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The purpose in the 'Ramp-up and Launch' phase is to ensure all functions are prepared for the General Availability of the offering. The purpose of the 'Manage Life Cycle' phase of a hardware, software, or services offering project is to manage the cross-functional business value proposition, adjusting to market responses (positive and negative) and production challenges and sales opportunities. Eventually, the PDT/LMT goes to the IPMT with an End of Life DCP package, including the end of marketing, end of production, and end of service.

A Structured Decision Process is followed so the IPMT can consistently

- Manage new opportunities and committed projects in the development pipeline
- Review and approve project plans
- Provide staffing and funding resources to teams in a manner that maximizes ROI
- Periodically measure progress against the plan
- Validate continued market opportunity
- Review technology and product roadmaps
- Set strategic direction
- Maintain a product portfolio consistent with the company's strategic plans
- Manage the overall business

6) Technical Approach / Project Management Plan

The technical approach is to advance the energy efficiency of water cooling which is inherently superior to air cooling , by developing new DELC and LMTI technologies which will allow for outside ambient environment water cooling. These programs will benefit from IBM's long term experience in chilled water cooling technologies, increasing the likelihood of success.

In addition IBM has a long history in innovation and product development experience from concept to product. A number of significant innovations have come from IBM Research over the years including: One-transistor memory cell, Fractals, Relational Databases, Speech recognition, RISC architecture, Silicon germanium chips, Deep Blue , SOI - Silicon-on-Insulator, Blue Gene/L, etc.

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Water Cooling Technology Advancement

The IBM Systems and Technology Group has a long history in chilled water cooling which it has deployed for both Enterprise and HPC computing systems. IBM is currently shipping several water cooled products including Power System 6 575 [8] and Blue Gene. In support of these efforts IBM has qualified vendors for multiple components including hoses, water connectors, filtration, cold plates and pumps and brought new technologies to the marketplace by creating commercial partnerships. This project will extend that base of knowledge to solve challenges in outside ambient environment water cooling by using the DELC technology. This project will extend water cooling to the Volume Server space through IBM's System X Intel servers.

A detailed project plan is described in the Project Management Plan Document which includes both the project work timeline and budget.

In the Appendix of this proposal, a Letter of Support from Gregg McKnight has been included that endorses the DELC/LMTI technology for potential widespread adoption inside IBM's own products. Gregg McKnight is, IBM Vice President and Distinguished Engineer, IBM Systems and Technology Group Modular Systems Development, and is responsible for the development of IBM Volume Server products.

7) Qualification and Resources

Personnel: The members of this team have been integrally involved in the development of IBM's thermal cooling technologies including experienced research scientists from the IBM TJ Watson Research Center who will collaborate closely with server and data center thermal engineering specialists from the IBM System & Technology Group to develop this ultra energy efficient server cooling hardware technology. The team has jointly co-authored more than 50 recent papers in conference proceedings and journals on server and data center thermal and energy management. This team of creative technologists also has a noteworthy record of data center innovation as evidenced by 50 relevant issued or pending US patents, several of which have been productized with realizable energy efficiency benefits to the server industry and customers of IT products.

Organizational Experience: The IBM System and Technology Group product division and Research teams have successfully developed and qualified advanced cooling technologies which are shipping in today's products. These have included the development of the IBM P6-575 water cooled server , the Cool Blue™ portfolio, which are a set of products from IBM's Systems and Technology Group, and include rack level cooling via the IBM Rear Door Heat Exchanger, and power usage monitoring and management via the IBM Active Energy Manager software.

Research Facilities: The IBM T.J. Watson Research Center hosts in the same building about 1,500 researchers, with sizable groups working on topics ranging from exploratory work in the physical sciences to semiconductors and systems technology, as well as high performance computing and computational biology. The facility has a wide array of assembly, fabrication, and test equipment including:

- Mechanical test equipment for evaluation of the mechanical properties of materials
- Sample cross-sectioning, FIB and SEM viewing and X-Ray analysis.
- Thermal Resistance Measurement Apparatus
- Stress testing including deep thermal cycling and high humidity. DTC , T&H
- Several leading commercial finite element modeling programs.
- Central Scientific Services for mechanical design and prototyping, electronic design and microfabrication.

System and Technology Group Test Facilities: The DELC cooling system will be installed in the IBM STG Advanced Thermal Laboratory (ATL) located in Poughkeepsie, New York. The rack and its' supporting liquid cooling and outdoor heat rejection apparatus will be installed on a 300-400 square feet raised floor space inside the ATL thus being housed on a advanced data center thermal test facility. The ATL will be used for the cold plate thermal testing for the DELC prototype while also serving as the test site for the control algorithm verification.

8) Appendix:

References

1. Y.Martin , T.Van Kessel, “High Performance Liquid Metal Thermal Interface for Large Volume Production”, IMAPS (Int.MicroelectronicsAndPackagingSoc.) Thermal and Power Management, San Jose CA, Nov.11-15 2007

2. T.Bunschwiler, B. Smith, E. Ruetsche, B. Michel, “Toward zero-emission data centers through direct reuse of thermal energy”, J. IBM Res. & Dev. 53, 3, 2009, p.11:1

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4. Koomey, Jonathan G., 2007, Estimating Total Power Consumption by Servers in the U.S. and the World, Feb. 15th thttp://enterprise.amd.com/Downloads/svrpwrusecompletefinal.pdf.

5. R. Schmidt and M. Iyengar, 2009, “Thermodynamics of Information Technology Data Center”, IBM Journal of Research and Development, Vol. 13, No. 3, paper 9.

6. B.K Furman, P.A. Lauro, D.Y.Shih, T.Van Kessel, Y.Martin, E.G. Colgan, W. Zou, S.Iruvanti, J.Wakil, R Schmidt, M.K. Iyengar “Metal TIM’s for High Power Cooling Applications”, IMAPS (Int.MicroelectronicsAndPackagingSoc.) Thermal Management, Palo Alto, Oct.25 2005

7. T.Van Kessel, Yves C. Martin, Robert L. Sandstrom, Supratik Guha,, “Extending Photovoltaic operation beyond 2000 suns using a LIQUID METAL THERMAL INTERFACE with passive cooling”, Proc. 33rd IEEE PVSC (PhotoVoltaics Specialists Conf.), San Diego, May 11-16 2008

8. M. J. Ellsworth, Jr., L.A. Campbell, R.E. Simons, M.K. Iyengar, R.R. Schmidt, and R.C. Chu, 2008, "The Evolution of Water Cooling for Large IBM Large Server Systems: Back to the Future", Proceeding of the 11th IEEE ITherm Conference, Orlando, Florida, USA, May 27th-31st.

Impact Projections Model

Project Name:	**Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.**
Preparer: Name and Organization	Timothy Chainer (PI), Senior Manager - IBM Research

Technology Description

Please provide a concise description (more than one-half page is unncessary) of the new technology you are proposing, addressing:
- Its function, and benefits to the industrial user of the technology
- The state-of-the art technology it replaces
- The target of the technology and potential limitations to its applications and barriers
- Plant modifications necessary to incorporate the new technology
- Competing technologies
- The definition of one technology unit-year

Function : This proposal will focus on the development of two complimentary novel technologies that can radically reduce the energy consumption of data centers when compared to the conventional techniques. The technologies will improve efficiency by enabling "free" cooling from the ambient environment.

Firstly, a server compatible direct liquid metal thermal interface will be developed to improve the thermal conduction path of the hot server components to the data center ambient cooling. The combined effect of liquid metal TIM and bare die attachment will provide a path to significant increases in the ambient cooling temperature needed to achieve the semiconductor junction temperature specifications.

Secondly, a dual enclosure based air/liquid warm coolant cooling system will be developed so to allow the direct thermal coupling of the server devices with the outside environment. This Dual Enclosure Liquid Cooling (DELC) system eliminates the need for the refrigeration chiller plant as well as several other cooling components, thus allowing for as much as 85% reduction in the cooling energy cost. In addition to explicitly and dramatically reducing cooling energy at the source, the use of direct cooling from the outsdie ambient enviroment provides an opportunity to recover the waste heat from the servers in the form of hot water that could be utilized for low grade heating for commercial or residential heating.

State of the Art : These technologies will replace state of the art Refrigeration Chiller Plants and CRACS with "free cooling" from the ambient environment.

