The Economics of Energy Storage:

comparing technologies using real-world examples

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Outline

- Need for, and Value of, Energy Storage for the Electric Grid
  - Impact of intermittent renewable power
- Energy Storage
  - Different technology types & characteristics
- Examples with Economics
- Summary and Conclusions

One option = low $ storage and low $ capacity

Terminology

- CAES - Compressed Air Energy Storage
- CHP - Combined Heat & Power
- CHW - Chilled Water
- CHWS/R - CHW Supply/Return
- CT - Combustion Turbine
- DC, DE - District Cooling, District Energy
- ES - Energy Storage
- FW - Flywheel Energy Storage
- LTF - Low Temperature Fluid
- PH - Pumped Hydro-electric Energy Storage
- SM - Superconducting Magnetic Energy Storage
- TES - Thermal Energy Storage
- TIC - Turbine Inlet Cooling

Introduction

- Storage is a useful part of many, if not most, man-made and natural systems:
  - Battery in your laptop computer
  - Ice-cube in your cold drink
  - Fuel tank in your car
  - Storage tanks in a municipal water system
  - Hot water tank in your home hot water system

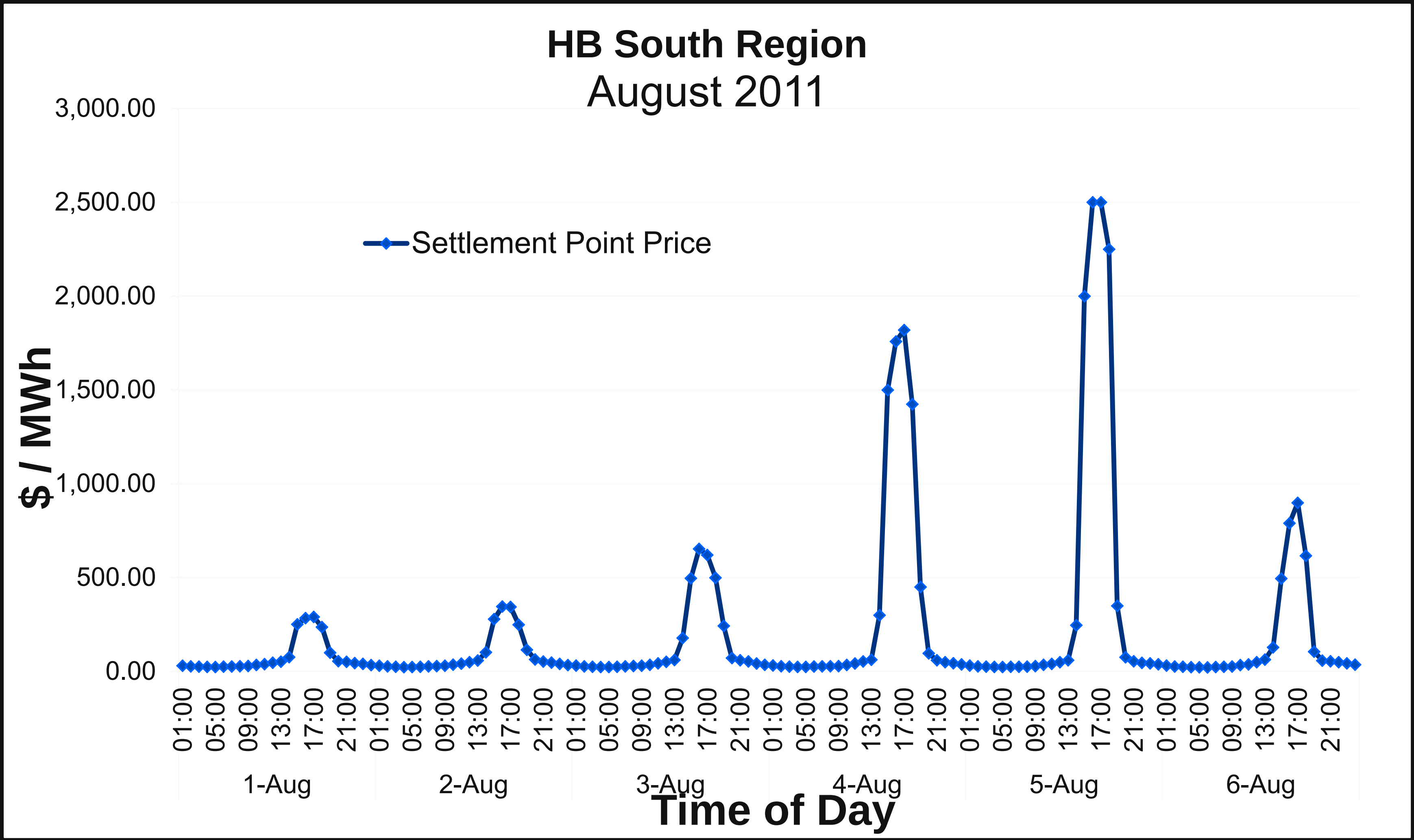
Storage is also very useful in an electric power system; however, this poses technical and economic challenges.

