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COMMERCIAL INTEGRATED ENERGY SYSTEMS PROVIDE DATA THAT ADVANCE COMBINED COOLING, HEATING, AND POWER

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ABSTRACT

The Department of Energy (DOE), though Oak Ridge National Laboratory (ORNL), has worked in partnership with industry to develop highly-efficient Integrated Energy Systems (IES) that provide combined cooling, heating, and power (CHP). Equipment configurations and performance have been optimized and system construction has been simplified, resulting in lower design and installation costs. Consequently, government-industry partnerships are achieving the goal of promoting replication of these advanced systems. This paper describes and presents data collected during the operation of on-site power generation systems developed and implemented by DOE/ORNL-industry teams: (1) Burns & McDonnell and (2) Honeywell Labs.

The Burns & McDonnell IES is operated by Austin Energy, the municipal utility in Austin, Texas. The gas turbine produces 4.5-MW of electricity, and its exhaust drives a 2,500-ton absorption chiller. The featured project implements a modular system design that is being used to construct a medical district utility at Dell Children's Medical Center of Central Texas – another government-industry project carried out in partnership with Austin Energy.

The Honeywell IES at Ft. Bragg, North Carolina, is anchored by 5.7-MW natural-gas turbine that uses turbine exhaust to drive a 1,000-ton absorption chiller and/or an 80,000-lb/h heat recovery steam generator. An optimization software program provides system operators with hour-by-hour information on system costs associated with various operating scenarios. The project developed reference designs for 1.2-5.7 MW turbine-based systems to better communicate options for system design and facilitate feasibility studies.

These systems demonstrate the thermal and economic value of "waste heat" by providing space heating and/or cooling with no additional fuel use. Field data confirms that the fuel use efficiency of these combined cooling, heating and power systems approaches 80% based on the higher heating value (HHV) of natural gas.

NOMENCLATURE

ABS	= absorption chiller
CHP	= cooling, heating, and power
EIS	= Energy Information System
HHV	= higher heating value
HRSG	= heat recovery steam generator
IES	= integrated energy systems
LHV	= lower heating value
RT	= refrigeration ton

INTRODUCTION

Integrated energy systems (IES) combine distributed generation with thermally-activated technologies for heating and/or cooling. These combined cooling, heating and power (CHP) systems, achieve high energy efficiencies using prime mover exhaust, or waste heat, to fire absorption chiller/heater equipment. A 2001 National Energy Policy Development Group report identified the concept of CHP, or IES, as a strategy to address increased energy demands and peak power issues [1].

Advantages of the IES concept over a traditional, central power plant-based approach include:

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- efficient recycling of waste heat from on-site power generation to produce chilled water, and/or steam for hot water, heating, and/or cooling,
- potential thermal efficiencies of 70-80% - compared to 30-40% for traditional systems,
- reduction of need for new electric transmission and electric distribution infrastructures to meet increasing power demands,
- compliance with reliability needs – from peak demand to power quality,
- reduction of total fuel consumption,
- low emissions in compliance with the strictest environmental regulations.

The most promising non-industrial markets for IES appear to be commercial or institutional buildings, government facilities, and district energy systems that distribute thermal energy to buildings in a college campus, hospital complex, or industrial park. Furthermore, the development of "packaged" or "modularized" IES for use in commercial and institutional settings is an effective method for penetrating these markets.

This paper focuses on the successful implementation of IES technology in two DOE/ORNL-industry projects and the development of IES reference designs that cover a wide range of desired output parameters.

4.5-MW TURBINE-BASED INTEGRATED ENERGY SYSTEM AT AUSTIN, TEXAS

The first full-scale IES plant that uses an absorption chiller (ABS) fired only with turbine exhaust was built in Austin, Texas. The facility includes a natural gas-fired turbine with electric power output of 4.5 MW and an ABS with a cooling capacity of 2,500 RT. The system is operated by Austin Energy and located in Domain Industrial Park, providing both electric power and chilled water to the park facilities. A view of the turbine and a diagram of the plant are shown in Figures 1 and 2.

