

Center for Energy Harvesting Materials and Systems

The CEHMS Chronicle

Technical Article: Energy Harvesting: Enabling Technology for the Internet of Things

Special points of interest:

- Next Energy Summit/IAB meeting / INAMM Symposium will take place in Dallas, Texas from January 28–30.
- CEHMS proudly announces the upcoming “Energy Harvesting and Systems” (EHS) Journal. The first issue will be released in January 2014.
- The [CEHMS website](#) has recently been revamped. Check it out for up to date CEHMS Information.

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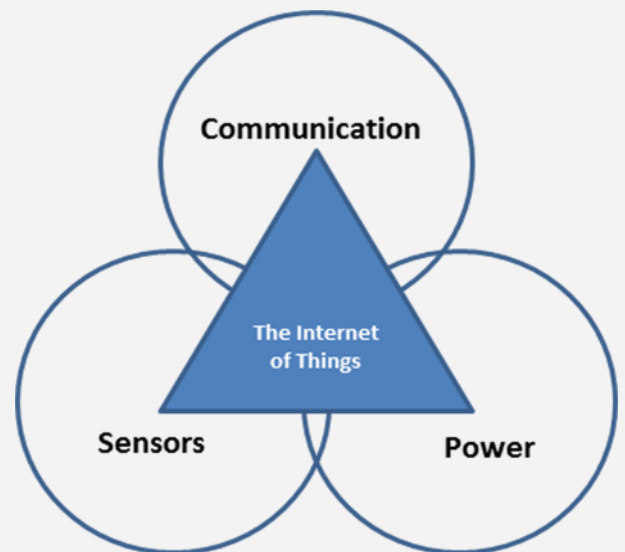
Energy Harvesting: Enabling Technology for the *Internet of Things*

Benjamin Lund, Connie Manz, Cary Baur, and Walter Voit

The *Internet of Things* (IoT), or the Internet of Everything, is a phrase used to describe the way in which researchers envision the connectivity of today exploding into the integrated world of tomorrow. While the term is used very differently depending on the source, the IoT generally refers to wireless networks that work collectively to monitor and perform designated tasks. For instance, the “smart” phone, for all of its functions, is technically not that smart. Rather, it relies on you, the user, to feed it information, and with that information, it performs tasks for you. But what if your phone did not need your eyes and ears to gather information, or if your car could check on traffic conditions and route you around accidents, or if your canceled morning meeting could be translated into a few more precious minutes of sleep, or if your mobile device could automatically pull up the menu of the restaurant you are thinking about entering? The possibilities are endless. Are all of these seemingly

futuristic technologies even possible? Leveraging world class research at top national and international universities, the Center for Energy Harvesting Materials and Systems (CEHMS) and its board of leading companies, certainly think so. Welcome to the Internet of Things - machines communicating with machines, making decisions, helping you control your world, and enabling you to be freer to live your life.

So how does the IoT work? Basically, distributed sensor networks gather information on everything from your car to your home to your clothes and funnel this information into nodes where the data are sorted, processed, and utilized. While there are many technical hurdles that continue to be an issue such as the limitations of the current IP address system, the physical size requirements of micro-processors, data interpretation



For the Internet of Things to be effective, each connected device must possess three components: communication, sensors, and power. **Sensors** allow the device to gather data. **Communications** facilitate dialog between devices. **Power** enables sensors and communications to function.

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and the distribution of data, one of the greatest challenges to the realization of the IoT lies in powering the sensor networks which gather the information.

Conventional means of powering sensing devices include hard wiring or batteries, which require fixed locations or tedious and expensive maintenance. The bulky size of these

power supplies greatly limits the location of the devices, and the necessity of eventual battery replacement makes placing these devices in inaccessible places impractical, ruling out many applications such as smart clothes, health monitoring and sensors in machinery. For the IoT to be realized, sensors must be ubiquitous, mobile, and self-powered. This is where energy harvesting comes into the picture. Energy harvesting allows for the continuous, point of use power generation necessary for the

functioning of IoT networks without the confinement of fixed locations or battery replacement. With potential power sources from vibrational, thermal, mechanical, and solar energies as well as radio frequency and ambient backscatter, the options for energy harvesting powered devices are limited only by the imagination of those engineering them.

