Submersion Cooling Evaluation

ET Project Number: ET13PGE1101

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# Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2N</td>
<td>Type of redundancy where the components (N) have double the amount of components necessary for operation.</td>
</tr>
<tr>
<td>AB32</td>
<td>Assembly Bill 32</td>
</tr>
<tr>
<td>CFM</td>
<td>Cubic Foot per Minute</td>
</tr>
<tr>
<td>CRAC</td>
<td>Computer Room Air Conditioner</td>
</tr>
<tr>
<td>CRAH</td>
<td>Computer Room Air Handler</td>
</tr>
<tr>
<td>CTE</td>
<td>Cooling Tower Emulator</td>
</tr>
<tr>
<td>DCIM</td>
<td>Data Center Infrastructure Management</td>
</tr>
<tr>
<td>DEER</td>
<td>Database for Energy Efficient Resources</td>
</tr>
<tr>
<td>Delta-T</td>
<td>Temperature Difference</td>
</tr>
<tr>
<td>EUL</td>
<td>Expected Useful life</td>
</tr>
<tr>
<td>FLOPS</td>
<td>Floating Point Operations per Second</td>
</tr>
<tr>
<td>GRC</td>
<td>Green Revolution Cooling</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>HP</td>
<td>HorsePower</td>
</tr>
<tr>
<td>kW</td>
<td>kilo-Watt</td>
</tr>
<tr>
<td>kWh</td>
<td>kilo-Watt per hour</td>
</tr>
<tr>
<td>N+1</td>
<td>Type of redundancy where the components (N) have one backup component (+1)</td>
</tr>
<tr>
<td>MW</td>
<td>Mega-Watt</td>
</tr>
<tr>
<td>VFD</td>
<td>Variable Frequency Drive</td>
</tr>
</tbody>
</table>
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1 EXECUTIVE SUMMARY

PROJECT GOAL
The project goal of Submersion Cooling for Data Centers was to evaluate the technology’s ability to provide adequate cooling (heat rejection) for an existing data center’s servers and determine the technology’s energy consumption for one field installation of Submersion Cooling in a large telecommunications data center. This data was used to estimate the energy savings over theoretical baseline; with incremental project costs, it was used to estimate the simple payback period. Finally, the data was used to make recommendations for further study and potential for involvement in utility Energy Efficiency programs.

PROJECT DESCRIPTION
The Submersion Cooling for Data Centers proposes to provide energy savings through submerging computational servers in a Green Revolution Cooling CarnotJet™ system. The system uses mineral oil to remove waste heat from the servers. The heated mineral oil is pumped through a heat exchanger, which is connected to the facility’s chilled water, ultimately rejecting the heat to the ambient outside air via cooling towers. Since the specific heat of the mineral oil is claimed to be approximately 1,200 times that of air by volume, the heat transfer between the servers and mineral oil is claimed to be much more effective, therefore requiring less power compared to the incumbent technology of air cooled servers.

Submersion Cooling also proposes to provide energy savings through reduced server power for a given script compared to an air-cooled environment. It is suggested this is due to a lower, and more constant, chip and processor temperature. As inclusion of this aspect is outside the scope of this study, a discussion may be found in “Areas for Further Study.”

In this retrofit installation, the servers need to be modified to be submerged in the mineral oil; servers’ fans and thermal paste need to be removed. Additionally, load banks will be installed to reach the test power density, while reducing test costs and shortening test timeline. Multiple mineral oil and cooling water temperatures will be tested to determine the technology’s ability to reject heat from the servers at both typical and extreme conditions. The cooling water temperatures will be modulated by a technology called a Cooling Tower Emulator, that according to the vendor is not typically installed, but is required to test multiple cooling water temperatures. The ability to reject heat and energy consumption required to do so will be evaluated as a part of this project.

PROJECT FINDINGS/RESULTS
The Submersion Cooling system was shown to be capable of maintaining the rack coolant temperature at setpoint for all manufacturer recommended test conditions. The system was not able to maintain the rack coolant temperature setpoint for the extreme tests, done beyond manufacturer recommended temperatures. This was determined by observing both the the oil pump speed and tank temperatures. As the tank temperature increases, so does the oil pump speed, in order to reject additional heat to the cooling water. When the pump speed reaches 100%, the system is rejecting all the heat possible. If the temperature then continues to rise, the system is beyond its capacity.
During two of the tests, Test #1 and Test #4, the CarnotJet™ system was shown to approach its capacity to maintain coolant temperature. During these two tests the average recorded oil pump speed was 95% and 99%, respectively. During Test #2 and Test #3 the CarnotJet™ system was beyond its capacity, as the pump speed was at 100% and the rack coolant temperature was rising. It should be noted that the setpoints used for this test were not recommended by the manufacturer.

**Table 1 Test Setpoints and Results**

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Rack Coolant Temperature Setpoint (°C / °F)</th>
<th>Cooling Water Temperature Setpoint (°C / °F)</th>
<th>Average Recorded Rack Coolant Temperature (°C / °F)</th>
<th>Average Recorded Cooling Water Temperature (°C / °F)</th>
<th>Recorded Pump Speed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45/113</td>
<td>29*/85</td>
<td>45.1/113.2</td>
<td>29.0/85.0</td>
<td>95%</td>
</tr>
<tr>
<td>2</td>
<td>45/113</td>
<td>32/90</td>
<td>46.8**/116.2</td>
<td>32.0/90.0</td>
<td>100%</td>
</tr>
<tr>
<td>3</td>
<td>30/86</td>
<td>18/65</td>
<td>35.1**/95.2</td>
<td>18.0/65.0</td>
<td>100%</td>
</tr>
<tr>
<td>4</td>
<td>40/104</td>
<td>24/75</td>
<td>40.1/104.2</td>
<td>24.0/75.0</td>
<td>99%</td>
</tr>
<tr>
<td>5</td>
<td>45/113</td>
<td>24/75</td>
<td>45.1/113.2</td>
<td>24.0/75.0</td>
<td>70%</td>
</tr>
<tr>
<td>6</td>
<td>45/113</td>
<td>18/65</td>
<td>45.1/113.2</td>
<td>18.0/65.0</td>
<td>54%</td>
</tr>
<tr>
<td>7</td>
<td>40/104</td>
<td>18/65</td>
<td>40.2/104.4</td>
<td>18.0/65.0</td>
<td>71%</td>
</tr>
<tr>
<td>8</td>
<td>40/104</td>
<td>18/65</td>
<td>40.0/104.0</td>
<td>18.0/65.0</td>
<td>42%</td>
</tr>
</tbody>
</table>

* Product’s claimed maximum incoming cooling water temperature setpoint.

**Rack coolant temperature was not maintained at setpoint.**

The energy consuming equipment contained in the installed GRC CarnotJet™ system consists of two separate pumps, a GRC CarnotJet™ system Pump Module coolant pump (oil pump) and a GRC CarnotJet™ Cooling Tower Emulator pump (water pump). Over the course of the testing the electrical demand of these two pumps was measured and the average value was calculated to be 2.00 kW. As a percentage of the average server (I.T.) power the total average GRC CarnotJet™ electrical power demand was found to be 2.94%, or about 0.104 kW of pump power per ton of heat rejected.

The annual energy and peak demand, and energy cost savings (assume an annual average cost of $0.14/kWh) of the GRC CarnotJet oil pump with a CTE water pump, compared to the baseline is estimated to be:

**Table 2 Estimated Annual Energy and Cost Savings**

<table>
<thead>
<tr>
<th>Demand Savings</th>
<th>9.25 (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Savings</td>
<td>81,030 (kWh/yr)</td>
</tr>
<tr>
<td>Energy Cost Savings</td>
<td>$ 11,344 ($/yr)</td>
</tr>
</tbody>
</table>

The demand savings are 100% coincident with the utility peak demand period, as the pump and fan equipment operates at 100% duty cycle.
PROJECT RECOMMENDATIONS

The assessment showed that the Green Revolution Cooling CarnotJet™ system provides for energy and peak coincident demand savings over the incumbent technology and we-recommend its adoption into Energy Efficiency programs. The technology currently fits into the Customized Retrofit and Customized New Construction Programs.

For an installation similar to the one installed in this project, which included a Cooling Tower Emulator system, the key variables in determining energy savings are server power, CarnotJet™ oil pump power, CarnotJet™ cooling tower emulator pump power, and the facility’s pre-existing fan power. Again the vendor stated that a Cooling Tower Emulator is not typically installed, as it was specifically in place to for this test in order to be able to control the system cooling water temperatures with a high degree of accuracy. The technology has significant energy savings potential, a long expected useful life, and a high incremental cost. This makes it a good technology for the utility companies to

Based upon conversation with the vendor there appears to be low market penetration to date, due to a variety of reasons including but not limited to the lack of off the shelf server availability, requirement to use expensive solid state drives, and uncertainty around server warranty when submerged in mineral oil.

The current Database for Energy Efficiency Resources (DEER) compliance tool does not address this technology. There are still a number of suggestions that the Emerging Technologies Team suggests for further investigation, shown below.

Further Study is highly recommended for the following topics:

1) Estimate the energy and coincident demand savings potential with the cooling water coming directly from condenser water, instead of from chilled water or chilled water with a cooling tower emulator. It is hypothesized that significantly more energy and coincident demand savings will result from this analysis.

2) Evaluate the market penetration and possible portfolio energy savings for utility energy efficiency product design and possibility of workpaper development.

3) Evaluate any energy savings claim for increased server efficiency in FLOPS per Watt. Vendor claims reduced server power and increased computation due to a lower, and more constant, chip and processor temperature. Data for this has been collected, but has need been analyzed to substantiate the claims made.

4) New Construction application – There is significant savings in Data Center Infrastructure Management through this type of installation. The avoided costs of chiller, pumps, piping, wiring, controls, building, and workers to house such reductions could be significant.
2 INTRODUCTION

2.1 MARKET ENERGY CONSUMPTION AND TRENDS

The energy consumption and greenhouse gas emissions of data centers is of great importance as our world evolves to become more digital with cloud computing, smart phones, virtualization, and electronic-based business models. It is estimated that worldwide 1.5% of all energy consumed is by data centers (US EPA), and this will most likely continue to rise, especially with the advent of higher density servers. A typical data center will use about 100-200 times more energy per square foot than an office building (Pacific Gas & Electric Company, 2013).

Data centers are in use for the financial, banking, medical, business (online and retail), governmental, educational, telecommunications, and many other industries. These users of the data center services expect 24/7/365 instantaneous access to their data. This results in high operating costs.

