Energy Storage
to Help Meet the Challenge of Integrating Renewable Resources

John S. Andrepont, President

The Cool Solutions Company

Trevor Richter, Vice President

stellar | Energy Systems

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Outline

- Introduction
  - Renewable Energy and the Need for Storage
  - CTs and Turbine Inlet Cooling (TIC)
- Energy Storage (ES) Technologies
  - Desired Characteristics; Technology Types
- Thermal Energy Storage (TES)
  - Types; TES-TIC Examples; ES Comparisons
- Summary and Conclusions

Introduction

- Storage is a useful part of many, if not most, natural and man-made systems:
  - Battery in your PC
  - Ice-cube in your cold drink
  - Fuel tank in your car
  - Hot water tank in your home heating system
  - Storage tanks in a potable water utility system
- Storage also very useful for electric power. *However, there are tech & econ challenges.*

Renewable Energy and Storage

- The value of storage has only grown as:
  - air-conditioning loads drive demand, widening the gap between peak and 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.
- Thus, practical, economical energy storage can play a key role in elec power systems.

CTs and Turbine Inlet Cooling (TIC)

- Combustion Turbines (CTs) provide:
  - Relatively clean Natural Gas combustion
  - Power at relatively low unit capital cost
  - Relatively fast response to demand spikes
- But output derates 15-25% in hot weather (when power is highest in demand & value)

TIC, via evaporative or chiller-based cooling, can recover some or all of the lost capacity.

*And **TIC** can incorporate **Energy Storage**.*

TIC's Effect on CT Heat Rate

- Combustion Turbine Heat Rate (Fuel Use):
  - Improves as TIC cools inlet air
  - Heat Rate benefits at the CT are offset by electric chiller power requirements
- Thermal Energy Storage:
  - Allows chillers to be driven by renewable or other efficient energy sources, off-peak
  - Improves chiller plant efficiency and on-peak CT Heat Rate

Key Energy Storage Characteristics

- Tech’ly reliable & econ’l in util.-scale app’s
- Initial unit capital cost ($/kW and $/kWh)
- Life expectancy and life cycle costs
- Round-trip efficiency (energy out/energy in)
- Practicality for rapid discharge
- Practicality for extended discharge
- Ease of siting (practically and/or environ’ly)

These vary with individual storage technology

Types of Energy Storage

- Traditional commercial-scale utility storage:
  - Pumped Hydro (PH)
- Developing utility storage technologies:
  - Compressed Air Energy Storage (CAES)
  - Electro-Chemical Batteries
  - Flywheels
  - Superconducting Magnetic ES (SMES)
- Another available storage technology:
  - Thermal Energy Storage (TES)

Thermal Energy Storage (TES)

- Fully commercial, demand-side history
- Very low unit capital costs ($100-500/kW)
- Long life expectancy (30+ years)
- Near 100% round-trip energy efficiency
- Not suited to fully cycling in sec's or min's
- Well-suited for multi-hour discharge periods
- Easy to site (technically & environmentally)
- Modest permitting & construction periods

Types of Cool TES

- Ice TES (latent heat)
  - Water to ice off-peak; then melted on-peak
  - Conventional or Low Temp CHWS possible (34 to 44 ºF typical)
- Chilled Water (CHW) TES (sensible heat)
  - An insulated tank with cooler denser CHWS stratified below warmer less dense CHWR
  - Conventional CHWS temps (39 to 42 ºF typ.)
- Low Temperature Fluid (LTF) TES
  - Similar to CHW TES, but using fluid <39 ºF
  - Lower supply temp (30 to 36 ºF typical)

Inherent Characteristics of TES

	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 Discharge Capability	fair	good	good
Simplicity and Reliability	fair	excell	good
Site Remotely from Chillers	poor	excell	excell
Dual-use as Fire Protection	poor	excell	poor

Case Studies of TES-TIC

Range of TES-TIC Examples

- Applications: SC & CC CTs; new & retrofits
- Locations: worldwide (NA,Asia,Europe,Australia)
- Initial Operation: increasingly, over past 20 years

Detailed Case Study of TES-TIC

- Application: utility Turbine Inlet Cooling (TIC)
- Location: Riyadh, Kingdom of Saudi Arabia
- Initial Operation: 2005

