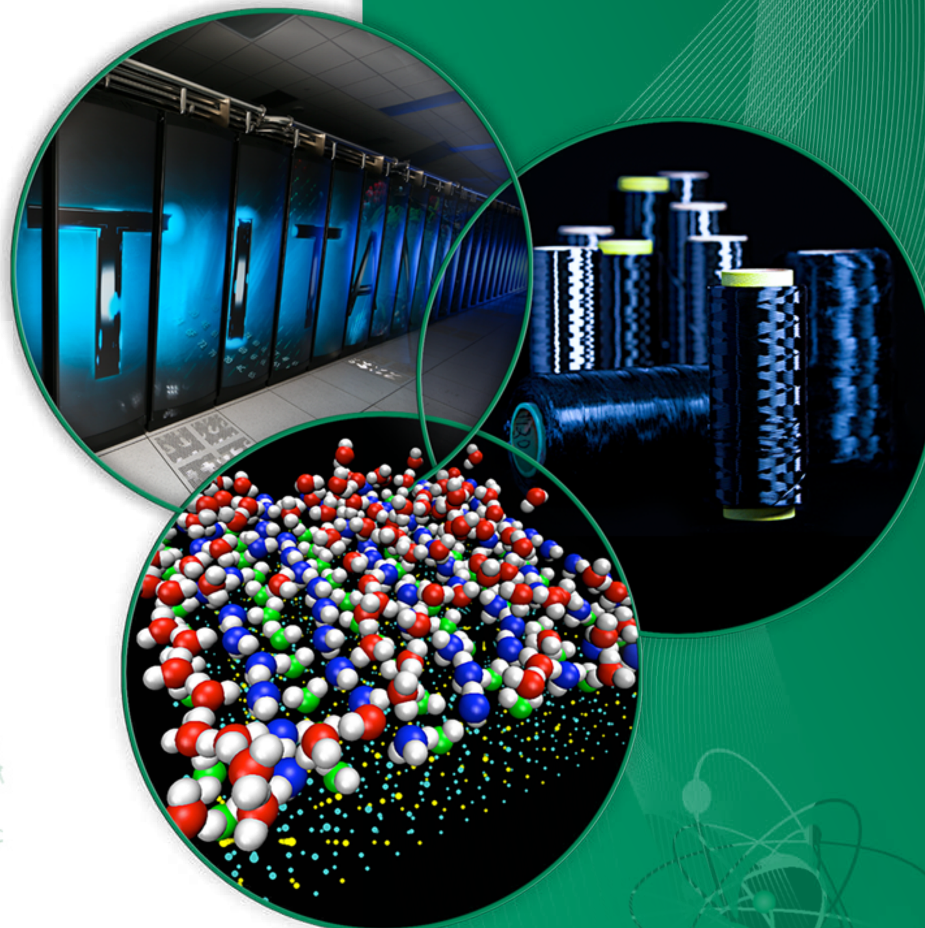
Electronics, Sensing, and Communications Research for City System Design

2014 Crosscutting Review Meeting
Pittsburg, Pennsylvania

May 19-23, 2014



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Director / Corporate Research Fellow
Electrical and Electronics Systems Research Division

ORNL's Mission

Deliver scientific discoveries and technical breakthroughs that will accelerate the development and deployment of solutions in clean energy and global security, and in doing so create economic opportunity for the nation

Director's R&D Research Priorities

FY 2015 Grand Challenge Focus Areas

Science and Informatics for Energy and Urban Infrastructure

- Develop science and technology to observe and measure through direct instrumentation of our environment and infrastructures from buildings to planet scale
- Innovative, pervasive sensing combined with scalable data collection, integration, analysis, and knowledge dissemination techniques for cross-domain applications

Integrated Energy Systems

- Revolutionize the way we produce, utilize, and distribute energy
- Small-scale distributed energy generation that is disconnected from the grid could give consumers more control over their energy choices and be more resilient to extreme weather events

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The City as a System

In an **urban computing** environment, the city is a computer, the streetscape is the interface, you are the cursor, and your smartphone the input device …

From the **city system** point of view, we apply IT principles and connectivity to the various urban infrastructure processes to create a **smart city** …

Paul McFedries, IEEE Spectrum, April, 2014

Future built-from-scratch smart cities: ***Cyburgs***

Songdo, South Korea
(Aerotropolis)

Masdar City, UAE
(Archology)

Great City, China
(Pedestrian-only)

*Planned for efficiency, wired for data and services, controlled by an **urban operating system**. Citizen access to services is networked and ubiquitous using **cityware** …*

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The Internet of Things (IoT)

Kevin Ashton

The Internet of Things was the title of a presentation Kevin Ashton gave to Proctor and Gamble in 1999 while he was the Center Director of MIT's Auto-ID Center, an RFID research consortium

… If we had computers that knew everything there was to know about things—using data they gathered without any help from us—we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best.

http://kevinjashton.com/2009/06/22/the-internet-of-things/

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Rapid Evolution of IoT Infrastructure

Electronics

- The electronics industry has undergone tremendous change since the 1960s
  - Device density: 2,300 to 3B transistors (CPU)
  - 800kHz to 5GHz clock speeds
  - 10µm to <30nm features

1971
Intel 4004
(2300 transistors)

2008
Intel Core i7
3.2 GHz
(731,000,000 transistors)

Ethernet Comms

- First developed by Xerox PARC between 1973 and 1974
- First commercially introduced in 1980 and standardized in 1983 as IEEE 802.3
- Ethernet expected to be $39B by 2017

Wireless Comms

- Wireless data communications are essential to mobile computing
  - **Wi-Fi** is a local area network for connecting devices to the Internet
  - **Cellular** data service covers 10-15 miles
  - **Mobile satellite** communications for transportation, aviation, maritime, and military

Smartphone shipments to top 1 billion in 2014

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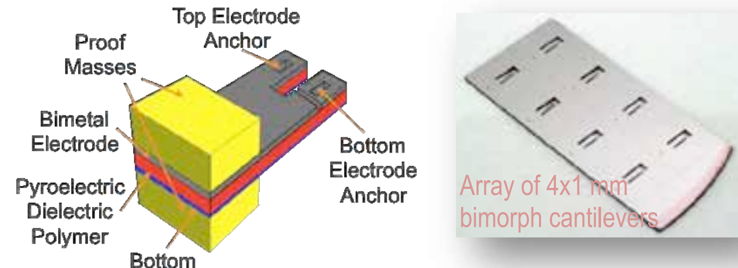
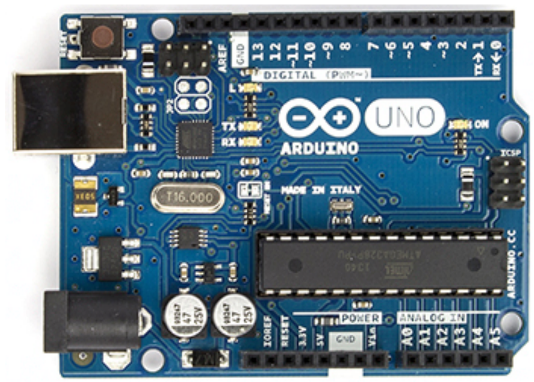
Sensor Technology