Figure 1. Turbine at the Domain Industrial Park IES plant in Austin, Texas

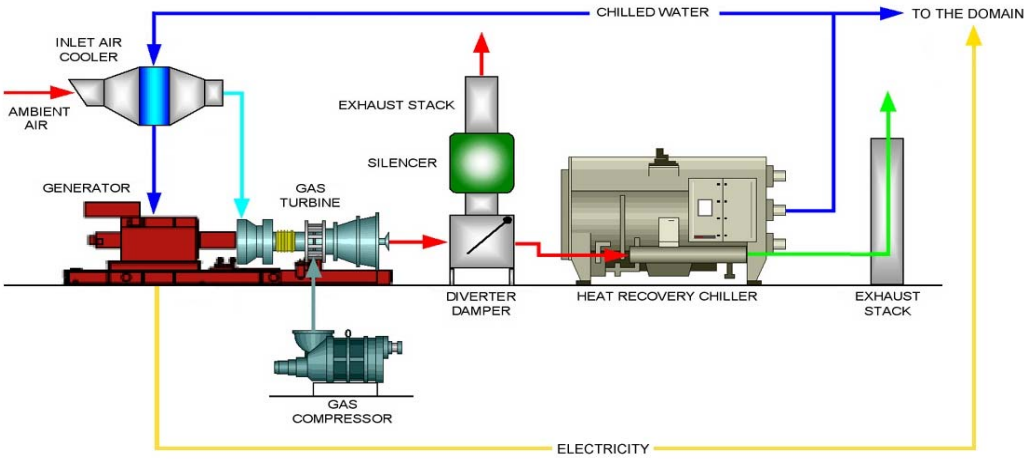

Figure 2. Diagram of the IES Plant at Austin, Texas

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A detailed description and performance analysis of the Austin IES plant has been given in previous publications [2-6]. The system operates in parallel with existing electric centrifugal chillers and is configured to supply power to the local electric grid. Due to Austin Energy protocols, the IES plant mostly operates in peak-load mode. Figure 3 depicts IES performance during peak load hours for five consecutive days in August 2005 since the IES operated for a portion of the day during this period. There are alternative methods to define IES efficiencies [7]: with or without auxiliary power consumption (net or gross efficiency), and with the use of either lower heating value (LHV) or higher heating value (HHV) of fuel. Each alternative has certain advantages and disadvantages, and the selection of one method over another is usually project-dependent. The protocol developed by the Association of State Energy Research and Technology Transfer Institutions (ASERTTI) provides IES efficiency determination based on LHV of fuel [8]. It should be noted that natural gas is sold and purchased on HHV basis; the ratio between HHV and LHV values is approximately 1.11. Data based on HHV result in gross efficiencies of 30% (33.3% based on LHV) and 70% (77.7% based on LHV) for gross turbine output and gross IES efficiency, respectively (see Figure 3). The maximum HHV-based IES net efficiency of 83.4% was observed in March 2005 [9].

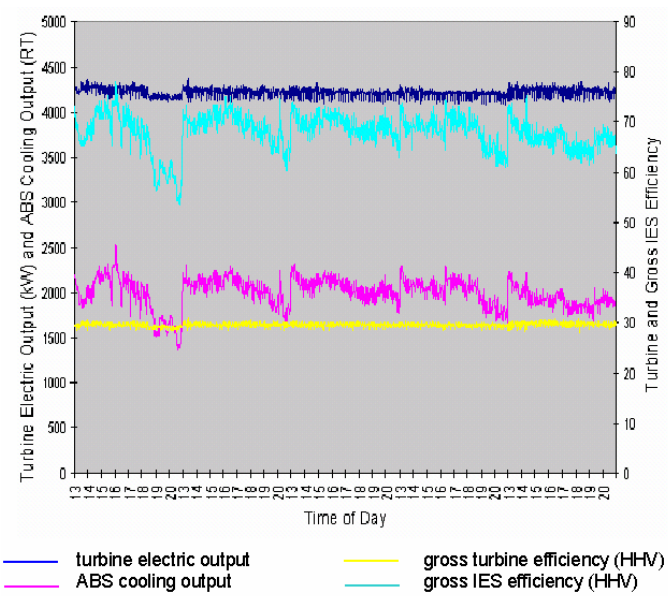

Figure 3. Austin IES Performance during August 2005

The prediction that the optimized, packaged system would achieve high fuel-use efficiency is, therefore, confirmed by performance data analysis. The maximum system efficiency during the analysis period was over 80 percent, and there is a potential for the IES plant at Domain to achieve higher efficiencies when the system is operated at full electric and thermal loads. In summary, the packaged IES plant at Domain is able to help meet the electric and thermal needs of the Domain end-users in Austin, Texas through the efficient use of natural resources.

