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INTEGRATED COOLING, HEATING AND ENGINE POWER MODULE

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), cond ucts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Integrated Cooling, Heating and Engine Power Module is the final report for the Combined Heat and Power project (Contract Number 500-03-038) conducted by DE Solutions, Inc. and key subcontractors Integrated Combined Heat and Power Systems, Corp. and BluePoint Energy, Inc. The information from this project contributes to PIER's Environmentally Preferred Advanced Generation Program.

For more information about the PIER Program, please visit the Energy Commission's website at: www.energy.ca.gov/research or contact the Energy Commission at 916-654-4878.

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Abstract

This California Energy Commission project successfully designed, fabricated and tested an integrated cooling and heating module. The device was implemented with a high temperature reciprocating engine in a combined heat and power package. The integrated cooling and heating module is a pre-engineered and factory-assembled solution to the integration of heating and cooling with reciprocating engine combined heating and power packages. The approach greatly reduces site engineering costs, as well as component costs due to repeat business, and replaces site labor with factory labor in a controlled environment where fabricators are experienced with the system.

The development and demonstration project focused on a 260 kilowatts engine system with heat recovery and a 75-ton absorption chiller. The resulting technology is applicable to cooling modules up to 400 tons in size and engine systems up to 2 megawatts in size.

The project included component and subsystem design, factory testing, field validation, technology transfer, and production readiness. The project showed a 30 percent cost improvement on the heating and cooling subsystem, improved effectiveness of engine heat, and a resulting reduction in the cost of electric generation.

The project is expected to provide multiple benefits to California electric ratepayers through more widespread penetration of combined heat and power in the commercial and industrial markets. Benefits include end-user capital cost reductions, reliability improvements, greenhouse gas reduction, natural gas savings, grid support and new central station capacity cost savings, and avoidance of transmission and distribution system line losses.

Keywords: Combined heat and power, CHP, combined cooling, heating and power, CCHP, distributed generation, integrated cooling and heating module, absorption cooling

Executive Summary

Introduction

The majority of California's remaining combined heat and power potential is in the commercial and light industrial sectors. Commercial and light industrial heat loads will not be the large steady steam loads that have historically been a combined heat and power plant signature. Making thermally activated cooling (using heat energy to cool) economically viable will be important to obtaining the operating benefits necessary for cost-effective combined heat and power projects in the commercial and light industrial sectors.

Problem to Be Solved

Current combined heat and power systems involve the custom integration of engine, generator, heat recovery, and cooling. This drives up engineering, equipment and construction costs, often ruining combined heat and power economics, particularly in small and medium-sized applications (less than 1 megawatt [MW]). Also, customized to the specific needs of the site, combined heat and power systems have greater performance, reliability, and less warranty risks relative to standardized systems.

Developed Technology

The developed technology integrates electricity generation and heating and cooling system hardware into a prepackaged, standardized system with reduced engineering and capital costs, improved system reliability, lower maintenance expenses, and optimized performance. The absorption cooling equipment is optimized for heat available from ultra-low emission reciprocating engine systems. The system is designed to interface with a natural gas internal combustion engine-based combined heat and power package that is capable of meeting the California Air Resource Board's (ARB) Distributed Generation Certification Regulation 2007 Fossil Fuel Emission Standards through the employment of exhaust gas recirculation with a three-way catalyst. The quality of heat (temperature) from BluePoint Energy's 260 kilowatts (kW) exhaust gas recirculation engine combined heat and power package will be increased as much as possible without compromising engine durability or performance. The target market is commercial and light industrial applications with base electric loads between 250 kW and 3 MW. The current California market potential represented by these applications is 19,000 MW.

The Integrated Cooling and Heating Module includes an absorption system that maximizes efficiency and capacity at the lower hot water temperatures available from internal combustion engines equipped with exhaust gas recirculation. The package also includes a cooling tower, a load hot water heat exchanger, three-way valves, condenser water pumps, sensors, gauges, a thermal system controller, a power distribution panel.

The product developed with the California Energy Commission's Public Interest Energy Research Program support is a 75-ton absorption-based heating and cooling package that is

optimally interfaced with BluePoint Energy's 260 kW ultra-low emission reciprocating engine combined heat and power system.

A portfolio of integrated cooling and heating modules ranging from 75 to 400 tons is planned. This product lineup will be coupled with reciprocating engine combined heat and power packages in the 200 kW to 2 MW range. The market reach could extend up to applications with 3 MW loads through the use of multiple units.

The integrated cooling and heating module would be supplied as a single package with a detached cooling tower, which can be located close to the skid or remotely. The module would be provided with an integrated control system for all onboard items and the cooling tower. The control system will also provide a link to the building automation system or engine controller for on/off control and data acquisition.

Both the generator package and the integrated cooling and heating module are skid mounted and designed to be dropped on a concrete pad. The integrated cooling and heating module is designed to establish a quick and easy connection with the engine heat recovery system, cooling tower, and building hydronic cooling and heating systems, which use water as a heat transfer medium. The engine package would also be designed to quick couple with the integrated cooling and heating module and gas supply.

Project Goal and Objectives

The project goal was to significantly reduce the cost of combined heat and power integrated heating, ventilation, and air conditioning (HVAC) systems for commercial and light industrial applications. Specific project objectives were to:

- Reduce the costs of the HVAC system and its interface by 35 percent through cost reductions in engineering and construction of the thermal balance of plant combined with a more comprehensive control system that allows for low cost integration with the building's HVAC system. Significant reductions in footprint requirements and project management expenses also contribute to the overall cost reduction.
- Increase engine exhaust heat recovery outlet temperature from 203°F to 215°F by incorporating exhaust heat recovery without compromising engine reliability.
- Increase combined heat and power market by threefold by reducing thermal system costs and footprint requirements, improving reliability and providing simultaneous production of chilled and hot water to maximize waste heat usage.
- Reduce cost of electricity by 25 percent through the generation of simultaneous cooling and power. The project adds approximately 0.25 tons of cooling from waste heat for every 1 kW of electric output, resulting in a further reduction in building peak power demand and usage.

Technical Approach and Project Steps

The technical approach used for this project was to optimize the engine's heat recovery system and to optimize the absorber's performance. The project started with design of the heat recovery and absorption systems, then developed these systems into production prototypes, tested each subsystem in the factory, and installed and tested the combined heat and power system for real-world performance validation.

Results

American Refrigeration Institute's tests of the integrated cooling and heating module at the JCI/York factory verified a cooling capacity of 74 tons and a coefficient of performance of 0.69, which shows high efficiency. The absorption chiller capacity benefits of higher engine coolant temperatures were verified in American Refrigeration Institute factory tests and in the field. The integrated cooling and heating module controls in both the cooling and heating modes were demonstrated in the field.

BluePoint Energy's Deutz engine specification called for a maximum coolant return temperature of 176°F corresponding to an outlet or supply temperature after heat recovery of 203°F. The project targeted a coolant return temperature of 193°F and a corresponding supply temperature of 215°F. However, as a result of engine durability issues encountered during the field test, the engine coolant return temperature was reduced for long-term operation from 193°F to 185°F, still significantly higher than the original engine specifications.

The intent is to have the utility satisfy all fluctuations in facility demand, while the generator satisfies a non-fluctuating base-load. Baseload control is the preferred operating mode because stable power output lends itself to stable thermal characteristics and eases exhaust after-treatment emissions control. As a result of multiple efficiency and control measures that were implemented along with the combined cooling, heating and power system, initial field observations showed that Normandie Casino in Gardena, California, no longer has an electric demand profile that would allow the engine to operate at a fixed full output during all hours of operation and is not conducive to the available control option that would otherwise provide a means for demand response. The lack of sufficient steady electric and chilled water demand throughout the field demonstration greatly complicated the task of demonstrating the full output capabilities of the combined heating and cooling systems and continues to complicate the sequence of operations.

The data in the tables of this document was obtained by the author unless otherwise noted in a source line beneath the table in question.

Conclusions

The project met or nearly met each of the objectives. Specifically:

- Based on an independent analysis of the cost of an 80-ton integrated cooling and heating module, the project was estimated to cost 32 percent less than a similarly sized stick-built HVAC system.

- Durability issues limited the coolant temperature limits of the BPE engine to 205°F, 10°F less than the project objective. This limitation is engine specific and is not expected to be a restriction on other select engine platforms.
- The integrated cooling and heating module substantially reduces the cost of engine combined cooling, heating and power applications and enables accelerated market implementation when coupled with supporting energy policy and legislation.
- The detailed production readiness plan coupled with ongoing technology transfer activities have enabled product launch 2009. Specifically,
    - Preliminary engineering for a fleet of chiller sizes from 75 to 250 tons is complete.
    - Three fabricators have been qualified to assemble the integrated cooling and heating module product portfolio.
    - Johnson Controls International/York, Inc. has branded the integrated cooling and heating module for sales and marketing through its distribution channels.
    - The education process is ongoing with regional Johnson Controls International/York, Inc. distributors, engine original equipment manufacturers, engine packagers and dealers, project developers, engineering firms, and energy service companies, including presentations at regional and national conferences as well as one-on-one meetings.

Recommendations

The following recommendations are provided to fully realize the benefits of the integrated cooling and heating module in California:

Combined cooling, heating and power needs to be better integrated across State energy, policy, regulations and legislation to maximize its cost, environmental, reliability and grid benefits. Of particular note:

The Self-Generation Incentive Program for combined heat and power needs to be restored.

Utility tariff barriers for combined heat and power need to be removed.

Utility interconnection requirements need to be simplified to enable inadvertent export or sale back to utility of excess power production.

The integrated cooling and heating module should be promoted in Energy Commission publications, through the regional combined heat and power application centers, and at appropriate conferences.

Continued attention needs to be given to further Integrated Cooling and Heating Module cost reductions particularly in the smaller sizes (80 – 150 tons).

Additional technology development is warranted to improve absorber performance with lower temperature heat.

The market should be cautioned against oversizing combined cooling, heating and power systems for the base coincident electric and thermal loads. Instead, combined cooling, heating and power systems should be sized so that capacity usage is maximized and partial-load operation is minimized.

Public Benefits

The public benefits were planned to begin accruing in 2010 with early market entry deployment of three to six units followed by a steady market ramp-up in California over a six-year period. California's ratepayers will realize significant near-term benefits from this project. These benefits that accrue within 10 years from commercial introduction are summarized below:

Combined heat and power capital cost savings of $240 million to commercial/industrial adopters.

- Annual electricity savings of $150 million to commercial/industrial adopters.
- Annual natural gas savings of 15 billion cubic feet.
- Annual CO_2 reduction of 800,000 tons.
- Deferred central station plant and transmission costs of $800 million.
- A strengthening of California's economy and energy security along with customer choice.

1.0 Introduction

1.1. Background and Overview

Combined Heat and Power (CHP) and Combined Cooling, Heating and Power (CCHP) are integrated energy systems located at or near a building or facility that supply a portion of the facility's electrical demand and utilize heat recovered from the power generation equipment to provide heating and/or cooling to a building or process. CHP is rooted in sound energy and environmental performance. Properly applied CHP achieves high overall gas utilization efficiencies (70 - 80% Higher Heating Value (HHV) or more), and saves 40% or more of the fossil fuel otherwise required to produce an equal amount of electricity. Greenhouse gas (GHG) emissions are likewise reduced by 40% or more. The California Climate Action Team Report targets CHP to be a major near-term contributor of California's climate change Initiative. In addition to its efficiency and GHG advantages, CHP: 1) reduces gas consumption in the State and improves utilization of the gas distribution system; 2) provides California businesses an option to curb energy costs and improve power reliability; 3) eliminates transmission and distribution (T&D) losses and reduces the need for new T&D; and 4) eases grid congestion.

In California, CHP is an important element of the state's energy and environmental policy:

- CHP is deemed the most cost-effective form of Distributed Generation (DG) in the California Energy Commission's (Energy Commission) *2005 Integrated Energy Policy Report (IEPR).*
- CHP is listed as an important energy resource in the California *Energy Action Plan* (EAP) and is among the top measures called out in the Loading Order.

According to the 2005 Energy Commission report CEC-500-2005-173, "Assessment of California CHP Market and Policy Options for Increased Penetration", there is an untapped market potential for CHP and CCHP of 30,000 MW between 2005 and 2020. However, implementation of CHP is hindered by a myriad of technical, economic and regulatory barriers. These barriers include

- Price uncertainty
- Gas price volatility
- Electric tariff structures
- Regulations and legislation inconsistent with state policy
- High installed cost, particularly for smaller systems (< 2 MW)
- Lack of traditional thermal demand in many commercial applications
- Unfamiliarity with CHP and lack of experience

Based on policies recommended in the *2005 IEPR*, actual implementation of new CHP and CCHP is projected to be in excess of 5,300 MW from 2005 through 2020.

Most high electrical capacity applications in California's commercial, institutional and light industrial sectors lack sufficient traditional thermal loads (i.e. domestic hot water, space heating, and process heat) to optimally match a CHP system to the electric loads. Without consideration of cooling loads, the design choices are to install a CHP system much smaller than the base electric demand or install a larger system matched to electrical requirements but with poor thermal utilization. Absorption chillers can provide the thermal load to support better electrical matches with the application while maintaining high overall efficiencies. Unfortunately, absorption cooling can add significantly to the cost of CHP and is oftentimes not cost justified.

This CHP proposal is aimed at improved economics for heat-actuated absorption cooling systems and optimal integration with reciprocating engine CHP systems. The proposed initiative will expand the economically addressable market for CHP in California and will increase overall CHP utilization efficiencies.

1.2. Problem Statement

A major market barrier to robust deployment of CHP and CCHP systems is high capital cost. This is particularly true for smaller systems less than 5 MW in size. The cost of an engine CHP package is not the crux of the cost dilemma. The balance of plant and integration with the existing heating and cooling system and with the electric distribution system are where the real cost challenges lie. Because of California's warm climate, the application of thermal driven cooling equipment is often required. The U.S. Department of Energy (DOE) and Oak Ridge National Laboratory (ORNL) have recognized this problem but have not been able to adequately address the issue due to budget constraints.

Current CHP systems involve the custom integration of disparate pieces (prime mover, generator, controls, heat recovery, and cooling). Such practice drives up engineering, equipment and construction costs, oftentimes ruining CHP economics particularly in small and medium sized applications. Also, absorption cooling has a reputation for poor reliability and maintainability and is not configured for effective utilization of engine heat. Improvements to absorption technology in the past 20 years have been miniscule primarily due to lack of demand.

Outside of electrical grid integration and permitting issues, the main barriers to the implementation of CHP systems have been caused by the lack of CHP system engineering experience, the absence of integrated standard products and the variance in performance and cost data. Because this has resulted in low market demand, the private sector has been unwilling to develop the necessary product and system technology in anticipation of market demand solely with internal resources. It is estimated that the development and commercial introduction of integrated CCHP products could reduce balance of system costs by 30% or more while enhancing reliability and reducing footprint.

1.3. Report Organization

Section 2 lists the project goal and objectives. It also describes the various work tasks, their sequence and linkages.

The Project Outcomes Section (Section 3) addresses the findings of the technical development activities and testing. This section also covers technology transfer activities and the Integrated Cooling and Heating Module Production Readiness Plan.

Section 4 addresses the commercial potential for the ICHM, provides conclusions and recommendations, and lastly depicts the benefits of the ICHM to California.

2.0 Project Approach

2.1. Project Goals and Objectives

The project goal was to significantly reduce the cost of CHP integrated heating, ventilation and air conditioning (HVAC) systems for commercial and light industrial applications. Specific project objectives were to:

- Reduce HVAC system interface costs by 35% – The pre-engineered modular approach greatly reduces site engineering costs, provides better component purchasing power due to repeat business, and replaces site labor with factory labor in a controlled environment with fabricators experienced in working with the system. In addition the purpose designed, open protocol thermal control system provided with the ICHM allows for easy integration with the building HVAC system with a minimum of additional controls expense. Due to its compact design, the ICHM requires approximately 50% less ground space than a similar stick-built system, and as the complete thermal balance of plant is provided as a module, there is a significant reduction in project management and administration expenses. All of these factors combine to provide a significant cost reduction over similar stick-built plants.
- Increase engine/exhaust heat recovery outlet temperature from 203°F to 215°F – In order to optimize the performance of the chiller system, the heat recovery quantity and quality (temperature) need to be maximized. This goal combines recovering the exhaust heat into the jacket loop and adjusts engine flow rates and return temperature tolerance to increase the outlet temperature to the ICHM as much as possible. This goal must be achieved through extensive testing and coolant system design modifications so that engine reliability is not decreased or maintenance costs are not significantly increased.
- Increase CHP economically addressable market by threefold – high cost and uncertain performance expectations are two of the major barriers to the implementation of CHP. By significantly lowering the price of adding cooling, as well as optimizing chiller design and providing simultaneous cooling and heating to maximize waste heat utilization, the cost of implementing CHP is reduced while the economic benefits are increased. Based on the comprehensive modeling of the York absorber with a large variety of popular engines, the ICHM provides significantly more reliable performance data than previously available from chiller suppliers. This removes the need to conservatively estimate thermal output and enhances confidence in feasibility economics. Combined, these two changes can significantly enhance CHP market performance.
- Reduce cost of electricity to target markets by 25% – By allowing the conversion of waste heat to cooling, the ICHM provides approximately 0.25 tons per kW of generator output. Allowing 0.6 kW per ton for typical water cooled chillers, this equates to an additional 0.15kW per kW of engine output. In addition the ICHM provides the necessary justification to install many CHP systems in previously marginal applications. The

combination of on-site generation with increased effective power output results in a significant reduction in electricity cost.

2.2. Technical Approach

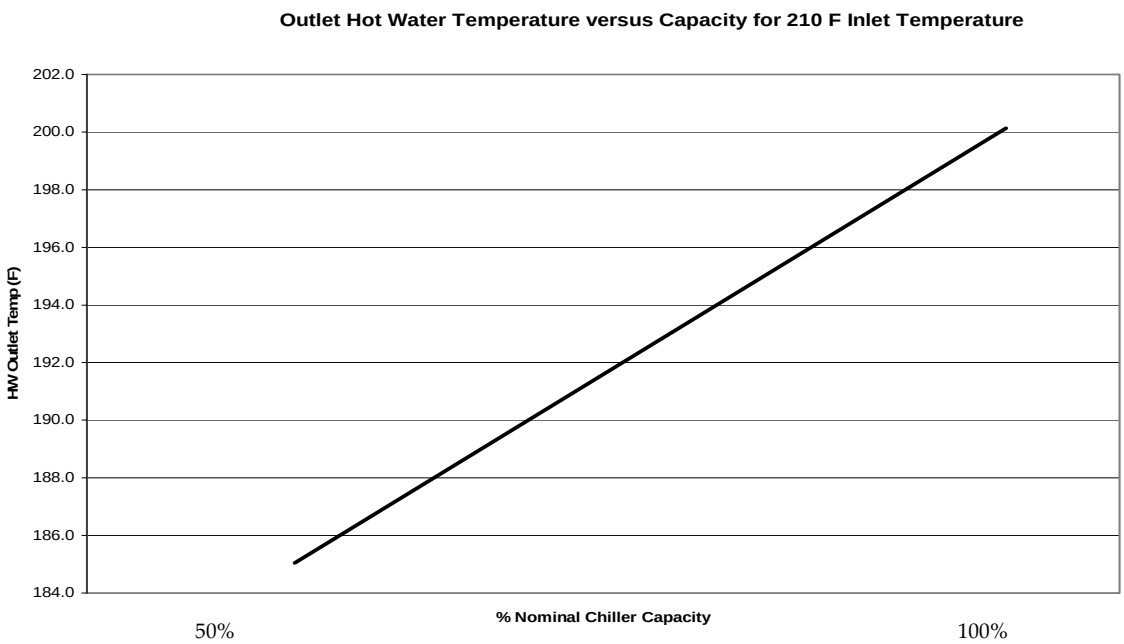
The technical development work consisted of three main areas – redesign of the engine heat recovery system, design of the ICHM and performance validation testing in the factory and in the field, as well as documentation. In addition, the project included technology transfer activities and the preparation of a production readiness plan.

2.2.1. *Engine Heat Recovery Modifications*

An exhaust heat recovery unit (EHRU) was designed that integrated exhaust waste heat with the jacket water and maximized the recovered thermal output at a temperature sufficient to operate the absorber at a high capacity and efficiency to increase chilling output. This design was then used to fabricate the EHRU as part of the standard engine skid for CHP applications.

Low temperature absorbers are often benchmarked at 210°F entering water, but the leaving temperature determines the average temperature in the absorber, which is the real basis for calculating capacity and efficiency. As the average temperature is reduced, the capacity and efficiency (to a lesser extent) are reduced; therefore the return water temperature is an important factor in improving absorber efficiency. Figure 1 indicates the effect on capacity of reducing outlet temperature from the absorber for a given inlet temperature of 210°F.

Figure 1. Outlet hot water temperature versus capacity for 210°F inlet temperature



Source: Johnson Controls International/York, Inc.

Current engine cooling systems often operate at lower than the desired return jacket water temperatures for optimal performance of absorption systems. The Blue Point Energy, Inc. (BPE) engine coolant system design required a return temperature to the jacket of 175°F. BPE worked with the engine manufacturer (Deutz AG) to develop a higher temperature jacket coolant system in order to allow higher return temperatures and therefore increase capacity of the absorber. The target return temperature was 193°F, which would enable the outlet temperature from the heat recovery system to reach 215°F. This increases the capacity and efficiency of the absorber by approximately 20% and is an important step in lowering capital costs, increasing system efficiency, and reducing the economic payback period.

2.2.2. *ICHM System*

The ICHM includes a York single stage absorption chiller, cooling tower, pumps, heat exchanger, valves, piping, instrumentation, controls, etc., each of which requires a detailed evaluation. This project does not aim to reinvent absorption technology, but to optimize the integration of components and thereby increase absorber output and reliability while reducing system cost and maintenance.

Absorption chillers use lithium bromide (LiBr) as an absorbent and water as the refrigerant. Dilute LiBr is pumped by the solution pump to the generator where hot water from the heat recovery system is used to evaporate the water within the LiBr. The concentrated LiBr is sent to the absorber section and the high temperature water vapor is directed to the condenser where cooling tower water is introduced to condense the vapor to its liquid form. The condensed water is sprayed on the tube bundle in the evaporator where vacuum conditions allow the return building chilled water to boil off the refrigerant water converting it to vapor. The latent energy required to vaporize the refrigerant is taken from the building water in the form of sensible energy resulting in a drop in temperature from 54°F to 44°F. The refrigerant vapor migrates towards the absorber section where concentrated LiBr absorbs the vapor to maintain the absolute pressure within the evaporator. The resulting dilute LiBr flows to the suction end of the solution pump to begin the process again.

An intermediary heat exchanger is included to separate the engine coolant loop from the absorber hot water loop. This protects the engine loop from any possible infiltration of LiBr which could cause serious damage to the engine. The heat exchanger is selected for high efficiency and minimal approach temperature.

The cooling tower is used to reject the heat from both the hot water and the building loop. Cooling tower operation is extremely important to the optimal function and reliability of the absorber. Slightly over sizing the tower is an optimization enhancement to extract additional capacity from the absorber.

The controls for each component were integrated through a central controller which will have the ability to communicate with the engine and the building. The York Millennium control panel will be provided with a communication board to allow export and import of control and information signals. The selected communication protocol was Modbus Remote Terminal Unit, which is an open protocol and is the same as that used by the original BPE engine controller.

Control logic was developed to integrate the operation of the cooling tower, pumps and automatic valves with the absorber and the engine operation. The system can be controlled and interfaced with the Building energy management system through a single control connection.

Pumps, valves, sensors, etc. are selected to meet specific size, installation and control requirements, considering the interaction of each with the system. Piping sections are prefabricated and designed for use with multiple sizes where practical. The absorber and all accessories excluding the cooling tower will be prefabricated on a single skid. The cooling tower will be supplied as a separate skid to allow remote connection. An outdoor enclosure is also provided with an option for freeze protection.

The integration, optimization and prefabrication of the ICHM will remove the requirement for engineering design, individual component selection and purchase as well as greatly reduce project time and construction expenses. This approach will remove some of the significant barriers to wider application of CHP systems. No system or component engineering is required thereby greatly reducing the potential for design errors. Prefabrication using standardized components from contract suppliers will reduce component costs to a minimum and eliminate much of the site work.

2.2.3. *Testing, Validation, and Documentation*

Once ICHM fabrication was complete, it was transferred to a certified test platform at JCI/York for complete functional and performance testing. ARI standards were used to test the absorber performance, and an overall system performance specification was developed, as well as identification of parasitic loads. The system was subsequently installed at the field test host site for site performance testing and long term validation. Performance, application and service data for engineers, operators and service personnel was developed after testing and design verification.

Accurate technical information enhances confidence in the system and assists in the sales and marketing process. This removes some of the 'soft barriers' to implementation, which assists wider application of CHP in California.

2.2.4. *Technology Transfer*

A technology transfer plan was developed and activities implementing the plan were ongoing over the course of this project. Activities included:

Promotional and technical information including brochures, presentations, specification packages, and installation and operations manuals.

Market outreach to market participants through presentation and conference exhibits.

Individual meetings with engine packagers, energy service companies (ESCOs), engineering firms, project developers and utilities.

Training and support to JCI/York sales and marketing team.

A detailed discussion on the Technology Transfer Plan can be found in Section 3.4.

2.2.5. ***Production Readiness Plan***

A Production Readiness Plan was prepared that outlines the major production steps, fabricator qualifications and costs associated with building the ICHM. The ICHM will be fabricated to order. The production plan is designed to minimize the time between order acceptance and billing.

The ICHM is designed to be fabricated by qualified third party fabricators according to the design provided by Integrated CHP Systems Corp. (ICHPS) and in accordance with approved practices as determined by ICHPS. The goal is to provide a streamlined method for providing the client with a fully functional 'plug-n-play' module to meet site requirements which can vary from project to project. Furthermore the goal is to provide this module as a highly reliable system with optimized performance at a cost that can be borne by the market.

Agreements are already in place with the major component supplier, and an agreement with the fabricator would allow for a practical cash flow with sufficient return to allow the business to develop. The Production Plan does not require high product volume for a profitable operation which fits well with a startup operation.

A detailed discussion on the Production Readiness Plan can be found in Section 3.5.

3.0 Project Outcomes

3.1. Design

This project involved the design of two separate modules – the ICHM developed by ICHPS and the High Temperature Engine Package developed by BPE. Each module was developed independently, and a design discussion is provided for each developer.

The goal of the Engine CHP Integrated Cooling and Heating Module Development Project was to significantly reduce the installed cost of CHP integrated HVAC systems for commercial and light industrial applications. The goal was to be accomplished through: 1) the development of standardized factory assembled heating/cooling modules, and 2) absorption chiller and engine heat management systems that are cost optimized for CHP performance.

Table 1 gives the CHP performance parameters presented by BPE to Integrated CHP Systems early in the project for making estimations of the chiller performance. Four scenarios were evaluated with 1300-1400 Mega British Thermal Units (MBTU)/hr heat inputs as well as 193-195°F coolant return temperatures.

Table 1. CHP parameters for York chiller performance estimation

Table 2 - CHP Parameters For York Chiller Performance Estimation				
Total CHP Heat Output [kBtu/hr]:	1,400	1,400	1,300	1,300
Coolant Flow [gpm]:	145	145	145	145
Engine Inlet Temp [F]:	195	193	195	193
Coolant Temp Loss Engine-to-EHX [F]:	0.3	0.3	0.3	0.3
Engine Outlet Temp [F]:	206.1	208.1	205.4	207.4
Jacket dT [F]:	13.1	13.1	12.4	12.4
EHRU Coolant Inlet Temp [F]:	205.8	207.8	205.1	207.1
EHRU dT [F]:	7.3	7.3	6.6	6.6
Coolant Exit Temp From EHRU [F]:	215.2	213.2	213.7	211.7

The ICHM design performance is based on the quantity and quality (temperature) of the hot water provided by the engine package. The engine package incorporates jacket and exhaust heat recovery in a single standardized module. The ICHM and BPE High Temperature Engine Package design efforts and system tests were carried on concurrently with performance data and design parameters evolving as the project moved ahead. This section of the report discusses the design effort and outcomes which are at slight variance with the original design goals.

3.1.1. *Integrated Cooling and Heating Module*

Introduction

The ICHM is a complete, pre-engineered thermal system that optimizes the heat recovered from the engine and provides simultaneous cooling and heating for a building's HVAC system. The ICHM consists of a York hot water fired absorber, cooling tower, condenser water pump, load controls, heat exchangers, pipe, valves, fittings, sensors, base frame, outdoor enclosure and

system control panel. The ICHM controller integrates the thermal equipment with the generator and/or building and provides a single open protocol connection point.

The ICHM is connected to an IC engine generator coolant loop and to the building hydronic loops. The unit is driven with the heat rejected by the engine and provides both cooling and heating. The cooling and heating heat exchangers are in series and normally operate simultaneously for high load factor. The ICHM controller will maintain the correct coolant water leaving temperature through fluctuating loads.