Will this wonderful vision ever become a reality? The answer is that we are already well on our way. One well known connected device is Apple's iBeacon, which will run on Bluetooth, low energy technology which allows data to be transferred to your phone from up to 160 feet away. The goal of the iBeacon is to make life easier by enabling local transmission of store coupons, meeting notes and register free payment.

Indeed, tech giant Cisco estimates that there will be 25 billion connected devices by 2015, doubling to 50 billion by 2020 [1]. With this large number of devices numerous companies have developed technologies to power sensors for the IoT including Cymbet, EnOcean, Greenpeak and Perpentuum, to name a few.

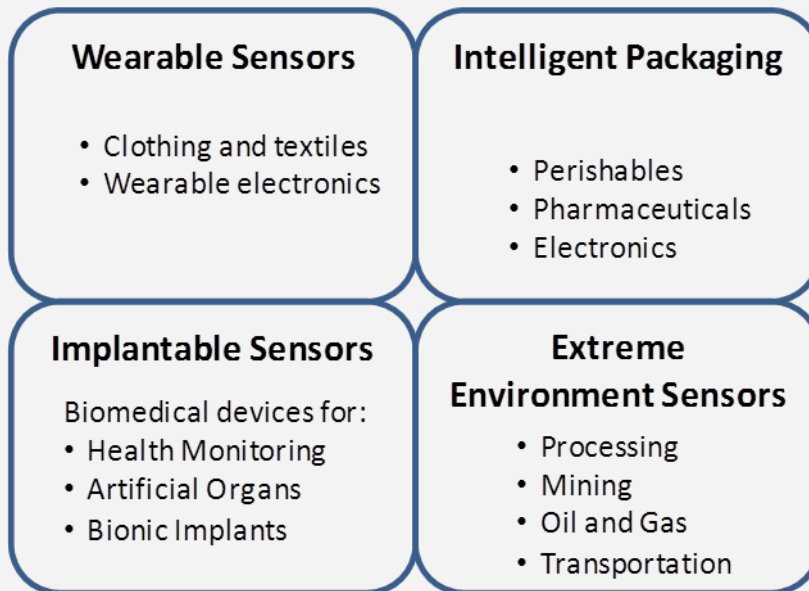
transportation (automotive, locomotive, aviation, and nautical). Extreme environment sensors allow for on-site process control and optimization, real time fatigue monitoring, and more.

Intelligent packaging focuses on systems where time or exposure leads to degradation or spoilage. It is estimated that \$35 billion of perishable

goods are wasted each year due to overheating and excessive shock [2]. Additionally, over \$41 billion worth of temperature sensitive biopharmaceuticals are transported annually [3]. Imagine pharmaceuticals and vaccines which are packaged with sensors that can warn distributors if the medicine has gone bad. Imagine produce which can detect the presence of harmful

bacteria, or even microprocessors that can communicate increased levels of deleterious moisture. While RFID tags are already being used to track products through the supply chain, more advanced sensors, utilizing new forms of energy harvesting, are able to expand these capabilities to include information regarding, lifespan, temperature, moisture content, etc.

Wearable sensors focus on the growing sectors of health and fitness related apparel and health monitoring (first responders, soldiers, and patients with chronic conditions). The health and fitness field is exploding with applications for monitoring heart rate, blood oxygen levels, steps, etc. during active duty. Current devices generally rely on bulky batteries to power sensors. Energy harvesting devices, such as those utilizing ambient motion will enable



Due to the large corporate interest in the IoT and energy harvesting, we at the CEHMS have focused our research efforts on the fundamental issues regarding energy harvesting and how these technologies will enable the IoT. We have developed 4 major research test beds that we believe are critical to the development of IoT technology. These test beds include energy harvesting solutions for sensors in: extreme environments, intelligent packaging, wearable systems, and implantable systems.

Extreme environment sensors focus on applications where intense heat, pressure, vibration, or other ambient energy cause normal sensors and energy harvesters to fail. These include applications in mining and processing, oil and gas (including downhole and offshore) and

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reductions in device size and increase options for sensor incorporation.

Implantable sensors focus on technologies for the biomedical industry. The nature of these sensors makes conventional powering methods particularly unappealing. No matter how minor the surgical operation to implant these sensors, it can be assumed that patients do not want to repeat these surgeries on a regular basis in order to replace batteries.