5.7-MW TURBINE-BASED INTEGRATED ENERGY SYSTEM AT FT BRAGG, NORTH CAROLINA

Ft. Bragg, a U.S. Army base, implemented a distributed energy and power management program [10-12] to provide secure and reliable energy to the facility in the event of sustained, regional power outages. Specifically, this program built and commissioned an IES plant to provide military barracks and buildings with electrical power, steam for heating, and chilled water for cooling.

An overview and diagram of the IES at Ft. Bragg are shown in Figures 4 and 5. The system includes a natural gas-fired turbine with electric power output of 5.7 MW, an exhaust-fired ABS with cooling capacity of 1,000 RT, and a heat recovery steam generator (HRSG) that produces 27,800 lb/h of saturated steam with 125 psig pressure in the exhaust-fired mode of operation. The natural gas-fired duct burner located upstream of the HRSG can increase the steam output to 81,200 lb/h.

The major auxiliary equipment includes an inlet air cooler, a natural gas compressor, a diverter damper and stack, and an induced draft fan. The inlet air cooler takes in air at ambient conditions, cools it, and then delivers it to the turbine. At the same time, the natural gas compressor compresses all natural gas to a pressure in the range of 220-230 psig to be burned in the turbine. The diverter stack is located between the turbine and the HRSG. Exhaust air from the turbine that is not used by the chiller goes through the diverter, where it can be either sent on to the HRSG or vented through the diverter stack. The induced draft fan, located at the exit of the chiller, is used to control the flow rate of exhaust through the chiller unit and out the chiller stack [13].

The IES plant can operate using different load-following strategies to achieve the best economic performance. The appropriate operating strategy is determined by an on-line optimization function embedded in the Energy Information System (EIS), a centralized computer terminal center [10] (Figure 6). The EIS analyzes the following key decision factors: fuel selection (natural gas or #2 fuel oil) and inlet air cooling to maximize throughput to the turbine; fuel price economics versus system output; moderation of chilling load and chilling capacity to provide inlet air cooling. The EIS controls other central plant and facilities equipment in addition to the IES. It identifies facilities with high conservation potential and analyzes their load profiles to determine the most economical power use and power purchases. The EIS also analyzes real-time pricing data from suppliers to optimize the balance between purchasing power and use of the on-site generation. During moderate temperature seasons it can be more cost effective to shut the IES down and rely on utility power.

