Building Technologies Office (BTO)
Sensor and Control Technologies R&D Program Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Marina Sofos, Ph.D.

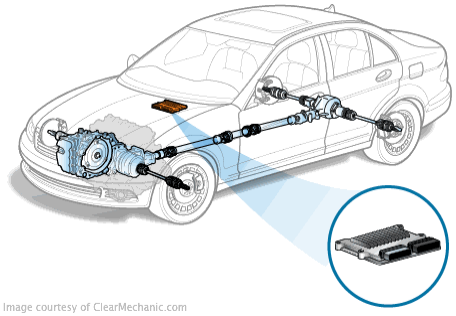
BTO Peer Review

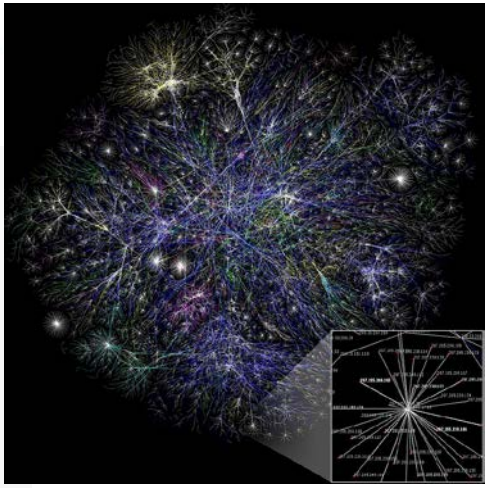
April 6, 2016

Marina.sofos@ee.doe.gov

Sensors and Controls are Everywhere

- Automotive
- Aerospace
- Industrial control of machines and processes
- Biomedical uses, including robotic surgery and drug discovery and development
- Electronics and communication networks





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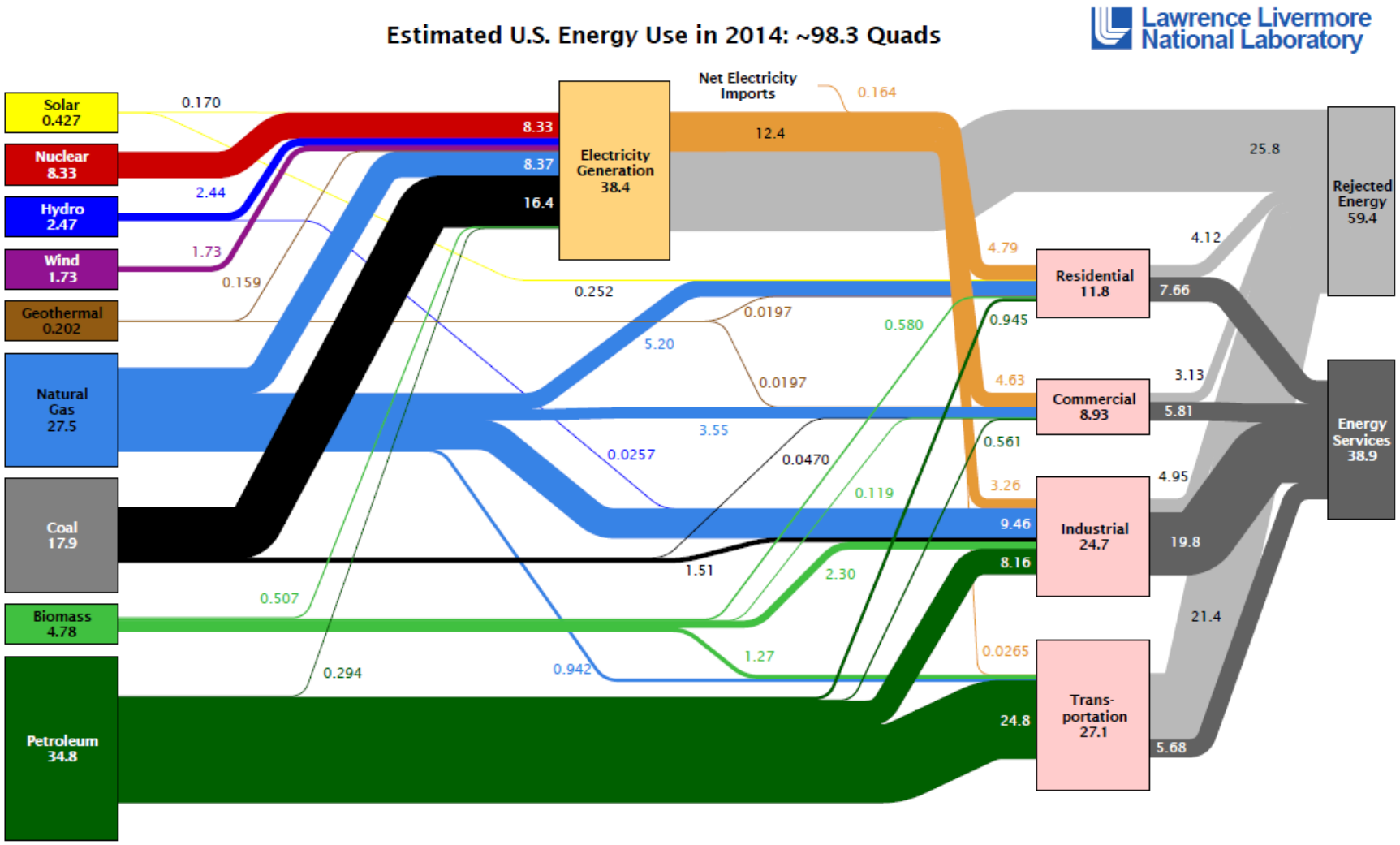
Optimizing Energy Use and Reducing Losses



Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

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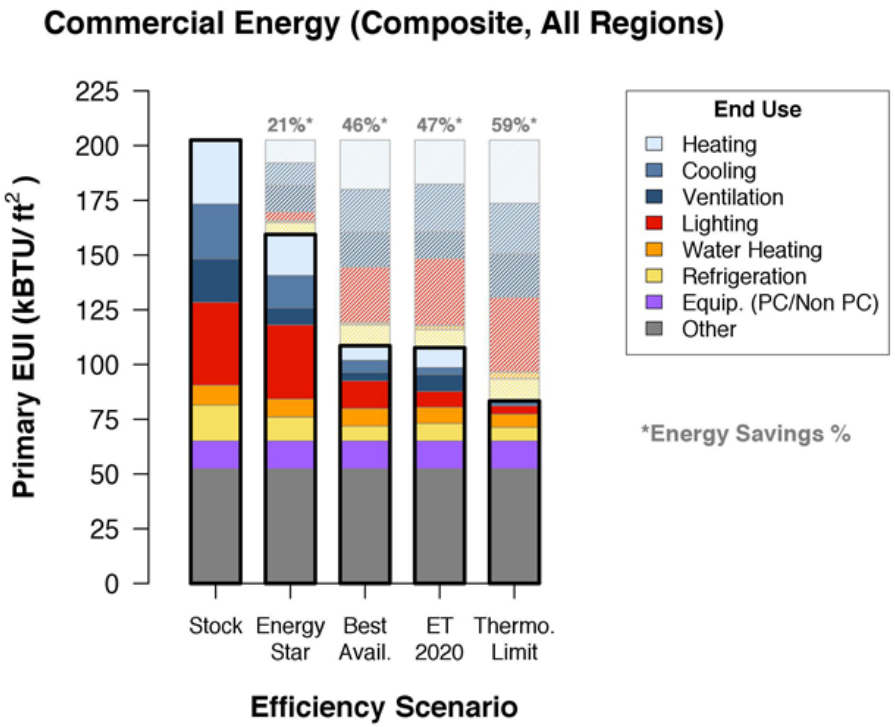
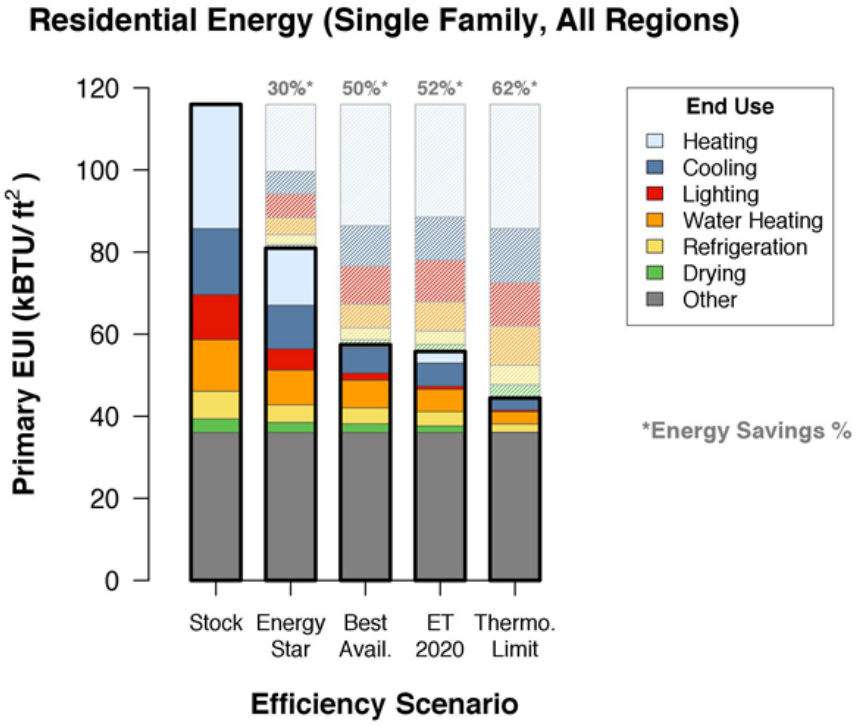
Achieving BTO R&D Goals

ET 2020 – ET Multi-year Program Plan Targets for 2020





"Other" dominates in future: Transformers, medical imagers, elevators, escalators, pumps, laundry equipment, pumps, fume hoods, CHP, Small electric devices, heating elements, outdoor grills, exterior lights, pool/spa heaters, etc.