Use of TES for TIC – 1988-1997

Applicat'n		CT No. / Type	Ton-hrs	TES	Boost
CHP	CA	1 x GE LM2500	3,500	ChW	16%
Util	NE	1 x GE 7B	45,000	Ice	27%
Util	NC	8 x GE Fr 5	not avail.	Ice	26%
CHP	CA	1 x GE 7EA	40,000	Ice	24%
CHP	CA	1 x CT	14,800	Ice	23%
Util	Malays	6 x GE 7EA	not avail.	Ice	28%
Util	NC	1 x W 251	not avail.	Ice	42%
Util	NE	2 x CT	165,000	Ice	21%

Use of TES for TIC – 1997-2005

Applicat'n	CT No. / Type	Ton-hrs	TES	Boost
DC IL	3 x Turbomeca	123,000*	LTF	35%
DC FL	1 x GE LM5000	57,000*	ChW	31%
DC Portug	1 x CT	39,800*	ChW	17%
Util Austral	3 x GE Fr 6	36,932	Ice	21%
Util SaudiA	6 x GE 7EA	120,000	Ice	35%
CHP TX	3 x W 501 D5	107,000	ChW	21%
Hosp TX	1 x Solar Merc50	8,000*	ChW	
Univ NJ	1 x GE LM1600	40,000*	LTF	
Util SaudiA	10 x GE 7EA	193,000	ChW	30%

Use of TES for TIC – 2006-2011

Applicat'n		CT No. / Type	Ton-hrs	TES	Boost
Util	SaudiA	40 x GE 7EA	710,000	ChW	31%
Util	CA	2 x GE 7FA	39,000	ChW	
Util	PA	4 x GE 7FA	129,000	ChW	13%
Util	TX	4 x GE 7FA	110,016	ChW	11%
Util	TX	1 x SW 501F	28,989	ChW	15%
Util	VA	2 x GE 7FA	78,710	ChW	14%
IPP	NM	2 x MHI 501FD2	55,500	ChW	10%
Univ	TX	2 x CHP CTs	40,000*	ChW	~20%

Analysis of TES-TIC Data

- 25 examples, over 24 years
- 107 CTs, from 1 to 175 MW, new & retrofit
- **Ice**, **CHW** and **LTF** TES
- 2.3 million T-hrs total; 92,000 T-hrs avg.
- TIC for avg. of 6 hrs/day; range 4-13 hrs/d
- Hot weather power augmentation:
  - range 10 to 42%; most are 20 to 31%.

Evident Trends in TES-TIC

From:	To:
utility; indust. cogen	util; CHP+DC; hosp; univ
primarily in U.S.	U.S. + worldwide(4 cont.)
medium-scale CTs	1 to175 MW CT capacity
medium-scale plants	3 to 3,000 MW plant size
TIC 4 to 6 hrs/day	TIC 5 to 10 hrs/day
most **Ice** harvesters	most **CHW** (or **LTF**) TES
weekly cycle TES	daily cycle TES
single use TES (TIC only)	single and dual-use TES (TIC+other cooling loads)

Example TES-TIC - Riyadh, KSA

Electric utility power generation facility:

10 existing 75 MW Combustion Turb's (CTs)

At design ambient air temp of 50 °C (122 °F),

power output only 75-80% of nominal rating.

Saudi Electricity Co. (national electric utility):

- Needs to meet rapidly increasing demand
- Could add 3 more CTs for 30% more power
- Instead chose Turbine Inlet Cooling (TIC)
- TIC has lower capital $/kW than new CTs.

TES Solution / Results

Add TIC (at 3,100 T per CT x 10 CTs).

Do not install 31,000 T (non-TES) chiller plant;

instead, only 11,000 T, running 17-hrs/night,

plus193,000 T-hr (31,000 T x 6 hr) **CHW** TES.

TES adds 48 MW x 6 hrs net on-peak power;

+ over $10 million in net capital cost savings!!

TIC-TES adds 180 MW (30%) net increase,

and adds power at <1/2 $/kW of new CTs.