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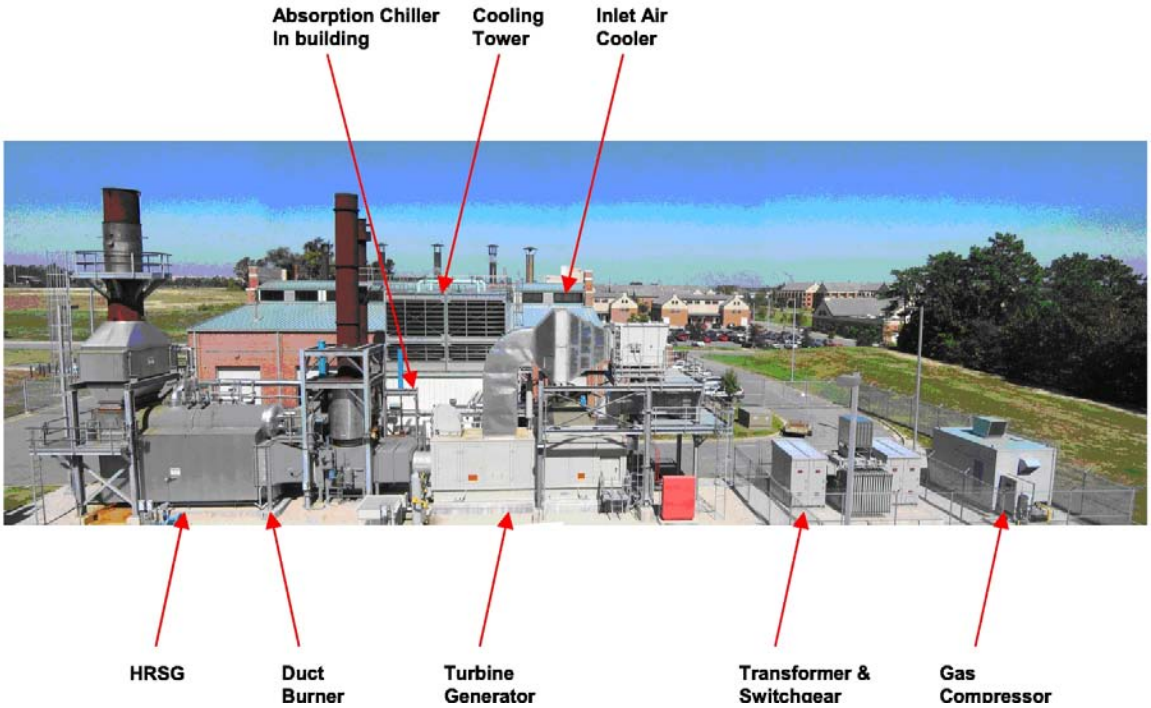