Target : The target of the technology are Volume, Mid-range and High-End servers for mid-tier and enterprise class data centers. Barrier for implementation is acceptance of water cooling in the data center.

Plant Modifications : The servers would need to be configured for liquid cooling, and the data center infrastructure would need to support ambient warm water cooling loops which reject heat to the outside environment.

Competing Technologies : Technologies which can reduce IT power usage and therfore cooling requirements.

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References

1- Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431, August 2007

2- IDC Market Analysis US and Worldwide Installed Base Forecast , June 2009

Impact Projections Model

Unit Inputs

Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.

Per Unit Impacts per year			
	New Technology	Current Technology	Net Impact

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Impact Projections Model

Impacts: New Technology vs Current Technology							
Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.							
Impact By Year	2010	2015	2020	2025	2030	2035	2040
Cumulative Units installed							
Annual New Units Installed							
Annual Replacement Units Installed							
Annual Installations Total							
Market penetration							
ANNUAL SAVINGS							
Energy Metrics							
Total primary energy displaced (trillion Btu)							
Direct electricity displaced (billion kWh)							
Direct natural gas displaced (bcf)							
Direct petroleum displaced (million barrels)							
Direct coal displaced (million short tons)							
Feedstock energy displaced (trillion BTU)							
Biomass energy displaced (trillion BTU)							
Waste energy displaced (trillion BTU)							
Other energy displaced (trillion Btu)							
Financial Metrics							
Energy-cost savings ($MM/yr)							
Environmental Metrics							
CO Displaced (Metric tonnes)							
Carbon Dioxide emissions displaced (MM TCE)							
Other greenhouse emissions displaced (MM TCE							
SO2 displaced (Metric tonnes)							
NOx displaced (Metric tonnes)							
Particulates displaced (Metric tonnes)							
VOCs displaced (Metric tonnes)							
Hydrocarbons displaced (Metric tonnes)							
Solid Waste (Metric tonnes)							
Other environmental benefits (Metric tonnes)							

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IBM.

International Business Machines Corporation
Research Triangle park, NC, USA

July 13[th] 2009

Subject: Letter of Support for DE-FOA-0000107 "*Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces*".

To Whom It May Concern,

I am delighted to write this letter of support for the IBM' DoE proposal entitled "Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces" that is in response to DE-FOA-0000107. The study will further the productization of cutting edge cooling technology via Research and Development leading to actual hardware build and data collection in relevant settings. This work will enable the assessment of the obtaining substantial cooling energy efficiency improvements in IT data center facilities from the adoption of advanced metal thermal interface and liquid cooling technologies in combination with economizer devices. Widespread implementation of such technology can lead to dramatic reduction in cooling energy use in IT data centers.

It is evident that the combination of various trends such as the rapidly increasing power dissipation of IT technology (processors, servers, racks, and data centers), the emerging societal and customer driven demands for energy efficiency, and the continued business as usual emphasis on "easy" air cooling, create significant challenges for future server thermal designers. We believe the proposed work will pave the way to explore and productize innovative hybrid air/liquid cooling technologies and systems for data centers that will address this critical energy consumption issue.

Early comparative analyses between traditional air-cooled data centers and these novel concepts proposed reveal that such improvements in data center energy efficiency are indeed possible. This technology also lends itself for commercialization using technology partners which has served as a proven model in the data center cooling products market space. The initial application of this technology via this proposal if granted would be for the IBM System X brand of servers for which I serve as the IBM VP for Development of Energy Efficiency and Power Packaging and Cooling (Modular Systems).

If awarded, the IBM Systems & Technology (STG) group will collaborate closely with IBM Research to research and develop these technologies. I believe that the core team with Tim Chainer (Research) as the PI and Roger Schmidt (STG) as the lead technologist, and including several highly capable technical specialists such as Vinod Kamath (STG), Yves Martin (Research), and Madhu Iyengar (STG), will ensure the creation of valuable and useful energy-efficient thermal technologies.

Sincerely,

Gregg McKnight

Gregg McKnight
IBM Vice President & Distinguished Engineer
Modular Systems Development
greggmck@us.ibm.com, Phone: 919-543-3561

Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces

ABSTRACT

The objective of this proposal is to reduce the cooling energy to 5% of total data center energy. The proposal will focus on the development of two complimentary novel technologies that can radically reduce the energy consumption of data centers by using direct cooling from the outside ambient environment and eliminating refrigeration equipment, along a viable commercialization path.

Firstly, a server compatible liquid metal thermal interface (LMTI) will be developed to improve the thermal conduction path of the hot server components to the data center ambient cooling. This liquid metal thermal interface has a thermal conductivity an order of magnitude better than state of the art materials. When integrated directly between a bare die and a water cooled heat sink, this technology will achieve a significant improvement in thermal conduction and enable the computer devices to operate in a much higher ambient temperature environment.

Secondly, a dual enclosure air/liquid cooling system will be developed to allow direct cooling from the outside ambient environment. This Dual Enclosure Liquid Cooling (DELC) system uses re-circulated air and water, cooled only by heat exchange with the outside ambient air. Sensors and algorithms will control air and water flow to minimize the cooling energy as a function of server heat load and outdoor air temperature.

The integration of LMTI and DELC will eliminate the data center refrigeration chiller plant as well as several other cooling components, thus minimizing cooling energy and equipment. The water, cooled only by heat exchange with the outside ambient environment, will enter the DELC at a temperature above the outdoor air temperature and increase as it exchanges heat with the higher temperature server components. In cases when the DELC outlet water temperature exceeds 40C., this provides an opportunity to recover the waste heat from the servers in the form of hot water that could be utilized for low grade commercial or residential heating.

To maximize the energy impact, this proposal will focus on the largest segments of the server market which are the Volume and Mid-range servers.

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IBM has long term experience in manufacture and commercialization of chilled water cooled computers. It has established partners and know how in qualification of components and supply chain for water cooling. Highly experienced materials scientists from the renowned IBM Watson Research Center will collaborate closely with server and data center thermal engineering specialists from the IBM System & Technology Group to develop this highly energy efficient solution. The team has jointly co-authored more than 50 recent papers in conference proceedings and journals on server and data center thermal and energy management. This team of creative technologists also has a noteworthy record of data center innovation as evidenced by 50 relevant issued or pending US patents, several of which have been productized with realizable energy efficiency benefits to the server industry and customers of IT products.

Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces
PROJECT MANAGEMENT APPROACH

Successful conclusion of this project requires more than careful planning. IBM understands that the right management controls, resources, and quality assurance processes are essential to success in this endeavor.

IBM will use the established and proven program management processes defined in its World Wide Project Management Method (WWPMM) to create effective management controls specifically tailored to this project. WWPMM is a robust project and program management methodology that is used to manage all IBM projects worldwide. It incorporates IBM lessons learned from the successful execution of tens of thousands of complex projects, as well as best practices identified by the Project Management Institute (PMI), the Institute of Electrical and Electronics Engineers (IEEE), and the Software Engineering Institute.

WWPMM provides consistent rules of engagement within and across teams and establishes a standardized program environment and common expectations on scope, cost, performance, risk management, and quality. This is crucial for evaluating performance, identifying problems, and sustaining progress. The chart below describes the dimensions and level of control IBM will apply to this project:

Dimension / Work Products	Monitor Tasks	Control Costs	Minimize Management Overhead
Project Planning	Prepare and maintain Project Plan defining activities, tasks, responsibilities, milestones, and schedule	Single-focused Project Plan	Establish standards for deliverables
Status Reporting	Report and forecast status, issues, dependencies, corrective actions	Consolidated and consistent progress reporting and tracking	Uniform collection and sharing of project work products
Work Plan Management		Limit redundancies and task repetition through coordinated work plans	Assign tasks to teams who will develop work products. Reconcile task work products with the overall Project Plan. Reconcile plan deviations.
Communications Management	Evaluate project progress against Project Plan and actual expenditures against forecasts.	Evaluate actual expenditures by task. Forecast run rates. Report funds status against Project Plan	
Quality Assurance	Validate alignment of Project Plan and execution with project expectations. Confirm deliverables conform to expectations for accuracy, completeness, and timeliness and support Gate decisions	Review all aspects of the project performance and delivery, including compliance with industry best practices and IBM Methods.	Shared work products allow all to share the responsibility of Quality Assurance.
Risk Management	Shared work products add visibility and reveal issues across the entire project team.	Identify, mitigate, and track issues for program scope, cost, schedule, and synchronization with DOE decision-making.	Consistent work products make it easy to effectively address issues with the current environment and identify enhancements during the design of the 'to-be' system.
Issues Management	Manage and resolve issues by priority, cost, schedule, and corrective actions.	Track issues by task, impact, likelihood, cost, and schedule.	
Technical Environment Management		Establish service levels, availability, and access rules.	
Contract Change Management		Determine impacts of changes in the hours, price, or performance. Obtain collaborative agreement.	

