U.S. Department of Energy
Energy Efficiency and Renewable Energy

industrial technologies program

DOE Sensors & Automation 2007 Annual Portfolio Review

PROJECT SUMMARY FORMS

sensors expo
& conference

Rosemont, Illinois
June 13, 2007

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ADMINISTRATIVE INFORMATION

1. **Project Name:** Eaton Wireless Sensor Network for Advanced Energy Management Solutions
2. **Lead Organization:** Eaton Corporation
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   Milwaukee, WI 53216
3. **Principal Investigator:** Peter J. Theisen
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   (414) 449-6924
4. **Project Partners:** Red Wing Technologies – Brian Bischoff
   Georgia Institute of Technology – Dr. Thomas Habetler
   Truva – Dr. Ian Akildyz
5. **Date Project Initiated:** 1/1/2004
6. **Expected Completion Date:** 6/30/2009

PROJECT RATIONALE, STRATEGY, AND METRICS

7. **Big Picture Overview:** U.S. Department of Energy (DoE) research has shown that industrial motor energy use could be reduced by 11 to 18 percent if proven methods typically used on larger motor systems could be widely deployed. DoE estimates that electric motor-driven systems used in industrial processes consumed 679 billion kWh, or 23 percent of all electricity sold in the United States. Implementation of advanced energy management monitoring and diagnostic systems in medium and large electric motor (>200 HP) applications has proven dramatic energy savings, economic benefits, and reduced environmental impacts. However, 98% of all electric motors in the U.S. industry are small motors <200 HP and they consume 71% of all electrical energy used in industrial process plants. If monitoring, protection and prognostic systems similar to the ones for large electric motors were implemented for small electric motors, the DoE estimates industry would realize 11-18% energy savings in process areas. The goal of this project is to achieve this level of energy savings by the use of novel, non-intrusive energy, efficiency, and wellness monitoring enabled by wireless sensor networks.

8. **Project Description:** The focus of the project is to research, test, develop and deploy a Wireless Sensor Network (WSN) for advanced energy management solutions. To accomplish this vision, the proposed WSN will: 1) operate with a variety of open wireless protocols, 2) self-configure a network that will operate robustly and securely in harsh industrial environments, and 3) inferential energy, efficiency, and wellness monitoring enabled by wireless sensor networks.

9. **Core Technology and Novel Element:** The core technology to be created is an open architecture, low-cost, robust, self-configuring wireless network operating in industrial environments for the Industries of the Future. That network will gather energy data based on Eaton's novel on-line non-intrusive inferential algorithms for energy estimation and condition-based monitoring of electric motors and connected loads.

10. **Technology Applicability:**
    - Aluminum
    - Chemicals
    - **Forest Products**
    - Glass
    - Metal Casting
    - Mining
    - **Petroleum Refining**
    - Steel

11. **Project Objective:** Eaton's Wireless Sensor Network team is researching, testing, and developing a Wireless Sensor Network (WSN) to enable significant energy savings and Advanced Energy Management Solutions for Electric Motors in the Industries of the Future. The WSN will support open wireless protocols and be self-configuring, robust, and secure in industrial environments, and will enable Eaton's novel online electric motor energy and condition-based monitoring.

12. **Project Deliverables:**
    - Requirements – Completed 12/2004
    - Baseline Network – Completed 12/2004
    - Alpha Testing – est completion 6/2007
    - Wireless Security – est completion 6/2007
    - Energy/Efficiency/Wellness algorithms development and testing
    - Advanced WSN – est completion 9/2007
    - Commercialization Plan - Continuing
    - Wireless Prognostics / Diagnostics – Phase III

13. **Technical Barrier(s) Being Addressed:**
    - Pervasive sensing enabled by Wireless Sensor Networks can realize 11-18% improvements in industrial energy efficiency only when those networks operate robustly in harsh industrial environments, accommodate electromagnetic compatibility and interference issues, and are implemented in a way that is both low cost and interoperable.
    - Effective deployment requires an architecture that is both low cost and powerful enough to run the Eaton's novel inferential algorithms for on-line energy measurement and efficiency/wellness estimations for electric motors and connected loads.

14. **Project Pathway:** Development of robust, self-configuring wireless sensor networks for advanced energy management solutions. Advanced modeling to develop and design on-line electric motor energy/wellness monitoring systems using distributed data. Eaton's positioning as thought leaders and industry drivers through IEEE802.15.4, ISA/SP-100, AADL and the ZigBee Alliance to promote interoperability and rapid commercialization across industries. Communication of value proposition to customers focusing on uptime and return on investment (ROI).

15. **Energy Savings - How:** Wireless sensor networks and non-intrusive inferential algorithms remove cost barriers allowing energy, efficiency, and wellness estimation to be applied to small motors using only existing sensors, thus reaping the energy saving potential that exists.

16. **Energy Savings - Quantity:** DoE estimates that industrial motor systems consumed 619 billion kWh, or 23% of all electricity sold in the United States. Using conservative DoE-based data yields significant electrical energy savings of 279 Trillion Btu's per year by 2020. U.S. Department of Energy (DoE) research has shown that industrial motor energy use could be reduced by 11 to 18 % if proven methods used on larger motor systems could be widely deployed.

17. **Other Important Benefits and Metrics:**
    - 11% to 18% energy reduction in industrial motor energy consumption by 2020.
    - 80% cost saving in the deployment of wireless vs. wired sensors.
    - Creation / Adoption / Deployment of Wireless Industrial Communications Standards.

PROJECT PLANS AND PROGRESS

18. **Past Accomplishments:**
    - **Requirements – Completed 12/2004**
    - **Baseline Network – Completed 12/2004**

- **Alpha Testing – est completion 6/2007**
  - These tests defined for the Advanced WSN and inferential algorithms will continue to be performed at customer/partner locations, in both laboratory and industrial environments. The results will guide future commercialization and product development decisions.
- **Wireless Security – est completion 6/2007**
  - Wireless security protocols will be implemented in the generation II hardware.
- **Advanced Energy Management – est completion 9/2007**
  - Completed Phase II Interim Demo - Lab-based demo of Advanced Wireless Network and On-line Energy Monitoring System.
  - Developed and tested 10+ innovative methods for evaluating in-service motor efficiency, wellness, and energy consumption. These nonintrusive methods use only motor voltages and currents to estimate motor parameters such that no additional physical sensors are needed.
  - Improved the robustness of algorithms (pump cavitations, bearing, efficiency, rotor faults, winding temperature, misalignment, etc) through extensive lab and field tests.
  - 3 Gen-1 hw/sw prototype systems have been tested in Weyerhaeuser paper plant since November 2006. 6 Gen-1 systems are tested in Milwaukee Eaton Innovation Center since January 2007.
  - Using the data from field tests, the effects of various motor types and load conditions on algorithm accuracies have been analyzed.
  - Identified the optimum software architecture for algorithm integration.
- **Advanced WSN – est completion 9/2007**
  - Developed a wireless network assessment suite that can be rapidly deployed to assess network reliability and performance in a given environment. Wireless performance data collection and analysis is underway using this system.
  - Development of simulation models to analyze and predict wireless performance for different channel conditions is underway.
  - Developed an open architecture for creating commercial grade wireless life-cycle tools that will reduce the cost of ownership of industrial wireless networks. A wireless commissioning tool is being developed based on this architecture.
  - Working on the definition of industrial standards for wireless sensor networking. The Eaton WSN team continues participating actively in standards committees and industry consortia, including the IEEE 802.15.4, Zigbee, ISA/SP-100 and SAE/IEEE AADL.standards committee.
- **Commercialization Plan - Continuing**
  - A Wireless Steering Committee was established with the Eaton Electrical business to integrate wireless technology into Eaton Electrical strategic plans.
  - Energy, efficiency, wellness is added to Eaton's Industrial Control's Division (ICD) technology roadmap and strategic plan.
  - Eaton will assess how to integrate wellness into its services offerings
  - Key wellness/efficiency algorithms have been identified by the Eaton ICD technology groups. Several algorithms have been tested on Eaton product hardware platform.

