DISTRIBUTED ENERGY PROGRAM REPORT

Database of U.S. Combined Heat & Power (CHP) Installations Incorporating Thermal Energy Storage (TES) and/or Turbine Inlet Cooling (TIC)

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By

Cool Solutions Company

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

ABSTRACT

Many combined heat and power (CHP) systems can and do incorporate thermal energy storage (TES) and/or turbine inlet cooling (TIC) systems to improve the overall system economics.

The primary objective of this project was to develop a database of CHP Installations incorporating TES and/or TIC systems, throughout the U.S. (but emphasizing the power constrained locales of California, Texas, and the Northeast U.S.). The database developed in this project is also to form the basis for performing technical and economic analyses in subsequent projects, developing guidelines for incorporating TES and/or TIC in CHP systems, and for developing estimates for the market potential for such systems.

The database is in Excel format, and contains the following data categories for each installation entry:

- CHP Facility Name and Location
- Year CHP in Service
- Complementary Technologies
- Types of Building Applications Served by the System
- Power Generation from CHP Prime Mover(s) Only
- Total On-site System Capacity
- Thermally-Activated System Outputs (Associated with the CHP System)
- Timing of CHP Project
- Local Electric Utility Rate (approximate)
- Thermal Energy Storage (TES)
- Turbine Inlet Cooling (TIC)
- Reasons Cited for Installing the System(s)
- CHP System Capital Cost
- System Benefits
- Comments
- Primary Information Source
- Applicable Website Address
- CHP Facility Contact Information

U.S. CHP Installations Incorporating TES and/or TIC

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BACKGROUND AND INTRODUCTION

Many combined heat and power (CHP) systems can and do incorporate thermal energy storage (TES) and/or turbine inlet cooling (TIC) systems to improve the overall system economics.

Thermal Energy Storage (TES)

Thermal energy storage (TES) systems store hot or chilled water, or ice, for use during on-peak periods to supplement heating or cooling systems. TES allows for time-based decoupling of all or some of the heating or chiller plant operation. These systems are charged with the appropriate temperature water or ice during off-peak periods when the value of electric power is relatively low. Subsequently, during on-peak periods, when the value of electric power is high, the storage is discharged to meet peak heating or cooling loads. TES systems can be used with or without TIC, depending upon various economic parameters affecting the specific facility and its load characteristics.

The TES systems achieve dual benefits: 1) parasitic loads associated with chiller operation are eliminated or reduced significantly during on-peak periods when the electric power is relatively high, because chillers operate entirely or primarily during off-peak periods when the value of power is lower, and 2) the capacity and capital cost of the chiller plant can be reduced, often more than compensating for the capital cost of the TES installation. Information on the various technologies for TES and their economics is available in conference papers (e.g. Andrepont, J.S., "Thermal Energy Storage: Solutions for Demand Management", Proceedings of Association of Energy Engineers (AEE) Business Energy Solutions Expo, November 2001).

Turbine Inlet Cooling (TIC)

The rated capacities of all combustion turbines are based on the standard ambient air conditions of 59 °F and 14.7 psia at sea level, as selected by the International Standards Organization (ISO). One unattractive characteristic of all combustion turbines is that their power output decreases as the ambient air temperature increases, as shown in Figure 1.

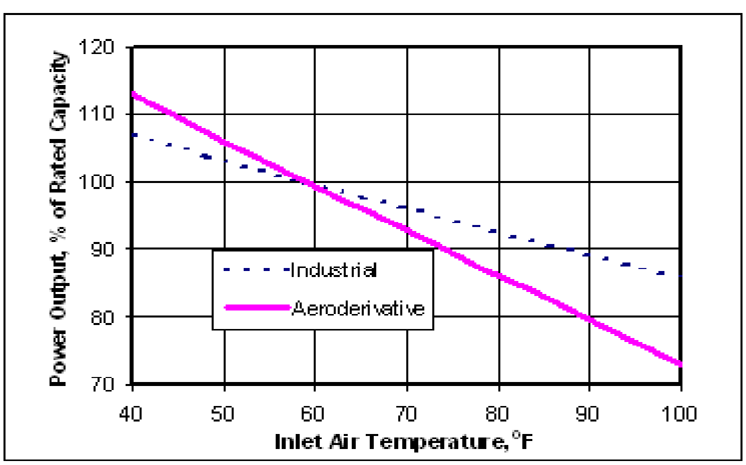

Figure 1 - Effect of Ambient Temperature on the Output of Combustion Turbines

Figure 1 shows the typical effect of inlet air temperature on power output for two types of combustion turbines: Aeroderivative and Industrial/Frame. For example, an increase in inlet air temperature from 59 °F to 100 °F on a hot summer day, for an aeroderivative turbine decreases power output to about 73% of its rated capacity. This could lead to a loss of opportunity for power producers to produce and sell more power, just when the rise in ambient temperature increases power demand (and power value) to serve markets driven by air-conditioning loads.