The IoT is growing exponentially and we, at CEHMS, are striving to ensure that the technology and graduate student intellectual capacity to enable this transformation

are available. There is little doubt that a paradigm shift in wireless electronics is upon us. The ever decreasing size and power consumption of electronics is resulting in a renewed effort to develop “self-powered” devices that harvest regenerative power from their surroundings. By identifying the major areas in which the CEHMS can provide research expertise, solutions to problems pertaining to the development of energy harvesting systems for the IoT can be obtained quickly and efficiently, enabling the vision of the internet of things to come to reality in the near future.

- [1] Evens, D. (2011) *The Internet of Things, How the Next Evolution of the Internet is Changing Everything*. Cisco Internet Business Solutions Group (IBSG), White Paper
- [2] Delen D, Hardgrave BC, Sharda R (2008) *The promise of RFID-based sensors in the perishables supply chain*. RFID Research Center, University of Arkansas, Fayetteville, AR
- [3] Bishara RH (2006) *Cold chain management – an essential component of the global pharmaceutical supply chain*. *Am Pharm Rev* Jan/Feb pages 1–4

Current News and Happenings

There is a new CEHMS website! Please check it out. <http://brabantio.me.vt.edu/wp/cehms/> We now have a blog so you can keep up to date with CEHMS happenings!

The next CEHMS meeting will be the Energy Summit 2014/ 7th CEHMS IAB Meeting/ 7th INAMM Symposium . The meeting will take place in Richardson, Texas at the University of Texas at Dallas. A call for papers has been released. Please see the announcement on page 5 of this newsletter.

On pages 6—9 of this newsletter, there are factsheets from UT Dallas on their

focus: The Internet of Things . Please have a look at them to learn more about this fascinating topic.

CEHMS PhD students Daniel Apo and Nathan Sharpes traveled to Dulles, VA from September 27-28 to give demonstrations at the “Change the World: Science and Engineering Careers” which was a Science, Technology, Engineering and Math (STEM) career fair. Daniel and Nathan presented hands on demonstrations of their work. Daniel, who works on the Levitation Induced Vibrations Energy (LIVE) harvester project, demonstrated a battery that when shaken could power an iPhone.

Nathan’s work with the Tile Energy Harvester project was demonstrated with a tile and lamp setup. When a person stepped on the tile, it sent a signal to turn the light on or off. Both demonstrations successfully showed participants in the fair how Energy Harvesting could apply to their lives and their futures.

For pictures and videos of their demonstrations, please see [the blog post](#).

The first issue of the new Energy Harvesting and Systems (EHS) journal, edited by Dr. Shashank Priya, will be released in January, 2014.

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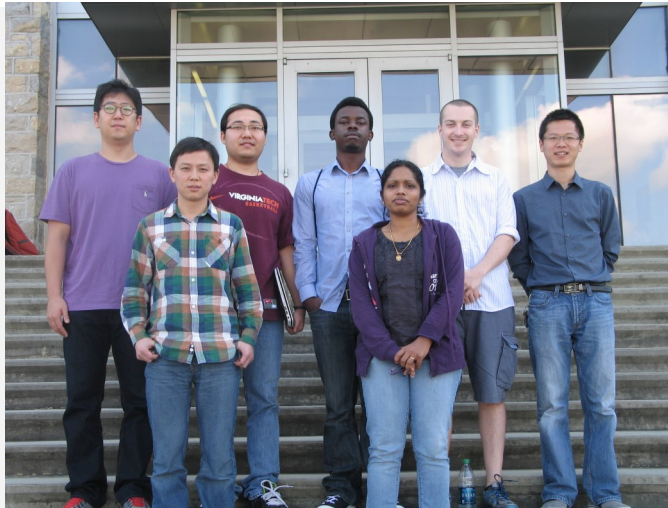


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Meet the Virginia Tech's CEHMS Researchers

Hyuncheol Song joined Virginia Tech. in fall 2013 as Ph.D student. He received his B.S. and M.S. degrees in Materials Science and Engineering from Korea University, Seoul, Korea, in 2004 and 2006, respectively. Before joining Virginia Tech., he worked at the Korea Institute of Science and Technology (KIST) as research scientist. His research interests are piezoelectric thin films, nano materials, micro actuator, MEMS energy harvesters and magneto-thermoelectric generators.



