Current Trends in Thermal Energy Storage

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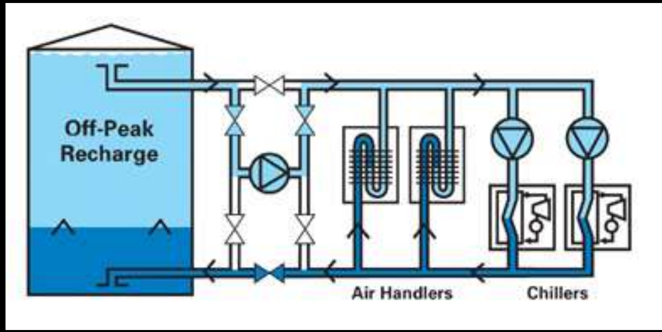
Outline

- Introduction: Thermal Energy Storage (TES) in District Cooling
- Current and Growing Trends in TES Applications:
  - Emergency cooling for Mission Critical Facilities
  - Improved economics for CHP
  - Maximizing wind & solar resources
  - Turbine Inlet Cooling (TIC)
  - Low Temp Fluid TES
  - Complementing CHW TES with HW TES
  - Optimizing value with changing/emerging electric rate structures
- Conclusions and Recommendations

Chilled Water (CHW) Thermal Energy Storage (TES)



- An insulated tank, full of water at all times.
- Cool, dense CHW Supply in lower zone, at ~40 °F;
- Warm, less dense CHW Return in upper zone, typically at 50 to 60 °F;
- Narrow “thermocline” (temperature gradient) in between the zones.
- TES is charged, off-peak (nighttime): CHWR pumped from top of tank, cooled in chillers; CHWR flows to bottom of tank; thermocline rises in tank, until tank is 100% cool water.
- TES is discharged, on-peak (daytime): CHWS pumped from bottom of tank, meets cooling loads; CHWS flows to top of tank; thermocline falls in tank, until tank is 100% warm water.

No moving parts or heat exchange in tank; just pumps & valves outside.

30+ years of CHW TES – Including Repeat Owners

From many hundreds of CHW TES, here are just a few Owners, each with *Multiple* TES Installations	# of TES	On-Peak Thermal Storage (ton-hrs)	On-Peak Thermal Peak Shift (tons)	On-Peak Electrical Storage (MWh)	On-Peak Electrical Peak Shift (MW)
California State Univ. campuses	18	309,000	52,000	216	36
Univ. of California campuses	9	281,000	47,000	197	33
Univ. of Nebraska campuses	2	68,000	12,000	51	8
Univ. of Texas campuses	7	152,000	25,000	106	18
U.S. (FDA, NASA, Nat'l Labs, NIH, VA)	12	269,000	45,000	202	34
U.S. DOD (Air Force, Army)	9	203,000	34,000	152	25
Airports(DFW, LAX, Love, Reagan, SanAnton)	5	152,000	40.000	106	28
Boeing / Lockheed Martin	5	230,000	38,000	172	29
Ford / GM / Toyota	13	381,000	63,000	263	44
Halliburton / Saudi Aramco	4	62,000	10,000	48	8
Honeywell / IBM / Texas Instruments	8	186,000	31,000	139	23
3M / State Farm / UPS	10	188,000	31,000	143	24
Distr St. Paul/ Qatar Cool/ Tabreed/ Trigen	16	517,000	86,000	346	58
Totals (from just these few)	**118**	**3 million**	**514,000**	**2,141**	**368**

Emergency Cooling of MCFs

- Mission Critical Facilities (MCFs) include especially data centers, medical, research, etc. in which cooling cannot be interrupted.
- Power outages can be addressed with on-site UPS; but it may take 10 to 90 minutes to restore full chiller plant operation.
- During that transition, emergency cooling can come for TES.
- That TES must be:
  - Automatic and reliable
  - Able to discharge very rapidly to meet 100% of the critical loads.

CHW TES is a typical choice for that emergency reserve.