Introduction

- The value of storage has only grown as:
  - air-conditioning drives demand growth and widens gaps between peak & baseload demand,
  - time-of-day differentials grow in marginal heat rates, emissions, and value of electricity, and
  - power gen from renewable energy grows, but often with a significant intermittent, or even out-of-phase, nature relative to demand (e.g. wind).

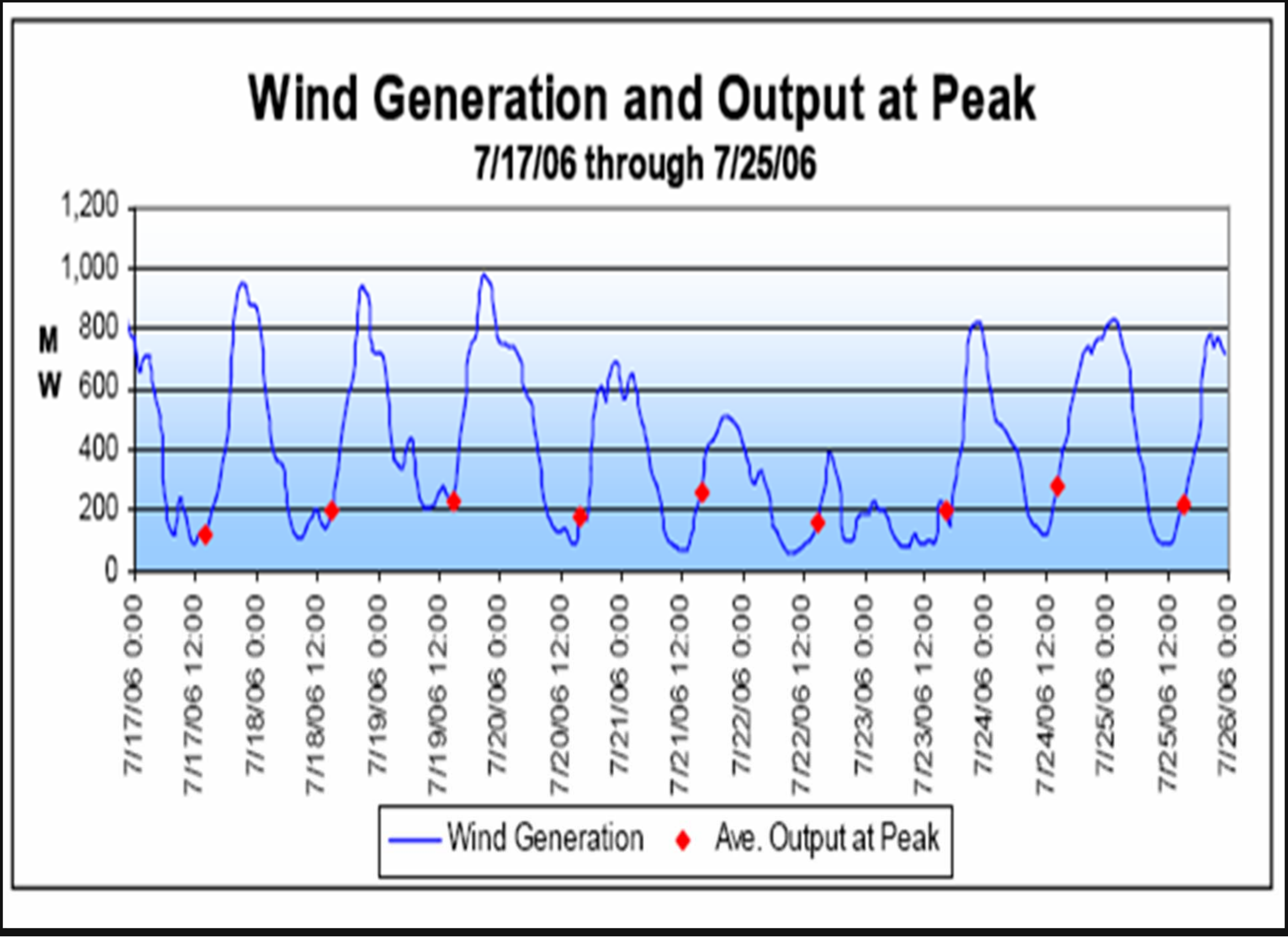
Thus, practical and economical energy storage can be key in electric power systems - whether the grid or a campus micro-grid.