The US Department of Energy estimates that the cost of power to operate a data center over its useful life is expected to exceed the cost of original capital investment (United States Deparment of Energy, 2006). Industry trends have shown recent construction of new data centers in areas with low energy costs and favorable ambient conditions to take advantage of free cooling. These trends are especially crucial to the existing data center market in California and Silicon Valley, the high-tech innovation hub, which has high energy costs and greenhouse gas limitations through legislation such as AB32 which require's California to the state’s GHG emissions to 1990 levels by 2020. In order to maintain the existing data center population in California, and to reverse the trends of more new data centers being built elsewhere, methods to lower the operational energy cost, and therefore energy consumption, for the operation of data centers is crucial.

2.2 CURRENT TECHNOLOGY TO REMOVE HEAT

The main drivers for energy consumption of a data center are the computational equipment and the removal of its by-product, heat, by mechanical equipment. Removing of heat from the computational equipment (servers) is crucial, since to operate consistently and reliably for its expected useful lifespan, they must stay below certain temperatures thresholds. These thresholds are in place for good reasons, since data centers are known as mission critical facilities, have requirements for security and reliability, and are rated by the amount of uptime.

In data centers the servers are stored in racks. In data centers with load densities of 0-10 kW/rack, the servers are typically air-cooled. As server power density increases beyond 10 kW/rack, alternative cooling strategies are required. For load densities of 10-30 kW/rack, one currently available solution is in-row cooling. This requires the piping of chilled water or refrigerant to each rack of servers. Water cooling allows for higher load densities, but adds cost, complexity, and the possibility of leaks within a data center. The figures below, from the PG&E Data Centers Best Practices document, show examples of the physical layout of these technologies.
2.3 **Submersion Cooling History**

Submersion cooling technology is not new, as early Governmental supercomputers in the 1980s such as the Cray 2 utilized direct liquid cooling. Systems with a phase-change, liquid immersion, evaporative cooling technology such as with 3M Novec™ has also been available, though they have not been widely adopted by industry, the study of which is beyond the scope of this project. It is hypothesized that these systems have very high costs and detailed design requirements; they are not readily available “off the shelf” in the way that in-row cooling and air-cooling systems are. In fact, the PG&E Data Center Best Practices document states:

“In the future, products may become available that allow for direct liquid cooling of data center servers and equipment more directly, via methods ranging from fluid passages in chip heat sinks to submersion in a dielectric fluid. While not currently widely available, such approaches hold promise and should be evaluated as they continue to mature and are commercialized for the data center equipment market.”

2.4 **Submersion Cooling Technology to be Assessed**

The technology which will be assessed for this project is the Green Revolution Cooling (GRC) CarnotJet™. The technology proposes to allow server densities between 8-40 kW/rack. The CarnotJet is a system of technologies which allows servers that have been modified to be cooled directly (called immersion or submersion) within proprietary mineral oil, GreenDEF™, that is thermally but not electrically conductive. The mechanical equipment is designed to have 2N redundancy, with N+1 redundancy on the heat exchangers.
A complete system, or module, consists of four x 42 U racks (or tanks) to make a “quad”. Each rack holds 271 gallons of GreenDEF™ mineral oil, or coolant, for a total volume of 1084 gallons. The project also required the installation of a crane. This is due to the servers being inserted from the top, instead of from the side as in a typical air cooled environment. The crane serves to also allow the servers to “drip dry” when they are removed.

The CarnotJet system oil is pumped through a continuous circuit of tanks, pipes, pumps, and a heat exchanger. In this technology assessment, replaces air as the cooling medium that is directly in contact with the servers. Since the specific heat of the mineral oil is claimed to be approximately 1,200 times that of air by volume, the heat transfer between the servers and mineral oil is claimed to be much more effective, therefore requiring less power to maintain server temperatures compared with an air-cooled environment. Figures 2.4 through 2.8 show images of the CarnotJet system, servers and motherboard submerged in GreenDEF™ cooling. Figure 2.9 shows a schematic. Images are from the GRC website.
**Figure 6** Servers Submerged

**Figure 7** Motherboard Submerged

The Rack holds all the Servers and Load Banks

70 kW IT load

**Figure 8** GRC Carnot Jet™ System and Cooling Tower Emulator
2.5 **Scope of Technology Assessment**

The pre-existing server cooling system at the test location is air-cooling. The air-management scheme is Level II, hot and cold isle containment with ducted-return for a Large Data Center, as described by the PG&E Energy Efficiency Baselines for Data Centers document. It consists of chilled water CRAHs, Water cooled chillers in the facility’s basement provide chilled water for the data center. Cooling tower water (condenser water) is delivered to the chillers, and is not directly available in the data center.

The system to be evaluated consists of the standard CarnotJet™ equipment plus a Cooling Tower Emulator (CTE). A standard installation of a CarnotJet™ system consists of 4 x 42U racks and one pump module. The pump module provides circulation of the coolant (oil) within the server racks and is responsible for rejecting all server heat to the data center’s water source; in this case chilled water.

In this specific technology assessment, the CTE is designed to be supplied with chilled water and, by means of control valves and a water pump, to deliver warmer water to the CarnotJet™ pump module. The CTE provides a means for testing the CarnotJet™ system’s capabilities at a variety of cooling water supply temperatures. Using the CTE the team was able to test at cooling water temperatures which would typically be available directly from cooling towers.

The technology assessment will evaluate:

1) effectiveness at providing adequate cooling to the servers at the test load density of approximately 17.5 kW/rack, over a range of cooling water temperatures
2) energy consumption of the GRC CarnotJet™ system components’
3) estimated energy savings from the most appropriate baseline air-flow management scheme
4) applicability to retrofit and new construction opportunities

Due to resource limitations such as measurement equipment, access to motor control panels, assessment budget, and facility personnel, this technology assessment will not:

1) Measure the energy consumption of pre-existing equipment (incumbent technology)
2) Separate the energy consumption of pre-existing facility equipment such as central plant equipment (chiller, pumps, cooling towers), CRAHs, humidifiers, pumps, etc.
3) Evaluate any energy savings claim for reduced server power due to a lower, and more constant, chip and processor temperature, via LINPACK test.
4) Address any hypothetical other scenarios, such as green-field new construction or brown-field with condensing water instead of chilled water available. Though it is hypothesized that significant energy savings and Data Center Infrastructure Management gains can be made through this type of installation.

Some of these issues will be address in the suggestions for areas of further study.
3 BACKGROUND

3.1 DATA CENTER BACKGROUND

Data centers are in use for the financial, banking, medical, retail (online and brick/mortar), oil & gas exploration, governmental, educational, telecommunications, and many other industries. These users of the data center services expect 24/7/365 instantaneous access to their data.

The critical nature and 24/7/365 operation of data centers comes at a great cost. The mechanical equipment to condition the environment, and the infrastructure to house the computing equipment (server) and mechanical equipment it is expensive to design, install, maintain, and operate. The mechanical equipment typically includes include power supplies for the servers with redundancy, backup power equipment, and HVAC equipment for cooling with redundancy.

The operation and management of data centers has gotten so complicated that its experts have coined a new term, Data Center Infrastructure Management (DCIM), which “is a category of solutions which were created to extend the traditional data center management function to include all of the physical assets and resources found in the Facilities and IT domains. DCIM deployments over time will integrate information technology (IT) and facility management disciplines to centralize monitoring, management and intelligent capacity planning of a data center’s critical systems” (Wikipedia). This can be interpreted to mean that the management and operation of data centers and the equipment on site, has gotten to be so complex, intertwined, and expensive that efforts are taken to manage the physical assets surrounding the server.

3.2 SIMILAR TECHNOLOGY BACKGROUND

Submersion cooling technology is not new, and has been used by many specialized industries for many years. Governments, universities, computer chip manufacturers’, and even utilities use similar principals to provide cooling to electrical components. However, it has not been available “off the shelf” for use as server cooling in the way the GRC CarnotJet™ technology proposes.

Early Governmental supercomputers in the 1980s, such as the Cray 2, utilized direct liquid cooling. High powered computer chip manufacturers have used similar technologies for testing purposes, prior to final module assembly (Tulkoff, 2013).

Systems with a phase-change, liquid immersion, evaporative cooling technology such as 3M Novec™ also are available, though they have not been widely adopted by the data center industry for reasons beyond the scope of this work. It is hypothesized that these systems have very high costs and detailed design requirements; they are not readily available “off the shelf” in the way that the incumbent technologies of in-row cooling and air-cooling systems are. An investigation of this technology by Lawrence Berkeley National Laboratory is being done for this technology.

Finally, a similar principle, utilizing thermally but, not electrically, conductive liquids is utilized in power distribution in transformers, which change the voltage of electrical power. However heat sinks instead of mechanical equipment is used to reject the heat to the atmospheric conditions.
3.3 Incumbent Technology

The prevalent types of technology used in the cooling is dependent upon the IT equipment load in the data center, kW/rack, and site restrictions, among other factors (Pacific Gas & Electric Company, 2013). They are:

1. Hot Aisle/Cold Aisle, Open
2. Hot Aisle/Cold Aisle, Ducted Return
3. Hot Aisle/Cold Aisle, Fully Enclosed
4. In-Row Cooling