IBM's Project Manager will establish the framework for project communications, reporting, procedural, and contractual activity described above. These activities will include:

a. Review the Statement of Work and the contractual responsibilities of both parties with the DOE Project Manager.
b. Maintain communications with the DOE Project Manager.
c. Establish documentation and procedural standards for the development of the project.
d. Maintain a Project Plan for performance of the work, which defines the detailed tasks, schedule, and responsibilities.
e. Measure and evaluate progress against the Project Plan.
f. Resolve deviations from the Project Plan.
g. Establish the Communication Plan for regularly scheduled project status meetings.
h. Prepare and submit Status Reports to DOE.
i. Coordinate and manage the technical activities of project personnel.
j. Define and mutually agree with DOE on the guidelines for each deliverable.
k. Assist DOE in developing specific Gate Review Criteria.

The attached Project Management Plan outlines the organization, subcontract management, communications, tasks, schedule, spending plan, and gate criteria for this project.

PROJECT MANAGEMENT PLAN

Organization

The project will be led by:

- **Principal Investigator (PI),** Dr. Timothy Chainer, Senior Manager, IBM Research will be responsible for overall technical direction and end-to-end system implementation.
- **Project Manager (PM)** will assist the PI in managing schedules, milestones, meetings and communications.

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The program staffing spans three departments within IBM:

1) The Advanced Thermal Interface Team (IBM Research) will develop the liquid metal thermal interface from concept to implementation into System X processor modules.

2) The Systems Integration Thermal Development Team (IBM Systems and Technology) will

a) Develop the DELC technology for IBM System X volume server systems,
b) Construct a Data Center test facility with external heat exchanger to characterize system cooling performance under varying operating conditions,
c) Measure the System X with the DELC integrated at the rack level,
d) Measure the System X with LMTI technology integrated into server nodes which was assembled by the Research team,
e) Characterization the System X in the data center test facility under varying conditions including water temperature, water flow and air flow rates, and
f)_Perform system experimental evaluation of Dynamic Control Methodology.

3) The Server Systems Development Team (IBM Systems and Technology) will
   a) Assist in the configuration and installation of a System X rack with 42 1u server nodes,
   b) Collaborate on the DELC/LMTI System X performance measurements, and
   c) Perform product commercialization evaluation and planning.

Communications Plan
As the work will be performed at various geographically dispersed IBM regular communications are essential to a successful project.

To that end, the PI will conduct a *weekly* telephone conference call with all team members. The purpose will be for information sharing and project status towards milestones. Additionally, issues needing attention will be identified and tracked to closure. IBM will also have quarterly face-to-face meetings with all team members. It is anticipated that this meeting will define and decide architecture, design, and implementation details that span the overall project or that span multiple teams. Monthly integration status, issues, and results will also be discussed at these meetings.

Team members will also communicate individually via email, phone calls, and text messaging.

Schedule Category Description & Personnel PY Allocation
The activities of this program fall into the following main categories.

Program Management

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System X

REDACTED
EXEMPTION 4

Data Center Test Facility

REDACTED
EXEMPTION 4

Dual Enclosure Liquid Cooling (DELC)

REDACTED
EXEMPTION 4

(All materials purchased in Year 1, Side Car related CSS in Year 1)

Liquid Metal Thermal Interface (LMTI)

REDACTED
EXEMPTION 4

(All materials purchased in Year 1, 50% of CSS in Year 1, 50% of CSS in Year 2)

System Measurements and Characterization

REDACTED
EXEMPTION 4

Risk Mitigation

REDACTED
EXEMPTION 4

(50% of CSS in Year 1, 50% of CSS in Year 2)

A Gantt chart below shows the scheduling for each of the main project categories

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The key milestones from the Gantt chart are summarized in the table below.

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Risk Mitigation

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Spending Plan

Costs are estimated by task, category, and period of performance.

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Gate Criteria

IBM proposes the following for the Gate 3 Decision at the end of this effort. Criteria are listed below that will be used to demonstrate the project has achieved the following:

1) **Technical feasibility has been demonstrated**
   A detailed description of the technical methods has been provided in the next section. The technical approach will utilize a systematic progression of the design from theoretical predictions of performance metrics to use sophisticated modeling techniques leading to CAD design and then hardware build and ultimately the experimental verification testing of the DELC unit as well as the LMTI based module, servers and rack level assemblies. At each

stage, there will be a performance metric value for evaluation. The test data collected will include detailed temperature data and real time energy consumption data for the various components. The cooling energy use (kW) will be the key criteria for evaluating the performance of the DELC/LMTI devices.

2) **The solution will scale up**
As described in the preceding text, the DELC/LMTI units will be tested at the module level, the server level and finally at the rack level with multiple servers. While the rack level test will represent a single unit test for the DELC, there will be an inherent scaling of thermal technologies. This demonstration will be assisted and supplemented by detailed modeling analyses which will capture the effects of the rack heat load and the outdoor air temperature patterns on the cooling energy efficiency of the loop. Thus, the refined and validated modeling capabilities will enable the projection of the DELC/LMTI performance for a wide range of operating parameters and geographic locations.

3) **Energy benefits have been calculated**

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4) **Legal and regulatory issues have been addressed (if necessary)**
IBM has a long history of exemplary compliance with legal and regulatory standards. One completion of the major milestones, a review with respect to legal and regulatory issues will be conducted. Compliance and regulatory issues are not expected.

5) **The technology will be competitive in the marketplace.**

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IBM will work with DOE to refine and finalize these criteria.

Project Activity Detailed Descriptions

Technical Approach

Research, design, and technology validation will consist of various theoretical and experimental techniques using test vehicles and actual servers.

- Analytical computations using correlations from literature & thermal models coded into Math software's such as MathCAD, Matlab, & Engineering Equation Solver (EES).
- Numerical Computational Fluid Mechanics (CFD) simulation of CPU modules and servers to optimize thermal design of cold plates, metal TIMs, and heat exchangers.
- Hydraulic numerical simulation of water manifolds and plumbing to optimize flow distribution in the manifolds and the building layout.
- CAD design of prototypes using CATIA software to facilitate volume manufacturable designs.
- Experimental wind tunnel based & liquid flow bench based validation of first prototype build to verify thermal performance and energy use.
- Stress testing of parts for pre-qualification, including thermal cycling, exposure to temperature and humidity, and accelerated aging (exposure to high temperature, typ. 120C)
- Two rounds of design optimization for critical new technology parts, including cold plates, water distribution components, LMTI and processor packaging; with the second design following results of stress testing and lessons learned from the 1st design.
- Rack level installation of a single rack with commercial IBM servers with a cooling loop coupled to an outdoor exchanger.
- Data center level thermal test data from IBM product labs and from literature used for benchmark base line conventional design data.
- Comparison of collected data for new technology to energy data for conventional configurations.

Description of Technical Tasks

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Impact Projections Model

Project Name:	Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.
Preparer: Name and Organization	Timothy Chainer (PI), Senior Manager - IBM Research

Technology Description
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- The target of the technology and potential limitations to its applications and barriers
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- Competing technologies
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State of the Art : These technologies will replace state of the art Refrigeration Chiller Plants and CRACS with "free cooling" from the ambient environment.

Target : The target of the technology are Volume, Mid-range and High-End servers for mid-tier and enterprise class data centers. Barrier for implementation is acceptance of water cooling in the data center.

Plant Modifications : The servers would need to be configured for liquid cooling, and the data center infrastructure would need to support ambient warm water cooling loops which reject heat to the outside environment.

Competing Technologies : Technologies which can reduce IT power usage and therfore cooling requirements.

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Impact Projections Model

Unit Inputs

Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.

Per Unit Impacts per year	New Technology	Current Technology	Net Impact

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EXEMPTION 4

Market Inputs

Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.

Total Market	x	Ultimate Potential Market Share	x	Market Penetration

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Impact Projections Model

Impacts: New Technology vs Current Technology
Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces.