Best available does not consider cost

ET 2020 includes cost effectiveness

ET = Emerging Technologies

EUI = Energy Use Intensity

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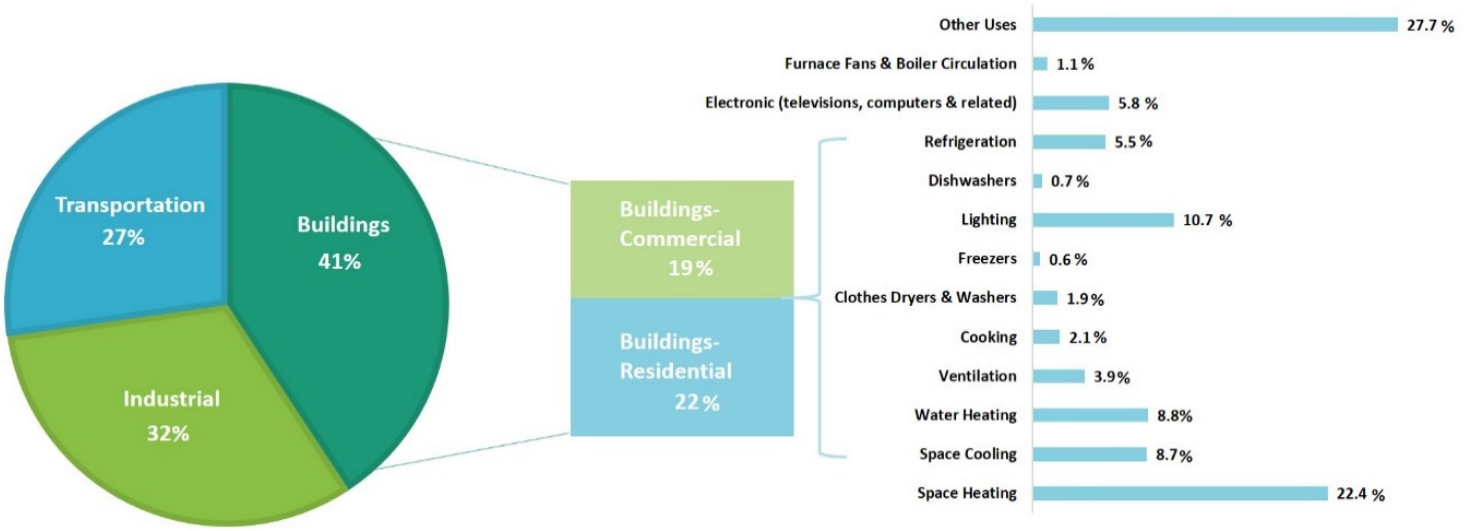
Opportunity space

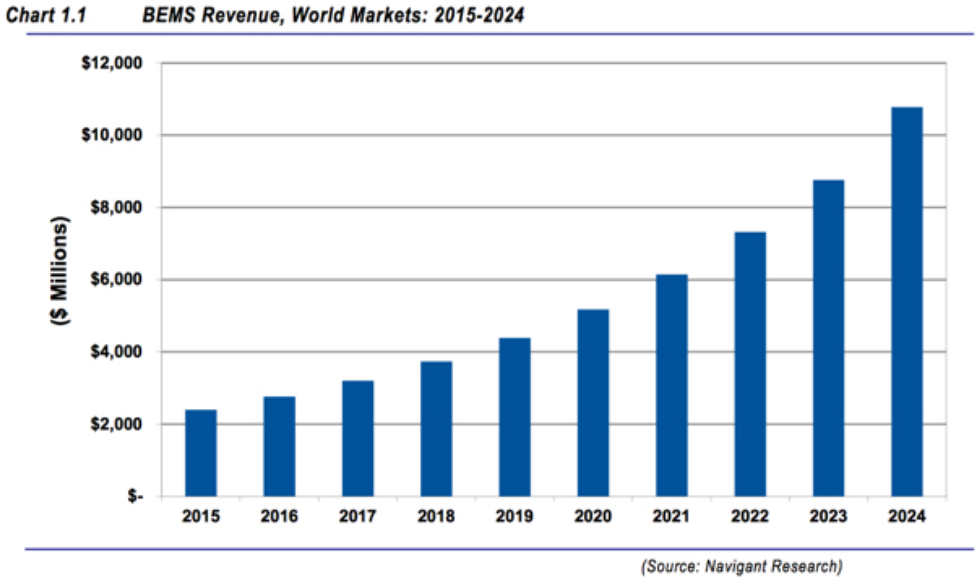


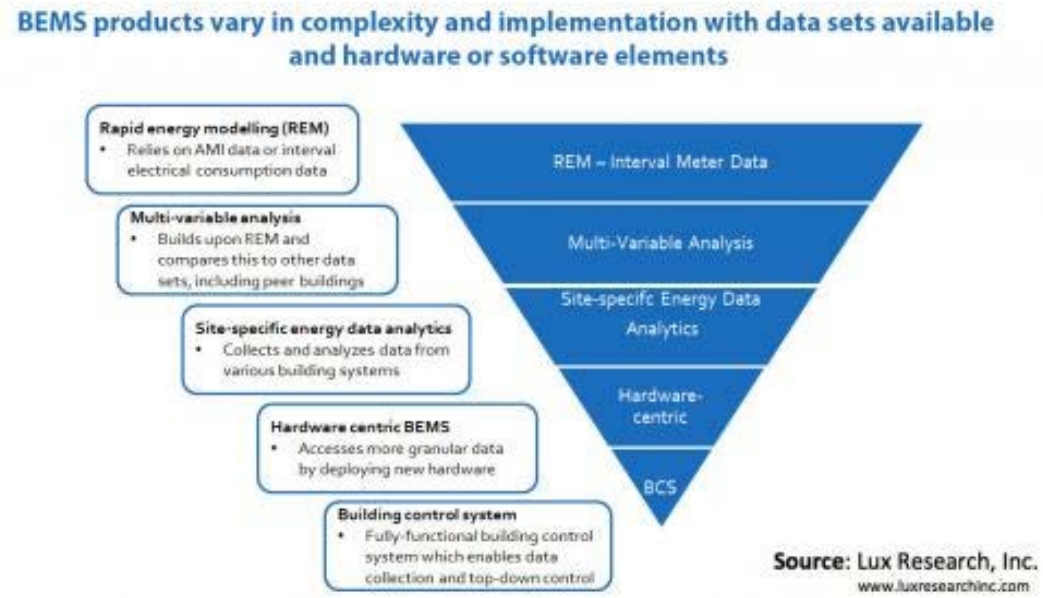
Source: 2015 Annual Energy Outlook with Projections to 2040, U.S. EIA. April 2015.