By cooling the inlet air from 100 °F to 59 °F, we could prevent the loss of 27% of the rated generation capacity. In fact, if we cool the inlet air to about 42 °F, we could enhance the power generation capacity of the turbine to 110% of the rated capacity. Therefore, if we cool the inlet air from 100 °F to 42 °F, we could increase power output of the turbine from 73% to 110% of the rated capacity, i.e. boost the output capacity by about 50% above that at 100 °F.

Accordingly, combustion turbine-based CHP systems could benefit significantly by cooling the ambient air before it enters the turbine's inlet compressor section. Such cooling systems are generally known as TIC systems. Information on the various technologies for TIC and their economics is available at the web site of the Turbine Inlet Cooling Association (TICA) at www.turbineinletcooling.org.

TES and TIC in Combination

Although there is no inherent connection between these two technologies, neither are they necessarily mutually exclusive. This analysis investigates each technology individually, as it applies to CHP, but also identifies to what extent both technologies are used in combination within in CHP installations.

Project Background

In August 13, 2002, The Cool Solutions Company submitted a proposal to the U.S. DOE in response to Solicitation No. 6400002073. The scope of the proposal covered the following five tasks for CHP installations in the U.S. that incorporate TES and/or TIC:

Task 1 – Database Development
Task 2 – Development of Fact Sheets (Project Profiles) of Selected Installations
Task 3 – Development of Case Studies (Technical & Economic Analyses) of Select Installations
Task 4 – Summary Report in "White Paper" format, analyzing and illustrating the technical and economic impact of integrating CHP with TES and TIC
Task 5 – PowerPoint presentation, for use in presenting the highlights of the White Paper.

In March 2003, The Cool Solutions Company received a contract (#4000021850) for performing Task 1 only of the subject proposal. The project has been successfully completed, and is concluded by the issuance of this final report for the project.

Project Objective

The primary objective of this project was to develop a database of CHP Installations incorporating TES and/or TIC systems, throughout the U.S. (but emphasizing the power constrained locales of California, Texas, and the Northeast U.S.).

The database developed in this project is also to form the basis for performing technical and economic analyses in subsequent projects, developing guidelines for incorporating TES and/or TIC in CHP systems, and for developing estimates for the market potential for such systems.

Project Methodology

We used multiple sources of information for developing the database for this project. We attempted to collect information from the following sources:

1. In-house database of the Cool. Solutions Company
2. In-house database of Avalon Consulting, Inc.
3. The International District Energy Association
4. The Turbine Inlet Cooling Association
5. The Installation Database of the DOE Website for CHPB
6. Websites and communications with various TES system suppliers
7. Websites and communications with of various TIC system suppliers
8. Websites of various power generation equipment manufacturers
9. Communications with Resource Dynamics Corp.
10. Communications with Energy & Environmental Associates
11. Communications with Burns & McDonnell
12. Communications with I.C. Thomasson Associates
13. Review of back issues of various relevant journals and magazines
14. Review of back issues of various relevant conference proceedings

Initial efforts focused on identifying the facilities that use CHP systems incorporating TES and/or TIC. Database details were filled in as the information became available. Attempts were also made (via e-mails and/or phone calls) to contact the facility director, manager or engineer to collect database details not available from the in-house or other published sources.

Format and Content of the Database

The database is in the form of an Excel spreadsheet and is included as an appendix to this report. The database format includes the following data categories, and sub-categories, for each installation entry:

<u>CHP Facility Name and Location</u>

- Name of Facility, Owner, or Operator
- City
- State

<u>Year CHP in Service</u>

<u>Complementary Technologies</u>

- Thermal Energy Storage (TES)
- Turbine Inlet Cooling (TIC)

<u>Types of Building Applications Served by the System</u>

- Education
- Medical
- Airport
- Government
- Commercial
- Industrial
- Other
- District

<u>Power Generation from CHP Prime Mover(s) Only</u>

- Technology Type and Details
- MW(e)

<u>Total On-site System Capacity</u>

- Power
- Heating
- Cooling

<u>Thermally-Activated System Outputs (Associated with the CHP System)</u>

- Power
    - Technology
    - Megawatts, MW(e)
    - % of Total
- Heating
    - Technology
    - Millions of Btu per hour, MMB/h
    - % of Total
- Cooling
    - Technology
    - Tons
    - % of Total
- Dehumidification
    - Technology
    - Cubic Feet per Minute, cfm

Timing of CHP Project

- New Construction
- Retrofit Expansion
- Pure Retrofit

Local Electric Utility Rate (approximate)

- On-Peak Duration, hrs/day
- On-Peak Energy Charge, $/kWh
- Off-Peak Energy Charge, $/kWh
- Demand Charge, $/kW-mo.

Thermal Energy Storage (TES)

- Technology Type and Details
- Secondary Fluid
- Supply / Return Temperatures
- TES Design Shift
- TES Capacity, ton-hours
- Demand-Side Management (DSM) Impact, MW(e)

Turbine Inlet Cooling (TIC)

- Technology
- Cooling, tons
- Enhancement, MW(e)
- Enhancement, %

Reasons Cited for Installing the System(s)

CHP System Capital Cost

System Benefits

- Economic Benefits
- Environmental Benefits

Comments

Primary Information Source

Applicable Website Address

CHP Facility Contact Information

- Name
- Title
- Affiliation
- Address
- City, State and Zip Code
- Telephone
- E-mail

RESULTS

1. CHP Facility Name and Location

56 CHP installations have been identified and entered into the database, each incorporating either TES or TIC, or both. 53 of these installations are in the U.S. Although the scope of the project was focused on U.S. installations, the process of identifying U.S. installations also served to identify non-U.S. installations. Three of these foreign installations, from three different continents, have been included in the database simply to provide additional detail and context.