Details surrounding them are shown in Table 3 Baseline Air Management Scenarios

### Table 3 Baseline Air Management Scenarios

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>IT Load Density at Full Build-Out</th>
<th>Design IT Load Density at Full Build-Out</th>
<th>Return Air Dry bulb Temp, Temp.</th>
<th>Operating Supply Air Temp.</th>
<th>Operating Airside Delta-T</th>
<th>RH Setpoint and Tolerance</th>
<th>Fan Airflow Efficiency Metric</th>
<th>Operating CRAC Airflow Capacity at Baseline Conditions</th>
<th>Cooling Coil Capacity per unit at Baseline Conditions</th>
<th>Total Static Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hot Aisle/Cold Aisle, Open</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>10</td>
<td>74</td>
<td>64</td>
<td>10</td>
<td>50% +/- 10%</td>
<td>1,536</td>
<td>16,800</td>
</tr>
<tr>
<td>2</td>
<td>Hot Aisle/Cold Aisle, Ducted Return</td>
<td>101</td>
<td>220</td>
<td>0</td>
<td>10</td>
<td>78</td>
<td>65</td>
<td>13</td>
<td>50% +/- 10%</td>
<td>1,598</td>
<td>15,800</td>
</tr>
<tr>
<td>3</td>
<td>Hot Aisle/Cold Aisle, Fully Enclosed</td>
<td>221</td>
<td>400</td>
<td>0</td>
<td>10</td>
<td>85</td>
<td>67</td>
<td>18</td>
<td>50% +/- 10%</td>
<td>1,482</td>
<td>13,875</td>
</tr>
<tr>
<td>4</td>
<td>In-row Cooling Solution</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Notes:
1. Air Management Scheme III: A fully enclosure hot aisle scheme is modeled to also be an enclosure cold aisle scheme, from the standpoint of temperature, humidity, and total static pressure drop.
2. Load Density is actual measured unit load density at full build-out, not design density including a safety factor, and is based on total data center floor area.
3. Airside delta-T does not include fan motor head. Delta-T is the temperature difference between the supply air leaving the CRAC and the air returning to the CRAC.
4. Humidity Control Range: *Thermal Guidelines for Data Processing Environments, Second Edition*, ASHRAE, 2009. The minimum dewpoint temperature and maximum relative humidity shown in this table is the “Recommended” range for Class 1 and 2 facilities. These values apply to the air entering the computer equipment. Baseline facilities employ RH sensors, not dewpoint sensors. The baseline relative humidity setpoint and tolerance are set as shown in the table. See the following psychometric charts.
5. Airflow Efficiency Metric was created based on baseline static pressure drop and baseline fan, drive, and motor efficiencies for a 1.8hp motor.
6. The denominator kW value refers to the power demand.
7. Determined based on a survey of CRACs and CRAHs from prominent manufacturers operating at the baseline static pressure drop.

The mechanical equipment used to provide heat rejection is primarily dependent upon the size of the IT load, as described within the PG&E Baseline document:

**Small (<1 MW IT load) Data Centers – Schemes I, II, and III**

Recirculation is provided by air-cooled DX computer room air conditioner (CRAC) units equipped with constant-speed fans. Specifications for CRACs from prominent manufacturers were evaluated to determine the nominal airflow per unit at an external static pressure drop of 0.3, 0.6, and 1.1 in. for air management scheme I, II, and III, respectively.

**Large (>1 MW IT load) Data Centers – Schemes I, II, and III**

Recirculation is provided by chilled water CRAHs equipped with constant-speed fans. Specifications for CRAHs from prominent manufacturers were evaluated to determine the nominal airflow per unit at the baseline external static pressure drop of 0.3, 0.6, and 1.1 in. for air management scheme I, II, and III, respectively.
**High Density Data Centers – Scheme IV**

The baseline system for scheme IV is an in-row cooling solution. An in-row cooling solution is defined as a system which cools one rack or one aisle of equipment only and is physically located in the row. An in-row solution requires running chilled water or refrigerant to each rack or aisle.

### 3.4 TEST FACILITY TECHNOLOGY

The test facility, which is a Large Data Center by the above definition, utilizes Level II air-management scheme with hot and cold isle containment and ducted-return. Air recirculation somewhat aligns with the baseline document, as it utilizes chilled water CRAHs, however it has variable speed fans. In the basement, there are water cooled chillers and chilled water circulation pumps to provide chilled water for the data center. In the basement there are also condenser water pumps to circulate condenser water to the cooling tower, which is located outside the facility.

The existing servers utilize air-cooling, with four heat transfer mediums:

1. Ambient air to condenser water
2. Condenser water to refrigerant
3. Refrigerant to chilled water
4. Chilled water to data center air forced over the server

**Figure 9 Simple Schematic of Existing Air Cooled System**

Due to customer’s desired test parameters, schedule, and on-site physical piping restrictions the cooling water for the GRC system will be plumbed into the existing chilled water system, and the water temperature to the CarnotJet™’s heat exchanger will be modulated with a Cooling Tower Emulator (CTE). Thus there will still be four heat transfer mediums:

1. Ambient air to condenser water
2. Condenser water to refrigerant
3. Refrigerant to chilled water
4. Chilled water to oil, in which the server is submerged

The baseline comparison will be for a Large Data Center, Level II air-management scheme with hot and cold isle containment and ducted-return with constant speed fans. The baseline energy consumption will be from the PG&E Energy Efficiency Baselines for Data Centers document, taken with a load factor of 1.0. This will be done in order to assure that the energy savings estimates are conservative.
4 **Emerging Technology/Product**

4.1 **Green Revolution Cooling CarnotJet™**

The Green Revolution Cooling (GRC) CarnotJet™ proposes to allow server densities between 8-40 kW/rack. The CarnotJet™ is a system of technologies which allows servers that have been modified to be cooled directly (called immersion or submersion) within oil that is thermally, but not electrically conductive. The mechanical equipment is designed to have 2N redundancy, with N+1 redundancy on the heat exchangers.

A complete system, or module, consists of four 42 U racks (or tanks) to make a “quad”. A system covers an area of approximately 128 square feet, with a footprint of approximately 8 feet by 16 feet. Each rack holds 271 gallons of GreenDEF™ mineral oil, or coolant, for a total volume of 1,084 gallons. It is required that the floor be level because there is a liquid involved. The system requires the installation of a few additional items that the incumbent technology does not, liquid containment and a crane.

According to the manufacturer and International Building Code, secondary containment is required. The capacity required is 10% over the largest single container volume in the installation. The project also required the installation of a crane. This is due to the servers being inserted from the top, instead of from the side as in a typical air cooled environment. The crane serves to also allow the servers to “drip dry” when they are removed. The crane can be constructed on site, and made to be mobile so that it can be moved above each system as needed.

In this specific technology assessment, the CTE is designed to be supplied with chilled water and, by means of control valves and a water pump, to deliver warmer water to the CarnotJet™ pump module. The CTE provides a means for testing the CarnotJet™ system’s capabilities at a variety of cooling water supply temperatures. Using the CTE the team was able to test at cooling water temperatures which would typically be available directly from cooling towers. According to GRC engineering staff the CTE is designed to mimic the operation of a cooling tower and it is their estimation that the power consumed of this equipment (a water pump) should be equivalent to the energy used by a typical cooling tower.

The CarnotJet™ system oil is pumped, and in this technology assessment, replaces air as the cooling medium that is directly in contact with the servers. Since the specific heat of the mineral oil is claimed to be approximately 1,200 times that of air by volume, the heat transfer between the servers and mineral oil is claimed to be much more effective, therefore requiring less power compared to an air-cooled environment. The energy consuming equipment consists of a pump module:

- one primary 2.9 kW oil pump that is controlled by a VFD
- one secondary 3.0 kW oil pump that is constant speed (backup)

and a Cooling Tower Emulator:

- one primary 5.0 hp water pumps that is controlled by a VFD
- one secondary 5.0 hp water pump that is constant speed (backup)
There are numerous sensors performing measurements throughout the system including:

- Oil Pressure
- Estimated filter life
- Pump Command
- Water temperature (multiple locations)
- Oil temperature (multiple locations)
- Rack temperature (multiple locations)
- Power consumed
- Coolant level at rack
- Leak detection in pump module
- Estimated heat rejection
- System Health & Diagnostic Output

Based on information from GRC the CarnotJet™ system maintains the coolant temperature in the racks at a predetermined constant setpoint. While this setpoint is a “constant” in the control sequence it can be adjusted locally at the system’s controller. The typical temperature setpoint is 40°C (104°F) but at setpoints as high as 45°C (113°F) or greater are expected to be possible.

There are eight (8) rack coolant temperature sensors used in the CarnotJet™ system’s primary temperature control sequence, two in each rack. Rack coolant temperature is maintained at setpoint by continuously monitoring these eight sensors and varying the flow rate of coolant delivered to the pump module’s heat exchanger such that the maximum rack coolant temperature is kept at setpoint. Coolant flow rate is varied using a variable frequency drive housed within the pump module’s housing. An equal flow rate of coolant is delivered to each of the four racks in the typical CarnotJet™ system and there is no provision to reduce or increase the flow to any particular rack automatically.

Finally both the incumbent and technology assessed technologies are electric driven, and do not involve any natural gas. Therefore this technology assessment has no component of fuel switching.

4.2 INCUMBENT TECHNOLOGIES

In data centers with load densities of 0-10 kW/rack, the servers are typically air-cooled. As server power density increases beyond 10 kW/rack, alternative cooling strategies are required. For load densities of 10-30 kW/rack, one currently available solution is in-row cooling. This requires the piping of chilled water or refrigerant to each rack of servers. This allows for higher load densities, but adds cost, complexity, and the possibility of leaks within a data center.

The equipment used for air-management schemes I-III is typically:

1. Raised floor environment of with CRAC, CRAH, or air handlers
2. Chillers & Chilled water pumps or Direct Expansion Cooling
3. Humidifiers
4. Cooling Towers and Condenser water pumps
5. Hot Aisle/Cold Aisle curtains, enclosures, ducting
The equipment used for air-management schemes IV, In-Row Cooling, is typically:

1. Raised floor environment of with Air Handlers
2. In-Row Cooling pumps or refrigerant compressors
3. In-Row Cooling piping and heat sinks
4. Chillers & Chilled water pumps
5. Humidifiers
6. Cooling Towers and Condenser water pumps

4.3 **GRC CarnotJet™ Purported Advantages**

According to company literature the GRC CarnotJet™ liquid submersion cooling system for data center servers promises to:

- Reduce data center cooling power by up to 95%
- Reduce data center build-out costs by up to 60%
- Reduce total data center power by up to 50% ongoing
- Allow for rack densities of up to 40 kW/rack (for 42U rack)

Additionally, in speaking with GRC representatives, they discussed other advantages over the incumbent technologies:

1. Increased Server Computations (Productivity)
2. DCIM for systems that would utilize condenser water directly as the cooling water, since a chiller, chilled water pumps, controls, maintenance, and associated service contacts would not be required.