Impact By Year	2010	2015	2020	2025	2030	2035	2040
Cumulative Units installed							
Annual New Units Installed							
Annual Replacement Units Installed							
Annual Installations Total							
Market penetration							
ANNUAL SAVINGS							
Energy Metrics							
Total primary energy displaced (trillion Btu)							
Direct electricity displaced (billion kWh)							
Direct natural gas displaced (bcf)							
Direct petroleum displaced (million barrels)							
Direct coal displaced (million short tons)							
Feedstock energy displaced (trillion BTU)							
Biomass energy displaced (trillion BTU)							
Waste energy displaced (trillion BTU)							
Other energy displaced (trillion Btu)							
Financial Metrics							
Energy-cost savings ($MM/yr)							
Environmental Metrics							
CO Displaced (Metric tonnes)							
Carbon Dioxide emissions displaced (MM TCE)							
Other greenhouse emissions displaced (MM TCE							
SO2 displaced (Metric tonnes)							
NOx displaced (Metric tonnes)							
Particulates displaced (Metric tonnes)							
VOCs displaced (Metric tonnes)							
Hydrocarbons displaced (Metric tonnes)							
Solid Waste (Metric tonnes)							
Other environmental benefits (Metric tonnes)							

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Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces

RESUME FILE

1 PRINCIPAL INVESTIGATOR - Timothy Chainer

Dr. Timothy Chainer is a research Scientist and Senior Manager in the Science and Technology Department at the Watson Research Center in IBM Research. He manages a technical team of Research Scientists and Engineers in Electronic Packaging Technology and has led technical programs in all aspects of packaging from first level packages to data centers which have included; organic substrate design, thermal interface material characterization, 3D packaging, micro channel cooling and thermal characterization study of data centers. Dr. Chainer received his BS in Engineering Science from New Jersey Institute of Technology in 1973 and his PhD in Physics from Rutgers University in 1980 in Condensed Matter Low Temperature Experimental Physics. His thesis title was "Size Effects in Superfluid Helium3". Dr. Chainer has been the recipient of numerous technical honors in his distinguished 29 year career at IBM, including several Outstanding Technical Achievement Awards, one Outstanding Innovation Award, and two Research Division Awards, for invention and successful implementation of technologies into IBM products. Prior to his current managerial assignment he has held several technical and management positions within IBM including Technical Staff to Research VP Technical Planning in 1992 when he developed the IBM Research Division Technical Strategy. He is a Senior Member of IEEE and a member of IMAPS. He holds 69 US patents.

EDUCATION

PhD, Physics, Rutgers University 1980
Condensed Matter Low Temperature Experimental Physics
Thesis was "Size Effects in Superfluid Helium3"

BS, Engineering Science, New Jersey Institute of Technology 1973

PROFESSIONAL EXPERIENCE

2004-2010 Senior Manager, Packaging System Technology Dept
- Managed a technical team of 20 Research Scientists and Engineers in Electronic Packaging Technology including three departments ; 3D System on Package , Packaging System Integration and Packaging Manufacturing and Test. The technical program covered all aspects of packaging from first level package to data centers.

2000-2004 Senior Manager, Storage and Exploratory Subsystems Dept
- Managed a technical team of 10 Research Scientist and Engineers in Storage Technology to develop Self–servowrite manufacturing technology and Disk Drive Adaptive Track Format product architecture.

1993-2000 Manager, Storage Instrumentation and Measurements Dept
- Managed a technical team of Research Scientist and Engineers to develop the first dynamic servo controlled tracking for Tape Storage products in IBM.

1992 Technical Staff to Research VP Technical Planning
- Developed Research Division Technical Strategy

1986-1992 Manager, Magnetic Recording Applied Physics Dept

- Managed a program to develop compact storage technology and the first small form factor 2.5" disk drive within IBM.

1981-86 RSM, Applied Business Ventures, Signature Verification
- Technical team member of a program to develop and productize Bio-metric signature verification for personal identification.

1980 Postdoctoral Fellow, Magnetic Recording Dept
- Led a project on Multilayer Ceramic Modules manufacturing measurement methods.

HONORS/AWARDS

2003 Outstanding Innovation Award *Hard Disk Drive Adaptive Track Format*
2003 Outstanding Technical Achievement *Award Self Servowrite Technology*
2002 Elected Master Inventor
1997 Outstanding Technical Achievement Award *No Clock Head Technology for Performance HDD*
1996 Outstanding Technical Achievement Award *Flexural Actuator for Tape Storage Applications*
1991 Outstanding Technical Achievement Award *Enhanced Signature Verification System and its application to the Transaction Security System Product*
1985 Research Division Award *Design, Development and Implementation of a Small Exploratory Disk File Prototype*
1982 Research Division Award *Hall Effect Magnetometer for Multilayer Ceramic Module Program.*

PUBLICATIONS / PATENTS - Selected from 69 Patents / 18 Technical Publications

[1] US Patent Application, US 20090019201A1, "Identification of equipment location in a data center" , T. Chainer, H. Dang, Jan 2009.
[2] US Patent Application, US20080305585A1, "Method for Direct Heat Sink Attachment", T. Chainer Feb 2008.
[3] US Patent Application, US20090039499A1, "Heat Sink with thermally compliant beams", T.Chainer, Feb 2009.
[4] US Patent 7,473, 577, "Integrated chip carrier with compliant interconnect", T. Chainer Jan 2009.
[5] US Patent Application, US 20090044032A1, "Method, Apparatus and Computer Program Product Providing Instruction Monitoring for Reduction of Energy Usage", T. Chainer Feb 2009.
[6] US Patent Application, US 20090043944A1, "Method, Apparatus And Computer Program Product Providing Energy Reduction When Storing Data In A Memory", T. Chainer, Feb 2009.
[7] M. Iyengar, R. Schmidt, A. Sharma, G. McVicker, S. Shrivastava, S. Sri-Jayantha, Y. Amemiya, H. Dang, T. Chainer, and B. Sammakia, 2005, "Thermal Characterization of Non-raised Floor Air Cooled Data Centers using Numerical Modeling", Proceedings of the Pacific Rim/ASME International Electronic Packaging Technical Conference (InterPACK), Paper number IPACK2005-73387, July 17th-22nd, San Francisco, California.

SOCIETY MEMBERSHIP

IEEE Senior Member
IMAPS

2 TECHNICAL LEAD - Roger R. Schmidt

IBM Fellow, Chief Engineer for Data Center Energy Efficiency
Chair of Corporate Cooling Development Council; Chair of TCC for Power, Packaging and Cooling
Technical leader for STG Power and Cooling Lab Services
Master Inventor with 33rd level plateau; Over 100 technical publications
ASME Fellow
Member, IBM Academy of Technology
Member, National Academy of Engineering

Dr. Schmidt, awarded IBM Fellow in 2009, elected to the National Academy of Engineering in 2005, and the 2004 IEEE Themi Award winner for his significant contributions to electronic cooling, is a recognized expert in the field of electronic cooling and in providing energy efficient solutions for data centers. He recently formed a new team that focuses on providing customers with support in the power and cooling area related to data centers, specifically, developing a number of services offerings for customers as well as hardware solutions. Also he took a leadership role on an academy study on power and cooling of the data center. He has made sustained technical and leadership contributions for cooling our eServer products, from x to z, utilizing such cooling mediums as air, water, and refrigerants. He has published more than 100 technical papers and has 101 patents/patent pending in the area of electronic cooling. Roger has been the technical leader of a number of advanced cooling projects including several water cooling projects currently underway in IBM, specifically the p6 water cooled IH system. He designed and developed the first Coolblue product - rear door heat exchanger for x and pseries products and is now leading the effort for enhanced follow-on products. He was technical leader in the development of the first modular refrigeration unit implemented in IBM's largest servers in 1997 which resulted in a 7% system performance improvement. This highly successful hardware achievement has continued to be employed in five generations of large servers. His knowledge of the electronic cooling and data center cooling has made him a recognized leader in this area and a frequently requested speaker with recent keynote speeches given at EPRI(Electric Power Research Institute), Uptime Institute, 7 x 24 Exchange, NSF, and the Austin Conference on Energy Efficient Design Conference. He has been a consultant to a number of large data centers with IBM clusters and now spends most of his time with customers on their power and cooling issues in the data center. Dr. Schmidt generously contributes his time to a broad range of professional service activities and has organized many international conferences. He interacts with students at universities through his research activities and through teaching.