Top row (left to right): Hyuncheol Song, Yuan Zhou, Daniel Apo, Nathan Sharpes, Bo Chen
Bottom row (left to right): Yongke Yan, Saranya Dorairajan

Yuan Zhou received his B.E. degree in Electronic Science & Technology in 2009 from Xi'an Jiaotong University, China. Now he is a PhD candidate in the Department of Materials Science and Engineering. His research interests include: Energy Harvesting and Conversion, Magnetolectric Sensor & Transformer, Pulsed Laser Deposition of multiferroic self-assembled thin films and piezoelectric thin films for smart structures and devices. Currently, he is developing a dual-phase self-biased magnetolectric energy harvesting system that can simultaneously scavenge magnetic and vibration energy in the absence of DC magnetic field.

Daniel Apo received a B.Eng. in Mechanical Engineering in 2007 from the University of Benin, Nigeria. In 2012, he completed his S.M in Mechanical Engineering at Massachusetts Institute of Technology (MIT), and is now a Mechanical Engineering PhD candidate. Dan's current research covers modeling, fabrication and testing of small-scale energy harvesting devices. His research interests include microelectromechanical systems (MEMS), electromagnetic and piezoelectric devices, combustion, and

fluid Dynamics.

Dan's industry experience includes an internship at Schlumberger, and a one year project engineering job at ExxonMobil.

Nathan Sharpes earned his B.S. degree in Mechanical Engineering at Virginia Tech in 2012 and is currently pursuing his PhD in Mechanical Engineering. He researched many topics as an undergraduate, including solar powered engines, scaling factors of radial turbines, and automation and robotics. He currently works as a graduate research assistant at CEHMS. His current research involves development of piezoelectric and electromagnetic induction energy harvesters, powered by mechanical vibrations and/or human motion.

Dr. Bo Chen is a postdoctoral associate in CEHMS. Before joining CEHMS, he received his B.S. degree in Physics from Zhejiang University, China, in 2007 and Ph.D. degree in Material Science and Engineering from Virginia Tech in 2012. Dr. Chen works on two projects: flexible dye-sensitized solar cells (DSSCs) and light and

mechanical energy harvest. His research focus on fabrication of 1D TiO₂ nanostructured photoanode with large surface area for efficient DSSCs, developing solid-state DSSCs on flexible substrate, designing flexible DSSCs module, preparation of multi-type energy harvester to simultaneously scavenge different energies in environment.

Dr. Yongke Yan is a Research Associate in CEHMS. He received his B.S. in Materials Science and Engineering in 2003 from Central South University, China, and his Ph.D in Materials Science and Engineering in 2008 from Tsinghua University, China.

Before he joined CEHMS in 2010, he worked on solid oxide fuel cells at the National Institute for Materials Science in Japan. His current research at CEHMS is focused on ceramic processing, microstructure and property characterization of textured piezoelectric and magnetolectric materials for sensor, actuator and energy harvesting application. He has authored over 30 publications in peer-reviewed international journals and has granted or filed 4 patents.

Dr. Saranya Dorairajan received her bachelor's degree with a specialization in Physics from Bharathidasan University in 2005. She completed her Masters in Materials Science at Anna University, Guindy Campus in 2007 and her PhD from the Indian Institute of Science in Bangalore in 2012. During her Ph.D. work, Dr. Dorairajan focused on Electrocaloric effect in Relaxor Ferroelectric thin films for energy harvesting applications. She is currently a part of CEHMS as a Post-Doctoral Fellow working with piezoelectric nanostructures for energy harvesting applications.

2014 Energy Summit Call for Papers

Dear Colleague,

There is growing industrial and academic interest in the way in which devices wirelessly communicate with each other. Often described as the *Internet of Things*, the concept of inter-device connectivity is exploding and is predicted to surpass 20 billion connected devices by 2020. To facilitate this exponential growth in smart devices, sensor technology will need to be incorporated into a myriad of new devices and materials. Powering these sensors and devices, to both collect and transmit data is a significant challenge to the industry. Harvesting ambient energy to power these devices is a promising solution to eliminate the need for replaceable batteries and hardwiring. Therefore:

We are proud to announce **ENERGY SUMMIT 2014** to be held at UT Dallas on January 27-29, 2014.

Energy Summit 2014 will focus on energy harvesting solutions for “Powering the *Internet of Things*.”

Sessions will include generating point-of-use power for:

- Implantable Sensors (Biomedical)
- Wearable Sensors (Textiles and Flexible Electronics)
- Intelligent Packaging (Electronics and Perishables)
- Extreme Environment Sensors (Transportation, Mining, Oil, etc.)