kWh Value Varies: +$2.50 to -$0.10 while grid demand varies: 100-50%



Source: ERCOT, *www.ercot.com*

Wind Power ~20% during Peak Dmnd



Types of Energy Storage

- Traditional commercial utility-scale storage:
  - Pumped Hydro-electric (PH) Energy Storage
- Developing utility storage technologies:
  - Compressed Air (CA) Energy Storage
  - Advanced Electro-Chemical Batteries
  - Mechanical Flywheel (FW) Energy Storage
  - Superconducting Magnetic (SM) Energy Stor.
- Thermal Energy Storage (TES):
  - Cool (Ice, Chilled Water, or Low Temp Fluid)
  - Hot (Hot Water, Hot Oil, or Molten Salt)

Key Energy Storage Characteristics

- Technical development status; readiness for reliable & economical utility-scale appl’ns
- Practical for rapid discharge (secs or mins)
- Practical for extended discharge (hours)
- Ease of siting (practical & envir’l concerns)
- Life expectancy and life cycle costs
- Round-trip energy efficiency
- Initial unit capital cost ($/kW and $/kWh)

But each individual storage technology differs.

Key Energy Storage Characteristics

	PH	CA	Bat	FW	SM	*CHW TES*
develop't	exc	fair	good	fair	poor	excellent
fast disch	no	no	yes	yes	yes	not<0.25hr
long (hrs)	yes	yes	poor	poor	???	multi-hour
siting	lmtd	lmtd	easy	easy	easy	easy
schedule	v.lg	long	fast	fast	???	fast
life (yrs)	30+	20+	~15	20?	???	30+ yrs
effic (%)	~80	mod	~75	mod	???	near 100%
$/kW	>2K	>1K	>3K	v.hi	???	hundreds

Latent Heat TES Systems for DC (typically Ice TES)

- Inherent Benefits, typically:
  - relatively compact storage volume
  - capability (of some Ice TES designs) for low supply temps during discharge (34 to 44 ºF typ.)
  - std modular units in small to moderate sizes
- Inherent Drawbacks, typically:
  - low temps required for charging Ice TES
  - relatively little economy-of-scale

Sensible Heat TES Systems for DC (typically CHW or Low Temp Fluid)

- Inherent Benefits, typically:
  - relatively simple & efficient - due to relatively constant, warm (conventional) oper'g temps
  - dramatic economy-of-scale - low capital cost per ton-hr or per ton, for large appl'ns, e.g. DC
- Inherent Drawbacks, typically:
  - Large CHW TES vol. (but reduced by 33-50% with LTF TES, though still larger than Ice TES)
  - Min. CHWS of 39 to 40 ºF with stratified CHW (but 30 to 36 ºF or lower, with LTF)

Inherent Characteristics of TES

(typical generalizations only)	Ice	CHW	LTF
Volume	good	poor	fair
Footprint	good	fair	good
Modularity	excell	poor	good
Economy-of-Scale	poor	excell	good
Energy Efficiency	fair	excell	good
Low Temp Capability	good	poor	excell
Ease of Retrofit	fair	excell	good
Rapid Charge/Dischrg Capability	fair	good	good
Simplicity and Reliability	fair	excell	good
Can Site Remotely from Chillers	poor	excell	excell
Dual-use as Fire Protection	poor	excell	poor

CHW TES
Round-trip Energy Efficiency

- There are inherent <u>in</u>efficiencies in CHW TES:
  - Pumping energy to/from TES (typical loss of 3-6%)
  - Heat gain into TES (typical loss of 1-2% per day)
- But there are also inherent <u>e</u>fficiencies:
  - Avoid low part load equip oper (typical gain 3-6%)
  - Cooler off-peak condensing temp (typ gain 5-10%)

Net round-trip energy efficiency of CHW TES is typically ~100%, or even up to ~110% (compared to same cooling without TES).