SUMMARY of IBM CAREER

2009 – Present IBM Fellow, Chief Engineer for Data Center Energy Efficiency
2006 – 2008 Distinguished Engineer, Chief Thermal Architect, IBM Corp.
Technical Lead for Power/Cooling Lab Services
Responsibilities: Develop customer offerings and cooling solutions for customers
2001 - 2005 Distinguished Engineer, IBM Corp.
1999 - 2001 Senior Technical Staff Member, IBM Corp.
1997 - 1999 Senior Engineer, Thermal Architect, IBM Corp.
Responsibilities: Develop strategies and cooling technologies for future IBM products. Team leader on a number of advanced cooling projects including several water cooling projects that will apply to near-term products.
1993 - 1997 Senior Engineer, Team lead on first refrigeration system for largest IBM server
Responsibilities: Project lead to design, develop and implement refrigeration system for microprocessor cooling
1988 - 1993 Manager Water Cooling Group, Senior Engineer, IBM Corp.
Responsibilities: Manager of technical group responsible for all water cooling aspects of mainframes
1984 - 1988 Manager Air Cooling Group, Advisory Engineer, IBM Corp.

Responsibilities: Manager of technical group responsible for all air cooling aspects of IBM's mainframes
1980 - 1984 Advisory Engineer, Team Lead on first water to air cooling unit, IBM Corp.
Responsibilities: Lead engineer on first water to air cooling unit and provided thermal profile of the TCM

CURRENT PROFESSIONAL ACTIVITIES

- Chair of International (ASHRAE) committee on Mission Critical Facilities, 2006 - 2008
- General Chair Interpack (ASME International Conference on Electronic Packaging) , 2007
- Vice Chair of National Academy of Engineering Peer Review Committee, 2007
- Advisory board, National Electronic and Manufacturing Initiative (iNEMI), 2001 - present
- Associate Editor, ASHRAE Journal of Research, 2005 - present and ASME Journal of Heat Transfer, 2006 - 2009
- Associate Editor, Journal of Electronic Packaging, 1996-2001
- Teaching for New York State Mechanical Engineer Professional Engineering Exam, 1984 - present
- President of Mechanical Engineering Advisory Board, Bradley University, 2002-2006
- Mentor for New York State Energy Research on Data Centers - 2004 - present
- Advisory Board for Energy Efficient Data Centers - Lawrence Berkeley National Lab - 2004 -present
- Advisor to ONR (Office of Naval Research) on 5 year project on enhanced electronic cooling

EDUCATION

B.S.M.E., 1968, Mechanical Engineering, Bradley University, Peoria, Illinois
M.S.M.E., 1969, Mechanical Engineering, U. Of Minnesota, Mpls., Minnesota
Westinghouse Nuclear Power Engineering School, 1970, Bettis Atomic Power Lab, Pittsburgh
Ph.D., 1977, Mechanical Engineering, U. of Minnesota, Mpls., Minnesota

3 THERMAL ENGINEER – Madhusudan Iyengar

2455 S. Road, IBM-P520, Poughkeepsie, NY 12601, 845-433-3708, mki@us.ibm.com.

Server & Data Center Cooling R&D Accomplishments

At IBM, Dr. Iyengar has been intimately involved in the development of future high performance energy efficient cooling technology for servers and data centers. He is the co-inventor and co-developer of the IBM proprietary Mobile Measurement Technology (MMT) which is a data center energy efficiency service offering from STG Lab Services. He is also the co-inventor of liquid cooling concepts for the p-series IH HPC water cooled product, and of the iDataplex heat exchanger product. He was responsible for the thermal modeling and visualization of the Cool Blue Rear Door Heat Exchanger product, the thermal qualification of the Side Car enclosed rack liquid cooling product, the iDataplex Rear Door Heat Exchanger product, and the thermal optimization and testing of the ASC Purple supercomputer.

EDUCATION

Ph.D., Mechanical Engineering, March 2003, University of Minnesota, Minneapolis, MN.
B.E., Mechanical Engineering, June 1994, University of Pune, Pune, India.

JOB HISTORY

International Business Machines, October 2003 - present, Advanced Thermal Lab, System & Technology Group.
Description: Current responsibilities as Senior Engineer include invention and development of advanced thermal design concepts, heat transfer analyses, modeling, and experimentation, as well as CAD and manufacture of product prototypes of cooling hardware for computers.
Purdue University, April 2003 - October 2003, School of Mechanical Engineering, NSF - Cooling Technologies Research Center.
Description: Conducted post-doctoral research to develop methodology and software to perform optimization and "design for manufacturability" of high performance micro-channel and heat exchanger based liquid cooling systems for electronics applications.
University of Minnesota, September 1995 - March 2003, Mechanical Engineering.
Description: Graduate research was focused on the development of methodologies and software for cost-effective, energy-efficient, and minimum-mass, optimal designs of thermal/hydraulic products with an emphasis on air-cooled heat sinks.

HONORS & PROFESSIONAL ACTIVITIES

- Inducted as IBM Master Inventor in 2006 for Intellectual Property contributions.
- 1-23rd IBM Invention Achievements Awards between 2004 and 2009.
- 2008 IBM Research Division Award for "Data Center Mobile Measurement Technology."
- 2008 IEEE-ITherm Best Paper award in energy efficient electronics track for data center paper.
- 2009 IEEE-CPMT Outstanding Young Engineer Award.
- Active member of ASME, IEEE, ASHRAE, and IMAPS.
- PhD committee member for data center cooling research at Georgia Institute of Technology
- Promoting interest in Math, Science, and Engineering among local schools.
- Chair of "System Liquid Cooling" session at the IEEE ITherm Conference in 2006.
- Chair and co-chair of two Liquid Cooling sessions at the IEEE ITherm Conference in 2008.
- Reviewed over 50 papers for thermal sciences journals and conferences.
- Program committee member for the 2007 and 2008 IBM conferences on "Energy Management in Data Centers" in New York.
- Industry Track Co-chair for the 2009 ASME InterPACK conference in San Francisco, July.

PATENTS & PUBLICATIONS

- 33 issued US patents, 40 patents pending, and 13 IBM technical disclosures.
- 75 technical papers in journals, conference proceedings, book chapters, & other publications.

SELECTED ISSUED PATENTS

[1] U.S. Patent 7,450,385, *"Liquid-Based Cooling Apparatus for an Electronics Rack"*.

[2] U.S. Patent 7,408,776, *"Conductive Heat Transport Cooling System and Method for a Multi-Component Electronic System"*.

[3] U.S. Patent 7477514, *"Method of Facilitating Cooling of Electronics Racks of a Data Center Employing Multiple Cooling Stations"*.

[4] U.S. Patent 7,397,661, *"Cooled Electronics System and Method Employing Air-to-Liquid Heat Exchange and Bifurcated Air Flow"*

[5] U.S. Patent 7,286,351, *"Apparatus and Method for Facilitating Cooling of an Electronics Rack Employing a Closed Loop Heat Exchange System"*.

[6] U.S. Patent 7,086,247, *"Cooling System and Method Employing Auxiliary Thermal Capacitor Unit for Facilitating Continuous Operation of an Electronics Rack"*.

[7] U.S. Patent 7,349,213, *"Coolant Control Unit, and Cooled Electronics System and Method Employing the Same"*.

[8] U.S. Patent 7,380,409, *"Isolation Valve and Coolant Connect/Disconnect Assemblies and Methods of Fabrication for Interfacing a Liquid Cooled Electronics Subsystem and an Electronics Housing"*.

[9] US Patent 7,366,632, *"Method and Apparatus for Three-Dimensional Measurements"*.

[10] U.S. Patent 7,400,505, *"Hybrid Cooling System and Method for a Multi-Component Electronics System"*.

SELECTED PUBLICATIONS

[1] R. Schmidt, and M. Iyengar, 2007, "*Best Practices for Data Center Thermal and Energy Management -Review of Literature*," Proc. of the ASHRAE Annual Winter Mtg., DA-07-022.

[2] R. Schmidt and M. Iyengar, 2009, *"Thermodynamics of Information Technology Data Center"*, IBM J. of Research and Development, Vol. 53, No. 3, Paper 9.

[3] M. Iyengar & R. Schmidt, 2009, *"Analytical Modeling for Thermodynamic Characterization of Data Center Cooling Systems"*, ASME J. of Elec. Packaging, Vol. 131, June.