4.4 **Potential Market Barriers**

Based upon conversations with the vendor and facility personnel, the following market barriers were identified:

1. Requires the use of solid state drives, which are expensive
   a. typical magnetic style hard drives are not hermetically sealed, and allow mineral oil through their seals and ruins drive
2. Server Manufacturers do not yet offer “off the shelf” servers to submerge into mineral oil. Currently each server requires (at minimum):
   a. Removal of thermal paste (clouds oil & could plug orifices)
   b. Removal of air-cooling fan
3. Obtaining Server Manufacturer support to fully honor the server warranty for those modified and submerged. Currently the vendor is working with numerous server manufacturers’ to address this issue, and the server manufacturers are aware of the potential interest by customers.
4. Network gear manufacturers (switches, network interface cards, etc) lagging further behind server manufacturer
5. Meeting criteria for return on investment

6. Site plumbing specifics
   a. Availability of condenser water within the data center is preferred
   b. If this is not available, chilled water will suffice

It was asked if maintenance issues of the CarnotJet™ or servers by facility personnel was a barrier. Real Estate Facility personnel stated that they were capable of maintaining the technology assessed. IT personnel stated that the servers require extra time to remove and maintain, as the oil is dripped from the server, and it needs to be packaged in a plastic bag if it is transported. This was viewed as an inconvenience, but not a barrier.
5 **Assessment Objectives**

This project is a technology assessment, where the main objectives of this project are as follows:

1) Evaluate the technology’s effectiveness at providing adequate cooling to servers, at the test load density of approximately 17 kW/rack, over a range of cooling water temperatures

2) Evaluate the technology’s system components’ energy consumption

3) Determine the estimated energy savings from the most appropriate baseline air-flow management scheme

4) Applicability to retrofit and NC program

Additional Objective of the project are to:

5) Identify market barriers

6) Identify areas for further study such as
   a. Green-field data centers
   b. Server performance at a consistent temperature (flops/watt)
   c. Server performance at varying mineral coolant temperatures
   d. How to overcome market barriers
   e. How to estimate energy savings compared to a baseline technology
6 Technology/Product Evaluation

6.1 Evaluators Involved

Luke Werner, P.E. is a principal engineer with Energy Resources Integration (ERI). ERI is an independent firm providing services to integrate the numerous energy resources available, to both improve customers’ bottom lines, and the planet which we all call home. ERI accomplishes this through integrating their knowledge of the physical sciences and business strategies with an inquisitive nature and desire for reliable, cost effective solutions for customers. As the principal engineer, he leads ERI’s technical group in energy engineering and technology investigation. He has performed hundreds of energy analysis for a wide variety of end-use customers, including the high-tech market segment of data centers.

Adam Fernandez, P.E. is a senior mechanical engineer with PG&E’s Applied Technology Services (ATS) department. In his role with ATS he provides engineering and testing support to a variety of internal PG&E departments including the Customer Energy Solutions Department, the Corporate Real Estate Department, and the Power Generation Department. He is the lead data center energy efficiency engineer within ATS and has provided energy analyses and analyses review of data center projects since 2008.

6.2 Evaluation Objectives

According to company literature the GRC CarnotJet™ liquid submersion cooling system for data center servers promises to:

- Reduce data center cooling power by up to 95%
- Reduce data center build-out costs by up to 60%
- Reduce total data center power by up to 50% ongoing

The objectives of this evaluation are to assess the performance of the GRC CarnotJet™ system related to cooling effectiveness, energy consumption, operating sequences, and to develop insight into methodology for future retrofit savings estimates. Performance data will be monitored on an installed, operating, GRC CarnotJet™ system. Criteria for the selection of a suitable installation site include:

- The installation site must have cooling water available within the data center. The CarnotJet™ system rejects server heat by use of oil to water heat exchanger. Cooling water of sufficient flow rate must be available at the GRC system. Condenser water is preferred but chilled water is acceptable if the system installation includes a GRC Cooling Tower Emulator system.

- The test system must include the installation of servers (and/or load banks) of sufficient power to create appreciable temperature difference between supply and return oil. The GRC system oil pump will likely have a minimum speed setpoint. An installation of insufficient load may cause the temperature difference between oil supplied to and returned from the rack to be too low to measure accurately. A 50% load factor is considered the minimum.

- The selected site must allow for power monitoring using temporarily installed power meters. We anticipate installing power monitoring data loggers for all loads in the GRC system including: Server power, GRC oil pump power, GRC Cooling Tower Emulator pump power (if so equipped). The site must allow for the installation of these meters for the duration of the testing.
With the exception of the materials used to modify servers for oil submersion the technologies employed by GRC and used in the CarnotJet™ system are typical mechanical devices, pumps, valves, and heat exchangers.

7 TECHNICAL APPROACH/TEST METHODOLOGY

The desire in evaluating the effectiveness of the CarnotJet™ system with respect to cooling capacity is to have the system loaded to as a high percentage of its capacity as the customer is agreeable to. This approach will allow the test methodology to determine the limits of the system.

Note: Achieving a high load factor is important and potentially difficult as the specified capacity of the GRC CarnotJet™ is 90 kW of server load for the 4 x 42U racks (25 kW per rack). Comparing this with a 42U server rack in an air-cooled environment (typical), which would not be loaded with more than 2.4 kW of server power, a GRC CarnotJet™ system is capable of more than 9 times typical equipment loading. In the test a server load of approximately 70 kW was accomplished.

The criteria for site selection related to evaluation, are described in Section 3.4. The only other criteria are in regards to data logger accessibility and loading, and are shown in Section 7.3.

Test cases will be run at various combinations of server loading, rack temperature setpoint, and cooling water temperature setpoint. Data will be recorded using temporary power meters, GRC internal controls data, third-party software. Each combination of server loading, rack temperature setpoint and cooling water temperature setpoint test case will be chosen to stress both the CarnotJet™ system and the installed servers and will be based on requirements of the customer.

We will use internal server temperature data, rack oil temperature data, and oil pump power data to determine the system’s capability to provide cooling during the tests. And to evaluate the electrical energy performance of the CarnotJet™ system data of server power, rack oil temperatures, Cooling Tower Emulator and Pump Module power will be recorded.

7.1 FIELD TESTING OF TECHNOLOGY

The pre-existing cooling system at the test location consists of chilled water computer room air handlers (CRAHs) with partial hot and cold isle containment. In this arrangement cold air from the CRAHs is delivered to the front of the server racks then drawn through and exhausted out the back of the servers into a return air plenum. The air is continuously re-circulated, being cooled at the CRAHs with chilled water cooling coils and heated by the servers. The chilled water cooling coils within the CRAHs are served by water-cooled chillers located in the facility’s basement. Condenser water from cooling towers is delivered to the chillers and is not directly available in the data center.

A standard installation of a CarnotJet™ system consists of 4 x 42U racks and one pump module. The pump module provides circulation of the coolant (oil) within the racks and is responsible for rejecting all server heat to the data center’s water source.

The actual system in this evaluation consists of the standard CarnotJet™ equipment plus a Cooling Tower Emulator (CTE). This CTE is designed to be supplied with chilled water and, by means of control
PG&E’s Emerging Technologies Program

valves and a water pump, to deliver warmer water to the CarnotJet™ pump module. The CTE provides a means for testing the CarnotJet™ system’s capabilities at a variety of cooling water supply temperatures. Using the CTE the team was able to test at cooling water temperatures which would typically be available directly from cooling towers. According to GRC engineering staff the CTE is designed to mimic the operation of a cooling tower and it is their estimation that the power consumed of this equipment (a water pump) should be equivalent to the energy used by a typical cooling tower.

![CarnotJet System and Cooling Tower Emulator](image)

Based on information from GRC the CarnotJet™ system maintains the coolant temperature in the racks at a predetermined constant setpoint. While this setpoint is a “constant” in the control sequence it can be adjusted locally at the system’s controller. The typical suggested temperature setpoint is between 35-40°C (95-104°F) but setpoints as high as 45°C (113°F) or greater are expected to be possible.

There are eight (8) rack coolant temperature sensors used in the CarnotJet™ system’s primary temperature control sequence, two in each rack. Rack coolant temperature is maintained at setpoint by continuously monitoring these eight sensors and varying the flow rate of coolant delivered to the pump module’s heat exchanger such that the maximum rack coolant temperature is kept at setpoint. Coolant flow rate is varied using a variable frequency drive housed within the pump module’s housing. An equal flow rate of coolant is delivered to each of the four racks in the typical CarnotJet™ system and there is no provision to reduce or increase the flow to any particular rack automatically.

To evaluate the CarnotJet™ system’s capability to maintain cooling rack coolant temperature data will be recorded at analyzed to verify temperature stability at the various test points. Additionally, Pump Module power data and control signal data will be used to shed light on pump module sequence of operations.

### 7.2 Test Plan

The energy consuming components of the typical GRC CarnotJet™ system includes two water pumps (primary and secondary) which are housed within the Pump Module. For the installation under test the
customer also installed a Cooling Tower Emulator which also has a pump. (The control unit draws minimal power and is not considered to be a significant load.)

Installing server loads into the CarnotJet™ system is the responsibility of the customer. At the time of the testing the system was loaded to approximately 69.8 kW, which was as high a load as could be attained within the time constraints of this evaluation. Achieving this maximum load was accomplished with the use of both servers and load banks.

Operationally the installed servers ran a combination of production software and test scripts, the details of this were based on customer requirements. This was done to ensure that the consistent computational load for each test case, reducing the variables in the test data and strengthening the results. The load banks were set to draw constant power. Details of the server internal operations are not included in this report, however the Figure 11 CarnotJet™ Rack Loading below shows a diagram of the loading of the racks.

To test the system a series of test cases would be run at various combinations of server loading, rack temperature setpoint, and cooling water temperature setpoint.

Table 4 Test Case Time and Temperature Details shows the details of the setpoints and loads associated with the eight test cases.

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Test Start Day</th>
<th>Approximate Test Start Time</th>
<th>Rack Coolant Temp Setpoint* °C (°F)</th>
<th>Cooling Water Temp Setpoint °C (°F)</th>
<th>Average Total Load kW</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>29 (85)</td>
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<td>11:00</td>
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<td>32 (90)</td>
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</tr>
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<td>45 (113)</td>
<td>24 (75)</td>
<td>69.82</td>
</tr>
<tr>
<td>6</td>
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<td>15:00</td>
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<td>18 (65)</td>
<td>69.84</td>
</tr>
<tr>
<td>7</td>
<td>10-Oct</td>
<td>20:22</td>
<td>40 (104)</td>
<td>18 (65)</td>
<td>69.84</td>
</tr>
<tr>
<td>8</td>
<td>18-Oct</td>
<td>15:00</td>
<td>40 (104)</td>
<td>18 (65)</td>
<td>44.83</td>
</tr>
</tbody>
</table>

Data were recorded using temporary power meters, GRC internal controls data, and third-party software (for internal server performance data). GRC internal controls data was chosen for the task of recording coolant and CTE water temperatures because of logistical complexities at the test site.