Emergency Cooling of MCFs

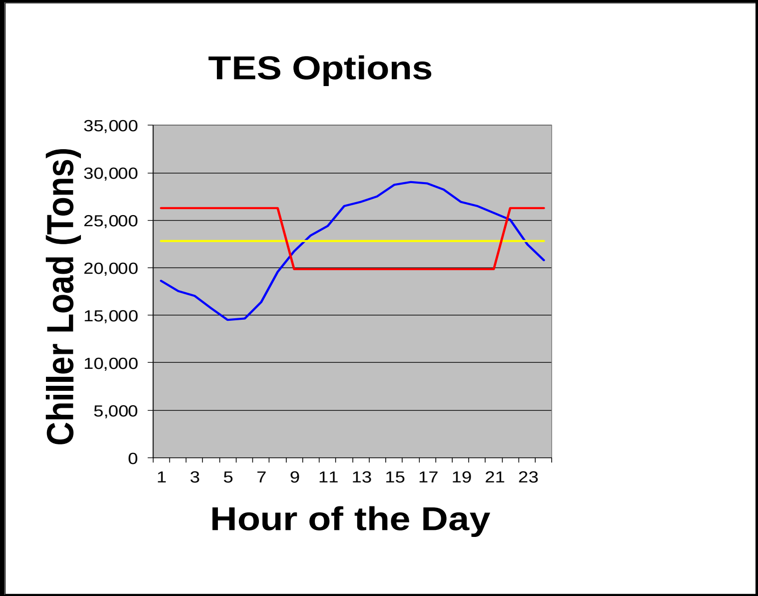
A few examples:

Owner	S/R Temps (deg F)	Capacity (ton-hrs)	Discharge (tons)	(mins)
Bank of America	45 / 70	2,000	4,170	29
Capital One	65 / 75	900	1,500	36
DuPont Fabros	65 / 84	1,050	6,030	10
Kaiser Hospitals	45 / 60	3,880	2,700	86
Princeton Univ.	45 / 60	1,000	2,000	30

Many have multiple installations of CHW TES, e.g.
AOL, B of A, CapOne, DuPont, Equinix, MCI, Nationwide . . .

Flattened Load Profiles for CHP

- CHP is expensive; needs high operating hrs/yr to be cost effective.
- Elec power above CHP must be purchased at high $/kW & $/kWh.
- TES “flattens” peak day elec & thermal profiles.
- This allows:
  - use of larger CHP (at lower Cap$/kW),
  - more hrs/yr of fully loaded CHP operation,
  - fewer kWh/yr of peak elec power purchases, and
  - thus, improved economic results for CHP.



Sometimes, CHP is economically justified, when it wouldn’t be w/o TES.

Flattened Load Profiles for CHP

A few examples:

Texas A&M Univ.	Princeton Univ.	Nat'l Inst's of Health	TECO
College Park, TX	Princeton, NJ	Bethesda, MD	Houston, TX
24,000 Ton-hrs	40,000 Ton-hrs	47,500 Ton-hrs	70,000 Ton-hrs
50 MW CT	15 MW CT	23 MW CT	48 MW CT

Flatter profiles = More hrs/yr of fully loaded CHP = Better CHP economics.