19. Milestones:

- December 2006: Concept Feasibility Demonstration performed - Laboratory-based demonstration of advanced wireless network and on-line energy monitoring estimators addressing industrial environment and application conditions
- December 2007: Concept Validation Demonstration performed – Demonstration in end-user facility using test / prototype hardware. Wireless / inferential systems may be tested separately.
- November 2008: Integrated Concept Validation Demonstration performed — Demonstration at end-user facility of integrated wireless / inferential / actionable / information system
- March 2009: All external testing completed
- May 2009: Draft final report completed

- June 2009: Commercialization plan report completed
- June 2009: Final program report completed

20. Project Changes: No project changes since last report. DoE / Eaton have mutually agreed on a six-month, no-cost extension to this project. Eaton is proposing accelerated timeline to complete project by December 2008.

21. Next Steps:

- Design, develop and test a unique set of wireless reliability and performance enhancement mechanisms that will assure accepted performance level of wireless networks in dynamic RF environment conditions. This has the potential of dramatic improvement of communication performance to minimize the adverse effect of coexistence, EMI and EMC.
- Continue aggressive testing of wireless networks with above enhancements and commercial grade wireless commissioning tool at customer sites.

22. Commercialization Plans and Activities:

- End Use Application - The technology will be applied in a replacement for the Overload Relay/Meter in a motor control center application
- Plans for implementation - Eaton is in the early phases of developing a motor wellness platform which will provide the overload relay, metering, power quality monitoring, and motor prognostic capabilities. The technologies developed in this program will become part of this product platform.
- Product - A hybrid of an Overload Relay and Power Meter with added features of Power Quality monitoring / inferential-based Prognostics & Diagnostics for motor and many connected loads
- Marketing is clarifying the end customer value proposition of energy savings and commercial payback of deploying the products resulting from this project.
- The Eaton team held a product and service strategy review for the motor wellness platform with the VP/GM of the Industrial Components Division and the CTO of Eaton in March 2007, resulting in commitment of engineering and marketing resources to develop the product/service roadmaps to launch the motor wellness platform.

23. Payback: Industrial users of the technology developed here will save significant amounts of energy, with a return of investment of 18 to 24 months. Actionable information from this platform takes the form of capital appropriations/proposals for new equipment with the estimated payback time.

24. Patents, Publications, Presentations:

- Bin Lu, Thomas G. Habetler, Ronald G. Harley, José A. Gutiérrez, and David B. Durocher, "Applying wireless sensor network in industrial plant energy evaluation and planning systems," IEEE Industrial Applications Magazine, vol. 13, no. 2, pp. 17-23, March/April 2007.
- Eaton/Georgia Tech "A nonintrusive efficiency estimation method for in-service motor testing using a modified induction motor equivalent circuit," IEEE Pow Electron. Spec. Conf., Jeju, Korea, 2006.
- Eaton / Georgia Tech "A nonintrusive and in-service motor efficiency estimation method using air-gap torque with considerations of condition monitoring," & "A novel motor energy monitoring scheme using wireless sensor networks," in Proc. IEEE Ind. Appl. Annu. Meeting, Tampa, Oct. 2006.
- Eaton proposed new language extension areas in wireless sensor networks for architecture and reliability analysis and assessment at the SAE/IEEE AADL industry standards committee held from Sept 24-26, 2006 in Jacksonville, FL.
- Theisen, Peter J. "Applying Wireless Sensor Networks in Industrial Plant Energy Evaluation and Planning Systems" at the IEEE Pulp and Paper Conference, 2006.
- Eaton presented a paper at the Third International Conference on Networked Sensing Systems entitled "An Efficient Graph Theoretic Routing Framework for Industrial Wireless Sensor Networks.""Use AADL to analyze and design your wireless embedded system" in the July issue of Embedded Systems Design, by Hui Cao, Ting Yan, Luis R. Pereira, Sujit R. Das, and Bruce Lewis (US Army)

ADMINISTRATIVE INFORMATION

1. **Project Name:** Distributed Wireless Multi-sensor Technologies

2. **Lead Organization:** General Electric Global Research
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4. **Project Partners:** Sensicast Systems – Subcontractor Wireless Protocols
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5. **Date Project Initiated:** 1/1/2004

6. **Expected Completion Date:** 12/31/2007

PROJECT RATIONALE, STRATEGY, AND METRICS

7. Big Picture Overview

Currently electric motors consume 60% of the electricity consumed by industry. There are also significant costs in waist and lost production time if an unanticipated failure occurs. This project will enable industry to place sensors where it was once not economically viable or technically possible. These additional sensors will provide valuable information about equipment condition and process factors that will allow industry to operate more efficiently. This is a far better solution then traditional wired sensor where wiring cost can range from $40.00/foot to more the $2000.00/foot.

As equipment ages it can become inefficient in its operation. Continuous equipment condition monitoring is currently only done for high value assets because of the cost of installing the sensors required so that much of the equipment is left unmonitored. If sensors can be made which can be installed and maintained easily, the use of equipment monitoring diagnostics and prognostics technologies could proliferate to more assets thus extending proper maintenance practices. Equipment will operate more efficiently and there will be few unscheduled outages and less wasted in process material.

8. Project Description:

In this project we are developing wireless sensor technology that can be used for motor as well as other equipment monitoring and environmental condition monitoring in industrial settings.

9. Core Technology and Novel Element:

We will be using and developing unique wireless networking technologies and applying reliability models of the physical environment that will yield long life and highly reliable wireless sensors.

10. Technology Applicability

- Pharmaceutical

- Petrochemical
- Metals
- Pulp and Paper/Forest Products
- Mining
- Metal Casting
- Power Generation

11. Project Objective:

We will develop and field test wireless sensor technology for the targeted use of equipment condition monitoring applications. These devices must meet the following requirements:

1) Battery life of 5 to 6 years
2) Maintain plant data security
3) Scalable to support plant and enterprise installations up to 10,000 sensor points.
4) Easy to install by factory maintenance personnel

12. Project Deliverables:

- Wireless sensor technology suitable to a broad range of monitoring applications.
- Industrial demonstration which will promote confidence in the technology
- Transition of the technology into industry

13. Technical Barrier(s) Being Addressed:

As equipment ages it can become inefficient in its operation. Continuous equipment condition monitoring is currently only done for high value assets because of the cost of installing the sensors required so that much of the equipment is left unmonitored. If sensors can be made which can be installed and maintained easily, the use of equipment monitoring diagnostics and prognostics technologies could proliferate to more assets thus extending proper maintenance practices. Equipment will operate more efficiently and there will be fewer unscheduled outages and less wasted in-process material. The main technical barriers to achieving these goals are:

1. The wireless channel in industrial environments is harsh and unreliable
2. Wireless devices must have a long battery life to prevent further maintenance issues
3. Network Security is required to minimize plant infrastructure risks
4. Gateways are needed to bridge between different system types and facilitate information flow.

14. Project Pathway:

We are approaching these issues by focusing on the reliability of the system. We have researched the following areas:

1. Characterizing different industrial environments to be able to perform a basic capability analysis.
2. Focusing on the minimizing the amount of data we must communicate and the duty cycle for that communications so that we may maximize battery life at the sensor. In addition, we have focused on low power design techniques and energy consumption tradeoffs.
3. We have been utilizing off the shelf devices, maximizing integration and minimizing physical size to achieve a low cost point so that device cost will not be an issue.
4. We are investigating current wireless network security techniques, utilizing hardware with built in security capabilities and augmenting these as require.
5. At the interface to the end users system we have focused on providing standard protocols such as OPC and ModBus – both widely accepted in the industry. This will allow rapid adoption without the need for further bridging devices.