For each test case GRC staff programmed the CarnotJet™ coolant temperature and cooling water temperature setpoint locally at the system controller. Each test was run for a period of at least 2 hours, which was proven long enough to reach rack temperature stability. Data was collected throughout the testing and made available in spreadsheet format at the end of the testing.
<table>
<thead>
<tr>
<th>GRC TANK 1</th>
<th>GRC TANK 3</th>
<th>GRC TANK 2</th>
<th>GRC TANK 4</th>
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<tr>
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<td>APC 5.75 kW Load Bank</td>
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<td>Dell R910 113798 HLTD429 SN 7Q01TW1 (~500 W)</td>
<td>Dell R910 113798 HLTD429 SN 7Q01TW1 (~500 W)</td>
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<td>Open</td>
</tr>
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<td>Dell R910 113798 HLTD428 SN 7Q11TW1 (~500 W)</td>
<td>Dell R910 113798 HLTD428 SN 7Q11TW1 (~500 W)</td>
<td>Dell R910 113798 HLTD428 SN 7Q11TW1 (~500 W)</td>
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<td>1.74 kW Load Bank</td>
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<tr>
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<tr>
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<td>Dell R910 113798 HLTD426 SN 7Q03TW1 (~500 W)</td>
<td>Dell R910 113798 HLTD426 SN 7Q03TW1 (~500 W)</td>
<td>Dell R910 113798 HLTD426 SN 7Q03TW1 (~500 W)</td>
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<td>Dell M1000 Blade Chassis 113959 CAYHWR1VB508 SNI#F1TSB8X (~3.2 kW)</td>
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<td>Dell R910 113798 HLTD426 SN 7Q03TW1 (~500 W)</td>
<td>Dell R910 113798 HLTD426 SN 7Q03TW1 (~500 W)</td>
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<td>Dell M1000 Blade Chassis 113959 CAYHWR1VB509 SN#F1TSB8X (~3.2 kW)</td>
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</table>
7.3 INSTRUMENTATION PLAN

Input power to the servers and system oil and water pumps was monitored and recorded using a combination of seven (7) Dent Instruments Elite-Pro power meters and one Powersight PS3000 power meter. The power meters were connected at the circuit level within the data center’s cabinet power distribution units (CDUs).

Servers were powered through a combination of single-phase and three-phase power distribution units (PDUs) wired to the data center’s CDUs. Each PDU was used to power multiple servers and/or load banks and therefore direct measurements of individual server and load bank input power was not possible.

There are eight (8) rack coolant temperature sensors used in the CarnotJet™ system’s primary temperature control sequence, two in each rack. The system’s controller continuously monitors these eight sensors and maintains the worst case (warmest) sensor by adjusting coolant flow rate. The oil coolant temperature data for this testing was taken from the GRC internal controls system. CPU temperature data was made available and reported using Sentilla software. All data was recorded as 5 minute averages. Details of the monitored data points are shown in the Table 5 Data Points List.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Loggers</th>
<th>GRC System Data</th>
<th>Sentilla Data</th>
<th>LINPACK Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Server Power</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual CDU (power strip) Power</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pump Module Primary Pump Power</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump Module Secondary Pump Power</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling Tower Emulator Primary Pump Power</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling Water Flow</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rack Return Coolant Temperatures (8 total, x2 per rack)</td>
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<tr>
<td>Rack Oil Temperature Setpoint</td>
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<tr>
<td>Pump Module Coolant Pump Speed Signal</td>
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<tr>
<td>CTE Water Pump Speed Signal</td>
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<tr>
<td>Server CPU Temperatures</td>
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<td>X</td>
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<tr>
<td>CPU Performance</td>
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</table>
8 RESULTS

8.1 SUMMARY

8.1.1 TECHNOLOGY’S EFFECTIVENESS AT PROVIDING ADEQUATE COOLING

The GRC CarnotJet™ Submersion Cooling system was shown to be capable of maintaining the rack coolant temperature at setpoint for all manufacturer recommended test conditions. The system was not able to maintain the rack coolant temperature setpoint for the extreme tests, done beyond manufacturer recommended temperatures. Additionally the system pump energy consumption remained low relative to the server heat rejected throughout the tests. Coolant (oil) pump power and cooling tower emulator (water) pump power were, at their maximums, approximately 1.3% and 3.5% of rejected server heat respectively.

During two of the tests, Test #1 and Test #4, the CarnotJet™ system was shown to approach its capacity to maintain coolant temperature. During these two tests the average recorded oil pump speed was 95% and 99%, respectively. Since the CarnotJet™ system relies on varying oil pump speed to maintain rack coolant temperature, if the pump speed reaches 100% the system can no longer be considered to be controlling rack coolant temperature, and is beyond its capacity.

During two of the tests, Test #2 and Test #3, the CarnotJet™ system was shown to be beyond its capacity to maintain coolant temperature. This was determined by observing both the oil pump speed and tank temperatures. As the tank temperature increases, so does the oil pump speed, in order to reject additional heat to the cooling water. When the pump speed reaches 100%, the system is rejecting all the heat possible. However, it is not likely that the temperature setpoints in these tests would ever be used in actual operations, as they are not recommended by the manufacturer.

On the remaining Tests #5-#8, the CarnotJet™ system easily maintained stable rack coolant temperatures at setpoint. These tests used setpoints that are most likely to be encountered in the typical installation.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Server Power (kW)</th>
<th>Oil Temp (°C)</th>
<th>Water Temp (°C)</th>
<th>Coolant Oil Pump Power (kW)</th>
<th>CTE Flow (GPM)</th>
<th>CTE Pump Power (kW)</th>
<th>LMTD (°C)</th>
<th>Oil Pump (kW/ton)</th>
<th>CTE (kW/ton)</th>
<th>Total GRC Power (kW)</th>
<th>Total GRC (kW/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.81</td>
<td>45.1</td>
<td>29.0</td>
<td>0.61</td>
<td>121.6</td>
<td>2.04</td>
<td>10.34</td>
<td>0.031</td>
<td>0.103</td>
<td>2.65</td>
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<tr>
<td>2</td>
<td>69.80</td>
<td>46.8</td>
<td>32.0</td>
<td>0.80</td>
<td>128.2</td>
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<td>0.040</td>
<td>0.120</td>
<td>3.19</td>
<td>0.161</td>
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<td>3</td>
<td>69.77</td>
<td>35.1</td>
<td>18.0</td>
<td>0.86</td>
<td>128.5</td>
<td>2.40</td>
<td>10.93</td>
<td>0.043</td>
<td>0.121</td>
<td>3.26</td>
<td>0.164</td>
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<td>4</td>
<td>69.78</td>
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<td>24.0</td>
<td>0.83</td>
<td>127.8</td>
<td>2.37</td>
<td>10.40</td>
<td>0.042</td>
<td>0.119</td>
<td>3.20</td>
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<td>69.82</td>
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<td>0.29</td>
<td>91.3</td>
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<td>0.044</td>
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<td>6</td>
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<td>0.45</td>
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<td>0.022</td>
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<td>0.030</td>
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<td>0.33</td>
<td>93.5</td>
<td>0.96</td>
<td>14.34</td>
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<td>0.048</td>
<td>1.29</td>
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<td>40.0</td>
<td>18.0</td>
<td>0.08</td>
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<td>0.006</td>
<td>0.015</td>
<td>0.27</td>
<td>0.021</td>
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</table>

* Average values
8.1.2 ESTIMATED ENERGY AND DEMAND CONSUMPTION

The annual energy and peak demand, and energy cost (assume an annual average cost of $0.14/kWh) of the GRC CarnoJet oil pump with a CTE water pump is estimated to be:

<table>
<thead>
<tr>
<th>Table 7 Summary of Annual Energy and Demand Consumption</th>
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</thead>
<tbody>
<tr>
<td>Demand</td>
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<tr>
<td>Total Energy</td>
</tr>
<tr>
<td>Total Cost</td>
</tr>
</tbody>
</table>

8.1.3 ESTIMATED ENERGY AND DEMAND SAVINGS

The annual energy and peak demand, and energy cost savings (assume an annual average cost of $0.14/kWh) of the GRC CarnoJet oil pump with a CTE water pump, compared to the baseline for a Large Data Center with Level II air-management scheme, hot and cold isle containment, ducted-return, with a constant speed CRAH fan, is estimated to be:

<table>
<thead>
<tr>
<th>Table 8 Summary of Energy and Demand Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Savings</td>
</tr>
<tr>
<td>Energy Savings</td>
</tr>
<tr>
<td>Energy Cost Savings</td>
</tr>
</tbody>
</table>

The demand savings are 100% coincident with the utility peak demand period, as the pump and fan equipment operates at 100% duty cycle. This is due to the data center operating at a constant cooling load throughout the entire year, 24/7/365, and the equipment associated with the energy savings operating independent of outdoor ambient condition. The pump and fan equipment are located inside the data center, a data center’s cooling load is driven the constant IT load, not ambient conditions per the baseline document. The demand savings come from pump power instead of fan power.

8.1.4 APPLICABILITY TO RETROFIT AND NC PROGRAM

The technology currently fits into both the Customized Retrofit and the Customized New Construction Programs. There are two main schematic designs for the technology’s implementation, depending upon the facility’s piping into chilled water or condenser water. In this technology assessment it was into the chilled water, and therefore the energy savings came from pump power replacing fan power. Key variables to measure and/or record include: server (IT) power, oil pump power, and CRAH fan power.

In a situation where the technology is plumbed into the condenser water, additional variables should be recorded. Determining which are most crucial is beyond the scope of this assessment, see Section 9.7 “Areas for Further Study.” The following list of variables is that which should be included, but not limited to, for further investigation: chilled water temperature (supply and return), condenser water temperature (supply and return), chiller power, chilled water pump power, condenser water pump power, cooling tower fan power, and outside air temperature (dry and wet bulb).
8.2 **INCREMENTAL COST**

The incremental cost of the technology is estimated to be $55,154. The baseline project cost is from the 2013 RSMeans Mechanical Cost Data, adjusted for Oakland, California location, and the assessment technology cost is from the actual project cost.