- Over 90% of commercial buildings are small (< 5,000 square feet) or medium (between 5,000 and 50,000 square feet) in size with little or no whole-building automation systems.
- Sensors and controls have the potential to reduce the energy consumption of the existing commercial building stock by 20%–30%.* (Roth et al, TIAXX 2005)

*Updated analysis underway by PNNL estimating the benefits and impacts of sensors and controls across the commercial building stock (Expected Release: Fall 2016).

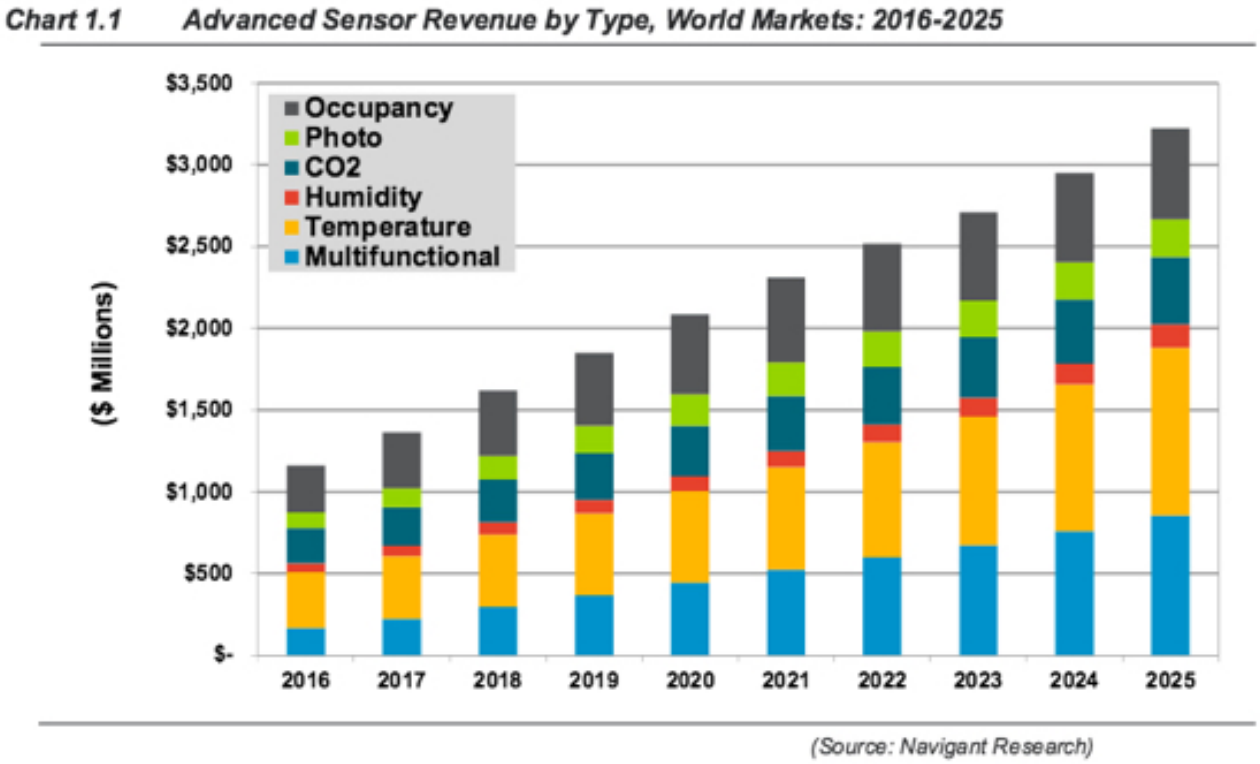
The Market is Growing for Building Energy Management





- Building Energy Management Systems (BEMs) attracted $1.4 B in VC Funding from 2000-2014 (26% of all investment in building energy technology): 30% software, 27% energy services, 25% sensors and controls; 13% semiconductors
- Market transitioning from BAS-dominant to BEMS. In 2020, about 77% of the $2.14 billion U.S. market will comprise BEMS applications, and 40% will come from buildings below 50,000 square feet.
- U.S. market for sensors and controls for BEMs will rise at a 17% compound annual growth rate to $2.14 billion in 2020.

Advanced Sensors in Buildings are Expanding



- Global advanced sensor revenue for buildings is expected to grow from $1.16 B in 2016 to $3.22 B in 2025

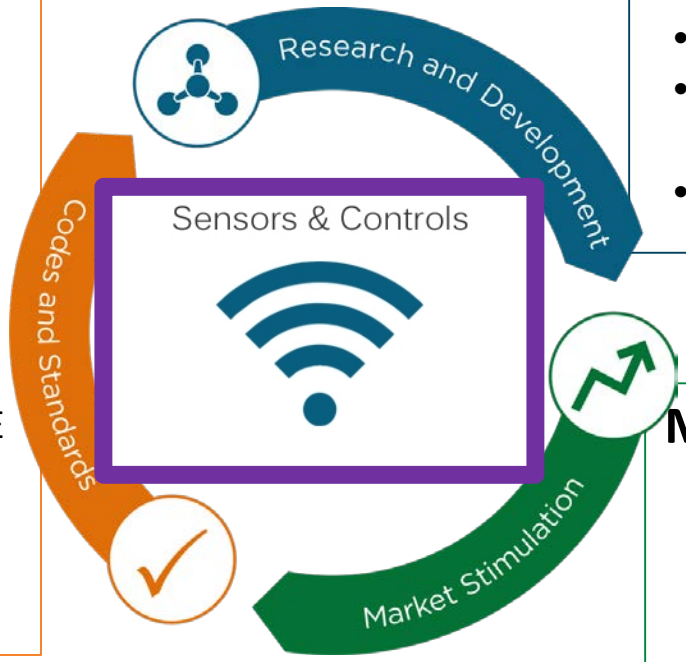
Vision for Sensing and Controls in Buildings