15. Energy Savings - How:

As motor parameters are measured, devices that may be operating in a degraded state can be identified. By analyzing possible failure modes a period of remaining life can be predicted and maintenance can be scheduled during normal plant outages rather than running a device to failure. By quickly removing devices that are exhibiting poor performance energy will be saved as more efficient devices are installed. In addition, unscheduled outages due to unanticipated failures cause wasted energy during plant idle periods and potentially wasted material and scrap which also have energy associated with their production.

16. Energy Savings - Quantity:

- Projected 2010 Savings – 20 Trillion BTU
- Projected 2015 Savings – 81 Trillion BTU
- Projected 2020 Savings – 122 Trillion BTU

Based on 2002 energy consumption levels.

17. Other Important Benefits and Metrics: Indicate how success or failure will be measured for this project by stating the baseline technical metric(s) and the metric(s) needed for realization of the project objectives.

- Five or more years of battery life.
- Able to be packaged in a robust container suitable for Class I DIV II installations.

PROJECT PLANS AND PROGRESS

18. Past Accomplishments: Note briefly the very most important accomplishments to date.

- Major customer requirements gathered and sensitivity analysis performed.
- Lower power sensor platform designed, prototyped and successfully demonstrated
- Initial networking software designed and implemented tested and debugged
- Typical channel characteristics field data collected and analyzed and applied to the design.
- Component and system level simulations built which include radios, channels, and power consumption.
- Successful deployment of first generation technology in two real applications, these include a Nuclear Power plant and a portable sensor package for steam cycle isolation.
- Deploy 12 alpha nodes 2.4GHz Hybrid Spread Spectrum technology in industrial setting
- Deploy network in operating industrial facility operating with Motor Monitoring Software
- Complete beta testing in operating paper mill monitoring 4 DC motors.
- Developed Network security stack and contracted external audit to verify design
- Organized ISA standards activity to standardize wireless sensing technology to accelerate market adoption
- Transition to product for Pharmaceutical Industry

19. Milestones: Summarize important future milestones **including dates** for the life of this project. Milestones should be the start or the completion of an activity, not the activity itself. [**Note: This item is critical for review of your project.**]

- Standardize and optimization Network operation with Security Q3 07
- Product transition and Beta and preproduction deployment for Motor Monitoring Q3 07
- Promote Standards efforts for wireless sensor networks Q3 07

20. Project Changes

Over the first year of the program we ran into several problems with the development of the networking firmware and algorithms. These problems along with funding delays have delayed the initial deployment of our test network by 6 months and our first field trial by 3 months. However, we have had several successful short duration deployments in experimental settings.

During the course of the project we successfully developed a vibration energy-harvesting device but we concluded through the analysis of field data that sufficient vibrations will not always be available and that batteries will still be required. We have discontinued any development in this area and will evaluate the outcome of other projects in this area.

As we collected and analyzed RF channel data in many locations and compared this to past results published in the literature we discovered that the techniques used in the past do not give us the required information needed to estimate network reliability and to guarantee a level of reliability the system will need to be over designed. Initial simulations have shown that the result of this over designing will cause further reliability issues as the networks grow in size. We have therefore added Northeastern University to our team to help us analyze multipath shape factors that will refine the characterization of the channel particularly as antenna patterns change due to installation restrictions.

The market demand for this technology has been so strong that we have deployed early versions (915MHz Frequency Hopped Spread Spectrum versus 2.4GHz Hybrid Spread Spectrum) of the technology to end users to support specific needs. Two examples of this include motor winding temperature monitoring at San Onofre Nuclear Generation Station which has been successfully monitoring the condition of large motors used to pump cooling water into the facility and GE Energy that has been using this technology for steam cycle isolation in steam turbine generators. The results of these applications have validated our analysis of the reliability gains our research can obtain.

21. Next Steps:

- Field Coexistence testing for dissimilar networks
- Refine installation guidelines tailored to specific installation types to assure system reliability.
- Field trials to gain experience in unforeseen issues and build end user confidence.
- Develop interoperability standards to further facilitate industry wide acceptance.

22. Commercialization Plans and Activities:

Three core businesses within the GE portfolio are supporting the research in this project and are eagerly seeking to take this technology to market. GE Sensing Solutions has been the primary supported to date. GE Consumer and Industrial is awaiting the outcome of this project so that it can move this technology into applications such as building energy control through aggregation and motor protection through performance monitoring. GE Energy is currently utilizing an earlier version of this technology in steam cycle isolation in power plants and if successful, GE Optimization services (Bently Nevada) will incorporate this product into future offerings of System One – a leading diagnostics and maintenance package for equipment monitoring.

23. Payback:

- Reduced unplanned outages
- Lower energy consumption
- Increased plant utilization and productivity.

24. Patents, Publications, Presentations: List number and reference, as applicable. (Do not include S&A annual review presentations.)

1. Wireless Mesh Networks: How Radios Really Perform; Sensors Magazine Jan 2005
2. Radio Channel Quality in Industrial Wireless Sensor Networks; IEEE SICON 2005
3. Wireless Mesh Condition Based Monitoring; 51st International Instrumentation Symposium 2005

ADMINISTRATIVE INFORMATION

1. Project Name: Wireless Network for Secure Industrial Applications
(Part A of "Wireless and Sensing Solutions Advancing Industrial Efficiency")

2. Lead Organization: Honeywell Laboratories
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5. Date Project Initiated: September 1, 2003

6. Expected Completion Date: December 31, 2007

PROJECT RATIONALE, STRATEGY, AND METRICS

7. Big Picture Overview:

This effort involves initiatives in robust wireless communications to address critical obstacles in enabling enhanced industrial efficiency. An industrial wireless sensor communication network architecture will be designed, developed, and tested in operational environments and will offer a level of robustness and reliability not available in current wireless sensor systems leading to the opportunity for broader market acceptance of wireless solutions. The goal of the sensor network is to enable "pervasive sensing" for industries and factories to cost-effectively obtain increased levels of energy and operating efficiency through lower cost access to enhanced monitoring and information analysis. The other two components of the overall project involve initiatives in advanced sensor development, and configurable sampling & deployment sensor platforms (these are included in Part "B" of "Wireless and Sensing Solutions Advancing Industrial Efficiency" and are described in a separate report).

8. Project Description:

The Honeywell Team will develop, demonstrate, and test a number of leading edge technologies that will enable the emergence of wireless sensor systems for the industrial market space. The wireless

technology developed will provide highly reliable and secure wireless communications for industrial applications.

9. Core Technology and Novel Element:

An industrial wireless sensor communication network architecture will be designed, developed, and tested in operational environments that will offer a level of robustness and reliability not available in current wireless sensor systems leading to the opportunity for broader market acceptance of wireless solutions. Security of the wireless communications is another important feature of this architecture.

10. Technology Applicability:

- Petrochemical refining
- Pulp and paper manufacturing
- Continuous process industries
- Power generation and distribution

11. Project Objective:

Design, develop and demonstrate a wireless sensor network capable of supporting industrial-specific requirements to produce increased levels of energy and operating efficiency through lower cost access to enhanced monitoring and information analysis.

12. Project Deliverables:

- Voice of the customer interview data
- Industrial wireless requirements document
- Test results of FHSS vs 802.15.4 radios
- Industrial wireless over-the-air protocol
- Field test results from operational testing of wireless sensing system

13. Technical Barrier(s) Being Addressed:

Industrial wireless networks must achieve currently unmet industrial requirements of very high data reliability, long battery life, scalability up to 1000's of nodes, security and latency management to ensure that data is received by the control system within a predetermined period of time.

14. Project Pathway:

The wireless network development was initiated with an extensive Voice of the Customer analysis followed by a detailed requirements analysis reflecting the specific needs of the industrial marketplace and an identification of the critical feature sets required to catalyze the market. Multiple wireless components using existing commercial solutions were evaluated for elements of robustness, interference rejection, and low-power consumption. These elements were combined into a network architecture that introduces enhanced data reliability, long battery lifetimes, scalability to large systems, and message latency guarantees. Critical to the success of the program is to ensure the solution is widely acceptable to the marketplace and available from multiple sources. Thus industry organizations such as WINA and SP100 have been engaged to ensure the requirements and proposed solutions have broad applicability.