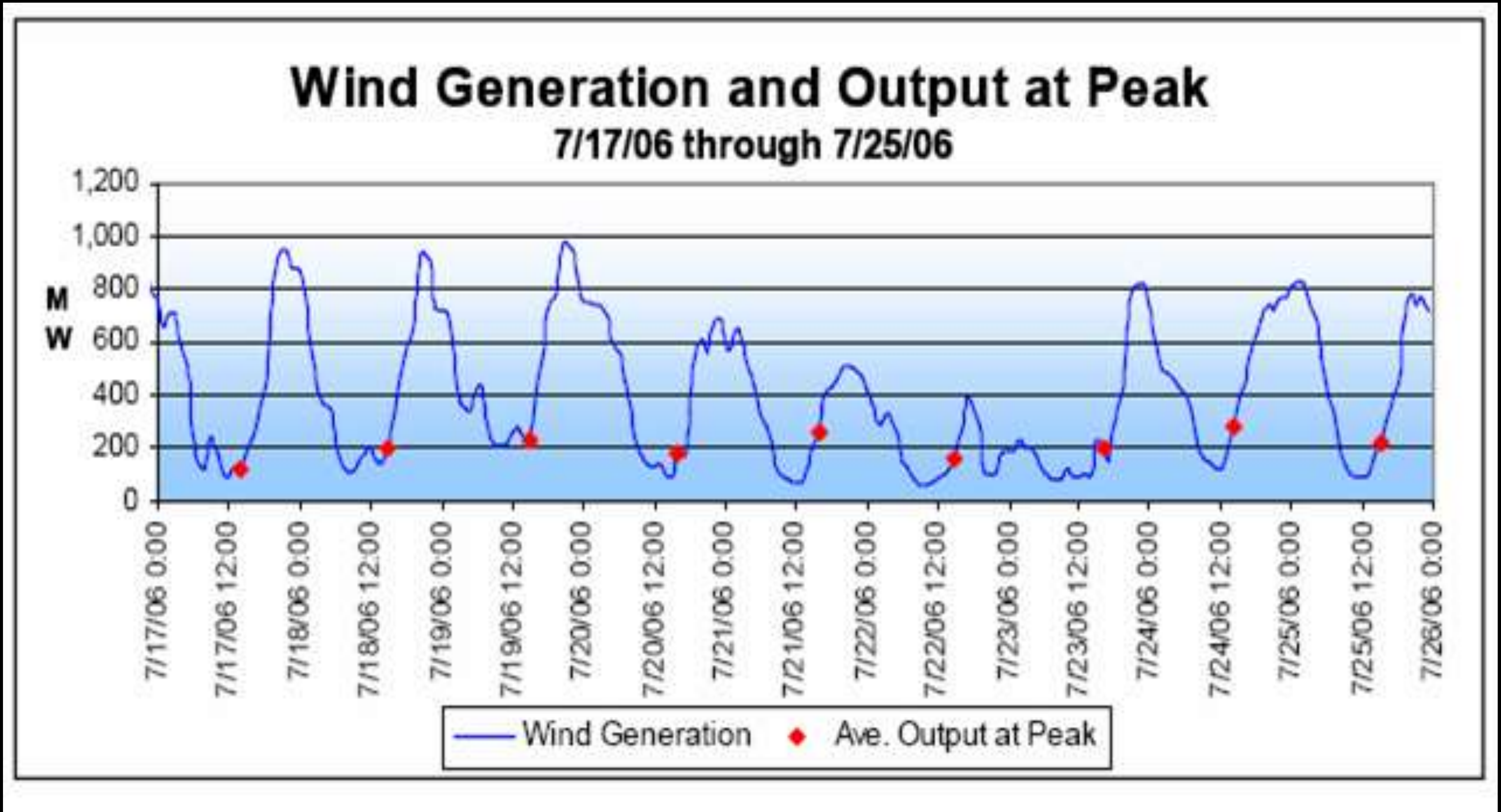
Maximizing Intermittent Wind & Solar Power

- Renewable Portfolio Standards = Increased Wind & Solar power
  - But they are intermittent and often out-of-phase with demand.
  - Coal + Nuclear + Wind power often exceeds nighttime demand.
  - Nighttime power trades negative at times, e.g.:
    - In Texas, as low as negative $0.10/kWh !
    - In Nebraska, as low as negative $0.20/kWh !!
- Therefore, Energy Storage is increasingly critical; one can consider:
  - Batteries, Pumped Hydro, Compressed Air, Flywheels, SMES, Fuel Cells .

*But large **CHW TES** often excels over other storage in terms of:*

maturity, safety, siting, permitting, schedule, lifetime, efficiency, cap$

Typical Wind Output Only 20% at Peak Demand Time



Texas Grid (ERCOT) Historical Peak Demand

- 2017 summer peak demand: ~70,000 MW
- Installed wind generation: ~23,000 MW (nameplate)
- But wind output during that peak: <600 MW,

  i.e. only ~2.5% of the installed nameplate wind capacity!