### TABLE 9 BASELINE COSTS

<table>
<thead>
<tr>
<th>Baseline Costs</th>
<th>Mat'l</th>
<th>Labor</th>
<th>Tax</th>
<th>SubTotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 20 ton Computer Room Unit (for water cooled system, not incl cond, water supply, CT)</td>
<td>$45,353</td>
<td>$4,221</td>
<td>$4,309</td>
<td>$54,000</td>
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<td>Contingency, Overhead/Profit, Design, Misc</td>
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<td></td>
<td>35%</td>
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<tr>
<td>Shipping (estimated)</td>
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<td><strong>Total</strong></td>
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<td><strong>$75,700</strong></td>
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### TABLE 10 TECHNOLOGY ASSESSMENT COSTS

<table>
<thead>
<tr>
<th>Technology Assessment Project Costs</th>
<th>SubTotal</th>
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</thead>
<tbody>
<tr>
<td>Green Revolution Cooling 4x42U CarnotJet (~16 kW/rack) and installation</td>
<td>$121,876</td>
</tr>
<tr>
<td>tanks, oil coolant, overhead hoist, tank covers, graphics, tax and shipping piping (and installation) between the main chilled water line and the GRC</td>
<td>$8,978</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$130,854</strong></td>
</tr>
</tbody>
</table>

8.2.1 **TYPICAL PROJECT COSTS**

The project cost for this technology assessment is very site specific, based upon the wiring, piping, equipment, labor, and site peculiarities. To address this, the vendor has provided the following example pricing.

### TABLE 11 TYPICAL PROJECT COSTS

<table>
<thead>
<tr>
<th>EXAMPLE PRICING MATRIX COMPARING SERVER DENSITY*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>POWER DENSITY (kW/RACK)</strong></td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>32</td>
</tr>
</tbody>
</table>

Installation ($2500/1st Quad, then $750/Quad thereafter) 
Cooling Tower ($0.19/Watt of Critical Load): System includes (N+1) Towers, Pumps, VFDs, plumbing, and automated chemical water treatment system.

*Quad pricing includes seismic reinforcing
8.3 Expected Useful Life

The expected useful life of the technology as a whole is estimated to be 15 years. The major equipment included in the system is shown below, with the DEER 2011 Expected Useful Life (EUL).

<table>
<thead>
<tr>
<th>Equipment</th>
<th>EUL Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>water loop pump</td>
<td>15 none - directly from DEER 2013</td>
</tr>
<tr>
<td>oil loop pump</td>
<td>15 same as water loop pump</td>
</tr>
<tr>
<td>coolant</td>
<td>infinite from vendor</td>
</tr>
<tr>
<td>racks</td>
<td>infinite from vendor</td>
</tr>
<tr>
<td>controller</td>
<td>15 same as other mechanical controllers in DEER 2013</td>
</tr>
</tbody>
</table>

8.4 Data Analysis

8.4.1 GRC CarnotJet™ System Cooling Effectiveness

During six tests, Tests #1, and #4 through #8, which used setpoints that are recommended by the manufacturer, and most likely to be encountered in a typical installation, the CarnotJet™ was able to maintain stable rack coolant temperatures at setpoint.

Test #1 combined the full server load of approximately 69.8 kW with rack coolant temperature setpoint of 45°C and cooling water temperature setpoint of 29°C. This cooling water temperature is expected to be capable of being maintained by a cooling tower without the use of a chiller in many areas in CA. Under these conditions the system’s pumps ran at nearly full speed but the worst case error in rack the coolant temperature, the biggest difference between setpoint and recorded values, was less than 1°C.

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Coolant Oil Pump Power (kW)</th>
<th>CTE Pump Power (kW)</th>
<th>Server Power (kW)</th>
<th>Oil Pump/Server Power</th>
<th>CTE Pump/Server Power</th>
<th>CTE Flow calculated</th>
<th>Water Temp (°C)</th>
<th>Oil Temp (°C)</th>
<th>LMTD (°C)</th>
<th>Pump Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>0.611</td>
<td>1.834</td>
<td>69.51</td>
<td>0.877%</td>
<td>2.632%</td>
<td>117.23</td>
<td>28.51</td>
<td>45.05</td>
<td>10.0</td>
<td>91.8%</td>
</tr>
<tr>
<td>Max</td>
<td>0.819</td>
<td>2.408</td>
<td>70.24</td>
<td>1.173%</td>
<td>3.452%</td>
<td>128.57</td>
<td>29.45</td>
<td>45.23</td>
<td>10.7</td>
<td>97.6%</td>
</tr>
<tr>
<td>Avg</td>
<td>0.707</td>
<td>2.042</td>
<td>69.81</td>
<td>1.013%</td>
<td>2.925%</td>
<td>121.56</td>
<td>29.0</td>
<td>45.13</td>
<td>10.3</td>
<td>94.7%</td>
</tr>
<tr>
<td>SdtDev</td>
<td>0.030</td>
<td>0.086</td>
<td>0.118</td>
<td>4.38E-04</td>
<td>1.23E-03</td>
<td>1.71</td>
<td>0.254</td>
<td>0.044</td>
<td>0.2</td>
<td>0.07</td>
</tr>
<tr>
<td>Rel StdDev</td>
<td>4.31%</td>
<td>4.19%</td>
<td>0.17%</td>
<td>4.32%</td>
<td>4.21%</td>
<td>1.41%</td>
<td>0.88%</td>
<td>0.10%</td>
<td>0.0</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Test #2 was designated as a worst case condition. During this test cooling water was set to 32°C and the heat load and rack coolant temperature were kept the same as those in Test #1. A cooling water temperature of 32°C is considered extremely high and was tested to verify what may happen in the event of a cooling water system failure (assuming a cooling tower failure). Under these conditions the system’s pumps ran at full speed continuously and rack coolant temperature could not be maintained.
Test #3 was designed to test system response at low temperatures. Both the cooling water temperature setpoint and the rack coolant temperature setpoint were minimized in this test. Heat load was maintained at 69.8 kW. As a result of these low temperatures the cooling pumps ran at full speed and rack coolant temperature did not get down to within 4°C of the setpoint. This test showed the limitations of the system to produce low coolant temperatures when the heat load (servers) is high.

Tests #4 through #7 tested system response under the full system heat load (server load) of 69.8 kW with a variety of temperature setpoint combinations which may be considered typical practice for this technology. Test #8 tested what the vendor deemed to be a more likely server load of 44.8 kW at temperature setpoints that they considered to be a most energy efficient operation. Test results are shown in Table 8.10 through 8.14.
## Table 16: Test #4 Data Summary

<table>
<thead>
<tr>
<th>Test 4</th>
<th>Cooling Oil Power (kW)</th>
<th>CTE Pump Power (kW)</th>
<th>Server Power (kW)</th>
<th>Oil Pump/Server Power</th>
<th>CTE Pump/Server Power</th>
<th>CTE Flow calculated</th>
<th>Water Temp (°C)</th>
<th>Oil Temp (°C)</th>
<th>LMTD (°C)</th>
<th>Pump Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint</td>
<td>0.732</td>
<td>2.058</td>
<td>69.48</td>
<td>1.049%</td>
<td>2.949%</td>
<td>121.90</td>
<td>24.00</td>
<td>40.00</td>
<td>9.8</td>
<td>95.0%</td>
</tr>
<tr>
<td>Min</td>
<td>0.859</td>
<td>2.468</td>
<td>70.26</td>
<td>1.231%</td>
<td>3.531%</td>
<td>129.65</td>
<td>24.85</td>
<td>40.86</td>
<td>11.8</td>
<td>100.0%</td>
</tr>
<tr>
<td>Max</td>
<td>0.828</td>
<td>2.368</td>
<td>69.78</td>
<td>1.186%</td>
<td>3.394%</td>
<td>127.84</td>
<td>24.00</td>
<td>40.14</td>
<td>10.4</td>
<td>99.4%</td>
</tr>
<tr>
<td>Avg</td>
<td>0.013</td>
<td>0.052</td>
<td>0.124</td>
<td>1.81E-04</td>
<td>7.56E-04</td>
<td>0.97</td>
<td>0.182</td>
<td>0.057</td>
<td>1.0</td>
<td>0.04</td>
</tr>
<tr>
<td>SdtdDev</td>
<td>0.14%</td>
<td>2.12%</td>
<td>0.18%</td>
<td>1.47%</td>
<td>2.14%</td>
<td>0.75%</td>
<td>0.76%</td>
<td>0.14%</td>
<td>0.0</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

## Table 17: Test #5 Data Summary

<table>
<thead>
<tr>
<th>Test 5</th>
<th>Cooling Oil Power (kW)</th>
<th>CTE Pump Power (kW)</th>
<th>Server Power (kW)</th>
<th>Oil Pump/Server Power</th>
<th>CTE Pump/Server Power</th>
<th>CTE Flow calculated</th>
<th>Water Temp (°C)</th>
<th>Oil Temp (°C)</th>
<th>LMTD (°C)</th>
<th>Pump Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint</td>
<td>0.164</td>
<td>0.466</td>
<td>69.57</td>
<td>0.235%</td>
<td>0.668%</td>
<td>73.67</td>
<td>23.27</td>
<td>44.91</td>
<td>12.8</td>
<td>65.6%</td>
</tr>
<tr>
<td>Min</td>
<td>0.401</td>
<td>1.172</td>
<td>70.17</td>
<td>0.574%</td>
<td>1.679%</td>
<td>100.72</td>
<td>24.97</td>
<td>45.60</td>
<td>14.0</td>
<td>77.0%</td>
</tr>
<tr>
<td>Max</td>
<td>0.294</td>
<td>0.880</td>
<td>69.82</td>
<td>0.421%</td>
<td>1.260%</td>
<td>91.32</td>
<td>24.00</td>
<td>45.12</td>
<td>13.5</td>
<td>70.1%</td>
</tr>
<tr>
<td>Avg</td>
<td>0.024</td>
<td>0.072</td>
<td>0.113</td>
<td>3.51E-07</td>
<td>1.04E-06</td>
<td>2.61</td>
<td>0.280</td>
<td>0.070</td>
<td>0.2</td>
<td>0.10</td>
</tr>
<tr>
<td>SdtdDev</td>
<td>0.09%</td>
<td>6.17%</td>
<td>0.16%</td>
<td>0.01%</td>
<td>0.01%</td>
<td>2.59%</td>
<td>1.17%</td>
<td>0.16%</td>
<td>0.0</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