15. Energy Savings - How:

- Improved control of industrial processes leading to improved product quality and fewer process upsets
- Condition-based diagnostics and maintenance resulting in fewer unexpected shutdowns

- Monitoring of steam traps in industrial processes: Steam production accounts for 34% of all energy consumed by industry, or 8,091 TBtu per year.
- Monitoring steam injection devices used in oil production: Oil fields that produce heavy crude account for 4 to 5% of the oil in the U.S. Steam injection heats the crude and gets it to the surface more easily. Over-injection of steam wastes energy without increasing production. By adding wireless monitoring to these steam injectors, energy savings of 5.3 TBtu/year can be achieved by 2020.
- Monitoring electric motors used in industrial processes: Rotating machinery driven by electric motors account for 34% of the total energy usage by industry in the US; this can be improved by 12%, according to the DOE. Wireless monitoring for vibration and temperature can identify inefficient operation and timely maintenance resulting in energy savings of 41 TBtu per year by 2020.

16. Energy Savings - Quantity:

Application	Industry Group (NAICS Codes)	Type of Savings	2010 Savings (TBtu)	2015 Savings (TBtu)	2020 Savings (TBtu)
Acceleration of Adoption	324,325,331,332	Various	7.9	26.7	27.5
Steam Traps	All	Waste reduction	21.3	78.9	117.7
Rotating Machinery	All	Efficiency	7.5	27.7	41.4
Steam Injection	324	Waste reduction	1.2	4.0	5.3
TOTAL			37.9	137.2	192.0

17. Other Important Metrics:

- Simple security key insertion for new devices and highly secure communication infrastructure
- Battery life in excess of 5 years
- Latency controlled network with known message latency deliveries in spite of network failures
- Coexistence with other common industrial networks (e.g. WiFi)
- Highly robust behavior of sensor messages being received by control system
- Ability to scale system up to 1000's of wireless devices in a single factory area with high sensor reporting rates.

PROJECT PLANS AND PROGRESS

18. Past Accomplishments:

- Voice of the customer interviews
- Industrial wireless requirements document
- Wireless protocol specification
- Detailed comparison testing of FHSS design and 802.15.4 design against industrial requirements
- Robust wireless network architecture design
- Performance measurements on numerous wireless mesh networks
- Wireless components build and testing
- Integration of field demo system
- Design, building and testing of Installation, Configuration Tools
- Installation and configuration of 2 field demo systems

19. Milestones:

Milestone	Planned Completion
Reporting & Dissemination	12/31/07

20. Project Changes:

The project has deviated little from the original project plan and remains on track to deliver operational wireless architecture. The Project end date has been moved to 12/31/2007 following the approval of a six month no-cost extension.

21. Next Steps:

- Complete field tests and submit final report

22. Commercialization Plans and Activities:

Honeywell is dedicated to the development of an industrial wireless product and intends to continue to provide competitive solutions initially introduced with the XYR 5000. The inclusion of new technology and market assessment data developed as part of the DOE program can be expected to significantly enhance acceptance of the solution. Honeywell's second generation of wireless-enabled solutions is set to be released very soon. Second-generation multi-functional wireless mesh network supports wireless-enabled applications within a single wireless network to optimize plant productivity and reliability, improve safety and security, and ensure regulatory compliance. Supporting existing XYR 5000 and future wireless transmitters, this network delivers a global solution with robust security, predictable power management and multi-speed monitoring.

23. Payback:

- Enhanced ability to deploy additional process sensing in areas where sensor installation was not possible or excessively costly leading to enhanced process control
- Ability to install temporary sensors to diagnose process problems previously located with significant additional time and cost
- Improved alarming and identification of process problems early leading to reduced process upsets and loss of material and product quality

24. Patents, Publications, Presentations:

Presentations:

Steve Huseth, "Wireless Architecture for Industrial Systems", EPRI Wireless Working Group, Comanche Peak, TX, Jan 20, 2005.

Patent Applications filed:

R. Budampati, P, Gonia, S. Kolavennu, "Wireless Communication System with Collision Avoidance Protocol"
R. Budampati, P, Gonia, S. Kolavennu, "Wireless Transmitter Initiated Communication Methods and Systems"

PLEASE NOTE: *All information you submit on this form is **public information** and will be provided to S&A Portfolio Review attendees.*

ADMINISTRATIVE INFORMATION

1. **Project Name:** Development and Field Test of PHASED MicroAnalyzers on NeSSI. (Part B of "Sensing Solutions Advancing Industrial Efficiency")

2. **Lead Organization:** Honeywell Laboratories
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5. **Date Project Initiated:** September 1, 2003

6. **Expected Completion Date:** December 31, 2007

PROJECT RATIONALE, STRATEGY, AND METRICS

7. **Big Picture Overview:** This effort combines initiatives in advanced sensor development, configurable sampling and deployment sensor platforms, and robust wireless communications to address critical obstacles in enabling enhanced industrial efficiency. This effort consists of three components. The first element of the program will develop and demonstrate innovative technology for preconcentrating and analyzing the composition of gaseous process streams (PHASED). The second part of the project will demonstrate a new modular, networked, intrinsically safe and industry accepted standardized process stream sampling and microanalytical system (NeSSI) that will be extended and tested in operational process plant environments to validate its suitability for a spectrum of industrial process applications. The third element of this effort (described in a separate report, under Part "A") consists of an industrial wireless sensor communication network architecture that will be designed, developed, and tested in operational environments and will offer a level of robustness and reliability not available in current wireless sensor systems leading to the opportunity for broader market acceptance of wireless solutions.

8. **Project Description:** The Honeywell Team will develop, demonstrate, and test a number of leading edge technologies that will enable the emergence of wireless sensor and sampling systems for the industrial market space. This effort combines initiatives in advanced sensor development, configurable sampling and deployment platforms, and robust wireless communications to address critical obstacles in enabling enhanced industrial efficiency.

9. **Core Technology and Novel Element** This effort consists of 3 components, the first two of which are covered by this document. The first element of this effort will develop and demonstrate innovative technology for preconcentrating and composition analysis of gaseous process streams (PHASED). The second element of the project will demonstrate a new modular, networked, intrinsically safe and industry accepted standardized process stream sampling and microanalytical system (NeSSI) that will be extended and tested in operational process plant environments to validate its suitability for a spectrum of industrial process applications. Finally, an industrial wireless sensor communication network architecture (described separately) will be designed, developed, and tested in operational environments that will offer a level of robustness and reliability not available in current wireless sensor systems leading to the opportunity for broader market acceptance of wireless solutions.
   1-3 sentences

10. **Technology Applicability:** Design, develop and demonstrate an advanced sensor for cost effectively performing composition analysis of gaseous process streams to produce increased levels of energy and operating efficiency through lower cost access to enhanced monitoring and information analysis, and demonstrate that sensor deployed on a NeSSI platform in industrial processes.

11. **Project Objective:** Design, develop and demonstrate an advanced sensor for cost effectively performing composition analysis of gaseous process streams to produce increased levels of energy and operating efficiency through lower cost access to enhanced monitoring and information analysis, and demonstrate that sensor deployed on a NeSSI platform in industrial processes.

12. **Project Deliverables:**

    - Field test results from operational testing of wireless sensing system
    - Operational PHASED sensor performance data
    - NeSSI field test data

13. **Technical Barrier(s) Being Addressed:** The barriers to success in this project being addressed are: (1) lack of an agreed communications protocol for NeSSI, (2) lack of intrinsically safe commercial NeSSI components, and (3) development of phase materials that will provide adequate separation of analytes.