The ICHM design optimizes the heat recovery in a skid mounted, prefabricated outdoor package. The ICHM is designed specifically for application with continuous duty IC Engines that incorporate jacket and exhaust heat recovery. The control systems are designed to seamlessly integrate, and the ICHM can accept control signals from either the building automation system or the generator.

The ICHM includes a rigid steel frame with lifting eyes and mounting holes. Flanged connections to the building cooling and heating loops as well as the generator coolant loop are provided. A detached cooling tower is provided to allow for close or remote coupling. The ICHM is placed on a level concrete pad with the cooling tower sump located at least two feet above the top of the concrete pad. Treated make-up water is required for the tower along with drain connections at the ICHM and tower. A single power supply is required for the ICHM. The cooling tower is powered by the ICHM.

ICHM Scope

The ICHM integrates the absorber and load heat exchanger with the generator's heat recovery system. It includes all pipe, valves and fittings required to operate the system and provide chilled and/or hot water. The ICHM is built on a steel frame and includes a weather proof enclosure. A cooling tower is provided to match the heat rejected from the absorber and is provided with an enclosure, axial fan, mechanical fill control and overflow and blow down connections.

Table 2. Major equipment provided with ICHM

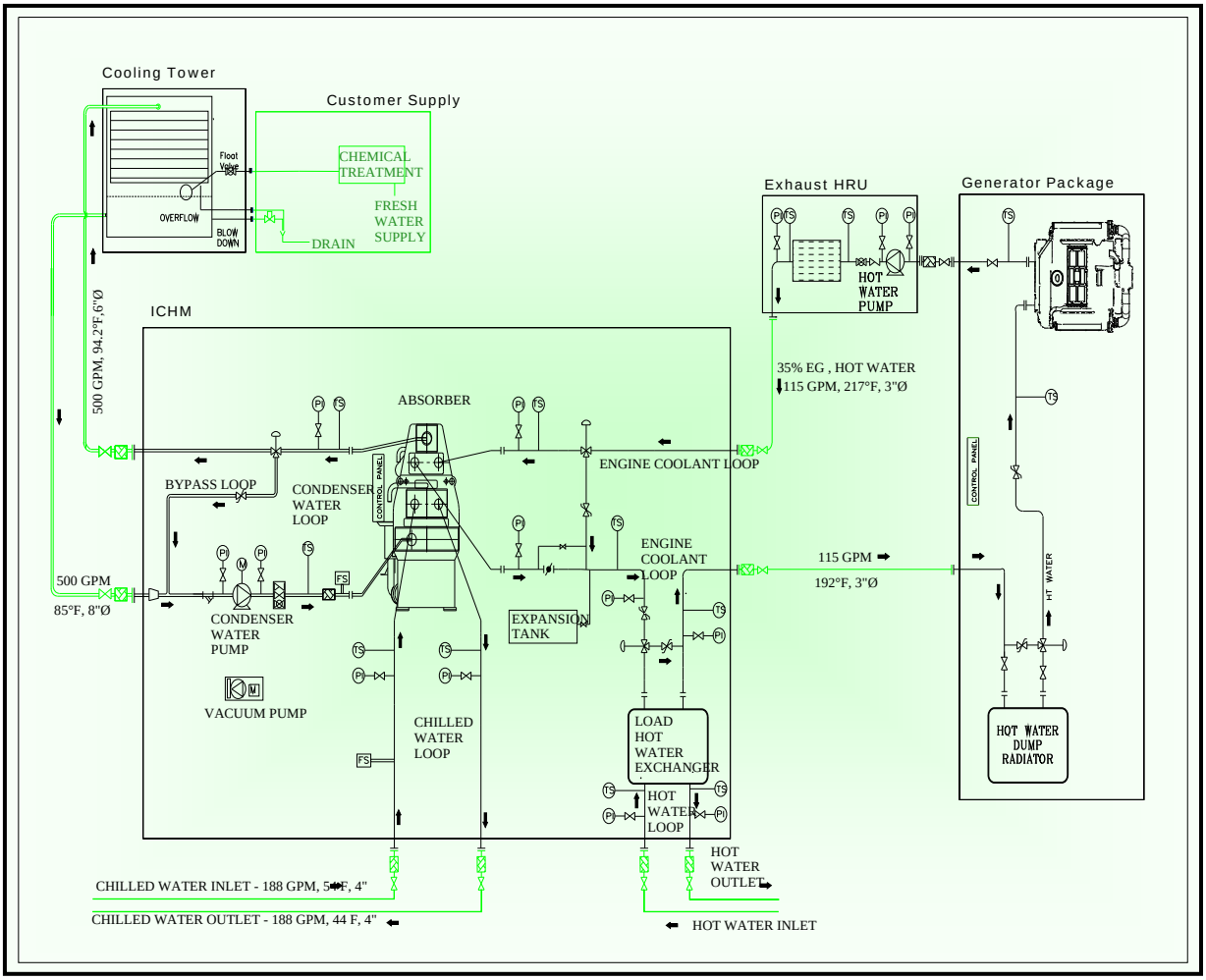
Item	Description
Absorber	York YIA Hot Water Fired Absorption Chiller
Absorber	ADVAGuard 750 LiBr Solution
Load Heat Exchanger	Flat Plate FP Series - 35% EG/H20
Cooling Tower	Baltimore Air Coil or equal
Controls	ICHM Control Panel with Local Readout and Indicator Lights
Controls	York Iso-Flow Absorber Control Panel
Controls	MODBUS RTU open Communications Protocol
Power	Main Disconnect
Power	Power Panel with Starters
Enclosure	Structural Steel Frame
Enclosure	Weatherproof Enclosure with Lights and Exhaust Fan
Condenser W Pump	In-Line TACO or equal
Vacuum Pump	Welsh or equal
Valves	Coolant, Hot Water and Condenser Water By-Pass Valves

The chilled and heating water pumps and the tower make-up water treatment singular system are part of the building scope. The generator package shall be supplied with the generator, exhaust heat exchanger and dump radiator.

The installing contractor provides all interconnecting piping requirements between the ICHM and generator package, heat recovery unit and cooling tower. Make-up water and drain connections and a power supply and drain for the ICHM are required at the cooling tower. The power to the cooling tower fan is provided by the ICHM with a local disconnect by others. Control cable needs to be run from the ICHM to the generator and power cable from the ICHM to the cooling tower. Foundation pads and anchor bolts are required for the ICHM and cooling tower.

All items supplied by the installer should comply with local structural and code requirements. It is the responsibility of the installer to connect all lines and cables to the ICHM.

Figure 2. Customer mechanical supply is indicated in green



Source: Integrated CHP Systems Corporation.

Outline Design

Internal piping was laid out to allow for easy service access with minimum space requirements. Flanged connections were provided for the HVAC system, cooling tower and coolant loop. Building water circuits and coolant loop are rated to 125 psig and the coolant loop is rated to 150 psig. All internal pipe, valves, fittings and equipment are rated for the service provided in accordance with standard mechanical practice. Suitability for specific locations and local code compliance should be verified in advance. Components have been designed to allow for maximum of prefabrication of spool pieces and space saving. A bill of materials, Process and Instrumentation Diagram (P&ID) drawings, and equipment specifications have been developed to enable the construction of the ICHM by a third-party fabricator.

A single 3 Phase (PH), 60 Herz (Hz) power supply will be provided from the building to the ICHM power panel. 110 V and 24V feeds will be provided by the ICHM panel to the absorber,

motors and sensors. The cooling tower can have its power supply from the ICHM or from a separate source for remote location. All motorized valve operators are slow acting for thermal stability. A twin service 110 Volts (V)/ 1 PH outlet is provided as well as a ventilation fan and lights.

The ICHM controller communicates with the generator controller and operates all on-board equipment and the cooling tower. The ICHM provides a single connection to the engine controller which will provide data acquisition, operation control and status indication. Local status indication and alarm contacts are provided. The ICHM power panel distributes power to the various electrical components and the cooling tower. The controller provides operating data in the MODBUS RTU or other protocol as required to match the client requirements. The following control and data points are available:

Table 3. Control points and data points available for ICHM controller

CONTROL POINTS
ICHM On/Off
Heating Start/Stop
Chilling Start/Stop
Stand-by
DATA POINTS
Chilled Water In
Chilled water Out
Coolant Temp In
Coolant Temp Out
Coolant Valve Position
Load Hot Water Temp In
Load Hot Water Temp Out
Condenser Water Flow Status
Chilled Water Flow Status
Operating Mode
Operation Status
Fault

Installation Considerations

Site selection should consider structural support, service access with tube pull area and air flow to the generator and cooling tower. Follow standard engineering practices and local code requirements in laying out equipment, designing interconnecting piping, wiring and foundations. Adequate support must be provided to assure no weight is put on the pipe connections to the ICHM, cooling tower or generator package.

The recommended support arrangement for the ICHM is a concrete pad at least 2 inches above grade. The ICHM is vibration free and does not require spring type vibration isolators. The recommended support arrangement for the Cooling Tower is parallel I-beams. Vibration isolators are not required for the tower unless noise is a major concern.

The ICHM and Cooling Tower are provided as two separate packages. Rigging points are provided in the ICHM frame. Do not use pipe nozzles or other points other than the rig points

to lift or move the unit. Do not sling the unit against any projecting objects which may either damage the object or the unit.

Thermal Design and Performance

The system heat balance was analyzed to provide the optimum thermal output for both cooling and heating. The engine heat recovery system and ICHM were modeled to ascertain the optimum operating conditions for the integrated system. The engine heat recovery was originally calculated at 1,400 MBH (one thousand BTU/hr) with an outlet temperature of 215°F and a return temperature of 195°F.

Upon review of the data and allowing for thermal losses, it was determined to use the following characteristics as input to the absorber:

Table 4. Absorber model runs – highlight indicates changes from Case 1 conditions

York International Corporation - YIA Single Stage Absorption Chillers
For: Integrated CHP Systems Corporation

	Case 1		Case 2		Case 3		Case 4		Case 5	
Evaporator	Rated	Adjusted	Rated	Adjusted	Rated	Adjusted	Rated	Adjusted	Rated	Adjusted
Leaving Temp (F)	44.0		44.0		44.0		44.0		44.0	
Entering Temp (F)	54.0		54.0		54.0		53.3		53.3	
Flow Rate (GPM)	188.4		188.4		188.4		188.4		188.4	
Fouling (hr ft2 F/BTU)	0.00010		0.00010		0.00010		0.00010		0.00010	
Tube Material/Wall Thk	Std		Std		Std		Std		Std	
Fluid Type Concentration	100% H2O		100% H2O		100% H2O		100% H2O		100% H2O	
No. of Passes	3		3		3		3		3	
Pressure Drop (ft. H2O)	6.8		6.8		6.8		6.8		6.8	
Heat Input (MBH)	942.0		942.0		942.0		876.1		876.1	
Absorber/Condenser										
Entering Temp (F)	85.0		85.0		85.0		85.0		85.0	
Leaving Temp (F)	94.2		94.2		94.2		94.2		94.2	
Flow Rate (GPM)	500.0		500.0		500.0		500.0		500.0	
Fouling (hr ft2 F/BTU)	0.00025		0.00025		0.00025		0.00025		0.00025	
Tube Material/Wall Thk	Std		Std		Std		Std		Std	
Fluid Type Concentration	100% H2O		100% H2O		100% H2O		100% H2O		100% H2O	
No. of Passes (Abs/Cond)	2/1		2/1		2/1		2/1		2/1	
Pressure Drop (ft. H2O)	10.3		10.3		10.3		10.3		10.3	
Heat Rejected (MBH)	2300.0		2300.0		2300.0		2300.0		2300.0	
Generator										
Entering Temp (F)	215.1	215.1	213.1	213.1	211.8	211.8	213.7	213.7	210.5	210.5
Leaving Temp (F)	192.6	195.0	192.6	193.0	192.6	193.0	189.0	194.9	189.1	193.0
Flow Rate (GPM)	129.4	145.0	141.9	145.0	151.7	155.0	110.1	145.0	126.8	155.0
Fouling (hr ft2 F/BTU)	0.00010		0.00010		0.00010		0.00010		0.00010	
Tube Material/Wall Thk	Std		Std		Std		Std		Std	
Fluid Type Concentration	35% E.G.		35% E.G.		35% E.G.		35% E.G.		35% E.G.	
No. of Passes	2		2		2		2		2	
Pressure Drop (ft. H2O)	5.7	7.1	6.8	7.1	7.7	8.0	4.2	7.1	5.5	8.0
Rated Heat Input (MBH)	1455.8		1454.5		1456.3		1359.7		1356.8	
Target Heat Input (MBH)	1457.3		1457.3		1457.0		1355.6		1356.0	
Capacity (Tons)	78.5		78.5		78.5		73.0		73.0	
% flow adj. Vs ABBSEL	1.12		1.02		1.02		1.32		1.22	

1,400,000 Btu/hr input

213°F to the absorber inlet, 193°F from the absorber outlet at full load

Coolant flow is 145 gallons per minute (GPM) @ 35% Ethylene Glycol

Multiple chiller configurations were reviewed and the final modeling cases were based on the selected 1A1 frame type per the following table.

The heat recovery potential of the engine provides the basis for design of the ICHM. On this basis the system would provide 74 tons or 0.28 tons per kW, which is above the industry average of 0.25 tons/kW[1]. The ICHM will be designed to provide all the required equipment to convert the generator waste heat into useful thermal energy. The ICHM will accept all the recovered heat at full thermal load and provide simultaneous heating and cooling for increased load factor.

Table 5. Design ICHM performance based on BPE 260 heat recovery data

BPE 260 ICHM Performance	
Coolant Water	
Entering Temp (F)	213.1
Leaving Temp (F)	193.0
Flow Rate (GPM)	145.0
Fluid Type Concentration	35% E.G.
Pressure Drop (ft. H2O)	25.0
Rated Heat Input (MBH)	1400.0
Chilled Water	
Capacity (Tons)	78.5
Leaving Temp (F)	44.0
Entering Temp (F)	54.0
Flow Rate (GPM)	188.4
Fluid Type Concentration	100% H2O
Pressure Drop (ft. H2O)	20.0
Hot Water	
Capacity (MBH)	1400.0
Leaving Temp (F)	180.0
Entering Temp (F)	160.0
Flow Rate (GPM)	139.8
Fluid Type Concentration	100% H2O
Pressure Drop (ft. H2O)	10.0
Cooling Tower Water	
Entering Temp (F)	85.0
Leaving Temp (F)	94.2
Flow Rate (GPM)	500.0
Fluid Type Concentration	100% H2O
Heat Rejected (MBH)	2300.0

1. Based on studies of multiple different generators and an absorber COP of 0.65.

3.1.2. *High Temperature Engine Package Design*

Introduction

BPE is a manufacturer of pre-packaged CHP systems driven by a 15.9 liter Deutz natural gas engine. BPE's CHP design philosophy is to combine the major subsystems of a CHP application into a skid mounted package that is pre-tested at the factory. These systems include the engine, generator, fuel control system, emissions control components, thermal control valves, an engine jacket heat exchanger, monitoring systems, on-board back-up radiators, and electrical interconnect gear to synchronize and parallel with the utility. The goal of this design philosophy is to minimize costly delays at the construction site, improve manufacturing productivity and quality, increase commonality between different job sites for more efficient service and maintenance, and decrease the difficulty of implementing CHP in the marketplace.

Figure 3. BluePoint Energy 260 kW CHP module

Source: BluePoint Energy, Inc.

The prime mover is manufactured by Deutz and is an industrial lean-burn (7.8% exhaust O_2), turbo-charged and intercooled spark ignition engine. Like all lean-burn engines, it cannot meet the Best Available Control Technology (BACT) limits in the populated areas of California without the application of selective catalytic reduction (SCR) exhaust after treatment or modifying the combustion strategy to one that does not include excess-air. Thus, the solution for offering engine-driven CHP systems has been to modify the combustion strategy to a stoichiometric air/fuel ratio and use non-selective catalytic reduction to meet BACT standards. BPE modified the typical emissions compliance approach by introducing cooled recirculated exhaust gas into the exhaust stream to simulate the charge-dilution effect of excess-air while maintaining stoichiometry for compatibility with a three-way catalyst. The following table provides a comparison of engine variables before and after BPE's emissions strategy changes.

Table 6. Baseline Deutz engine versus BPE modifications

Baseline Deutz Engine Vs. BPE Modifications		
Parameter	Lean-Burn Deutz	BPE Modified Deutz
Engine Shaft Power [kW]:	260	~283
Engine Efficiency:	34.2%	34.7
Bore x Stroke [in (mm)]:	5.19 (132) x 5.71 (145)	same
Displacement [in3 (liters)]:	971 (15.9)	same
Compression Ratio:	12:1	12:1
Geometry:	4 valve/cylinder, V8	same
Combustion Type:	lean-burn, 1.52 lambda	cooled Exhaust Gas Recirculation (EGR), 1.0 lambda
Cylinder Heads:	1 head per cylinder	same
Fuel System:	mechanical	electronic, O2 feedback

Standard Engine Module Design Modifications

Although BPE already had a commercially developed CHP system at the initiation of the Energy Commission project, that CHP system was not optimized for driving absorption chilling in terms of both heat quantity and quality. Prior to the Energy Commission contract, BPE's CHP modules were optimized for low quality hot water heating applications delivering working fluid at 180°F from the engine jacket heat only. Absorption chilling has more sensitivity to heat quality and quantity than most other CHP processes. The performance of the generator section of an absorption chiller is very sensitive to heat quality and is generally derated when the heat input is from the waste heat of a reciprocating ICE. The design goal is to minimize that derate by providing the highest quality (temperature) waste heat.

Several important modifications to the BPE CHP system will be required to achieve the project's heat quantity and quality, and thus, chilling goals. The activities that relate to these CHP system modifications are listed and then described below.

- Increase the nominal operating temperature of the engine jacket.
- Integrate the engine cooling jacket into the absorption chiller hot water loop.
- Increase the engine jacket coolant flow significantly.
- Increase the operating pressure capability and heat rejection capacity of the on-board heat rejection radiators.

- Change EGR source location.
- Modify engine's charge-air intercooler to a two-stage strategy.
- Maximize exhaust heat recovery.

Engine System Design

The following discussion focuses on the design requirements for the various engine components to bring it into compliance with the overall design goals for the project.

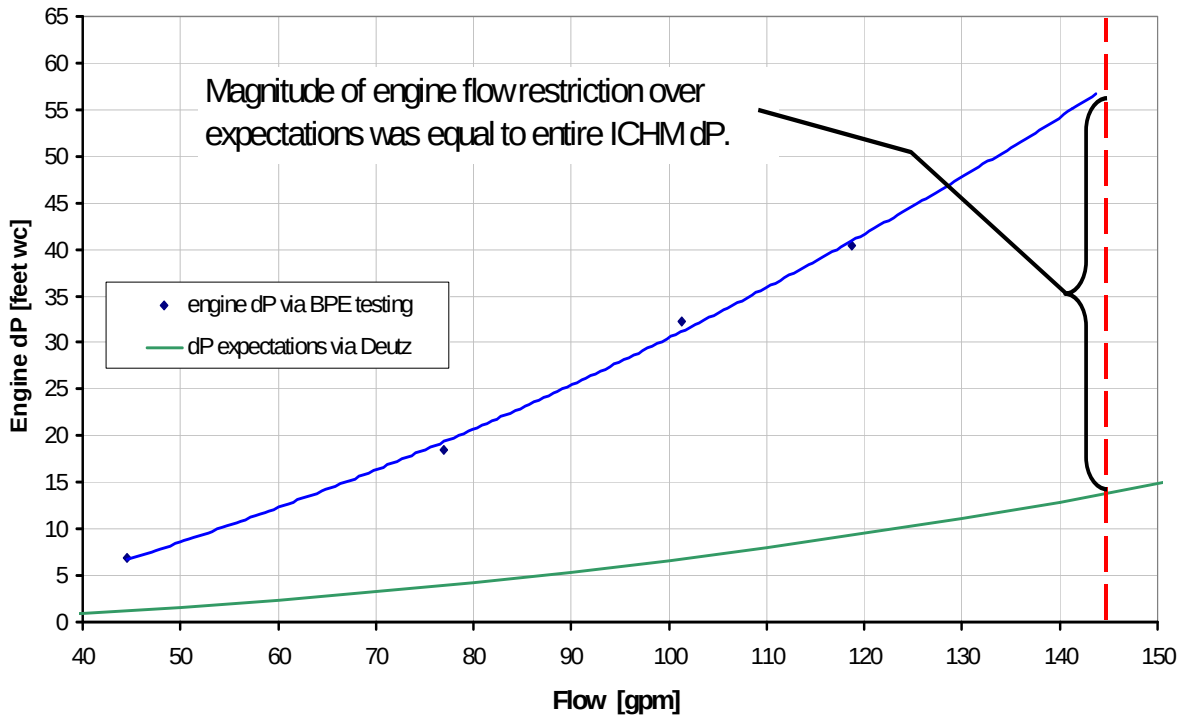
Increase the Nominal Operating Temperature of the Engine Jacket: It should be quite clear that the quality of recovered heat can be increased with increases in the nominal engine cooling jacket temperature (i.e., the heat source). At the time of project initiation, the maximum continuous cooling water inlet/outlet temperature was 176/194°F, a profile that would not serve to provide the best performance from an absorption chiller. Therefore, one of BPE's tasks in the ICHM project was to increase the jacket temperature while maintaining particular cooling jacket temperature and pressure guidelines provided by Deutz over the course of the project. The stated goal of the project proposal was to raise the maximum continuous engine inlet temperature to 195°F and delivery working fluid to the ICHM at 215°F. Through correspondence with Deutz, it was also clear that the coolant flow rate would have to be increased from the typical BPE design in order to address concerns of localized coolant boiling within the engine. Throughout the project, this task involved monitoring particular pressure and temperature differentials across components such as the block, water-jacketed exhaust manifolds, and engine as a whole.

Integrate the Engine Cooling Jacket into the Absorption Chiller Hot Water Loop: BPE's standard CHP configuration is to separate the engine cooling jacket from the heat-driven process with a decoupling heat exchanger. This has many benefits, but also reduces the maximum temperature than can be delivered to the client. In order to optimize the heat quality to the absorption chiller, BPE removed the decoupling heat exchanger from its hydronic loop. Thus, engine coolant would travel directly through the EHRU and to the ICHM for this project, whereas normally it would be only water from an independent, lower temperature loop that would flow through those devices.

There were some direct design consequences to accommodate due to this change in hydronic methodology. First, the standard engine driven coolant pump would no longer be able to accommodate the flow needs of the engine CHP package due to the increased flow losses from the additional components not normally in BPE's hydronic loop, namely the EHRU, absorption chiller, two ICHM thermal control valves, and intermediate piping between the CHP and ICHM systems. Thus the new system required an electrically driven pump sized to accommodate both the CHP and ICHM systems. This higher pumping capacity also necessitated a second distinct design change, a requirement for BPE to alter its on-board dump radiators to accommodate higher system pressures. The standard BPE radiators could not withstand the higher operating pressures that would result from the engine CHP cooling loop being integrated with the ICHM hot water loop and would have to be constructed with a different core methodology.

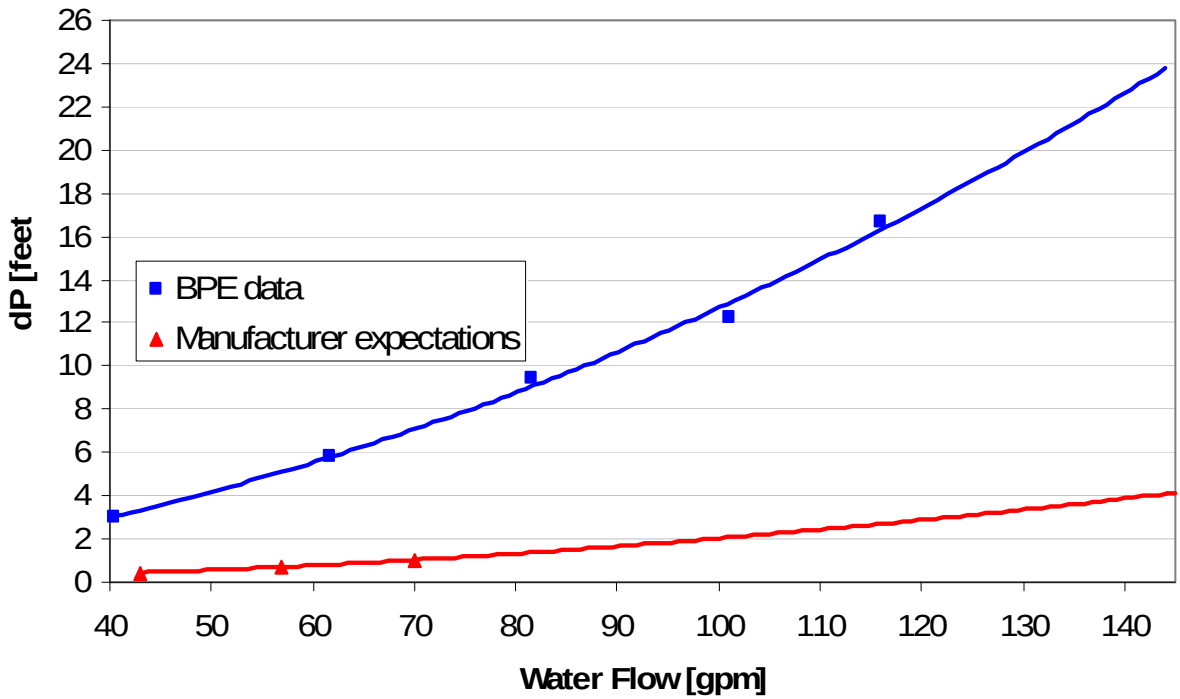
Both of these design consequences had unforeseen challenges that created delays during the course of the project. Several delays were associated with discovering and overcoming great difficulty in achieving higher coolant flow rate targets. It was found that the engine and EHRU both had pressure versus flow characteristics that were several times more restrictive than manufacturer guidance had predicted (see Figures 4 and 5). The additional pressure drop quantified in the engine alone was more than the predicted pressure drop from the entire ICHM system. The flow issues were overcome via a combination of modifying the EHRU flow circuit and simply increasing the size of the pump.

Figure 4. Engine flow versus pressure drop – expectations and reality



Source: BluePoint Energy, Inc.

Figure 5. EHRU flow versus pressure drop – expectations and reality



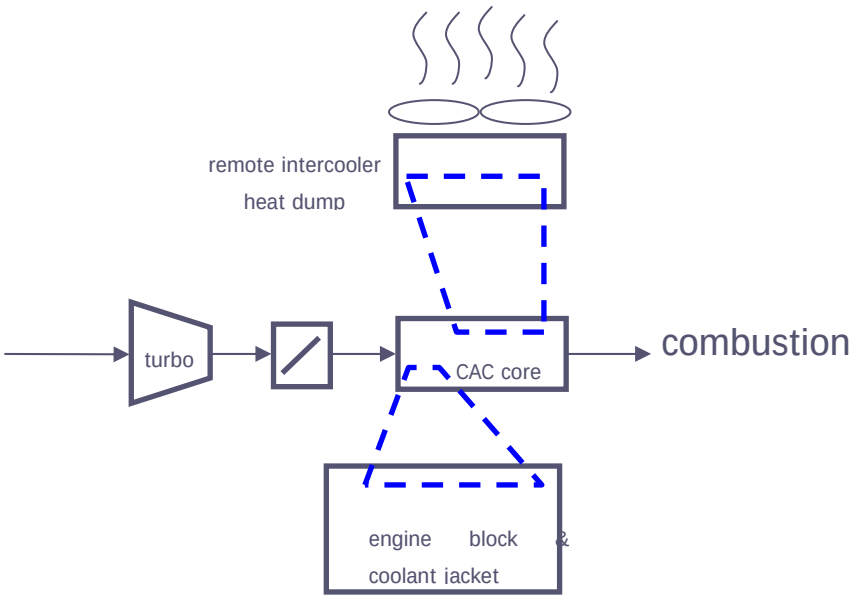
Source: BluePoint Energy, Inc.

Increase the Engine Jacket Coolant Flow significantly: As stated above, it was a design element of this project to increase the nominal flow rate of the coolant through the engine from its original CHP flow of approximately 100 gallons per minute (gpm). This requirement was based on a number of factors. First, the goal for higher nominal engine jacket temperatures required a need for higher flow rates through the jacket to address concerns of localized coolant boiling. Second, the jacket heat was going to increase as a result of the project in such a way as to require the higher flow rates to further protect engine components. Lastly, guidance from Integrated CHP Systems, Corp, the lead for chiller activities in the ICHM project, suggested a higher flow rate, such as 145 gpm, that produced a smaller chiller differential temperature, was better for chiller performance than a lower flow rate and higher differential temperature.

Modify the Engine's Charge-Air Intercooler to a Two-Stage Strategy: In the standard BPE charge-air intercooler circuit, the intercooler heat is rejected to the atmosphere through an independent cooling circuit rather than to the engine jacket coolant. The advantage of this strategy is that it provides superior charge-air cooling and increases the allowable power output from the engine for a given level of detonation tolerance. The disadvantage of the independent cooling circuit is that the heat is rejected to atmosphere rather than to a recoverable fluid; thus, lowering the total system CHP efficiency.

