Recovery Act: Energy Efficient Information and Communication Technology

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Edison Materials Technology Center (EMTEC), Clustered Systems Company Inc, Emerson/Cooligy Inc.

Development of Very Dense Liquid Cooled Compute Platform

Revision History

Date	Version	Description	Authors
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Project information

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Project Objectives

The objective of this proposed work is to design and develop a prototype ultra high-density compute platform with 100% liquid cooling using commodity components and high volume manufacturing techniques. The system will be powerful enough for HPC applications and cost effective enough for general enterprise applications. Out target is 300-400 CPUs per standard data center rack with a performance of 25 petaFLOPS (floating point operations per second) in 2010 and 50 petaFLOPS in 2011. The components to be developed include a 2 CPU compute module, a 3U shelf with built in cooling and rack plumbing. A Liebert XD pumped refrigerant platform connected to an existing cold water system will supply the coolant. When this very dense, liquid cooled computing system is coupled with a standard data center high efficiency cooling system that will:

- Achieve a Data center infrastructure efficiency (DCiE) of better than 0.85. Compared to today's average DCiE of approximately 0.61.
- Be capable of effectively supporting HPC applications and have a manufacturing cost that that makes it cost effective for mainstream applications.
- Have the capability of being cooled without the use of refrigeration systems for most of the year in the majority of US locations.

The design will culminate in the construction of a prototype evaluation system consisting of two racks containing the cooling systems and approximately 350 compute modules. A significant portion of this effort is related to the evaluation of the liquid cooled system performance at an actual end user data center test site. Over a period of 6-9 months key parameters including (but not limited to) the following will be recorded via the server management system plus minimal additional instrumentation:

- Cooling system and compute system power consumption.
- Internal server and coolant temperatures.
- Ambient conditions including temperature and humidity.
- System functional performance.

Both immediate and long-term jobs will be created as a result of this project. 25 people will be employed immediately to develop this product. In production, the economic stimulus contribution can be up to 500 jobs to support estimated annual revenue of over $3B within five years of market introduction.

Technical Merit

System description

This proposed project will develop a fundamentally new architecture based upon liquid cooling and encompassing both infrastructure and equipment. It will be low cost, have a small carbon footprint and a design that comprehends board layout for heat transfer from the servers' internal components to ultimate dissipation of the heat to the ambient environment. Existing components, technologies and work practices will be used wherever possible.

The system will be comprised of racks connected to a commercially available refrigerant cooling and circulation system (Liebert XDP) which in turn is connected to a cooling tower. Depending on location and requirements, auxiliary cooling may be provided by a chiller.

Each rack will be plumbed for refrigerant distribution and house a minimum of 168 modules in 12 shelves. Initial rack cooling capacity for this project is 70KW, with a design goal of achieving 200KW. . Cold plates will be integrated with the shelves and a mechanism to bring them into contact with the modules and a fluid distribution system. The racks will be plumbed to deliver liquid to each shelf.

Each module will contain 2 multi core CPUs and 8 DIMM sockets plus one or more network interfaces.

Network connectivity will be provided by multiple active mini backplanes housing the switch mechanism and topology of choice. .

Power to the modules will be 350VDC supplied from bulk power supplies. On board 1/8 brick DC-DC transformers will reduce this to 12V.

Two prototype evaluation racks will be fabricated as part of this project. Both racks will connect via a loop to a pump and heat exchanger unit which in turn will connect to a cooling tower via a secondary water loop.

DCiE will vary depending on application. In an HPC application, the chips may be aggressively cooled with the use of refrigeration systems to support over clocking. In more mainstream applications, the main cooling mechanism will be direct dissipation to outside ambient. In the former, DCiE would be 0.8 and in the latter, 0.92, best case with no chiller year round to 0.87 average, with chiller assist.

In practice, some servers will be populated with high performance CPUs with high dissipation to support HPC applications. The system fits precisely the new paradigms of cloud computing and web serving as it is compute and communication rich without the overhead of rarely used facilities and an air cooling system.

The system is also flexible. Additional card types could be added, such as hard disk arrays, GPUs etc. Upgrades are also more environmentally friendly. As the modules are generally single function, only those that require upgrade need be replaced

New Cooling System Concept

Liquid cooling has been an orphan technology for many years due to its cost and complexity. Clustered Systems' design solves all of these issues. Key design highlights include:

- The cold plates will be flexible, not rigid. They will be integrated with a rack or chassis allowing cooled components to be removed without breaking a liquid connection.
- In operation, heat will be moved from components to a single plane, usually the enclosure lid from where it is removed by liquid circulating through a cold plate pressing down on the lid.
- For cost and manageability, most electronics are typically housed in enclosures of light metal that are prone to sag. In addition, the heights of the same components on otherwise identical boards can be different. Clustered Systems' flexible cold plates combined with its highly compliant, highly conductive thermal interface effectively accommodated these variations. Hard cold plates cannot stand these differences without taking expensive, heroic measures.
- The design delivers both high density and lowered energy costs. Greater density offers shorter inter-processor wire lengths which require less driver power while speeding communication, which improves compute throughput, a very important factor in HPC. Equally important is the smaller footprint that is enabled. Data center buildings can be made much smaller resulting in less materials input (especially cement, the manufacture of which produces large quantities of CO_2) and cost. In addition, they are also much simpler.
- Complex air handling architecture will be replaced by simple plumbing.
- Cooling energy will be reduced considerably as liquid requires much less energy to circulate and is a considerably more efficient heat remover. These energy savings combined with the elimination of complex, ongoing air management processes results in a greatly decreased operation expense.

- The energy saved through equipment upgrade to liquid cooling could also be repurposed to run more computers, postponing the need to build new data centers.

Statement of Project Objectives (SOPO)

- **Develop detailed specification of the system and its components.**

  This will entail the creation of two documents, a PRD (product requirements document) and an engineering specification, which will be derived from the former. The PRD will involve Clustered Systems interviewing a sample set of customers with different applications requirements as well as soliciting input from CPU and DIMM vendors.

- **Design, build and test compute module**

  This is envisioned to be approximately a 5" x 16" card with 2 CPUs and 4 memory slots. The CPUs will be the latest model Intel Xeon models and be loaned to the program for three years by Clustered. As a minimum, the board will have a Gigabit Ethernet network connection and possibly Infiniband. The elimination of air as the heat removal medium will offer another degree of freedom to the designer, most probably permitting components to be in closer proximity. This may create other issues such as noise interference between ICs. The CPU and memory segment is known to be the most sensitive to these effects. It is expected that, besides developing the card, a set of design rules will be developed for future projects. Other issues to be addressed include DIMM configuration (standard or custom?) and positioning. As they are potentially the tallest devices on the board, special sockets may be required to lower them.

  Testing will require heat risers to be attached to the CPUs as a minimum and a cold plate impressed on top to remove the heat. Clustered will supply a simple water based cold plate to provide adequate cooling while the board is "brought up" and debugged.

- **Design and build 1 Gbps Ethernet switched backplane card**

  This is envisioned to be an 18" x 3" card with a 14 port switch IC providing connectivity between blades and an uplink.

- **Design and build 10 Gbps switched backplane card**

  This is envisioned to be an 18" x 3" card with a 14 port switch IC providing connectivity between blades and an uplink. Protoc0l may be either Infiniband or 10GBE

- **Design and build midplane card**

  This may be required as a temporary measure if appropriate connectors are not available off the shelf in order to save time and money.

- **Design, build and test a single blade and deflection mechanism**

  This will be a variant of the flexible plate technology employed in the 1U servers. The main difference being a much higher heat load per plate. Measurements to date have shown that the tubing used in current projects will have sufficient capacity. Some experimentation will be required to determine the optimum pressures and configuration in order to minimize space and maximize the number of modules in a 3U shelf. After successful completion of testing, drawings will be released to manufacturing for sufficient quantities to populate a complete shelf.

- **Design and build Heat risers**
  These will be made simply from blocks of aluminum. In volume production, OEMs may wish to save weight by utilizing heat pipes.

- **Design and build cooling crate and housing, test with heat source**
  The cooling plates and associated deflection mechanisms will be assembled into the crate, pressure tested and charged with refrigerant. Testing of single positions will be done in Cluster Systems' facility and full load testing at Emerson's Mountain View lab.

  We expect to demonstrate a cooling capability of 1KW per daughter card position and that refrigerant is evenly distributed to all positions.

- **Test crate with modules and switch cards**
  This will involve bench test of a single shelf, initially at Clustered and then at Emerson.

- **Design and build rack with integrated refrigerant distribution system**
  The issue will be the piping diameter. These may be some challenges to fitting these within the rack.

- **Build 12-14 shelves and integrate with rack, test with standard Liebert XDP pump and heat exchanger system connected to a chiller**
  This will involve dummy loads and will confirm that refrigerant is evenly distributed among all the shelves. We expect to demonstrate a capacity of 200KW. The XDP and chiller are installed at Cooligy's site.

- **Acquire bulk 208 VAC to 350VDC bulk converter**
  Potentially the bulk AC to 350VDC power supply module may be adapted to be cooled by contact. 120KW will be required.

- **Test system with full compliment of baseboards and daughter cards using Liebert XDP and chiller**
  We expect to confirm a cooling energy reduction of at least 20% compared with a traditional 1U system of the same compute capability. In addition, due to the use of right sized power supplies, power supply efficiency should increase by 1-2%. Using the Liebert XDP with chiller set at minimum temperature will allow the potential for overclocking to be explored. At the other end of the spectrum, refrigerant temperatures could be allowed to increase to 30C in order to simulate hot day operation without chiller.

- **Test system with chillerless system**
  Totally eliminating the chiller could reduce cooling energy by 22% (water cooled) to 36 % (dry cooled). We will test the system either at SLAC or at EBay. Optimally the test should last one year during which time it can be monitored, debugged and improved if necessary.

Feasibility
There are no serious technical obstacles. Although challenging, the design issues involved are a natural progression of Cluster System's established expertise.

Potential Benefits

Potential job creation opportunities

The following personnel, see Table 1, would be employed full or part time on this project

Table 1 – Project Employment Short Term

Activity	Engineers		Technicians		Proj Mgmt		Other	
	Heads	%	Heads	%	Heads	%	Heads	%
Baseboard and daughter cards	3	40%	2	40%	1	20%		
Cooling crate	4	75%	4	80%	1	100%	1	50%
Cooling Infrastructure	3	25%	1	50%	1	50%		
Component suppliers			4	30%				
Totals	10		11		3		1	
Grand total	25							

In addition the following personnel would have longer term employment.

Table 2 - Long Term Employment US only

Activity	Heads	Comment
Cooling Crate Manufacture	35	Primarily manufacturing staff based in MS
Cooling System	150	Manufacturing, field installation and some engineers (OH & US wide)
Server	50	Minimal creation as most manufacturing is done offshore US based include engineers & assemblers & admin
Cooling Design	10	Primarily engineers in CA
Total	**245**	

Table 2 assumes a run rate of 4,000 servers per week, about the forecast volume for 2011 (see table 4). New and preserved jobs should exceed 500 in the subsequent years.

The cold crate manufacturing activity is expected to be done at R2 Puckett. They have estimated a staff increase of 15 heads for 1,000 per week and 35 for 5,000 a week. As the components of the cold rail technology for the cooling crates was developed in the US and have been manufactured here to date, it is unlikely that this activity will move offshore in the medium term.

The cooling system consists of the Liebert XD line of product and specially adapted computer racks. They will require engineers for product development and upgrades, additional manufacturing personnel, and field installers. Manufacturing and engineering are mostly in OH and TX and the balance statewide.

It is our intention to license the compute module design to OEMs who will probably have it and descendants made offshore. US based staff is expected to include thermal and electronic engineers, assembly and shipping staff plus administration. Sales staff probably won't increase.

Clustered Systems business model is to outsource virtually all functions except core research and development.. Of necessity therefore out expansion will be small. Most employees will be engineers with 1-2 administration. However the 10 jobs will be new and well rewarded thus provide additional "trickle down" employment.