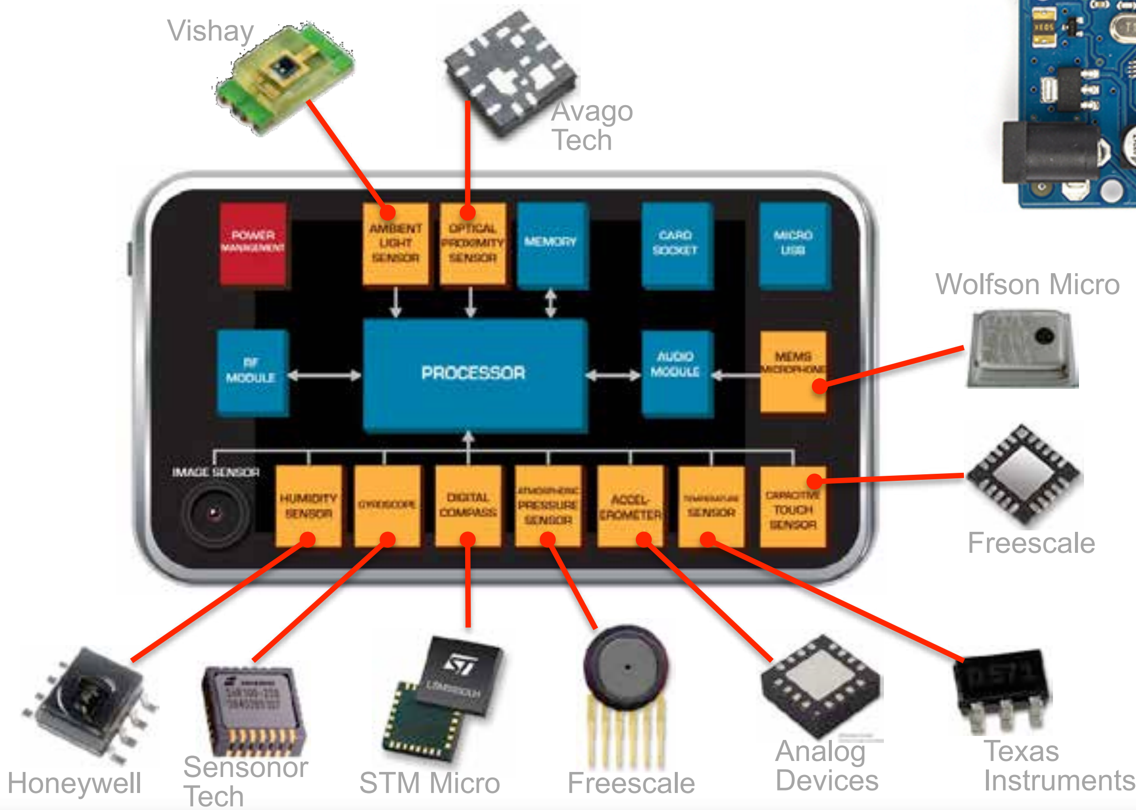
- Sensors are smaller, cheaper, low-power, with faster response
- APIs provide programmers with access to smartphone sensors



Power harvesting

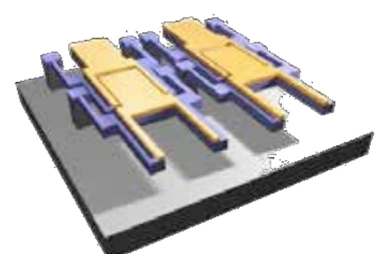



Cantilever-based antenna



Arduino
Microcontroller
14 digital I/O pins
6 PWM outputs
6 analog inputs
16MHz clock
USB connection
Power jack
Free S/W
$30 - $85


Chemical sensing


IR imaging array

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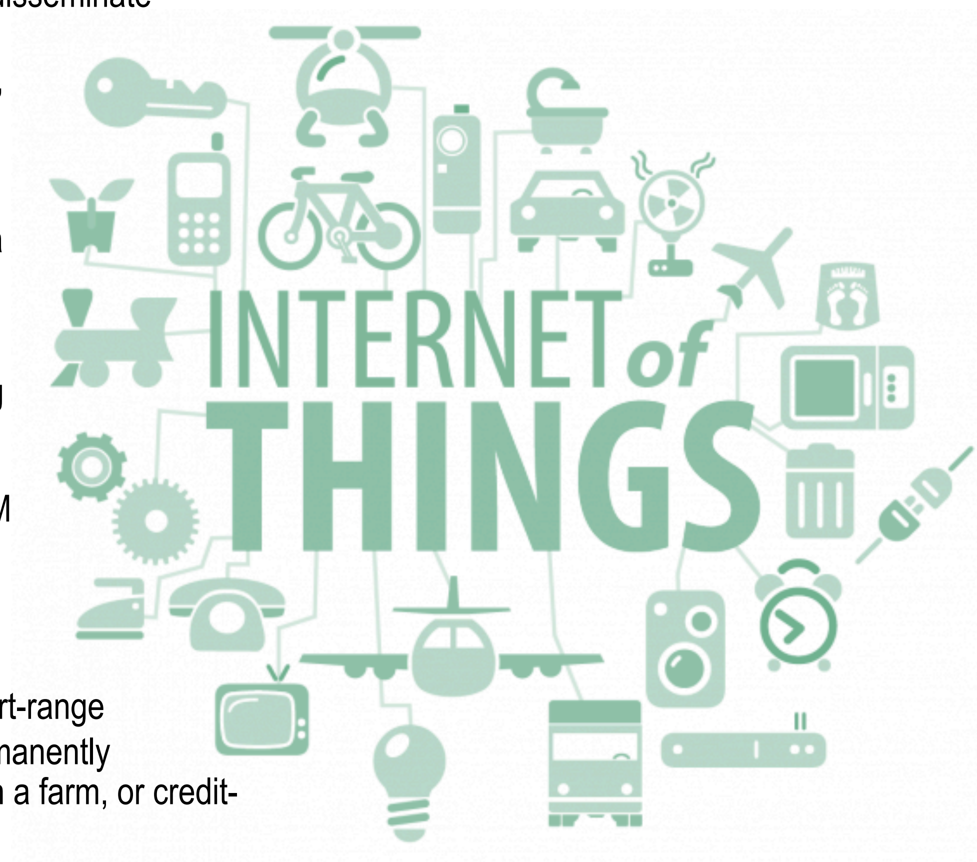
So This is the Internet of Things …

- **Things:** Physical entities whose identity or state is capable of being relayed to an internet-connected IT infrastructure.
- **Sensors:** Components of 'things' that gather and/or disseminate data — be it on location, altitude, velocity, temperature, illumination, motion, power, humidity, blood sugar, air quality, soil moisture… you name it.
- **Comms (local-area):** All IoT sensors require some means of relaying data to the outside world via RFID, NFC, Wi-Fi, Bluetooth, XBee, Zigbee, Z-Wave and Wireless M-Bus.
- **Comms (wide-area):** Mobile networks using GSM, GPRS, 3G, LTE or WiMAX, and satellite connections.
- **Server (on premises):** Some types of M2M installation, such as a smart home or office, will use a local server to collect and analyze data — both in real time and episodically — from assets on the local area network.
- **Local scanning device:** 'Things' with short-range sensors will often be located in a restricted area but not permanently connected to a local area network (RFID-tagged livestock on a farm, or credit-card-toting shoppers in a mall, etc.).
- **Storage & Analytics:** Hybrid Cloud Computing and Big Data for an incredible amount of data.
- **User-facing services:** Subsets of the data and analyses from the IoT will be available to users or subscribers.



http://www.zdnet.com/m2m-and-the-internet-of-things-7000008219/

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The IoT will Interact Through Two Primary Mechanisms