- Name of Facility, Owner, or Operator – All 56 database entries include the facility, owner, or operator name.

- City – 55 of the 56 entries include the city in which the CHP system is located.

- State – All 53 of the U.S. installations are identified by state. The distribution by state is as follows:

	CHP Installations with TES and/or TIC	
State	Number	Percentage of Total
California	19	35.8 %
New York	5	9.4 %
Texas	5	9.4 %
Florida	3	5.7 %
New Jersey	3	5.7 %
Connecticut	2	3.8 %
Michigan	2	3.8 %
Oklahoma	2	3.8 %
Colorado	1	1.9 %
Hawaii	1	1.9 %
Illinois	1	1.9 %
Indiana	1	1.9 %
Iowa	1	1.9 %
Maryland	1	1.9 %
Minnesota	1	1.9 %
Missouri	1	1.9 %
Nevada	1	1.9 %
North Carolina	1	1.9 %
Pennsylvania	1	1.9 %
Washington	1	1.9 %
Total U.S.	53	100 %

In addition, there is one entry from each of the following non-U.S. locations:

- Rio de Janeiro, RJ, Brazil
- Altamira, Tamaulipas, Mexico
- Lisbon, Portugal

No concerted effort was made to identify non-U.S. installations, as the scope of this study was focused on U.S. locations. However, these three non-U.S. systems and their pertinent data were identified while accumulating data on the U.S. installations. Although this non-U.S. data is too limited to draw definitive conclusions, the data was included in this summary report as it had become available. It does illustrate installations on three different continents that are not unlike those applications found in the U.S. portion of the database. No doubt there are many more non-U.S. installations, the data from which could be the subject of a subsequent study, if of interest.

It is estimated that the 53 identified U.S. installations represent 75% to 90% of all U.S. CHP systems incorporating TES and/or TIC. This judgment is based on the fact that the research involved communications with, or the review of data available from, all leading suppliers of TES and TIC systems.

2. Year CHP in Service

45 of 56 entries include the year of initial operation of the CHP system. The range covers more than 100 years, beginning with the University of Michigan in 1897 and ending with Dallas/Fort Worth (D/FW) International Airport with a system expected to begin service in 2007.

Year that CHP	CHP Installations with TES and/or TIC	
Was in Service	Number	Percentage of Total
1897-1979	2	4.4 %
1980-1984	3	6.7 %
1985-1989	12	26.7 %
1990-1994	10	22.2 %
1995-1999	6	13.3 %
2000-2003	10	22.2 %
Planned	2	4.4 %
Total	45	100 %

3. Complementary Technologies

All 56 CHP systems have been identified with the use of either TES or TIC technology, or both.

- Thermal Energy Storage (TES) – 33 of the 56 subject CHP systems (58.9 %) and 30 of the 53 U.S. CHP systems (56.6%) utilize TES.

- Turbine Inlet Cooling (TIC) – 31 of the 56 subject CHP systems (55.4 %) and 29 of the 53 U.S. CHP systems (54.7%) utilize TIC.

It is also noteworthy that 8 of the 56 subject CHP systems (14.3 %) and 6 of the 53 U.S. CHP systems (11.3%) utilize both TES and TIC.
Furthermore, it is observed that often TES and TIC technologies are retrofitted to existing CHP installations. And although, in item 2 above, it appears that there were relatively few CHP installations put into service with TES and/or TIC in the period from 1995 through 1999, in fact many of the earlier CHP installations were retrofit with TES and/or TIC in that period. During 1995-1999, at least 3 TES systems and 7 TIC systems were retrofitted to existing CHP installations.

4. Types of Building Applications Served by the System

All 56 CHP systems have been identified with the type (or multiple types) of buildings or facilities that are served by the electrical output and/or the thermal output of the CHP system.

- Education – 23 of the 56 subject CHP systems (41.1 %) and 23 of the 53 U.S. CHP systems (43.4%) serve educational buildings or facilities. Of the 23 educational facilities, 20 (87.0%) are universities or colleges, 2 (8.7 %) are high schools or school districts, and 1 (4.3 %) is a vocational school.

- Industrial – 21 of the 56 subject CHP systems (37.5 %) and 20 of the 53 U.S. CHP systems (37.7%) serve industrial facilities.

- Commercial – 12 of the 56 subject CHP systems (21.4 %) and 10 of the 53 U.S. CHP systems (18.9%) serve commercial buildings or facilities.

- Government – 11 of the 56 subject CHP systems (19.6 %) and 10 of the 53 U.S. CHP systems (18.9%) serve government buildings or facilities (non-educational, non-medical, and non-airport).