14. **Project Pathway:** The pathways being followed to complete the project are: (1) use of existing protocols for communications in test sites (USB and Ethernet), (2) restricting test sites to safe areas, and (3) development of other film materials and implementation of an optical.

15. **Energy Savings - How:**

- Improved control of industrial processes leading to improved product quality, fewer process upsets and waste avoidance in industrial processes across many industries accounts for 2020 savings of 254 TBtu/year.
- Condition-based diagnostics and maintenance resulting in fewer unexpected shutdowns
- Quicker introduction of new sensor and analytical technology: NeSSI is a sensor and sample conditioning system that will address the ability to place sensor systems at the point of measurement.

16. **Energy Savings - Quantity:** The following tables show the energy and emissions savings estimated for example applications using the DOE Energy Savings Calculator.

Application	Industry Group (NAICS Codes)	Type of Savings	2010 Savings (TBtu)	2015 Savings (TBtu)	2020 Savings (TBtu)
Ethylene Production	324110	Upset Avoidance & Process Improvement	2.14	10.26	18.25
Metals Processing	331, 332	Waste Avoidance	2.45	6.96	16.20
Hydrogen Production	325	Process Improvement	0.52	2.73	5.35
TiO_2 Drying	325	Process Improvement	0.01	0.04	0.06
Fired Heaters	324110	Process Improvement	2.14	10.26	18.15
Aluminum Production	3313	Process Improvement	0.39	1.12	2.61
Pulp Production	322110	Process Improvement	0.45	2.06	3.49
Refigerant Production	325	Upset Avoidance	0.00	0.02	0.04
TOTAL			8.11	33.44	64.14
Petroleum Refining	324110	Upset Avoidance & Process Improvement	18.59	86.48	149.36
Metals	331, 332	Waste Avoidance	4.41	12.54	29.20
Chemicals	325	Process Improvement	7.95	38.13	67.83
Pulp Mills	322110	Process Improvement	1.06	4.84	8.19
TOTAL			32.01	141.99	254.58

17. **Other Important Benefits and Metrics:** The primary metric that will influence this project is the ability to separate analytes in a sufficiently broad spectrum of applications At present, PHASED can achieve a separation of midrange hydrocarbons, and can separate the analytes needed for the field tests. Success will depend on the ability to separate both light gasses and more complex mixtures. Both issues are being addressed.

PROJECT PLANS AND PROGRESS

18. **Past Accomplishments:**

- Demonstrated high-speed µGC pre-concentrator & separation
- Demonstrated separation of H2O, CH4, C3H8, C4H10, CO2, …., C9, C10
- Modeled feasibility of separation up to C18, w/temp. ramp
- Calculated adsorption enthalpies on dry & hydrated films
- Demonstrated PC gain of 63x for hexane, and ~100x for CO2; modeled PC gains >10,000 for high MW compounds
- Increased PHASED chip fabrication yield to >90%
- Determined that a complete PHASED mGC with electronics will fit into one NeSSI's SP-76 modules
- Agreed with Users to base NeSSI device communication on Wireless or FieldBus; *however, since NeSSI components to support this are not yet available the field test uses USB or wireless*
- Identified 2 test sites and applications; agreed with field test participants on gases to be pre-concentrated, separated and detected
- Completed the design and fabrication of 2 PHASED µGC packages for NeSSI
- Improved preconcentration with heated connections
- Improved separation with OV-5 thin film material
- Improved TCD with thermal isolation
- Integrated MDD into PHASED for 2-D detection
- Started development of a Chemical Ionization Detector as an alternative to the TCD
- Developed electronics for PHASED in NeSSI package
- Designed, started programming and debugging the PHASED-µGC output software
- Designed, programmed and debugged the PHASED-NeSSI-SAM interface software

- Developed commercialization plan for all markets
- NeSSI systems built and debugged and ready for lab testing under field running conditions

19. Milestones:

• PHASED on SP-76 Demonstration	6/30/06
• PHASED on NeSSI lab test	7/31/07
• PHASED on NeSSI field test start	6/01/07
• PHASED on NeSSI field test complete	11/30/07
• Final Report	12/31/07

20. Project Changes: Field testing has been delayed for several reasons, primarily having to do with analyte separation, NeSSI scope reduction and funding schedules. No other significant changes have taken place.

21. Next Steps: .

- Lab testing of 2 PHASED μGC packages for field test
- Start and complete field tests
- Final report

22. Commercialization Plans and Activities: A comprehensive commercialization plan has been developed that addresses market size, rates of introduction, Honeywell organizations involved, outside partners anticipated, development steps required and progress gates. This will be described in detail privately.

23. Payback:

- Enhanced ability to deploy additional process sensing in areas where sensor installation was not possible or excessively costly leading to enhanced process control.
- Improved alarming and identification of process problems early leading to reduced process upsets and loss of material and product quality.

24. Patents, Publications, Presentations: *Presentations:*

- Ulrich Bonne, Bob Higashi, Tom Rezachek & Karen Newstrom-P., "PHASED Feasibility Demonstration," Session on: Technology Transfer and Innovative Technology II, DOE/ITP Program (Chair: G.Varga), IFPAC, Arlington, VA, 12-15 Jan. 2004
- U.Bonne, R.Higashi, T.Marta, F.Nusseibeh and T.Rezachek (Honeywell Labs), and C.Herring, D.Kellner, K.Kunze and M. Castelein (Caviton, Inc), "MicroGas Analyzer for NeSSI and DHS: Measurements and Simulations," PittCon 2006, Orlando, FL, 13-16 March 2006, Paper # 2020-6
- N.Iwamoto and U.Bonne, "Molecular Modeling of Analyte Adsorption on MEMS GC Stationary Phases Eurosime, Como, Italy, 24-26 April 2006; paper #293

Patent Applications filed:

- U. Bonne, R. Higashi, Cleo Cabuz, Cleopatra, "PHASED Micro Analyzer II, IIA"

ADMINISTRATIVE INFORMATION

1. **Project Name:** SQA™: Surface Quality Assured Steel Bar Program

2. **Lead Organization:** OG Technologies, Inc.
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3. **Principal Investigator:** Tzyy-Shuh Chang, Ph.D.
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4. **Project Partners:** Prof. Jan Shi at University of Michigan
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   Mr. Ray Hawkins, Plant Manager at Mittal Steel (Inland)
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   Mr. Chris Jones, Vice President at FormTech Industries
   248-597-3800

5. **Date Project Initiated:** 01/01/2004

6. **Expected Completion Date:** 12/31/2007

PROJECT RATIONALE, STRATEGY, AND METRICS

7. **Big Picture Overview:**
   The problem of surface quality, one of the most common quality issues faced by the American steel industry, is difficult to resolve because, unlike other problems such as the mechanical properties, most surface defects are sporadic and cannot be addressed based on sampling techniques. This project will enable the industry to effectively handle the surface quality issue with the development of a reliable surface inspection system, an advanced data analysis method and a new paradigm for process control and quality control. The approach is based on novel concepts and conducted by an experienced R&D team. The technology is expected to improve productivity, quality and efficiency for both the bar industry and its customers.

8. **Project Description:**
   This SQA program is to solve the major surface quality problems plaguing the US special quality steel bars and rods industry based on crosscutting sensors and controls technologies. The problem of surface defects in hot rolled steel bars is the most common quality issue faced by the American steel industry, accounting for roughly 50% of the rejects. This issue hurts both the rolling and forging industry in their process efficiency and operational costs. OGT expects to address this problem with advanced process control of surface quality and accurate-marking of the residual surface defects for improved rolling process control and rolling product quality control.

9. **Core Technology and Novel Element:**
   - In-line, real-time imaging based visual inspection for surface defects on hot rolled steel bars;
   - Advanced data analysis for process signatures and root cause identification;
   - Predictive process control to prevent surface defects;
   - A new quality control paradigm based on defect detection, marking and removal.