Estimated energy savings

The Table 3 below was derived from DoE's "DC pro" modeling tool from a theoretically optimal air cooled Tier III data center based in San Mateo County California.

Table 3 – Energy Savings Analysis

	Server+ Fans	**Server no fans**	**Liquid**
IT	**84%**	**76%**	**91%**
Lights	2%	2%	2%
Fans	2%	10%	0%
Cooling	8%	8%	2%
Elect	4%	4%	5%
	100%	100%	100%
DCiE	0.84	0.76	0.91
PuE	1.19	1.32	1.10

The first column shows the actual program output while the second column is recalculates with the server's internal fan power (10% of 84%) reallocated to the "fans" row. The liquid cooling column shows an estimated 2% of power allocated to cooling. This comprehends year round average consumption of a refrigerant pump, a water circulation pump and cooling tower fan.

Using these ratios with a 1MW IT load, made up of n standard servers with fans and n converted servers (without fans) we can show a 17% energy saving. See Table 3 below.

Table 4 – Air versus Liquid Power			
	Air	**Liquid**	**Units**
IT	1,000	900	KW
Lights	24	24	KW
Fans	24	-	KW
Cooling	95	18	KW
Elect	48	45	KW
Total W	1,190	987	KW
Power saving		**204**	**KW**
%		17%	

Tables 4 and 5 represent a minimum saving. As most data centers are markedly inferior and there is a large variation of climate across North America, in practice savings will be much larger.

Table 5 – Estimates Energy Savings by Year							
USA	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Volume Server Installed base KU	16,898	19,317	22,081	25,241	28,853	32,982	37,702
Nett Shipments KU		8,051	9,203	10,520	12,026	13,747	15,714
Percent liquid cooled shipped	0%	0%	2%	10%	20%	30%	40%
Liquid cooled shipments KU		8	184	1,052	2,405	4,124	6,286
Liquid cooled base KU		8	192	1,244	3,641	7,581	12,815
Liquid cooled Base %		0.04%	0.87%	4.93%	12.62%	22.99%	33.99%
DCiE Air (server fans in overhead)		0.61	0.63	0.65	0.67	0.70	0.72
DCiE Liquid		0.85	0.85	0.85	0.85	0.85	0.85
Mean DCiE		0.61	0.63	0.66	0.70	0.73	0.76
Peak power excluding fans W	289	317	349	384	423	465	353
Server power cons	37,971	47,746	60,036	75,491	94,923	119,358	150,082
Power saved GWH		**13**	**289**	**1,712**	**4,518**	**8,375**	**12,455**

IDC estimates that the volume server installed base is approximately 16M and has grown by 16% per year. Going forward, we estimate that base growth will drop to 14%. Further, server refresh rate is 3 years. From this we derive the net shipments. Although IDC previously estimated 10M ships, 8M is probably closer in today's environment.

The shipment forecast for liquid cooled servers is Clustered Systems' estimate based on customer input and the fact that we have Emerson, a major worldwide distributor under contract to sell our existing cooling system worldwide. We may use the same channel for this latest design.

In "Estimating Regional Power Consumption by Servers" published Dec 2007, authored by Jonathan G. Koomey, Ph.D., Project Scientist, Lawrence Berkeley National Laboratory, it is stated that in 2005, the energy overhead for cooling, electricity etc. is equal to the IT load that is, a DCiE of 0.5. Again, moving the fan energy from server to infrastructure, gives us a DCiE of 0.45. From the above example, we see that an optimized air cooled DC may have a DCiE (no fans in server) of 0.76 in a mild climate such as California's. As a typical data center's life is 12 years, it would take that amount of time for the industry to attain best in class. We assume a simple linear improvement and ignore such factors as increase in numbers of DCs and that some DCs in a more extreme environment may never achieve the target DCiE.

Increases in power supply efficiency are ignored. Thus air DCiE improves from 0.61 to 0.72, with the 12 year window starting in 2005. We have adjusted the liquid DCiE downwards to accommodate more extreme climates where some chiller input may be required.

We used Koomey's work for estimating the power of servers in 2005 and took our own measurements of more recent ones on 2008-9. We then used a straight-line projection from those two data points. This may understate projected CPU consumption as the introduction of multicore had the effect of temporarily slowing increases. This effect is passing and the rate of power increase may increase. Graphic Processor Units (GPUs) are already specified with 200W or more consumption.

By 2015 we calculate that our technology could cut total US DC consumption by 8% to 10%.

Using the ICT Benefits spreadsheet, in 2015 with a market penetration of 29%, energy savings (US) would be 6.38 BKWh and CO2 reduction, 1.05 MMTCE.

Potential economic benefits

Using Chakandra Patel's (HP Labs HPL-2005-107R1) model for estimating the cost of running a data center shows that costs per server can be reduced 36% in a new construction. For our model 1MW San Mateo, California data center the annual cost decreases from $2.7M to $1.7M inclusive of energy, maintenance and amortization and lease costs.

Table 6 – Economic Benefits

	Assumptions		
Lease cost	$60	per sq ft/year	
Electricity cost	$0.10	per KWh	
Elect plant maint & amort	$ 0.10	per KWh	
Cooling plant maint & amort	$ 0.05	per KWh	
	Air	**Liquid**	
Power density	100	2000	W/sq ft
DC Size	10,000	450	sq ft
Lease	$600,000	$27,000	
Annual Elect Cost	$1,042,857	$864,312	
Elect plant maint & amort	$1,042,857	$864,312	
Cooling plant maint & amort	$52,143	$7,884	
Annual operations cost	$2,737,857	$1,763,508	
Cost Saving		**$ 974,349**	
%		36%	

In the short term, very significant savings can be achieved in existing data centers by converting to liquid cooling. Based on the same assumptions and without increasing energy consumption the capacity of the subject 1MW could be increased by 20% by converting to liquid cooling. Five liquid cooled servers can replace four air-cooled servers. In addition, the bill for cooling system maintenance and amortization would drop 60% (assuming that the retired equipment could be recycled). Of course, if more power were available, and based on the installed chiller capacity, the capacity of the data center could be increased 20 times.

Of course, few existing data centers can boast a DCiE of 0.76. Today's average is estimated to be 0.61. That would offer the potential opportunity to increase capacity by about 40%.

Another aspect of economic benefit is the universality of our approach, being powerful enough for HPC yet cost effective for volume applications.

The latest Dell 1U server barebones (i.e. Chassis, motherboard and power supply only) has a list price of approximately $2,300. Configured for HPC, the price is $5,235 and for simpler tasks $3,245. In prototype quantities, the proposed bare bones compute module costs only $1,500. In high volume, this will drop to about $250 and the apportioned cost of the cooling system and infrastructure around $300, a total of $550. At 50% margin, list would be $1,100 or half the cost of the Dell barebones, representing a savings of 26% on the HPC price and 41% on the simpler system.

Three European companies, Bull (France), T-Platforms (Russia), and Eurotech (Italy), recently introduced very dense HPC products. Only Eurotech is using liquid cooling. Their system used a rigid cold plate which has to be disconnected form the cooling circuit in order to service the attached compute module. The other two use air cooling with a very high degree of customization. All price themselves out of the volume server market. This price positioning is probably one of the reasons why several US HPC companies (Woven, SciCortex, SGI) failed.

Our concept on the other hand is low cost and modular. The housing and cooling system are common across all applications. Compute modules can be populated with high or low performance CPUs and networking can be added with mini active backplanes. Additional functions (e.g. disk storage, GPUs) can be added as additional module types. Another interesting attribute of the mini backplanes is that they can support either or both central and distributed switching (e.g. torus, hypertorus etc.).

Customers can standardize on a single architecture for multiple applications and upgrade piecewise rather than replace whole servers. Saving on administration costs and upgrades would accrue.

Finally, technological leadership is important in creating national economic benefit. To our knowledge there is no other competitor proposing the use of flexible cold plates for cooling. The team intends to license the active component designs to OEMs and concentrate on cooling system innovation

Greenhouse gas emission reduction

Reduction in energy consumption translates directly into greenhouse gas reduction. Again using DoE's statistics for the amount of GHG produced by electricity generation in 2007 gives the following savings result.

Table 7 – GHG Emission Reduction

	2010	2011	2012	2013	2014	2015
CO2	7,635	170,702	1,012,492	2,671,979	4,952,413	7,365,557
SO2	33	729	4,321	11,403	21,136	31,435
Nox	13	291	1,724	4,549	8,432	12,541

As noted above, the design can be refreshed without replacing whole units (power supply, chassis, peripherals etc.) this prolongation of useful life will lead to further GHG reductions through cutting demand for longer life components and also cut waste.

Commercialization and Market Acceptance

Commercialization strategy

The consortium's strategy is multi faceted. Emerson would provide worldwide distribution of the cooling system infrastructure while CPU vendors would promote the compute hardware portion.

The technology developed within this DOE funded program will supplant air cooled volume servers used in many HPC and other applications and significantly reduce demand for computer room air conditioners. A minimum of the latter will be required to control humidity.

The proposed device interoperates Emerson's Liebert XD pumped refrigerant based product offerings which are installed at over 500 sites worldwide.

Because of the criticality of the IT equipment used in data centers, reliability is the primary market driver for precision cooling products. Cooling performance and energy consumption are important market drivers that have shifted to top drivers, as reliability is becoming a presumption with Liebert XD cooling products. Clustered Systems' technology, having no moving parts is also expected to be highly reliable.

Emerson's Liebert precision cooling products are sold through factory direct offices and independent manufacturer's representatives throughout the United States. These sales reps work closely with consulting engineering firms and mechanical contractors to specify the product requirements necessary to meet the facility requirements for individual data centers in diverse industries including financial institutions, hospitals, internet hosting business, and enterprise-size data centers. The close cooperation with the consulting engineering firms, mechanical contractors, and data center managers are integral to the commercialization strategy for new technology products. An understanding of the development effort and cooperation through field testing programs are key components of establishing confidence in the performance and reliability of new technological innovations.

The commercialization process for the new model line will follow a stage gate process. Upon completion of the development stage, planning for specific field test operations commences. In this particular case we have included one field test in our plan in order to accelerate adoption. Close cooperation of several server OEMs, data center managers, consulting engineering firms, and mechanical contractors are critical to establishing the breadth of operating conditions and model configurations necessary to evaluate performance in actual data center environments. The production stage follows the implementation of improvements identified through the field-testing effort. Subsequent models will follow similar development routines to fully evaluate the reliability and performance prior to market launch.

The technological breakthrough developed in this product line aligns precisely with a top Data Center Operator driver, energy efficiency. Emerson's Liebert has earned a reputation for successfully bringing new technologies to the data center market while maintaining the highest level of reliability and performance. As such, Emerson is well positioned to successfully commercialize these technologies to lower the energy consumption associated with precision cooling in the U.S. data center market.

Clustered Systems was approached by a major CPU manufacturer with a large presence in the HPC market. They were searching for a solution to cool a very dense HPC system. We were able to show how our methodology would solve their problem and that our technology was a natural fit for the proposed system. Not only would our technology fulfill their HPC needs but it would also address the needs of the general Data Center market place for highly energy efficient server cooling solution. As a result, we secured their backing. On successful completion of the project they are expected to participate fully in promoting the product. This CPU manufacturer has a worldwide presence and being one of the largest producers of microprocessors, exerts a very strong influence on its customers' product choice and strategies.

The commercialization process of this major CPU manufacturer typically involves providing evaluation systems and training to their OEM customers as well as reference designs and in depth engineering support, the latter generally provided by field application engineers and technical marketing engineers. Further, they drive demand through inviting companies they have partnered with, in this case, Clustered Systems, to exhibit and demonstrate new and innovative products as part of their booth at exhibitions nationwide. This commercialization support is reinforced by web links from their site, invitations to present at various events and co-written white papers.

The major CPU manufacturer may also choose to further develop the product internally and offer it as a branded product or as a "white box". That is, as a product that can be relabeled by a vendor for sale under its brand.

The consortium will license the compute module design to the vendor and permit sublicensing and modifications and improvements.