- Medical – 3 of the 56 subject CHP systems (5.4 %) and 3 of the 53 U.S. CHP systems (5.7%) serve medical buildings or facilities. However, it should be also noted that a number of the university applications include medical buildings or facilities, but have not been included in this category.

- Airport – 2 of the 56 subject CHP systems (3.6 %) and 2 of the 53 U.S. CHP systems (3.8%) serve airport buildings or facilities.

- Other – 1 of the 56 subject CHP systems (1.8 %) and 1 of the 53 U.S. CHP systems (1.9%) serve other buildings or facilities.

- District – 31 of the 56 subject CHP systems (55.4 %) and 30 of the 53 U.S. CHP systems (56.6%) serve buildings or facilities that are part of a District Energy (District Heating and/or Cooling) system. Such systems can be district energy utility systems in which one business entity operates the District Energy system and sells thermal energy to other entities (the users), or they can be single owner-user systems such as university campus district energy systems. In many cases, these district systems serve not only many individual customers (often numbering in the dozens or even hundreds), but many different types of buildings and facilities.

- Observations - It is perhaps not surprising to find a sizeable percentage (38%) in the Industrial sector. A large number of those industrial applications involve petrochemical industries and well-injection, while others comprise a variety of industries. However, it may be surprising to find even large percentages represented by the education (43%) and District (57%) sectors. First, it is noted that the District sector includes both district utility systems (businesses selling thermal energy to multiple customers) as well as district campus systems (such as universities). Recent studies by the International District Energy Association (IDEA) have found numerous CHP systems associated with university campuses. Also, it is noted that District and campus applications tend to often have large cooling networks, plus the space available for TES. Finally, it is noted that most of the government and commercial applications are in fact thermal customers of District Utility systems employing CHP.

5. Power Generation from CHP Prime Mover(s) Only

- Technology Type and Details – Of the 53 CHP systems with data reported in this category, 41 systems (77.4%) are reported to utilize one or more combustion turbines (CTs). 8 of the systems (15.1%) utilize one or more reciprocating engines, of which 4 systems (7.5%) use gas engines and 4 systems (7.5%) use diesel engines. 7 of the systems (13.2%) use no prime mover for CHP, but instead produce heat first (as steam) and then utilize one or more steam turbine generators to produce power, before subsequently using the exhaust steam (or condensate) to serve thermal loads. 3 systems (5.7%) use a combination of both CT and reciprocating engine generators. It should be recognized that as this study involved CHP installations using TIC, a relatively high percentage of the installations identified utilize CTs rather than alternative prime movers, compared to a more general sampling of CHP installations. Also, it may be surprising to find 4 systems with diesel engines; however, 3 of those 4 also have CTs which are used as prime movers.

- MW(e) – Based on the 55 CHP systems with data reported in this category, the sum of prime mover electric power output is 2,026 MW, with a range from 0 MW (i.e. no prime mover) to 316.8 MW per system and an average of 36.8 MW per system. Individual CT unit outputs range from 30 kW to 120 MW per unit, while individual reciprocating engine outputs range from 200 kW to 6.0 MW per unit.

6. Total On-site System Capacity

- Power – Based on the 47 CHP systems with data reported in this category, the sum of all on-site electric power generation is 1,959 MW, with a range from 60 kW to 412.0 MW per system, with an average and a median of 41.7 MW and 22.5 MW per system, respectively.

- Heating – Based on the 30 CHP systems with data reported in this category, the sum of all on-site heating capacity is 13,182 million Btu/hour, with a range from 0 to 1,900 million Btu/hour per system, with an average and a median of 439 million Btu/hour and 326 million Btu/hour per system, respectively.

- Cooling – Based on the 46 CHP systems with data reported in this category, the sum of all on-site cooling capacity is 421,054 tons, with a range from 85 tons to 41,000 tons per system, with an average and a median of 9,153 tons and 4,000 tons per system, respectively.

7. Thermally-Activated System Outputs (Associated with the CHP System)

- Power
  - Technology – Based on the 49 CHP systems with data reported in this category, 29 systems (59.2%) employ one or more steam turbine generators and 20 systems (40.8%) employ no technology (i.e. the only on-site power generation is from their prime mover(s)).
  - Megawatts, MW(e) – Based on the 45 CHP systems with data reported in this category, the sum of all thermally-activated power generation is 523.7 MW, with a range from 0 to 86.0 MW per system, with an average and a median of 11.6 MW and 4.4 MW per system respectively.
  - % of Total – Based on the 47 CHP systems with data reported in this category, thermally activated power, as a percentage of total on-site power generation, ranges from 0% to 100%, with a weighted average of approximately 25%.
- Heating
  - Technology – Based on the 39 CHP systems with data reported in this category, 33 systems (84.6%) generate steam, 5 systems (12.8%) generate hot water, and 1 (2.6%) does not generate heat (but instead directly employs heat recovered from a microturbine exhaust in driving an absorption chiller).
  - Millions of Btu per hour, MMB/h – Based on the 17 CHP systems with data reported in this category, the sum of all recovered heat is 3,834 million Btu/hour, with a range from 0 to 1,250 million Btu/hour per system, with an average and a median of 226 million Btu/hour and 90.0 million Btu/hour per system, respectively.
  - % of Total – Based on the 17 CHP systems with data reported in this category, recovered heating capacity, as a percentage of total on-site heating capacity, ranges from 0% to 100%, with a weighted average of approximately 29%.
- Cooling
  - Technology – Based on the 47 CHP systems with data reported in this category, 25 systems (53.2%) utilize absorption chilling, 7 systems (14.9%) utilize steam turbine-