Energy Storage CapEx Examples

- PH is grid-scale, ~$1,900 to 3,800/kW
- CA is grid-scale, “target” $800 to 1,200/kW
- Flywheel: ~$7,800 to 9,000/kWh
  - Therefore, impractical for multi-hour ES
- Advanced Batteries: ~$450 to 700/kWh
  - ~$2,700 to 4,200/kW, for 6 hrs of ES
- CHW TES: ~$50 to 200/kWh
  - ~$300 to 1,200/kW, for 6 hrs of ES

2007 survey: TES on 124 campuses, 1.8M T-hrs (~78% CHW/LTF), shifting 258,000 T & 194 MW

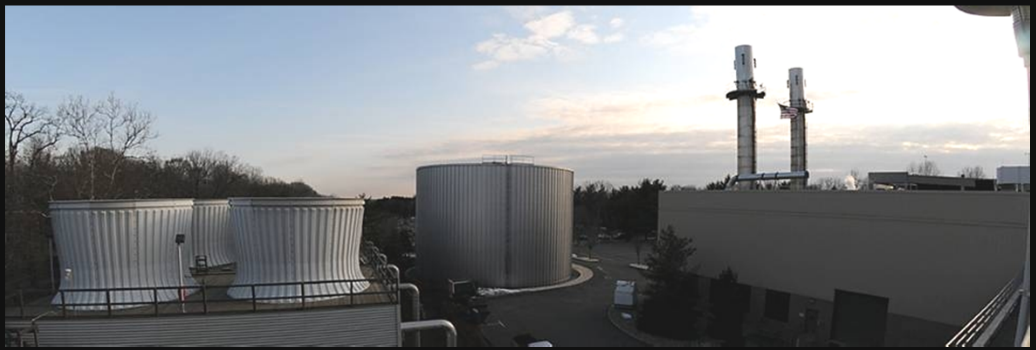
ES at Princeton U. - Princeton, NJ

Campus DE system

Elec & non-elec chillers

CHP w/ TIC: 14.6 MW

LTF TES: 40,000T-hrs



Max discharge = 10,000T at 24 °F ΔT

32 / 56°F CHWS/R = smaller, low cost, 2.7 Mgal tank

Low CHWS temp = more capacity in DC network

LTF for TIC = colder air, more power, more value

CHP + TIC + TES + non-elec chillers = reduced peak power demand 92.5%, from 27 MW to only 2 MW.

Tank installed unit CapEx (2010) = ~$316/Ton; and at 0.7 kW/T, LTF TES = $452/kW & $113/kWh

ES at the U of Texas at Austin

- Campus DE system
- CHP for 100% elec
- Two (2) CHW TES
- 69,000 Ton-hrs
- 40 / 52°F CHWS / R temps (conservative)
- Max discharge = 2 x 10,000 T at 12 °F ΔT
- Tanks: 4.3 Mgals (2010) + 5.7 Mgals (2015)

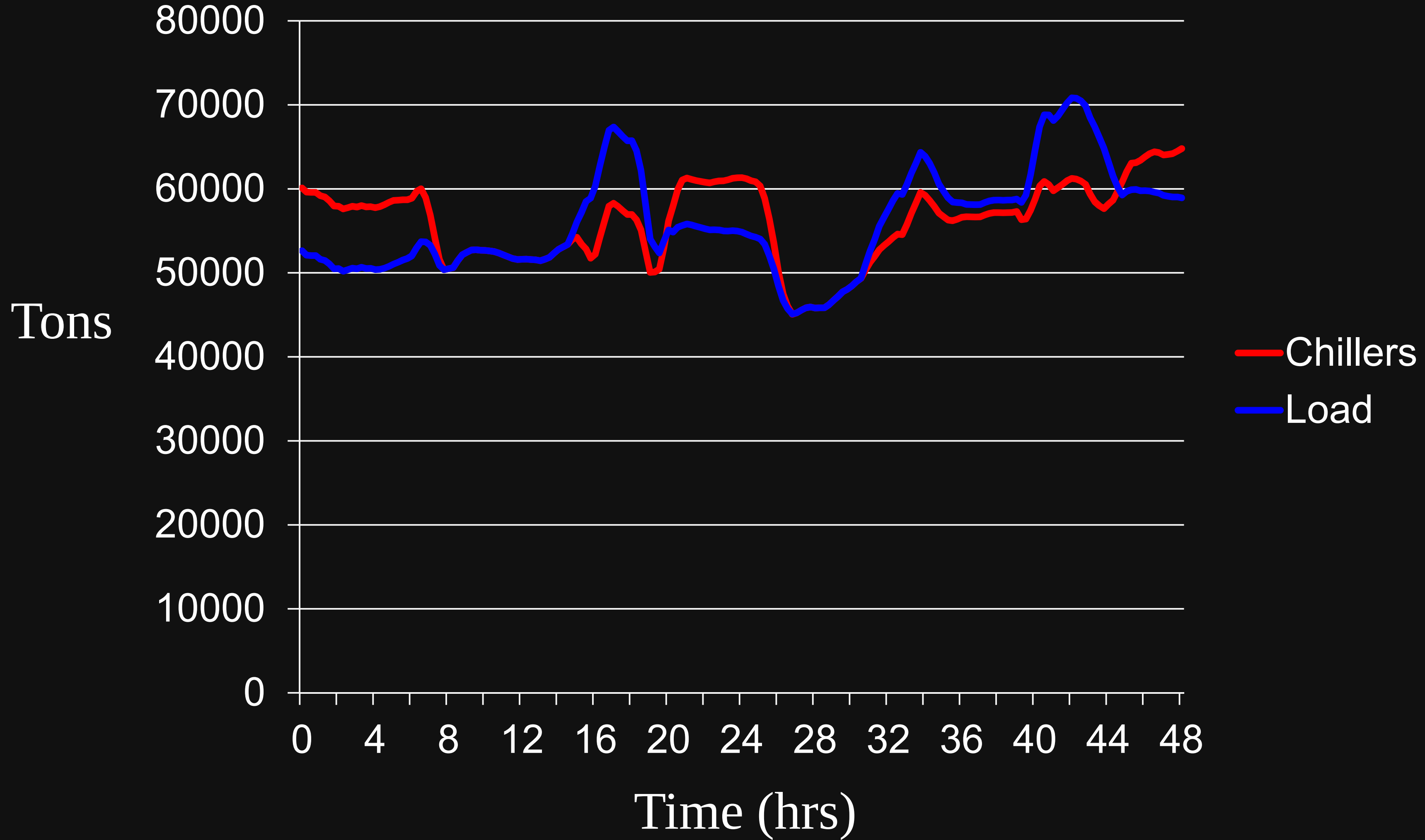
Tank installed unit CapEx (2010-15) = ~$425/T; and at 0.7kW/T, CHW TES = ~$607/kW & ~$176/kWh