## Table 18: Test #6 Data Summary

<table>
<thead>
<tr>
<th>Test 6</th>
<th>Cooling Oil Power (kW)</th>
<th>CTE Pump Power (kW)</th>
<th>Server Power (kW)</th>
<th>Oil Pump/Server Power</th>
<th>CTE Pump/Server Power</th>
<th>CTE Flow calculated</th>
<th>Water Temp (°C)</th>
<th>Oil Temp (°C)</th>
<th>LMTD (°C)</th>
<th>Pump Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint</td>
<td>0.124</td>
<td>0.379</td>
<td>69.53</td>
<td>0.177%</td>
<td>0.543%</td>
<td>68.68</td>
<td>17.08</td>
<td>44.87</td>
<td>17.2</td>
<td>45.6%</td>
</tr>
<tr>
<td>Min</td>
<td>0.396</td>
<td>1.249</td>
<td>70.34</td>
<td>0.565%</td>
<td>1.782%</td>
<td>102.91</td>
<td>18.30</td>
<td>45.40</td>
<td>18.3</td>
<td>65.4%</td>
</tr>
<tr>
<td>Max</td>
<td>0.147</td>
<td>0.447</td>
<td>69.84</td>
<td>0.211%</td>
<td>0.639%</td>
<td>72.52</td>
<td>18.00</td>
<td>45.11</td>
<td>17.5</td>
<td>54.5%</td>
</tr>
<tr>
<td>Avg</td>
<td>0.019</td>
<td>0.058</td>
<td>0.119</td>
<td>2.74E-04</td>
<td>8.21E-04</td>
<td>2.49</td>
<td>0.123</td>
<td>0.087</td>
<td>0.1</td>
<td>0.22</td>
</tr>
<tr>
<td>SdtdDev</td>
<td>4.84%</td>
<td>4.61%</td>
<td>0.17%</td>
<td>4.84%</td>
<td>4.61%</td>
<td>2.42%</td>
<td>0.68%</td>
<td>0.19%</td>
<td>0.0</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

## Table 19: Test #7 Data Summary

<table>
<thead>
<tr>
<th>Test 7</th>
<th>Cooling Oil Power (kW)</th>
<th>CTE Pump Power (kW)</th>
<th>Server Power (kW)</th>
<th>Oil Pump/Server Power</th>
<th>CTE Pump/Server Power</th>
<th>CTE Flow calculated</th>
<th>Water Temp (°C)</th>
<th>Oil Temp (°C)</th>
<th>LMTD (°C)</th>
<th>Pump Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint</td>
<td>0.219</td>
<td>0.579</td>
<td>69.55</td>
<td>0.313%</td>
<td>0.827%</td>
<td>79.30</td>
<td>16.95</td>
<td>38.71</td>
<td>13.4</td>
<td>62.8%</td>
</tr>
<tr>
<td>Min</td>
<td>0.855</td>
<td>2.484</td>
<td>70.33</td>
<td>1.223%</td>
<td>3.552%</td>
<td>129.93</td>
<td>19.65</td>
<td>44.52</td>
<td>16.3</td>
<td>77.0%</td>
</tr>
<tr>
<td>Max</td>
<td>0.330</td>
<td>0.958</td>
<td>69.84</td>
<td>0.472%</td>
<td>1.372%</td>
<td>93.47</td>
<td>18.02</td>
<td>40.20</td>
<td>14.3</td>
<td>70.5%</td>
</tr>
<tr>
<td>Avg</td>
<td>0.100</td>
<td>0.294</td>
<td>0.116</td>
<td>1.44E-03</td>
<td>4.21E-03</td>
<td>7.21</td>
<td>0.218</td>
<td>0.380</td>
<td>0.3</td>
<td>0.07</td>
</tr>
<tr>
<td>SdtdDev</td>
<td>11.74%</td>
<td>11.83%</td>
<td>0.17%</td>
<td>11.75%</td>
<td>11.84%</td>
<td>5.55%</td>
<td>1.21%</td>
<td>0.95%</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
As expected the GRC CarnotJet™ system pump operations appear to be correlated with server load and the temperature difference available at the heat exchanger. Of particular interest is the combination at which the pump speed reaches 100%. The CarnotJet™ system relies on varying pump speed to maintain rack coolant temperature. When the pump is at full speed the CarnotJet™ system is no longer considered to be controlling rack coolant temperature, and is beyond its capacity.

A predicted speed may be calculated using multivariate linear regression based on: 1) server load and 2) logarithmic mean temperature difference at the heat exchanger, with a relatively high degree of accuracy. Table 21 Test Data and Regression Analysis Predicted Pump Speed shows the predicted value of pump speed from this regression analysis. Details of this analysis can be found in the Appendix.

### Table 21 Test Data and Regression Analysis Predicted Pump Speed

| Test | Server Load (kW) | LMTD (°C) | Recorded Pump Speed | Predicted Pump Speed  
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.81</td>
<td>10.3</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>2</td>
<td>69.80</td>
<td>9.5</td>
<td>1.00</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>69.77</td>
<td>10.9</td>
<td>1.00</td>
<td>0.93</td>
</tr>
<tr>
<td>4</td>
<td>69.78</td>
<td>10.4</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>5</td>
<td>69.82</td>
<td>13.5</td>
<td>0.70</td>
<td>0.77</td>
</tr>
<tr>
<td>6</td>
<td>69.84</td>
<td>17.5</td>
<td>0.54</td>
<td>0.52</td>
</tr>
<tr>
<td>7</td>
<td>69.84</td>
<td>14.3</td>
<td>0.71</td>
<td>0.72</td>
</tr>
<tr>
<td>8</td>
<td>44.83</td>
<td>14.4</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>

### 8.4.2 Energy Consumption and Savings

As described in the project scope, no pre-existing condition data logging was performed. Therefore the energy savings is compared to a baseline for a Large Data Center, Level II air-management scheme with hot and cold isle containment and ducted-return with constant speed fans, from the PG&E Energy Efficiency Baselines for Data Centers document.
The baseline energy consumption will be taken with a load factor of 1.0.

**Baseline annual energy consumption**

For an annual average IT load of 69.8 kW the CRAH airflow is:

\[
\text{Airflow} = \frac{\text{kW of IT load } \times 3,412 \text{ Btu/hr-kW} }{1.08 \times \text{degrees F of operating airside Delta-T}}
\]

\[
\text{Airflow} = \frac{69.8 \times 3,412}{1.08 \times 13}
\]

\[
\text{Airflow} = 16.963 \text{ cfm}
\]

The CRAH fan power is calculated as:

\[
\text{CRAH Coincident Fan Power} = \text{cfm} \times \text{fan airflow efficiency metric} \times \text{duty cycle}
\]

\[
\text{CRAH Coincident Fan Power} = 16.963 \times 1,508 \times 100\%
\]

\[
\text{CRAH Coincident Fan Power} = 11.25 \text{ kW} \times 100\%
\]

For a data center operating 8,760 hours per year, the annual energy consumption is estimated to be:

\[
\text{Baseline Annual Energy Consumption} = 11.25 \text{ kW} \times 8,760 \text{ hr/yr}
\]

\[
\text{Baseline Annual Energy Consumption} = 98,550 \text{ kWh/yr}
\]

**Technology Assessment annual energy consumption**

For an annual average IT load of 69.8 kW, from the logged data the average GRC CarnotJet and CTE power is:

\[
\text{GRC Coincident Power} = (\text{oil pump power} + \text{CTE pump power}) \times \text{duty cycle}
\]

\[
\text{GRC Coincident Power} = (0.52 \text{ kW} + 1.48 \text{ kW}) \times 100\%
\]

\[
\text{GRC Coincident Power} = 2.00 \text{ kW}
\]

For a data center operating 8,760 hours per year, the annual energy consumption is estimated to be:

\[
\text{GRC Annual Energy Consumption} = 2.00 \text{ kW} \times 8,760 \text{ hr/yr}
\]

\[
\text{GRC Annual Energy Consumption} = 17,520.0 \text{ kWh/yr}
\]
The GRC Peak Power consumption was taken from the logged data during the “Extreme Summer” test name, and is

GRC Coincident Peak Power = (peak oil pump power + peak CTE pump power) * duty cycle

GRC Coincident Peak Power = (0.52 kW + 1.48 kW) * 100%

GRC Coincident Power = 2.00 kW

**Estimated Annual Energy and Peak Demand Savings**

Energy savings come from the GRC CarnotJet oil pump and CTE pump replacing the CRAH fan power. The Estimated Annual Energy Savings between the GRC and baseline systems is:

Estimated Annual Energy Savings = Baseline – GRC

Estimated Annual Energy Savings = 98,550 kWh/yr - 17,520 kWh/yr

Estimated Annual Energy Savings = 81,030 kWh/yr

The Estimated Peak Demand Savings between the GRC and baseline systems is:

Estimated Coincident Peak Demand Savings = Baseline – GRC

Estimated Coincident Peak Demand Savings = 11.25 kW – 2.00 kW

Estimated Coincident Peak Demand Savings = 9.25 kW
9 EVALUATIONS

9.1 COOLING PERFORMANCE

The GRC CarnotJet™ system was shown to be capable of maintaining the rack coolant temperature at setpoint in all but the most extreme test conditions. However, during two of the tests, Test #1 and Test #4, the CarnotJet™ system was shown to approach its capacity to maintain coolant temperature. During these two tests the average recorded pump speed was 95% and 99%, respectively. Because the CarnotJet™ system relies on varying pump speed to maintain rack coolant temperature, if the pump speed reaches 100% the system can no longer be considered to be controlling rack coolant temperature, and is beyond its capacity.

### TABLE 23 TEST DATA SUMMARY

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Rack Coolant Temp Setpoint (°C)</th>
<th>Cooling Water Temp Setpoint (°C)</th>
<th>Avg. Recorded Rack Coolant Temp (°C)</th>
<th>Avg. Recorded Cooling Water Temp (°C)</th>
<th>Average Total Server Load (kW)</th>
<th>LMTD (°C)</th>
<th>Recorded Pump Speed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>29*</td>
<td>45.1</td>
<td>29.0</td>
<td>69.81</td>
<td>10.3</td>
<td>95%</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>32</td>
<td>46.8**</td>
<td>32.0</td>
<td>69.80</td>
<td>9.5</td>
<td>100%</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>18</td>
<td>35.1**</td>
<td>18.0</td>
<td>69.77</td>
<td>10.9</td>
<td>100%</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>24</td>
<td>40.1</td>
<td>24.0</td>
<td>69.78</td>
<td>10.4</td>
<td>99%</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
<td>24</td>
<td>45.1</td>
<td>24.0</td>
<td>69.82</td>
<td>13.5</td>
<td>70%</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>18</td>
<td>45.1</td>
<td>18.0</td>
<td>69.84</td>
<td>17.5</td>
<td>54%</td>
</tr>
<tr>
<td>7</td>
<td>40</td>
<td>18</td>
<td>40.2</td>
<td>18.0</td>
<td>69.84</td>
<td>14.3</td>
<td>71%</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>18</td>
<td>40.0</td>
<td>18.0</td>
<td>44.83</td>
<td>14.4</td>
<td>42%</td>
</tr>
</tbody>
</table>

* Product’s claimed maximum incoming cooling water temperature setpoint.