driven chilling, 1 system (2.1%) utilizes diesel engine-driven chilling, and 18 systems (38.3%) have no thermally-activated cooling. 3 systems (6.4%) utilize both absorption and steam turbine-driven chilling, while 1 system (2.1%) utilizes both steam turbine-driven and diesel engine-driven chilling.

- Tons – Based on the 43 CHP systems with data reported in this category, the sum of all thermally-activated cooling is 137,348 tons, with a range from 0 to 22,500 tons per system, with an average and a median of 3,194 tons and 800 tons per system, respectively.

- % of Total – Based on the 43 CHP systems with data reported in this category, thermally-activated cooling capacity, as a percentage of total on-site cooling capacity, ranges from 0% to 100%, with a weighted average of approximately 32%.

- Dehumidification

  - Technology – There are 3 CHP systems with data reported that indicate the use of dehumidification technology. All 3 systems (100%) utilize desiccant technology.

  - Cubic Feet per Minute, cfm – There is only a single CHP system with data reported in this category. It is 3,000 cfm for its desiccant system.

8. Timing of CHP Project

- New Construction – Based on the 29 CHP systems with data reported regarding the timing of the CHP project, 10 systems (34.5%) were executed at a time associated with new construction.

- Retrofit Expansion – Based on the 29 CHP systems with data reported regarding the timing of the CHP project, 11 systems (37.9%) were executed at a time associated with retrofit expansion.

- Pure Retrofit – Based on the 29 CHP systems with data reported regarding the timing of the CHP project, 8 systems (27.6%) were executed as pure retrofit projects.

9. Local Electric Utility Rate (approximate)

- On-Peak Duration, hrs/day – Based on the 41 CHP systems with data reported in this category, the range of on-peak periods varies from 4 to 24 hours per day, with an average and a median of 8.8 hours per day and 8.0 hours per day, respectively.

- On-Peak Energy Charge, $/kWh – Based on the 40 CHP systems with data reported in this category, the range of on-peak energy charge varies from $0.016 to $0.195/kWh, with an average and a median of $0.101/kWh and $0.069/kWh, respectively.

- Off-Peak Energy Charge, $/kWh – Based on the 40 CHP systems with data reported in this category, the range of off-peak energy charge varies from $0.010 to $0.095/kWh, with an average and a median of $0.053/kWh and $0.048/kWh, respectively.

- Demand Charge, $/kW-mo. – Based on the 42 CHP systems with data reported in this category, the range of demand charge varies from $0.00 to $24.55/kW per month, with an average and a median of $13.26/kW per month and $10.17/kW per month, respectively

10. Thermal Energy Storage (TES)

- Technology Type and Details – Based on the 33 CHP-TES systems with data reported in this category, 26 systems (78.8%) utilize sensible heat TES and 7 systems (21.2%) utilize latent heat TES. Of the 26 sensible heat TES systems, 22 systems (84.6%) utilize stratified water TES and 4 systems (15.4%) utilize stratified low temperature fluid TES, while 2 of the 22 water TES systems (9.1%) are pre-designed for future expansion as low temperature fluid TES systems. Of the 7 latent heat TES systems, 6 (85.7%) utilize static ice storage ("ice-on-pipe" or "ice-on-coil" systems) and 1 (14.3%) utilizes dynamic ice storage (an "ice harvester" system). Based on the 24 stratified, sensible heat TES systems for which tank data is reported, 19 (79.2%) use above-ground storage, 4 (16.7%) use below-ground storage, and 1 (4.2%) uses partially buried storage. Based on the 19 above-ground TES tanks for which tank data is reported, 18 (94.7%) use steel tanks and 1 (5.3%) uses a concrete tank.

- Secondary Fluid – Based on the 26 CHP-TES systems with data reported in this category, 20 systems (76.9%) utilize water, 3 systems (11.5%) utilize ethylene-glycol/water, and 3 systems (11.5%) utilize an aqueous low temperature fluid (SoCool®).

- Supply / Return Temperatures – Based on the 22 CHP-TES systems for which data is reported in this category, supply temperatures range from 30 to 45 °F, return temperatures range from 53 to 64 °F, and the supply-to-return temperature differentials ("Delta Ts") range from 10 to 32 °F.

- TES Design Shift – Based on the 16 CHP-TES systems for which data is reported in this category, 12 systems (75.0%) operate as "partial shift" systems and 4 systems (25.0%) operate as "full shift" systems.