Risk

While Liebert is well positioned to bring technological innovations to this market, the potential risk exists for industry regulations to become a barrier to innovation by establishing prescriptive requirements for data center cooling products. With energy reduction as a goal, prescriptive requirements favoring the use of certain technologies or requiring the use of specific technologies are frequent topics of debate within industry organizations. These methods ultimately fail to achieve the optimal energy reduction goal because they select the technology rather than establishing performance metrics that drive industry innovation to achieve real results.

A secondary risk to the implementation of technologies to drive significantly lower energy consumption is the aversion to risk for most data center managers relative to disruptive technology thus some hesitancy to try something new.

Both Liebert and the CPU vendor have established reputations and experience bringing new technologies to this market to mitigate much of this risk associated with the commercialization of the technologies in this proposal. Both have consistently been the industry leaders in their respective fields and have successfully gained acceptance of new technologies for the past 20 years with many first to market technologies. Clustered Systems' principals also have a record of innovation and bringing new product to market.

In building its business case Clustered Systems spoke to several data center operators. Many indicated that power availability was becoming a major concern. In fact, to such an extent that their risk aversion threshold is markedly reduced. One major web commerce company has already invested in our earlier 1U technology and is placing an order for some yet to be tested next generation product.

Technology Viability

The proposed technology has been well explored during the development of the 1U cooling system. In many ways, the issues likely to arise when applying the technology to smaller form factors are lesser. For example, the forces involved will be much smaller. In the 1U, to produce a pressure of 0.5PSI over the 200 sq in 1U server lid results in a 100lb downward force. Further we will be dealing with a module that is constructed for contact cooling as opposed to air.

Three vendors have already announced highly dense products targeted at the HPC market. This is a clear existence proof of demand for high density.

Manufacturing costs are expected to be on par with existing air-cooled 1U and blade technology. The proposed architecture would also eliminate complex and costly backplanes and fans, simplify power distribution and be easy to administer. The cooling infrastructure will be manufactured on a production line for automotive air conditioners, consequently potentially enjoying the same economies of scale.

The lower cost compared to other products targeted at the HPC space widens its applicability and makes it a viable replacement for both 1U servers and existing blade architectures. Appeal will be further widened by the addition of other subsystems such as storage and compute acceleration.

With energy savings potential of up to 50% in the data center and capital expenditure savings of 20% or more on new builds, as well as the accompanying GHG reductions and waste reduction make this technology extremely attractive to end customers. There may of course be some resistance to adoption by server OEMs as it will be disruptive to their existing business.

Liebert Inc. has its pumped refrigerant (XD) system widely deployed worldwide and has licensed Clustered Systems' 1U server cooling system for worldwide distribution.

Technical Approach / Project Management Plan

State of Art

Air and liquid are today's two choices for equipment cooling. Air has been perceived as the cheapest and simplest and liquid as complex and more expensive.

With air, extreme measures are required to accommodate ever-increasing component power dissipation. For dense systems, very powerful fans must drive high volumes of air through small spaces. The energy penalties are large under some conditions, fan energy can reach 40% of IT load. An alternative is to minimize density with big increases in capital expense and energy consumption and GHG emissions for construction (cement manufacture is a major GHG producer). Even with oversized buildings, an additional 20% of IT energy is still required for cooling.

"DC pro" modeling tool shows that a near perfectly optimized air cooled Tier III DC in San Mateo County, a very temperate part of California, would have a DCiE of 0.84 when server fans are included in the IT load. However if the fans are included in the cooling load (typically 10% of server power) the DCiE falls to 0.76.

Even to achieve this, there must be tremendous attention to detail in steering air, sealing gaps, optimizing multiple motors, balancing CRACs etc. in an ongoing process. The same data center without optimization would have a DCiE of 0.77 (0.69 w/o fans).

There is no such a thing as a standard data center design so users pay premium prices for custom design for every new or upgraded air cooled data center.

In the same scenario with liquid cooling (unfortunately not modeled with DC pro) we estimate that, with no chiller would deliver a DCiE of 0.91 and an energy saving of 17%.

To date, most liquid cooled systems work by piping fluids directly to individual components, to a rigid cold plate atop groups of components, spraying liquid on them or even immersing whole circuit boards in liquid. In each case, liquid is piped into the enclosure. All these methods dictate that pipe connectors are used in order to extract a board for servicing. With large numbers of connectors, as in an HPC system, some will eventually leak with potentially disastrous effects. Such systems are also expensive. Consequently liquid cooling has been an orphan technology for the last 20 years.

Clustered Systems has solved these issues.

Previous Work

Clustered Systems' first product was a cooling system for 1U servers, the workhorses of the IT industry. Over 90% of compute servers shipped today are in this form factor. They are used for a wide range of applications form Web hosting to HPC.

A typical 1U server will have between 8 and 12 fans for cooling, taking up to 20% of the internal volume. In normal operation they will consume about 10% of IT load (i.e. motherboard and peripherals). At maximum specified air temperature the fans will consume up to 40% of the IT energy (source: measurements on a Sun x4100 server) and generate considerable noise. The power supply must therefore be 50% oversized to handle worst-case motherboard plus fan load.

For the 1U adaptation, the fans and heat sinks and are replaced with heat risers which carry the heat to a specially treated lid. This has a highly compliant, thermally conductive layer applied to each side. See Fig 1 below.

The server is placed in a specially adapted standard rack, which has a cold plate above each position. Refrigerant is circulated through the cold plate. To enable to cooling, the cold plate is pressed into contact with the server lid.

The novelty of the concept lies in a) the design of a highly compliant thermal interface to apply to the server lid and b) the use of a flexible cold plate which could be made to comply with the server lid.

The former was vital in achieving a low thermal resistance path between the cooled components and the lid as few if any components are exactly coplanar with either the lid or even the motherboard. Edge to edge height variations of the heat risers can be as much as 1.5mm. Further, the low cost cold plates have some variability, which also needs to be accommodated, by the thermal interface.

As 1U servers are flexible and sag in the middle when supported by rails attached to their side edges, stiff plates, would simply not work, as they would not flex to comply with the server lid.

Manufacturing cost of 1U servers for liquid cooling will be approximately $50 lower than for air-cooled ones. As there are no fans, power supplies can be smaller and the servers are completely quiet.

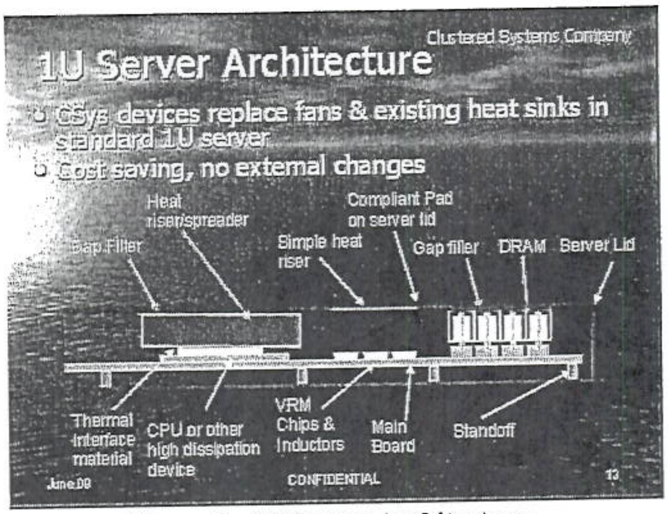

Figure 1 - 1U Server Architecture

The system has been thoroughly tested in small scale and has now undergoing full scale testing in a full size rack. The typical thermal resistance of the group of Dell servers is shown in Table 8 below.

Table 8 – Dell Server Thermal Resistance

From	To	Air	Refrigerant	
Junction	Case	0.15	0.15	$^{o}C/W$
Case	Medium	0.18	0.16	$^{o}C/W$
Junction	Medium	0.33	0.31	$^{o}C/W$
Note: Refrigerant case to medium Rt includes VRM power				

While the thermal resistance from case to medium is almost the same for air and refrigerant, the thermal resistance from refrigerant to chilled water is about 0.02C/W whereas for air it is 0.13C/W. There is also the uncertainty factor with the latter as in all but the most perfectly engineered systems, hot and cold air mix. This may result in some servers taking in 40C air. Table 9 below illustrates the effect of converting to a liquid based system.

Table 9 – Benefits of Liquid Cooling			
Hottest Water	Air	Refrig-erant	
Max power	120	120	W
Case Max	70	70	^{0}C
Cooling Gap	37	22	^{0}C
Worst case margin	20	5	^{0}C
Chilled water temp	**13**	**43**	**^{0}C**

Either the refrigerant liquid temperature can be elevated to over 40C without exceeding manufacturers' temperature limits. Similarly, it can be shown that the maximum processor power consumption with chilled water could be 300W

These factors combined serve to reduce radically the cooling energy requirement and permit a 10X increase in compute density to as much as 2KW per square foot. Further, the need to provide additional power supply capacity for fans is eliminated, reducing the power range over which the power supplies have to operate. This could increase supply conversion efficiency by 1-2% (to be confirmed)

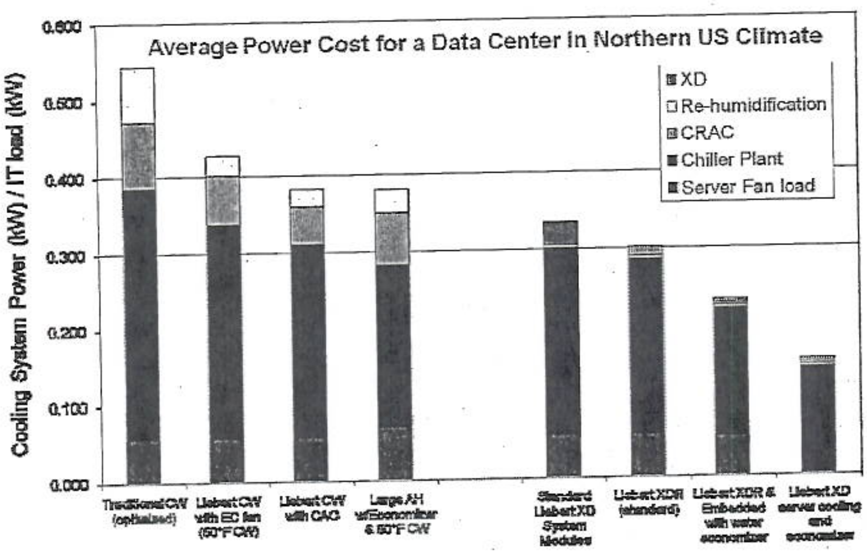

Figure 2 - US Data Ceneter Power Cost

By September 2009 a single rack with 36 1U servers will have been tested be tested as part of the chill off being organized by the Silicon Valley Leadership Group (SVLG). The results will be available on line shortly thereafter. The system will be compared with several other cooling methodologies.

In this test we expect to demonstrate a DCiE of 0.87 (excluding electrical and UPS). Liebert's promotional material (above) shows the expected performance improvement. The far right column shows the performance of a system using Clustered Systems' technology.

Clustered Systems Inc. developed this version of its technology for 1U servers under CEC PIER grant 06-02-23. It was subsequently licensed to Liebert Inc. for worldwide distribution. Several end users have expressed a desire to obtain preproduction units in order to test the system in their environment.

Work Distribution & budget distribution

The participants will jointly develop and agree on the specification of the target system. This work will be carried out at their individual facilities. Approximately, $2,657,845 of the Clustered System budget including cost share will be spent on materials and equipment, which will be funded the first year of the project. Clustered's cost share will consist of $250,000 from the California Energy Commission and $350,000 in kind, courtesy of Intel. Clustered Systems will provide the subcontractor selection and direction of activities.

The single instance prototype of the cooling plate its attachment mechanism and heat risers for the compute blade will be developed in Clustered Systems leased space in an incubator. This is fully equipped with CAD software and a wide range of metalworking and other facilities. Clustered also maintains a small test station with a cooling capacity of 2KW.