BPE designed a modification to the intercooler circuit for the Energy Commission ICHM project in order to maintain superior charge-air cooling while not losing all of the potential heat to the atmosphere. This modification turned the Deutz intercooler into a two-stage device rather than single-stage (see Figure 6). Intercooler plenums were modified such that two independent cooling circuits would exist with the same intercooler core. The engine jacket water would perform the initial phase of cooling from the charge-air exiting the turbocharger compressor and would capture heat in a recoverable fashion. An independent cooling circuit would be maintained within the latter portion of the engine's intercooler core to maintain a charge-air temperature that would mitigate any need for a reduction in the maximum power output. This design change was predicted to increase recovered heat by up to 100,000 Btu/hr.

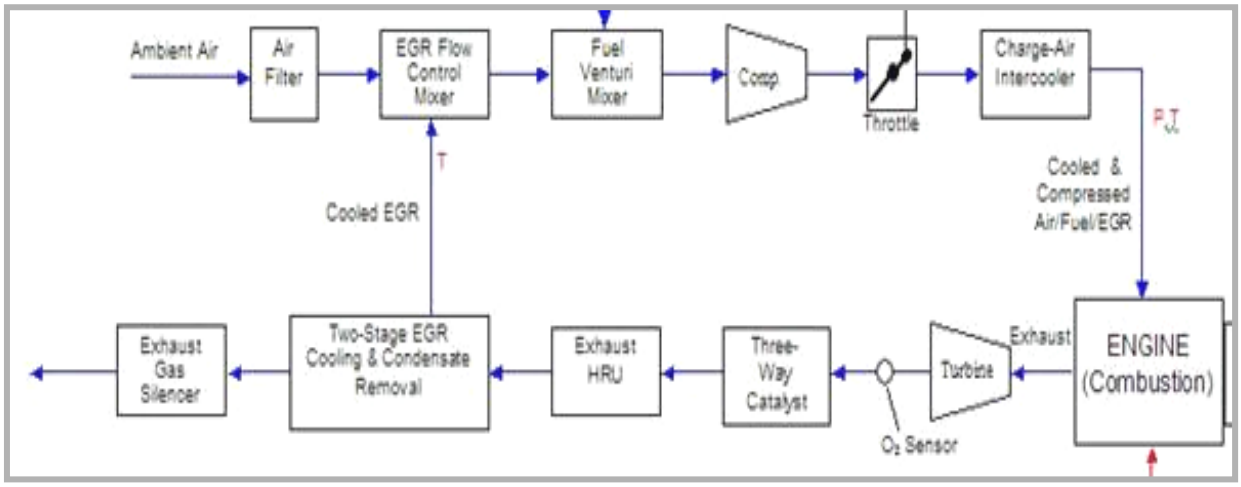
Figure 6. BPE modified the intercooler to increase heat recovery



Source: BluePoint Energy, Inc.

Change EGR Source Location: BPE's standard EGR cooling methodology involves a two-stage cooling process with the EGR being sourced before the catalyst. As with the original intercooler circuit, the EGR cooling process rejects heat to the atmosphere for optimum cooling at the expense of total recovered heat. To meet the goals of the Energy Commission ICHM project, the EGR process was modified as shown in Figure 7. The first stage of EGR cooling was modified to be the external exhaust gas heat exchanger. Thus, the total recovered heat was increased over the standard configuration by increasing the total exhaust mass through the EHRU. It was predicted that up to 100,000 Btu/hr could be gained by modifying the EGR cooling process as described.

Figure 7. The modified EGR process for the ICHM project



Source: BluePoint Energy, Inc.

Implementing the modified EGR process involved modifying the EGR induction and regulation process to be compatible with the changed flow scheme. Testing was required to demonstrate EGR control over the full load spectrum and continued emissions control capability. These internal goals were met for the modified EGR process.

Dump Heat Radiator Design

BPE was going to make two changes to the CHP package for the Energy Commission ICHM project that would have implications on its standard integrated dump radiators. The engine's cooling jacket was going to be integrated with the hot water circuit for the absorption chiller, which dictated a requirement for higher operating pressures at the dump radiators, in fact, more that the standard radiator core design allowed for. Second, the CHP package was going to be modified to drive more heat into the coolant than ever before by increasing engine jacket heat and adding exhaust heat; thus, requiring additional heat rejection capacity from the radiators. Neither of these requirements were expected to pose any notable problems. Rather they were simply addressed in enhanced specifications to the heat exchanger manufacturer. The manufacturer responded with an alternative core design compatible with the pressure requirements and larger dimensions for the enhanced heat requirement.

Once received and integrated into the CHP package, however, the radiators were found to have insufficient heat rejection capacity by approximately 45%. BPE performed a number of experiments over time in order to generate a full data set that convinced all involved parties that the deficiencies were real. Every parameter important to the radiator performance, air flow, ambient air temperature and density, and coolant flow, was verified through testing. Unfortunately, even with the performance limitations defined and accepted by the radiator manufacturer, there was no immediate solution. The radiator cores were the maximum length available from the manufacturer, and increasing the height was not conducive to the package

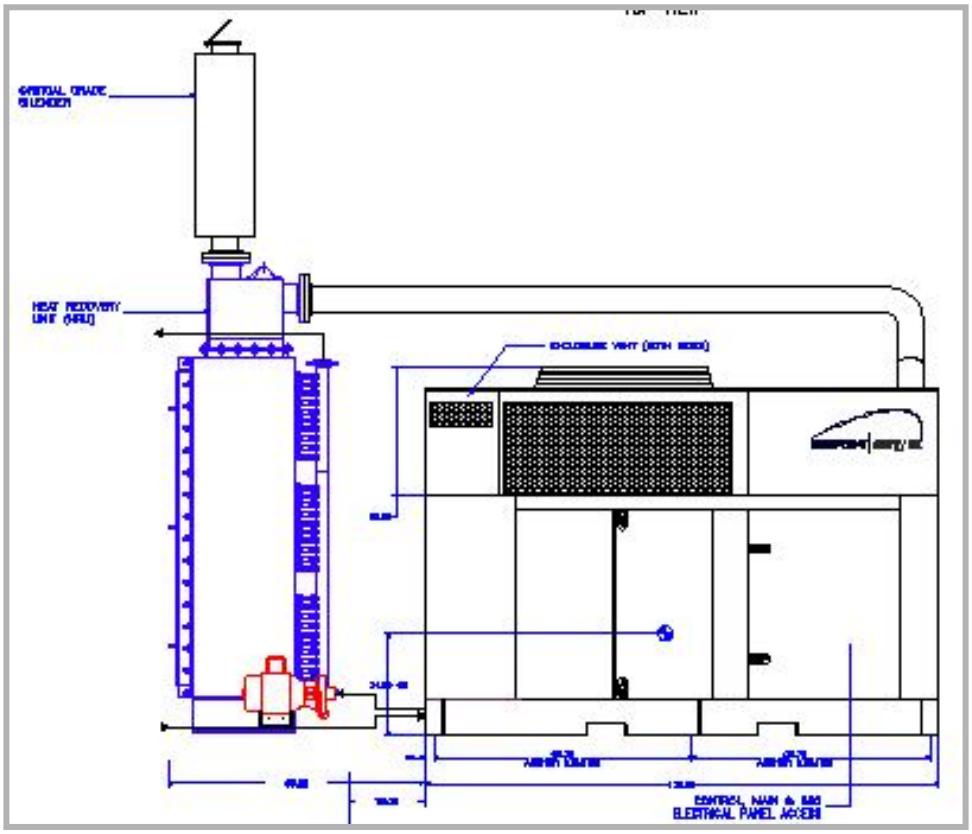
that had already been built. The fact that the dump radiators had been integrated into the general design of the cabinet greatly complicated any efficient resolution to the problem. The final solution involved providing a single larger stand-alone dump radiator coil equipped with three Variable-frequency Drive (VFD) controlled three-phase motor driven fans. This external dump radiator system was integrated into the site after the High Temperature Engine Package (HTEP) was modified heavily to remove the integrated dump radiators and associated three-way bypass valve.

Exhaust Heat Recovery Unit (EHRU) Design

Achieving the goals of the Energy Commission ICHM project would require a high level of exhaust gas heat recovery; thus, would require a relatively large heat exchanger. Furthermore, with at least two three-way catalysts and silencer in the exhaust stream, it was further desired to use an EHRU with low exhaust pressure drop to mitigate total exhaust backpressure effects. The low backpressure requirement resulted in the need for an even larger EHRU. To accommodate both of these design goals, the EHRU specified for this purpose was a self-supported vertically oriented finned tube assembly with an integrated exhaust bypass valve. The purpose of the bypass valve was to function as a reserve mechanism to reduce thermal transfer to the ICHM and BPE's on-board dump radiators in the event there was a temporary lack in client chilling or heating demand. Although the dump radiators were being designed to accommodate all of the heat from the engine and the EHRU, the exhaust bypass was seen as a way to increase the safety margin for heat rejection capability. The very size of the EHRU required the use of a self-supporting architecture separated from the main body of the engine CHP system.

The heat recovery process proved problematic. A significant lack of EHRU performance from the manufacturer's predictions created significant delays and induced many series of tests and experimental setups that would have otherwise been unnecessary. The evolutionary performance of the EHRU is described in the Test Results and Analysis sections of this report.

Figure 8. The EHRU was selected for high heat recovery and low pressure drop



Source: BluePoint Energy, Inc.

3.2. Factory Testing

As with the design task, the ICHM and BPE Engine Package were tested independently in separate locations. Each test plan and factory test was designed and performed to simulate the output from the other device if appropriate and provide guidance on the integrity of each component as well as to project integrated performance. The main reason for factory testing was to identify shortfalls in performance, component defects, or control problems so that these items could be remedied before the sub-system was delivered to the site.

3.2.1. *Integrated Cooling and Heating Module Test*

ICHM Test Introduction

The ICHM was subject to a functional test and leak check at the fabrication facility before it was shipped to the York factory for full performance testing. A test plan was then devised to provide sufficient data to measure the performance of the ICHM at site conditions. The system was shipped to York, Pennsylvania and installed and tested at the factory using available hot water, condenser water and cooling load to emulate expected site conditions.

ICHM Functional Test and Leak Check

Three phase power of 230 V, was applied to the ICHM distribution panel and the unit was turned on. The ICHM panel, lights and fan were powered on and inspected. Control voltage of 24 V was applied to the 3-way valves and rotation was checked.

The ICHM control panel was bench tested using a laptop computer with Allen Bradley software installed. The program was tested by observing relay sequencing indicator lights on the Programmable Logic Controller (PLC). The modem was also tested for connectivity. The tests indicated the program to operate the correct relays according to the computer generated input values.

Finally, a pump was connected to the inlet end of the loop and the outlet was blanked off. Eighty five psig was applied to each loop. The pressure was maintained and each joint was bubble tested. The first test indicated a leak in one loop. This was repaired and a second leak check applied, which resulted in no leak in any loop.

ICHM Performance Test Plan

York International Corporation will test the ICHM in accordance with the industry standards set forth by the ARI. The specific standard related to absorption chillers is ARI 560-2000, *Absorption Water Chilling and Water Heating Packages*. The standard clearly outlines the definitions, standard equipment, and rating requirements involved with measuring a chiller's performance.

As the researchers are testing only the ICHM, we are concerned with the thermal device only. The ICHM device boundary incorporates the chiller, condenser water pump and cooling tower fan. The ICHM does not incorporate the hot fluid (engine coolant) pump. This pump is incorporated in the engine generator device boundary.

The ICHM test at York cannot incorporate condenser water pump or cooling tower fan parasitic loads as the York test platform uses a centralized condenser water system. This does not allow for simulation of the device or system boundary according to the Association of State Energy Research and Technology Transfer Institutions (ASERTTI) field test protocol. In addition, the coolant rig available at the test site is a steam-to-hot water heat exchanger with no glycol present, so the authors are unable to test the system with the intended hot fluid per the protocol requirements. Extrapolations will be made based on the hot water performance, but this is not in line with the protocol. Furthermore, the intended fluid is ethylene glycol while the protocol only refers to propylene glycol.

The York test facility and procedures are set-up in accordance with ARI 560, which has different tolerances to those incorporated in the ASERTTI protocol. ARI flow accuracy is +/- 5% and temperature accuracy is +/- 0.5°F, whereas the protocol calls for a flow accuracy of 1% and a temperature accuracy of 0.6°F. These tolerances should be standardized around one method because hot fluid and cooling tower flow can vary based on valve position. The authors would suggest the wider tolerance is more appropriate.

The absorption test facility in York, PA is designed to performance test absorption water chillers within the specification outlined in ARI 560-2000. The test stand utilizes pumped chilled and condenser water circuits to simulate actual conditions experienced in a field application. Loading of the chiller is accomplished by mixing a portion of warmer condenser water into the chilled water circuit. The water flows and temperatures are controlled by pneumatic operated valves. Excess heat not needed to load the chiller is rejected by the cooling towers. To emulate hot water supply, steam from the boiler passes through a heat exchanger, heating a closed water loop, which is run through the chiller and supplies the hot water at the necessary conditions.

The test data is measured by means of calibrated and traceable Resistance Thermometer Devices (RTDs), as well as turbine flow meters for the chilled (evaporator) and tower (absorber/condenser) circuits. Pressure drop data is taken by the differential pressure gauges on both the chilled and condenser circuits. Calibrations are performed in accordance with ARI, American Society of Mechanical Engineers (ASME), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), National Institute of Standards and Technology (NIST), and internal York standards. Additional temperatures and pressures are taken to monitor various internal conditions for reference only. The temperatures are typically taken by thermocouples and the pressures are taken by transducers. Pressure gauges are also used to verify transducer readings.

The ICHM is to be connected to the heating, chilled and condenser water circuits as well as the electrical power. Solution (LiBr) and refrigerant (deionized water) are then charged into the chiller and optimized for the best performance. The chiller flow control valves are then set to optimize the internal cycle flows and concentrations. These concentrations are verified by taking samples at various locations on the chiller. The ICHM flow control valves are then set and balanced in accordance with design parameters.

ICHM Test Results

The factory performance test is conducted based on the above mentioned ARI 560 –2000. This allows certain tolerances on performance and energy input based on the percent load and evaporator temperature split. A typical 10°F evaporator split allows +/-5% tolerance on both the capacity and heat input per ton at the full load point. Additional tolerances are also specified in the ARI 560-2000 for all performance temperatures (+/-0.5°F), flow rates (+/-5%), and pressure drops (+/-15%). A Resident Engineer is present to verify the test data to ensure it complies with the standards discussed above. Once the chiller achieves the necessary performance, a series of data is taken to verify steady state.

The data is then used to generate a test report which shows the design conditions as well as the actual results of the test. During the testing period, personnel from ICHPS as well as the controls designer from Kent Academic Repository (KAR) were available to participate in the testing and observe the performance.

The factory performance test parameters were somewhat different than the original design test parameters or the eventual field test parameters. As the BPE Generator Package was being tested concurrent with the ICHM testing, the hot water conditions were slightly changed from those given in the original design conditions. In addition, as mentioned above, the York test platform did not have ethylene glycol available, so hot water flows were corrected to account for the different heat transfer properties.

The ICHM JCI/York Absorption Chiller Factory Test Report is attached (Appendix). The cover page for this report is shown in Figure 9.

Figure 9. ICHM/YIA Absorption Chiller Factory Test Report Cover

YORK® INTERNATIONAL CORPORATION

ICHM/YIA Absorption Chiller Factory Test Report

York Order: 04-106497-01
Model: ICHM YIA-HW-1A1-28-C-S-B
Serial Number: UKNM018428
Tested: April 8, 2005

UNIT SPECIFICATIONS:

78.0 Evaporator Tons at **44.0**°F Leaving Chilled Water and **53.9**°F Entering Chilled Water
188.4 US GPM of Chilled Water Flow with **6.8** ft. of H_2O Pressure Drop
0.00010 Btu/h·ft·°F Evaporator Tube Fouling Factor

500.0 US GPM of Cooling Water Flow through the Absorber/Condenser with **10.3**ft. of H_2O Pressure Drop
85.0°F Water entering the Absorber and **94.1**°F Water leaving the Condenser
0.00025 Btu/h·ft·°F Absorber/Condenser Tube Fouling Factor

1330.1 MBH Cooling Heat Input
115.0 US GPM of Cooling Water Flow through the Generator with **4.5** ft. of H_2O Pressure Drop
217.4°F Water entering and **192.2**°F Water leaving the Generator
0.00010 Btu/h·ft·°F Generator Tube Fouling Factor
35% Ethylene Glycol

Testing Method

The factory performance test is conducted based on ARI 560-2000. This allows certain tolerances on performance and energy input based on the percent load and evaporator temperature split. Design temperatures are adjusted to allow for the clean tube conditions of a newly manufactured unit and also a temperature adjustment is made allowing for 100% water (design condition is 35% E.G.) in the hot water circuit.

The ICHM unit was connected to the 100 ton Test Facility at York International, Building 19. Equipment within the ICHM such as the cooling water pump, temperature sensors, control panel, electrical transformer, flow control valves, etc. were powered and operated during the testing.

Monday, April 11, 2005.max

Source: Johnson Controls International/York, Inc.

3.2.2. *High Temperature Engine(HTE) Package Test*

HTE CHP Test Introduction

A variety of functionality tests were performed on the High Temperature Engine CHP Module at the BPE facility. The intent of these tests was to exercise the various subsystems of the CHP module to increase the efficiency of the installation of the system during the Field Test by uncovering subsystem issues in the factory rather than in the field. Functionality tests were performed in the following areas:

- Hydronic integrity
- Air/fuel ratio and emissions control
- Ignition control
- Governor speed control on load bank and grid parallel operation
- Generator voltage regulator control for power factor and VAR control
- Dump radiator capacity

Engine Module Test Description

Hydronic Integrity: The hydronic system in the HTE CHP Module consists of custom piping, fittings, pressure relief components, and a thermal control valve. The purpose of testing the hydronic integrity is to verify that the system is not delivered with leaks due to component cracks, porous welds, improper flange and gasket interfaces, or installation error. This test was performed by running the HTE CHP Module for several hours at operating temperature while allowing the system pressure to cycle to maximum allowable conditions. The hydronic system was inspected during and after the testing and zero observable leakage was verified.

Air/Fuel Ratio & Emissions Control: The air/fuel ratio control system consists of a fuel shutoff valve, a full-authority fuel delivery control valve, and heated exhaust gas oxygen (HEGO) sensor. The fuel control valve is an electronic pressure control valve programmed to deliver a constant fuel supply pressure to the intake air stream (open-loop control) unless biased by feedback from the HEGO sensor (closed-loop control). A series of steps defined the functionality testing process for the air/fuel ratio and emissions control system. These steps were:

- Perform hardware and software setups that achieve proper engine starting and no-load 60 Hz operation.
- Confirm the valve has reserve capacity at full load in order to ensure “full-authority” is maintained under high demand.
- Tune the HEGO feedback control loop to achieve proper TWC reduction of emissions and compliance within regulatory limits.
- Repeat the process with complete start/full load/stop cycles and make adjustments as necessary until all conditions are mutually satisfied.

Ignition Control: Functionality testing of the ignition system is obviously a required component of having a running engine. The functionality testing proved: 1) the capacitive discharge system wiring and control setup achieved ignition in the proper firing order; 2) desired ignition timing values were achieved in actual operation; and 3) the Hall effect sensor responsible for providing piston position information to the ignition control unit was properly configured to facilitate #1 and #2.

Governor Speed Control: Stable engine speed control requires tuning of the mechanical arrangement of the linkage between the throttle-to-actuator and tuning of the proportional and integral gain settings in the closed-loop speed controller. This process was implemented and tested at BPE with a load bank. Operation with a load bank allowed the speed control system to be tested from no load to full load without the interfering constraints that would have occurred if paralleled to the grid. Successful testing of the speed governing then allowed testing of generator-to-grid synchronization and automatic load control.

Automatic Voltage Regulator Control: The ability to operate in parallel to the utility grid requires precise control of the generator voltage. BPE's functionality configuration and testing of generator voltage control proceeded as follows. First the automatic voltage regulator (AVR) was configured for nominal operating conditions. BPE ensured that the control system could manipulate the AVR to achieve the complete range of voltage adjustment expected to be encountered in the field. This initiated the process of tuning the voltage control algorithms in the grid synchronizer such that the generator could be initially connected to the grid. Next, the algorithms were tuned until power factor and reactive power could be controlled at specific settings as the generator was loaded in parallel with the utility. Functionality testing of the AVR and external biasing systems was complete when the generator could synchronize to the grid and hold any commanded power factor or reactive power set point between 0.8 lagging and 0.95 leading.

Dump Radiator Capacity: BPE's current radiator supplier was tasked to design and build radiators for BPE's role in the Energy Commission ICHM project. These new radiators were to accommodate the heat rejection of both the engine jacket and exhaust heat. It was identified that the enhanced radiators would have to use a different design and construction methodology to accommodate much higher pressures expected in the HTE CHP Module development. Operational conditions and/or performance parameters for the radiator design are defined in the following table. The design dictated that the radiators were to accommodate 1.44 MMBH of heat rejection on a 110°F day at sea level or a 95°F day under conditions representative of BPE's test facility at 4400 ft. altitude. Other parameters and constraints were developed between BPE and the supplier prior to production and then the radiators were constructed. After receiving the radiators, BPE performed two basic functionality tests to assess radiator capacity.

Table 7. BPE radiator test conditions

Parameter	warm Reno	hot sea level	Source	Comment
Ethylene glycol fraction:	35%	35%	BPE	Design parameter.
Ambient air pressure [psia]:	12.5	14.7	BPE	Amb. profile at non-ideal conditions.
Ambient air temp [°F]:	95	110	BPE	Amb. profiles at non-ideal conditions.
Radiator core length [in]:	88	88	BPE	Maximum real estate parameter.
Radiator core height [in]:	20	20	BPE	Maximum real estate parameter.
Radiator core width [in]:	4	4	BPE	Assumed max.
Coolant inlet temp [°F]:	215.2	215.2	BPE	Design parameter.
Coolant exit temp [°F]:	194	194	BPE	Design parameter.
Coolant flow rate [gpm]:	145	145	BPE	Design parameter.
Density of Water [lb/gal]:	8.34	8.34	BPE	
Specific Gravity of solution:	1.02	1.02	BPE	
cp [Btu/lbm-R]:	0.925	0.925	BPE	
Heat rejection required [Btu/hr]:	1,451,320	1,451,320	BPE	Design parameter.
Core Height (in.)	58	58	supplier	Max core parameter per supplier.
Core Width (in.)	23.125	23.125	supplier	Limited based on BPE needs.
Core Depth (in.)	4.5	4.5	supplier	Limit based on core design.
Core Type	Alum.	Alum.	supplier	
# Cores Req'd (in parallel)	2	2	supplier	
Operating Press. (psig)	60	60	supplier	
Airflow reqd by cores (cfm)	16500	16500	supplier	Supplier calculation.
Core DP (in. H2O)	1.1	0.85	supplier	

Engine Module Test Results

Tests of the air/fuel ratio, emissions, ignition, speed governing, voltage, power factor, real power, reactive power, and utility synchronization control systems showed acceptable performance. Testing of the on-board radiator capacity demonstrated unacceptable performance that will be rectified at the field test site. While the effects of the radiator capacity have been troublesome to the project, the experience serves to demonstrate the value of prepackaged CHP equipment that is pre-tested rather than "stick-built" at the installation location. Each functionality test could have uncovered a flaw between manufacturer claims and reality, issues that are more difficult to resolve in the field.

The basic expectation for the radiator functionality test was for the engine to be able to operate at full load at BPE's 4400 ft altitude at 95°F with only the integrated radiators providing heat rejection for the engine jacket and EHRU. However, the factory testing demonstrated far less performance than required as evidenced by the inability to operate the engine at full load without exceeding engine coolant temperature limits.

Typical of many functionality tests is the fact that test conditions were not controlled to the conditions specified in the radiator design, something which must be considered when claiming that a device is not working to expectations. A brief review of the parameters most likely to have negatively influenced the radiator performance, showed that the test conditions were quite beneficial to the performance. Deviation highlights from the two functionality tests include:

- Total radiator air flow was measured at 19,211 cfm rather than 16,500 cfm required by supplier calculations. This should have benefited the radiator performance.
- Ambient air temp was < 62°F for Test #1 and 76°F for Test #2. This was beneficial to performance compared to design parameters.
- Test #1 and Test #2 were performed with water rather than an EG mix. This was beneficial to performance compared to the 35% EG design parameters.
- During Test #2, total coolant flow was limited to approximately 95 gpm. This parameter does not account for the performance deviations.

The first test involved a cooling circuit that included the engine, an EHRU, the new supplier radiators, pumps, and a flow meter. The flow meter and two temperature sensors provided heat data through an Onicon Btu meter.

Previous testing had demonstrated a maximum of 1300 MBTU/hr heat output from the engine and exhaust for the configuration tested while at 268 kW gross electric output. Heat output expectations from the engine system were originally thought to be 1400 MBTU/hr of rejection, so this test was actually a less demanding test than was intended for the radiators. The simplistic goal of the test was to determine whether or not the engine inlet temperature could be maintained at 195°F with the engine at full load and the system producing ~1300 MBTU/hr of heat.

Unfortunately, a 195°F engine inlet temperature could not be maintained for loads over 195 kW. Heat measurements showed 977 MBTU/hr at 195 kW giving some indication of the upper performance limit of the radiators.

In a second test, the EHRU was completely removed from the engine configuration. The maximum heat output from the remaining engine system had been previously quantified as 900-930 MBTU/hr for the configuration tested. The goal of Test #2 was to determine whether or not the radiators could accommodate just the base full load engine heat. The complete flow circuit for the Test #2 experiment included the engine, a plate heat exchanger, a thermal control valve, the engine's mechanical water pump, and the dump radiators. The engine's mechanical water pump replaced the remote electric pumps of Test #1. This had the effect of reducing total water flow to approximately 95 gpm. The plate heat exchanger provided no heat exchange as the second circuit was dry. The thermal control valve was fixed such that all available flow went through the radiators.

Ambient air to the radiators was 76°F while gross generator output was 268 kW and maximum heat rejection requirements were expected to be about 900-930 MBTU/hr. The experiment was stopped when the engine water inlet temperature climbed through 190°F at a rate that suggested maintaining 195°F on a hot summer day was not realistic.

Twenty five air velocity measurements were made on the face of each radiator (50 points total) to determine total volumetric air flow. The calculated flow was over 19,000 cfm and applies to both Test #1 and #2. This was much higher than the 16,500 cfm recommended by supplier calculations and clearly should have increased the radiator's heat rejection capacity, especially given low ambient air temperatures.

The radiator manufacturer was never able to explain the severe lack of performance even after an on-site investigation of the radiator construction, BPE test data, data collection methodologies, test facilities, and a subsequent review of the manufacturer's performance modeling using inputs from the actual test conditions.

Out of concern for the needs of the host of the field test, it was decided that an external dump radiator system would be purchased and integrated at the site. The heat rejection capacity for this system is rated at 1700 Btu/hr and was procured through an alternative vendor other than BPE's current production integrated radiators. The functionality test for this system will occur at the site.

3.3. Field Test

3.3.1. *Field Test Site Selection*

An engine CHP ICHM brochure describing the BPE ICHM system was put together along with a prospectus to solicit prospective field test site hosts. Select DG Developers along with BPE's Southern California Sales network were contacted regarding prospective field test host sites. Desired host site features include adequate base electric, chiller and hot water loads, in Southern California Gas service territory, location for CHP system near other utilities, willingness to pay for a majority of the project costs, acceptable project economics, simple

ownership structure, and in good credit standing. Based on these criteria, Normandie Casino in Gardena was selected for the field test. Several engineering coordination meetings were held with the Normandie staff and with the selected installation contractor, next>edge before Normandie was notified of their selection. The field test agreement outlining the respective roles and responsibilities among the field test participants was signed in July 2005 by DE Solutions, BPE, and next>edge.

3.3.2. *Site Design*

General Description

The Normandie Casino has installed a CHP generation plant to provide electricity, chilled water for air conditioning and heated water for domestic consumption. The generator system was supplied as a multiple skid-mounted package of components with points of connection shown for product interconnection and building system integration. Control of the package is a self-contained network of PLC and Application Specific controllers, and interfaces to and reports its status via a ModBus RTU data network connected to a new Siemens Building Technologies (SBT) Apogee digital building control system. Most of the major existing building air handling units have been connected to the SBT system to provide a coordinated system control scenario that maximizes CHP utilization.

Design Intent

The CHP system was located on the ground outside and to the rear of the casino facility, adjacent to an existing chiller building, cooling tower, pumps and emergency generators. Chilled water was designed to be piped in parallel with the existing chiller plants and intercept the chilled water lines outdoors, feeding the original mechanical equipment room.