Figure 4. View of the IES Plant at Ft. Bragg, North Carolina

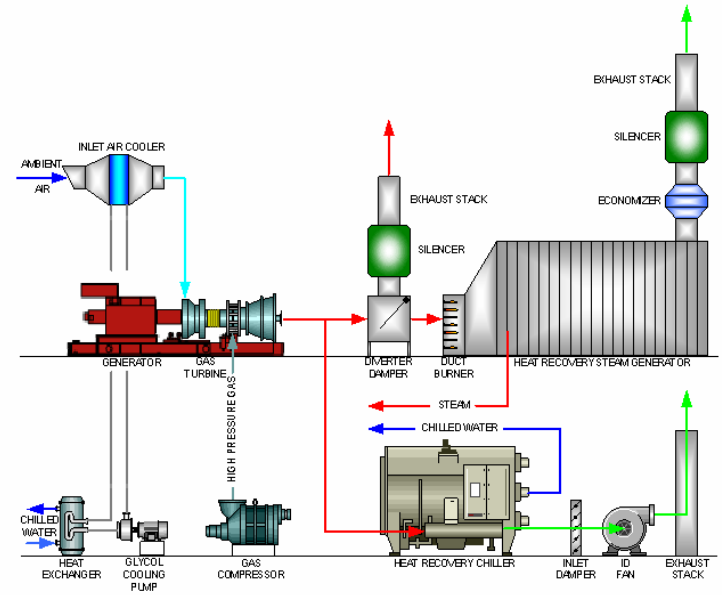

Figure 5. Diagram of the IES Plant at Ft. Bragg, North Carolina

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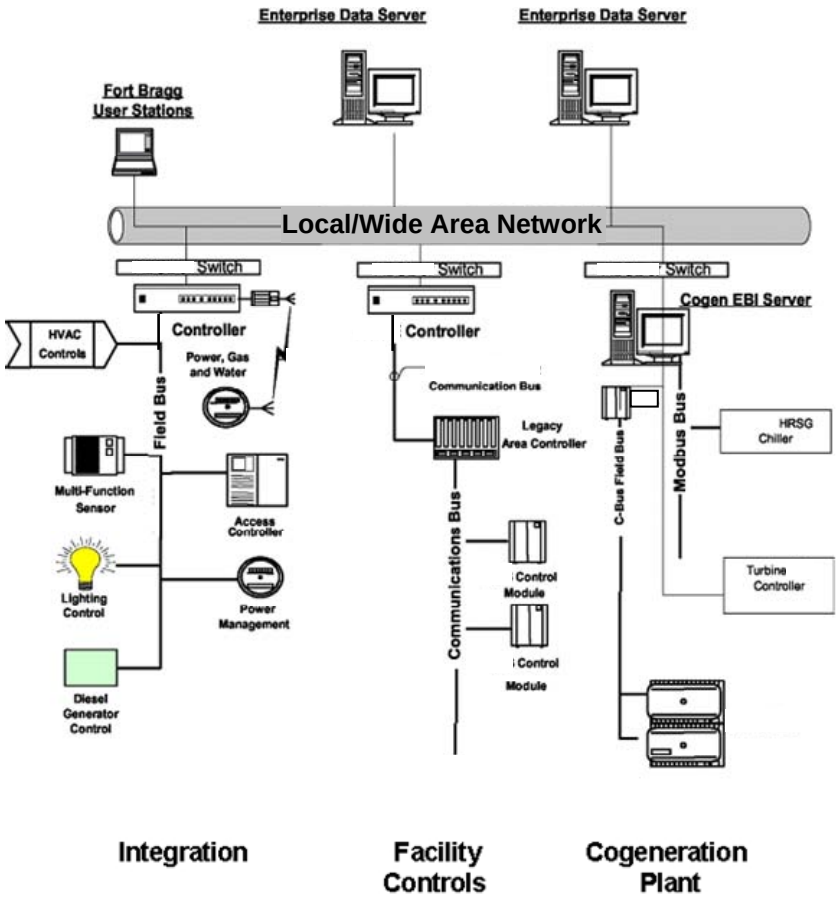

Figure 6. Energy Information System of the IES Plant (aka Cogeneration Plant)

Figures 7 – 11 illustrate aspects of IES plant performance during January-August 2005 [14, 15]. IES efficiency was calculated according to the ASERTTI long-term monitoring protocol [8], where the use of LHV, instead of HHV, of natural gas is specified. To convert from LHV-based to HHV-based efficiency, LHV values are multiplied by 0.89 resulting in average HHV-based efficiencies of 64.8% (72.0%x0.89) for January 2005 and 69.5% (77.2%x0.89) for July 2005.

Successful implementation of the IES project at Ft. Bragg resulted in total energy cost savings of more than 2 million US dollars during 2005 [16]. The on-site generation capacity of the IES plant is a valuable asset that can be used to mitigate the effects of utility plant outages and other disruptions of the electric grid.

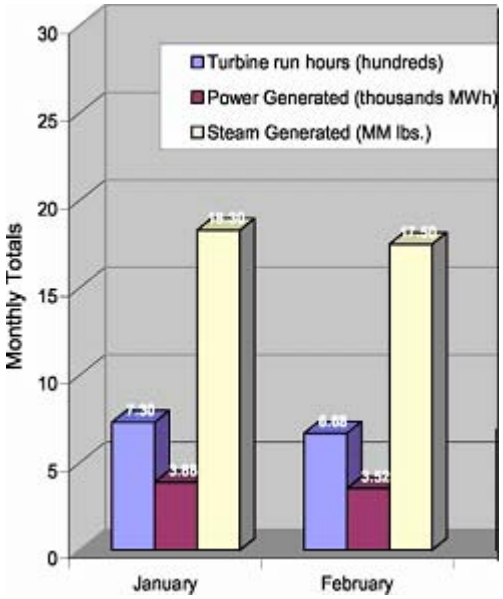

Figure 7. IES Performance during January and February 2005 (Turbine Run Hours, Electric Power and Steam Generated)