Concurrently, Clustered Systems, with advice from microprocessor vendors will select an ODM (other design and manufacturer) to design and build the circuit board. Preference will be given an ODM who can design and manufacture in the US. On request the companies will submit their choice to the DoE for approval of facilities.

When the single instance and engineering sample of the compute board have been completely tested the individual component designs will be sent to Clustered Systems' subcontractors for manufacture of sufficient pieces for a single shelf. These may include the following:

- WIN-enterprises Andover MA, board design and manufacturing, accredited by Intel & AMD
- R Squared Puckett (MS): Cold plate fabrication. Facilities have been approved by Emerson for their production and are also used to build auto air conditioners.
- California Machining, San Jose, CA, Heat riser and mechanism production
- Eclipse Manufacturing, Redwood City, CA, Sheet metal fabricators for chassis
- Microform Precision, Sacramento, CA, Sheet metal fabricators
- Initial assembly and test will be carried out at Clustered Systems.

The rack is based on a standard designed and manufactured by Emerson in Ironton (TX) and modified at Emerson's Cooligy facility in Mountain View. This location has a well equipped machine shop, and a fully instrumented test facility with pumped refrigeration system capable of cooling up to 80KW. Full power test of a single shelf will be carried out at the Emerson Mountain View facility. Cooligy will receive approximately $284,376 including cost share to support this effort. On successful test completion, two full racks will be built out and tested.

On completion of this phase, the two racks will be moved to an equipment hut on SLAC's recently decommissioned collider where there is an unused of 40 megawatts of cooling tower capacity and 70 megawatts of electrical supply available. A Liebert XDP pumped refrigerant system will be installed together with adequate power and network connections. This field test phase will involve the use of the system to run live production applications.

Qualifications and Resources

EMTEC – Principal Investigator

EMTEC is a not-for-profit Ohio Edison Center located in Dayton, Ohio, that has successfully managed multiple collaborative projects and consortia over the past twenty-two years. With an advanced materials and advanced energy focus, EMTEC is committed to its mission of accelerating materials technology to market. EMTEC combines extensive business and commercialization experience with the breath of materials engineering science technology capabilities plus utility delivery experience. Our management savvy engineers enable EMTEC to form and lead collaborative teams focused on improving manufacturing and processing of materials for the commercialization of potentially high-growth materials technology. Each year EMTEC selects and self funds up to a half dozen materials technology projects as part of its CT (Commercialization Technology) program. To date there have been over 100 CT projects. Since 2003 EMTEC has been actively involved in promoting the development of fuel cell and hydrogen technology clusters in Ohio and has either funded, managed or participated as collaborators in 67 projects. EMTEC's leadership and support of Solar, Wind and Algae biomass development account for an additional 13 projects since 2008. Fiscal administration, intellectual property neutrality and technical participation are keys to EMTEC's successful project management. Because EMTEC does not take an intellectual property position on any project that it manages we are able to help protect existing IP and help each collaborator advance their IP.

Dr. Michael C. Martin will be responsible for the contractual execution of this project. He has can speak for and has access to the resources of EMTEC plus the full support of the project collaborators. Dr. Michael C. Martin is the Vice President of Alternative Energy Technology at the Edison Materials Technology Center (EMTEC). He has received a BSEE from Arizona State, MBA from UCLA, MS and PhD in Materials Science from University of California at Irvine. Dr. Martin has greater than thirty five years experience in engineering design, product manufacturing and business development in both very large corporations (General Dynamics) and very small companies (Composite Specialties Inc.). He has designed and manufactured over a hundred products utilizing circuit design, electromechanical controls and/or electro-optics. Many of these product lines grossed over a million dollars including several with a patented infrared sensor. Dr. Martin's broad based technical and fuel cell background includes superplastic ceramic deformation, impedance spectroscopy, grain boundary microscopy and solid state ionics. Dr. Martin is admitted to prepare and prosecute patent applications before the United States Patent & Trademark Office (USPTO) as a registered patent agent (63,567).

Clustered Systems

Clustered Systems operates as a "virtual company," outsourcing all manufacturing and sales, non-core development and most marketing functions. They are backed by Intel.

Computers are again reaching power densities that make air cooling difficult and expensive. Realizing this, we set out to develop a cooling system that would bring all the advantages of liquid cooling without any of its drawbacks. Our first product is a standard 1U server adaptation and a rack adapted for cooling the converted servers. The system has the following advantages:

- Reduces data center energy consumption up to 50%
- Reduces new build capital expenditure by up to 20%
- Is compatible with existing infrastructure and practices
- Is capable of cooling multiple CPUs/GPUs with >200W consumption
- Is ideal for container applications

Our business is selling cooling racks for standard servers, storage systems and related applications. We also design, sell and license adapters to enable volume servers to be used with our racks

Clustered Systems' principals have founded several companies and raised over $115M funding. They have managed successful development of both semiconductor and system level products and possess 18 patents. Most they recently licensed Emerson to sell its 1U design worldwide. Phil Hughes, CEO Clustered Systems. Phil has wide experience in engineering design, sales and marketing. Also, Phil is highly successful in establishing strategic relationships. Robert Lipp, VP Engineering and Manufacturing, Clustered Systems. Awarded 18 patents, long record of successful development programs, set up and manages Clustered's manufacturing subcontractors.

Emerson – Cooligy

Cooligy, Inc. is a wholly owned subsidiary of Emerson Electric, Co. and designs high capacity, energy efficient, data center liquid cooling solutions for Liebert Corporation. They are a recognized technological leader in electronics thermal management, providing high performance, high reliability custom liquid cooling systems to cool commercial and military computer electronics, LEDs, IGBTs, and laser diodes. Their core competencies include thermal design and testing, mechanical design and prototyping, materials design and testing, and the transfer of new products into high volume manufacturing. They have been issued 30 patents covering cooling component and system designs since Cooligy was founded in 2002. Cooligy, Inc. is located in Mountain View, CA, in the heart of Silicon Valley.

Emerson Network Power technologies are at work throughout the world to help customers operate their data centers more efficiently and effectively. In 2009, Emerson will put these solutions to work in their own new global data center. The 35,000-square-foot facility will enable Emerson to consolidate 100 global data centers into four locations in coming years. These technologies, combined with the overall design, will enable the company to use 31% less energy than a traditional data center. Emerson anticipates receiving LEED Silver Certification from the U.S. Green Building Council and plans to use the new facility as a showcase for data-center developers around the world. Emerson Network Power has extensive experience in precision, energy efficient cooling system design, test, and verification.

Douglas Werner will be Emerson's lead for this program. Doug came to Cooligy in early 2002 from Corning, Incorporated where he served as program manager for Micro-Optics and manager of Micro-Optics Technologies within the Photonics Technologies organization. There he was responsible for developing new lower cost micro-optic packaging for passive components. Prior to that, he spent 4 years as technical manager and senior scientist in Tyco Electronics Technology and Business Development Group where he delivered new technology platforms to business units based on developing novel material's and processes. Douglas started his career in Raychem's Wire and Cable product development organization and went on to serve as manager and staff engineer for new materials development in Raychem's Display Products Group. Doug earned his bachelor's degree in chemistry from the University of Wisconsin-Madison and MS in chemical engineering from Stanford University

SLAC

SLAC's PEP-II accelerator was shut down in 2008 after close to a decade of service to particle physics. PEP-II consumed tens of MW to power its magnets and Klystrons, and had corresponding cooling tower capacity. This power and cooling capacity may be used for future accelerator-based science at SLAC, but these possibilities are at least 8–10 years in the future. For the proposed project, part of a technical building (a PEP-II Klystron Hall) is available with adequate floor space, adequate electrical power, and readily available cooling tower water. The building is also linked by fiber-optic networking to SLAC's main computer center, facilitating the integration of the proposed cluster into SLAC's scientific computing environment.

SLAC has some recent experience of using a variety of cooling solutions to achieve high physical density for computationally intense facilities. The proposed approach promises to revolutionize such installations and could usher in a major rethinking of SLAC and Stanford University's approach to housing such facilities. The potential to achieve a significant lowering of net power costs to deliver computing is very attractive. Given SLAC's interest, it is expected that the floor space will be made available at no charge. Assuming that the cluster can be exploited to serve SLAC science as outlined below, it would also be appropriate for SLAC to cover the power costs for the cluster.

The collider would be an ideal site for a peta FLOPS (floating point operations) system. This would consist of consisting of 40 racks of the proposed product and consume about 2.4MW. No buildout would be required as there appears to be adequate space in the existing buildings. Dr Richard Mount, Director of Computing Services will be SLAC's representative.

American Recovery and Reinvestment Act (ARRA) Information

The "Development of Very Dense Liquid Cooled Compute Platform" application to the Funding Opportunity Announcement Number: DE-FOA-0000107 meets and exceeds the expectation of the sponsoring American Recovery and Reinvestment Act (ARRA). The application is projected to create and or preserve 25 jobs, in California, Mississippi, Ohio and Massachusetts in the short term and create approximately 245 jobs by 2011, potentially doubling thereafter. This will be accomplished by using grant funds to expeditiously develop advanced technology within the two year time frame. Once developed, economic benefits include incremental sales of $600M in 2011 and $3Bn in 2012 and comply with the goal of the FOA to generate an energy efficiency savings of direct electricity displacement of 6.38 and 48.31 billion kWh and a reduction of CO_2 emissions of 1.05 and 7.41 MMTCE in years 2015 and 2020 respectively.

Job Creation and Preservation

The cumulative effect of the projects in this application is a creation of 245 jobs and preservation of 25 jobs. This is broken down to include 85 plant workers, 33 engineers, 50 installation personnel, 50 contractors, 10 suppliers and 17 business development. The jobs created during the grant period is projected to be 25 in the first 2 years and estimated to be up to 500 over the next 5 years. These jobs are incremental to existing jobs that support technology that is currently supplied to the data center industry. In addition to applications in data centers, this technology can be applied to telecommunications products such as switches and routers sales with an estimated 100 jobs created over 5 years.

Expeditious Manner

The requirements of this grant are for 2 year project time frame resulting in demonstration of advanced technology that can be commercialized immediately. The cumulative research and development potion of this project will be completed in 6 to 12 months and the field testing of this application will be completed within 24 months. Once the technology is tested, commercialization is projected to begin 15 months from start of the project. Market adoption is anticipated to grow from 8,000 units in the first year to 1,000,000 units by the third year. This will represent a market adoption of 10 %. This adoption rate is based on price, regulatory constraints, energy efficiency and performance of the new technology. It is a conservative adoption rate, reflecting a conservative market that is risk adverse and assumes a server replacement rate of 33% per year and an installed base growth rate of 16%

Economic Recovery

This project is proposing to develop and market new to the world technology that can be used for the data center and beyond. Initially, it is focused on 80% of existing and new data center applications over the next 10 years. At a 10 % adoption rate in the marketplace, discussed above, this new technology will create sales of $3Bn in 3-4 years to new and existing data center applications. In addition to applications in data centers, this technology can be applied telecommunications sales with an estimated $200M over 5 years.

Another aspect of economic recovery is also a key goal of the FOA - energy efficiency. This application will provide $638M of data center energy efficiency savings by 2015. This is achieved through a reduction of direct electricity of 6.38 and 48.31 billion kWh and a reduction of CO_2 emissions of 1.05 and 7.41 MMTCE in years 2015 and 2020 respectively.

Ph. 937-259-1365
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1-888-55-EMTEC
www.emtec.org

3155 Research Blvd.
Dayton, OH 45420

The Center of Solutions

July 16, 2009

U.S. Department of Energy
Golden Field Office

RE: Letter of Commitment (LOC) for Recovery Act: Energy Efficient Information and Communication Technology - DE-FOA-0000107

Dear Reviewers,

The Edison Materials Technology Center (EMTEC) is very pleased to assume the lead of a world class team for the proposed project entitled, "Development of very dense liquid cooled compute platform."