Heating water from a heat exchanger on the ICHM skid will be circulated by a water pump up to a double-walled secondary heat exchanger in the boiler room. A domestic heating water pump circulates water from the domestic hot water storage tank through the secondary side of the heat exchanger, thus heating the domestic water in the storage tank while reducing the heating demand on the existing gas heater system. Control of the two existing heaters and the new heat exchanger with pumps will be integrated into the SBT digital control system. The heat exchanger and pump answers the first call for heat, followed by the lead heater/pump and then by the lag heater/pump. Lead heater operation will be switched daily to balance the wear between the two. When the Domestic Hot Water (DHW) storage tank has reached the setpoint temperature, the new circulating pump to the double-walled heat exchanger will be stopped. The pump at the cogeneration skid providing the heated primary water will continue to run as long as the cogeneration system is in operation.

Chilled water from the absorption chiller on the ICHM skid will be circulated by a new chilled water pump into the existing outdoor chilled water tie lines feeding the “rack” chiller and its loads in the original second floor mechanical room. The injection rate will be controlled by a mechanically operated flow regulating valve to maintain constant chilled water flow to “base-load” the absorption chiller in either existing chiller operational scenario. Between the rack chiller and the absorption chiller, the facility cooling load could be covered the majority of the

time and the centrifugal chiller would only need to be operated during peak summer weather conditions.

Starting and stopping of the existing building chillers is accomplished manually by operator intervention. Starting the centrifugal chiller will require opening the manual stop valves at the condenser and cooler, and then enabling one chilled water pump and one condenser water pump.

The "rack" chiller must be stopped manually and its condenser valved off when the centrifugal chiller is started, as both existing chillers cannot operate simultaneously. When the centrifugal chiller has been lined up and started, the new absorption chiller will remain base loaded with its flow rate adjusted automatically by the flow regulator to inject the proper flow with the new set of pumping dynamics established by the centrifugal chiller's chilled water pump. The centrifugal chiller has two chilled water pumps, one of which must operate when the centrifugal chiller is to be used.

Each domestic hot water heater has a 24 volts of alternating current (VAC) start/stop command relay interfaced with the SBT digital control system. The circulating pumps for each heater are started immediately after the start command has been issued and are delayed via internal timing relays after the stop command is issued, to cool down the heater before stopping the pump.

Water temperatures are monitored via 1000 ohm platinum sensing elements connected to the SBT digital control system, located as shown on the P&ID drawings. Chilled and heated water flows are monitored by a third-party Supervisory Control and Data Acquisition (SCADA) system (DCS) and BTU's will be calculated to provide trends for performance verification of the entire system. The third-party SCADA system is not deployed as a permanent feature of the installation.

Interior space temperatures will be monitored by 1000 ohm platinum sensing elements in wall mounted enclosures, in the same positions as the present pneumatic thermostats. Space temperatures will be sent to the SBT control system for control of the respective air handlers as an indication of space temperature inside the casino.

Each air handler has a 1000 ohm platinum averaging type supply air temperature sensor located in the discharge plenums of the respective air handling units. An outside air temperature sensor is located on the north side of the building, providing ambient information for system operating reset and lockout functions. These sensors are connected to the SBT digital control system.

Three of the older five large air handling units had new cooling coils added. New control valves with electric actuators connected to the SBT digital control system have been provided for each air handler. The cooling coils for the air handlers will be controlled to maintain a reset schedule for space temperature control. The economizers on the original Air Handling Units (AHUs) will not be used, nor will the return fans on the two original casino systems.

The large, newer variable air volume (VAV) air handler received a new electric actuator for its cooling coil control valve. The return air damper was placed back into service with a new electric actuator to restore economizer service to the areas served by this system.

The economizer can be enabled or disabled by a common dry bulb temperature based control strategy, comparing average space temperature to outside air temperature with a high limit of 75°F outside air (OA) to prevent refrigeration system overload. Once enabled, the economizers will provide as much cooling as they can and chilled water will be metered in to satisfy additional cooling need past what the economizer can handle. The economizer will be throttled back in sequence with the cooling coil control valve so that the space temperature can be controlled proportionally. This will prevent the tendency to overcool the spaces during the winter months.

New control valves for each air handling unit and the economizer dampers have new analog electric actuators responding to 0-10V DC proportional control signals.

PID set points, tuning constants and event pick-points were established as a means for easy adjustment by the user from the operator workstation. Each shall be available for adjustment from a graphic screen without having to open the system programming code to make the adjustments.

Coordination of the operation of the absorption chiller with its condenser water pump, tower fan and chilled water medium pump, as well as the heating water heat exchanger, heating water medium pump and equipment status inside the skid will be relayed via the ModBus RTU connection to SBT.

Certain variables and event toggles are needed to properly coordinate the building system operation with the CHP plant operation. The details of this interface are being worked out with the CHP skid supplier for proper coordination. Please see point list definitions for these functions.

3.3.3. *Site Construction*

Site construction commenced in December 2005. By March 2006: a) major equipment such as the HTEP, ICHM, cooling tower, exhaust gas heat exchanger, and external dump radiator coil were crane-lifted into place; b) 80% of high-voltage wires were pulled and; c) the Southern California Edison (SCE) utility panel was installed.

Figure 10. Site equipment installation

Source: DE Solutions, Inc.

The setting of these components and the receipt of pumps and other hydronic hardware in the following month allowed the significant task of electrical and mechanical interconnection between major equipment and the facility to commence.

While there were many delays on individual site construction tasks, some items stand out as having caused significant disruption to the timeline of the installation. Significant delays to the construction phase were associated with: a) relocating the remote dump heat radiator assembly; b) designing and installing a replacement to the Encorp generator and utility interconnect control system (Encorp had gone out of business); and c) performing a number of significant retrofits to the BPE HTEP to accommodate system changes that were not in the original as-shipped design, but were deemed to be beneficial to the installation. A permit for the dump radiator relocation was not obtained until late August 2006. The relocation and electrical/mechanical integration of the dump radiator assembly occurred in September 2006. A new generator control system was designed and installed by April 2006, but not operational until December 2006. By December 2006 to January 2007, the site construction was complete enough to support pre-parallel testing, SCE and emissions source testing with AQMD, and initial field commissioning work for the combined major equipment.

Figure 11. Remote heat dump radiator shown at final location with new pad and new piping

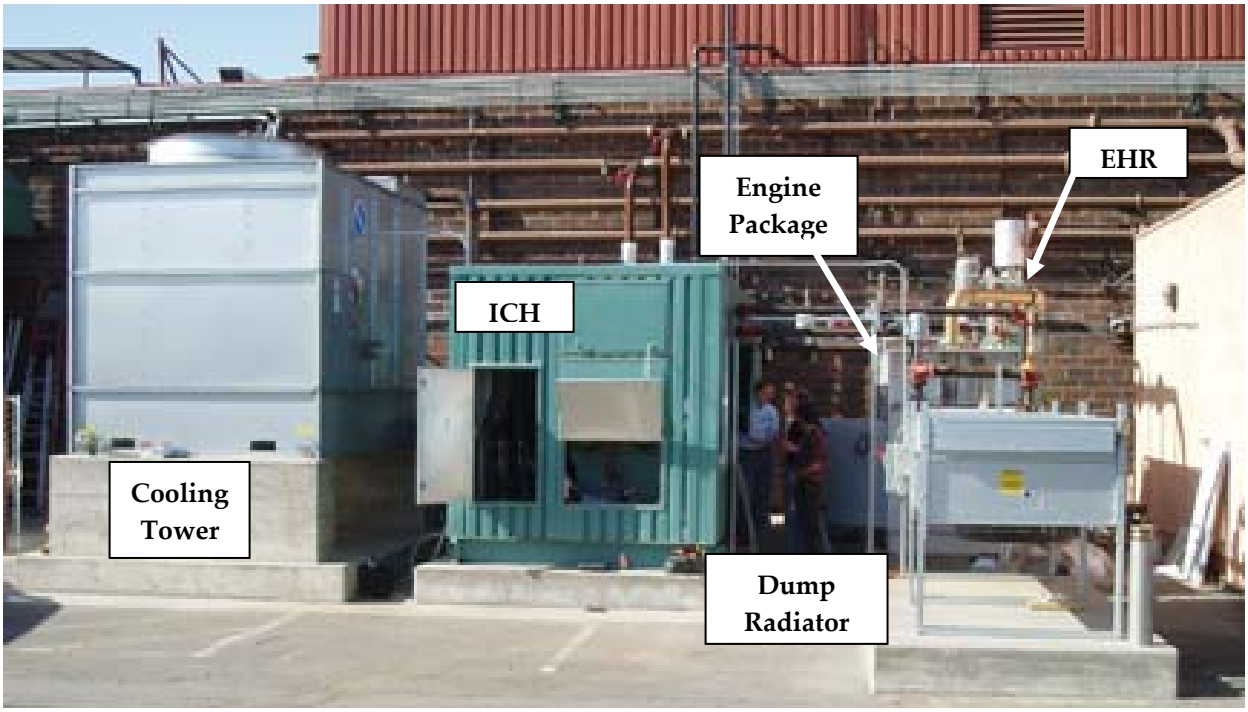
Source: DE Solutions, Inc.

3.3.4. *Commissioning*

Introduction

The CHP system was installed in 2006 and prepared for commissioning by Next-Edge who was the general contractor for the project. The BPE High Temperature Engine Package and the Integrated CHP Systems' ICHM were placed on concrete pads and were interconnected to each other and the building hot water and chilled water loops. The ICHM cooling tower, condenser water chemical water treatment, EHRU and coolant circulating pump were installed and plumbed into the system in accordance with the plans and specifications. As previously mentioned, a separate dump radiator was required and was also installed.

Figure 12. CHP system layout



Source: DE Solutions.

The various loops were pressure tested and filled in preparation for commissioning by BPE and ICHPS. Commissioning took place in March of 2007, and the system was tested for functionality and performance as much as site conditions would allow. During the test period, it was discovered that the hot water loop had not been flushed and so was not available for the commissioning testing. Full cooling load was also not available so the full capacity was not able to be verified during commissioning. Both parameters were subsequently tested during the monitoring period as reported in the following data acquisition system (DAS) section.

Site Conditions

The ICHM was commissioned by a team from JCI/York, ICHPS and KAR Engineering. The chiller had previously been tested at the JCI/York facility in York, PA and so was ready for operation. The generator was commissioned by BPE who had also previously test run the system at their fabrication facility in Reno, NV.

The ICHM chilled water supply and return were piped in parallel with the two other existing electric chillers that all fed the same chilled water header. Each chiller had a separate pump associated with it but the system had not been balanced prior to commissioning. Likewise, the hot water supply and return were piped in parallel with the two existing hot water boilers that operated as a lead and lag system. The 'load' hot water heat exchanger on board the ICHM was connected to a double walled heat exchanger using a dedicated circulating pump. Domestic hot water from the storage tank flowed on the other side of this heat exchanger and was circulated using a dedicated pump.

The generator was configured to run in parallel with the grid and to either load follow based on a minimum import level or to operate on a fixed schedule that could be programmed into the engine controller. The coolant loop had previously been run tested and flushed and the engine generator was allowed to run at full capacity to provide hot water to enable the ICHM absorption chiller.

The building automation system had not been fully installed by commissioning time so the CHP system was operated manually using the generator and ICHM controls. The existing electric chillers had previously been manually operated and this policy was continued.

There were various flow problems in both the chiller water and hot water loops which required some time to evaluate. Lines had not been flushed and air handler valves had been configured to act as on/off valves so they exerted wide flow variations on the system. These issues were overcome by flushing the lines and using the building automation system to force the valves open.

During commissioning, the facility personnel and a representative from the general contractor were available. There were no representatives from the design engineer, building automation system company, or from the mechanical subcontractor who did the physical installation.

Results

The ICHM and generator both performed well and met the functionality goals in terms of operation, control, protection verification, and remote access through their individual monitoring systems.

Performance was not fully tested as there were no sufficient loads on the building and the hot water loop was not available. These tests were carried out later in the year and are reported under the DAS section.

During the commissioning period the generator provided 260 kW and the ICHM provided up to 50 tons of cooling at which point the absorption chiller was not fully loaded. The systems all checked out as being operational against the check list for both the ICHM and the generator. Following are the check list forms from commissioning.

Figure 13. ICHM commissioning report

Integrated CHP Systems Corp.
15 Berkeley Pl., Fair Lawn, NJ 07410
(201) 791 0180 Fax (201) 791 9273

Integrated Cooling & Heating Module

Commissioning Report

Name BluePoint Energy Inc. Phone Number (775) 246-8111

Location Normandie Casino Contact Name Ranson Roser

1045 Rosecrans Blvd.

City Gardena State CA Project Number 105

Equipment/Installation Conditions

ICHM	Check	Comments
Absorber under vacuum	☑	
Control System access available	☑	
Service access available	☑	ICHM panel door to be replaced
ICHM Electric Supply connected to local BUS	☑	
Power available to Condenser Water Pump	☑	
Power available to York Chiller Power Panel	☑	
Power available to ICHM Control Panel	☑	
Electric Supply from ICHM to CT connected	☑	
Power available to Cooling Tower Fan	☑	
Drain connected	☑	
Piping		
Coolant Piping connected	☑	Small leak on customer side
Chilled Water Piping connected	☑	Parallel with existing chillers
Condenser Water Piping connected	☑	
Load Hot Water Piping connected	☑	Parallel with existing boilers
Pressure Test/Leak Check completed	☑	Hydronic circuits tested by York
Piping/Strainers flushed	☑	Hydronic circuits flushed by York
Coolant & Water Systems filled and vented	☑	
Cooling Tower		
Make-up Water Line connected/Float operating	☑	
Chemical treatment/bleed system connected (Optional)	☑	
Drain Line connected	☑	
Basin & Screen clean	☑	Some debris in basin
Fan & Drive rotate freely	☑	
Local CT Disconnect connected	☑	
Power Supply from ICHM connected	☑	

Source: Integrated CHP Systems Corporation.

Figure 14. ICHM building systems and general comments

Integrated CHP Systems Corp

15 Berkeley Pl., Fair Lawn, NJ 07410
(201) 791 0180 Fax (201) 791 9273

Building Systems	Check	Comments
Modbus Connection available	☐	No
Chilled Water Pump available	☑	Manual control
Load Hot Water Pump available	☑	Manual control
Generator		
Coolant Temperature above 150 F	☑	
ICHM Controller		
Power to controller	☑	
Display on	☑	
Remote Modbus Connection made	☐	No

General Comments

Site Readiness:

All piping connections were made and the coolant loop had been flushed and tested.
Hot water and chilled water lines were not flushed or tested by installing contractor.
Building automation system connection to ICHM was not available.
Existing chillers and boilers were piped in parallel to ICHM.

Load Availability:

Full load was not available during the commissioning period.
Air handlers did not have flow by-pass capability so at low load flow was below minimum.
Hot water was not available during the commissioning period due to plumbing problems

Other Comments:
ICHPS/York had to test, clear and flush chilled and hot water loops in order to allow commissioning.
Shipping cap was left in chilled water line causing flow problems until detected.
Chilled water flow variations due to interaction of existing chiller pumps and AHU valves.

Personnel Available:
Facility Personnel: Yes
General Contractor: Yes
Design Engineer: No
Installation Contractor: No
Controls Contractor: No

Source: Integrated CHP Systems Corporation.

Figure 15. ICHM performance parameters

Integrated CHP Systems Corp.
15 Berkeley Pl., Fair Lawn, NJ 07410
(201) 791 0180 Fax (201) 791 9273

ICHM Performance Parameters

The following parameters have been measured and noted during site commissioning of the ICHM.

Performance Ratings		Reading	Design	Comments
Ethylene Glycol Percentage	%	35	35	Per BluePoint
Coolant Flow	GPM	135	115	
Coolant Water Outlet Temperature	°F	200.4	217.4	
Coolant Water Return Temperature	°F	185	192.2	
Coolant Water Pressure Drop	' H_2O	7	4.5	
Chilled Water Flow	GPM	258	188.4	Varied due to system design
Chilled Water Outlet Temperature	°F	44	44	
Chilled Water Return Temperature	°F	48.7	54	Full load not available
Chilled Water Pressure Drop	' H_2O	10.8	6.8	
Condenser Water Flow	GPM	500	500	
Condenser Water Outlet Temperature	°F	86.8	94.1	
Condenser Water Return Temperature	°F	77.7	85	
Condenser Water Pressure Drop	' H_2O	10	10.3	
Load Hot Water Flow	GPM			Not Available
Load Hot Water Outlet Temperature	°F			Not Available
Load Hot Water Return Temperature	°F			Not Available
Load Hot Water Pressure Drop	' H_2O			Not Available

General Comments:

Prevailing Load = 50 Tons cooling. Coolant hot water diverting valve position = 44%.

Hot Water System isolated due to site failure to clean construction residue from the system.

Source: Integrated CHP Systems Corporation.

Figure 16. ICHM follow-up requirements

Integrated CHP Systems Corp.

15 Berkeley Pl., Fair Lawn, NJ 07410
(201) 791 0180 Fax (201) 791 9273

Follow-up Requirements:

ICHPS was required to follow-up on the following issues:	Status
Replace missing panel access door	Completed 3/19/07
Replace missing plastic shield from disconnect	Completed 3/19/07

Date Reviewed & Verified: ___March 19th 2007_____

The Integrated Cooling & Heating Module has been tested and operated according to the above parameters at the site location noted above.

Verified by:

For Integrated CHP Systems Corp:

_____
Signature

Print Name: ____Gearoid Foley_____

Source: Integrated CHP Systems Corporation.

Figure 17. ICHM Bluepoint Energy start-up checklist

BLUEPOINT | energy inc.
www.bluepointenergy.com

BLUEPOINT ENERGY COGENERATION MODULE START-UP CHECKLIST
Normandie Club Casino (1045 West Rosecrans Avenue, Gardena, CA 90247)
Commissioning Engineer: Ramon rosar
Commissioning Date(s): (January 6-11, 2007), (April 2-5, 2007), (March 12-17, 2007)

OIL SYSTEM		
CHECKLIST ITEM	Y/N	COMMENT
Hands-off-Jumper "OK" matches displayed	Y	
Oil heater functionals	Y	
Oil pump filled	Y	
Oil pressure > 30 psi on manual pump-up	Y	

GAS SUPPLY		
CHECKLIST ITEM	Y/N	COMMENT
Gas filter installed	Y	Filter is installed in PG&E gas line
Static gas pressure (psi)	1.0	Meets EPS installation specifications

JACKET WATER SYSTEM		
CHECKLIST ITEM	Y/N	COMMENT
Glycol = ~ 35%	Y	35% PG
Is fluid visible in expansion tank sight glass?	Y	
Is nitrogen expansion air space visible in expansion tank sight glass?	Y	
Air bleeds checked and open	Y	
Is an automatic air vent installed with the air separator?	Y	

PROTECTIONS		
CHECKLIST ITEM	Y/N	COMMENT
On-board E-Stop functionality verified?	Y	Initiates a hard stop via the GCP-30
External E-Stop functionality verified?	NA	There is not remote E-Stop
Low oil switch functionality verified?	Y	Initiates a hard stop via the GCP-30
External fan/pump interlock protection functionality verified?	Y	Initiates a hard stop via the GCP-30 but does not cover all
Electrical breaker trip functionality verified?	Y	Initiates a hard stop via the GCP-30
Low oil pressure sensing and limit safety verified?	Y	Limit violation initiates a hard stop via the GCP-30
Charge temp sensing and limit safety verified?	Y	Limit violation initiates a hard stop via the GCP-30
Controls temp sensing and limit safety verified?	Y	Limit violation initiates a soft stop via an ADAM logic input
Jacket water temperature sensing and limit safety verified?	Y	Limit violation initiates a GCP-30 hard stop via an ADAM logic
Exhaust temperature sensing and limit safety verified?	Y	Limit violation initiates a GCP-30 hard stop via an ADAM logic
Ambient air temperature sensing and limit safety verified?	Y	Limit violation initiates a GCP-30 hard stop via an ADAM logic
EGR temperature sensing and limit safety verified?	Y	Limit violation initiates a GCP-30 hard stop via an ADAM logic
Pre-catalyst temperature sensing and limit safety verified?	Y	Limit violation initiates a hard stop via an ADAM logic input. If the function is not known a hard stop via the ADAM logic will not disrupt operation.
Post-catalyst temperature sensing and limit safety verified?	Y	Initiates a hard stop via contact closure on the AFRC as measured by the GCP-30
Interconnect generator protection functions configured?	Y	Correct generator power, voltage, current, and overspeed

THERMAL CONTROL		
CHECKLIST ITEM	Y/N	COMMENT
VFD fan control logic verified?	Y	
VFD controlled VFD fan speed achieves stable jacket temperature control?	Y	
Jacket control temp control loop and limit functions calculated functionals	Y	Low oil interlock by fan is not an issue because fan is cool
Control during disabled fans action is fully adaptive	Y	Full heat rejection capability demonstrated

GENERATOR CONTROL		
CHECKLIST ITEM	Y/N	COMMENT
Generator power factor control verified?	Y	Witnessed by SCE team during pre-parallel testing
Verified generator stable, clean, 3-phase, sine wave?	Y	Witnessed by SCE team during pre-parallel testing
Verified agreement between voltage and kW functionals in the GCP-30?	Y	Witnessed by SCE team during pre-parallel testing
Verified reactive power (kVar) trip for generator offline?	Y	Witnessed by SCE team during pre-parallel testing
Verified the generator is able to provide breaker closure without redundant sync check agreement?	Y	Witnessed by SCE team during pre-parallel testing
Interconnect bus voltage regulator control verified?	Y	Tested from redundant & Remote voltage bias control
Interconnect bus frequency/speed control verified?	Y	Tested from redundant & Remote speed bias control
Redundant speed bias control verified?	Y	Witnessed by SCE team during pre-parallel testing
Woodward load control of 0-100 kW to 0-100 load verified?	Y	Witnessed by SCE team during pre-parallel testing
Power control (kW and kVar) verified?	Y	Does not (in 0-5% load control)
Enable and disable cycle protection verified?	Y	

REMOTE COMMUNICATIONS		
CHECKLIST ITEM	Y/N	COMMENT
Internet access verified?	Y	
Remote system control capability verified?	Y	Remote control and logging functional.
Remote alarming notification verified?	Y	System generates alarm/shutdown emails to service personnel.

Source: BluePoint Energy, Inc.

3.3.5. *Performance Monitoring and Analysis*

Introduction

The Cogeneration Plant Commissioning Report includes two major sections. The first discusses the electric demand of the facility and its impacts on the engine-generator system as the prime mover for creating thermal energy to drive the ICHM. The second section illustrates the performance of the ICHM under various conditions. Both sections demonstrate the operation of the equipment and also illustrate the need to create a flexible sequence of operations to accommodate the varying loads provided by the building.

The ideal application of an engine-based CHP system operating in parallel with the utility is one in which the engine can operate at a fixed power output while the utility compensates for any fluctuation in electric demand. As a result of multiple efficiency and control measures that were implemented in parallel with the CCHP system, initial field observations showed that Normandie Casino does not have an electric demand profile that would allow the engine to operate at a fixed full output during all of the hours of operation and is not conducive to the available control option that would otherwise provide a means for automatic demand compensation. This subject is described in more detail below with observations made during the field evaluation of the system over several months of operation. It should be noted that the lack of sufficient steady electric and chilled water demand over the course of the field demonstration greatly complicated the task of demonstrating the full output capabilities of the combined heating and cooling systems and continues to complicate the sequence of operations.

Electric Demand and Generator Control Modes

The original generator control and generator-to-utility synchronization and paralleling control were provided by Encorp equipment, but Encorp went out of business before the installing contractor acquired the complimentary facility-side Encorp gear needed to complete the installation. To overcome this impediment, BPE removed the Encorp gear from the HTEP already installed at Normandie Casino and replaced it with a Woodward power generation PLC in conjunction with additional hardware and BPE software that allows remote interface with the functions of the Woodward. Like the original Encorp system, the Woodward has two modes of generator power control, namely base-load control and import control.

Base-load control produces a target generator power output that the Woodward then achieves via the governor control system. The intent is to have the utility satisfy all fluctuations in facility demand while the generator satisfies a non-fluctuating base-load. Base-load control is the preferred operating mode because stable power output lends itself to stable thermal characteristics and eases exhaust after-treatment emissions control.

The control loop for base-load operation is based on the actual generator output versus the target output only. This mode does not include functionality that anticipates or prevents violations of minimum import requirements imposed by utility interconnect agreements. Such requirements are enforced by monitoring equipment that will shut the engine system off abruptly in the event of minimum import violations. These hard shutdowns are abusive to the engine and must be avoided for the long term durability of the engine-generator equipment.

The BPE remote interface software includes limited provisions to set different base-load power targets as a function of time-of-day.

Import control uses variation in generator power output to maintain a constant level of imported electricity from the utility. The utility import level, the amount of electricity fed to the facility at any given moment, is measured by a watt transducer and becomes a variable into the import control PID algorithm of the Woodward. This control methodology results in a form of utility load following and can be used to prevent violations of minimum import requirements in utility interconnect agreements. If the total electric demand is high enough, the generator output reaches its maximum rated kilowatt output and the import level of the utility increases beyond the target condition in the generator control loop. Above a certain threshold, fluctuations in total electric demand are accommodated by the utility, but below that threshold, the fluctuations are accommodated by the engine-generator.

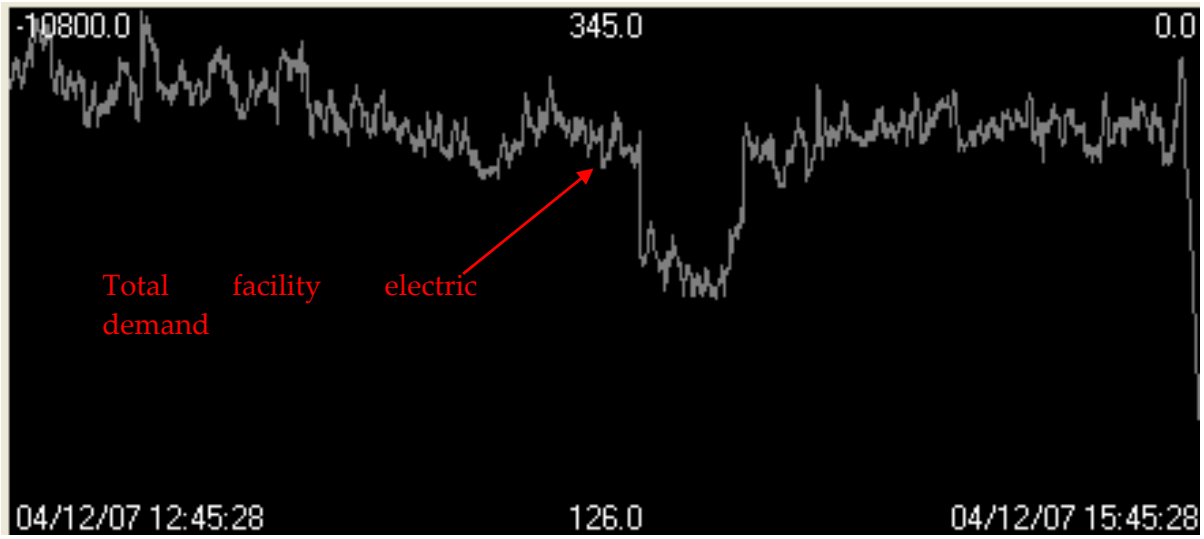
During import control, the user enters a target utility import level into the Woodward engine-generator control system. The selection of the programmed import target setting should be greater than the largest instantaneous drop in demand that could occur. Otherwise, the demand will drop faster than the generator can unload, the utilities minimum import requirement will be violated, and the generator operation will be interrupted in a hard-stop fashion by the interconnect monitoring equipment, in this case a Beckwith 3410A, utility approved protection relay.

Site Power Demand

It was very clear during the first days of commissioning that Normandie Casino did not have the electric demand to start the unit in a base-load mode at the maximum generator output of 260kW. Thus, the natural fluctuations in demand needed to be observed to determine what near-instantaneous demand drops could occur at the facility, so a reasonable minimum utility import level could be input into the Woodward and so the import control mode could be evaluated.

Figure 18 shows an example of a 60 kW near instantaneous drop in total electric demand during a random observation in April 2007. Normandie's interconnect agreement requires at least 13 kW of utility import at all times. If the generator output had been such that 70 kW were still being imported from the utility before the load drop, then the Beckwith 3410A would have tripped the generator off-line during this event, because the load drop would have reduced the import to 10 kW. From the observation in the following graph and others like it during the early phase of commissioning, it was determined that the import control setting in the Woodward could be no less than 80 kW to reliably prevent hard stops induced by the Beckwith interconnect equipment.