Buildings will automatically configure, commission, and learn so that the integrated result is optimized operations, maximized energy savings, and participation in grid services

Cross-cutting Approach to Implement Vision

Codes and Standards

- Establish minimum energy use in a transparent public process
- Protect consumer interests
- Reduce market confusion
- Enhance industry competitiveness & profitability
- Expand portfolio of EE appliances & equipment
- Raise the efficiency bar



Research & Development

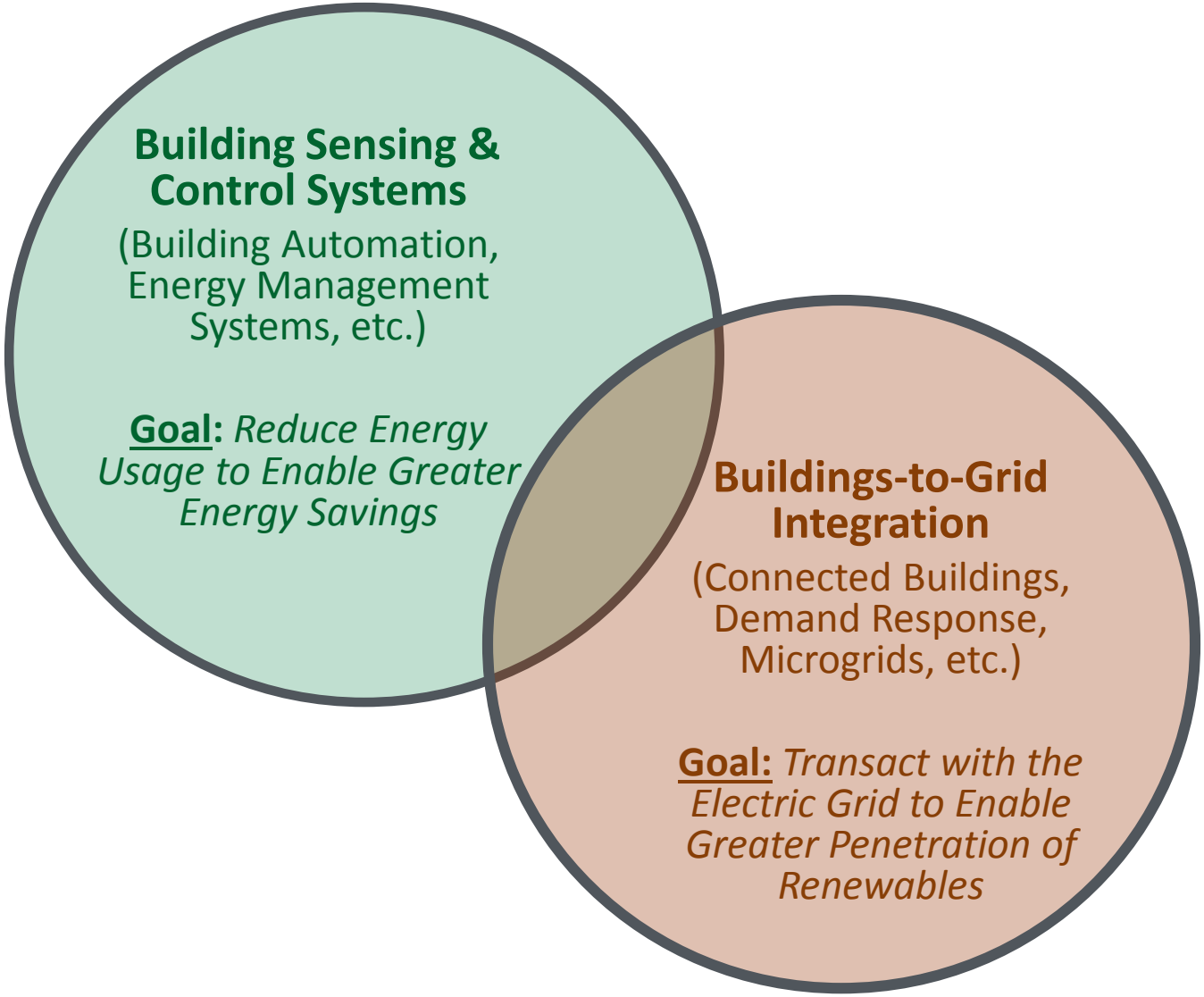
- Develop technology roadmaps
- Prioritize opportunities
- Solicit and select innovative technology solutions
- Collaborate with researchers
- Solve technical barriers and test innovations to prove effectiveness
- Measure and validate energy savings