EMTEC will provide Project Leadership, including both administration and task management, and Collaborator Relationship Management. As part of Project Leadership EMTEC will provide a Project Director to oversee financial and program management. EMTEC staff will assist the EMTEC Project Director and the Collaborators by serving as an administrator of the collaborative work. This task will entail the convening and conducting of regular technical progress meetings and quarterly meetings of the Collaborators; collection and assembly of reporting and invoicing information; providing timely reports and project invoices to the contracting officer and dispensing project funds to the collaborators and service providers. As part of Collaborator Relationship Management EMTEC will meet regularly with each collaborator PI with the objective of identifying and resolving differences that inevitably arise in large, multi-organizational endeavors. The intent is to act as a neutral advocate and arbiter among the collaborators, resolving issues before they become divisive.

In order to adequately support the tasks described above including travel cost, quarterly review hosting and participation in supporting commercialization events EMTEC expects to receive $100,000 dispersed uniformly over the 24 month project period. In complementary support for the received funds EMTEC commits to $25,000 of in-kind cost share to be provided from State of Ohio and privately funded synergistic EMTEC projects.

EMTEC is a non-for-profit Ohio Edison Center located in Dayton, Ohio, that has successfully managed multiple collaborative projects and consortia over the past twenty years. We have an enviable record of commercial successes, startups, and spin-offs. We are focused on accelerating technology to market, green job growth, improving the economics of manufacturing by investing in instruments, controls, electronics and materials.

Sincerely Yours,

Michael C. Martin, Ph.D.
Vice President, Alternative Energy Technology

EMTEC Programs:

Energy Development
- Alternative Energy Materials
- Supply Chain Development

Advanced Materials
- Core Technology
- New Product Development PDQ Center

Commercialization
- Business Development
- Materials Help Desk – RFH

International Services
- Bilateral Trade Support
- Foreign Company Attraction

Technology Transfer
- Air Force Research Lab
- SBIR Support

Procurement Technical Assistance Center
- Training
- Networking

Small Business Centers
- Business Assistance
- Capital Formation

The Edison Materials Technology Center

An Ohio Edison Technology Center

Ohio Department of Development

Clustered Systems Company, Inc.
522 San Benito Avenue
Menlo Park
CA 94025
Tel: 415 613 9264

Michael Martin
EMTEC
3155 Research Blvd.
Dayton, OH 45420
16 July 2009

Recovery Act: Energy Efficient Information and Communication Technology
Development of very dense liquid cooled compute platform

Dear Mr. Martin,

I confirm Clustered Systems' intention to partner with you in this project, subject to your success in obtaining the requested grant and a subsequent detailed agreement on the timing and nature of resources required from Clustered Systems.

Clustered Systems is one of the more innovative developers in the area of liquid cooling. Through the adaptation of existing technologies and practices, we have succeeded in reducing the cost of liquid based cooling to a point where it is economically feasible for many applications, especially in the field of electronics.

The validity of our concepts is being confirmed on a daily basis by the level of interest and commitment from both end customers and OEMs. We have demonstrated our technology on Dell, Super Micro, Sun and Intel platforms and Emerson's Liebert division has licensed our system for worldwide distribution. Intel has also expressed a desire for us to develop a solution for high performance computing (HPC).

We have been informed that our approach is a potential game changer in the construction, management and operation of data centers. As the industry weans itself from air cooling, the total cost of ownership will drop an estimated 30% to 40% due to savings in energy consumption, simplification of cooling systems, a smaller electrical infrastructure, and the elimination of the need for special construction. In many cases, due to increased density and lower power consumption more compute power can be installed in a given space thus obviating the need for new buildings. Another often overlooked factor is the total silence of our liquid cooled systems, leading to a much improved work environment. Finally, eliminating moving parts, such as fans, increases reliability.

Liquid cooling systems also have the advantage of supporting increased density at the board design level. No allowance has to be made for the undisturbed passage of air through or over the system. This is especially important in high performance computing as higher density improves the overall performance as communication distances are reduced.

In addition to the commercial market, silent, dense, lower cost, robust high performance computing could have many interesting applications in the defense of our Country.

Clustered Systems is a small "virtual" company run by industry veterans with experience in all aspects of founding and running a high tech company. Collectively we have 18 patents. Our business model is to do business critical core development in house and outsource non critical development, manufacturing and most sales and marketing.

For this project our contribution would be the in house design of the cooling system and specifying and managing the compute module design. We generally use smaller manufacturers

Clustered Systems Company, Inc.
522 San Benito Avenue
Menlo Park
CA 94025
Tel: 415 613 9264

with fast turnaround times. Winning an award would help several of these to retain their employees and even stay in business.

As our contribution to the cost share will come from three sources; 1) Intel would make available a sufficient number of computer chips to populate the proposed design. These have a value of $350,000 to $450,000. Intel's letter of commitment to Clustered Systems is attached. 2) The California Energy Commission has committed $250,000 from Public Interest Energy Research (PIER) Program for this program. Their letter of commitment to Clustered Systems is attached. 3) Clustered System will also provide the lease of a Tekscan Measurement system with a cost share value of $12,000. The total Clustered Systems cost share contribution is $612,000.

Yours sincerely,

Phil Hughes
CEO

July 17, 2009

Mr. Phil Hughes
CEO, Principal Investigator
Clustered Systems Company
Menlo Park, CA 94025

Subject: High-End, High-Density HPC Cooling Racks

Intel supports industry research in innovative cooling and energy-saving solutions for data centers and server systems. Intel understands that Clustered Systems is submitting a proposal to the Department of Energy for cooling solutions for high-end, high-density HPC systems. Intel supports Clustered Systems' efforts and believes it will benefit the HPC industry.

In recognition of that support, Intel is considering providing parallel support to Clustered efforts to develop cooling technology. Such support could include a loan to Clustered of a significant number of Intel processors, up to 600, for Clustered's use in a cooling solution that it develops, and other Intel technical and engineering support for the project.

Intel's support would be parallel to that provided by the United States Government. Intel would not be a member of Clustered's consortium, or a party to Clustered's contract with the United States Government. Any United States Government terms and conditions applicable to Clustered would not be applicable to Intel.

Intel believes that funding for research related to cooling solutions for high-end, high-density HPC systems is necessary to move the technology forward and support capabilities required by the United States Government. That funding should come from a variety of sources, and it is Intel's hope that parallel support of this project by Intel could aid the advancement of this technology. If Clustered is successful in developing a new cooling system Intel would be interested in helping commercialize the technology.

Sincerely,

Richard Dracott,
General Manager, HPC Business Unit
Server Platforms Group,
Intel Corporation

Intel Corporation

STATE OF CALIFORNIA NATURAL RESOURCES AGENCY ARNOLD SCHWARZENEGGER, Governor

CALIFORNIA ENERGY COMMISSION
KAREN DOUGLAS, CHAIRMAN
1516 NINTH STREET MS 33
SACRAMENTO, CA 95814-5512
(916) 654-5036
FAX (916) 653-0040

July 21, 2009

Mr. Phil Hughes
Clustered Systems Company, Incorporated
522 San Benito Avenue
Menlo Park, CA 94025

Dear Mr. Hughes:

The California Energy Commission (Energy Commission) is pleased to inform you of the acceptance of your pre-proposal titled "Development of Very Dense Liquid Cooled Compute Platform," submitted in response to PON-08-011. This letter signifies the Energy Commission's intent to provide cost sharing for your proposal for an amount up to $250,000, provided your final proposal to the Energy Commission under PON-08-011 is successful and you receive a federal award in response to the Department of Energy's Recovery Act – Energy Efficient Information and Communication Technology Funding Opportunity Announcement (DE-FOA-00000107). You may include this letter in an application for DE-FOA-00000107 funds.

This letter does not guarantee funding by the Energy Commission. Due to the high response to PON-08-011, the Energy Commission may award less than the requested match funding amount. In addition, the Energy Commission may reduce an award in the event that the California Budget Act for 2009-10 allocates less funding than anticipated for the Public Interest Energy Research (PIER) Program. In either event, the applicant will be responsible for obtaining sufficient cost share to meet the funding requirements of DE-FOA-00000107.

You are invited to submit a final proposal to the Energy Commission. The final proposal must include the information specified in PON-08-011, including Addendum 2, and must be received by the Energy Commission no later than 4 p.m. on September 8, 2009.

Please include five hard copies and one electronic copy of your final proposal (including all applicable files) in one or more of the following formats: Microsoft Word, Microsoft Excel, or the format specified by the federal solicitation. The Energy Commission may invite applicants to a clarification interview for their final proposals. Following the final proposal evaluation, you will receive notification of the Energy Commission's final decision regarding funding.

Mr. Phil Hughes
July 21, 2009
Page 2

For administrative or process-related questions regarding PON-08-011, please contact Sarah Williams at (916) 654-4584. For technical related questions regarding PON-08-011, please contact Paul Roggensack at (916) 654-6560.

Thank you for your interest in our program.

Sincerely,

KAREN DOUGLAS
Chairman

Cooligy EMERSON

800 Maude Avenue; Mountain View, CA 94043; Phone: 650-417-0300; Fax: 650-417-0383

Date: July 20, 2009

Subject: Letter of Commitment for Cooligy to Collaborate on "Development of Very Dense Liquid Cooled Compute Platform"

Cooligy. Inc, (Cooligy) is pleased to provide this commitment letter for the Department of Energy project entitled "Development of Very Dense Liquid Cooled Compute Platform." Cooligy is actively involved in the development of energy efficient liquid cooling systems and components for the computer and consumer electronics industries. Cooligy has recently collaborated with Clustered Systems to design and build a fanless, high density server rack cooling product which is in the same product family.

For this project, Cooligy will work with Clustered Systems to develop and build multiple pre plumbed racks to accommodate Clustered Systems' fanless, very high density server shelf cooling units. These units will be outfitted with custom designed server blades and inserted into Cooligy's racks. The system will then be thoroughly tested at Cooligy. Thereafter the system will be moved to the DOE's Stanford Linear Accelerator Site for longer term testing. The proposed costs for Cooligy to develop and deliver this technology component are $284,376. Cooligy's proposed share of these costs, including engineering services, property and cash is $56,875 (20%).

Cooligy is located in Mountain View, CA and is a wholly owned subsidiary of Liebert Corporation. We have designed and shipped liquid cooling systems for OEM customers like Apple Computer, Samsung, Sony, IBM and Dell. Our engineering team consists of thermal, mechanical, and materials engineers who have the experience and skills necessary to design high performance and high reliability liquid cooling solutions for challenging thermal problems.

Sincerely,

Mark McMaster

Mark McMaster

Vice President

SLAC NATIONAL ACCELERATOR LABORATORY

PARTICLE PHYSICS AND ASTROPHYSICS

Dr. Richard P. Mount
Head of Scientific Computing
SLAC MS 97
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+1-650-926-2467

Michael Martin
EMTEC
3155 Research Blvd.
Dayton, OH 45420

20 July 2009

Dear Mr. Martin,

Recovery Act: Energy Efficient Information and Communication Technology

Development of very dense liquid cooled compute platform

I confirm SLAC's intention to partner with you in this project, subject to your success in obtaining the requested grant and a subsequent detailed agreement on the timing and nature of resources required from SLAC. Approval from the Department of Energy will also be required.

SLAC and Stanford University expect greatly increased requirements for the housing and cooling of computing equipment over the next 10 years. SLAC and the University are developing conceptual plans for meeting the requirements. The approach to high-density computing that you intend to implement could revolutionize the SLAC/Stanford approach to high-density computing needs.

Accordingly SLAC will make available to the project, as described above, a recently disused area in a technical building that has adequate floor space, electrical power, tower-chilled water, and network connectivity to enable the implementation of the planned compute platform. I note that the SLAC/Stanford conceptual plans involve the future exploitation of 10 or more MW of existing available electrical power and a corresponding existing cooling tower capacity.

SLAC provides part of the computing facilities needed to support US involvement in the LHC experimental program at CERN, Switzerland. This program represents the exciting frontier of fundamental physics and is strongly supported by the US Department of Energy and the National Science Foundation. SLAC would be able to put the proposed compute platform into demanding use in support of frontier science.