Figure 18. Total facility demand in mid-afternoon, April 12, 2007



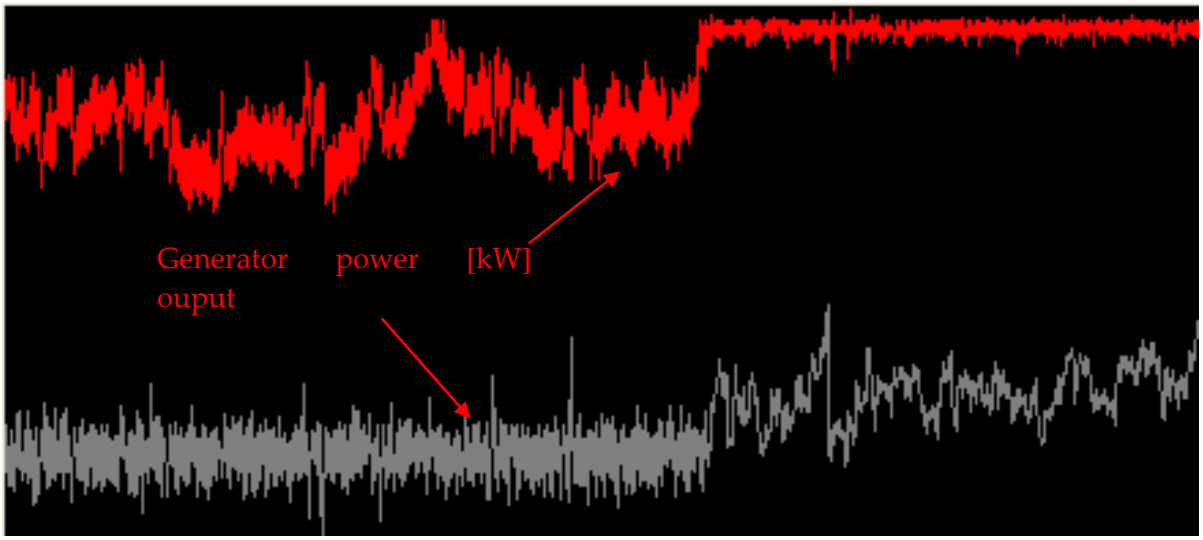
Source: BluePoint Energy, Inc.

Generator Import Control Mode

Figures 18, 19, and 20 show examples of the generator operating in Import Control Mode. The intent of operating in import control mode is to prevent Beckwith-induced hard-stop interruptions by altering generator output to maintain some minimum utility level that does not violate the Beckwith threshold. However, it was observed that the demand fluctuation, coupled with low nominal demand that was too low, was great enough to result in constant fluctuation of the engine power output to a degree that was considered unacceptable in the long run with concerns focused on thermal and emissions stability, as well as durability of the engine.

Figure 19 was generated in April 2007 during the early commercial operation of the system. The transition between unsteady generator (red) power output to the stabilized 260 kW condition was a function of the total facility demand. The generator power was steady when the total demand was greater than the full output of the generator and the import control setting (or buffer) in the Woodward. This transition did not occur until 7:30 pm in Figure 19.

Figure 19. Total facility demand for 3 hours during the evening of April 12, 2007



Source: BluePoint Energy, Inc.

Figure 20, generated in August 2007, illustrates the same findings as in Figure 19. Figure 20 is important because it was taken during the hotter electric and thermal demand conditions associated with summertime. Again, the generator was not able to operate at a steady 260 kW power output level until 7:45 p.m. while trying to maintain an 80 kW import control buffer.

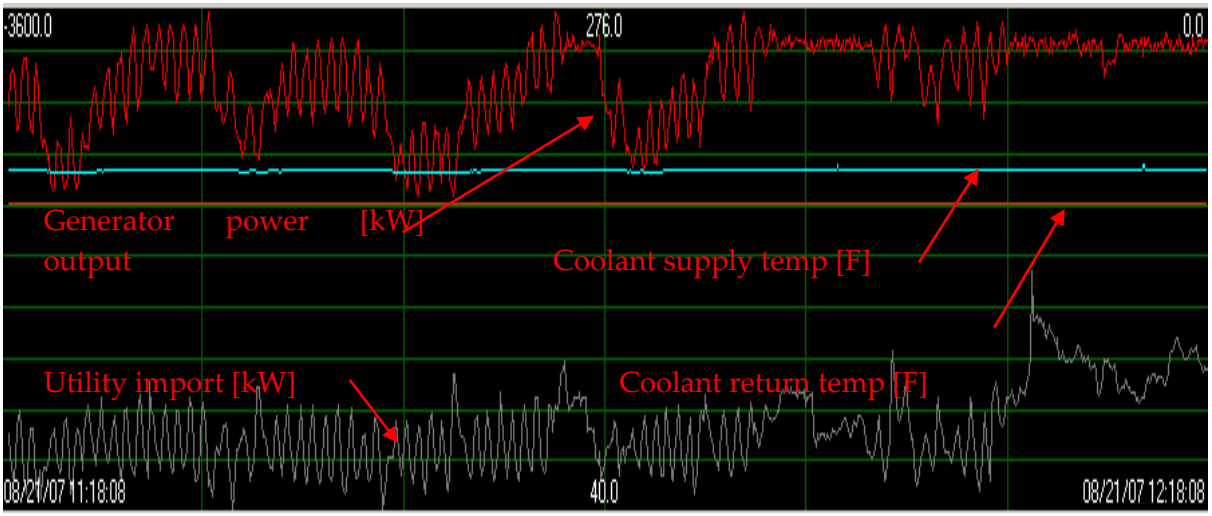
Figure 20. Total facility demand for 3 hours during the evening of August 13, 2007

Source: BluePoint Energy, Inc.

Figure 21 generated during August 21, 2007 shows one hour of utility import (grey) and generator output (red) with the Woodward set for 60kW import control for most of the profile. This provides better resolution of the load fluctuations imposed upon the generator during import control mode due to the 60 minute window whereas Figures 18-20 show three-hour windows. Also, coolant temperature in and out of the engine are represented by the two horizontal lines and are admirably stable during this snapshot of highly fluctuating load.

Despite the excellent temperature control shown at the engine in this plot, the constant engine power fluctuation associated with taxing the import control mode was still a concern for thermal, emissions, and durability issues in general. The system was manually transitioned to base-load control towards the end of the plot.

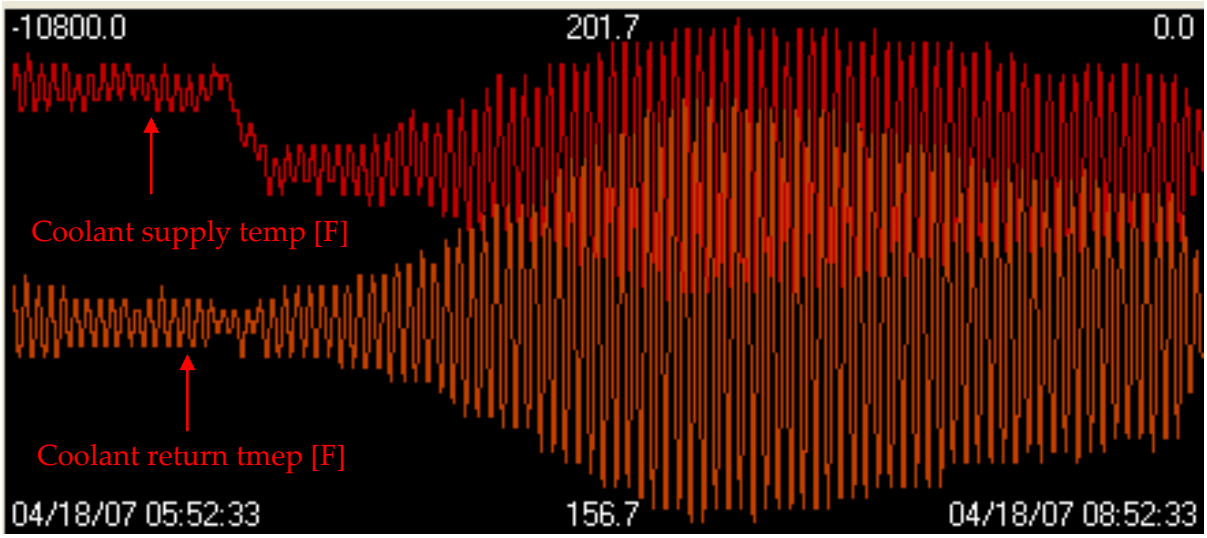
Figure 21. Total facility demand for 1 hour during August 21, 2007



Source: BluePoint Energy, Inc.

Figure 22 profiles an extreme case of engine inlet/outlet temperature control instability induced when the generator power was fluctuating heavily during import control mode. The temperature fluctuations were so severe and of such an oscillating frequency between high and low conditions that a subsequent water-jacketed exhaust manifold failure was attributed to this condition. While BPE observed many cases in which the dump radiator system with its VFD controlled fan could perform very well in maintaining stable engine temperature while the engine power fluctuated, there were also several cases similar to Figure 5 in which the wrong combination of thermal variables occurred to drive the temperature control process out of control stability. These observations were a major basis for stating the system should not operate in an import control mode.

Figure 22. Total facility demand for 3 hours during April 18, 2007



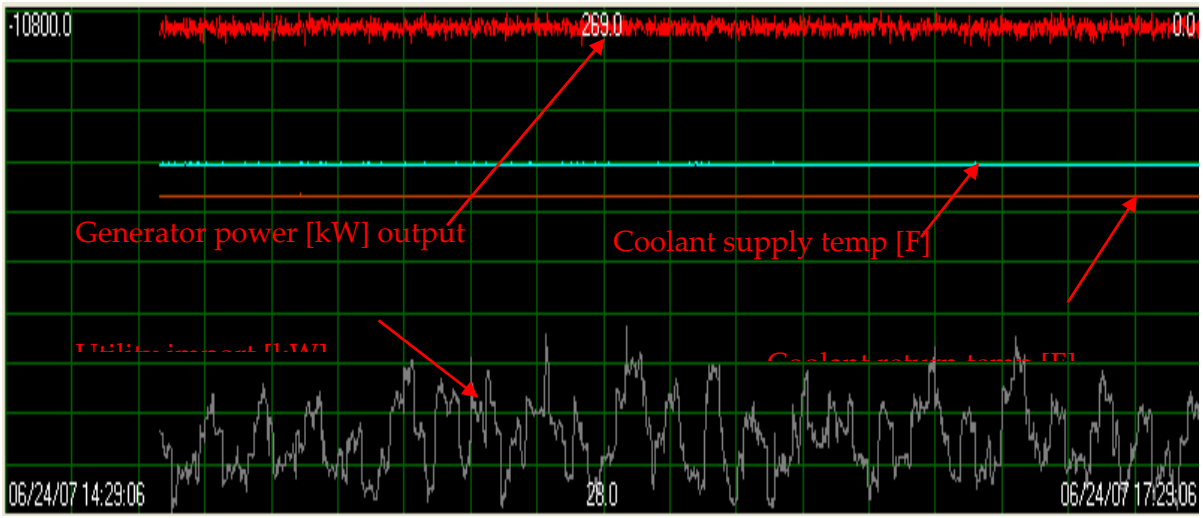
Source: BluePoint Energy, Inc.

Generator Base-Load Control Mode

Figure 23 developed from a three hour period in June 24, 2007 demonstrate what is so desirable about having enough electric demand to operate in base-load control. The generator is shown to operate at its maximum output of 260kW (red) with all fluctuations in facility electric demand being accommodated by the utility. The Figure 23 plot was taken with careful remote oversight by BPE. The utility import consistently dropped within 15 kW of violating the minimum import level of the utility interconnect agreement. Violation of that parameter would have resulted in an instant hard-shutdown of the unit, an abusive condition which may have contributed to mechanical failures of the Deutz engine that have occurred to date (Beckwith induced hard-stops have occurred at times).

The best course of action for the system at Normandie was determined to be one that uses multiple (at least two) base-load targets as a function of time-of-day. Setting the base-load schedule requires an understanding of the demand profile of the facility which changes with customer load as wells as long term and short term weather conditions. Observations over many months suggest a 150-200 kW base-load setting is appropriate from 6 a.m. to 6 p.m., 230 kW from 6-8 p.m., and 260 kW from 8 p.m. to 6 a.m. Since the commissioning of the unit to the date of this report, BPE was asked to program a run schedule from 11 a.m.-midnight, thus losing much of the time the generator could operate at maximum output. This schedule reflects changes in Southern California Edison's rates, implemented after the original design intent was developed, which dramatically reduced electrical costs after midnight.

Figure 23. 260 kW baseload operation on June 24, 2007



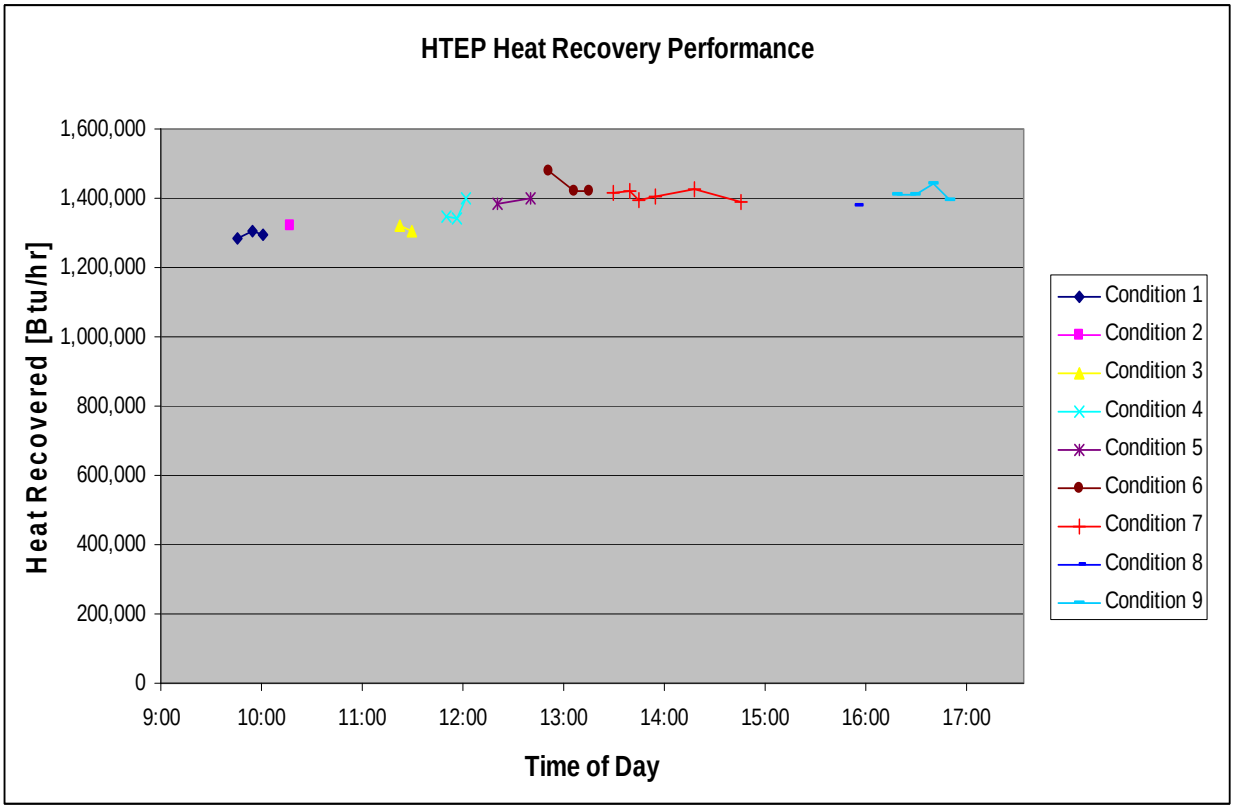
Source: BluePoint Energy, Inc.

Full-Output Heat Recovery Performance

Several focused and highly coordinated attempts were made to document the maximum field performance capabilities of the HTEP and ICHM. The ICHM's ability to delivery chilled water is dependent upon the quantity and quality of heat recovered from the HTEP and delivered to the ICHM, so an important step in ICHM performance considerations is to quantify the heat being recovered from the HTEP. Figure 24 shows HTEP heat recovery data from August 22, 2007 covering the first coordinated effort to derive maximum performance data from the combined systems. The HTEP clearly demonstrated the capability to achieve the 1.4 MMBtu/hr heat recovery target originally proposed for the Energy Commission project.

The data in Figure 24 is organized into groups of fixed operating conditions. Each "condition" represents a change in a major operating parameter of the combined HTEP and ICHM in an effort to maximize chilled water production from the ICHM. During the course of the day, changes were made to engine cooling water flow rate, cooling tower flow rate, chilled water flow rate, and engine jacket water return temperature. Decisions to modify such operating variables were based on on-the-fly analysis of performance by testing participants. The engine output was fixed at 260 kW during the efforts. The heat recovery stabilized nominally around 1.4 MMBtu/hr after the first couple of hours, regardless of the other parameters being manipulated.

Figure 24. Field test heat recovery data

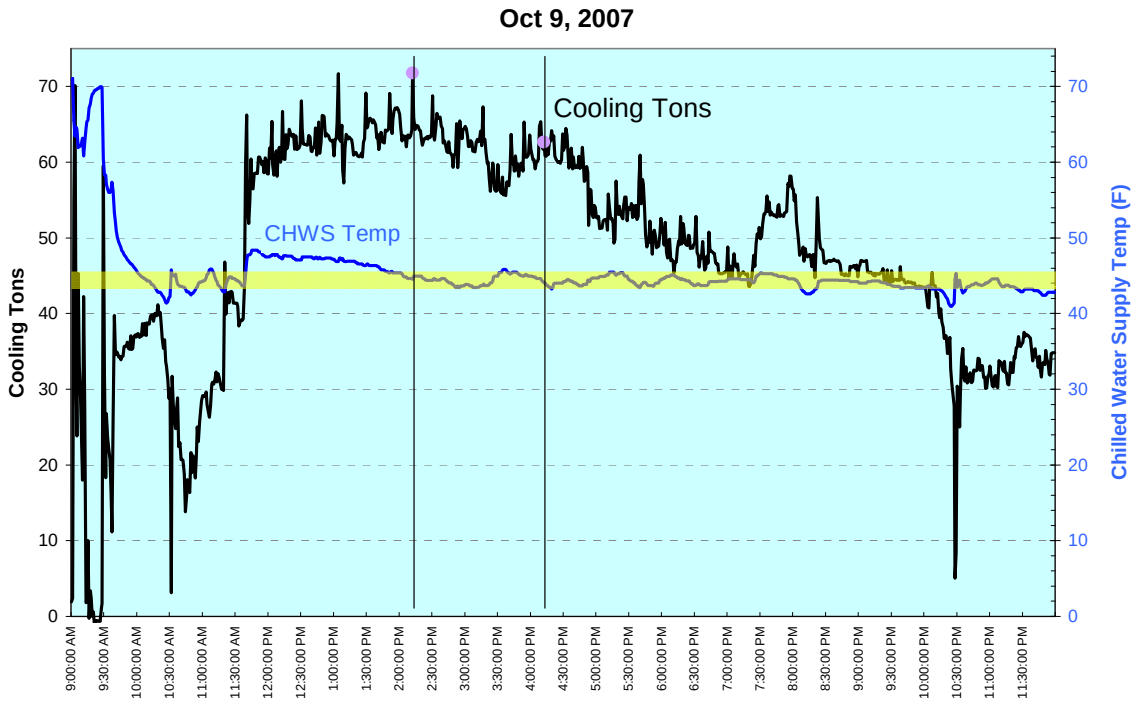


Source: Conservation Technology.

ICHM Field Performance

In the field test, the authors ran the ICHM by itself with the rack chiller locked out through the building automation system. The system was started up in the morning and allowed to stabilize. The engine generator was ramped up to 260 kW and the engine jacket return temperature was increased to 195°F. Load was gradually applied to the system, but the chilled water supply temperature was unstable. At 1 p.m, after some observation, both the coolant water flow rate and chilled water flow rate were adjusted. At these new settings the chilled water temperature was steadily pulled down until it reached set point of 44°F at 2 p.m. Data was taken after the system stabilized and showed the chiller was holding the load at between 60 to 70 tons between 2 p.m. and 5 p.m. and the chilled water supply temperature remained at set point showing the system was not overloaded. The ICHM chiller load peaked at 72 tons at 2:12 p.m. However, there was no more load available and after 4 p.m. ambient conditions further reduced the load. The chiller held set point throughout the remainder of the day. The following graph shows a plot of chilled water supply temperature and load from 9 a.m. through 11:59 p.m. on the test day. The yellow band represents the chilled water supply temperature set point of 44°F +/-1°F.

Figure 25. Cooling output and chilled water supply (CHWS) temperature

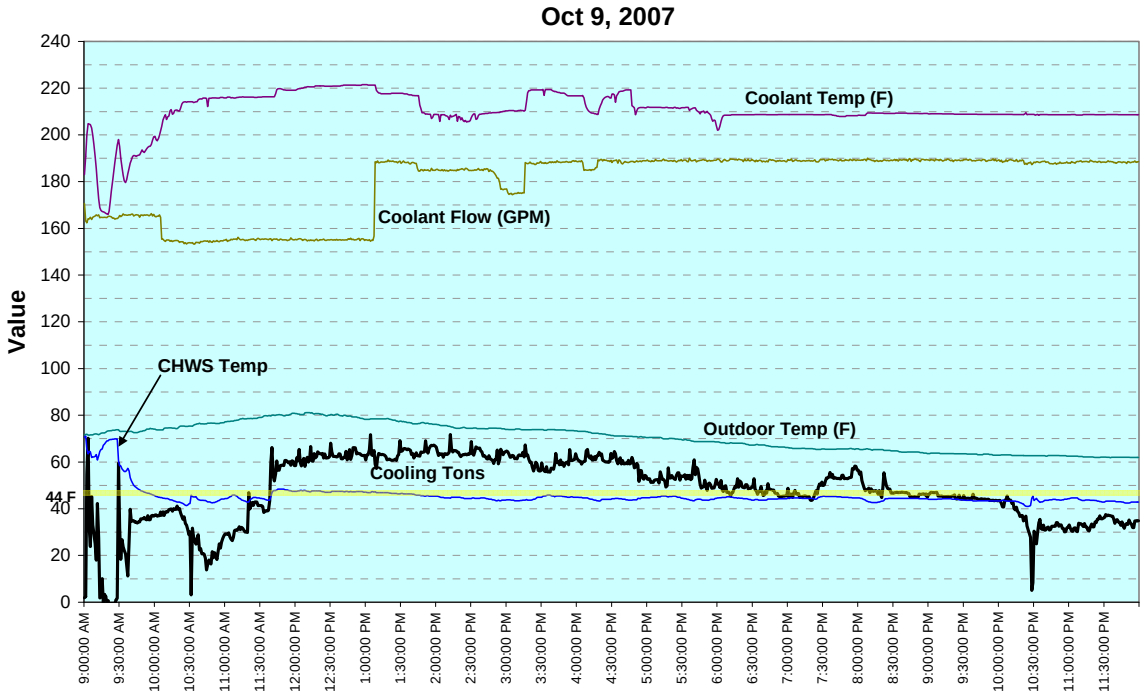


Source: Conservation Technology.

Test data was recorded during the higher load period after the chilled water supply temperature had reached set point. The performance data detailed below was recorded at 2:12 p.m. and 4:12 p.m. as indicated with the vertical lines in the graph above.

The following graph shows a plot of the load, coolant flow, coolant temperature, outdoor temperature and chilled water supply temperature. The yellow band represents the chilled water supply temperature set point of 44°F +/-1°F. From this chart we note that in the morning with relatively high coolant temperature and low flow the absorber was not able to hold set point. After the flow adjustment was made the coolant temperature was reduced from 220°F to 210°F at which point the absorber was able to meet capacity requirements.

Figure 26. Cooling output versus engine thermal output



Source: Conservation Technology.

It is important to understand the relationship between the various energy streams involved in the CHP system. The generator operates at various conditions and produces hot water (coolant), which drives the absorber in the ICHM. When analyzing the data, the authors needed to observe the coolant supply temperature to the chiller. The basic control parameter for chiller hot water supply temperature is the engine jacket return temperature. This utilizes the dump radiator when necessary to maintain a maximum temperature. The coolant then flows through the engine and exhaust heat exchanger which impart a fixed amount of energy depending on engine output. The resulting coolant supply temperature is a product of the flow rate and engine output.

When operational, the absorber acts as the engine heat dump and will reduce the coolant temperature proportional to the load on the absorber. These act independently of the engine return setting and therefore may reduce the coolant temperature below the engine return set point. In this case, the engine, dump radiator, exhaust heat recovery, chiller, cooling tower and load must all find a balance point where operation stabilizes. In order to emulate the design conditions, the engine jacket return temperature was elevated to 195°F from its delivered setting of 185°F (the standard Deutz return temperature is 176°F).

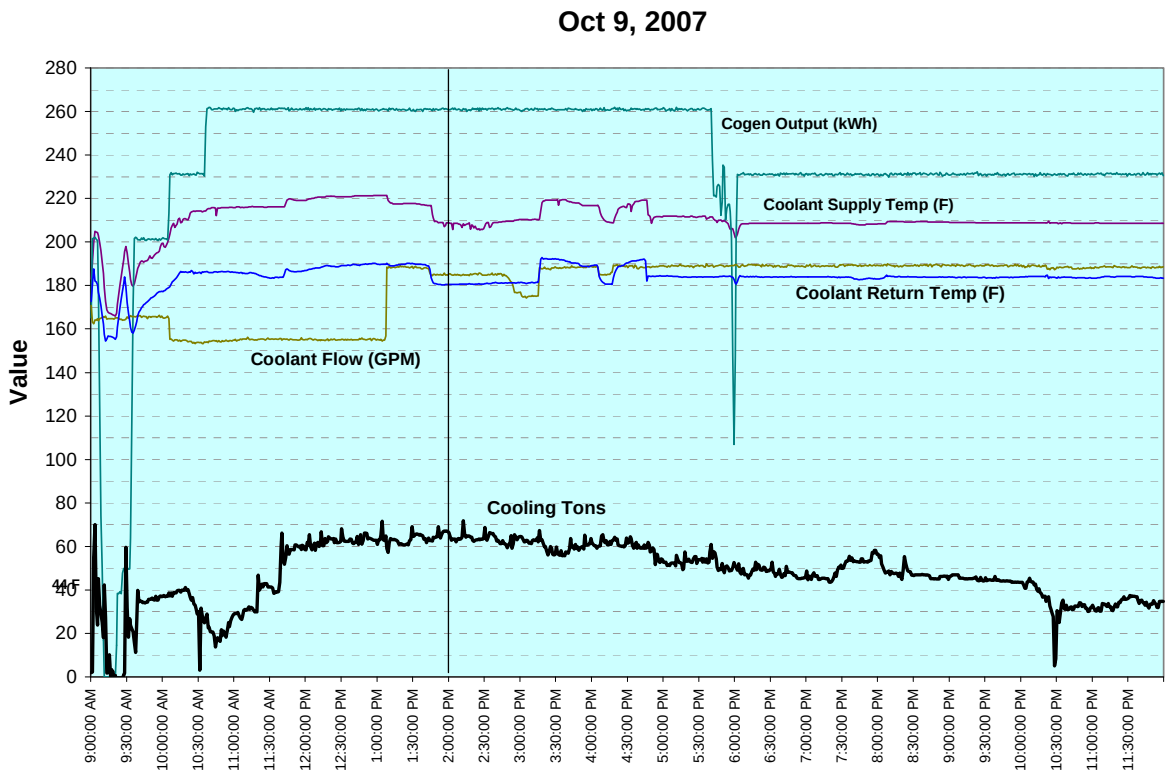
The following graph shows the engine output, coolant flow, supply and return temperatures versus chiller load. Conditions did not stabilize until 2 p.m. after an adjustment was made to

both the chilled water and coolant flow rates after which time the chiller continued to meet set point.

The coolant flow rate was set at 188 gpm at which point the difference between coolant return and supply as 27 to 28°F. The coolant return temperature was controlled by the absorber system rather than the dump radiator as all the available energy was converted into cooling. As the load reduced, more of the coolant energy bypassed the chiller and then the dump radiator took control of the return temperature.

When the generator is at 260 kW and the building load is at or above 60 tons, it appears that the absorber controls return temperature and will result in a coolant return of around 180°F, which results in a coolant supply to the chiller of around 208°F. As the building load drops, the dump radiator takes over control of the return temperature and keeps it at a set point.