Market Stimulation

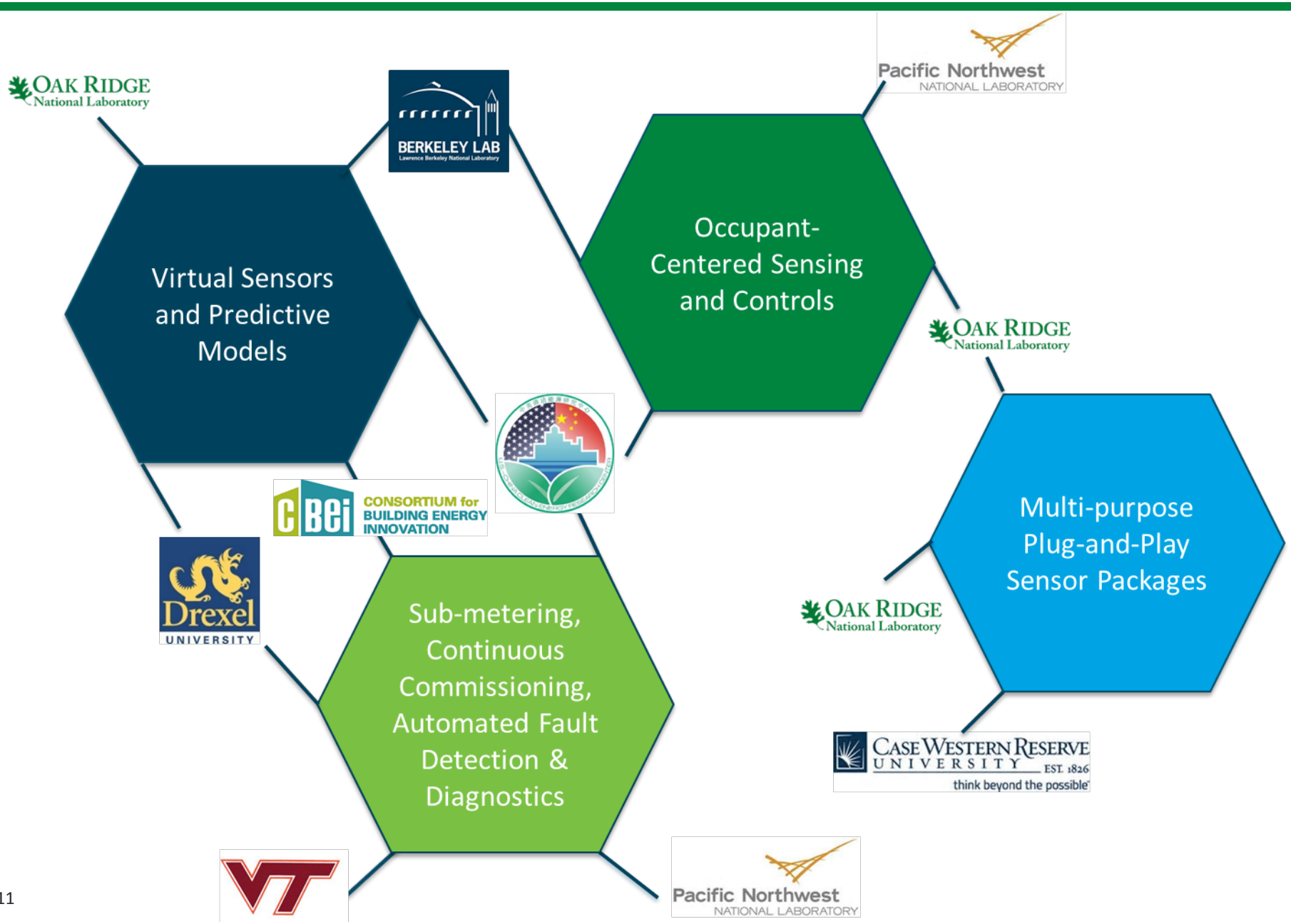
- Identify barriers to speed and scale adoption
- Collaborate with industry partners to improve market adoption
- Increase usage of products & services
- Work through policy, adoption, and financial barriers
- Communicate the importance and value of energy efficiency
- Provide technical assistance and training

BTO Sensors and Controls R&D Goals

1. Low-cost, self-powered plug-and-play wireless sensor platforms with automated calibration, communication, and configuration
2. Low-cost, fault-tolerant plug-and-play control systems with automated communication, configuration, and optimization



Current BTO-funded Sensors & Controls Projects



BTO Sensors and Controls R&D Portfolio

1. Directed National Laboratory Efforts

a) 1-3 Year ET S&C Merit Review Awards

b) DOE Grid Modernization Lab Consortium (starting in FY16/17)

