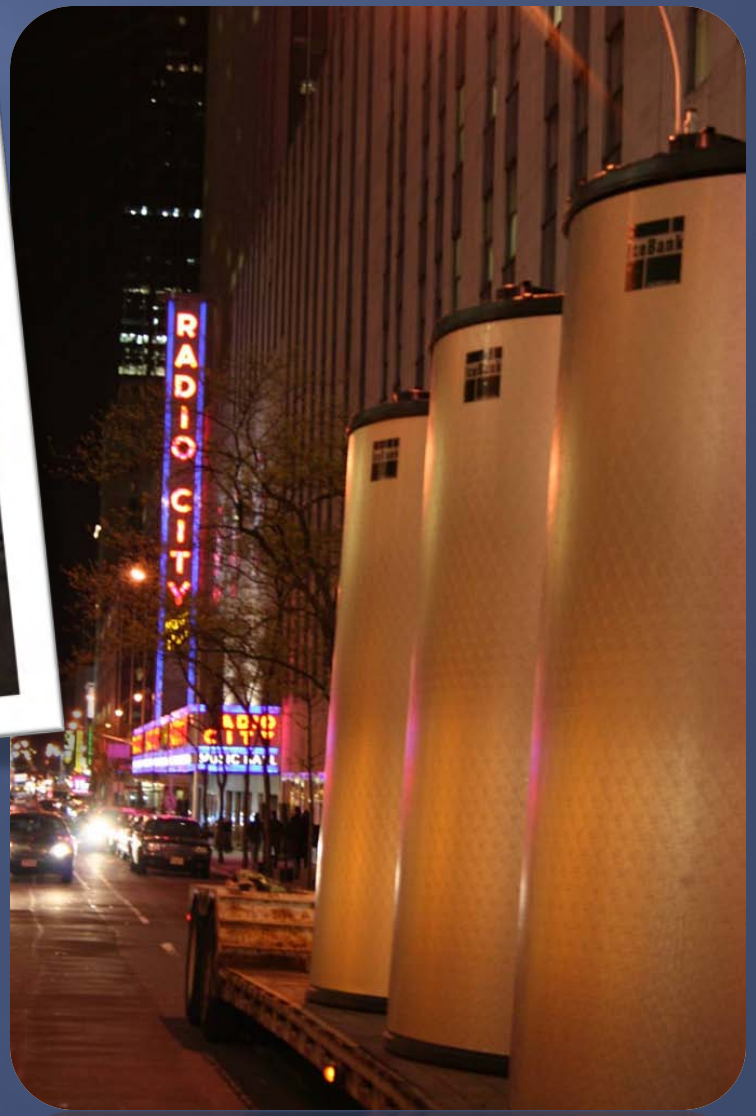
6200 Ton Hours Storage

Savings ~ £ 626,000/year
Avoids ~ 1000 kW

Main reason for Storage: Resiliency

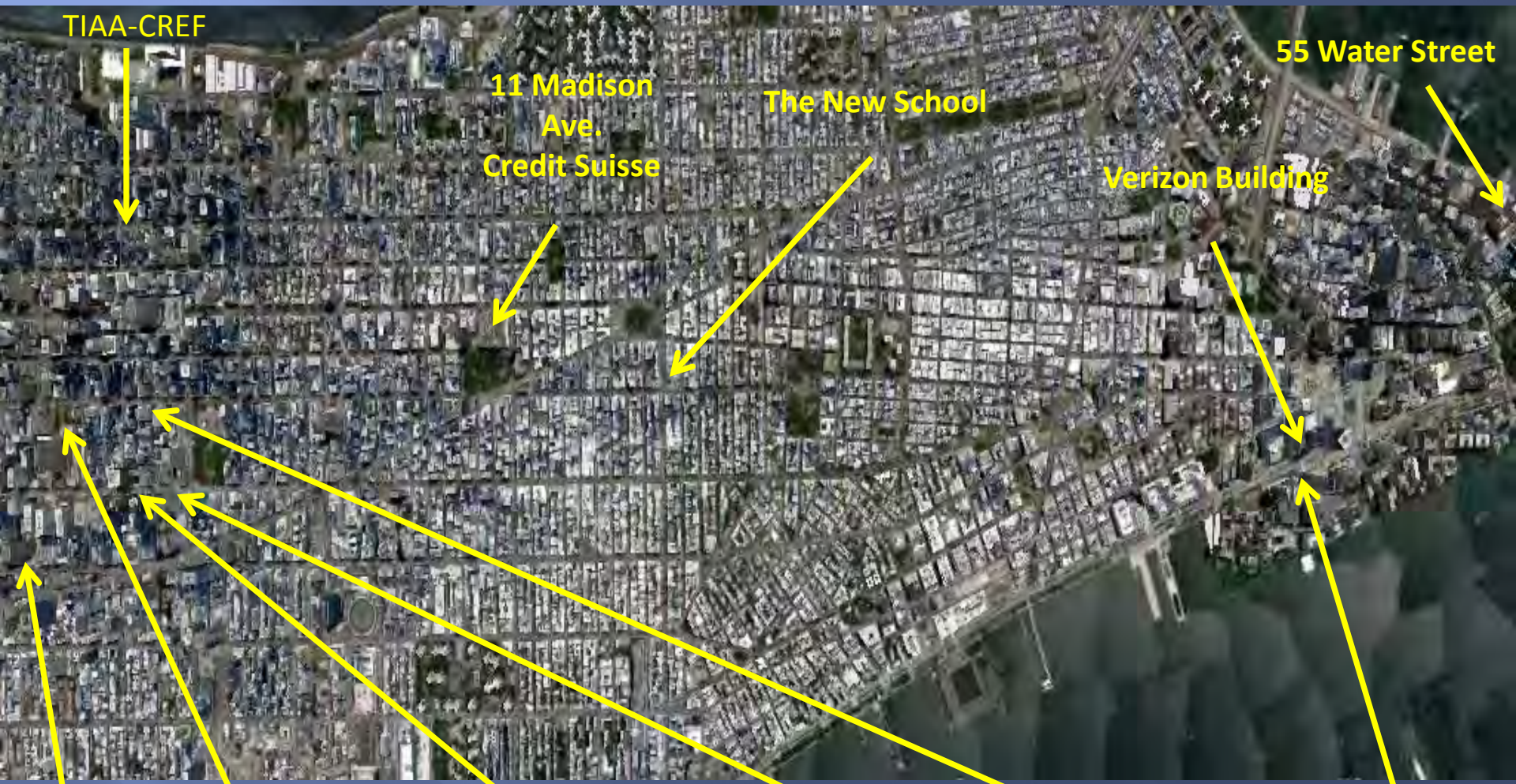
Rockefeller Center

New York, NY



9000 ton-hrs
Saving £ 750,000/year

CALMAC NEW YORK CITY ICEBANK® INSTALLATIONS



The PJ Carroll Building is home to the School of Informatics and Creative Arts.

Energy Storage Conclusions

1. The creation of cooling is what is the major cause of our electric Grid issues (US)
2. Ice Based Energy Storage is a proven technique to store cooling for commercial building
3. Everybody Wins
    1. Owners Lower Operating Costs
    2. Enhances utilization of Renewables
    3. Reduces Grid Load at most critical times in most critical locations

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