Figure 27. Cooling output versus engine output



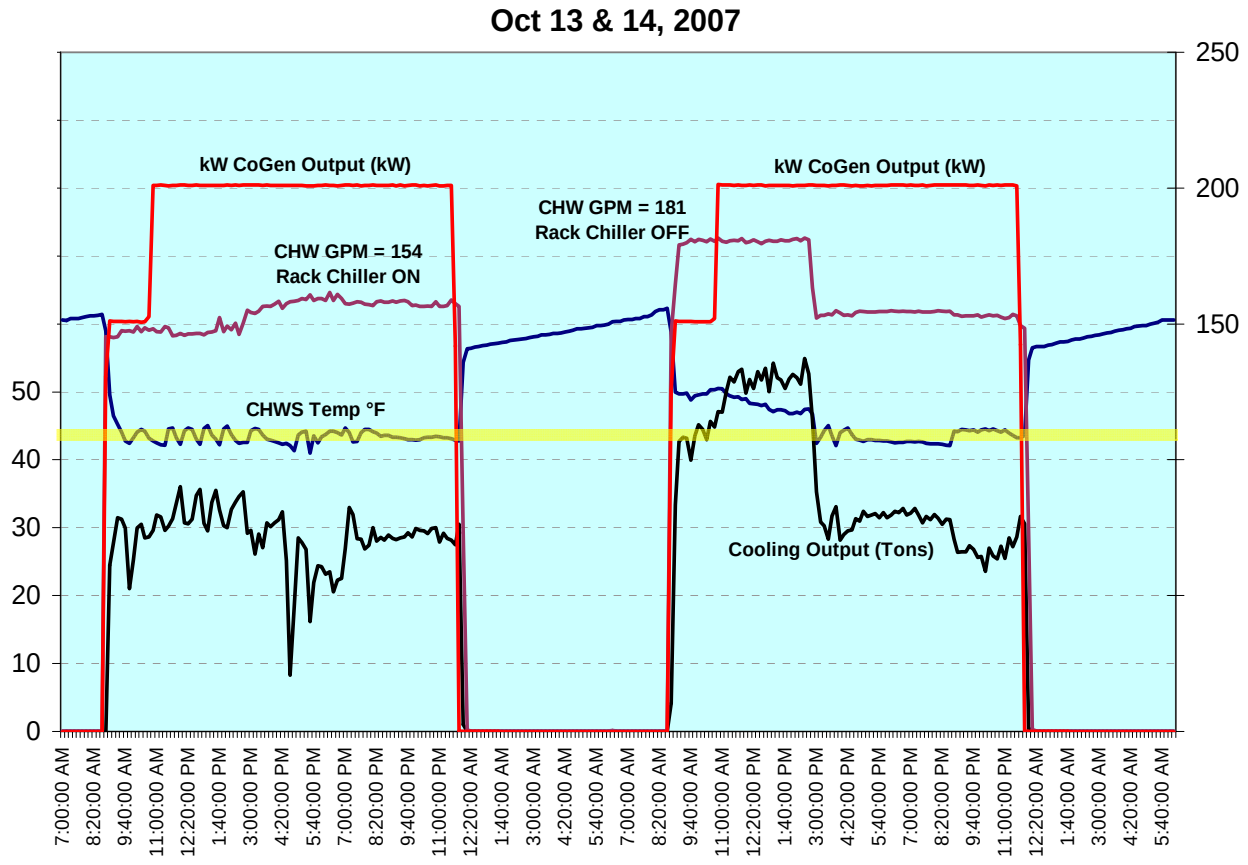
Source: Conservation Technology.

Further monitoring was carried out after the test day to observe the system at low load conditions. It is necessary to understand the system operation at low power and low cooling load conditions.

The system was run as normal on October 13th and 14th with low ambient conditions resulting in low power and cooling loads. As shown in the chart below the generator starts at 150 kW in the morning and then runs at 200 kW output through the rest of the day. The rack chiller is also operating all day on the 13th and is turned on at approximately 3 p.m. on the 14th. When the rack chiller pumps are operating, the chilled water flow through the absorber is approx. 150 gpm and when these pumps are off the flow through the absorber is 188 gpm.

On the morning of the 14th, the system starts with the generator output at 150 kW. The building load is estimated at 40 tons, although there is no information from the building system to allow calculation of the total cooling load. At 60% generator operation, the ICHM is over loaded and cannot hold the 44°F set point. As the engine output is ramped up to 200 kW, the chiller begins to slowly bring down the chilled water supply temperature, but the rack chiller is turned on before the absorber is allowed to stabilize. The slow chilled water pull down indicates that the chiller is at its maximum capacity. Once the rack chiller is operating, the chilled water supply temperature is brought down to 44°F and the ICHM provides approximately 30 tons of cooling.

Figure 28. Cooling output at off-design conditions

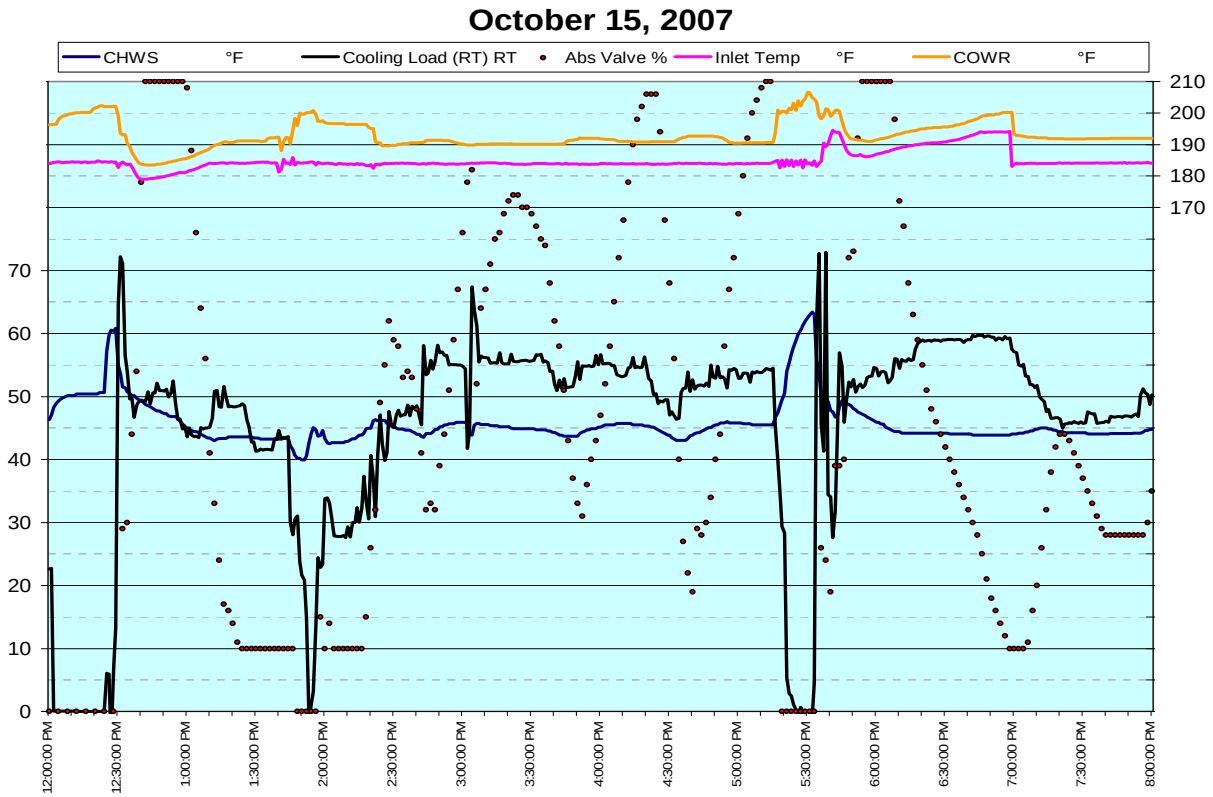


Source: Conservation Technology.

The above data suggests that the ICHM chiller is capable of holding 30 tons when the engine is at 200 kW output. It should be noted that as the generator output is lowered, the total energy output to the coolant loop is lowered proportionately down to approximately 60% output. However, the coolant temperature is also lowered resulting in a lower approach between the absorber solution and the coolant. This further degrades the chiller output so that output tonnage is not linear with engine operation.

Further testing was carried out on October 15th, including operation of the load hot water heat exchanger with the engine output raised to 260 kW at 1:30 p.m. and the rack chiller turned off. In the following chart, we have included a plot of the absorber by-pass valve, which is controlled by the chiller load. This valve opens when load is applied to the absorber and modulates to maintain chilled water supply set point. The engine coolant return temperature is set to 195°F and the authors see for most of the day that the chiller controls coolant return temperature below set point. The "COWR" yellow line is the coolant temperature being returned from the ICHM before the dump radiator while the "Inlet Temp," in pink, is the actual return temperature to the engine after the dump radiator. There is a 4.5°F temperature differential between these two readings when the absorber is fully loaded and there is no energy being dumped. When this differential grows, heat is being dumped through the radiator.

Figure 29. Cooling output and hot water bypass valve position

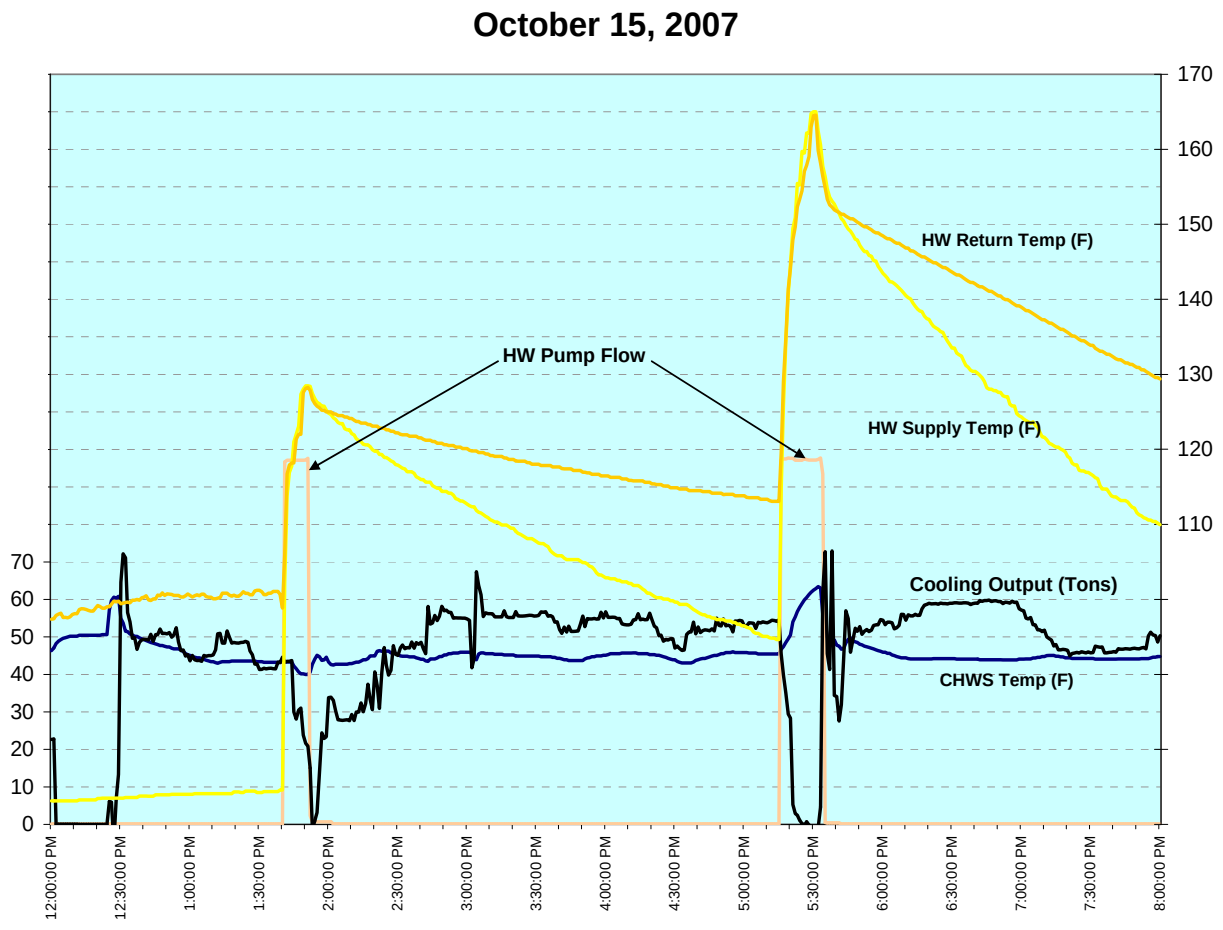


Source: Conservation Technology.

As the graph shows, the absorber was not fully loaded for most of the day after the generator output was raised to 260 kW at 1:30 p.m. Only at around 6 p.m. when the highest load was applied, was the absorber valve fully opened for any sustained period. The absorber pulled down the load in less than 15 minutes and held the maximum load of 60 tons without using all the available heat from the generator. As the absorber valve bypasses the coolant, the COWR is observed to increase and heat dumping begins as the load is reduced to 50 tons.

During the test, the load hot water system was activated. The ICHM load hot water heat exchanger is in series after the chiller on the coolant loop. For both hot water tests, the absorber was deactivated and the absorber valve was closed to full bypass. In the first test, the hot water supply temperature increased from ambient temperature of 74°F to set point of 130°F within 10 minutes and the hot water pump was shut off. In the second test, the ICHM increased the hot water supply temperature from 95°F to 165°F within 15 minutes and again the pump was shut off.

Figure 30. Load hot water operation



Source: Conservation Technology.

This test demonstrates that the ICHM can provide heating to the building's domestic hot water system although the loads are relatively small.

ICHM Test Results

Table 8 provides data points taken after the system had stabilized. These data points are taken from the independent monitoring system and are the same as those used to create the above graphs.

Table 8. ICHM test results

Time	Cooling Output Tons	CHWS Temp °F	CHWR Temp °F	CHWS Flow GPM	CoGen Output kW	COWS Temp °F	COWR Temp °F	Inlet Temp °F	COWS Flow GPM	Outdoor Temp °F	Rack Chiller
October 9, 2007											
Rack Chiller Off, Generator Output = 260 kW											
Time	Cooling Output	CHWS Temp	CHWR Temp	CHWS Flow	CoGen Output	COWS Temp	COWR Temp	Inlet Temp	COWS Flow	Outdoor Temp	Rack Chiller
2:12 PM	**71.8**	44.5	54.3	176.2	261.3	208.5	184.9	180.7	185.0	75.2	Off
4:12 PM	**62.6**	44.0	52.6	175.5	260.0	209.4	185.6	180.6	184.7	72.5	Off
October 14, 2007											
Rack Chiller Off, Generator Output = 150 kW											
Time	Cooling Output	CHWS Temp	CHWR Temp	CHWS Flow	CoGen Output	COWS Temp	COWR Temp	Inlet Temp	COWS Flow	Outdoor Temp	Rack Chiller
10:30 AM	**45.6**	50.3	56.3	181.2	150.7	186.1	172.2	169.7	192.6	72.8	Off
Rack Chiller Off, Generator Output = 200 kW											
Time	Cooling Output	CHWS Temp	CHWR Temp	CHWS Flow	CoGen Output	COWS Temp	COWR Temp	Inlet Temp	COWS Flow	Outdoor Temp	Rack Chiller
2:30 PM	**54.9**	47.4	54.7	181.6	201.0	198.4	183.2	178.7	191.6	73.1	Off
Rack Chiller On, Generator Output = 200 kW											
Time	Cooling Output	CHWS Temp	CHWR Temp	CHWS Flow	CoGen Output	COWS Temp	COWR Temp	Inlet Temp	COWS Flow	Outdoor Temp	Rack Chiller
7:10 PM	**32.8**	42.6	47.7	154.6	200.1	203.3	191.5	184.2	190.1	65.9	On
October 15, 2007											
Rack Chiller Off, Generator Output = 260 kW, Additional Cooling Load Applied											
Time	Cooling Output	CHWS Temp	CHWR Temp	CHWS Flow	CoGen Output	COWS Temp	COWR Temp	Inlet Temp	COWS Flow	Outdoor Temp	Rack Chiller
6:15 PM	**55.7**	44.2	51.5	181.9	260.6	N/A [1]	194.2	189.6	182.3	65.3	Off
6:30 PM	**59.0**	44.2	51.9	182.6	261.4	N/A [1]	195.6	190.8	181.8	65.0	Off
6:45 PM	**59.7**	43.9	51.7	182.7	261.5	N/A [1]	198.6	194.0	181.6	64.7	Off
7:00 PM	**57.1**	44.1	51.6	180.8	260.9	N/A [1]	193.2	183.7	182.5	64.6	Off

Note 1: COWS Temperature sensor failed during the test.

3.4. Technology Transfer Plan

3.4.1. *Background*

The majority of California's remaining CHP potential is in the commercial and light industrial sectors. Commercial and light industrial heat loads will not be the large steady steam loads that have historically been linked to CHP plants. Economic integration of thermally activated cooling will be key to obtaining the operating benefits necessary for cost effective CHP projects in the commercial and light industrial sectors. Another unique characteristic of California is its stringent environmental requirements, which can add cost and complexity to a CHP project.

Current CHP systems involve the custom integration of disparate pieces (prime mover, generator, controls, and heat recovery, cooling). Such practice drives up engineering, equipment and construction costs, often times ruining CHP economics, particularly in small and medium sized applications (i.e. < 1 MW). Also, because of the uniqueness of CHP applications today, performance, reliability and warranty risk are added.

The ICHM technology integrates the heating and cooling functions and hardware into more efficient and less costly prepackaged standardized systems that will reduce engineering and capital costs, improve system reliability, lessen maintenance expenses and optimize performance. The absorption cooling equipment will be optimized for temperature sources available from ultra-low emission reciprocating engine systems.

The market applicability will be measured among the commercial and light industrial applications having base electric loads between 250 kW and 3 MW. The current California market potential represented by these applications is 3,000 MW[2].

The ICHM includes a York single stage hot water fired absorber optimized to maximize efficiency and capacity at the lower hot water temperatures available from IC Engines equipped with EGR. The package also includes cooling tower, hot water heat exchanger, condenser water pump, pipe valves and fittings, outdoor enclosure, integrated single point controls, and documentation.

The initial product to be developed with PIER funding support will be a 75 ton absorption-based heating and cooling package that will be optimally interfaced with BluePoint Energy's 260 kW ultra-low emission reciprocating engine CHP system. The quality of heat (temperature) from BPE's 260 kW EGR engine CHP package was increased as much as possible without compromising engine durability or performance. The engine, emission control technology and CHP package will be 2007 ARB capable and will include a high temperature heat recovery sub-system that is optimized for performance with the ICHM.

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2. Onsite SYCOM Energy Corporation; *Market Assessment of Combined Heat and Power in California*; 1999; prepared for the California Energy Commission.

3.4.2. *Target Market*

The ICHM portfolio is planned to span 65 ton to 400 tons. These will match up with ultra-low emission engines in the 250 kW to 2,000 kW size range. With multiple units, the application reach for the planned ICHM portfolio includes sites with base electric loads up to 5 MW. Using the 1999 Energy Commission report *Market Assessment of CHP in California* as a reference, the estimated market size for this technology is 2,000 MW and 460,000 tons of cooling in the Commercial and Institutional sectors. Traditional industrial CHP sites with high process heat loads will not be the best markets for the ICHM. However, there are significant numbers of industries in California that have good CHP electric profiles (i.e. long hours of operation and steady electric loads), but lack traditional process heating loads. Most of the sites do have significant space heating, cooling and/or process cooling requirements, making most of them good candidates for the ICHM. The target market for the ICHM is shown in Table 9 below:

Table 9. Target market sectors for ICHM

Commercial	Institutional	Industrial
• Retail	• Colleges	• Food Processing
• Hospitals	• Prisons	• Manufacturing
• Hotels	• Military	
• Nursing Homes	• Municipal	
• Office		

The authors conservatively estimate the current California CHP potential for these industrial market segments at 1,000 MW and 230,000 tons. Outside California, CHP implementation activity has been and will continue to be highly regional. California and the Northeast have been where most small-to-medium-sized CHP development has occurred in recent years with minor activity in the Midwest and Mid-Atlantic regions. CHP economics are very dependent on above average electric rates and favorable regulatory support. The authors see a continuation of the same regional makeup for the foreseeable future. Factoring in growth in target market sectors over the next 10 years in key regional markets, a total potential U.S. market size of 3,900 MW and 900,000 tons is estimated.

3.4.3. *Commercial Deployment Challenges and Solutions*

Although the benefits appear compelling and the potential market size is very large, the ICHM must overcome barriers that plagued conventional CHP including utility resistance, marginal economics, and sluggish customer acceptance. Important hurdles that must be cleared with the new technology are highlighted in Table 10 below:

Table 10. Commercial deployment challenges and solutions

Hurdle	Solution
Marginal CHP economics	Lower cost absorption chiller integration
Poor absorber performance	Standardized design, factory assembly, reputable manufacturer and service
Low heat utilization	Cost effective absorption integration with ICHM
Acceptance of ICHM benefits	Field test and case studies Target customer mailings and meetings
Recognition of Demand Side Response value	Demonstration of Peaking capability Utility acceptance as DSR method
Difficulty obtaining local building permits	Standardized Designs
Difficulty obtaining air quality permits	Partner with 2007 capable packagers

CHP in California is beginning to experience good momentum, and that momentum is expected to continue for CHP technologies that can keep pace with California's requirements for emissions. The proposed CHP sub-system improvement will enable engine CHP systems to see increased market activity and to participate in the improving climate for CHP in California.

3.4.4. *Technology Transfer Approach*

The planned ICHM platform sizes will be 65 tons to 400 tons, which match up with ultra-clean engine CHP systems in the 250 kW to 2,000 kW size range as they are introduced to the market in 2008 and beyond.

It should be noted however, that South Coast Air Management District (SCAQMD) is the only California Air Pollution Control District (APCD) that has moved to adopt ARB 2007 thus far. Effective February 1, 2008, SCAQMD did adopt ARB 2007 for NOx, but eased up on the requirements for CO and VOC. Regardless, the progress toward achieving a commercial solution for ARB 2007 is encouraging. There are a couple rich burn engine packagers who currently advertise ARB 2007 capability, but fall short of guaranteeing continuous operation at those ultra-low levels. Jenbacher's lean burn engine distributor in California claims they will guarantee ARB 2007 performance, if required. With ongoing support from the Energy Commission and Southern California Gas Company, it is expected that several more engine packagers will have commercially deployable ARB 2007 solutions as the market demands it.

Primary responsibility for commercial deployment of the ICHM resides with Johnson Controls International, Inc. (JCI/York) and ICHPS will sell the ICHM through the JCI/York sales channels and will work with the JCI/York sales offices to market the system. DE Solutions, Inc. will assist with technology transfer initiatives and will provide sales and marketing support for the ICHM in the Western United States as a representative for ICHPS. JCI/York will supply the absorber and select other ICHM components at preferred OEM pricing. JCI/York will also provide technical assistance to ICHPS and service and maintain the ICHM fleets through their service network.

The marketing channels for the ICHM product line will be through engine CHP packagers, JCI Sales Representatives, Energy Service Companies (ESCOs), CHP Project developers, System Integrators, and select engineering firms specializing in CHP projects.

As California has less of a need for space heating and more of a need for cooling than most of the other CHP regions, California is the logical state to rollout the ICHM and is expected to remain the primary market for the foreseeable future.

3.4.5. *Technology Transfer Activities*

The following technology transfer activities have been conducted or are planned:

- ICHM Development - Successful technology development, system integration and ARI performance testing validated the functionality, performance and cost characteristics of the ICHM.
- Field Test – Demonstration of the ICHM over a range of "real" ambient and occupancy conditions tested the ICHM performance and control software. Also, the ICHM capacity gain with higher temperature engine coolant temperatures was measured to confirm temperature – capacity relationship.
- Market Outreach – The ICHM technology benefits and progress with the field test at Normandie Casino has been presented at key conferences including CADER, Power Generation, ASHRAE, the Advanced Stationary Reciprocating Engine Conference, select AEE conferences, Energy Solutions Center meetings, and other significant meetings that bring CHP industry stakeholders together. Specific conferences and dates are listed below:
    - The following are seminars where the ICHM was the topic:

      March 2005 – 2nd Annual ASRE Conference, SCAQMD, CA
      September 2005 – 6th Annual International Symposium on DER, Santa Clara, CA
      October 2006 – Energy Solutions Center TMAF, Indianapolis, IA
      March 2007 – ASHRAE 2007 Winter Meeting, Dallas, TX
      June 2007 – Northeast CHP Initiative Conference, UCONN, Stores, CT
    - The following are exhibitions where the ICHM was exhibited:

      2006 – Keyspan Breakfast CHP Seminar, Staten Island, NY
      April 2007 – Globalcon 2007, Atlantic City, NJ
      September 2007 – 4th Annual ASRE Conference, Downey, CA

- The following are a partial list of seminars where the ICHM was part of a presentation by either ICHPS or JCI/York:

  June 2006 – Northeast CHP Initiative Conference, UCONN, Stores, CT
  June 2007 – PGW CHP Seminar, Philadelphia, AP
  September 2007 – 4th Annual ASRE Conference, Downey, CA
  January 2008 – 10th Annual CADER Conference, La Jolla, CA

- In addition presentations on the ICHM have been given to the following JCI/York sales offices:

  Southern California
  New York City
  New Jersey
  Connecticut

- ICHM Commercial Deployment – A standard ICHM offering has been developed to fit a variety of popular engine CHP system sizes, with ICHM cooling capacities ranging from 75 to 400 tons. The ICHM offerings include physical descriptions, performance characteristics, pricing lists and optional features.
- Engine OEM Packager Offering – ICHM offerings have been offered to natural gas engine OEMs and major engine CHP packagers. Efforts have focused on engines that show the best market prospects for the ICHM.
- Other Market Channels – Other market channels through ESCOs, CHP developers and engineering construction firms with CHP experience are being explored.
- Utility Alliances – ICHPS and DE Solutions are seeking to forge alliances with California and other U.S. utilities around the ICHM. The nature of the alliances will vary by utility but can include the availability of incentive payments, joint marketing, ownership, customer services, promotional programs, etc.
- Sales and Marketing – The ICHM will be sold and serviced through the JCI/York distribution network. Sales and marketing literature will be prepared and a product name and logo will be created. ICHPS will train and provide technical assistance to JCI sales personnel as well as engine CHP packagers.
- Installation and Operations Manual – ICHPS is preparing an installation manual which will detail all the information an engineer will need to design the ICHM into the building's thermal systems and to interface with the engine CHP package. ICHPS will also produce an operating manual on the ICHM including general theory of operation, detailed customer interface specifications, service information, and troubleshooting information. This manual will provide all the information the end user will need to operate the unit. These manuals and other product information will be disseminated to key players in the CHP market to ensure that they are informed of the capabilities of the ICHM.
- Product Launch – The initial product launch will be with motivated CHP packagers matched with engines that have been proven in the marketplace. The initial regional

focus will be in California. ICHPS will leverage these early applications to other sizes and packagers.

- California Northeast Market Rollout – Market conditioning and product rollout will initially be focused on California and the Northeast.

3.5. Production Readiness Plan

3.5.1. *Introduction*

The ICHM is designed to be fabricated by qualified third party fabricators according to the design provided by ICHPS and in accordance with approved practices as determined by ICHPS. The goal is to provide a streamlined method for providing the client with a fully functional 'plug-n-play' module to meet site requirements, which can vary from project to project. Furthermore, the goal is to provide this module as a highly reliable system with optimized performance at a cost that can be borne by the market.

The ICHP production plan is also designed to minimize the cash investment required in order to perform the contract. Agreements are already in place with the major component supplier and an agreement with the fabricator would allow for a practical cash flow with sufficient return to allow the business to develop.

This document outlines the major production steps, fabricator qualifications and costs associated with building the ICHM. The ICHM will be fabricated to order, and the production plan is designed to minimize the time between order acceptance and billing. The final section deals with anticipated cash flow during the performance of an ICHM contract.

3.5.2. *Production Processes*

Production of the ICHM consists of assembling and integrating multiple components in an enclosure according to the design drawings, specifications and approved production methods. There are no special requirements beyond normal mechanical fabrication requirements consisting of rigging, pipe fitting, welding and electrical work. All components, including the control system are provided as complete subassemblies by individual suppliers. Fabrication of the prototype unit that was shipped to the Normandie field test site provided a *dry run* for the future production process and no significant deviations from the methods employed in the prototype fabrication are anticipated at this time.

The production process plan is broken down into several sequential steps:

- Design
    - Mechanical
    - Structural/Enclosure
    - Electrical
    - Controls
    - Fabrication drawings

- Fabrication
    - Base frame and enclosure
    - Major equipment installation
    - Piping
    - Electrical
    - Controls [3]
- Shipment Preparation
    - Functional and pressure testing
    - Control testing
    - Clean-up and painting

Design

ICHPS will provide the complete fabrication drawings with the assistance of a design engineering company. These drawings will be transmitted to the third-party fabrication company who will be required to interpret them and fabricate the ICHM according to the approved methods. As each application will typically have different requirements in terms of size, engine, wet bulb, and options, a unique set of drawings will be supplied for each unit. The design is modular based on chiller frame sizes and has several options associated with each ICHM so that the basic ICHM drawings will be utilized multiple times with variances based on site defined options.

Fabrication

As mentioned above, there are no special requirements beyond normal fabrication capabilities available from a wide range of third-party companies in multiple locations. There are minimum requirements in terms of space, lift capacity and personnel, which are detailed below. In addition, support services are required to facilitate production, including engineering, offloading and receiving, as well as storage space for components. The control system consists of a control panel with PLC controller and I/O bus. This will be fabricated by a specialist control company and will be shipped to the main fabricator as a component to be integrated into the ICHM.