- TES Capacity, ton-hours – Based on the 29 CHP-TES systems for which data is reported in this category, the sum of all TES capacity is 1,033,767 ton-hours, with a range from 450 ton-hours to 123,000 ton-hours per system and an average of 35,647 ton-hours per system.

- Demand-Side Management (DSM) Impact, MW(e) – Based on the 14 CHP-TES systems for which data is reported in this category, the sum of all DSM impacts is 64.9 MW, with a range from 0.1 MW to 20 MW per system and an average of 4.6 MW per system.

11. Turbine Inlet Cooling (TIC)

- Technology – Based on the 30 CHP-TIC systems with data reported in this category, 21 systems (70.0%) use water coils at the turbine inlet, 4 systems (13.3%) use direct expansion ammonia evaporator coils at the turbine inlet, 2 systems (6.7%) use evaporative media, 1 system (3.3%) uses evaporative inlet air fogging, 1 system (3.3%) uses fog overspray ("wet compression"), 1 system (3.3%) uses desiccant (in conjunction with inlet water coils), and 1 system (3.3%) uses conditioned air from within an air-conditioned building. Of the 21 CHP-TES systems using turbine inlet water coils, 5 systems (23.8%) are integrated with stratified chilled water TES and 1 (4.8%) is integrated with ice TES. Of the 4 systems using turbine inlet ammonia evaporator coils, 1 system (25.0%) is integrated with stratified low temperature fluid TES.

- Cooling, tons – Based on the 20 CHP-TIC systems for which data is reported in this category, the sum of all cooling capacity applied to TIC is 47,048 tons, with a range from 30 tons to 18,700 tons per system and an average of 2,352 tons per system.

- Enhancement, MW(e) – Based on the 20 CHP-TIC systems for which data is reported in this category, the sum of all hot weather turbine power enhancements is 200.2 MW, with a range from 0.1 MW to 49.0 MW per system and an average of 10.0 MW per system.

- Enhancement, % - Based on the 20 CHP-TIC systems for which data is reported in this category, the percentage improvement in hot weather turbine power output is in a range from 4% to 48%, with the enhancement for the 18 reporting systems using inlet coils ranging from 16% to 48%, the enhancement for the 1 reporting system using fog overspray (wet compression) being 17%, and the enhancement for the 1 reporting system using evaporative media being 4%.

12. Reasons Cited for Installing the System(s)

34 of 56 CHP systems reported one or more reasons for installing the CHP systems.

Reason(s) Cited for The CHP Installation	CHP Installations with TES and/or TIC Number	Percentage of Total (34)
Economics	31	91.2 %
Energy or Fuel Efficiency	8	23.5 %
Reliability	5	14.7 %
Flexibility	2	5.9 %
Environmental Benefits	1	2.9 %
Demand Reduction	1	2.9 %
R&D / Demonstration	1	2.9 %

13. CHP System Capital Cost

Limited capital cost data is reported for 9 of the 56 subject CHP systems and 7 of the 53 U.S. CHP systems. The smallest reported cost is $575,000 (projected) for a 120 kW microturbine based system (4 x 30 kW), including hot water heat recovery for 450 tons of cooling, plus heating, domestic hot water, and clothes drying, to serve a U.S. Air Force barracks. The highest reported cost is $175 million (special project bonds) for a 110 MW CT combined cycle (2 x 42.5 MW CTs + 1 x 25 MW steam turbine), including a central plant with 450 million Btu/hour of heating capacity and 28,000 tons of cooling capacity, to serve a major international airport. As the characteristics of the various CHP systems in the database vary significantly in terms of scopes of work associated with reported capital costs, average or median installed cost per MW are not being reported because such numbers would not be very meaningful or useful.

14. System Benefits

- Economic Benefits – Limited data is reported for 8 of the 56 subject CHP systems (14.3%) and for 7 of the 53 U.S. CHP systems (13.2%). Some noteworthy entries include the following:
    - "Added electric generation with zero additional fuel use"
    - "Saves $3 to 5 million per year"
    - "TIC/TES added power at only $367/kW"
    - "TIC: 8% more power generation per year, 3-yr payback"

- Environmental Benefits – Limited data is reported for 13 of the 56 subject CHP systems (23.2%) and for 11 of the 53 U.S. CHP systems (20.8%). Some noteworthy entries include the following:
    - "Reduced fuel use by 22%, CO_2 by 41%"
    - "Reduces coal use by 80%, soot by 50%"
    - "Added electric generation with zero additional emissions"
    - "Cut CO_2 35.6% (48,572 tons/yr)"
    - "Cut NO_X, SO_2, CO, and particulate matter 93%, CO_2 54%"
    - "Trigenerator cut fuel and emissions 47%"
    - "Added 100 MW, while slashing emissions"
    - "TIC/TES improved heat rate by 4%"
    - "Saved 45% energy, 54% CO_2 (20,000 tons/yr)"

  A more detailed analysis of environmental benefits could be undertaken in the proposed subsequent development of Fact Sheets and Case Studies of specific installations. Although the use of renewable fuels in these CHP systems was not specifically explored, it is noted that the District Energy St. Paul system in Minnesota relies primarily on renewable wood waste fuels.