Sincerely,

R P Mount

Dr. Richard P. Mount

SLAC NATIONAL ACCELERATOR LABORATORY • 2575 SAND HILL ROAD • MENLO PARK • CALIFORNIA • 94025 • USA

SLAC is operated by Stanford University for the U.S. Department of Energy

Instructions and Summary

Award Number: DE-FOA-0000107
Award Recipient: Edison Materials Technology Center (EMTEC) (Lead)

Date of Submission:
Form submitted by: EMTEC - TOTAL PROJECT
(May be award recipient or sub-recipient)

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED

(Note: The values in this summary table are from entries made in each budget category sheet.)

CATEGORY	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Total Costs	Project Costs %	Comments (Add comments as needed)
a. Personnel	$67,409	$67,409	$0	$134,818	3.8%	
b. Fringe Benefits	$22,245	$22,245	$0	$44,490	1.2%	
c. Travel	$6,000	$6,000	$0	$12,000	0.3%	
d. Equipment	$0	$0	$0	$0	0.0%	
e. Supplies	$500	$500	$0	$1,000	0.0%	
f. Contractual					0.0%	
Sub-recipient	$3,152,989	$159,872	$0	$3,312,861	93.0%	
FFRDC	$0	$0	$0	$0	0.0%	
Vendor	$0	$0	$0	$0	0.0%	
Total Contractual	$3,152,989	$159,872	$0	$3,312,861	93.0%	
g. Construction	$0	$0	$0	$0	0.0%	
h. Other Direct Costs	$0	$0	$0	$0	0.0%	
i. Indirect Charges	$28,846	$28,846	$0	$57,692	1.6%	
Total Project Costs	$3,277,989	$284,872	$0	$3,562,861	100.0%	

Additional Explanations/Comments (as necessary)

total direct (less contractual) *$96,154* *$96,154*

Development of Very Dense Liquid Cooled Compute Platform

Project Summary / Abstract

The electricity consumed in data center and telecom system is 3 percent of the U.S. total and growing rapidly. Historically the energy used to provide cooling for Data Centers is upwards of 45% of the total facility power. Over the last several years, there have been significant efforts to improve the energy used for IT cooling by making small improvements to the cooling equipment and the control of air movement. However, moving air is energy intensive because air circuits have a high thermal resistance; hot and cold air mix in unpredictable ways; and air is simply incompatible with high density systems that are required for HPC (High Performance Computing). The approach of technology improvements to date has been to push air through ever decreasing gap sizes, but the energy required is becoming unacceptably large. Liquid circulation for cooling, on the other hand requires only 0.5% of the 20% of IT load for air circulation and on average less than 1/3 of the 20% to 30% of IT load used by air conditioning systems. In temperate climates liquid systems may be operated year round with no chiller.

We proposal a project entitled, "Development of Very Dense Liquid Cooled Compute Platform," to design and develop a prototype ultra high density compute platform with 100% liquid cooling using commodity components and high volume manufacturing techniques. The system will be powerful enough for HPC applications and cost effective enough for general enterprise applications. Out target is 400 CPUs per standard data center rack with a performance of 25 petaFLOPS (floating point operations per second) in 2010 and 50 petaFLOPS in 2011. Two racks will be built. The components to be developed include a 2 CPU compute module, a 3U shelf with built in cooling and rack plumbing. A Liebert XD pumped refrigerant platform connected to an existing cold water system will supply the coolant.

In HPC applications energy saved is 39% as cooling overhead is about 80% of IT load (LLNL data). Compared with an ideal air cooled conventional DC in a temperate climate, energy saved is 17% (calculated with "DC pro"). TCO is 36% less. In 2015 with a market penetration of 29%, energy savings (US) would be 6.38 BKWh and CO2 reduction, 1.05 MMTCE. (source: ICT Benefits calculation). Market pull will speed up technology adoption (and further savings) because these dense systems cost less require less floor space and can be housed in existing buildings. Development is expected to take 9-12 months. Installation will be 3-4 months. Thereafter the system will be installed at a test site and used to run production applications. All key parameters will be recorded over a 6-9 month period. In addition, system breakdowns (if any) and causes will be logged. This data will be available to the DoE and the public. As part of the commercialization phase, the site will be available for customer outreach.

Intel has expressed interest in driving commercialization. They may offer the board design both as a product and as a reference design to their customers. Clustered Systems will productize the cooling shelf and Emerson the rack and arrange worldwide distribution. The rest of the cooling system is off the shelf.

This $3.2 million project includes 20% cost share from the collaborators. The team will be consisting of Emerson/Cooligy, Clustered Systems, who has the backing of Intel and be directed by Edison Materials Technology Center (EMTEC) with PIs assigned from each collaborator. Both immediate and long term jobs will be created as a result of this project. 25 people will be employed immediately to develop this product. In production, the economic stimulus contribution can be up to 500 jobs to support estimated revenue of over $3B within five years of market introduction. Without this grant, and further development of the technology, market adoption rates of liquid cooled systems will suffer and support from other server manufacturers could be jeopardized. This would result in a 3-5 year delay in the realization of these energy savings plus puts job creation in jeopardy.

	Item	Vendor	Budget		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
						Q1			Q2			Q3			Q4			Q1			Q2			Q3			Q4	
1	Develop detailed specification of the system and its components.	All	$	31,900	x																							
2	Sample Compute Module	ODM1	$	344,180		x	x	x	x	x	x																	
3	Design, build and test a single blade and deflection mechanism	Clustered	$	39,800		x	x	x	x	x																		
4	Design, build and test heat risers and TIM	Clustered	$	14,842		x	x	x	x	x																		
5	Test cooling blade and Comput e Module	Clustered	$	10,000							x																	
6	Design and build cooling crate and housing, test with heat source	Clustered Emerson	$	104,440			x	x	x	x	x	x																
7	Integrate Deflection Mechanism, Compute modules with crate	Clustered	$	256,310								x	x															
8	10 Gbps card engineering sample & test	ODM3	$	200,640						x	x	x	x	x														
9	Design and build rack with integrated refrigerant distribution system	Emerson	$	231,500			x	x	x	x	x	x	x	x														
10	Build 12 shelves and integrate with rack, test with standard Liebert XDP pump and heat exchanger system connected to a chiller	Clustered Emerson	$	196,280									x	x														
11	Test single rack with full complement of modules using Liebert XDP and chiller	Emerson	$	950,960										x	x	x	x											
12	Build out second rack, conduct full systems test at Emerson	Clustered Emerson	$	730,660														x	x	x	x	x	x					
13	Test system with chillerless system 1 rack to SLAC	All	$	194,115															x									
	Install XDP at selected site	Emerson	$	145,465													x	x										
	System Commissioning	Emerson	$	8,650														x	x	x	x	x						
	Monitoring	Clustered	$	40,000																			x	x	x	x	x	x
14	Move Second rack to SLAC	Csys/Emer																							x	x	x	x
15	Transfer activities, reporting etc.	Clustered	$	50,000																							x	x

Comments

1) Specifications will consist of a Product Requirements Document (PRD) and an Engineering Specification.
2) Compute module will have 2 advanced multi core microprocessors and 8 DIMM slots, it will be powered with 350VDC for maximum efficiency and have 1Gbps Ethernet management interface and 10Gbps Ethernet or Infiniband. Built by outside contractor. The contractor will be supplied with temporary heat risers and a simple contact cooling mechanism for debug if necessary.
3) Clustered will prototype the deflection/engagement mechanism in house, make refinements and sent out for manufacture
4) The heat risers will be designed in conjunction with the board supplier.
5) MILESTONE: Clustered will test the compute module separately and then in conjunction with the deflection/engagement mechanism to confirm operation. Passing this test is necessary prior to releasing the next build of modules and mechanisms
6) MILESTONE: Delivery of single crate (chassis) and 12-14 cold plates. The cooling blades and crate (chassis) are integrated and heaters are attached to each cooling blade. Clustered and Emerson will cooperate on capacity testing. The goal is 1KW per blade. However, for refrigerant management, this may be later artificially reduced for the first prototypes.
7) MILESTONE: 12 Units of deflection mechanism, 12 compute modules delivered and 12 Heat riser kits delivered, 1GBps switched backplane card and midplane card (if required) delivered. On successful completion of 5) and 6) the deflection mechanisms, will be integrated with the chassis and the modules and 1Gbps switch loaded in and the whole tested. After successful testing orders will be placed for the rack buildout.
8) The 10Gbps card will be tested. This is a non critical item at this point.
9) Care will be needed to ensure proper placement of plumbing in relation to crates' refrigerant connections.
10) 144 or 168 cooling plates & deflection mechanisms plus 12 midplanes. 2 Chassis will be installed in the rack and connected to the rack plumbing. After refrigerant charge, the assembly will be tested for thermal capacity. While the end goal is 200KW per rack, the initial build of compute modules will only draw 70KW.
11) MILESTONE: 144/168 Modules, Heat Risers Volume plus 12 each 1 Gbps card and 12 10 Gbps cards and one Bulk 208 VAC to 350VDC converters delivered. The rack is built out, chassis by chassis and tested.
12) After successful completion a second rack is assembled and tested and the whole system is exercised for at least 4 weeks.
13) MILESTONE: A single rack is moved to SLAC where it is connected to the local network, power and cooling and exercised. The first rack remains at Emerson for further testing and for debug on a duplicate system.
14) When testing is complete the second rack is moved to SLAC and connected to the first. Monitoring will continue during the whole period and key temperatures, clock frequencies and faults recorded in addition to any corrective actions taken.
15) Clustered and Emerson will be working with OEMs and microprocessor vendors to accelerate adoption of the technology.

Resumes

Michael C. Martin, Ph.D – Principal Investigator

Dr. Michael C. Martin is the Vice President of Alternative Energy Technology at the Edison Materials Technology Center (EMTEC). He has received a BSEE from Arizona State, MBA from UCLA, MS and PhD in Materials Science from University of California at Irvine. Dr. Martin has greater than thirty five years experience in engineering design, product manufacturing and business development in both very large corporations (General Dynamics) and very small companies (Composite Specialties Inc.). He has designed and manufactured over a hundred products utilizing circuit design, electromechanical controls and/or electro-optics. Many of these product lines grossed over a million dollars including several with a patented infrared sensor. Dr. Martin's broad based technical and fuel cell background includes superplastic ceramic deformation, impedance spectroscopy, grain boundary microscopy and solid state ionics. Dr. Martin is admitted to prepare and prosecute patent applications before the United States Patent & Trademark Office (USPTO) as a registered patent agent (63,567).

Experience:

2004 – Present **Vice President of Alternative Energy Technology**
EDISON MATERIALS TECHNOLOGY CENTER (EMTEC)

1996 - 2003 **Materials Science Engineering (Fuel Cell / Energy Technology)**
UNIVERSITY OF CALIFORNIA at IRVINE, CA

1994 – 2002 **Engineering Manager & Chief Engineer**
COMPOSITE SPECIALTIES INCORPORATED, Corona, CA

Resolved the myriad of problems that keep a small company profitable.

Designed all electronics-based products and associated test equipment and procedures

- Developed the **processes** and **procedures** required to manufacture, test and certify products (5 models, plus 17 versions of a *Coffee Maker*) per **FAA** requirements. [**Certification** included tests and analysis reports on - EMI, Flammability, Structural, Acoustic and Functional Acceptance.]
- Established a drawing release system that included digitized drawings, change requests, change orders, service bulletins and materials change board control.
- **Electro-mechanical design** of the *coffee maker* included a patented infrared level sensor. (This followed the successful CCA release.) *Teams of engineers at other companies had failed to design similar sensors and systems.*
- Modified existing *oven design* with a solid state power controller for superior EMI performance.
- Designed a *water resistant cart controller* that won accolades at **United Airlines.**
- Designed many innovative *coffee maker* improvements: electronic vent valve; solid state relay.

1990 – 1993 **Engineering Consultant**, CALIFORNIA CLIENTS

Customers included *Composite Specialties .. Pegasus Technology .. Superior Metal Shapes .. Driessen Aircraft.*

Tasks included circuit design, ACAD drawing capture, CNC programming and machine repair.