The fabrication methods will be developed in conjunction with the fabricator and will incorporate the following basic process approach:

Fabrication of the frame and floor assembly: The frame is constructed of structural steel tubing, with a floor fabricated of diamond plate on a combination of C channels and structural tubing to provide rigidity during transportation and rigging. Additional structural members are installed for shipping, and are easily removed and returned to the fabrication facility once the system is put in place, unless the system is expected to be relocated in the future. The additional members are interchangeable throughout the side range of the ICHM frames for simplicity. The

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3. The control panel will be supplied as a complete subassembly by a specialist control company not related to the main fabricator.

welded steel frame does not rely on the "skin" for support, and therefore once the frame is fabricated, access to the entire area is open for ease of fabrication until the end of the project, when the removable skin is installed.

Fabrication of the removable roof assembly frame: The roof section and main structural members on the top are removable for both ease of fabrication and should it ever be necessary to remove or reconstruct the York unit. The separate roof structure is designed to be easily installed to the lower part of the frame with self aligning structures and clevis pins. Separate fabrication allows the roof to be fully fabricated in parallel with the rest of the unit's construction, and therefore can be completed well in advance of receiving all the equipment. The roof panels are prefabricated, insulated with a STC 3.0 rating for sound attenuation and a 30 psf wind rating. The roof will be fabricated in two sections with a joining strip at the center. This makes handling the roof section easier during the installation without adding to the cost. Lifting lugs are attached through the roof and into the main lower frame assembly. A removable roof means that even if the York unit is delayed in shipment, the rest of the facility can be plumbed and virtually completed prior to arrival, and as most items have a shorter delivery time, this may become a standard operating procedure.

The system is designed so that the pipes leave the unit just under the roof, and as high as possible. This maximizes the available room inside the box for the pumps and heat exchangers. A novel "rack" system in incorporated into the right hand side of the ICHM, so that each of the heat exchangers, pumps and valves can be either serviced in place, or easily disconnected from a piping manifold and removed from the rack quickly and effectively. Heavy items can be lifted or removed from the unit using the overhead rail and chain-fall system; all but eliminating the need for special handling equipment on site should repairs become necessary. A pipe-rack and slab design is provided so that the locations of all pipes are well defined for the field contractor. All dimensions are referenced with respect to the top of the concrete support slab (or bottom of steel floor supports). The rack assembly can be fully fabricated independently of the structural steel tubing frame, and put into position with the overhead crane, front or side entry. All equipment can be mounted after the rack is in place. This allows the rack to be constructed in parallel with the roof and system frame.

The piping can all be pre-fabricated with the final length left long and cut to fit to allow for minor adjustments. In this way, almost 90% of the piping welds can be done before the equipment is mounted. Flanged connections allow for ease of assembly/disassembly, and eliminate the possibility of bad threads or union castings.

Control valves are mounted at the same time that the piping is, or can be prefabricated and painted prior to installation with the final weld area left unpainted and retouched with paint at completion.

The roof frame and lower frame are painted after fabrication and before the floor plate or wall panels are installed. The bottom of the unit is painted with the frame suspended from the overhead crane to eliminate areas that do not get painted because of "chocking". Alternatively, the bottom of the frame can be painted prior to the vertical members being welded to the frame.

Once the frame is painted, the unpainted "diamond plate" floor is installed, and then the rack can be installed on the right side of the unit. The rack unit is painted separately once fabricated.

The fabrication schedule is developed around the following steps in consultation with the fabricator:

- Fabricate the base and roof frames
- Paint the base and roof frames
- Fabricate and paint the rack
- Install diamond plate floor on base frame
- Install rack
- Install the cooling water pump
- Install the HX1 and HX2 heat exchangers
- Install the HX3 and HX4 heat exchangers (as applicable)
- Install the cooling water valves and piping (pre-painted)
- Install the chilled water piping
- Install the engine coolant piping
- Install the electrical service
- Install the VFD
- Install the lighting
- Install the local cooling/heating unit for environmental control.
- Install the control panel
- Install the York Unit
- Install conduits between the control panel and the York control panel
- Install front door into frame
- Install upper wall panels that are not normally removed
- Install the roof panels onto the roof frame
- Install lower "removable" wall panels
- Install roof
- Connect power to unit
- Control system is started up
- Pump is verified for rotation, phases are identified, tagged and labeled
- Pipes and other areas are insulated
- Final finished painting and branding
- Nameplate and specification plate attached
- Operator manuals put into storage area in unit.

Shipment Preparation

Prior to completion of the ICHM, the fabricated system will be checked for leaks using a wet pressure test and the controls and electrical equipment will be tested for functionality. Once the ICHM has been proven or any corrective action has been completed, the system will be cleaned, painted and identification tags and tape will be added. The system will then be loaded on a truck and shipped to the destination site.

ICHM Major Equipment

Table 11 below lists the major components that are included in the ICHM. The cooling tower will be shipped directly to the site from the manufacturer.

Table 11. ICGM major equipment

ICHM Major Equipment	
Absorber	**Enclosure**
Absorber	Base Frame
Gateway Card	Structural Support
Insulation	Access Doors
Vacuum Pump	Louvers
LiBr Solution	Exhaust Fan
Cooling Tower	Light Fixtures
Cooling Tower	Paint/Decals
Fan & Motor	Drains
Mechanical Equipment	**Electric Equipment**
Circulating Pump	Power Panel
Expansion Tank	Starters
Heat Exchangers	Disconnects
Float Switches	VFD
Pressure Indicators	Fuses
Temperature Sensors	**Control System**
Diverting Valves	Control Panel
Butterfly Valves	Allen-Bradley PLC
Check Valves	Keypad & Screen
Strainers	Programming
Pipe & Fittings	Data Logger
Supports	Modem

3.5.3. *Required Resources*

In order to fabricate the ICHM, there are certain minimum requirements in terms of space, lift capacity, skills, etc. that need to be evident in order for a fabricator to be considered. These resources are required, not only for proper fabrication of the system, but also to reduce costs and minimize fabrication schedule in all types of weather conditions. Fabricators need to be able to receive components, store them locally and have easy access to them when required. They also need to be able to work on the system through various weather conditions without interruption to meet anticipated delivery schedules.

3.5.4. *Facilities*

The fabrication site should be an enclosed space capable of maintaining a proper working environment through all local ambient conditions. There should be a minimum of 30,000 square feet of contiguous production area with a minimum ceiling height of 35 feet.

Facilities for offloading chillers up to 40,000 lbs from trucks and moving the chiller to storage or onto the frame must be available. In addition, the facility needs to be able to fork-lift pallets and other equipment out of enclosed delivery trucks.

Approximately 2,000 square feet (flat or rack) of secure storage space needs to be provided for heat exchangers, valves, etc., which will be shipped as they become available. If the absorber is delivered prior to the fabrication of the base frame then it will also need to be stored in a clean dry space. Temperatures for storage should not exceed 100°F or go below 35°F.

The fabricator will conform to the quality control standards and inspection system, as well as related standards and systems that are established under ISO 9000.

The fabricator will comply with all applicable laws, including rules, regulations, orders, conventions, ordinances and standards, that relate to the manufacture, labeling, transport, import, export, licensing, approval or certification of the services and equipment, including laws relating to environmental matters, hiring, wages, hours and conditions of employment, subcontractor selection, discrimination, occupational health or safety, and motor vehicle safety. All materials used by the fabricator will satisfy current governmental and safety constraints on restricted, toxic and hazardous materials as well as environmental, electrical and electromagnetic considerations that apply to the local area or ICHM destination state or region.

Seller will maintain the insurance coverage listed below or in additional amounts as may be reasonably requested by ICHPS or (to the extent directed by ICHPS) ICHPS's customer(s), in each case naming Buyer and its affiliates and customer(s) as "additional insured" as requested by ICHPS. The fabricator will furnish to ICHPS a certificate showing compliance with this requirement or certified copies of all insurance policies within 10 days of ICHPS's written request. The certificate will provide that ICHPS (and, if applicable, ICHPS's customers) will receive 30 days prior written notice from the insurer of any termination or reduction in the amount or scope of coverage. The existence of insurance does not release the fabricator of its obligations or liabilities under any purchase order.

Except as otherwise agreed, minimum coverage is highlighted in Table 12 below:

Table 12. Insurance coverage requirements for sellers

COVERAGE	LIMITS OF LIABILITY
Workers compensation	Statutory
Employer's liability	US$100,000 / each accident, disease policy limit, disease each employee
Comprehensive general liability insurance, including contractual liability coverage	US$5,000,000 / each occurrence, general aggregate, products & completed operations aggregate
Comprehensive automobile liability insurance	US$1,000,000 / each occurrence, combined single limit

3.5.5. *Fabrication Equipment*

The site needs to have lift capabilities of 60,000 lbs to load the completed ICHM on a truck as well as to lift a 40,000 lbs absorber 15 feet high, move it, and place it into the fabricated enclosure.

The site needs to be capable of providing 480 V power to test the ICHM, as well as providing water and pumps to pressure test all hydronic lines.

The following additional capabilities are required:

- Steel pipe cutting up to 12 inches
- Mobile welding stations (MIG)
- Drill presses
- Pipe bending up to 6 inches
- Mechanical saws
- Spray paint equipment

3.5.6. *Personnel*

The following labor skill sets are required:

- Certified welders
- Pipe fitters
- Engineering
- Supervisor
- Electrician (can be sub)

3.5.7. *Support Systems*

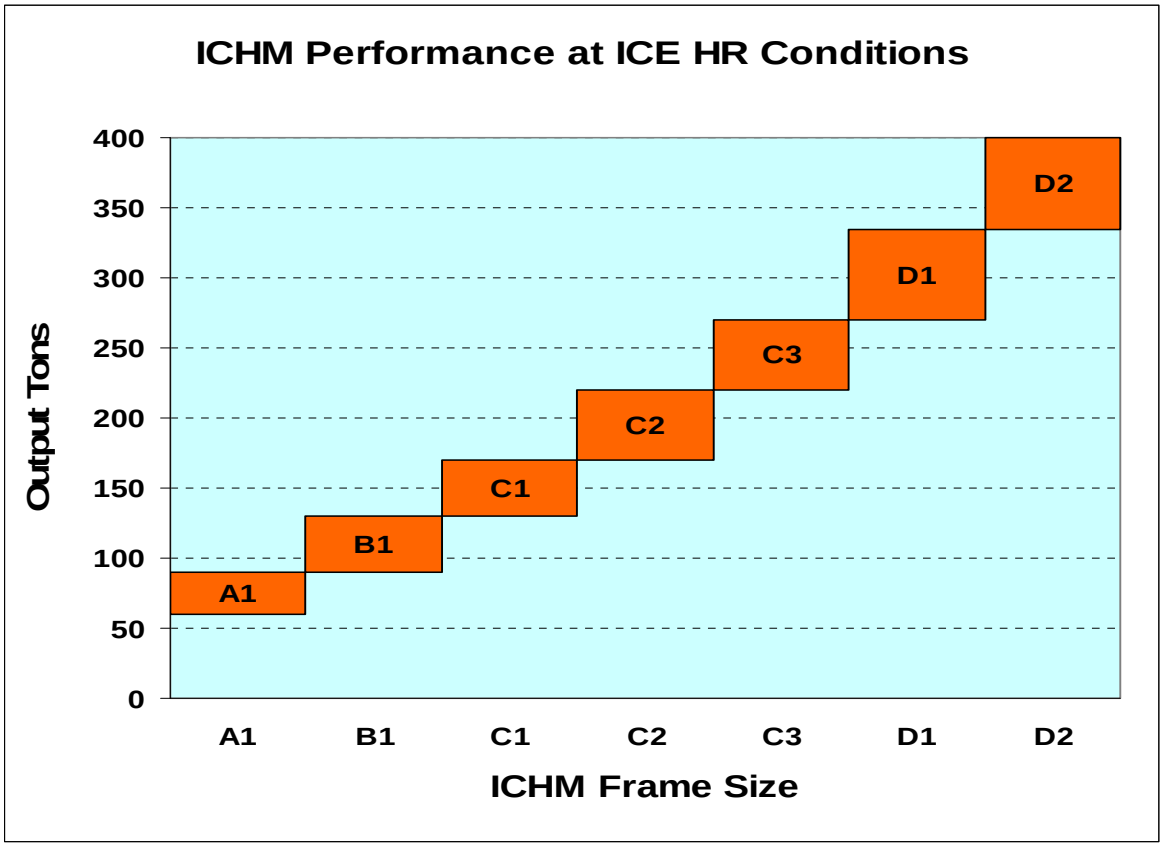
The following administrative software and support functions are required:

- Read AutoCAD drawings
- E-mail
- Safety record
- Parts maintenance
- Shipping and receiving
- QA/QC

3.5.8. *Budget Costs*

The planned ICHM range covers approximately 65 tons to 400 tons depending on the engine configuration and site conditions. Within this range the ICHM has been split into seven frame sizes that are used as price points. As indicated in the table below, each ICHM has a varied capacity, which is based on the volume and quality of heat recovery of the specific engine applied. It should also be noted that each ICHM will have several equipment variations and options depending on the engine type and configuration as well as site specific requirements.

Table 13. ICHM performance at ICE HR conditions



Notwithstanding the variations that will affect project specific pricing, an estimated cost for each frame size was developed to provide guidance and budgetary pricing capability. This pricing is based on current expectations for the cost of construction.

The following chart (Table 14) outlines the projected current budget costs and average output for each frame size. The budget cost includes the ICHM, freight, and commissioning as well as sales commissions for the agent.

Table 14. Projected current budget costs and average output by frame size

Frame Size	Budget Price	Output Tons	Budget $/Ton
A1	$250,000	78	$3,205
B1	$334,000	112	$2,987
C1	$378,000	153	$2,474
C2	$467,000	202	$2,310
C3	$495,000	236	$2,098
D1	$567,000	290	$1,956
D2	$623,000	337	$1,850

As part of the project, a study was carried out by the field test site installing contractor to determine the cost comparison between the ICHM and the alternative traditional approach of site construction. Based on this study, the ICHM demonstrated a 32% savings in terms of total installed project cost for the thermal equipment.

The following table (Table 15) presents the results of this study, which includes all mechanical, electrical and control equipment, engineering, installation, and commissioning. In addition to the cost benefits, the ICHM is also quicker to install and provides higher reliability.

Table 15. projected costs for ICHM based on study

Item	Site Construction	ICHM
Equipment		
Cooling Tower	$14,600	Incl.
Pumps & flow Switches	$18,850	Incl.
Valves & Expansion Tank	$16,900	$1,890
Pipe, Fittings & Insulation	$39,880	$9,746
Heat Exchanger	$5,890	Incl.
Enclosure	$23,930	Incl.
Starters & Disconnects	$7,820	$500
Power Panel	$4,540	Incl.
Transformer	$1,000	Incl.
CHP Control Center	$11,900	Incl.
Chemical treatment	$6,780	$6,780
Absorber	$79,500	Incl.
ICHM	N/A	$225,000
Equipment Subtotal	***$231,590***	***$243,916***
Subs/Labor	***$247,981***	***$90,582***
Overhead	***$9,133***	***$4,733***
Commissioning	***$24,640***	***$10,000***
Total Project Cost	**$513,344**	**$349,231**

Please note that the ICHM cost is based on dealer cost price rather than budget price.

Based on the comparative cost analysis together with industry estimates for site construction of thermal systems, we believe that the ICHM price basis is competitive in the market place. However, the authors are still above original target price estimates, especially for the smaller systems and will continue to work toward refining the fabrication process as well as working with component suppliers to further reduce the cost.

It is not yet possible to project the savings derived from these areas, but at an estimate of 20% reduction in fabrication labor costs combined with a 10% reduction in component costs would have the effect of reducing the overall budget price by approximately 10%. The authors believe that this is possible in the short term with even more reductions in cost for the larger systems.

3.5.9. *Implementation Plan*

The production plan calls for third-party fabrication of the ICHM from the design supplied by ICHPS. ICHPS will also supply all the major components to the fabricator and will oversee construction. After-sales service, which is as critical to the success of the overall production plan as the other elements, is regarded as an important component of the ICHM.

Implementation of the fabrication plan will require completion of the following tasks:

- ICHM design
- Component ID
- Fabricator ID
- Major component supply
- Fabrication and testing
- Service availability.

3.5.10. *ICHPS Supplier Team*

Engineering

The ICHM was designed as a modular system with multiple frame sizes and multiple options for each application. During the initial stages of production, new sets of drawings will be provided for each application as orders come in. Ultimately, fabrication drawings will be developed from a set of pre-designed modules.

KAR Engineering Associates of Bridgewater, NJ was selected as the design engineer for the ICHM. KAR is a small company that has been in business for more than 30 years and provides consulting engineering in electrical, mechanical, structural and controls (www.kar.org). KAR originally designed the controls for the ICHM prototype at Normandie, and the authors have expanded their role to include mechanical and electrical design also. ICHPS will continue to work closely with KAR to optimize and supervise design work. KAR will provide fabrication drawings for each ICHM and will assist in supervision of the construction. KAR already provides construction drawings to fabricators for their own fuel distribution and combustion systems.

Component Suppliers

The major component (over 50% of the total component cost) is the absorption chiller. The ICHM design is based on the York hot water fired single-stage model YIA absorption chiller. ICHPS has an agreement in place with York/JCI to purchase the "YIA" as exclusive fabricators for the CHP market. This agreement recognizes ICHPS as an OEM and provides maximum discount on cost as well as full engineering support.

The other major components are the cooling tower, condenser water pump, various heat exchangers, automated control valves, enclosure panels and PLC-based control system. The authors have an agreement in place with Baltimore Aircoil to provide ICHPS with OEM status and deal directly with the factory for pricing and technical support. The PLC-based control system will continue to be supplied from KAR. Suppliers for the other major components have been identified and will be contacted for OEM status and maximum discount once the authors have established some sales activity.

Minor components such as pipe, fittings, steel members, etc. will be supplied by the fabricator. Costs for these items will be compared in a bid request to multiple fabricators.

Fabricator Selection

A set of plans and specifications for a typical ICHM, including many of the typical options was developed. The authors will use this documentation to solicit bids from at least four fabricators including Enercon Engineering, Superior Boiler Works and Welding, Pletz Contracting, and Tulsa Combustion. Each of these companies has already been identified as having all the required resources listed above and as being qualified to provide the services required.

The company that can accomplish the required scope at the lowest cost will be regarded as the fabricator of first choice and will be awarded the contract to fabricate ICHM's as they are sold. It is intended that ICHPS will establish an ongoing relationship with the fabricator of first choice while also maintaining some options to keep prices in control as well as to meet customer schedules should multiple orders be obtained at once.

3.5.11. *Fabrication and Testing*

System fabrication consists of various tasks that are organized to streamline the production schedule while realizing that any individual component cannot be allowed to prevent the later tasks from proceeding. This allows the production facility to allocate manpower resources effectively. The system design is both modular and flexible, allowing almost any component (after the original frame is constructed) to be installed at any point.

The production steps detailed in the production process above is a guideline that will be used to develop a production schedule, track production progress as well as reduce the learning curve for the fabrication vendors. Progress will be continuously monitored against the agreed schedule with the intention being that the system will be almost complete by the time the absorber is shipped to the fabricator. This reduces ICHM lead time to allow for client billing to occur as soon as possible after components are ordered.

Fabricator qualifications as detailed above will be required to be met so that there is an assurance that the fabricator can carry out the work required. Specifications for components supplied by the fabricator were developed and agreement will be reached with the fabricator, ICHPS and KAR Associates, on the production methods to be employed. These methods will be based on the above described production process and will also be subject to the capabilities and normal production methods of the chosen fabricator. During the initial production runs, ICHPS will work closely with the fabricator to ensure specifications are met throughout the production process. ICHPS in coordination with KAR Associates will do a final check of all assemblies, paint, visual condition, leaks, etc. in accordance with the testing plan.

After final inspection the unit is prepped for shipping including plastic wrapping and stowing of any loose items. The unit will be lifted onto a low-boy trailer with lifting lugs provided. Lifting lugs are designed to hold the unit stable and horizontal during lifting and will not cause undue deflection. Unit is strapped to trailer and paperwork is transmitted to driver, client and ICHPS. This includes all Quality Assurance/Quality Control (QA/QC), Department of Transportation (DOT) required paperwork.

3.5.12. *Investment Requirements*

As the ICHM is fabricated by a third-party in an outside facility, the main investment costs of production equipment and space are avoided. The remaining costs include design and application engineering, labor for oversight and administration, which includes purchasing, shipping, site coordination, etc., components and fabricator charges. The supplier agreements and production methods are partially designed to minimize the cash investment required to build the ICHM. Particularly in the initial phases of developing ICHM sales, this will be an important issue.

The ICHM modular design is completed and requires little further investment. Application engineering will be carried out by ICHPS in the normal course of their business. Final unit engineering will be subcontracted to KAR Associates and will be paid from engineering costs associated with the specific unit. Labor for oversight and administration will be supplied by ICHPS and will be paid for from overhead costs associated with the specific unit.

Components represent a significant portion of the ICHM costs with the York absorber accounting for approximately 50% of the component costs. ICHPS has an agreement with York that allows for extended payment terms allowing ICHPS to pay for the absorber after receipt of payment from the client. Other components will generally be purchased on a net 30-day term and will require some upfront cash investment. Terms for payment of fabricator charges will be negotiated with the chosen company to allow progress payments and allow at least 40% of the cost be paid in 30 to 60 days after shipment to allow for client payment prior to paying for the final fabrication charges.

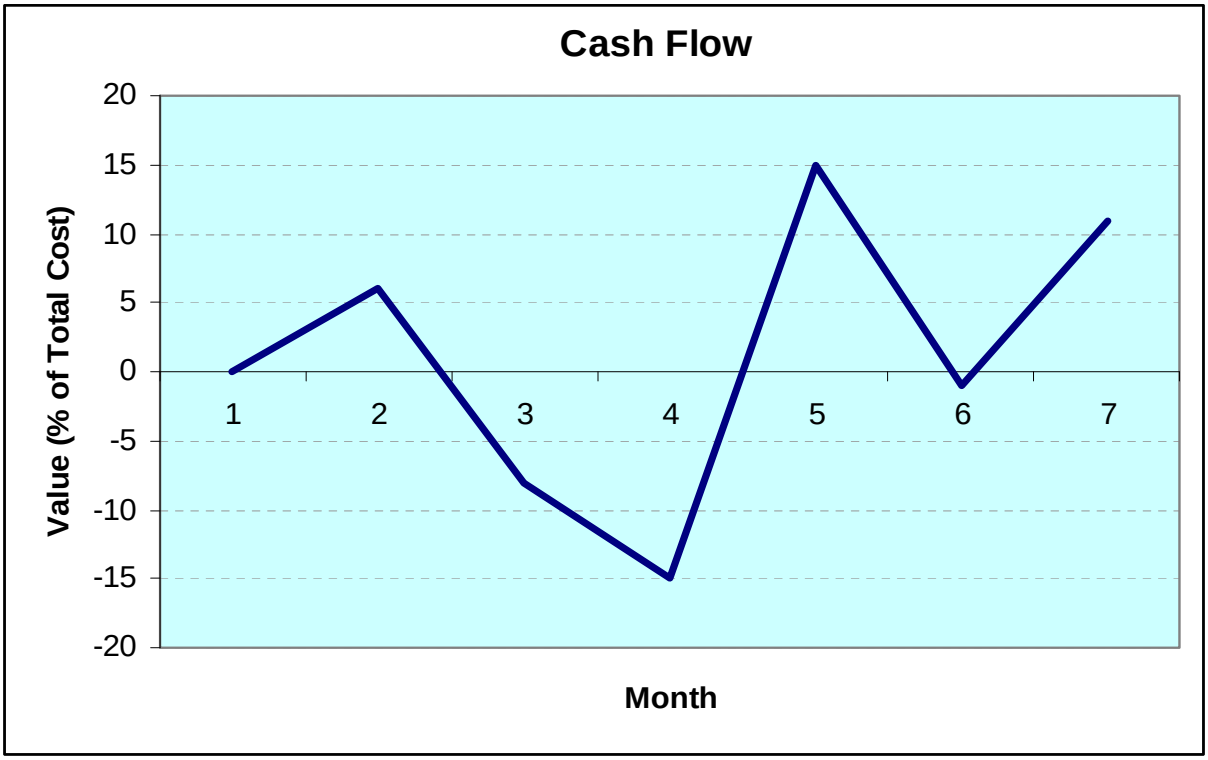
The following table indicates the percentage of total cost associated with each vendor. These costs do not include profit or commissions paid to resellers, which are included with the budget ICHM prices.

Table 16. Percentage of total cost of project by vendor

	Supplier	Cost
Overhead	ICHPS	11%
Engineering	KAR	6%
Absorber	York/JCI	25%
Other Components	Miscellaneous	28%
Fabrication	Contractor	22%
Shipping & Commissioning	Shipper/JCI	8%
Total:		100%

The following graph shows the anticipated cash flow resulting from an ICHM order in terms of percentage of total cost not including ICHPS costs which are covered as part of its normal business costs.

Figure 31. ICHM anticipated cash flow as a percentage of total cost (does not include costs associated with normal business costs)



Source: Integrated CHP Systems Corporation.

The graph projects that the total cash investment required by ICHPS, to perform an ICHM contract, will be 8% of the ICHM cost over two months and a maximum of 15% over a period of approximately one month. This is based on a client payment schedule of 30% with order, 30% upon shipment, and 40% upon commissioning.

In cases where the client has sufficient credit worthiness and demands net 30 payment terms, ICHPS investment will grow to 50% of cost over 6 months. Financing costs to borrow this amount of cash will be added to the ICHM cost. In this scenario, a typical ICHM model C2, which has a pre-commissions sale value of approximately $420,000 and a total cost of approximately $365,000 (not including ICHPS overhead revenue), the maximum cash investment for ICHPS would be $182,500 accumulated over 6 months. The resulting profit and overhead revenue of $55,000 or 30% return on investment (ROI) is sufficient to justify the investment.

4.0 Conclusions and Recommendations

4.1. Conclusions

The goals and objectives of this agreement have largely been realized. In summary, the goal of this project was to significantly reduce the cost of CHP integrated HVAC systems for commercial and light industrial applications. The project objectives were to:

- Reduce HVAC system and interface costs by 35%.
- Increase engine/exhaust heat recovery outlet temperature to 215°F.
- Increase CHP economically addressable market by threefold.
- Reduce the cost of electricity to target markets by 25%.

In addition, specific performance targets for the field test system included:

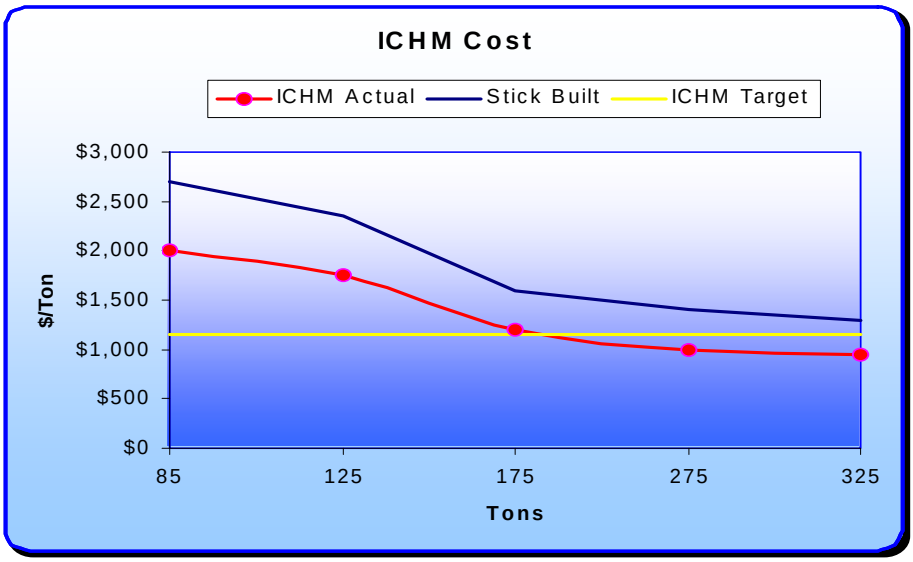
- Achieving a cooling capacity of 80 tons and a COP of 0.68 with heat input of 1.4 MMBTU/hr.
- Reaching a recovered heat output from the engine package of 1.4 MMBTU/hr and an electric efficiency of 34%.

4.1.1. *ICHM Cost Advantage*

The ICHM is 30% cheaper to install than stick built systems.

Equipment and installed cost estimates for a range of ICHM sizes were measured up to comparably sized stick built systems. As Figure 31 shows, the ICHM maintains a 30% cost advantage over the entire range of targeted sizes. However, costs for ICHM systems less than 150 tons still strain market viability without further cost reduction.

Figure 32. ICHM vs. stick built system cost



Source: Integrated CHP Systems Corporation.

Next>edge, the independent contractor responsible for field test design and construction, performed an independent cost comparison of the ICHM vs. stick built system for the 80 ton absorber at the field test site. The comparison is summarized in Table 17.