10. **Technology Applicability:**
    Bar/rod rolling, billet casting/reduction, slab casting, cold bar processing, paper production, rail production, other metal productions

11. Project Objective:

The goal of this program is to develop and demonstrate an SQA™ prototype that enables efficient steel bar rolling process control of surface quality and effective quality control on the residual surface defects for downstream removal. The SQA™ technology has the potential to result in a 2.5% boost in the productivity of the target industries, generating significant savings in energy consumption and pollutant release. The extended applications such as billet inspection may further the energy savings by multiples.

12. Project Deliverables:

- A reliable and accurate HotEye™ surface inspection system.
- An effective, non-contact vibration reduction device.
- A methodology for rolling process signature identification.
- An integrated prototype of an on-line automatic root cause identification system.
- A system for automatic defective segment removal.

13. Technical Barrier(s) Being Addressed:

The primary technical barriers are (1) the lack of a reliable surface defect detection system, (2) the complexity of the rolling process, and (3) the lack of a means for accurately verifying and tracking surface defects in steel bars. Surface defects, given their sporadic nature, cannot be effectively addressed through sampling based process controls.

14. Project Pathway:

The project partners recognize that a systematic approach with advanced sensing and data analysis is required to effectively address the issues of surface quality associated with steel bars. The partners are working toward the objectives by developing:

- Improved in-line surface defect detection capability with state-of-the-art signal processing algorithms and innovative bar speed measurement;
- Integrated database systems to capture both the mill operation data and the surface defect data;
- Advanced pattern extraction models to establish the causal relationship for steel surface defects;
- New logistics for steel bar delivery to facilitate surface defect verification and removal; and
- Intensive on-site test and refinement.

15. Energy Savings - How:

The developed technology is expected to help the target industry reduce the amount of scrap and the amount of peeling, thereby reduce the energy put into the production of the steel and forging scrap. Also the simplified process (facilitating direct charge) may reduce the energy requirement when the extended application is accounted for.

16. Energy Savings - Quantity:

Year	2003	2010	2020
Expected Energy Savings (bar rolling)	Baseline	0.65 T BTU	10.97 T BTU
Extended Billet/Slab Inspection	Baseline	1.31 T BTU	22.82 T BTU
TOTAL		1.96 T BTU	33.79 T BTU

17. Other Important Benefits and Metrics:

- Decrease defect detection false positive accuracy to 2%, from ~20% prior to the project.
- Improve the capability of inspecting small bar to ϕ5.5 mm (ϕ13/64", state-of-the-art rolling capability), from ϕ8 mm capability.
- Improve the defect position registering (speed measurement) accuracy to 0.2%, from ~2%.
- Decrease the surface defect caused rejection rate to 2.5%, from ~5% as in 2003.

PROJECT PLANS AND PROGRESS

18. Past Accomplishments: Note briefly the very most important accomplishments to date.

This project is highly linked to a NICE^3 project. Under the previous program, the project partners have successfully implemented a full-scale in-line surface defect detection system at a steel mill, demonstrated and verified the detection capability of critical surface defects for hot rolled special quality steel bars, demonstrated the beneficial impact of using the surface defect detection data to reduce scrap, energy consumption, waste and carbon equivalent emissions, and induced a commercial purchase of the in-line surface defect detection system from another steel mill.

Under the current ITP program, the project partners have:

- Achieved the target surface detection accuracy of the in-line surface detection system.
- Demonstrated the target speed measurement accuracy on rods as small as ϕ9 mm.
- Demonstrated the prototype of a vibration suppression device.
- Demonstrated the capability of in-line pattern identification for selected surface qualify faults.
- Demonstrated the capability of off-line root-cause analysis for selected surface quality faults.
- Demonstrated manual identification and root-cause analysis for on-site, near-real-time implementation of predictive process control.
- Developed the approaches of implementing the defect verification and removal for delivery quality control.

Under an extended program, the project partners have demonstrated the capability to inspect hot cast billets in-line.

19. Milestones:

- Demonstration of surface defect verification and removal in the delivery quality control by 12/31/2007.
- Demonstration of 80% surface defect reduction (compared to the surface defect rates prior to this project) by 09/30/2008.

20. Project Changes:

Due to funding schedule, the milestone timeline is adjusted to address the higher priority items, in hope that the entire project objective is not jeopardized. In 2006, one of the two milestones was not met due to fund availability. For this reason, the remaining milestones are adjusted with a potential no-cost extension. Nevertheless, there is not significant technical change to overall scope of this project.

With respect to the applications, the technology is applied to billet production and rail production, due to the industrial needs. Additional applications such as slabs, ring rolling, and tubes are pending.

21. Next Steps:

After a technology is successfully developed:

- For developed technologies, it is to prove the on-site stability with a 6-month trial of production usage at beta site and to integrate into the base HotEye™ sensor system.
- Document the performance and benefits.

22. Commercialization Plans and Activities:

The SQA technology can support a sensor-based process control and quality control in a multiple-stage forming process such as the steel rolling industry and the rail industry. The expected global market potential for the primary target industry is over $100M in the US and over $600M globally.

OGT is commercializing the SQA technologies piece by piece as soon as they are ready, through both direct sales and partnering. The timeliness is due to the needs of a small business on getting immediate market feedback and maintaining cash flow. We have integrated the sophisticated defect detection algorithms and a pattern recognition algorithm (both delivered in this ITP program) into our

HotEye™ system. The HotEye™ system is also offered to inspect steel rods as small as ϕ5.5 mm. These newly added capabilities enhanced the marketability of the HotEye™ system. OGT showcased the alpha version of a Rolling Process Informatics (RPI) system. By the end of this ITP project, OGT plans to demonstrate a fully integrated SQA system.

OGT has a very good chance of being the world's leading provider of the Surface Quality Assured Steel Bar technologies, if ITP continues to support this SQA project. OGT has established its footing in the primary target market based on the technology and product developed with the support from the NIST Advanced Technology Program and the ITP NICE^3 program. Currently OGT is actively marketing its HotEye™ in-line surface inspection system and receiving very positive responses from the industry.

In addition, OGT is reaching out to the global market based on the HotEye™ surface defect detection system through sales representatives or direct sales. OGT installed HotEye™ systems at Baosteel (China) and Stelco (Canada). The technology has also attracted many steel mills from Japan, Korea and Europe. Examples are Daido Steel (Japan), Nippon Steel (Japan), Ovako Steel (Sweden), POSCO (Korea) and Saar Stahl (Germany).

OGT's product, the HotEye™ system, is being promoted in the primary target industry through technical conference presentations, on-site presentations and site visits to the beta testing hosts. Specifically, the product is promoted by the beta testing hosts in various industrial gatherings. Such promotion has been very effective.

The technology is also being implemented for applications in billet/slab inspection and rail inspection. Commercial pilot projects have started in North America. Additional R&D for advanced process control and in-line billet/slab repair is being planned.

23. Payback:

- The users will get the payback on their investment of adopting the developed technologies through improved productivity (proven improved yield), quality (better quality control) and efficiency (simpler operations).
- The expected payback per installation in a steel bar mill is at least $1 million per year (mill dependent). The expected return on investment is no more than 2 years. The fastest reported was 6-month payback.

24. Patents, Publications, Presentations:

Two Publications during the last 12 months

Jin, N., Zhou, S., Chang, T.S. and Huang, H., 2007, "Influential Process Variable Selection for Surface Quality Control in Hot Rolling Processes," accepted to *IEEE Transactions on Automation Science and Engineering*.

Li, J., Shi, J., and Chang, T.S., 2007, "On-line Seam Detection in Rolling Processes using Snake Projection and Discrete Wavelet Transform," accepted by *ASME* Transactions, Journal of Manufacturing Science and Engineering.