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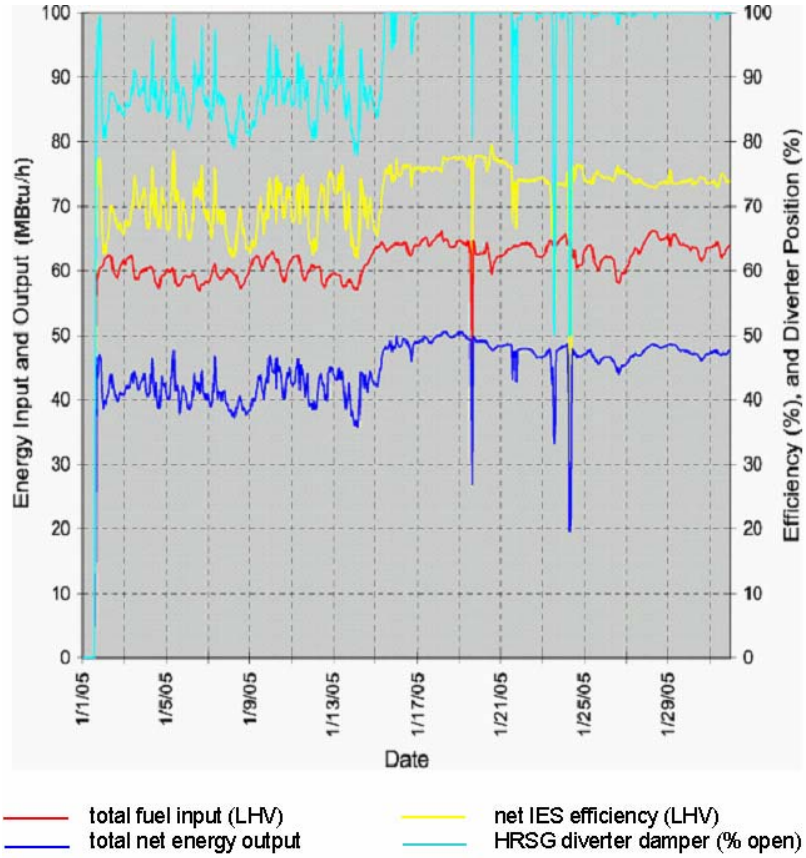

Figure 8. IES Performance during January 2005

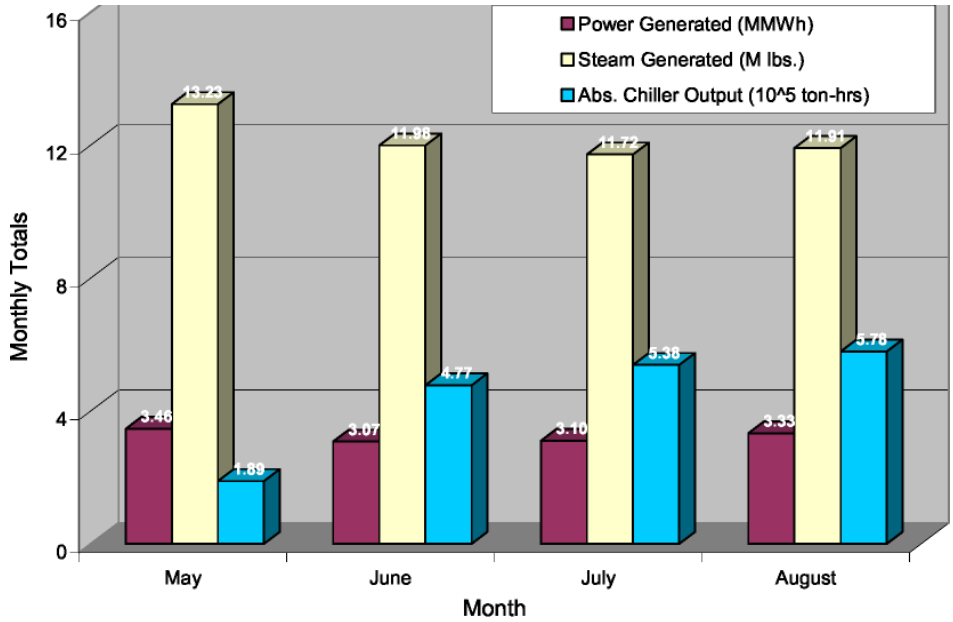

Figure 9. IES Performance during May - August 2005 (Electric Power and Steam Generated, ABS Output)