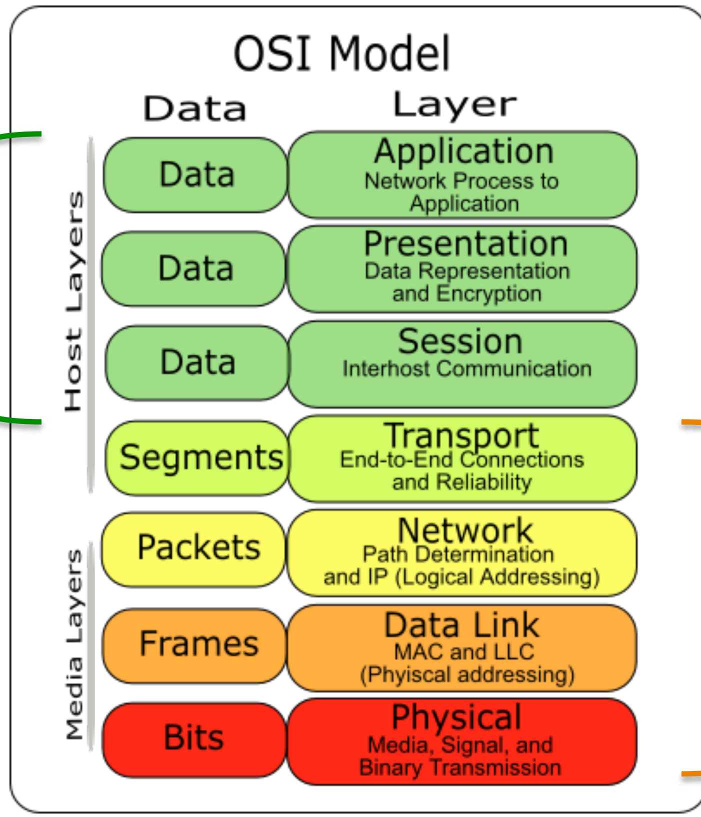
Thing-to-person (person-to-thing)

Fairly common today. People interact with data from things through apps, databases, cloud storage, etc.

Thing-to-thing

Less common today but changing fast. Devices and sensors interact with other objects to monitor, control, notify humans, etc.

Human interactions and analysis through the host layers



Sensors
Controls
Diagnostics
Prognostics
Alarms

Sensors and measurement devices communicate through the media layers

Apps
Analytics
Modeling
Simulation
Visualization

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The Impact of Sensing on the City as a System

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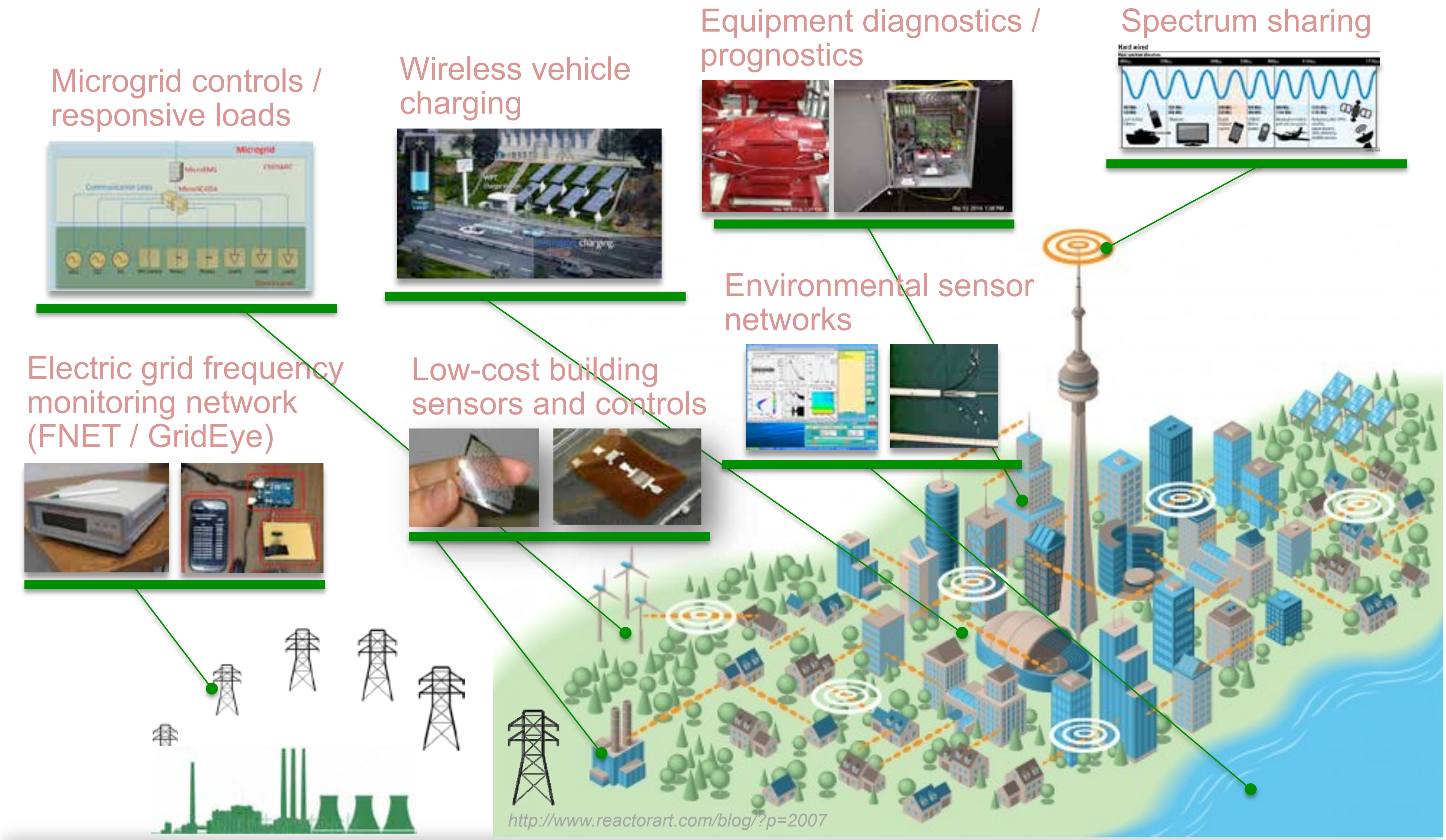
What is ORNL Doing to Impact the City System? Here are a few Topics …



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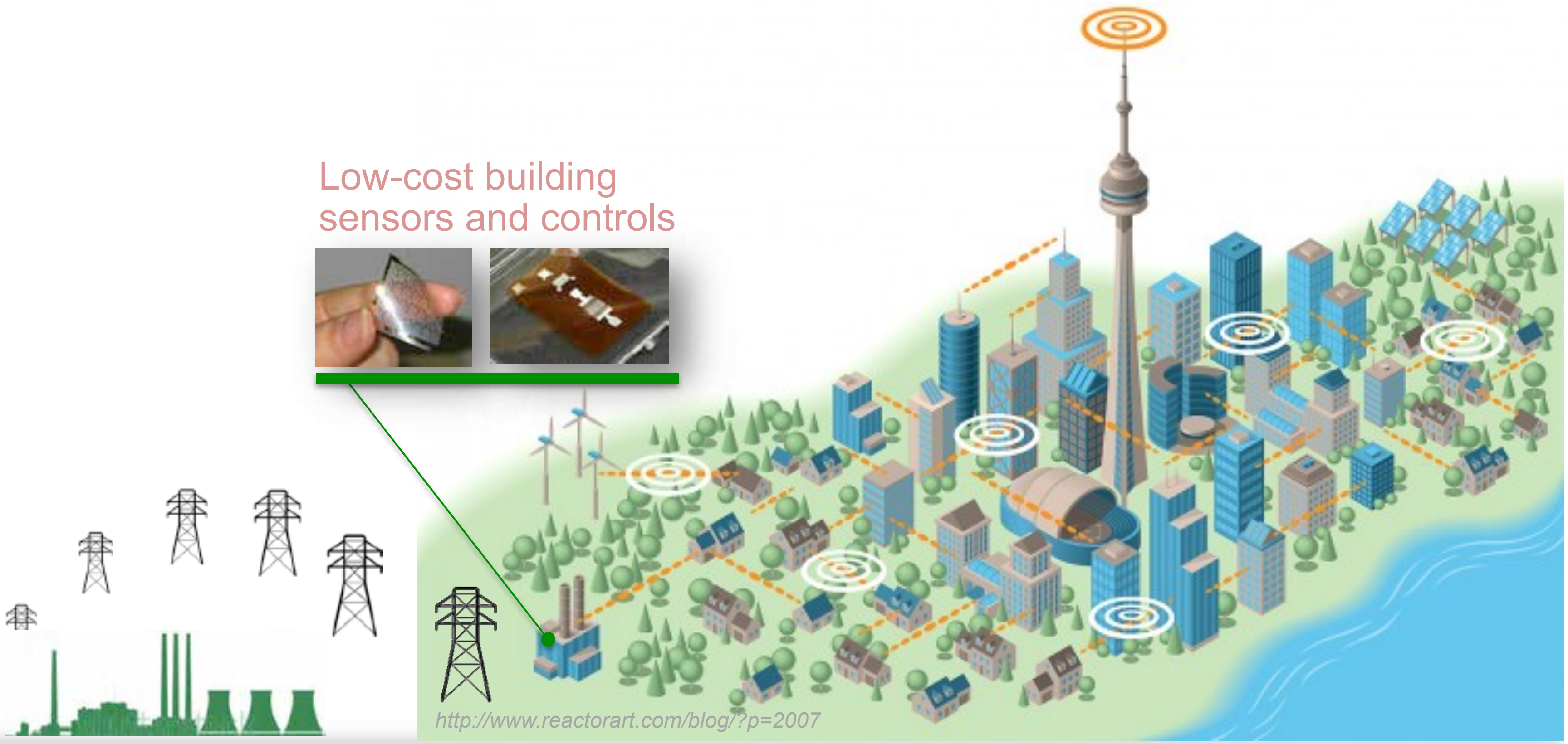