PLEASE NOTE: *All information you submit on this form is **public information** and will be provided to S&A Portfolio Review attendees.*

ADMINISTRATIVE INFORMATION

1. **Project Name:** Low Cost Vibration Power Harvesting for Industrial Wireless Sensors

2. **Lead Organization:** KCF Technologies, Inc.
112 W. Foster Avenue
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3. **Principal Investigator:** Dr. Jeremy E. Frank
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4. **Project Partners:** Penn State University
Project Role: Technology Partner, Research Institution
Technical POC/PI : Professor George Lesieutre, Department Head, Aerospace
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RLW, Inc.
Project Role: Strategic Partner, Wireless Sensor System Integration
Technical POC/PI: Bill Nickerson, VP
Phone: 814 867 5122

York Johnson Controls
Project Role : Customer / Beta Test Partner
Technical POC/PI : Curt Eichelberger

Omega Piezo Technologies
Project Role : Technology Partner, Manufacturing Process
Technical POC/PI : Dr. David Pickrell
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Crossbow Technology
Project Role : Wireless Sensor OEM / Customer / Partner
Technical POC/PI : Alan Broad

General Electric
Project Role : Wireless Sensor OEM / Customer / Partner
Technical POC/PI : Dan Sexton

5. **Date Project Initiated:** Phase I: July 11, 2004
Phase II : July 11, 2005

6. **Expected Completion Date:** July 10, 2007

PROJECT RATIONALE, STRATEGY, AND METRICS

7. Big Picture Overview: Provide a "high altitude," big picture overview of the project as if for management or a host site management. Relate the project to the problem being solved/barrier being addressed. State why the project technology is a better solution and why it will be a winner.

The wireless sensor market for industrial applications is entering an enormous growth phase, yet their acceptance is heavily dependent on life-cycle cost. The lifecycle maintenance cost of changing batteries for wireless sensors is estimated at $80-$500 per occurrence and can far exceed the cost of the sensor. KCF Technologies is developing vibration power harvesting devices to eliminate the need for battery change. This is an enabling technology to greatly expand the acceptance and deployment of wireless sensors in U.S. industry.

8. Project Description: Clearly summarize your project.

KCF Technologies is developing vibration power harvesting devices for industrial wireless sensors. The device converts vibration energy to regulated DC power, functioning as an unlimited-life self-charging battery.

9. Core Technology and Novel Element: Identify the core technology and describe what is novel or transformational about the technology.

The three core functions of an enabling vibration power harvester are that it be 1) low cost, 2) designed to supply sufficient power to existing wireless sensors, and 3) capable of generating power from low vibration levels and not overly sensitive to the frequency of vibration.

10. Technology Applicability: List industries that the core technology can be applied to, bolding the project focus industry.

- **Wireless sensors for condition monitoring of building HVAC systems and equipment manufacturers**
- Wireless sensor networks for mining, oil/gas drilling, pipeline and refinery industries
- Wireless sensor networks for energy generation industries
- Wireless sensors for Condition Based Maintenance (CBM) in process control and manufacturing
- Wireless sensor networks for various manufacturing and other heavy industry

11. Project Objective: Clearly describe the overall project objective.

KCF Technologies' objective is to develop, launch and commercialize a family of vibration power harvesting devices for existing wireless sensors.

12. Project Deliverables: Clearly identify the project output/deliverables.

- Internal report documenting user-defined needs for vibration power harvesting on 3 industrial wireless sensor platforms
- Design, construction, and testing of prototype, standalone energy harvesting circuits
- Design, including internal summary reports and part drawings, a family (3) of power harvesting devices for specific industrial wireless node applications
- Batch quantity (100) of power harvesting circuits using discrete components for each product family member
- Device prototype construction and batch quantity production (QTY 100 each)
- Facility set-up and tooling for high-volume production immediately following Phase II

13. Technical Barrier(s) Being Addressed: Describe the problem(s) and/or barrier(s) limiting industrial energy efficiency that this project is addressing.

Batteries that require changing are a primary technical barrier to the adoption of wireless sensors in industry and the efficiency benefits that will come with wireless sensors.

14. Project Pathway: Summarize the strategic approach, or pathway, being used to address the barrier(s).

KCF Technologies is developing an alternative to finite-life batteries. The technology scavenges energy from industrial vibrations, eliminating the need for battery change. The core focus and technical approach for technology acceptance is to develop a vibration power harvesting device that is low cost, supplies sufficient power to eliminate battery change for 5-15 years, and is not overly sensitive to frequency or other environmental characteristics.

15. Energy Savings - How: How will energy be saved by the technology under development?

Enabling the acceptance of wireless sensor technology greatly expands process control and measurement capabilities in nearly all industries, leading to more optimal systems. Such technology could reduce source energy consumption by 2 quads (quadrillion BTUs) in the US alone. This translates to 55 billion dollars per year, and 35 million metric tons of reduced carbon emissions.

16. Energy Savings - Quantity: How much energy will be saved and by when. Provide projections of energy savings including the year when the savings are expected and the base year.

Vibration power harvesting technology will enhance the deployment of wireless sensor networks. This is measured as a reduction of total life cycle costs for industrial sensing by up to 90% by permanently eliminating wires and batteries. The energy savings is therefore measured in the combined benefit of wireless sensor networks under programs funded by the DoE and in industry.

17. Other Important Metrics: Indicate how success or failure will be measured for this project by stating the baseline technical metric(s) and the metric(s) needed for realization of the project objectives.

- The vibration power harvesting device must be low cost
  - Baseline target: $50-$100/ea.
- The device must supply sufficient power for existing wireless sensors
  - Baseline target: 1 mW continuous power generation
- The technology must not be overly sensitive to vibration frequency or amplitude
  - Short-term target: 10% frequency range of operation
  - Long-term target: Broadband operation

PROJECT PLANS AND PROGRESS

18. Past Accomplishments: Summarize the major accomplishments to date.

- Gathered and documented in-situ vibration and environmental data, customer preferences, and wireless sensor requirements
- Tested hundreds of samples for manufacturing variation, output, durability and quality control
- Designed and fabricated batch quantity power harvesting devices (3 generations)
- Designed and fabricated energy scavenging circuit PCB (4 generations)
- Demonstrated self-powered wireless sensor at York Johnson Controls
  - September, 2006
  - February, 2007

19. Milestones: Summarize important future milestones **including dates** for the life of this project. Milestones should be the start or the completion of an activity, not the activity itself. [**Note: This item is critical for review of your project.**]

Milestone 1: June 29, 2007 Release of Self-Powered Wireless Sensor Kit product
Milestone 2: July 12, 2007 Complete Phase II work and prepare final report

Milestone 2: July 31, 2007 Release of VPH200, VPH300 harvester products

20. Project Changes: Describe changes in scope, approach, or schedule during the past year in response to any unforeseen problems/issues or successes.

No significant changes.

21. Next Steps: Assuming success, what are the next steps? Describe any next steps before commercial introduction of the technology into the marketplace.

- Quality control and production setup.
  - Pending Phase II Supplement funding
  - Investment in production tooling and assembly line setup
- Sales of product
  - Release 1: Kit with vibration power harvester and integrated wireless sensor (available for sale, June 2007).
  - Release 2: Customer-specific sensor board with integrated power harvester and sensor (available August 2007)
  - Release 3: Standalone vibration power harvesters for product integration

22. Commercialization Plans and Activities: Describe the end-use application and market potential for the technology, and the plans, progress, and partners for commercial application/adoption; identify what the product of the project will be and how this product will be introduced/disseminated to industry.

The end-use application for this technology is wireless sensor networks in U.S. industry. KCF has partnered with York Johnson Controls for initial testing in HVAC and thermal control for buildings. Additional markets and partners include Crossbow (various industrial wireless sensor customers, including energy production and refining) and Copeland/Emerson (compressor manufacturing and monitoring).

23. Payback: How will industry determine the payback for adopting the technology under development? What is the anticipated payback to an industrial user of the technology developed?