Energy Summit 2014 will be held jointly with the 7th INAMM Symposium.

We invite abstract submissions for our joint meeting. Abstracts must be no longer than 300 words and contain no special characters or illustrations. Submitted abstracts will undergo a peer review process coordinated by the Committee Members. Authors will be notified of acceptance and will be expected to attend the conference. Please submit abstracts to: energy@utdallas.edu.

Please contact Beth Keithly (keithly@utdallas.edu) or Benjamin Lund (energy@utdallas.edu) if you have problems with your submissions.

Abstract Deadline: November 25th, 2013

CEHMS Website: <http://brabantio.me.vt.edu/wp/cehms/>

Energy Summit 2014 Registration Website: : <http://energy2014.eventbrite.com>

We look forward to receiving your submission, and we do hope to see you in January!

Best Regards,

Energy Summit 2014 Organizing Committee

Center for Energy Harvesting Materials & Systems (CEHMS)

Powering Sensors for Extreme Environments: Energy Harvesting

WHAT: We are an NSF funded *Industry/University Collaborative Research Center* leveraging world class talent in energy harvesting in the areas of piezoelectrics, thermoelectrics, RFID energy transfer and low power electronics to solve critical power needs for sensors in extreme environments to enable smart mining, oil & gas production and manufacturing.

PROBLEM: Environments of extreme heat, pressure or shock are destructive to most electronic devices. Heavy industrial applications require remote sensing to monitor health, conserve energy and optimize processes. Ambient heat and vibration produce excellent “waste” energy which can be harvested to run these processes.

SOLUTION: Experts from UT Dallas, Virginia Tech and Leibniz Universität in Hannover, Germany are pursuing focused efforts to develop pre-competitive IP for energy harvesting based on new materials with sponsor companies.

RELEVANCE: Consumers demand increasing sophistication, device uptime and intelligence in clothing, electronic devices, glasses, and other accessories, especially in health fitness markets. Companies looking to enhance their own exciting technologies in these spaces can leverage unique energy harvesting capabilities developed at world class research universities to build more functional devices.

IMPACT: Companies will work closely with leading faculty members to discuss power needs, device interfaces and reliability parameters for operation in often harsh environments. Success is defined as the integration of new materials and energy harvesting technologies into commercial products and the development of an energy harvesting ecosystem to drive new innovations for all center members.

RISKS: Consumers demand high-functionality products that work to enhance their daily lives. Companies that fail to address the rapidly growing sensors market segments will lose competitive advantage in a changing global market.

COST: A \$40K investment will link highly technical faculty in materials science, physics, chemistry, and various engineering disciplines to aggressive market-based problems. Funds will directly support graduate research and provide a key recruiting avenue for companies to fill highly technical positions.

DURATION: Yearly projects and quarterly feedback keep companies engaged and aware of new developments across the industry.

SUCCESS: Successful projects engage top graduate students with innovative companies to integrate new technologies into a corporate strategy of innovation. Companies leverage small investments into shared pre-competitive IP with other Center companies to build a lasting energy harvesting ecosystem. Twice-a-year conferences and closed door meetings with Center members chart technology roadmaps and refocus center activities toward changing corporate needs.

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Thermoelectric
RFID energy transfer
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TEAM: UT Dallas, Virginia Tech and Leibniz Universität (Hannover, Germany)

FOCUS: Developing the next generation of engineers and scientists for energy harvesting technologies while generating pre-competitive IP for new energy harvesting materials and devices.

For more information please contact:

Rod Wetterskog, Associate Dean, Corporate Relations, Erik Jonsson School, 972-883-2182, watterskog@utdallas.edu

Barbara Hollis, Director of Development & Alumni Relations, NS&M, 972-883-6407, barbara.hollis@utdallas.edu



Center for Energy Harvesting Materials & Systems (CEHMS)

The Future of Wearable Sensors: Energy Harvesting

WHAT: We seek to solve critical power needs in wearable sensors to enable a new generation of smart consumer electronics.

PROBLEM: Intelligent devices for wearable sensors are predominantly battery powered and involve charging, downtime, added weight and increased logistical costs to manage.

SOLUTION: Energy harvesting devices can eliminate the need for battery replacement and significantly enhance the versatility of consumer electronics.