[4] M. J. Ellsworth, Jr., L.A. Campbell, R.E. Simons, M.K. Iyengar, R.R. Schmidt, and R.C. Chu, 2008, "*The Evolution of Water Cooling for Large IBM Large Server Systems: Back to the Future*", Proceeding of the 11th IEEE ITherm Conference, Orlando, Florida, USA, May 27th-31st.

[5] R. Schmidt, E. Cruz, and M. Iyengar, 2005, "*Challenges of Data Center Thermal Management*", IBM J. of Research & Development, Vol. 49, No. 4/5, July/September.

[6] R. Schmidt, R. Chu, V. Kamath, M. Ellsworth, M. Iyengar, D. Porter, and B. Lehman, 2005, "*Maintaining Datacomm Rack Inlet Temperatures with Water Cooled Heat Exchangers*", Proceedings of the Pacific Rim/ASME International Electronic Packaging Technical Conference (InterPACK), Paper number IPACK2005-73468, July 17th-22nd, San Francisco, California

[7] B.K Furman, P.A. Lauro, D.Y.Shih, T.Van Kessel, Y. Martin, E.G. Colgan, W. Zou, S. Iruvanti, J.Wakil, R Schmidt and M.K. Iyengar, "*Metal TIMs for High Power Cooling Applications*", IMAPS Symposium - Advanced Thermal Workshop, October.

[8] R. Schmidt, M. Iyengar, and R. Chu, 2005, "*Data Centers - Meeting Data Center Temperature Requirements*", ASHRAE Journal, April, pp. 44-49.

[9] H. Hamann, J. Lacey, M. O'Boyle, R. Schmidt, and M. Iyengar, 2008, "*Rapid Three Dimensional Thermal Characterization of Large Scale Computing Facilities*", IEEE Transactions of Components and Packaging Technologies, Vol. 31, No. 2, June, pp. 444-448.

[10] A. Bar-Cohen, R. Bahadur, and M. Iyengar, 2006, "Least-energy Optimization of Air-Cooled Heat Sinks for Sustainability – Theory, Geometry, and material Selection", Energy, Volume 31, Issue 5, April 2006, Pages 579-619.

4- Research Scientist - Yves Martin

IBM, T.J.Watson Research Center, 1101 Kitchawan Rd, Yorktown Heights NY 10598

Dr. Yves Martin has been a research scientist at IBM Thomas J. Watson Research Center, Yorktown Heights since 1986. He has worked on a number of projects related to semiconductor manufacturing and packaging, including testing and characterization, and high precision metrology. He has been involved in the invention and development of several forms of Atomic Force Microscopies (AFM), for metrology and surface characterization on a nanometer scale. He has explored novel near-field inspection techniques involving electric fields over a wide range of frequencies, from DC to optical wavelengths (via focused laser beams) and to X-rays. He has also contributed to the fields of high density data storage (thermal-assisted magnetic storage) and nano-imprint lithography (pattern formation and registration). For the past 5 years, he has focused his work on high-power processor cooling solutions, and particularly on the development of novel metallic thermal interfaces. He has published much of his work and holds 30+ patents in these areas. He obtained his Ph.D. in electrical engineering from University College, London, in 1985, and his engineering degree in physics from Grenoble Institute of Technology, France, in 1981.

Present research activity:

2004-2009 **Development of improved cooling solutions** for high performance processors, particularly novel metal thermal interfaces as part of processor cooling packages. Emphasis is on metal interfaces that can be directly applied between processors and efficient heat-sinks containing heat-pipes or a water-chamber.

Past activities at IBM research:

1. Scanned Probe Microscopy

Invention and development of several forms of scanned probe microscopy (following the Nobel Prize award to IBM researchers Binnig and Rohrer), in particular:

- non-contact AFM (Atomic Force Microscope) for profiling on a nanometer scale.
- magnetic force microscope: obtained the first images of magnetic fields
- electrical force microscope: first maps of electrical fields on a sub-100nm scale.
- apertureless near-field optical microscopy, with resolution on a few nanometer scale.

2. In-line SXM metrology tool

Development of an automated Atomic Force Microscope for metrology and process control in semiconductor manufacturing lines. Equipped with a boot-shaped tip and a novel scanning method, provided capability for accurate CD (Critical Dimension) metrology on a one nanometer scale.

3. Near-Field techniques for high-density storage:

Explored thermal and optical near-field effects for high density storage, and demonstrated read-out of high-density data (50nm data patterns) by near-field optical sensing.

4. Thermal Assisted Magnetic Recording: developed a novel recording head, where combined application of heat and magnetism boosted the recording density.

5. Nano X-Ray: invented a nano X-Ray source, and demonstrated X-Ray imaging and spectroscopy on a 100nm scale, with a potential to reach a 10nm scale.

6. Nano-imprint lithography: demonstrated multi-level registration on a nanometer scale, as well as a new method for robust pattern transfer.

PATENTS - selected among 30+ patents:

US5,347,854 Two dimensional profiling with a contact force atomic force microscope
US5,578,745 Calibration standards for profilometers and methods of producing them
US6,757,235 Assembly suitable for reading data based on thermal coupling
US7,280,297 Opt. storage syst. using an antenna for recording data to a phase-change medium
US7,262,936 Heating device and magnetic recording head for thermally assisted recording

US7,130,379 Device and method for generating an x-ray point source by geometric confinement
US20060147820A1 Phase Contrast Alignment Method and App. for Nano Imprint Lithography
US7,186,977 Method for Trench Depth Measurement using E-beam Source and X Ray Detection
US7,063,127 Method & Apparatus for Chip Cooling
US7,219,713 Heterogeneous thermal interface for cooling
US7,265,977 Active liquid metal thermal spreader

PUBLICATIONS - selected list among 40+ papers:

- Y.Martin : "In situ study of electromigration by Joule displacement microscopy", IEE Proc., Vol.132, Pt.I, No.1, Feb.1985, pp.9-12
- Y.Martin, C.C.Williams, and H.K.Wickramasinghe : "Atomic force microscope - force mapping and profiling on a sub 100 ang. scale", J.Appl.Phys., Vol.61, 1987, p.4723
- Y.Martin and H.K.Wickramasinghe : "Magnetic Imaging by 'Force Microscopy' with 1000 angstrom resolution", Appl.Phys.Lett., Vol.50, 1987, p.1455
- Y.Martin, D.W.Abraham, and H.K.Wickramasinghe: "High resolution capacitor-charge measurements and potentiometry by AFM" Appl.Phys.Lett., Vol.52, 1988, p.1103
- Y.Martin and H.K.Wickramasinghe, "Method for imaging side-walls by atomic force microscopy", Appl.Phys.Lett. 64 (19), May 1994, p.2498.
- "Scanning Probe Microscopes - Design and Applications", SPIE Milestone Series, MS 107, Ed. by Y.Martin, Feb. 1995.
- F.Zenhausern, Y.Martin and H.K.Wickramasinghe, "Scanning Interferometric Apertureless Microscopy: Optical imaging at 10 Ang. resolution", Science 269, 1083 (1995)
- Y.Martin and H.K.Wickramasinghe, "Precision micrometrology with scanning probes", 28. Future Fab International, 1, 253 (1996)
- Y.Martin and H.K.Wickramasinghe, "Optical Data Storage Read-Out at 256 bits/Square Inch", Appl.Phys.Lett.71 (1), 1 (July 1997)
- Y.Martin, H.Hamann and H.K.Wickramasinghe, "Strength of electric field in Apertureless Near-Field Optical Microscopy", J.Appl.Phys. Vol.89, May 2001 P5774-8
- H.F. Hamann, Y.Martin, H.K.Wickramasinghe, "Thermally-assisted recording beyond the super-paramagnetic limit", Applied Physics Letters, v 84, n 5, 2004, p 810-812
- Y.Martin and T.Van Kessel, "High Performance Liquid Metal Thermal Interface for Large Volume Production", IMAPS (Int.MicroelectronicsAndPackagingSoc.) Thermal and Power Management, San Jose CA, Nov.11-15 2007
- T.Van Kessel, Yves C. Martin, Robert L. Sandstrom, Supratik Guha,, "Extending Photovoltaic operation beyond 2000 suns using a LIQUID METAL THERMAL INTERFACE with passive cooling", Proc. 33rd IEEE PVSC (PhotoVoltaics Specialists Conf.), San Diego, May 11-16 2008

AWARDS:
Elected IBM Master Inventor in 2006
IBM Outstanding Technical Achievement Award 1992
IBM Outstanding Innovation Award 1991

EDUCATION:
1993 Graduate course: Object oriented programming in C++, Polytech.Univ. NY
1985 Ph.D. in Electrical Engineering, University College London, England
1981 D.E.A. (Diploma of advanced study, equiv. M.S.) University of Grenoble, France
1881 Dipl.Ing. (equiv. BsC) U. Genie Physique, Grenoble, France

5 - Vinod Kamath, PhD
Senior Technical Staff Member
Thermal Engineering, Systems & Technology Group, IBM, RTP, NC.