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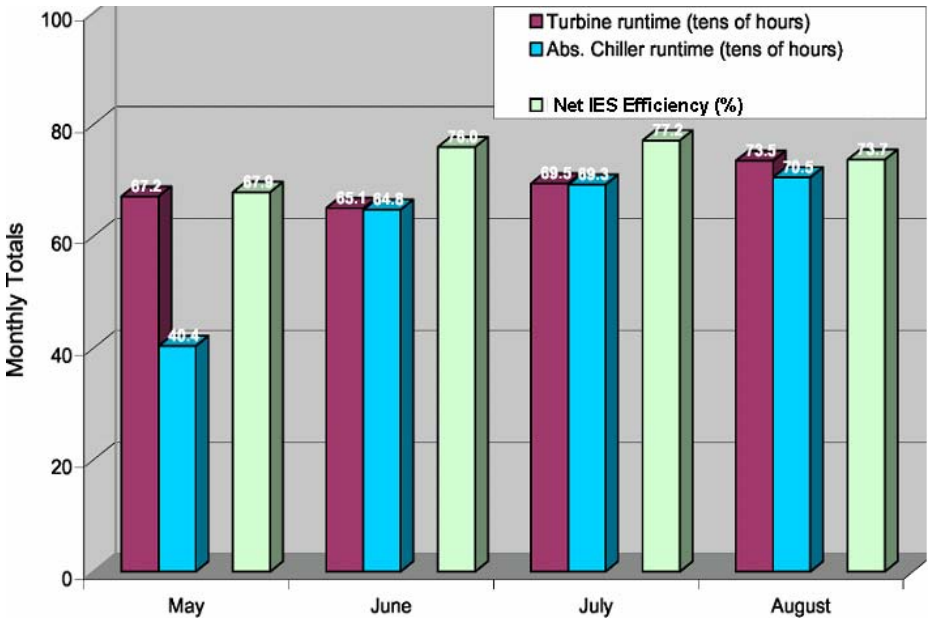

Figure 10. IES Performance during May - August 2005 (Turbine and ABS Run Hours, net IES LHV-Based Efficiency)