- Mean Time Between Attentions (MBTA) for wireless sensors
  - Currently 3-18 months
  - With this technology: **eliminated**
- Life cycle cost for wireless sensing in industry
  - Current total lifecycle cost is at least three (3) times higher than the installed sensor cost, estimated at $1,000 - $3,000.
  - With this technology: payback is measured in life-cycle cost savings for installed sensors

24. Patents, Publications, Presentations: List number and reference, as applicable. (Do not include S&A annual review presentations.)

Provisional patents filed, Spring, 2006.
Full patent filed, Summer, 2007.

PLEASE NOTE: This document should not exceed four pages.

PLEASE NOTE: *All information you submit on this form is **public information** and will be provided to S&A Portfolio Review attendees.*

ADMINISTRATIVE INFORMATION

1. Project Name: Robotically Enhanced Advanced Manufacturing Concepts to Optimize Energy, Productivity, and Environmental Performance
DE-FG36-05GO85046

2. Lead Organization:
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4. Project Partners:
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5. Date Project Initiated: June 30, 2005

6. Expected Completion Date: June 29, 2007

PROJECT RATIONALE, STRATEGY, AND METRICS

7. Big Picture Overview:

Early in 2004, the Robotically Enhanced Manufacturing Line (REML) was conceived for the production of small lots of tapered roller bearing races. The line was seen as an opportunity to reduce energy consumption, improve productivity, reduce health and safety risks, and reduce environmental impact when compared to conventional, low volume bearing manufacturing lines.

In the first phase of the REML project, major assets were acquired for a manufacturing line for follow-on installation, capability studies and optimization. That activity has been documented in the DE-FC36-99ID13819 final report. In this the second phase of the REML project, most of the major assets have been installed in a manufacturing line arrangement featuring a green cell, a thermal treatment cell and a finishing cell.

The REML line in its current state of development has been measured to be about 25% less energy intensive than the baseline conventional low volume line assuming equivalent annual production volume of bearing races. The reduction in energy consumption is largely attributable to the energy reduction in the REML thermal treatment cell where the heating devices are energized on demand and are appropriately sized to the heating load of a near single piece flow manufacturing line.

The capital cost of the REML line would be roughly equivalent to the capital cost of new conventional line. The unit raw material cost for REML is somewhat greater than raw material cost for the conventional line. However, changeover time, tooling costs, gauging costs, utilities and energy costs, and manning of REML are less than the conventional line. Since REML supports near single piece flow, work-in-process inventory and work flow time are much less on the REML line than on the conventional line. REML allows the reduction in inventory of source steel tube sizes from several hundred to a few dozen. As a result, the business model indicates that costs incurred on the manufacturing line would be less with the REML line than with the conventional line for low manufacturing run volumes.

The REML line when processing through-hardenable steel consumes far less hydrocarbon and other process gases as fuels or carburizing agents than the conventional line which processes case-hardenable steel. Hence the REML line produces fewer greenhouse gas emissions and less liquid and solid waste materials.

8. Project Description:

Construct an advanced, low-volume manufacturing line for the production of anti-friction bearing races. The line will consist of processes for cold working and green machining, for thermal treatment, and for finishing and inspection of the bearing races.

9. Core Technology and Novel Element:

Energy-efficient induction heating processes, which operate on demand, replace continuously heated, energy over-sized furnaces. Robotics, including low-mass gantry robotics, tend the processes thereby reducing manual repetitive labor.

10. Technology Applicability:

- Heat treatment of metals
- Robotic machine tending

11. Project Objective:

As compared to a conventional, low-volume bearing race manufacturing line,

- Demonstrate energy savings
- Demonstrate improved productivity
- Demonstrate improved environmental and operator health and safety performance

12. Project Deliverables:

- Analysis of potential for energy savings for bearing races and other heat treated, metal products
- Analysis of potential for reduction of environmental impact
- Analysis of potential for productivity increases

13. Technical Barrier(s) Being Addressed:

- Achieving induction heating processes which do not require part-specific tooling while achieving the required control over temperature uniformity across full range of part diameters, widths, and cross sections.

- Sensing and robotic gripping of hot parts (bearing races) without causing geometric distortion. Optimization of gripper actuation forces. Minimization of heat transfer from heated product to the grippers and ambient air. Robotic positioning of parts in assets which require high positional accuracies while the assets function in harsh, metal-removal environments.

14. Project Pathway:

- Design of experiment test matrix is establishing induction heating recipes and processing parameters which yield optimized cycle times and metallurgical properties for full range of product geometry.
- Optimization of gripper actuation forces and minimization of heat transfer from heated product to the grippers and ambient air by use of skeletized grippers and thermal barriers. Positional accuracy of robotics found to be generally acceptable.

15. Energy Savings - How:

- The reduction in energy consumption is largely attributable to the energy reduction in the REML thermal treatment cell where the heating devices are energized on demand and are appropriately sized to the heating load of a near single piece flow manufacturing line.

16. Energy Savings - Quantity:

- The REML line in its current state of development has been measured to be about 22% (338,000 kVA-hrs per year) less energy intensive than the baseline conventional low volume line assuming equivalent annual production volume of bearing races.

17. Other Important Metrics:

- Productivity (lower unit cost, dramatically reduced flow time, reduced labor content)
- Environment (less greenhouse gas emissions, less generation of liquid and solid wastes)
- Health and Safety (fewer repetitive motion injuries associated with manual manufacturing operations)

PROJECT PLANS AND PROGRESS

18. Past Accomplishments:

- Completion of installation of major assets including a low-mass, high-speed machine tending robot
- Purchase and installation of secondary and support assets
- Integration of thermal treatment cell assets with commercial gantry robot
- Integration of finish cell assets with low-mass, high-speed machine tending robot
- Completed improvement estimates
    - Energy Consumption Reduction
    - Productivity Improvement
    - Health and Safety Risk Reduction, Ergonomics Improvement
    - Environmental Impact Reduction
- Completed trial runs of major production assets across the entire line
- Deployed green cell assets and finish cell assets to Timken's Industrial Bearing Business

19. Milestones:

- All current contract milestones are completed.
- As a Timken-sponsored effort, complete development to optimize and qualify inductive heating and tempering efficiency and post-heat treat metallurgical properties of new steel grades, new (larger) part sizes and new part geometries and features (flanges, holes, slots, grooves) by 3Q 2007.

- Complete an associated investigation of opportunities for deployment of the thermal treatment cell into Timken's Industrial Bearing Business by 4Q 2007.

20. Project Changes:

- No major changes in scope or approach during the past year

21. Next Steps:

- Development of the thermal treatment cell for application to additional steel grades and product sizes.

22. Commercialization Plans and Activities:

Consistent with our contractual terms with the DOE:

- The Timken Company and its supplier of induction heating equipment will investigate licensing of induction heating technology to non-competitors of The Timken Company. The Timken Company will be the point of contact.
- CAMotion Inc. will promote and offer low-mass, high-speed gantry robotics, similar to that featured in the REML finish cell, to industry.

23. Payback:

- Industry will analyze their specific business cases and will project that manufacturing costs will be less with the REML line (or stand-alone cells) than with the conventional line for low run volumes. The basis for lower cost in thermal treatment will be reduced energy consumption.

24. Patents, Publications, Presentations:

- Steve Dickerson, CAMotion, Inc.; Ai-Ping Hu, CAMotion; Inc, Joe Pack, Timken Co. "A Large, High-Speed, Machine-Tending Robot", Cleveland Exposition and Conference Emphasis on Flexible Manufacturing, Cleveland OH, June 7 – 9, 2005.
- Joseph M. Pack "Robotically Enhanced Manufacturing Line", Department of Energy Showcase Presentation, Cleveland OH, September 28, 2005.
- Energy Industries of Ohio Robotics in Manufacturing Technology Roadmap", report from June 29, 2006 robotics in manufacturing workshop. Available online from the US Department of Energy's Energy Efficiency and Renewable Energy website http://www.eere.energy.gov/industry/sensors_automation/news_detail.html/news_id=10633

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