- Thus:
  1. All this expensive, subsidized wind generation has not effectively reduced the need for conventional generation, at all.
  2. Only Energy Storage can make fuller use of the wind power investment.

Issues with Battery Storage

All-electric grids or microgrids will necessarily use batteries for storage; but batteries (even today's leading choice, Lithium-Ion) are <u>not</u> ideal:

- Material Sourcing (exotic, costly materials, from unreliable locales)
- Safety (potential explosions & fires)
- Environmental (during mat'l extraction & end-of-life disposal)
- Life Expectancy (typically only 7-10 yrs, and with reducing capacity)
- Round-trip Energy Efficiency (typically only 80-85%)
- Capital Cost (typical installed project costs of $500-800/kWh)

But a microgrid which incorporates electric <u>and</u> thermal networks can consider <u>Thermal</u> Energy Storage (TES).

Massachusetts ESI (Energy Storage Initiative)

In December 2017, the State of Massachusetts announced:

- 26 Energy Storage projects
- $20 million in state grants
- $32 million in private “matching funds”
- Average installed capital costs (grants + matching funds):
  - Flywheel Storage @ $948/kWh
  - Battery Storage @ $656/kWh
  - **Thermal Energy Storage @ $240/kWh**

Batteries may need grants or tax credits to be economic.

TES does not.

Maximizing Intermittent Wind & Solar Power

An example:

Some nights in NE, wholesale electric has <u>negative</u> rates of ~$0.20/kWh.

	<u>UNL East Campus</u>	<u>UNL City Campus</u>
Storage of:	16,326 Ton-hrs	52,000 Ton-hrs
	(or 12 MWh electric)	(or 39 MWh electric)
Peak Shift of:	up to 4,000 Tons	up to 8,333 Tons
	(or 3 MW electric)	(or 6.25 MW electric)

CHW TES unit Cap$ < half battery $; + TES provides peak chiller plant capacity.

Turbine Inlet Cooling (TIC) of Gas Turbines

- Gas or Combustion Turbine (CT) machines are constant volume.
- High ambient air temps = low air density, mass flow, and power.
- Cooling inlet air with TIC = higher CT power output.
- Various types of TIC:
  - Evaporative cooling: low $; needs water; lmtd cooling & power
  - Chiller-based cooling: much more cooling & power; higher Cap$
  - Chillers with CHW TES (vs Chillers w/o TES):
    - reduced chiller plant size & cost (often saves more than $ of TES)
    - Increased on-peak power; lower Capital $/kW; TES essentially free!

Turbine Inlet Cooling (TIC) of Gas Turbines

A few examples:

Princeton Univ.	TECO	Chicago MPEA	Saudi Electricity Company
Princeton, NJ	Houston, TX	Chicago, IL	Riyadh, Saudi Arabia
40,000 Ton-hrs	70,000 Ton-hrs	123,000 Ton-hrs	190,000 Ton-hrs
1 x 15 MW CT	1 x 48 MW CT	3 x 1.1 MW CTs	10 x 75 MW CTs

Hot weather CT outputs are increased by 10 to 30 %, at very low Cap$/MW.

Low Temp Fluid TES

- Thermally stratified CHW TES limited to CHWS of 39 to 40 °F.
- At a typical CHWS-to-CHWR Delta T of 12 to 16 °F, CHW TES requires ~1 to 1.33 million gals tank volume per 10,000 Ton-hrs.
- Aqueous Low Temp Fluid = lower supply temp & larger Delta T:
  - LTF Delta T can be 24 °F, or more.
  - This reduces tank volume by 33 to 50%, or more.
  - Or a fixed tank volume stores an extra 50 to 100%, or more.
  - And a fixed pump/pipe size delivers extra 50 to 100%, or more.

And LTF can inhibit corrosion & microbiological growth.