Used SPICE and PCAD to establish requirements, concept, breadboard, brass board, CCA layout and CCA routing for the Composite Specialties *Coffee Maker Circuit Card Assembly* (CCA).

1979 – 1989 GENERAL DYNAMICS, Pomona Division, Pomona, CA

Responsible for **management** and coordination of division resources as applied to guidance-system **design** or **manufacturing** electronics issues, and for **technical management** of 7 NAVSEA funded contract line items (Technical Instructions) for improving missile performance.

$30M (approx.) **annual responsibility.**

Tasks included inter-discipline coordination for development, systems analysis, customer interface, presentation, requirements review, specifications review, project planning and performance monitoring.

GaAs hyper-abrupt varactor diode **failure analysis** and **process development** at vendor.

This resulted in successful technology transfer for multiple sources at a **dramatically improved yield and reduced cost.**

Machine shop robotic welder **test program development.**

Thin-film versus Thick-film resistor array production **yield improvement** and **cost reduction** in Hybrid Monolithic Arrays (HMA's).

Guidance and *Autopilot System* yield improvement through **root cause failure diagnosis**, leading to design, test and assembly corrective action identification.

VHSIC applications and three-micron silicon gate CMOS standard cell in-house IC design methodology. Included **strategic plan** (20 year) modification to hire and equip a **12-person design team**. ***The first 15 designs of my team were first pass successes!***

Data telemetry instrumentation and horizontal integration of propulsion test vehicle. ***Under my leadership we overcame a 4-month schedule slip in three months.***

ASSAULT BREAKER guidance integration and **test development**. Oversaw 28 engineers on three shifts trying to build a dozen of these IR guided bombs. ***We hit 7 for 7 at a NAVY flight test!***

Education: **(Electronic & Material Science Engineer)**

PhD-MSE, University of California at Irvine, 2003

MS-MSE, University of California at Irvine, 2000 (GPA 3.9)

ME-EEP, University of California at Los Angeles, 1979

BSE-EE, Arizona State University, 1976 (*Eta Kappa Nu*, Tau Beta Pi)

PHILLIP HUGHES

522 San Benito Ave,
Menlo Park. Ca. 94025

PROFILE

- 15 years as working engineer on multiple projects including aerospace, submarines, machine tools and test automation.
- Founder of startups in semiconductor, video server and networking markets, including Clustered Systems, BrightLink Networks and Q4
- Led new business development efforts at those companies and directly participated in raising over $100M in venture funding.
- Led strategic planning at startups and was primary author of their business plans, at National participated in strategy group leading to the creation of Fairchild Semiconductor and was also member of VLSI Technology's strategy team.
- Defined and introduced new IC product lines including switches, Ethernet NICs, clocks, display drivers, modems, high speed interconnect as well as BrightLink's BOSS 1000.
- Improved profitability of memory, interface and power semiconductor product lines by focusing on excellent service in the first and pruning and new product introduction in the others.
- Established technology alliances between Clustered Systems and Liebert, National Semiconductor and Tundra Semiconductor, Apple Computer (received Extraordinary Efforts Award) as well as between VLSI Technology and Ricoh and Sierra Semiconductor.
- Successfully built teams with individuals from diverse product lines and organizations, at National to address the company's approach to PCI bus and at VLSI Technology managed three teams from different companies to produce a fax modem chip on time and under budget.
- Led team responsible for building National's ASIC business from $0 to $20M in Europe working with three sites, at TAG Semiconductors managed 6 sales offices, worldwide and supported the establishment of VLSI Technology's European presence, building a $10M business.
- Became the "go to" person for crisis resolution including refreshing product lines at National and TAG Semiconductor, redirecting failed development program at VLSI technology, employee retention, IT restructuring and temporarily tasking over engineering management at BrightLink.
- Continuously involved at all levels in budgeting and forecasting for last several years
- Awarded one patent for work on SONET switching and "Pursuit of Excellence Award" for work on Video Server application at National.

2005-Present

CEO **Clustered Systems Company, Inc, Menlo Park, Ca**

Conceived revolutionary new supercomputer architecture incorporating high speed interconnect and integrated cooling technology together with commodity server platforms. This was very well received by Intel, LLNL and others. Due to government funding constraints we were advised to focus on the cooling aspects of our architecture. Subsequently developed working cooling system product and Licensed Liebert as worldwide distributor.. Drove demand with end customers (e-business, financial, manufacturing), developed marketing channels and set up subcontract manufacturing infrastructure.

2001-2005

VP Marketing and Business Development, Chairman **Q4, Menlo Park, Ca**

Company co-founder and co-developer of very high performance Ethernet switch/router/offload technology for the data center. Technology to be embodied in a custom chip marketed for adapter cards, blade servers and storage. Excellent customer reception by HP and IBM as well as numerous smaller OEMs. Received bridge funding, but ultimately unable to secure sufficient financing to proceed with costly chip development program; company was dissolved.

2001

President **VoDisk Inc., Menlo Park, Ca**

Company founder and co-developer of unique Video Server/Clustered Storage architecture. Targeted at Video on Demand applications, had excellent customer reception from Fox Sports, PBS, Warner Bros and numerous others.

1997-2001

Founder/VP Marketing, Project Management **BrightLink Networks Inc., Sunnyvale, Ca**

Conceived architecture for a novel partially connected mesh switching technology. The technology was adapted to satisfy full range of system applications from original application of multi-gigabit Ethernet LAN enterprise applications to very large SONET WAN POP cross-connects, with a common architecture and technology. .

As the VP of Marketing and Business Development, made high level connections at MCI, Global Crossing, Williams Communications and several smaller telecommunications carriers, developed the relationships into customer references and led the authoring of the business plans resulting in the securing the first three rounds of financing *(BrightLink secured over $110M financing)*; participated in the recruiting of board members and senior staff; wrote the Market Requirements Document (MRD)s for the BrightLink BOSS 1000 SONET cross-connect *(it was successfully qualified by several major vendors)*; as acting VP of Software Engineering, and Project Management maintained forward progress and stemmed attrition while a replacement VP of Engineering was recruited; managed leasing, buildout, networking and communications infrastructure installation and move-in for two facilities; de facto vendor contract negotiator.

Education: BS EE, University of Wales

Courses: Marketing Excellence at Western Business School (U. of Ontario), Leading Change, Leadership 2000, Strategic Planning, Contract Law, Managing Within the Law, MIR etc.

Other: Fluent German, Italian, some French, PPL.

Robert J. Lipp

Cofounder **Clustered Systems Company** **Menlo Park, CA**
Co-founder/consulting-partner working on developing a conduction based green cooling technology for compute servers that promises to reduce data center power by over 30% and lower both capital and operating costs.

2001 – 2005
CEO / CTO / Cofounder **Q4 Company** **Menlo Park, CA**
Company co-founder and co-developer of very high performance Ethernet switch/router/offload technology for the data center. Technology to be embodied in a custom chip marketed for adapter cards, blade servers and storage. Excellent customer reception by HP and IBM as well as numerous smaller OEMs. Received bridge funding, but ultimately unable to secure sufficient financing to proceed with costly chip development program; company was dissolved.
1997 - 2000

VP Technology / Co-Founder **BrightLink Networks, Inc.** **Sunnyvale, CA**
Co-developed architecture and algorithms for a novel partially connected mesh switching technology. Adapted technology to satisfy full range of system applications from original application of multi-gigabit Ethernet LAN enterprise applications to very large SONET WAN POP cross-connects, with a common architecture and technology. Developed system solutions to incorporate improved buffering, multicast, VLAN, QoS and layer 3 management functions into the LAN design while guaranteeing non-blocking, low latency delivery.

Applied technology to a large SONET cross-connect system; co-developed business plan that secured initial $2.5M first round financing *(BrightLink secured over $110M financing)*; hired initial key technologists for hardware and software development; as the de facto hardware system architect, led specification of key technical requirements for the BrightLink BOSS 1000 SONET cross-connect *(it was successfully qualified by several major vendors)*; in-house SONET and WAN networking technical resource and optical interfaces expert; filed four patents. Responsible for IP portfolio, future technical directions, and external technical liaison.

1997 (Q1) **Consultant**
AMD – Technical reviewer for 0.25u K6 program

1993 - 1996
VP Technology / Co-Founder **GateField Corporation** **Fremont, CA**
Member of the founding management team: co-developed and executed business plan, technology plan, budgets, etc. Responsible for all Flash FPGA design and process development activities: built strong IC design and development team, successfully developed and manufactured world's first Flash based FPGA. Managed corporate partners Rohm in Japan and Sican in Germany. GateField was acquired by Actel Corporation.

1990 - 1993
President / Owner **ASIC Specialties** **Los Gatos, CA**
Consultant / contractor in all areas of ASICs, with a focus on business development, IP protection, technology and patent licensing, IC product planning, development, and test. Developed, patented and licensed proprietary IC technologies: successfully developed gate array families on a turn-key basis and licensed low noise bus interface technology to Japanese and US clients. Extensive international experience, esp. Japan.

1987 - 1990

VP Technology / Co-founder **CrossCheck Technology** **San Jose, CA**

Responsible for development and practical application of CrossCheck's seminal IC test technology - this cost effective yet powerful technology combined on-chip circuit structures with dedicated software tightly integrated into the user's CAE design environment. Built strong core product development team. Very active in product and general business planning and development. Instrumental in the engagement and licensing of leading international ASIC manufacturers (*e.g. LSI Logic, Fujitsu, Sony*). CrossCheck was acquired by Duet Technologies.

1985 – 1987

ASIC Consultant **Los Gatos, CA**

Consulting assignments for users and manufacturers of ASICs have included product evaluation, CAE, design and development.

1978 - 1985

CEO and Chairman / Founder **California Devices, Inc.** **San Jose, CA**

CDI was an early leader in the development of CMOS gate array business. It was a pioneer of the fabless semiconductor business model, combining internal development, back end wafer finishing and test, with external wafer and assembly sourcing.

Wrote business plan, built team, and guided CDI to a sales rate of $8 million in the first five years. Self financed it for the first three years, and raised over $10 million in capital over the next two years. Directly managed development and manufacturing operations, establishing CDI as a reliable, cost efficient, high quality supplier of CMOS gate arrays. Developed domestic and international marketing and sales programs. Licensed the products and technologies internationally, including to LSI Logic as its first product offering, raising over $4 million. Presided over a sales growth exceeding 80% for every year of my tenure as CEO. Recruited a replacement CEO in 1983, remaining on as Chairman and Chief Technical Officer. Lead the development of the next product line, inventing the channelless gate array which was later embraced by all leading gate array companies.

1974 - 1977

Director Of Engineering **Integrated Circuits International, Inc** **Sunnyvale, CA**
(Samsung Semiconductor Bucheon, Korea)

Member of the founding team. Responsible for design and test activities in the U.S. and Korea. Designed and directed development of CMOS watch and custom circuits. Responsible for training Korean engineers in design and test. Spent considerable time in Seoul. ICII evolved into Samsung Semiconductor.