RELEVANCE: Consumers demand increasing sophistication, device uptime and intelligence in clothing, electronic devices, glasses, and other accessories, especially in health fitness markets. Companies looking to enhance their own exciting technologies in these spaces can leverage unique energy harvesting capabilities developed at world class research universities to build more functional devices.

IMPACT: Companies will work closely with leading faculty members to discuss power needs, device interfaces and reliability parameters for operation in often harsh environments. Success is defined as the integration of new materials and energy harvesting technologies into commercial products and the development of an energy harvesting ecosystem to drive new innovations for all center members.

RISKS: Consumers demand high-functionality products that work to enhance their daily lives. Companies that fail to address the rapidly growing sensors market will lose competitive advantage in a changing global market.

COST: A \$40K investment will link highly technical faculty in materials science, physics, chemistry, and various engineering disciplines to aggressive market-based problems. Funds will directly support graduate research and provide a key recruiting avenue for companies to fill highly technical positions.

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Center for Energy Harvesting Materials & Systems (CEHMS)

Enabling Intelligent Packaging: Energy Harvesting

WHAT: We are an NSF funded *Industry/University Collaborative Research Center* leveraging world class talent in energy harvesting in the areas of piezoelectrics, thermoelectrics, RFID energy transfer and low power electronics to solve critical power needs for intelligent packaging to enable the next generation of smart electronics, food and medicine storage.

PROBLEM: Perishable materials require unique environments for longevity. Intelligent packaging can report changes to that environment, however, space and weight limitations restrict many conventional power storage mediums, such as batteries. Small scale energy harvesting devices can provide sufficient power to monitor and report the health of intelligent packaging.

SOLUTION: Experts from UT Dallas, Virginia Tech and Leibniz Universität in Hannover, Germany are pursuing focused efforts to develop pre-competitive IP for energy harvesting based on new materials with sponsor companies.

RELEVANCE: Consumers demand increased device reliability and durability in electronics and storage time for perishable goods. Companies looking to enhance their own exciting technologies in these spaces can leverage unique energy harvesting capabilities developed at world class research universities to build more functional devices.

IMPACT: Companies will work closely with leading faculty members to discuss power needs, device interfaces and reliability parameters for operation in often harsh environments. Success is defined as the integration of new materials and energy harvesting technologies into commercial products and the development of an energy harvesting ecosystem to drive new innovations for all center members.

RISKS: Consumers demand high-functionality products that work to enhance their daily lives. Companies that fail to address the rapidly growing sensors market segments will lose competitive advantage in a changing global market.

COST: A \$40K investment will link highly technical faculty in materials science, physics, chemistry, and various engineering disciplines to aggressive market-based problems. Funds will directly support graduate research and provide a key recruiting avenue for companies to fill highly technical positions.

DURATION: Yearly projects and quarterly feedback keep companies engaged and aware of new developments across the industry.

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Center for Energy Harvesting Materials & Systems (CEHMS)

Enabling chronic implantable biomedical sensors: Energy Harvesting

WHAT: We are an NSF funded *Industry/University Collaborative Research Center* leveraging world class talent in energy harvesting in the areas of piezoelectrics, thermoelectrics, RFID energy transfer and low power electronics to solve critical power needs for wearable sensors to enable a new generation of smart consumer electronics.

PROBLEM: Implantable biomedical devices are predominantly battery powered and often have to be changed leading to additional surgeries, cost and inconvenience for the patient. Biomedical devices which utilize energy harvesting materials could solve the problem of chronic implantation through continuous power generation.

SOLUTION: Experts from UT Dallas, Virginia Tech and Leibniz Universität in Hannover, Germany are pursuing focused efforts to develop pre-competitive IP for energy harvesting based on new materials with sponsor companies.

RELEVANCE: Health care is increasingly moving towards preventative medicine. This requires screening and monitoring of vital functions to detect anomalies. Additionally, implantable biomedical devices, such as the Pacemaker, utilize battery power to keep the heart in rhythm. Regeneration of the power source of these devices is a significant obstacle to their adoption. Energy harvesting devices can solve this problem through generation of consistent power.

IMPACT: Companies will work closely with leading faculty members to discuss power needs, device interfaces and reliability parameters for operation in often harsh environments. Success is defined as the integration of new materials and energy harvesting technologies into commercial products and the development of an energy harvesting ecosystem to drive new innovations for all center members.

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