Low Temp Fluid TES

A few examples:

DFW International Airport
Dallas / Fort Worth, TX
60,000 Ton-hrs
36 / 60 °F

Princeton Univ.
Princeton, NJ
40,000 Ton-hrs
32 / 56 °F

Chicago MPEA
Chicago, IL
123,000 T-hrs
30 / 54 °F

24 °F Delta T means 50 to 100% more capacity in TES & in CHW pumps/piping.

Complementing CHW TES with HW TES

Hot Water (HW) TES has long been used:

- In District HW systems in Scandinavia, China, and Canada.

HW TES is now being used in the US, to complement CHW TES:

- Coupled with heat-recovery chillers for District CHW & HW.
- To store Condensate Return in a District Steam system.
- For seasonal (winter) conversion of a CHW TES tank.

Complementing CHW TES with HW TES

A few examples:

Stanford U – 2 x 45,000 Ton-hrs CHW TES + 1 x 600 MMBtu HW TES

Cal State U-Fullerton – 2 TES tanks

1 CHW TES, 37,000 Ton-hrs @ 40 / 64 °F

1 HW TES, 158 MMBtu @ 168 / 118 °F

District Energy St. Paul –

2 CHW TES tanks:

28,000 and 37,400 Ton-hrs,

One convertible to HW TES

We'll see more of this as District Steam converts to District HW.

Optimizing Value with Changing Elec Rates

Changing, new or future elec mkts offer opportunity for TES value:

- Various “demand charge” and “Time-of-Use (TOU)” rates
- “Coincident Demand” rates
- “Interruptible” rates
- “Real-Time Pricing (RTP)” rates
- “Global Adjustment (GA)” charges, as in Ontario, Canada
- Short “Super On-Peak” periods met by fast discharge TES

Some utilities pay cash incentives for peak load mgmt via TES.

Optimizing Value with Changing Elec Rates

Some examples, using <u>hourly real-time prices</u>:

<u>Princeton Univ.</u> (40,000 Ton-hrs)

Can fully discharge in only 4 hours.

On some days, it cycles <u>more</u> than 100% of TES capacity: discharge ~33% in a.m., then recharge mid-day, then discharge 100%.

<u>TECO</u> (70,000 Ton-hrs)

Some nights, they are <u>paid</u> ~$0.10/kWh to recharge TES.

Some days, they <u>save</u> up to ~$3.00/kWh or ~$25,000/hr.

TES provides <u>flexibility</u> for various & future electric market scenarios.

Operating and Capital Savings with CHW TES

TES Project Type	Owner	CHW TES Capacity (ton-hrs)	Savings vs. Non-TES Chiller Plants: Annual Operating Savings	Savings vs. Non-TES Chiller Plants: Initial Capital Savings
retro	Washington St U	17,750	\$ 260,000/yr	\$1 to 2 million
new	Lisbon Distr Energy	39,800	\$1,160,000/yr	\$2.5 million
retro	U of Alberta	60,000	\$ 600,000/yr	\$4 million
new	Chrysler R&D	68,000	>\$1,000,000/yr	\$3.6 million
retro	DFW Airport	90,000	~\$2,000,000/yr	\$6 million
retro	OUCooling district	160,000	>\$ 500,000/yr	>\$5 million

Net Capital Savings accrued from downsizing chiller plants.

CHW TES Cap\$ is < that of equivalent chiller plant capacity.

Conclusions and Recommendations

- TES always reduces peak demand and operating energy costs.
- Large CHW TES can also reduce capital costs (vs chiller plants).
- But TES also provides the flexibility to address a variety of emerging & evolving, current & future trends.
- Consider TES whenever planning Energy Storage or CHP.
- *Consider TES especially when planning thermal capacity investments, specifically at times of:*
  - *New construction,*
  - *Retrofit capacity expansions, or*
  - *Retirement / replacement of aging thermal plant equipment.*

Questions / Discussion ?

Or for a copy of this presentation, contact:

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Laissez les bontemps rouler ! (Let the good times roll !)