Dr. Vinod Kamath is Senior Technical Staff Member in Thermal Engineering for IBM System x Blade and Modular Products, based in RTP, North Carolina. Dr. Kamath has 17 years of experience in thermal product engineering at IBM. He currently servers in a leadership role for IBM System x brand of products. His product development focus is in the thermal management and systems cooling for rack and blade servers for IBM products using industry standard architecture components, energy efficient, reliable, thermal management for racks and data centers using IBM System-x and Blade Solutions. Dr. Kamath received his Ph.D. in Mechanical Engineering from Johns Hopkins University in 1991 and his B.Tech. in Mechanical Engineering from the Indian Institute of Technology in 1985. He has a more than 10 patents on cooling designs for desktop, portable and server systems.

IBM T.J. Watson Research Center
PO Box 218
Rte 134
Yorktown Heights, NY 10598

July 16, 2009

Department of Energy
Golden Field Office
1617 Cole Boulevard
Golden, Colorado 80401-3393

Attention: Michael Schledorn; Contracting Officer

SUBJECT: IBM's Proposal for DE-FOA-0000107, entitled "*Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces*"

Dear Sir,

In response to the subject FOA, IBM T. J. Watson Research Center is pleased to enclose its Technical and Cost Proposals.

In the event that our proposal is successful, we commit to perform and support the program in accordance with our Technical and Cost Proposals and mutually agreed upon terms and conditions.

IBM has invested substantial amounts of its own private funds in the development of certain technologies embodied by the proposed program, and IBM has an established, commercial, non-governmental trade reputation in these fields of technology. Therefore, any technical data/computer software delivered to the Government under the proposed program in the following areas of technology shall be delivered to the Government with Limited/Restricted Rights respectively as those terms are defined in the Federal Acquisition Regulations.

- US7,063,127 Method & Apparatus for Chip Cooling
- US7,219,713 Heterogeneous thermal interface for cooling
- US7,288,840 Structure for cooling a surface
- US20060157225A1 High Turbulence Heat Exchanger
- US20060131738A1 METHOD AND APPARATUS FOR CHIP COOLING USING A LIQUID METAL THERMAL INTERFACE
- US20080165502A1 PATTERNED METAL THERMAL INTERFACE
- US7440281 Thermal Interface Apparatus
- US20090146294A1 Gasket system for Liquid-Metal Thermal Interface
- US Patent Application - POU9-2008-0140-US1, "Energy Efficient Apparatus and Method for Cooling an Electronics Rack,"
- US 6775137 B2, Method and Apparatus for Combined Air and Liquid Cooling of Stacked Electronic Components,

In the event that you have any technical questions regarding our proposal, please contact Dr. Timothy Chainer at (914) 945-2641 or tchainer@us.ibm.com. Any other questions should be directed to Carl E. "Ed" Taylor at (713) 797-4625 or cetaylor@us.ibm.com.

Thank you for the opportunity to participate in this important program.

Very truly yours,

Carl E. Taylor
Senior Governments Contracts & Negotiations Manager
Business & Government Relations

Applicant Name: IBM Corporation

Award Number: ____________

Budget Information - Non Construction Programs

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds: Federal (c)	Estimated Unobligated Funds: Non-Federal (d)	New or Revised Budget: Federal (e)	New or Revised Budget: Non-Federal (f)	New or Revised Budget: Total (g)
1. Recovery Act: Energy E	81.086			$2,347,801	$586,950	$2,934,751
2.						$0
3.						$0
4.						
5. Totals		$0	$0	$2,347,801	$586,950	$2,934,751

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity (1)	(2)	(3)	(4)	Total (5)
a. Personnel					
b. Fringe Benefits					
c. Travel					
d. Equipment			REDACTED EXEMPTION 4		
e. Supplies					
f. Contractual					
g. Construction					
h. Other					
i. Total Direct Charges (sum of 6a-6h)					
j. Indirect Charges					
k. **Totals** (sum of 6i-6j)	$2,934,751				$2,934,751
7. Program Income	$0				$0

Previous Edition Usable

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

Section C - Non-Federal Resources

(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) **Totals**
8. Recovery Act: Energy Efficient Information and Communication Technology	$555,979	$0	$0	$555,979
9.				$0
10.				$0
11.				$0
12. **Total** (sum of lines 8 - 11)	$555,979	$0	$0	$555,979

Section D - Forecasted Cash Needs

	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th quarter
13. Federal	$0				
14. Non-Federal	$0				
15. **Total** (sum of lines 13 and 14)	$0	$0	$0	$0	$0

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project

	Future Funding Periods (Years)			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16. Recovery Act: Energy Efficient Information and Communication Technology				
17.				
18.				
19.				
20. **Total** (sum of lines 16-19)	$0	$0	$0	$0

Section F - Other Budget Information

21. Direct Charges	22. Indirect Charges	Provisional Rates, applied proportionally to labor, total indirect expense of $555979.43

23. Remarks IBM has an accounting system that has been approved by the Defense Contract Audit Agency (DCAA). The 2009 rates have been provisionally approved by the DCAA. The DCAA contact is Mr. Robert F. LeJeune, Branch Manager, GCBO at (203) 416-6905.

Instructions for the SF-424A

Public Reporting Burden for this collection of information is estimated to average 3.0 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Please do not return your completed form to the Office of Management and Budget; send it to the address provided by the sponsoring agency.

General Instructions
This form is designed so that application can be made for funds from one or more grant programs. In preparing the budget, adhere to any existing Federal grantor agency guidelines which prescribe how and whether budgeted amounts should be separately shown for different functions or activities within the program. For some programs, grantor agencies may require budgets to be separately shown by function or activity. For other programs, grantor agencies may require a breakdown by function or activity. Sections A, B, C, and D should include budget estimates for the whole project except when applying for assistance which requires Federal authorization in annual or other funding period increments. In the later case, Sections A, B, C, and D should provide the budget for the first budget period (usually a year) and Section E should present the need for Federal assistance in the subsequent budget periods. All applications should contain a breakdown by the object class categories shown in Lines a-k of Section B.

Section A. Budget Summary Lines 1-4 Columns (a) and (b)
For applications pertaining to a **single** Federal grant program (Federal Domestic Assistance Catalog number) and **not requiring** a functional or activity breakdown, enter on Line 1 under Column (a) the catalog program title and the catalog number in Column (b).

For applications pertaining to a **single** program **requiring** budget amounts by multiple functions or activities, enter the name of each activity or function on each line in Column (a), and enter the catalog number in Column (b). For applications pertaining to multiple programs where none of the programs require a breakdown by function or activity, enter the catalog program title on each line in **Column** (a) and the respective catalog number on each line in Column (b).
For applications pertaining to **multiple** programs where one or more programs **require** a breakdown by function or activity, prepare a separate sheet for each program requiring the breakdown. Additional sheets should be used when one form does not provide adequate space for all breakdown of data required. However, when more than one sheet is used, the first page should provide the summary totals by programs.

Lines 1-4, Columns (c) through (g)

For new applications, leave Columns (c) and (d) blank. For each line entry in Columns (a) and (b), enter in Columns (e), (f), and (g) the appropriate amounts of funds needed to support the project for the first funding period (usually a year).

For continuing grant program applications, submit these forms before the end of each funding period as required by the grantor agency. Enter in Columns (c) and (d) the estimated amounts of funds which will remain unobligated at the end of the grant funding period only if the Federal grantor agency instructions provide for this. Otherwise, leave these columns blank. Enter in columns (e) and (f) the amounts of funds needed for the upcoming period. The amount(s) in Column (g) should be the sum of amounts in Columns (e) and (f).