15. Comments

Brief comments are reported for all 56 subject CHP systems (100%) and for all 53 U.S. CHP systems (100%). Some noteworthy comments include the following:

- "IDEA's 1997 System of the Year Award"

- "TES was key in balancing loads for economic use of CHP (trigeneration)"

- "Burns 280,000 tons/yr of renewable fuel (wood waste), reduces Greenhouse Gas Emissions 280,000 tons/yr"

- "Steam turbine generators replaced PRVs (Pressure Reducing Valves); therefore, get electric generation without any additional fuel use"

- "Reported reliability: 98% electrical and 100% thermal"

- "70% CHP fuel conversion efficiency (more than double U.S. average), EPA awardee"

16. Primary Information Source

This data is reported for 55 of the 56 subject CHP systems (98.2%) and for 52 of the 53 U.S. CHP systems (98.1%).

17. Applicable Website Address

This data is reported for 14 of the 56 subject CHP systems (25.0%) and for 13 of the 53 U.S. CHP systems (24.5%).

18. CHP Facility Contact Information

- Name – This data is reported for 39 of the 56 subject CHP systems (69.6%) and for 38 of the 53 U.S. CHP systems (71.7%).

- Title – This data is reported for 37 of the 56 subject CHP systems (66.1%) and for 36 of the 53 U.S. CHP systems (67.9%).

- Affiliation – This data is reported for 41 of the 56 subject CHP systems (73.2%) and for 39 of the 53 U.S. CHP systems (73.6%).

- Address – This data is reported for 37 of the 56 subject CHP systems (66.1%) and for 35 of the 53 U.S. CHP systems (66.0%).

- City, State and Zip Code – This data is reported for 40 of the 56 subject CHP systems (71.4%) and for 38 of the 53 U.S. CHP systems (71.7%).

- Telephone – This data is reported for 38 of the 56 subject CHP systems (67.9%) and for 36 of the 53 U.S. CHP systems (67.9%).

- E-mail – This data is reported for 29 of the 56 subject CHP systems (51.8%) and for 28 of the 53 U.S. CHP systems (52.8%).

CONCLUSIONS AND RECOMMENDATIONS

It is apparent from the database that the use of CHP with TES and/or TIC has applicability in an extremely broad range of conditions. The identified and documented examples span all climatic and geographic regions, as well as wide ranges of end-use markets, system ages, and system capacities. CHP systems incorporating TES and/or TIC have been identified in hot-dry climates (such as in Southern California), in hot-wet climates (such as in Central Florida), in moderate seasonally-varying climates (such as in the New York City area), and in severe seasonally-varying climates (such as in the Upper Midwest). In particular, numerous database entries identify and illustrate installations in the power sensitive regions of California, Texas, and the Northeast U.S.

California installations represent 36% of the total number. Texas installations represent 9% of the total (or 13% when combined with those in Oklahoma). The Northeast (New England, New York, New Jersey, and Pennsylvania) installations represent 21% of the total. However, other examples range throughout all the other regions of the country, and across several continents. In fact, the several foreign installations (from three different continents) represent data not unlike those of the U.S. installations.

It should be interesting to perform technical and economic analyses as to why California and the Northeast have more of the subject installations than have other locations. It may be that CHP installations are more frequently found in those regions, and that CHP with TES and/or TIC are correspondingly present in those areas as well. However, such analyses are beyond the scope of the present project and should be conducted in subsequent studies that could utilize the data from this project's database.

The end-use buildings and facilities served by the CHP systems with TES and/or TIC span virtually all types, including educational, industrial, commercial, other governmental, medical, and airport buildings and facilities. A large number of systems (55%) serve District Energy systems in which multiple buildings (often including the various other types of end-use) are provided with heating and/or cooling from the central energy system. Such District Energy systems include many that operate as district utilities (in which the district owner-operator sells thermal energy to independent users), as well as many that are single owner-operator-end-user systems (such as university campus systems). It can be inferred from the data that such district systems (whether utility systems or single owner campus systems) are particularly well suited to the use of CHP and to the use of CHP with TES and/or TIC.

CHP-TES-TIC system ages vary widely, though the vast majority has occurred since 1985. Often, TES and or TIC have been retrofitted to existing CHP systems.

System capacities span a range of several orders of magnitude, from 60 kW to 412 MW. A wide range of technology types and system configurations are employed, for the prime movers as well as for the heating, cooling, TES, and TIC systems.

By far the most widely cited reason for the installation is economics, though the dramatic energy efficiency and environmental (emission reduction) benefits are also often recognized. There are also a wide variation of other, project-specific reasons cited for some installations, including reliability and flexibility.

The Market Potential for CHP and DG when Integrated with TES and/or TIC

It is clear that the incorporation of TES and/or TIC in CHP systems often provides benefits for those CHP installations. Firstly, the use of TES and/or TIC can often enhance the overall performance and economics of already viable (or even existing) CHP installations. And secondly, the use of TES and/or TIC can sometimes produce the enhancement to system performance and economics which may be necessary to render a specific CHP project viable. In the latter cases, the benefits accruing from TES and TIC are not merely the incremental (but significant) benefits from the TES and TIC enhancements themselves, but the full benefits of the entire CHP installation (assuming that it would not have been viable without the incorporation of TES and/or TIC).