ES at TECO - Houston, TX

- Medical system DE
- CHP w/ TIC: 45 MW
- Added CHW TES
- 64,285 Ton-hrs
- 40 / 52°F CHWS / R temps (conservative)
- Max discharge = 13,750 Tons at 12 °F ΔT
- Tank: 8.8 Mgals (100’D x 150’H)

Tank installed unit CapEx (2010) = ~$495/T; and at 0.7kW/T, CHW TES = ~$706/kW & ~$151/kWh

DC Operation with CHW TES



Some of the ES Operating Results

Since 2010, this IDEA member campus operated its 64,285 ton-hr, 8.8 million gal CHW TES tank:

- During 15 hrs in August 2011, local elec cost hit $3.00/kWh; TES saved $400K in just those 15 hrs!
- Due to excess wind power at night, there have also been periods when the DC system was paid up to $0.10/kWh to consume power to recharge TES!
- TES also flattens peak cooling & electric profiles, thus improving the economics for CHP.

TES captures value for campus DC owners,

and benefits the electric power grid as well.

ES at OUCooling - Orlando, FL

- DC utility system
- Expo, hotels, industry
- Added CHW TES
- 160,000 Ton-hrs
- 40 / 55°F CHWS / R temps
- Max discharge = 20,000 Tons at 15 °F ΔT
- Tank: 17.6 Mgals (223.5'D x 60'H)

Tank installed unit CapEx (2002) = ~$139/T; and at 0.75kW/T, CHW TES = ~$185/kW & ~$23/kWh

Summary and Conclusions

Storage is valuable; renewables increasing the need.

- PH: grid-scale, lmtd sites, low effic, high unit cap $
- CAES: grid-scale, lmtd sites, developmental tech
- SMES: very developmental technology
- Flywheel: OK for secs or mins, too high $ for hrs
- Battery: high $ if multi-hr, low efficiency, lmtd life

TES: benefits campus DC (oper & cap $ savings)

- flattens load; improves economics of CHP (& TIC)
- proven tech, easy to site, ~100% effic, 30+ yr life

CHW TES = low cap$ ES plus low cap$ DC capacity

Summary and Conclusions

Large CHW TES (or LTF TES) can and does often solve TWO economic challenges:

1. Multi-hour ES at a fraction the unit CapEx ($/kWh) of batteries or other ES options, and
2. Campus DC capacity at a fraction the unit CapEx ($/Ton) of conventional chiller plant capacity.

(Batteries cost more & you still need to add DC tons.)

Evaluate Cool TES whenever considering ES,

and especially when considering new DC capacity.

(And consider Hot Water TES for a HW DE system.)

Questions / Discussion ?

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