c) FY15 ET-CBI Open Lab Call

2. Awarded by Funding Opportunity Announcements to Industry, Academia or National Labs

a) FY13 Turn-Key and FY14 BENEFIT

b) Consortia: US-China CERC, US-India CBERD, Penn State CBEI

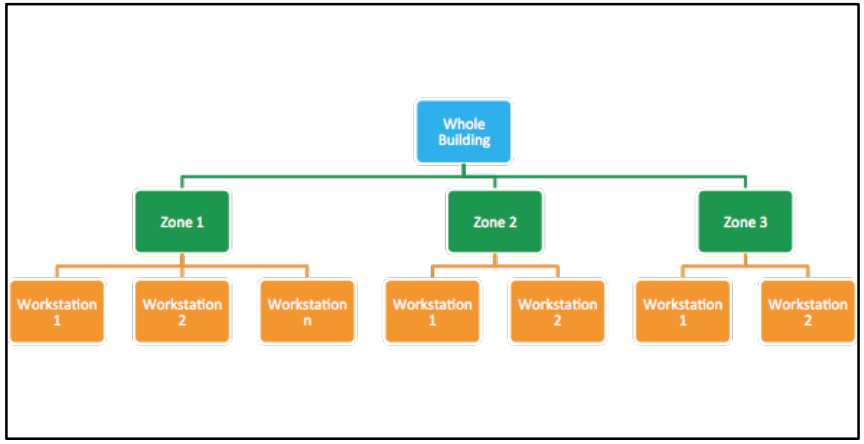
c) SBIR

Today's Agenda

Time	Session/Speaker	Project/Topic
9:50 am – 10:20 am	Marina Sofos (DOE/BTO)	Sensors & Controls Subprogram Overview
10:20 am – 10:50 am	Christian Kohler (LBNL)	U.S.-India CBERD Integrated Sensors & Controls
10:50 am – 11:05 am	Break	
11:05 am – 11:35 am	Saifur Rahman (Virginia Tech)	Building Energy Management Open-Source Software (BEMOSS)
11:35 am – 12:35 pm	Jordan Berg (NSF), Jennifer Gerbi (ARPA-E), & Trung Tran (DARPA)	Panel: Federal Perspectives on R&D Opportunities for Sensors and Controls in Buildings
12:35 pm – 1:35 pm	Lunch	
1:35 pm – 2:05 pm	David Fugate (ORNL)	Industry Partnership to Improve Building Energy Efficiency by Equipment Health Monitoring with Virtual Intelligence Sensing
2:05 pm – 2:35 pm	Pooran Joshi (ORNL)	Low-cost Manufacturing of Wireless Sensors for Building Monitoring Applications
2:35 pm – 3:05 pm	Philip Feng (Case Western)	Transforming Ordinary Buildings into Smart Buildings via Low-Cost Self-Powering Wireless Sensors & Networks
3:05 pm – 3:35 pm	REVIEWERS AND STAFF ONLY	Sensors and Controls Wrap-up
3:35 pm – 4:05 pm	Break	
4:05 pm – 5:40 pm	Harvey Sachs (ACEEE), Alan Meier (LBNL), Kurt Roth (Fraunhofer), & Isik Kizilyalli (ARPA-E)	Panel: Perspectives on R&D Opportunities for Miscellaneous Electric Loads

U.S.-India CBERD: Integrated Sensors and Controls

- Integrate control of HVAC, lighting, and plug loads into one platform, in order to provide better control (i.e., save energy) and reduce the cost of controls,
- Apply transaction-based controls at the level of the individual workstation, using personalized controls, to reduce the use of scarce energy resources,
- Use an integrated controls platform to reduce energy and load in grid-islanded, “resource constrained” buildings,
- Assess whether the Volttron platform is robust enough to handle conditions of grid intermittency and instability,
- Develop task-ambient lighting systems that reduce their power use in a way that maintains occupant comfort and productivity,
- Demonstrate that control of a group of office workstations can have a measurable energy savings and load reduction effect on a building zone.



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BEMOSS Development

Problem:

Lack of low cost, both equipment and installation, open-source building energy management (BEM) software that allow seamless integration with device controllers (HVAC, lighting and plug loads) from various manufacturers

Project Goal:

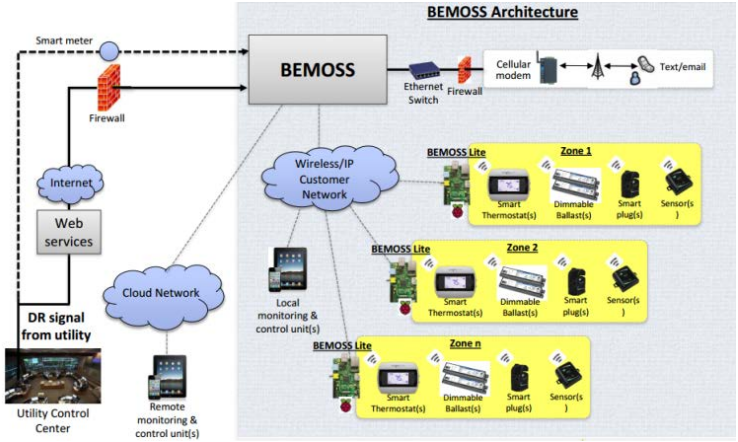
Develop a, plug and play open source open architecture control system that improves energy efficiency, optimizes electricity usage, and. improves the comfort for small and medium-sized buildings

Solution:

Development of cost-effective open architecture controls platform for small and medium-sized buildings

Key Features of platform:

- Open Source (first application to be built on DOE-developed transaction platform, VOLTTRON)
- Open architecture (interoperable)
- Plug and Play
- Auto mapping
- Thermostat, lighting, plug load devices
- Grid ready
- Agent based applications



Equipment Health Monitoring with Virtual Intelligent Sensing

Technology/Approach Summary

- Today's commercial market does not offer building equipment health monitoring system capabilities.
- The industry needs a scalable, robust health monitoring platform consisting of sensing, computation, and visualization that is suitable for retrofit applications at an installed cost significantly below the common industry average today.

Technology/Approach Impact

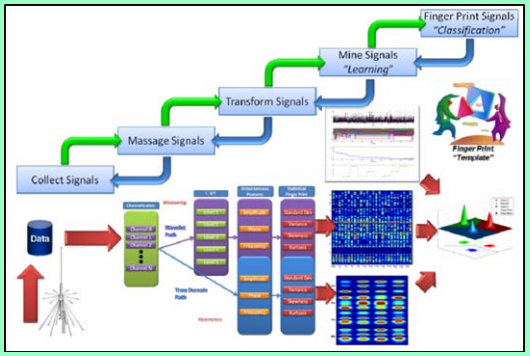
- Develop a comprehensive nonintrusive load monitoring system capable of identifying opportunities for energy efficiency within building subsystems.
- Identify equipment degradation and inefficiencies in energy delivery and improve the energy efficiency of the buildings by 15-25% while reducing the cost of deployment by 20-30% compared with the current sparse field diagnostics alternatives.