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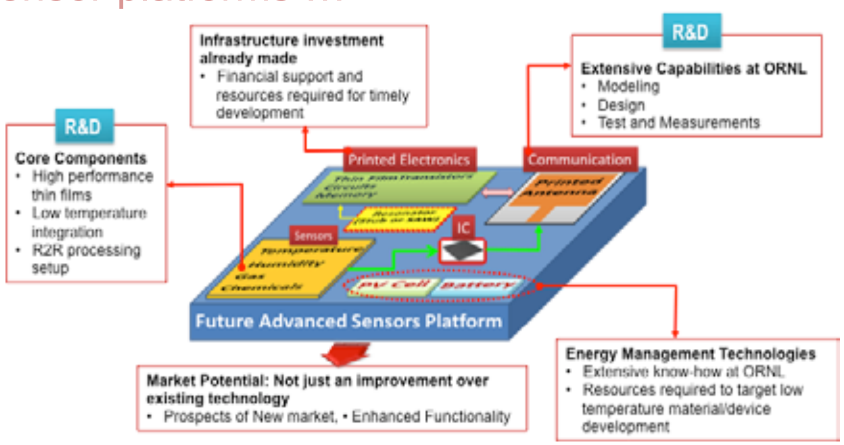
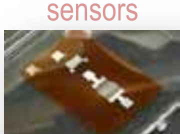
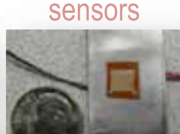
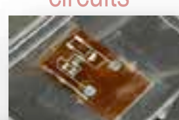
ORNL is Leveraging Unique Capabilities to Impact Energy Use in Buildings

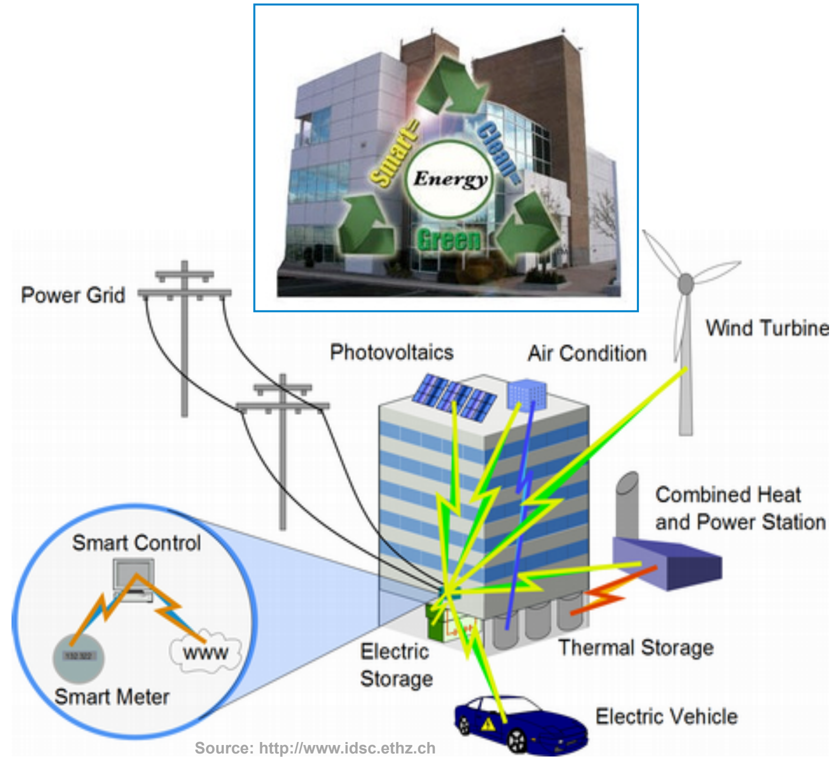
- Buildings consume up to 40% of the energy produced in the US today
- Advanced sensors and controls have the potential to reduce energy consumption by > 20%

We are building low-cost, low-power wireless sensor platforms …



Wireless communications	Environmental sensors	Mechanical sensors	Flexible circuits
			

Smart Buildings Technology



EERE energy goal in buildings - Improve building energy efficiency 50%, in a cost-effective manner, by 2030

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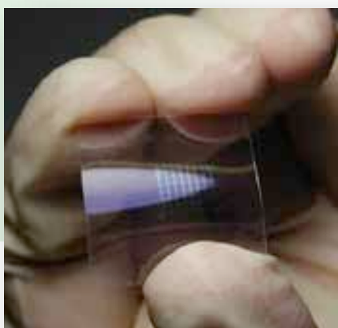
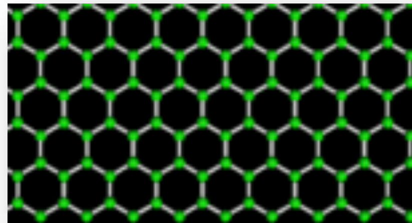
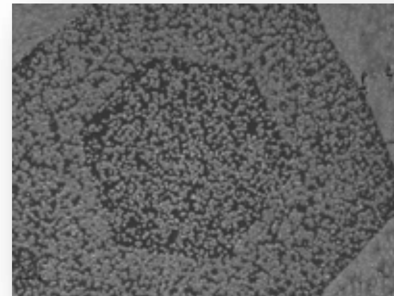
Printable, Low-Cost Electronic Components

- Graphene
  - Strong, light, nearly transparent, one atom thick
  - Excellent conductor of heat and electricity
- Zinc and Gallium Oxide
  - Developing materials for printable transistors
  - Produced dielectric aerogels of doped or chemically altered for their semi-conducting character
  - Researching conductive polymer additives to enhance conductivity
  - Goal is to develop printable electronic circuits on flexible materials