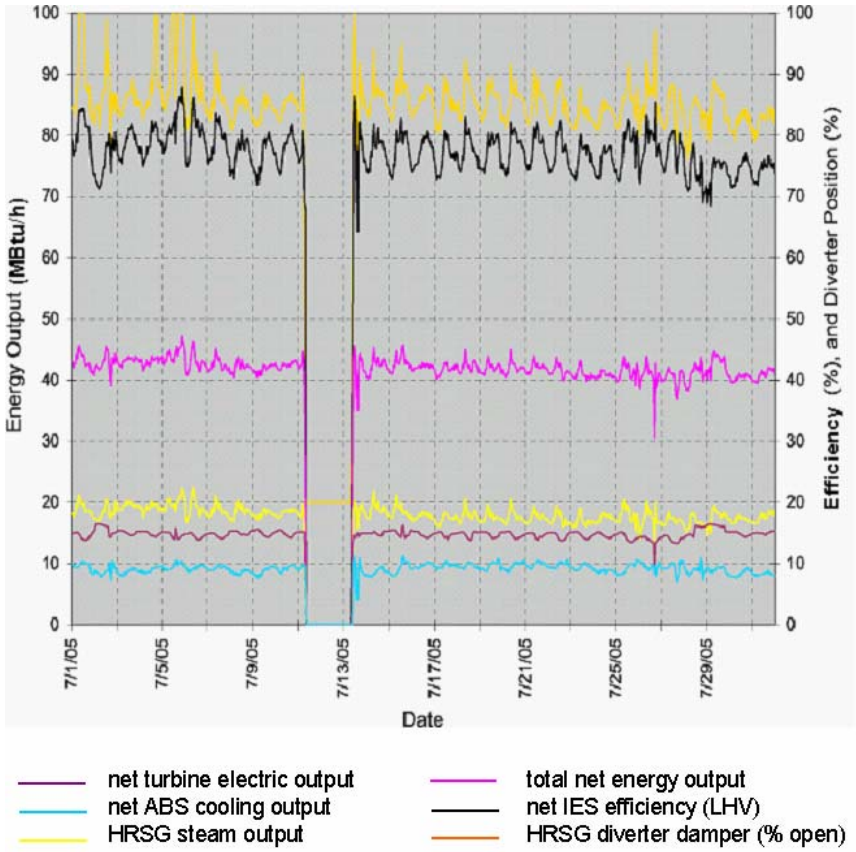

Figure 11. IES Performance during July 2005

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IES REFERENCE DESIGNS

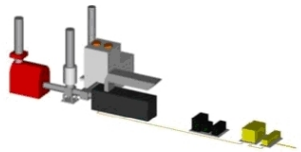
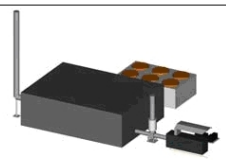
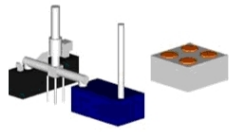
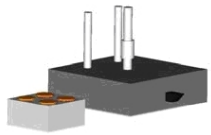
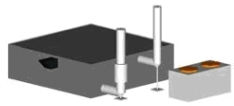
The IES package design process must be streamlined to maximize the benefits of this advanced technology. Development of standardized, modular systems will result in lower life-cycle costs and facilitate the acceptance of this technology in the marketplace. Standardized reference designs have been developed over a range of electrical and thermal outputs, 1.2 -5.7 MW (electric output) and 900 – 3,000 RT (cooling output) respectively. Typically, these systems are intended for district energy applications that serve multiple buildings [17].

Because installation scenarios of large IES systems vary widely, packaging is dependent on modularity—the ability to construct a system by choosing from a selection of compatible components that can be pre-fabricated and skid-mounted with standardized interfaces. This is particularly important for larger IES systems, where the physical size of the equipment prohibits the manufacture and shipment of an entire system in one enclosure. Designing systems in modules with the major equipment components (i.e., gas turbine-generator, heat recovery steam generator, and absorption chiller or chiller-heater) simplifies the design and installation process by reducing the amount of site-specific engineering and site preparation required. The benefits of applying a "reference" package design are:

- The amount of custom design work for a given site is reduced.
- Improved economics can validate applications that might otherwise be difficult to justify.
- Readily available reference designs can shorten the upfront time needed to quantify the economic and other benefits offered in individual applications.
- The time required for the evaluation of candidate IES applications is reduced.

All reference designs use a natural gas-fired turbine as the prime mover and, except for R-1, exhaust-fired ABS for cooling and heating purposes (see Table 1). The R-1 design is similar to the Ft. Bragg's IES plant described in the previous section.

Table 1. Overview of IES Reference Designs [17]

Title	Arrangement	Description
R-1		5.7-MW Turbine, 1,000-Ton Chiller, Outdoor Installation with HRSG and Inlet Air Cooler, New Chiller Building, Existing Plant Expansion
R-2		5.3-MW Turbine, 3,300-Ton Chiller-Heater, New Standalone Plant Building
R-4		4.6-MW Turbine, 1,300-Ton Chiller-Heater, Complete Outdoor Installation, Auxiliaries Installed in Existing Space
R-6		3.5-MW Turbine, two 1,000-Ton Chiller-Heaters (2000 Tons total), New Stand-alone Plant Building, Dual Chiller-Heaters
R-8		1.2-MW Turbine, 900-Ton Chiller-Heater, Existing Plant Expansion, All Contained in Existing Space

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CONCLUSIONS

Examination of the performance data from two IES plants – at Austin, Texas and Ft. Bragg, North Carolina – demonstrates the thermal and economic value of "waste heat" that provides heating and/or cooling with no additional fuel input. Efficiency of fuel utilization for these IES plants approaches 70-80% based on HHV of natural gas – a much higher efficiency than that of a conventional central electric plant. Successful implementation of these ORNL projects has encouraged others to consider this technology. For example, DOE/ORNL has partnered with Burns & McDonnell and Austin Energy again to construct a packaged CHP system sited at the Dell Children's Medical Center of Central Texas in Austin, Texas. Further development of IES technology will advance efforts to reduce fuel consumption and increase energy security, reliability, and efficiency on a nationwide basis.

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