** Rack coolant temperature was not maintained at setpoint.

9.2 ENERGY PERFORMANCE

The energy consuming equipment contained in the installed GRC CarnotJet™ system consists of two separate pumps, a GRC CarnotJet™ system Pump Module coolant pump (oil pump) and a GRC CarnotJet™ Cooling Tower Emulator pump (water pump). Over the course of the testing the electrical demand of these two pumps was measured and the average value was calculated to be 2.00 kW. As a percentage of the average server (IT) power the total average GRC CarnotJet™ electrical power demand was found to be 2.94%, or about 0.104 kW of pump power per ton of heat rejected. The annual energy and peak demand, and energy cost (assume an annual average cost of $0.14/kWh) is estimated to be:

### TABLE 24 SUMMARY OF ANNUAL ENERGY AND DEMAND CONSUMPTION

<table>
<thead>
<tr>
<th>Demand</th>
<th>2.00 (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Energy</td>
<td>17,520.00 (kWh/yr)</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$ 2,452.80 ($/yr)</td>
</tr>
</tbody>
</table>
9.3 **Energy Savings**

The annual energy and peak demand, and energy cost savings (assume an annual average cost of $0.14/kWh) of the GRC CarnotJet oil pump with a CTE water pump, compared to the baseline is estimated to be:

<table>
<thead>
<tr>
<th>TABLE 25 ESTIMATED ENERGY AND COST SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Savings</td>
</tr>
<tr>
<td>Energy Savings</td>
</tr>
<tr>
<td>Energy Cost Savings</td>
</tr>
</tbody>
</table>

The baseline system used for this analysis consists of an air-cooled rack arrangement with hot and cold isle containment, ducted-return, and constant speed CRAH fan.

The demand savings are 100% coincident with the utility peak demand period, as the pump and fan equipment operates at 100% duty cycle. This is due to the data center operating at a constant cooling load throughout the entire year, 24/7/365, and the equipment associated with the energy savings operating independent of outdoor ambient condition. The pump and fan equipment are located inside the data center, a data center’s cooling load is driven the constant IT load, not ambient conditions per the baseline document. The demand savings come from pump power instead of fan power.

![Figure 12: Coincident Peak kW Draw](image-url)
9.4 **Other Benefits**

Not evaluated as part of the scope assigned, but vendor has claimed – increased server efficiency in FLOPs per Watt. LINPACK results are in appendix.

9.5 **Applicability to Retrofit and New Construction Program**

The technology currently fits into both the Customized Retrofit and the Customized New Construction Programs. There are two main schematic designs for the technology’s implementation, depending upon the facility’s piping into chilled water or condenser water. In this technology assessment it was into the chilled water, and therefore the energy savings came from pump power replacing fan power. Key variables to measure and/or record include: server (IT) power, oil pump power, and CRAH fan power.

In a situation where the technology is plumbed into the condenser water, additional variables should be recorded. Determining which are most crucial is beyond the scope of this assessment. The following list of variables is that which should be included, but not limited to, for further investigation: chilled water temperature (supply and return), condenser water temperature (supply and return), chiller power, chilled water pump power, condenser water pump power, cooling tower fan power, and outside air temperature (dry and wet bulb).

The technology has significant energy savings potential, a long expected useful life, and a high incremental cost. Based upon conversation with the vendor there appears to be low market penetration to date.
9.6 **Market Barriers**

Based upon conversations with the vendor and facility personnel, the following market barriers were identified:

1) Requires the use of solid state drives, which are expensive
   a. typical magnetic style hard drives are not hermetically sealed, and allow mineral oil through their seals which ruins the drive

2) Server Manufacturers do not yet offer “off the shelf” servers to submerge into mineral oil. Currently each server requires (at minimum):
   a. Removal of thermal paste (clouds oil & could plug orifices)
   b. Removal of air-cooling fan

3) Obtaining Server Manufacturer support to fully honor the server warranty for those modified and submerged. Currently the vendor is working with numerous server manufacturers’ to address this issue, and the server manufacturers are aware of the potential interest by customers.

4) Network gear manufacturers (switches, network interface cards, etc) lagging further behind server manufacturer.

5) Meeting criteria for return on investment.

6) Site plumbing specifics
   a. Availability of condenser water within the data center is preferred
   b. If this is not available, chilled water will suffice, but will not result in as significant energy savings. This was the case in the technology assessment, and no chiller or chilled water pump savings was attained.

It was asked if any barrier due to maintenance or the CarnoJet or servers by facility personnel was a barrier. Real Estate Facility personnel stated that they were capable of maintaining the technology assessed. IT personnel stated that the servers require extra time to remove and maintain, as the oil is dripped from the server, and it needs to be packaged in a plastic bag if it is transported but that also was not a barrier.

9.7 **Areas for Future Study**

1) Detailed investigation of the potential energy and coincident demand savings with the cooling water for the GRC system coming from condenser water instead of a chiller. This would result in fan, pump, and chiller savings.

2) Market penetration and portfolio energy savings for product design and workpaper.

3) Evaluate any energy savings claim for increased server efficiency in FLOPS per Watt. Vendor claims reduced server power and increased computation due to a lower, and more constant, chip and processor temperature.
4) New Construction application – There is significant savings in Data Center Infrastructure Management through this type of installation. The avoided costs of chiller, pumps, piping, wiring, controls, building, and workers to house such reductions could be significant.

5) Similar study with all IT load from servers, instead of partially from load banks.

9.8 Financial Analysis

The financial analysis is based upon the estimated energy savings and incremental cost shown in the Results Section. It assumes an annual average electrical energy cost of $0.14/kWh. The technology is eligible under the Customized Retrofit Program for Incentive at a rate of $0.08/kWh and $100/peak-kW.

<table>
<thead>
<tr>
<th>TABLE 26 Financial Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Cost Savings</td>
</tr>
<tr>
<td>Incremental Cost</td>
</tr>
<tr>
<td>Simple Payback</td>
</tr>
<tr>
<td>kW INCENTIVE</td>
</tr>
<tr>
<td>kWh INCENTIVE</td>
</tr>
<tr>
<td>Total INCENTIVE</td>
</tr>
<tr>
<td>Simple Payback with INCENTIVE</td>
</tr>
</tbody>
</table>

The financial analysis does not take into account any costs or savings due to maintenance, infrastructure (central plant), or server modification.
10 RECOMMENDATIONS

10.1 ENGAGEMENT IN ENERGY EFFICIENCY PROGRAMS

The assessment showed that the GRC CarnoJet™ system provides for energy and peak coincident demand savings over the incumbent technology and we recommend its adoption into EE programs. The technology currently fits into the Customized Retrofit and Customized New Construction Programs.

For an installation similar to the one installed in this project, which included a GRC Cooling Tower Emulator system, the key variables in determining energy savings are server (IT) power, GRC CarnoJet™ oil pump power, GRC CarnoJet™ CTE pump power, and the facility’s pre-existing CRAH fan power. The technology has significant energy savings potential, a long expected useful life, and a high incremental cost. Based upon conversation with the vendor there appears to be low market penetration to date.

The current DEER compliance tool does not address this technology. There are still a number of suggestions that the Emerging Technologies Team suggests for further investigation, shown in the next section.

10.2 SUGGESTION FOR FURTHER INVESTIGATION

1) Determine energy and coincident demand savings potential, as well as incremental cost for re-piping a facility so that the cooling water comes from condenser water, instead of a chiller, for a brownfield retrofit of the numerous air flow scenarios. A rough estimate of the energy consumption for a four rack system, based upon load factor of 1.0 and equipment energy consumption metrics from the PG&E Data Center Baseline document is:

![Graph showing energy consumption for different air flow management schemes](image-url)
2) Market penetration and portfolio energy savings for product design, development of workpaper for a prescriptive, or deemed, rebate instead of a customized incentive. This would be a first step in having the compliance tool of DEER address this technology.

3) Evaluate any energy savings claim for increased server efficiency in FLOPS per Watt. Vendor claims reduced server power and increased computation due to a lower, and more constant, chip and processor temperature.

4) Data Center Infrastructure Management (DCIM) Investigation. In a new construction, green-field type installation of a CarnotJet system, the temperature of the oil exiting the CarnotJet system is high enough to allow for the server heat to be rejected in a cooling tower alone. No vapor-compression refrigeration system is necessary, greatly reducing the number of heat transfer mediums, mechanical equipment, and its associated costs. There would be only two heat transfer mediums:
   a. Ambient air to condenser water
   b. Condenser water to oil, in which the server is submerged

A significant amount of infrastructure first and operational cost savings, as well as significant energy savings may result from this. The only energy consuming equipment would be a cooling tower fan, condenser water pump, and the CarnotJet oil pump.

5) Similar study with all IT load from servers, instead of partially from load banks.
During testing servers running specially designed test scripts were analyzed for CPU performance. The data was made available to the team.

<table>
<thead>
<tr>
<th>TABLE 27 LINPACK DATA SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
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<td>Test Min</td>
</tr>
<tr>
<td>Test Max</td>
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<td>Test AV</td>
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<tr>
<td>Summer Min</td>
</tr>
<tr>
<td>Summer Max</td>
</tr>
<tr>
<td>Summer AV</td>
</tr>
<tr>
<td>Extreme Min</td>
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<tr>
<td>Extreme Max</td>
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<tr>
<td>Extreme AV</td>
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<tr>
<td>Winter Min</td>
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</table>
### GRC Online Systems Monitor

Last updated: 10/24/2013 11:24:31 AM

<table>
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<th>Ct Fan Speed / Status</th>
<th>Water Pump Speed / Status</th>
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<th>Tank TopB</th>
<th>Tank TopA</th>
<th>Tank TopB</th>
<th>Tank TopA</th>
<th>Tank TopB</th>
<th>Heat Dissipation</th>
<th>Water In</th>
<th>Water Out</th>
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</thead>
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</tbody>
</table>
12 REFERENCES