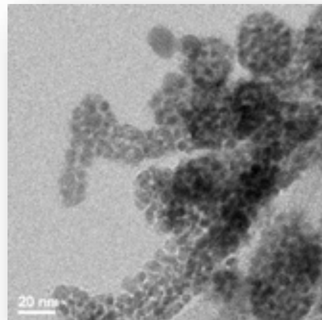




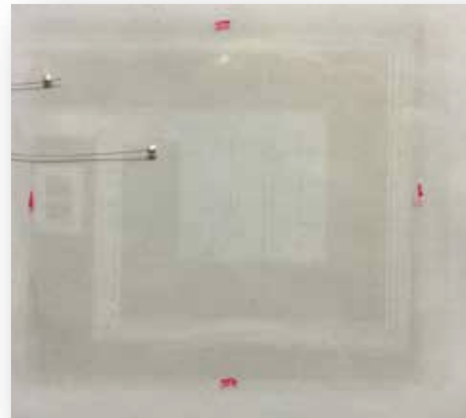
Carbon atoms in hexagonal lattice



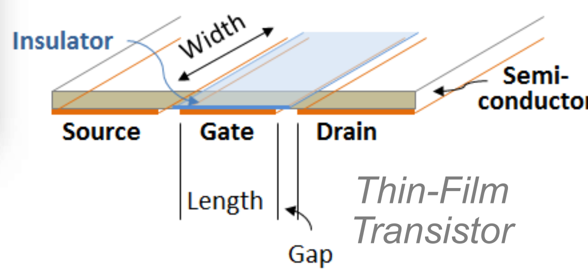
Graphene crystal decorated with nanoparticles



ZnO with 2nm Au nanoparticles



4-Monolayer Graphene Antenna



Thin-Film Transistor

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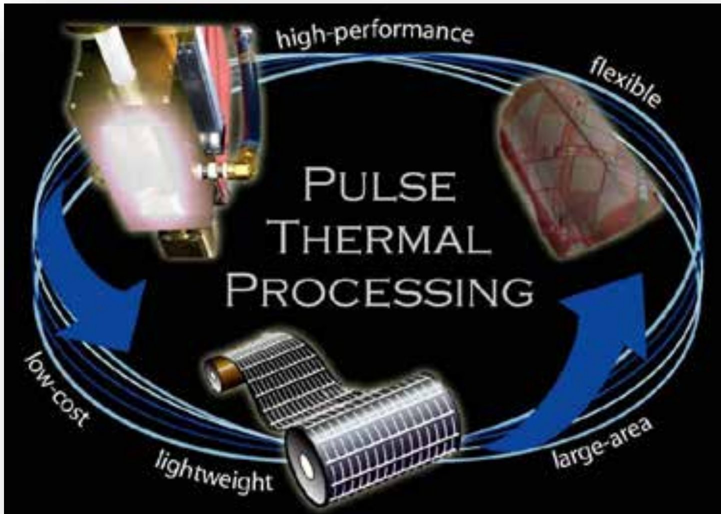
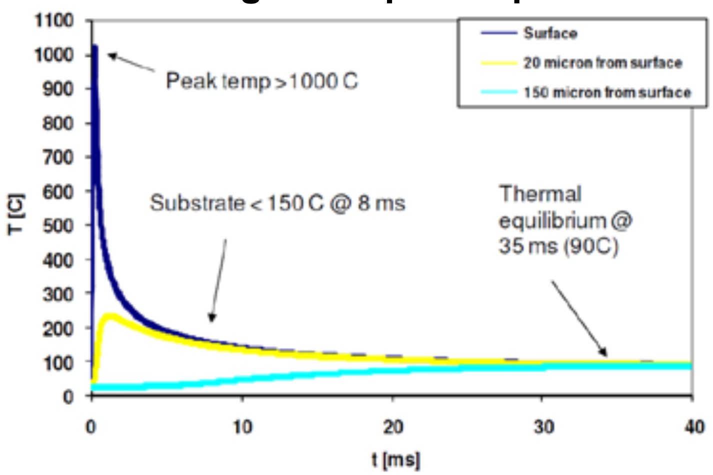
Pulsed Thermal Processing to Realize Low Temperature Electronics



Ag/PET: 1µm/150µm



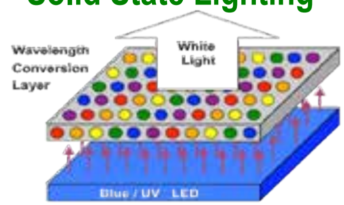
Flexible Displays

Crystallize a-Si thin film transistors for backplane

Thin Film Batteries

Increase storage capacity by controlling grain growth and orientation

Solid State Lighting



PTP anneals nanostructure to reduce defects and increase efficiency

Thin Film Photovoltaics

Crystallize Amorphous Silicon on Metal Foil

Texture CIGS Nanocrystals on Polymer Substrate

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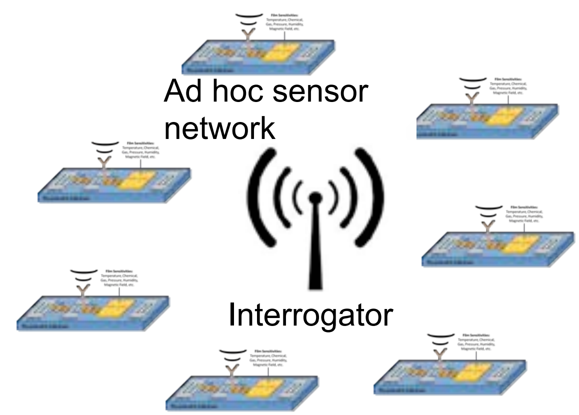
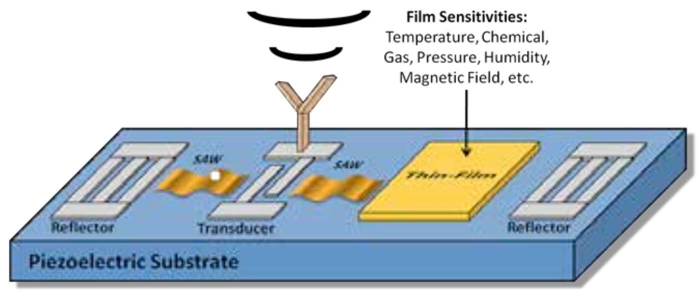
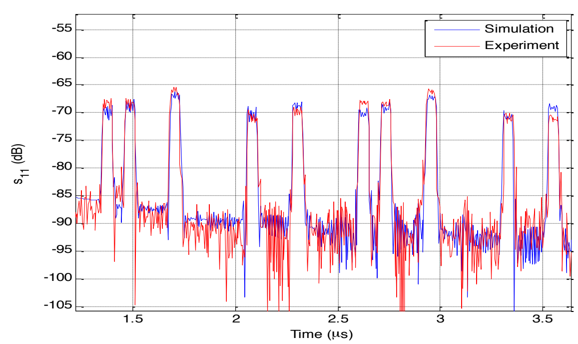
Ultra-low Cost, Battery-free, Mass Producible Sensors Using Radio Frequency Surface Acoustic Wave (RF-SAW) Micro-structures

- Printable antennas and sensors combine RF signals with SAW structures enabling passive micro-sensor platforms
- Sensor functions by receiving power from an RF interrogator; interrogator receives power from AM/FM/cellular broadcast signals
- Sensor can communicate over large distances (100s of meters)



- Tuned SAW structures provide each sensor with a unique ID and allow for many-sensor arrays
- Wide variety of thin film sensor types: temperature, humidity, VOCs, hydrogen, toxins, CO/CO2, etc. are possible