Chilled Water (CHW) TES for TIC

- Saudi Electricity Company - Riyadh, Kingdom of Saudi Arabia (2005)
- 193,000 ton-hrs **CHW** TES, with 45.5 / 86.1 ºF CHWS / R temps
- 140 ft diameter x 70 ft high (8 million gallon) CHW TES tank
- Provides Turbine Inlet Cooling for 30% more net power in hot weather

Turbine Inlet Cooling with CHW TES

	Entire Installation (TIC w/ **CHW** TES)	Storage Portion Only (**CHW** TES sub-sys)
Location	Saudi Arabia	Saudi Arabia
Year in operation	2005	2005
Peak power	180 MW	48 MW
Energy storage	288 MWh	288 MWh
Projected life	30+ years	30+ years
Round-trip effic'cy	near 100%	near 100%
Classification	commercial	commercial
Unit capital cost	$250/kW	$83/kW
Dispatch period	6 hours/day	6 hours/day

Pumped Hydro ES vs TES-TIC

	Pumped Hydro Energy Storage	Turbine Inlet Cooling with **CHW** TES
Location	Michigan	Saudi Arabia
Year in operation	circa 1990	2005
Peak power	1,200 MW	48 MW
Energy storage	9,600 MWh	288 MWh
Projected life	30+ years	30+ years
Round-trip effic'cy	~70-80%	near 100%
Classification	commercial	commercial
Unit capital cost	$2,000+/kW	$83/kW
Dispatch period	8 hours/day	6 hours/day

Compressed Air ES vs TES-TIC

	Compressed Air Energy Storage	Turbine Inlet Cooling with **CHW** TES
Location	Iowa	Saudi Arabia
Year in operation	201X (planned)	2005
Peak power	268 MW	48 MW
Energy storage	1,608 MWh	288 MWh
Projected life	20+ years	30+ years
Round-trip effic'cy	~70%	near 100%
Classification	developmental	commercial
Unit capital cost	$900/kW (target)	$83/kW
Dispatch period	6 hours/day	6 hours/day

Advanced Battery ES vs TES-TIC

	"Utility-scale" Na-S Advanced Batteries	Turbine Inlet Cooling with **CHW** TES
Location	West Virginia	Saudi Arabia
Year in operation	2006	2005
Peak power	1.2 MW	48 MW
Energy storage	7.2 MWh	288 MWh
Projected life	15 years	30+ years
Round-trip effic'cy	~70%	near 100%
Classification	"pioneering"	commercial
Unit capital cost	$4,500/kW	$83/kW
Dispatch period	6 hours/day	6 hours/day

Flywheel ES vs TES-TIC

	Flywheel Energy Storage	Turbine Inlet Cooling with **CHW** TES
Location	New York	Saudi Arabia
Year in operation	2011 (1st 20%)	2005
Peak power	20 MW	48 MW
Energy storage	5 MWh	288 MWh
Projected life	20 years	30+ years
Round-trip effic'cy	~80-90%	near 100%
Classification	demonstration	commercial
Unit capital cost	$3,440/kW	$83/kW
Dispatch period	15 minutes	6 hours/day

TES-TIC Potential in the U.S.

Assume:

- ~300 GW of total installed CT capacity
- ~50% is to be retrofit with TES-TIC
- ~20% output enhancement from TES-TIC

Then TES-TIC could provide:

- ~30,000 MW of hot weather peaking power, typically at only $200-400/kW, including
- ~180,000 MWh of Energy Storage per day

Summary

- Energy Storage is useful for most systems.
- It will aid electric systems and renewable energy.
- Many storage technologies, but with different traits:
  - Pumped Hydro – proven, but high cost, inefficient, difficulty and long lead time to site.
  - CAES, Batteries, SMES, Flywheel – promising, but developmental and costly (and some better suited to short-term discharge applications only).
  - **TES** – already in wide demand-side use; low cost and high efficiency; supply-side applications with TIC, in sizes from one to hundreds of MW, for 3 to 10 hours of storage.

Conclusions

- No single Energy Storage technology fits all cases; but TES-TIC is a viable and commercial option.
- TES-TIC represents Energy Storage that is:
  - Performance enhancement during hot weather (*when power demand and value are highest*); 15-30% more output, 3-7% lower heat rate, typ.
  - A way to consume excess off-peak(wind) energy.
  - Peaking power from any new or retrofit CT, simple or combined cycle; *easy to site & permit*.
  - Proven technology; *no development needed*.
  - Economic, at $200-400/kW; *no gov't subsidies, stimulus grants, or tax credits needed*. This is an order-of-mag lower $/kW than other multi-hr ES.

A Final Observation

"Storage will be critical
for large scale implementation
of sustainable energy."

– The November 2007 California ISO report "Integration of Renewable Resources"

For Questions or Follow-up

Contact:

John S. Andrepont

telephone: 1-630-353-9690

e-mail: CoolSolutionsCo@aol.com

or

Trevor Richter

telephone: 1-904-899-9231

e-mail: TRichter@stellar.net