It is apparent that the use of TES in CHP systems is not limited solely to locales with high demand costs and high on-peak to off-peak energy cost differentials. It is inferred (and specifically illustrated in some examples) that the use of TES provides an important means of time-leveling the thermal load demand, thus making it more practical and more economical to employ a base-loaded CHP system. Furthermore, the use of TES (particularly sensible heat TES systems applied in medium to large systems) often serves to reduce overall cooling system capital costs, as the capital cost of TES can be more than offset by the capital cost reduction due to a reduced capacity requirement for conventional (non-TES) chiller plant equipment.

It is also apparent that TIC systems can have a dramatic impact in terms of improving hot weather power output from CHP systems using CTs. It is almost always the case that power is in greatest demand and has its highest monetary value during periods of extreme hot weather. It is precisely at such times that CT power output is most severely de-rated, and at such times that TIC provides the greatest improvement.

Capital cost reduction is a fairly common benefit, especially in medium to large applications. The use of TES often reduces the total installed capital cost of cooling infrastructure, sometimes dramatically so when using sensible heat TES in large applications. And the use of TIC routinely achieves a lower unit capital cost per MW or power enhancement, versus the unit capital cost per MW for non-TIC prime mover installations.

TES and TIC are sometimes used together in a complementary manner. TES and TIC technologies have been employed in some cases during initial CHP installation, and in other cases as retrofit improvements to existing CHP systems.

It is concluded that a wider application of TES and TIC to CHP system design will often result in improved performance and improved economics. Additionally, appropriate use of those technologies should result in faster and greater market penetration of CHP in general, due to the enhanced performance and economics of many specific projects.

A further detailed understanding of how, and to what extent, the use of TES and TIC have enhanced CHP installations, and an effective means to disseminate that knowledge, would further the program goals of the U.S. DOE and will provide added momentum for the CHP marketplace.

RECOMMENDATIONS FOR PROPOSED FUTURE WORK

As discussed in the Background and Introduction section of this report, the August 2002 proposal of The Cool Solutions Company to the U.S. Department of Energy identified five suggested tasks, of which DOE initiated work only on Task 1 in March 2003. Now that Task 1 of the proposed work has been successfully completed, it is recommended that DOE consider and initiate work on the following logical subsequent tasks:

- Task 2 – Fact Sheets of select U.S. CHP installations incorporating TES and/or TIC,
- Task 3 – Case Studies of select U.S. CHP installations incorporating TES and/or TIC,
- Task 4 – Summary Report in "White Paper" format, analyzing and illustrating the technical and economic impact of integrating CHP with TES and TIC, based on the subjects of the select Fact Sheets and Case Studies, and
- Task 5 – PowerPoint presentation, for use in presenting the highlights of the White Paper.

Tasks 2 and 3 – The Fact Sheets and (in even greater detail) the Case Studies will provide critical data for better understanding and developing CHP markets (criteria 1c, from the original DOE RFP). The subject installations used in the Fact Sheets and Case Studies will be specifically selected to maintain the focus on the power sensitive regions of California, Texas and the Northeast, and to illustrate end-use markets with significant CHP/DG potential, including high tech, telecommunications, hotel, hospital and education markets. The substantive content and the presentation of the Fact Sheets and Case Studies will be comparable to the existing examples on the U.S. DOE website for Cooling, Heating, and Power for Buildings, www.chpb.net.

Task 4 – The White Paper will provide an important aspect of DG analysis (DOE criteria 2). The integration of TES and/or TIC into CHP/DG applications has been known to provide the critical technical aspect for achieving financial viability of certain CHP/DG projects. The White Paper will identify, explore and quantify the technical and economic aspects of the CHP/DG installations, and thus will serve to define and illustrate analysis methodologies appropriate to further application in expanding the market penetration of CHP/DG technologies.

Task 5 – The PowerPoint Presentation will serve as an important awareness tool (DOE criteria 1a). It can be used, within any of various current and future education and outreach campaigns, to graphically illustrate the broad scope (and even broader potential) of CHP/DG, across all climatic and geographic regions, as well as across a wide range of important end-use markets.

The Project in Total – The cumulative effect of the products of all five tasks (one now complete and four proposed for execution) will be to significantly assist in the advancement of the important criteria areas of raising CHP awareness (DOE criteria 1a), developing CHP markets (DOE criteria 1c), and DG analysis (DOE criteria 2).

An appropriate selection of installations to be further studied through the development of Fact Sheets and Case Studies should entail a mix of application types. Ideally, it should involve applications across a wide geographic and climatic range, covering a range of system capacities and end-use types. But certainly it should involve a focus on the most prevalent embodiments, namely, relatively large District (including campus) systems employing CT prime movers with TIC and cooling systems employing (primarily) chilled water TES systems.

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APPENDIX

Appended to this summary report is a copy of the complete Database of U.S. CHP Installations Incorporating TES and/or TIC, updated September 4, 2003.

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