Patents and Publications

18 patents granted; 5 personally owned* (6751238, 6751219, 6594261, 6252273, 5773862, 5764096, 5457653, 5371457*, 5367210*, 5347177*, 5309090*, 5038349, 5037771, 4975640, 4937826, 4682201, 4165642*, 3786442)

4 "Custom Integrated Circuits Conference" papers

Former ASIC columnist for "Electronic Engineering Times"

Former contributing editor for "ASIC Technology and News"

Many papers regarding ASICs published in trade journals

Education

BSEE, with honors, 1969, Clarkson University, Potsdam, NY

Stanford Executive Institute, 1983, Palo Alto, CA

Richard Philip Mount

SLAC National Accelerator Laboratory
Mail Stop 97, 2575 Sand Hill Road
Menlo Park, California 94025

Telephone: (650) 926 2467
Fax: (650) 926 3329
E-mail Richard.mount@stanford.edu

PROFESSIONAL PREPARATION

Institution	Major	Degree/Dates
Oxford University, Jesus College	Physics	BA (Physics) 1970
Cambridge University, Darwin College	Experimental High Energy Physics	Ph.D. 1975
CERN, Geneva, Switzerland	Experimental High Energy Physics	Fellow 1975-1977
Oxford University	Experimental HEP, deep inelastic muon scattering – the EMC Experiment	Research Officer 1997-1982

APPOINTMENTS

Period	Institution	Job Title	Activities
2008 on	SLAC National Accelerator Laboratory	Head of ATLAS Computing (Particle Physics and Astrophysics Directorate) Head of Scientific Computing (Operations Directorate)	Leadership of initiative to transform ATLAS data analysis Management and leadership of scientific computing
2005-2008	Stanford Linear Accelerator Center	Director Scientific Computing and Computing Services	Management and leadership of scientific computing and computing services.
1997-2005	Stanford Linear Accelerator Center	Director, Computing Services Assistant Director, Research Division	
1988-1997	California Institute of Technology	Senior Research Associate (Research Faculty)	L3 physics, Management of L3 computing CMS computing
1982-1988	California Institute of Technology	Senior Research Fellow (Research Faculty)	Mark J physics L3 physics, L3 computing

SELECTED PUBLICATIONS

R. P. Mount, Proceedings of the International Conference on Computing in High Energy Physics, Amsterdam, The Netherlands, June 25–28, 1985, Alternatives in High Volume HEP computing.

R. P. Mount, Proceedings of the International Conference on Computing in High Energy Physics, Asilomar, February 2–6, 1987, Computer Physics Communications (1987) 45, 299, Database Systems for HEP Experiments.

R. P. Mount, Eighth Conference on Computing in High Energy Physics, Santa Fe, New Mexico, April 9–13, 1990, Computing for High Luminosity and High Intensity Facilities, AIP Conference Proceedings **209**, 44, Recent Experiences and Future Needs at CERN and HERA.

D. Baden, B. Linder, R. Mount, J. Shiers, Proceedings of the International Conference on Computing in High Energy Physics, Annecy, France, 21–25 September 1992, Databases for High Energy Physics

R. Mount, Reports on Progress in Physics, 55 (1992) 1385, Off-line computing for experimental high-energy physics

R. Mount, Proceedings of the Thirteenth IEEE Symposium on Mass Storage Systems, Annecy, France, 12–16 June, 1994, Data Storage and Management for High Energy Physics: Technical and Sociological Requirements

L3 Collaboration (440 Authors: http://www.slac.stanford.edu/spires/find/hep/wwwauthors?key=3714071), Phys.Lett.B429:387-398,1998, Measurement of tau polarization at LEP

BABAR Collaboration (623 Authors: http://www.slac.stanford.edu/spires/find/hep/wwwauthors?key=4674430), Phys.Rev.Lett.87:091801,2001, Observation of CP violation in the B^0 meson system

R. P. Mount (editor and conference chair), The Office of Science Data-Management Challenge: Report from the DOE Office of Science Data Management Workshops, SLAC-R-782, 2004.

R. P. Mount, Data Analysis in High Energy Physics, Weird or Wonderful, proceedings of Astronomical Data Analysis Software and Systems XVII, ASP Conference Series Vol. 394, 2008

SYNERGISTIC ACTIVITIES

Chair of Geant4 Collaboration Board 2001-2006; Member of Geant4 Oversight Board 2006 on; Coordinating PI for US Geant4, 2009 on.

PI (with David Leith) of the PetaCache project funded by DOE/MICS. (2004 – present)

PI (with Miron Livny/Wisconsin, Harvey Newman/Caltech, Ruth Pordes/Fermilab) of the Particle Physics Data Grid Collaboratory Pilot. Funded by the US DOE SciDAC program at $3.2M per year. (2000 – 2006)

COLLABORATORS

Makoto Asai/SLAC, Jacek Becla/SLAC, Chuck Boeheim/SLAC/Cornell, Andy Hanushevsky/SLAC, David Leith/SLAC, Kian-Tat Lim,/SLAC Randy Melen/SLAC, Dennis Wright/SLAC; Miron Livny/U. Wisconsin; Ruth Pordes/Fermilab; Harvey Newman/Caltech.

GRADUATE ADVISORS

John Rushbrooke, Downing College Cambridge (Deceased)
Janet Carter, Cavendish Laboratory Cambridge

THESIS ADVISOR OF
John McNicholas, Oxford University, Anthony Johnson, Oxford University

Douglas E. Werner

SUMMARY OF QUALIFICATIONS

Results oriented Research and Development Engineer with broad corporate and business unit project leadership experience. Proven technical leader of cross-functional teams. Able to quickly grasp new technologies, apply knowledge to solve problems, effectively transition new technology platforms to product development organizations.

PROFESSIONAL EXPERIENCE

COOLIGY INCORPORATED — **MOUNTAIN VIEW, CA**

Senior Director of Research and Development — ***November 2006 to Present***

- Provided the key technology to enable a new refrigerant based passive rear door cooling product for the Liebert XD product line enabling $1M in sales in the first 6 months.
- Worked with OEM Server manufacturer to create 2 new high density computer platforms with integrated cooling systems capable of providing 60 kW of cooling in a single rack.

Director, Development — ***February 2003 to November 2006***

- Led the team for the development of all material sets used in Cooligy's first commercial liquid cooling system. This included the development of the coolant, low permeation tubing, joint sealants and freeze protection materials. The final product used a water based coolant that could be frozen solid without the system leaking. Approximately 50,000 liquid cooling systems were sold without a single failure or leak.
- Directed the design and manufacture of high performance liquid cooling system prototypes for a variety of products including silent workstation computers, compact graphic systems, high power LED rear projection televisions and medical instruments.

CORNING, INCORPORATED, — **FOUNTAIN VALLEY, CA**

Program Manager, Micro-Optics — ***July 2002 to February 2003***

- Led cross-functional product delivery team to identify and develop innovative, robust. cost effective products.

CORNING, INCORPORATED, — **SULLIVAN PARK, NY**

Manager, Micro-Optic Technologies — ***July 2001 to July 2002***

- Provided project leadership for Micro-Optic Packaging.
- Worked with Manufacturing to provide rigorous up-front cost modeling.
- Developed new method of packaging which provided an 80% decrease in labor.

TYCO ELECTRONICS TECHNOLOGY AND BUSINESS DEVELOPMENT GROUP, MENLO PARK, CA

Technical Manager, Senior Scientist — ***July 1997 to March 2001***

Simultaneously performed as an individual contributor, manager of a technical staff and staff member to the CTO of Tyco Electronics.

Technical Manager

- California Manager of Tyco Electronics Technology and Business Development Group. Managed a multi-disciplinary group in a broad range of technologies including Polymer Dispersed Liquid Crystal material development, development of injection moldable low CTE materials, moldable BiPolar plates for fuel cells, glass patterning by laser ablation, and materials development of nanoparticle filled materials

- Participated in and directed strategic product road-mapping discussions with the executive management of various business units in order to define technologies required for their next generation product development.

Senior Scientist

- Worked with business development to help create a market pull for displays for smart cards. Effort culminated in a booth at the largest smart card trade show complete with working demonstration cards.
- Designed new standardized display and interconnect layout suitable for smart cards which enabled a 40% reduction in display size.
- Worked with large smart card chip manufacturer to develop display driver
- Worked with dominant smart card manufacturers to develop a thin flexible display suitable for incorporation in a smart card.
- Negotiated and licensed the technology to a display manufacturer.

RAYCHEM CORPORATION DISPLAY PRODUCTS GROUP, **SUNNYVALE, CA**
Manager and Staff Engineer, New Materials Development ***January 1997to July 1997***
The Display Products Group was a start-up company incubated within Raychem.
Supervised a chemist and technician in the laboratory to develop new Polymer Dispersed Liquid Crystal (PDLC) emulsions and processes for manufacturing same.

- Led critical development effort for new low voltage Polymer Dispersed Liquid Crystal (PDLC) formulation through the creation of new formulations and processes.
- Led a team that solved the origin of a 10-year-old problem that limited the technology to very large displays. Solving this problem enabled $50M market opportunity.

RAYCHEM CORPORATION WIRE AND CABLE, **REDWOOD CITY, CA**
Staff Engineer for New Product Development ***January 1995 to January 1997***
Supervised two technicians to provide product and technology development as well as specific manufacturing engineering support.

Development Engineer

- Led seven member team in the scale-up effort of the first successful non-FEP plenum rated LAN cable resulting in $8-million in sales.
- Designed extruder head and breaker plate for production of the new LAN primary wire.
- Implemented new ultrasonic technology to reduce scrap rate from 40% to less than 10% on critical new production line.

Fluoropolymer Scientist

- Accountable for all fluoropolymer formulations used by Wire and Cable.
- Led all projects regarding reformulation of existing compounds and qualification ofnew vendors or new grades of materials.

EDUCATION
M.S. in Chemical Engineering, *Stanford University,* June 1990
B.S. in Chemistry, *University of Wisconsin at Madison,* June 1989

Demonstration of High Efficiency Liebert XDS Rack Cooling without Chiller Subsystem

Project Partners

Team Member	Project Role
EMTEC PI-Dr. Mike Martin	EMTEC will provide Project Leadership, including fiscal administration, task management, and collaborator relationship management.
Clustered Systems PI-Mr. Phil Hughes	Clustered Systems will provide the technical leadership and direction for this project. Clustered Systems is one of the more innovative developers in the area of liquid cooling. Through the adaptation of existing technologies and practices, they have succeeded in reducing the cost of liquid based cooling to a point where it is economically feasible for many applications, especially in the field of electronics.
Emerson – Cooligy PI-Mr. Doug Werner	For this project, Cooligy will work with Clustered Systems to develop and build multiple pre plumbed racks to accommodate Clustered Systems' fanless, very high density server shelf cooling units. These units will be outfitted with custom designed server blades and inserted into Cooligy's racks.
SLAC PI-Dr. Richard Mount	SLAC will make available to the project a recently disused area in a technical building that has adequate floor space, electrical power, tower-chilled water, and network connectivity to enable the implementation of the planned compute platform. SLAC/Stanford conceptual plans involve the future exploitation of 10 or more MW of existing available electrical power and a corresponding existing cooling tower capacity.

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The Edison Materials Technology Center

An Ohio Edison Technology Center

Ohio | Department of Development

July 18, 2009

U.S. Department of Energy
Golden Field Office

RE: Cost Share Reduction Justification for Recovery Act: Energy Efficient Information and Communication Technology - DE-FOA-0000107

Dear Reviewers,

The Edison Materials Technology Center (EMTEC) is requesting cost share reduction for our project entitled, "Demonstration of High Efficiency Liebert XDS Rack Cooling without Chiller Subsystem. " A portion of this project is developmental and the bulk of the project expense consists of equipment and modifications that will greatly benefit a national lab and provide a broad based advancement of data center cooling technology.

Although current technology encompasses all the components of our advanced technology demonstration project, we anticipate that significant effort will be required for establishing the detailed modifications of some equipment to achieve the project's objectives. Due to the risk introduced by this development, additional engineering resources may be needed to complete the development portion of our project within the timeframe of this demonstration. The challenge lies in demonstrating that the Liebert XD system that is currently tested up to an incoming chilled water temperature of 55°F can operate at up to 90°F water supplied from the cooling tower. Once a chiller is removed from the cooling system, the Liebert XDS is expected to cool server's heat generating components to below recommend manufacture levels.

This demonstration will place 288 of the latest technology Dell servers in a high performance cluster in a government laboratory, Lawrence Livermore National Lab - LLNL. During the demonstration and during the time the system is available for viewing, these computers are capable of running tasks that could share the load from other computer clusters at the lab.

LLNL will be required to make facilities modifications for this demonstration. Since LLNL is restricted from contributing cost share dollars, the resulting cost share expenditures for these modifications must come from the collaborators.

In summary, due to the potential of additional engineering resources, the large deployment of Dell hardware, the LLNL facilities modifications, and the broad based advancement of the technology we believe the 25% cost share is justified.

Sincerely Yours,

Michael C. Martin, Ph.D.
Vice President, Alternative Energy Technology