456MHz SAW orthogonal frequency coding

FM radio or cellular transmission tower

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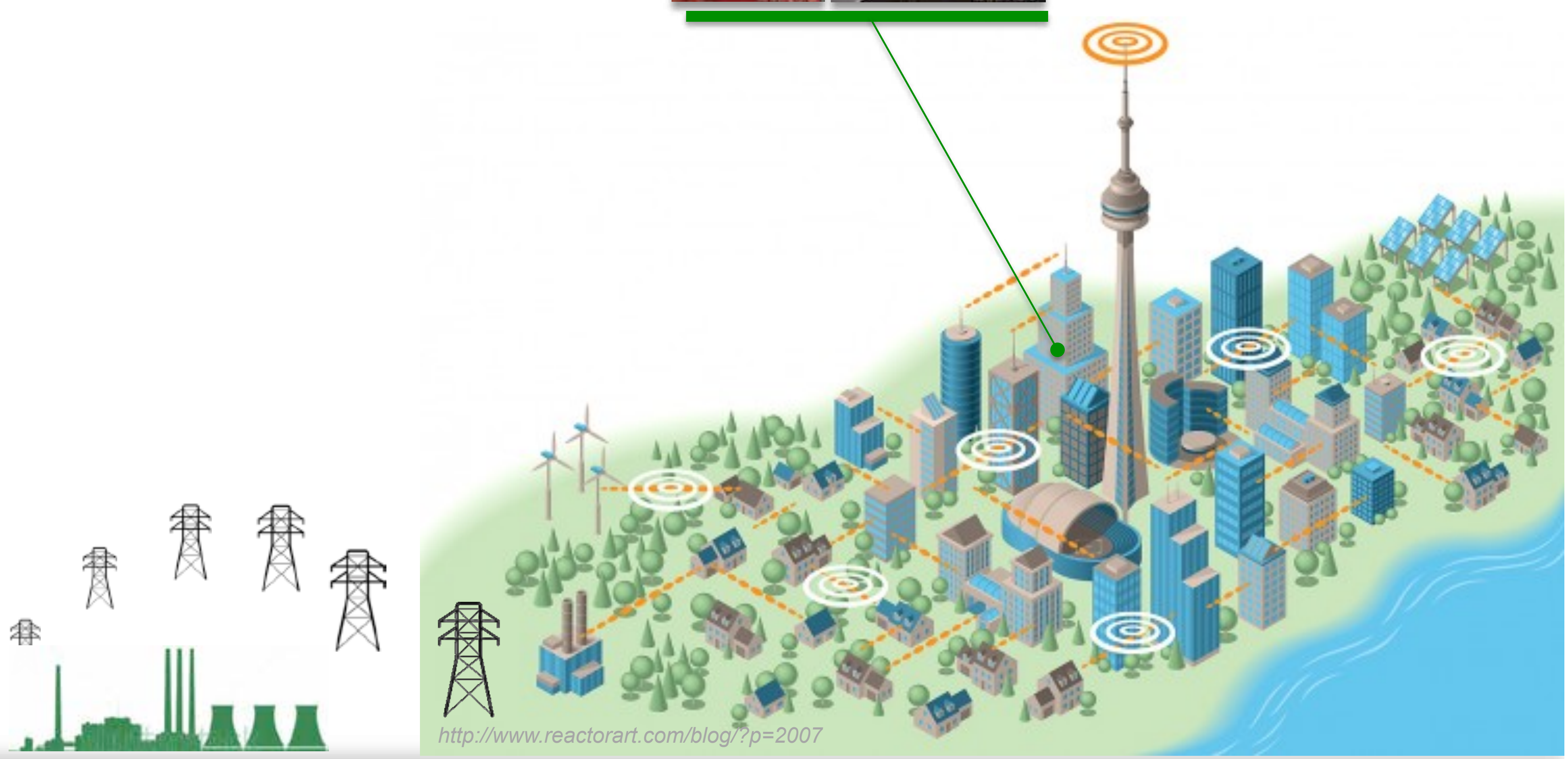
Equipment diagnostics / prognostics



http://www.reactorart.com/blog/?p=2007

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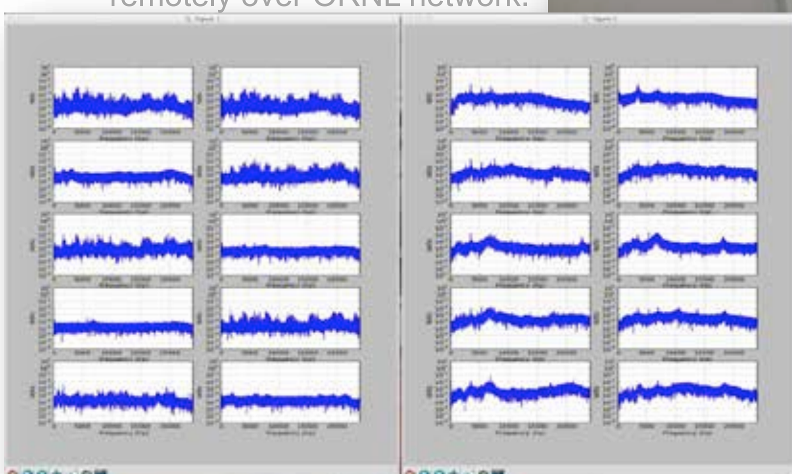
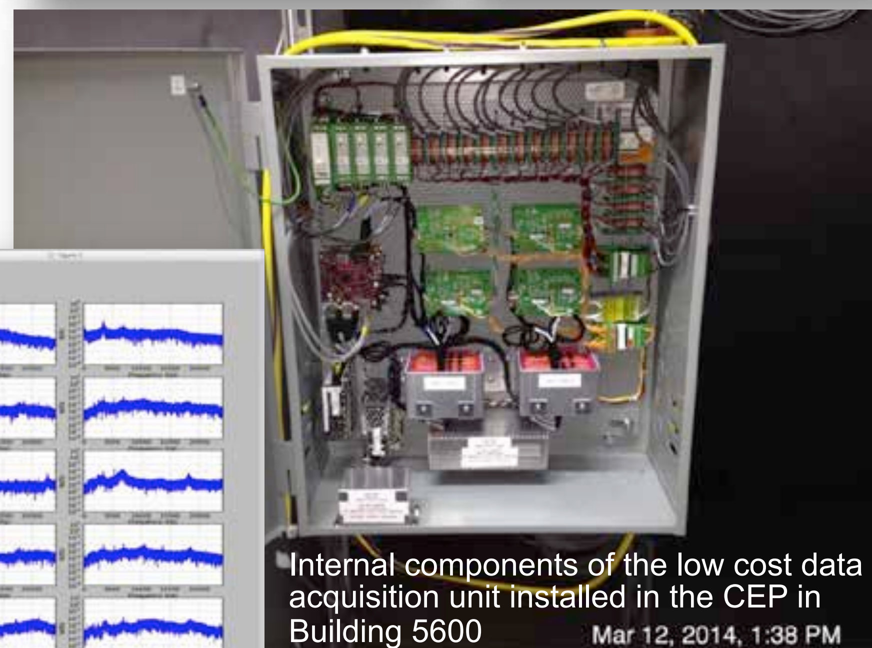
Rotating Equipment Monitoring System

- Central Energy Plant (CEP) Chiller system, Bldg. 5600 HPC Facility
- Developed low-cost solution to provide networked 20-channel data acquisition system for monitoring rotating equipment
  - Commercial system: $100K
  - Consumer-grade electronics and MEMS accelerometers: $10K
- CEP research platform for developing new diagnostic methods …

- Monitor / assess equipment health
- Predictive scheduling for maintenance
- Prevent catastrophic damage
- Archiving performance data for analysis

Frequency plots of all 20 channels in CEP acquired remotely over ORNL network.