Table 17. 80-ton absorber comparison

Item	Site Construction	ICHM
Equipment		
Cooling Tower	$14,600	Incl.
Pumps & flow Switches	$18,850	Incl.
Valves & Expansion Tank	$16,900	$1,890
Pipe, Fittings & Insulation	$39,880	$9,746
Heat Exchanger	$5,890	Incl.
Enclosure	$23,930	Incl.
Starters & Disconnects	$7,820	$500
Power Panel	$4,540	Incl.
Transformer	$1,000	Incl.
CHP Control Center	$11,900	Incl.
Chemical treatment	$6,780	$6,780
Absorber	$79,500	Incl.
ICHM	N/A	$225,000
Equipment Subtotal	***$231,590***	***$243,916***
Subs/Labor	***$247,981***	***$90,582***
Overhead	***$9,133***	***$4,733***
Commissioning	***$24,640***	***$10,000***
Total Project Cost	**$513,344**	**$349,231**

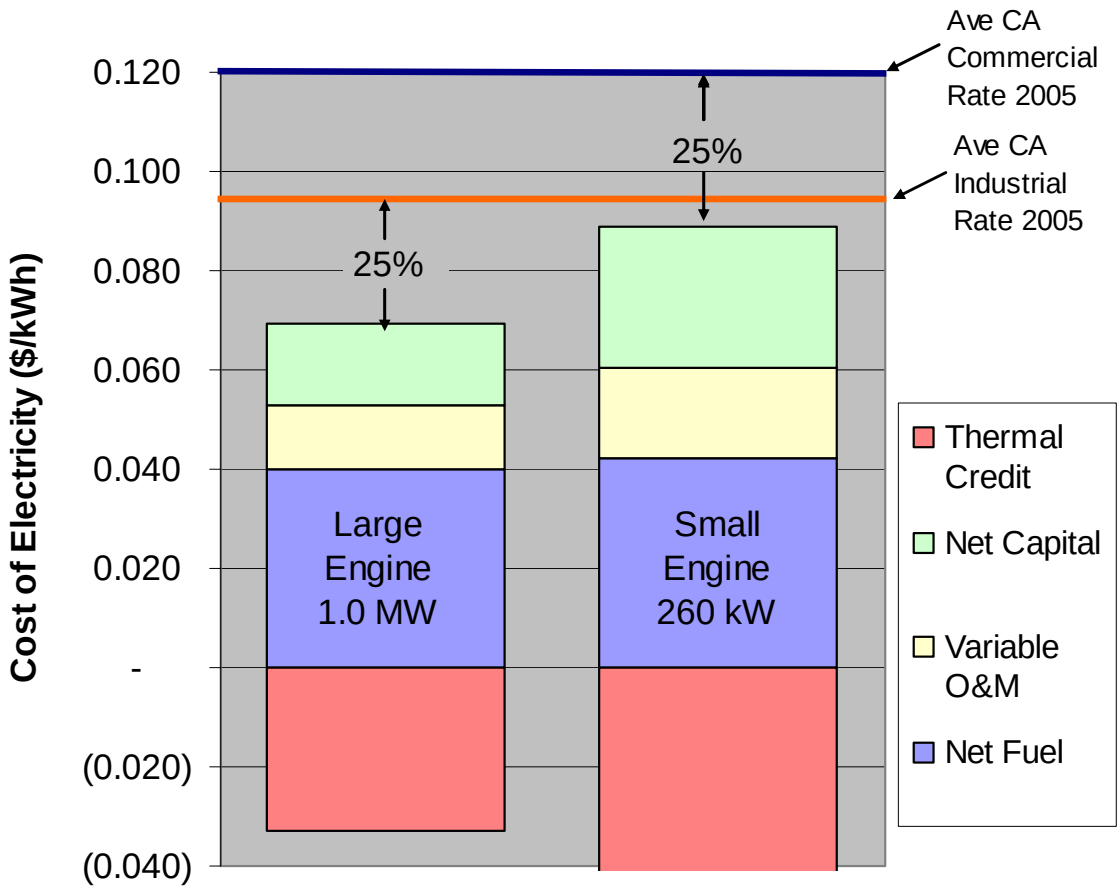
The ICHM saves 32% over the cost of a stick built system.

4.1.2. *ICHM Market Advantage*

Engine CHP ICHM reduces cost of electricity production by 25%.

CCHP site energy usage determines proper CCHP system sizing and applicable utility rates. Larger commercial and industrial sites generally benefit from economies of scale and lower utility tariffs. A large and small site is typified in Figure 32. The cost of CCHP incorporating an ICHM is compared against the average cost of electricity for smaller (commercial) and larger (industrial) sites. As shown, CCHP exhibits healthy cost benefits for both size classes.

Figure 33. Engine CCHP ICHM cost of electricity



Source: Integrated CHP Systems Corporation.

4.1.3. ***Economic Market Improvement***

Increases economic market more than threefold.

The CHP market has not been able to gain much traction over the last six years since the beginning of the Self-Generation Incentive Program (SGIP). The SGIP engine CHP market summary is shown in Table 18 for the size range addressable by the ICHM. Table 19 shows the estimated market potential between 2005 and 2020 for CHP over the same size range based on a CHP Market Assessment conducted by the Energy Commission in 2005. This figure also illustrates estimated market penetration of engine CHP over that same period for three energy policy scenarios. All cases assume technology and learning curve improvements over time such as the ICHM. As shown, the projections are far more robust than the recent market activity would suggest in part due to progress with system technology exemplified by the ICHM.

Table 18. SGIP engine CHP market summary

LEVEL 3-N (IC Engines)	Statewide SELFGEN Projects		
System Size	Total # Projects	Total kW	System Size Avg
201 - 500	56	19,015	340
501 - 1000	56	42,798	764
1001 +	48	67,334	1,403
Total Projects	160	129,147	807

Table 19. Market projections for engine CHP

Engine CHP Market Penetration (2005 - 2020), MW					
	50-500 kW	500-1,000 kW	1-5 MW	Est. Total 200 - 2,000 kW	Total All Sizes
Market Potential	6,766	6,814	10,282	19,000	27,458
Base Case	332	457	606	1,100	1,499
Aggressive Case	378	541	759	1,300	1,839
High R&D	358	349	740	1,100	1,592

4.1.4. *ICHM Performance*

With elevated engine coolant temperatures cooling output (COP) of 0.68 is realized and along with increased cooling capacity.

The field test unit was tested at the York factory under ARI standard test conditions prior to shipment to the field test site. At the time of testing, the expected output from the engine had been slightly reduced from the original design goal of 1.4 MMBH to 1.33 MMBH. The measure output was 74 tons, slightly less than projected, but considered within an acceptable tolerance range. The performance was also confirmed in the field although site requirements for cooling in the fall infrequently called for maximum output from the ICHM. Although most of the field test period found the ICHM operating at part-load with somewhat lower engine coolant temperatures, the ICHM performance was within specification.

4.1.5. *Engine Package Performance*

Engine package can be modified to run at elevated coolant temperatures without compromising efficiency and reliability.

Engine operation at 193oF coolant return temperature and 215oF EHRU leaving temperature was achieved in the factory. An efficiency of 32.6% was measured in the factory under the elevated temperature conditions, slightly below the projected efficiency of 34%. However, after several hours of operation in the field it was determined that the higher elevated temperatures

unacceptably impacted engine durability. The operating limits were reset to a 185°F return temperature, still higher than the 175°F specified by Deutz, the engine supplier.

4.1.6. *ICHM Market Acceptance*

ICHM Market Acceptance.

Overall, the ICHM project was considered a success. The capital cost and reliability advantages of the ICHM have been accepted by JCI/York who has decided to market and sell the ICHM through their sales and marketing channels. As of the end of this development and validation project, JCI/York has developed brochures, specification sheets and pricing for the range of ICHM sizes, and training of the JCI/York sales team is underway. A number of prospective customers are now evaluating the ICHM.

4.2. Commercialization Potential

4.2.1. *Technical Market Potential*

The ICHM portfolio spans 65 tons to 400 tons. These match up with engines in the 250 kW to 2,000 kW size range. With multiple units, the application reach for the planned ICHM portfolio includes sites with base electric loads spanning up to 5 MW. Using the 1999 Energy Commission Report "Market Assessment of CHP in California" as a reference, the estimated market size for this technology is 2,000 MW and 460,000 tons of cooling in the commercial and institutional sectors. Traditional industrial CHP sites with high process heat loads will not be the best markets for the ICHM. However, there are significant numbers of industries in California that have good CHP electric profiles (i.e. long hours of operation and steady electric loads) but lack traditional process heating loads. Most of the sites do have significant space heating, cooling and/or process cooling requirements making most of them ideal candidates for the ICHM. The California CHP potential for these industrial market segments is estimated at 1,000 MW and 230,000 tons. The sector breakdown for this market potential, which spans applications with base-load electric requirements between 250 kW and 3 MW, is shown below.

Table 20. Potential for CHP in California industrial market by sector

Sector	# sites	Capacity (MW)	Cooling (Tons)	# Units
Commercial & Institutional				
Health Care	231	123	28,336	274
Education	1,398	905	208,196	2,012
Lodging/Hotels	661	507	116,564	1,126
Multi-family	512	304	70,012	676
Museums/Zoos	33	26	5,934	57
Airports	39	27	6,256	60
Other	165	141	32,476	314
Total - Commercial	**3,039**	**2,034**	**467,774**	**4,520**
Industrial			**-**	
Total - Industrial	**1,000**	**1,000**	**230,000**	**12,500**
Total - C&I	**4,039**	**3,034**	**697,774**	**17,020**

Market sector growth in these sectors is estimated at 2% per year. So, given that this market data is 8 years old and projecting out 10 years from commercial introduction in 2005, the market size can be expected to be 30% larger than indicated above, increasing the totals to 3,900 MW and 900,000 tons.

4.2.2. *Quantity and Timing of California Market Potential*

The market launch of the ICHM will begin in 2008, following completion of the field test. The regulatory climate for ultra-clean CHP in California for the foreseeable future continues to be favorable as clean-CHP coalitions develop closer alliances with the renewable and efficiency communities.

The market will start slow due to stringent emission regulations that are beginning to be adopted ahead of commercially evolving engine technology. The market will also be slowed in 2008 as a result of the funding lapse for the SGIP.

The marketing channels for the ICHM product line will be through JCI/York traditional sales channels to engine CHP packagers, ESCOs, CHP project developers, system integrators, and select engineering firms specializing in CHP projects. Integrated CHP Systems Corp. will provide sales training, marketing assistance and applications engineering support to JCI/York.

The ICHM California market projection is shown below. Again, a favorable regulatory scenario is assumed for this projection. This implies a continuation of ongoing policies and regulations to encourage customer choice, end-use efficiency, renewables and demand response as part of the state's long-term electricity strategy.

Table 21. California market sales projection for ICHM

California ICHM Sales Projection										
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
CHP (MW)	2	8	18	28	40	50	55	60	66	73
ICHM (tons)	460	1,840	4,140	6,440	9,200	11,500	12,650	13,800	15,180	16,790
Units	3	11	24	37	53	66	72	79	87	96
Cumulative (MW)	2	10	28	56	96	146	201	261	327	400
Cumulative (tons)	460	2,300	6,440	12,880	22,080	33,580	46,230	60,030	75,210	92,000

Competing packages are expected to emerge in 2009. The total California market for packaged engine CHP cooling systems is projected to be three times the ICHM market size within four years after commercial introduction in 2008.

4.2.3. *Other Markets*

The market potential for the ICHM in the balance of the United States (excluding California) is estimated at 30,000 MW in the commercial and institutional sectors. This market mix consists of the same segments identified for the California market potential above. In the industrial market, the ICHM portfolio fits best in the non-process heat using industrial sectors where the primary thermal loads are space heating, cooling and/or process cooling. These market segments include light manufacturing, plastics, assembly, and electronics. The estimated size of these markets in

the 250 kW to 3 MW size range is 15,000 MW. The primary reference source for these estimates were two DOE funded assessments by Onsite Sycom Energy Corporation in January 2000 on the CHP potential in the commercial, institutional, and industrial sectors.

Most CHP implementation activity has been and will continue to be highly regional. California and the Northeast is where most small-to-medium sized CHP development has occurred in recent years with minor activity in the Midwest and Mid-Atlantic regions. CHP economics are very dependent on above average electric rates and favorable regulatory support.

The authors see a continuation of the same regional makeup for the foreseeable future. As California has less of a need for space heating and more of a need for cooling than most of the other CHP regions, California is the logical state to rollout the ICHM and will likely remain the primary market for the first two or three years. Long-term, the authors project ICHM to gain acceptance elsewhere in the United States and eventually surpassing sales in California by 20 to 30%.

4.3. Recommendations

The following recommendations are provided to maintain a healthy environment for CHP in California, to educate the CCHP industry on the ICHM value proposition, and to continue the ICHM improvement process:

- CCHP needs to be better integrated across state energy, policy, regulations and legislation in order to maximize its cost, environmental, reliability, and grid benefits. Of particular note:
    - The incentive for CHP needs to be restored.
    - Utility tariff barriers need to be removed.
    - Utility interconnection needs simplification to enable inadvertent export or sale back to utility of excess power production.
- The ICHM should be promoted in the Energy Commission publications, through the Regional CHP Application Centers, and at appropriate conferences.
- Continued attention needs to be given to further ICHM cost reductions particularly in the smaller sizes (75 – 150 tons).
- Engine limitations on higher coolant temperatures need to be recognized. Additional technology development is warranted to better optimize absorber performance with lower temperature heat.
- The market should be cautioned against over-sizing CCHP systems for the base coincident electric and thermal loads to maximize capacity utilization and reduce operation at less efficient part-load conditions.

Modifications should be considered to the ASERTTI CHP Long term Monitoring Protocol to be compatible with ARI test procedures.

4.4. Benefits to California

The ICHM will considerably broaden the horizon for CHP in the small/medium sized commercial and industrial markets by improving CHP economics and heat utilization efficiency in otherwise marginal applications that lack large process heating loads.

The benefits to California electricity ratepayers include:

- Reduces energy costs by
  - Lowering capital costs.
  - Increasing heat utilization efficiencies in applications that lack traditional CHP process heating loads.
- Improves energy sufficiency by reducing dependence on new central station plants and transmission lines.
- Provides customer choice.
- Strengthens the California economy.
- Increases implementation of CHP, which conserves natural gas and reduces greenhouse gas emissions.

These benefits are quantified in the discussion that follows. The benefits analysis considers ICHM deployment projections plus competitive packages expected to enter the California market within two years of ICHM commercial entry. Long-term, the market for *copycat* packages is expected to equal the market for ICHM in total tonnage.

Improves Energy Costs

The proposed project will lower the Installed capital costs by simplifying the thermal interface between the engine CHP module and the site heating and cooling system via the ICHM. Other cost savings will accrue through product and market maturity. Capital cost savings will vary by site but should average between $550 and $600/kW bringing the combined savings over the first ten years after commercial introduction to $240 million. Including competitive products introduced subsequent to the ICHM, the savings double.

There will also be improved chiller performance increasing the effective heat utilization.

Improves Energy Sufficiency

The proposed technology will offset electricity that would otherwise be required from new central station plants and transmission lines. The total central station system electricity avoidance is equal to the amount generated by the CHP system plus displaced electricity from the absorber (28% of CHP system electric capacity) plus T&D system losses (10%). With new central plants and transmission systems costing $800/kW or more, this savings is in excess of $400 million for the ICHM and $800 million when adding in competitor products.

Provides Customer Choice

This advanced CHP system will provide certain customers with a lower cost option for electricity. The ten-year ICHM customer cost savings is estimated at $70 million and $150 million overall.

Strengthens the California Economy

The ICHM will strengthen the California economy by:

- Lowering the cost of electricity helping retain business in the state.
- Increasing use of local generation will alleviate electric capacity shortages and relieve T&D congestion, thus reducing chance of power outages and keeping the economy going.
- Likewise, ICHM brings affordable CHP to a broader portion of commercial and industrial customers, increasing gas use efficiency and help curtail supply deliverability disruptions.

Conserves Natural Gas and Reduces Greenhouse Gas Emissions

Based on the 10-year market projection for the ICHM, the natural gas and greenhouse gas impacts are highlighted below. The calculations are based on the assumptions that CHP displaces California gas fired central plant generation, which has a fleet average heat rate of 8,500 BTU/kWh and an average T&D loss of 10%.

- ICHM gas savings of 7.3 Bcf annually.
- Total CHP/Chiller market gas savings of 15 Bcf annually.
- ICHM CO2 reduction of 400,000 tons annually.
- Total CHP/Chiller market CO_2 reduction of 800,000 tons annually.

5.0 References

Assessment of California CHP Market and Policy Options for Increased Penetration, EPRI, Palo Alto, CA, California Energy Commission, 2005.

Climate Action Team Report to Governor Schwarzenegger and the Legislature, Climate Action Team, California Environmental Protection Agency, 2006.

Market Assessment of Combined Heat and Power in the State of California, ONSITE SYCOM Energy Corporation, California Energy Commission, 1999.

Clean Distributed Generation Performance and Cost Analysis, DE Solutions, Inc., Oak Ridge National Laboratory and U.S. Department of Energy, 2004.

6.0 Glossary

AFRC	Air Fuel Ratio Control
ARI	American Refrigeration Institute
ASERTTI	Association of State Energy Research and Technology Transfer Institutions
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
AVR	Automatic Voltage Regulator
Bcf	Billion cubic feet
BPE	BluePoint Energy, Inc.
BTU	British thermal unit
CCHP	Combined cooling heat and power
cfm	cubic feet per minute
CHP	Combined heat and power
CHWS	Chilled water supply
CO2	Carbon dioxide
COP	Coefficient of performance
DAS	Data acquisition system
EG	Engine generator
EGR	Exhaust gas recirculation
EHRU	Exhaust heat recovery unit
ESCO	Energy service companies
Ft	foot, feet
GHG	Greenhouse gas
gpm	Gallon per minute
H2O	Water
HEGO	Heated exhaust gas oxygen sensor
HTEP	High temperature engine package
Hz	Hertz
I/O	Input/Output
ICE	Internal combustion engine
ICHM	Integrated cooling and heating module

ICHPS	Integrated CHP Systems Corp.
in	Inch
JCI/York	Johnson Controls, Inc. – York, Inc.
kWh	Kilowatt hour
LiBr	Lithium bromide
MBH	Thousand BTU per hour
mm	Millimeter
MMBH	Million BTU per hour
MBTU	One thousand British thermal units
MW	Megawatt
n>e	next>edge, Inc.
NIST	National Institute of Standards and Technology
O_2	Oxygen
OA	Outside air
P&ID	Process and instrumentation diagram
PH	Phase
PIER	Public Interest Energy Research Program
PLC	Programmable logic controller
ppm	Parts per million
Psig	Pounds per square inch gauge
RTDs	Resistance thermometer devices
RTU	Remote terminal unit
SCAQMD	South Coast Air Management District
SCG	Southern California Gas Company
MMBTU	Million BTU
T&D	Transmission and distribution
v	Volt
VAV	Variable air volume
%	Percent

7.0 Appendices

Appendix A

ICHM/YIA Absorption Chiller Test

York International Corporation
Performance Test at York, PA
Bldg. 19, 100 TR Test Facility

Customer:	INTEGRATED CHP SYSTEMS	Date:	4/8/2005
S.O. Number:	04-106497-01	Time:	2:52:07 PM
Unit:	YIA-HW-1A1-28-C		
Serial Number:	UKNM018764		

OPERATING CONDITIONS:	Test(1) Design	Test(2) Actual
Evaporator:		
Capacity (TR)	78.0	74.4
Flow (GPM)	188.4	194.8
Entering Temp (degF)	53.59	53.05
Leaving Temp (degF)	43.69	43.90
Range (degF)	9.90	9.15
Pressure Drop (ftH2O)	6.8	6.0
Liquid Type	WATER	WATER
Pass Arrangement	3	
Absorber/Condenser:		
Flow (GPM)	500.0	491.1
Entering Temp (degF)	86.38	85.87
Leaving Temp (degF)	95.48	95.18
Range (degF)	9.10	9.31
Pressure Drop (ftH2O)	10.3	9.2
Liquid Type	WATER	WATER
Pass Arrangement	2	
ENERGY INPUT:		
Hot Water:		
Flow (GPM)	115.0	115.2
Entering Temp (degF)	216.10	219.16
Leaving Temp (degF)	192.20	194.26
Range (degF)	23.90	24.90
Pressure Drop (ftH2O)	4.9	6.2
Pass Arrangement	0	
Calculated Energy In (MBH)	1379.9	1380.8
Voltage	230/3/60	227.1 227.2 227.6
Current	30.4	18.8 19.1 19.5
Power (KW)		3.7
Total Power (KW)	20.1	3.7

York International Corporation
Performance Test at York, PA
Bldg. 19, 100 TR Test Facility

Customer:	INTEGRATED CHP SYSTEMS	Date:	4/8/2005
S.O. Number:	04-106497-01	Time:	2:52:07 PM
Unit:	YIA-HW-1A1-28-C		
Serial Number:	UKNM018764		

OPERATING CONDITIONS:	Test Actual
Unit Temperatures and Pressures:	
Generator Temperature In (degF)	149.5
Generator Temperature Out (degF)	182.6
Generator Pressure (mmHg)	50.9
Absorber Solution Temperature Out (degF)	96.5
Refrigerant Temperature (degF)	45.3
Solution Concentrations:	
Solution From Absorber	56.5
Solution From Generator	58.2

PERFORMANCE RESULTS:(4)

% Capacity (Actual / Full Load Design) x 100%	=	95.4 %
% MBH/Ton (Actual / Design) x 100%	=	104.9 %
% Heat Balance Closure ((Qevap + Qinput - Qcond) / Qcond) X 100%	=	-2.5 %

Barometric Pressure: 14.484 psia
Ambient Temperature: 71.00 degF

York International Corporation
Performance Test at York, PA
Bldg. 19, 100 TR Test Facility

Customer:	INTEGRATED CHP SYSTEMS	Date: 4/8/2005
S.O. Number:	04-106497-01	Time: 2:52:07 PM
Unit:	YIA-HW-1A1-20-C	
Serial Number:	UKNM018764	

NOTES:

(1) Some conditions adjusted in compliance with ARI Standard 560-92. Additional adjustments, if necessary, will be covered below.
(2) ARI 560-92 allows +/- 5% of test flows and +/- 0.5 degF of temperatures.
(3) Heating input as tested without insulation is specified heat input times 1.04.
(4) Allowable tolerance per ARI 560-92 paragraph 5.5, at 100% load is 5.0%. Part load tests must be taken within +/- 2.0% of the full load tons at the specified part load capacity.

DATA REVIEWED AND VERIFIED:

J.R. Mann 4-11-05 Resident Engineer

Customer Representative

York International Corporation
Performance Test at York, PA
Bldg. 19, 100 TR Test Facility

Customer:	INTEGRATED CHP SYSTEMS	Date:	4/8/2005
S.O. Number:	04-106497-01	Time:	2:52:07 PM
Unit:	YIA-HW-1A1-28-C	Run:	1.20
Serial Number:	UKNM018764		

RTD TEMPERATURES

16	WATER ON EVAPORATOR	53.05
1	WATER OFF EVAPORATOR	43.90
12	WATER ON ABS/CONDENSER	85.87
6	WATER OFF ABS/CONDENSER	95.18
5	CROSSOVER PIPE	91.21
8	HOT WATER INTO ABSORBER	219.16
7	HOT WATER FROM ABSORBER	194.26

MISCELLANEOUS DATA

PERCENT FULL LOAD	%	100
EVAPORATOR P.D.	PSID	2.6
CONDENSER P.D.	PSID	4
CONC, WEAK	- VS19	56.54
CONC, STRONG SPRAY	- VS25	58.91
CONC, 1ST STG GEN	- VS18	58.23
HOT WATER P.D.		2.7
BAROMETER	PSIA	14.484
CAPACITY,	TONS	74.4

TRANSDUCER PRESSURES

4	ABSORBER	5.78
5	1ST STAGE GENERATOR	50.87

FLOW/FREQUENCY

1	EVAPORATOR FLOW	(GPM)	191.8
2	CONDENSER FLOW	(GPM)	491.1
3	HOT WATER FLOW	(GPM)	115.2

POWER, SYSTEM # 1

MOTOR VOLTAGE	A-B	227.1
MOTOR VOLTAGE	B-C	227.2
MOTOR VOLTAGE	C-A	227.6
MOTOR AMPS	A	19.9
MOTOR AMPS	B	19.1
MOTOR AMPS	C	19.5
MOTOR KW		3.7
MOTOR PF		0.507
VOLTAGE UNBALANCE		0.134
AMPERAGE UNBALANCE		1.987

TC TEMPERATURES

1	SOL INTO 1ST STAGE GEN	149.54
2	SOL FROM 1ST STAGE GEN	182.64
3	SOLUTION FROM ABSORBER	96.45
6	STRONG SOLUTION SPRAY	105.98
7	REFRIGERANT SPRAY	45.30
5	REFR VAPOR FROM 1ST STG	43.35
4	REFR FROM CONDENSER	101.12
9	WEAK SOL INTO HX2	96.16
8	STRONG SOL FROM HX2	123.26
10	AMBIENT	71.00

Monday, April 11, 2005.max

Rev. 11/5/1999

JOB NAME:	Integrated CHP Systems	**MODEL:**	YIA-HW-1A1-28-C-S-B
YORK ORDER:	04-106497-01	**SERIAL #:**	**********

Burner Invoice No. _____ EPROM Checksum _____

PUMP DATA	Initial Discharge	A	Current B	C
Solution Pump	CHECKED W/ ROTATION METER			
Soln. Spray Pump				
Refrig. Pump				

ELECTRICAL

DATA	A (A-B)	B (B-C)	C (C-A)
Current	23.0	23.0	23.0
Voltage	19.3	19.3	19.3

MICRO PANEL SET POINTS

Leaving Chilled Water Temp	43.53
Entering Condenser Water Temp	53.53
Leaving Hot Water Temp	213
Maximum Burner Firing Delay	4

Record this data during or after 1 Hour Run

BURNER DATA

EXHAUST

O2 (%)	
CO2 (%)	
CO (ppm)	
Efficiency	

Solution Cleanliness (check one)

- Clean
- Discolored
- Dirty
- Very Dirty

PRESSURE DROPS	PSID	GPM
Evaporator	2.5	179
Absorber/Condenser	3.8	475
HOT WATER --	2.3	194.

SAMPLES	S.G.	Temp.	Conc.	
1st Stage	1.684	35	58.91	STRONG
~~2nd Stage~~	1.622	31	58.23	INTERM.
Absorber	1.642	32	56.54	WEAK
Abs Spray				
Refrigerant	1.004			

Micro Panel Data at Capacity		DAS
Chilled In (.5 degF)		
Chilled Out (.5 degF)		
Cooling In (.75 degF)		
Cooling Out (.75 degF)		
1 Stage Temp (5 degF)		
1 Stage Press (.5 psia)		
Refrig Temp (.75 degF)		
Solution Temp (5 degF)		

SIGHT GLASSES

Evaporator	Refrigerant Tank	Solution Tank	1st Stage Generator	2nd Stage Generator

USEFUL CONVERSIONS

1 psi = 5.17 cm Hg	1 ft^3 = 7.48 gal
1 in Hg = 2.54 cm Hg	1 m^3 = 35.3 ft^3
1 psi = 51.7 mm Hg	1 gal = 3.785 l
1 psi = 2.309 ft H_2O	1 m^2 = 10.76 ft^2
1 ft H_2O = 0.433 psi	1 in^2 = 6.45 cm^2
1 atm = 14.7 psi	1 ton = 3.517 kW
1 torr = 1 mm Hg	1 ton = 12,000 BTU/hr
1 ft/s = 0.3048 m/s	1 lb = 453.6 gm
1°C = (°F + 40)/1.8 - 40	1°F = 1.8(°C + 40) - 40

Dry Weight [lb.]: _____

Wet Weight [lb.]: _____ (If unit is not discharged.)

Discharged Weight [lb.]: _____ (If unit is discharged.)

JOB NAME:	Integrated CHP Systems	MODEL:	YIA-HW-1A1-28-C-S-B
YORK ORDER:	04-106497-01	SERIAL #:	**********

LITHIUM BROMIDE SOLUTION — Gallons: 112

DATE	INITIALS		AMT (gal)
3/05	TK	INITIAL CHARGE*	100
		Charge / Discharge*	
		Charge / Discharge*	
		Charge / Discharge*	
		Charge / Discharge*	
		Charge / Discharge*	
		Charge / Discharge*	

REFRIGERANT — Gallons: 20

DATE	INITIALS		AMT (gal)
3/05	TK	INITIAL CHARGE	15
3/05	TK	(Charge) / Discharge	4
		Charge / Discharge	
		Charge / Discharge	
		Charge / Discharge	
		Charge / Discharge	
		Charge / Discharge	

ALCOHOL — Gallons: 1.5 quart

DATE	INITIALS		AMT ~~(gal)~~ QT.
4/05	TK	INITIAL	1 1/2
		(Charge)	1/2
		Charge	
		Charge	

Representative Samples (one per skid):

	Temp.	S. G.	Conc.
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

DISCHARGED FOR SHIPPING:

Refrigerant [ ] gallons [ ] barrels

Solution [ ] gallons [ ] barrels

Average Concentration of Discharged Barrels [ ]

* Please identify what type of solution is charged or discharged. It will either be virgin or trimmed.

2 [illegible]

Monday, April 11, 2005.mox