For supplemental grants and changes to existing grants, do not use Columns (c) and (d). Enter in Column (e) the amount of the increase or decrease of Federal funds and enter in Column (f) the amount of the increase or decrease of non-Federal funds. In Column (g) enter the new total budgeted amount (Federal and non-Federal) which includes the total previous authorized budgeted amounts plus or minus, as appropriate, the amounts shown in Columns (e) and (f). The amount(s) in Column (g) should not equal the sum of amounts in Columns (e) and (f).

Line 5—Show the totals for all columns used.

Section B. Budget Categories
In the column headings (a) through (4), enter the titles of the same programs, functions, and activities shown on Lines 1-4, Column (a), Section A. When additional sheets are prepared for Section A, provide similar column headings on each sheet. For each program, function or activity, fill in the total requirements for funds (both Federal and non-Federal) by object class categories.

Lines 6a-i—Show the totals of Lines 6a to 6h in each column.

Line 6j—Show the amount of indirect cost.

Line 6k—Enter the total of amounts on Lines 6i and 6j. For all applications for new grants and continuation grants the total amount in column (5), Line 6k, should be the same as the total amount shown in Section A, Column (g), Line 5. For supplemental grants and changes to grants, the total amount of the increase or decrease as shown in Columns (1)-(4), Line 6k should be the same as the sum of the amounts in Section A, Columns (e) and (f) on Line 5.
Line 7—Enter the estimated amount of income, if any, expected to be generated from this project. Do not add or subtract this amount from the total project amount. Show under the program narrative statement the nature and source of income. The estimated amount of program income may be considered by the federal grantor agency in determining the total amount of the grant.

Section C. Non-Federal Resources

Lines 8-11—Enter amounts of non-Federal resources that will be used on the grant. If in-kind contributions are included, provide a brief explanation on a separate sheet.

Column (a)—Enter the program titles identical to Column (a), Section A. A breakdown by function or activity is not necessary.

Column (b)—Enter the contribution to be made by the applicant.

Column (c)—Enter the amount of the State's cash and in-kind contribution if the applicant is not a State or State agency. Applicants which are a State or State agencies should leave this column blank.

Column (d)—Enter the amount of cash and in-kind contributions to be made from all other sources.

Column (e)—Enter totals of Columns (b), (c), and (d).

Line 12—Enter the total for each of Columns (b)-(e). The amount in Column (e) should be equal to the amount on Line 5, Column (f) Section A.

Section D. Forecasted Cash Needs

Line 13—Enter the amount of cash needed by quarter from the grantor agency during the first year.

Line 14—Enter the amount of cash from all other sources needed by quarter during the first year.

Line 15—Enter the totals of amounts on Lines 13 and 14.

Section E. Budget Estimates of Federal Funds Needed for Balance of the Project

Lines 16-19—Enter in Column (a) the same grant program titles shown in Column
(a), Section A. A breakdown by function or activity is not necessary. For new applications and continuation grant applications, enter in the proper columns amounts of Federal funds which will be needed to complete the program or project over the succeeding funding periods (usually in years). This section need not be completed for revisions (amendments, changes, or supplements) to funds for the current year of existing grants.
If more than four lines are needed to list the program titles, submit additional schedules as necessary.

Line 20—Enter the total for each of the Columns (b)-(e). When additional schedules are prepared for this Section, annotate accordingly and show the overall totals on this line.

Section F. Other Budget Information

Line 21—Use this space to explain amounts for individual direct object-class cost categories that may appear to be out of the ordinary or to explain the details as required by the Federal grantor agency.

Line 22—Enter the type of indirect rate (provisional, predetermined, final or fixed) that will be in effect during the funding period, the estimated amount of the base to which the rate is applied, and the total indirect expense.

Line 23—Provide any other explanations or comments deemed necessary.

Instructions and Summary

Award Number: ______________________

Award Recipient: ______________________

Date of Submission: ______________________

Form submitted by: IBM Corporation

(May be award recipient or sub-recipient)

Please read the instructions on each page before starting.

If you have any questions, please ask your DOE contact. It will save you time!

On this form, provide detailed support for the estimated project costs identified on the SF-424A form (Budget).

- The dollar amounts on this page must match the amounts on the associated SF-424A.
- The award recipient and each sub-recipient with estimated costs of $100,000 or more must complete this form and a SF-424A form.
- The total budget presented on this form and on the SF424A **must include both Federal (DOE), and Non-Federal (cost share) portions**, thereby reflecting TOTAL PROJECT COSTS proposed.
- For costs in each Object Class Category on the SF-424A, complete the corresponding worksheet on this form (tab at the bottom of the page).
- All costs incurred by the preparer's sub-recipients, vendors, contractors, consultants and Federal Research and Development Centers (FFRDCs), should be entered only in section f. Contractual. All other sections are for the costs of the preparer only.

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)
. Personnel						
. Fringe Benefits						
. Travel						
. Equipment						
. Supplies						
. Contractual						
Sub-recipient						
FFRDC						
Vendor						
Total Contractual						
. Construction						
. Other Direct Costs						
Indirect Charges						
otal Project Costs	$1,915,532	$1,019,219	$0	$2,934,751	100.0%	

dditional Explanations/Comments (as necessary)

Economizer Based Data Center Liquid Cooling with Advanced Metal Interfaces
TEAM DOCUMENT

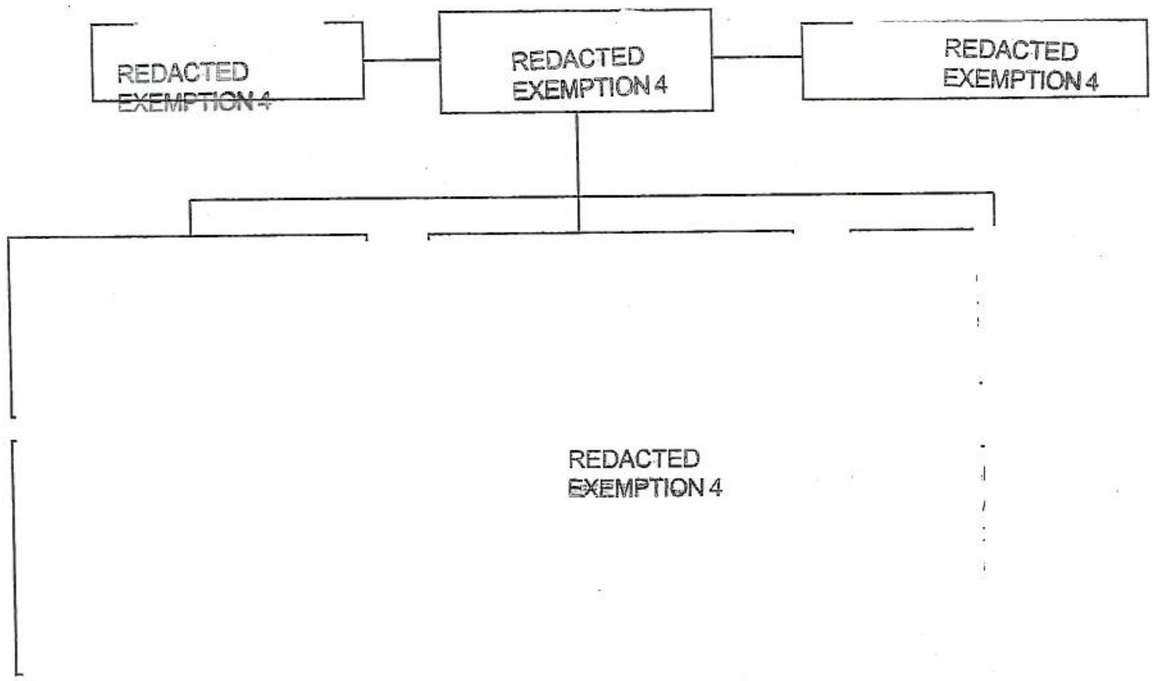
Table 1 details all the participating technical team members and describes their roles.

Table 1: Team roles for this project

Personnel	Role	Time	Expertise	IBM Division
				Research
				Systems & Technology
				Research
				Systems & Technology
	REDACTED EXEMPTION 4			Systems & Technology
				Systems & Technology
				Systems & Technology
				Research
Research Post Doctoral Fellow				Research

Figure 1 illustrates the organizational hierarchy for this project.

Figure 1: Project Organizational Chart


REDACTED EXEMPTION 4
REDACTED EXEMPTION 4
REDACTED EXEMPTION 4
REDACTED EXEMPTION 4