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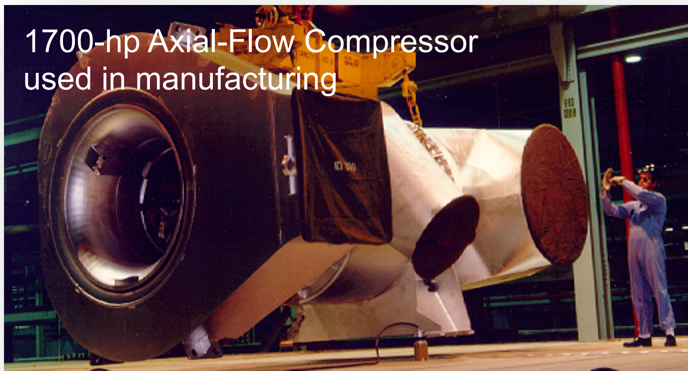
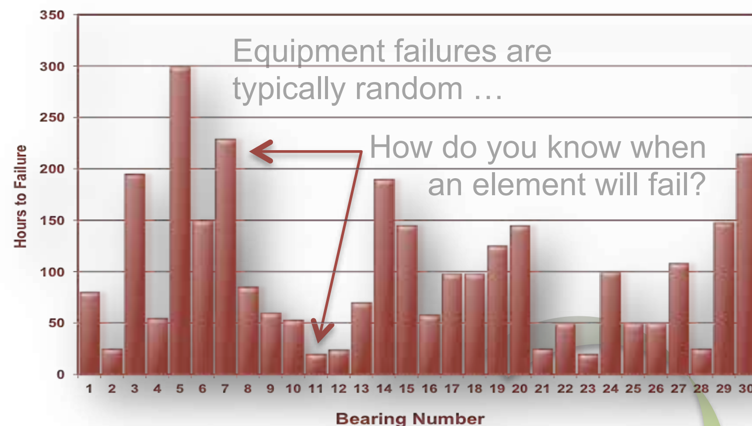
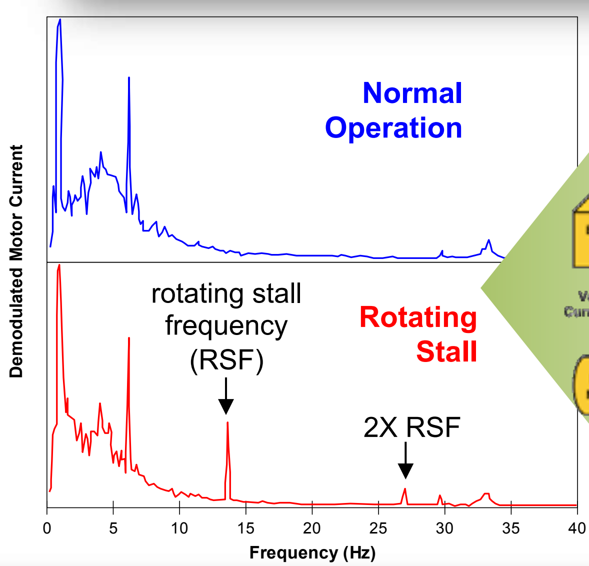
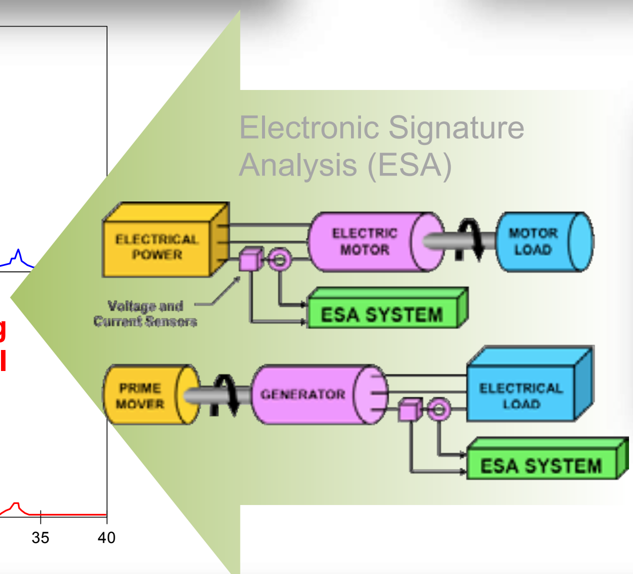
Machine Diagnostics / Prognostics

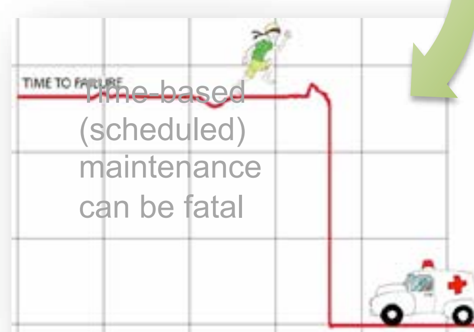
- m2m capabilities integrated with control systems will automate our ability to diagnose and predict equipment drift, optimize maintenance scheduling, and predict imminent failure in real-time











mPower SMR

SMRs are small (95% reduction in containment), compact, and full of opportunity for embedded I&C to improve condition monitoring and control

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Electric grid frequency monitoring network (FNET / GridEye)

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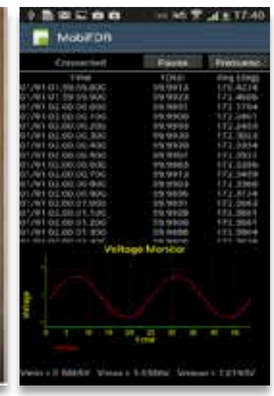
Grid Monitoring: FNET/GridEye

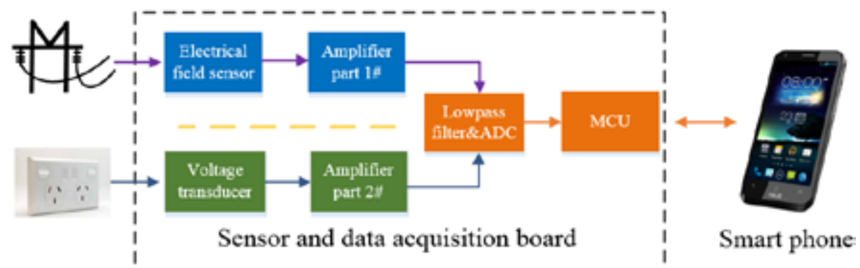
- Low-cost frequency disturbance recorder (~ $1000/unit) – records fluctuation in power grid frequency from consumer voltage measurements
- Automated reporting to industry of disturbances
- Device network provides wide-area visualization across the three major grid interconnections

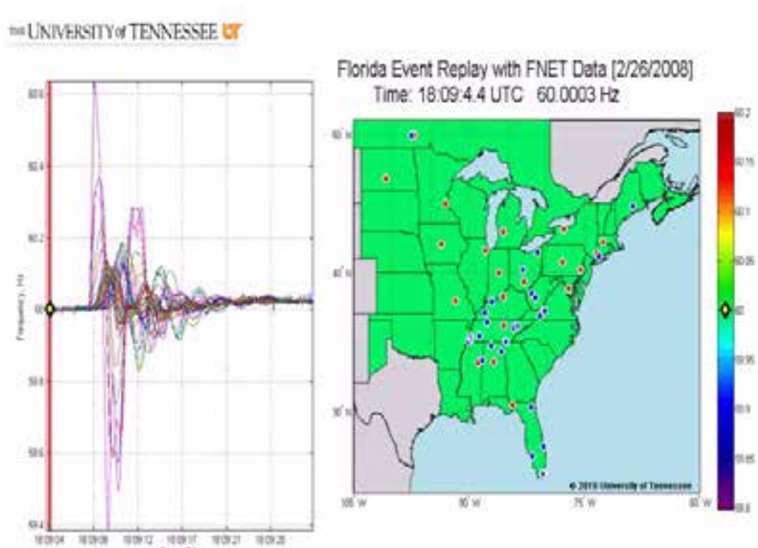
First generation GridEye

TMS320C6678 8-core floating point DSP



Next generation smartphone based recorder





Event initiated by turbine trip in Florida

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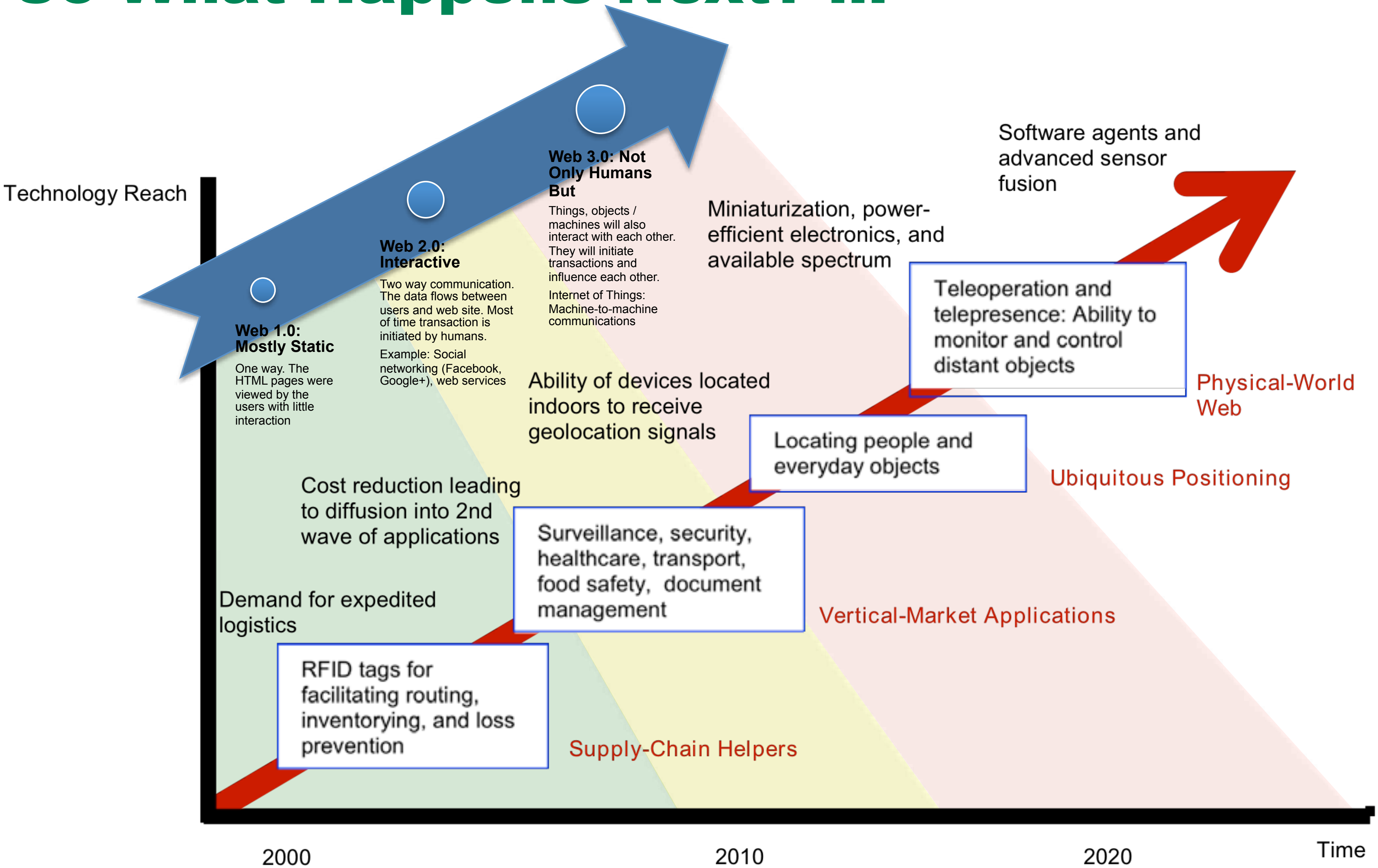
So What Happens Next? ...



Source: SRI Consulting Business Intelligence

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Consumer Marketplace Certainly Drives IoT Innovation …

Transportation

Consumer and market-driven products will drive technology adoption and advancement in many sectors

Health

Energy

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There are Many Services Available Today to Log and Access Your Sensors and Data …

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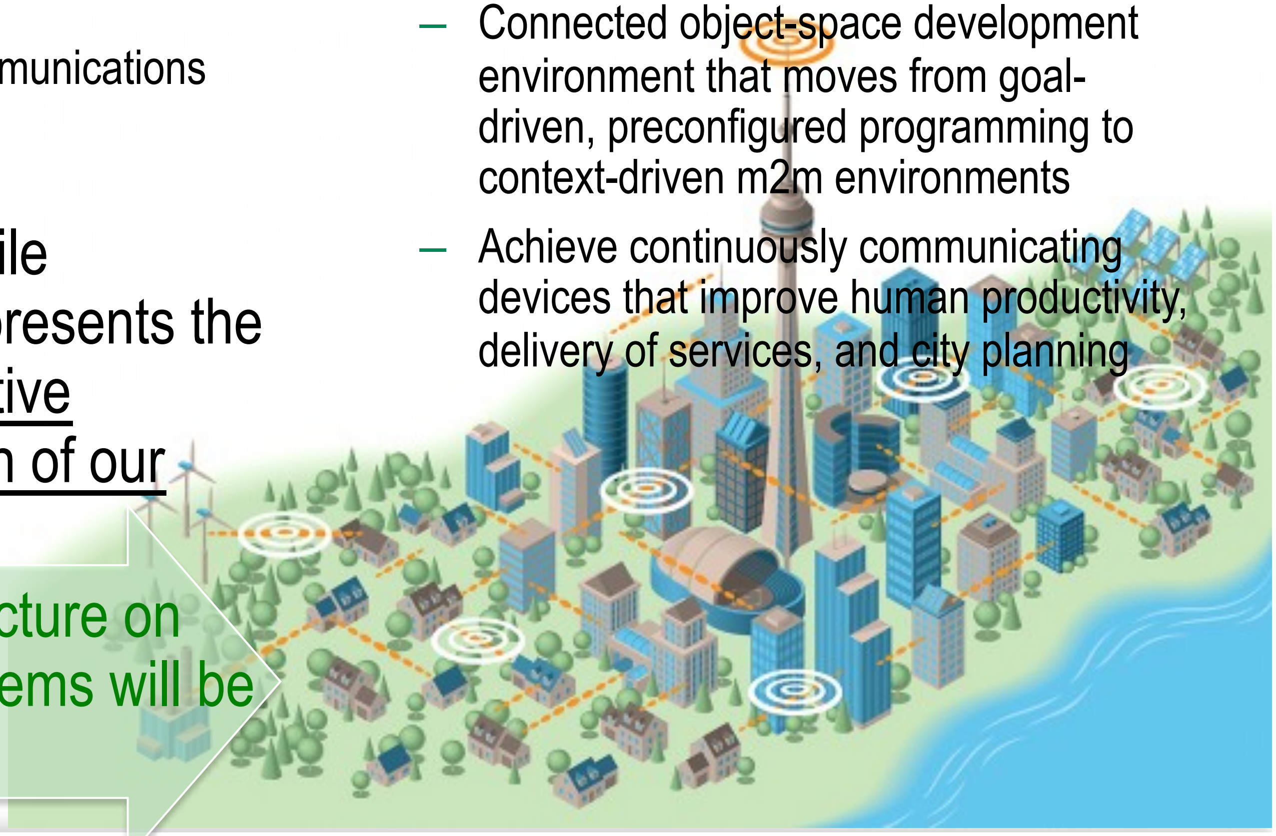
Conclusion: Where do we Need to go?

- The IoT describes the confluence of several technologies that enable the Internet to reach into the real world
  - Low-cost, high-performance electronics
  - RFID technology
  - Short-range wireless communications
  - Real-time localization
  - Sensor networks
- After the web and mobile networking, the IoT represents the <u>most potentially disruptive technological revolution of our lifetime</u>
- The IoT is the infrastructure on which modern city systems will be built

- Most of our "smart things" are not very smart today, so what do we need?
  - Efficient power and power harvesting electronics for unattended long-term use
  - Connected object-space development environment that moves from goal-driven, preconfigured programming to context-driven m2m environments
  - Achieve continuously communicating devices that improve human productivity, delivery of services, and city planning



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Oak Ridge National Laboratory:
Meeting the challenges of the 21st century

Questions?

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