Proposed Goals

Metric	State of the Art	Proposed
Efficiency gain for small/medium commercial buildings by fault detection	~0%	15-25% energy efficiency gain 0.4 quad

Richman Surrey Power Measurement

ORNL Signal Processing



Project's Key Idea

This integrated system consists of:
(1) low-cost, nonintrusive power metering to augment existing sensor sources;
(2) an integrated power disaggregation fault identification system based on signal unmixing techniques; and
(3) a capability to deliver diagnosis information to building managers, including impact of fault on energy efficiency, for rapid response.

OAK RIDGE National Laboratory

RICHMAN SURREY
Alert, monitoring, and automation

THE UNIVERSITY OF TENNESSEE

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Low-cost Manufacturing of Wireless Sensors

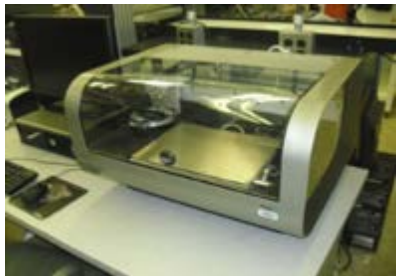
Project Goal:

Develop and deploy low-cost wireless sensors for building monitoring to realize energy savings through optimal control of building subsystems.

- Reduce cost to manufacture and commission ($1-$10/node)
- Low-power wireless communication driven by energy harvesting techniques
- Retrofit-friendly devices with minimal maintenance
- Multi-sensor platform tailored for building monitoring needs
- Leverage additive, roll-to-roll manufacturing techniques to enable rapid adoption

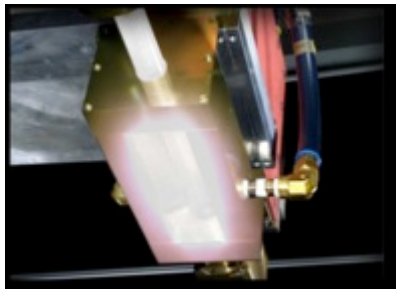
Recent Accomplishments:

Cooperative Research and Development Agreement (CRADA) recently established with commercial manufacturer, Molex to reduce cost through manufacturing improvements.



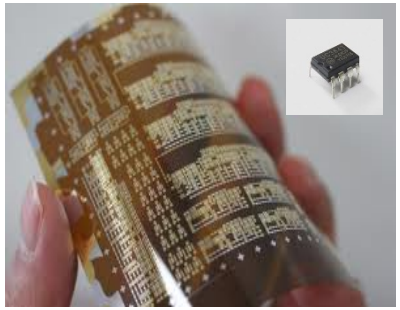
Print components on flexible substrates:

- circuits
- sensors
- antenna
- photovoltaics
- battery



Low temperature photonic curing:

- sinters ink for high electric conductivity
- plastic substrate undamaged



Peel and stick flexible platform:

- pick and place unprintable components

molex
one company › a world of innovation

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Low-Cost, Self-Powering Wireless Sensors & Sensor Networks

Opportunity:

Low cost, maintenance-free wireless sensors will enable enhanced building controls for energy efficient operation

Problem:

Existing wireless sensors require battery or AC power, leading to high maintenance labor and cost, especially for large, distributed sensor networks

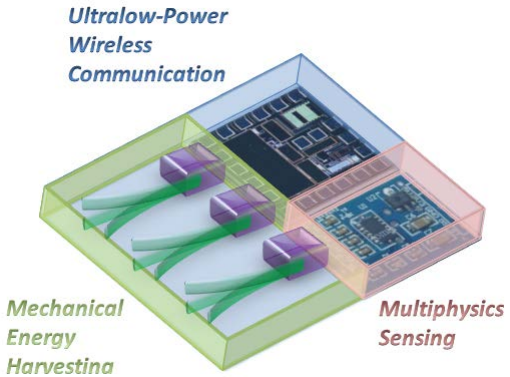
Solution:

Self-powering low cost wireless sensors ~***$15***/node (compared to *$25-$225* for existing products), and annual maintenance cost of ***$0*** (vs. *$160k-270k*/year for existing products) for a small town.

Goals (metrics):

Prototype sensor network, ready for production

- Self-powering sensor nodes, harvesting vibrational energy in indoor environments.
- Wireless connectivity through standard Zigbee network
- Technical Advantages:
  - Easy installation: no professional required
  - Self-sustaining: no battery needed
  - Cloud based: accessible and controllable from computer or mobile devices
  - Multiphysical measurement: temperature, humidity, illumination, pressure *etc*.
  - Fully adaptive: transmission rate self-adjustable and remote programmable



Case Western Reserve University

connect intwine

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S&C Roadmap Priority Research Areas

- Multi-functional, wireless plug-and play sensors

  Key metrics: Cost, Power Consumption/Lifetime, Level of Interoperability

- Occupancy-based sensors and controls

  Key metrics: Cost, Detection Accuracy, Human Comfort

- Building equipment sub-metering

  Key metrics: Cost, Coverage, Meter Accuracy

- Adaptive and fault tolerant controls

  Key metrics: Cost, Accuracy, Reliability

- Automated configuration, plug-and-play controls

  Key metrics: Cost, Coverage, Level of Interoperability

What are the estimated energy savings?

S&C Roadmap – Cross-cutting Challenges & Opportunities

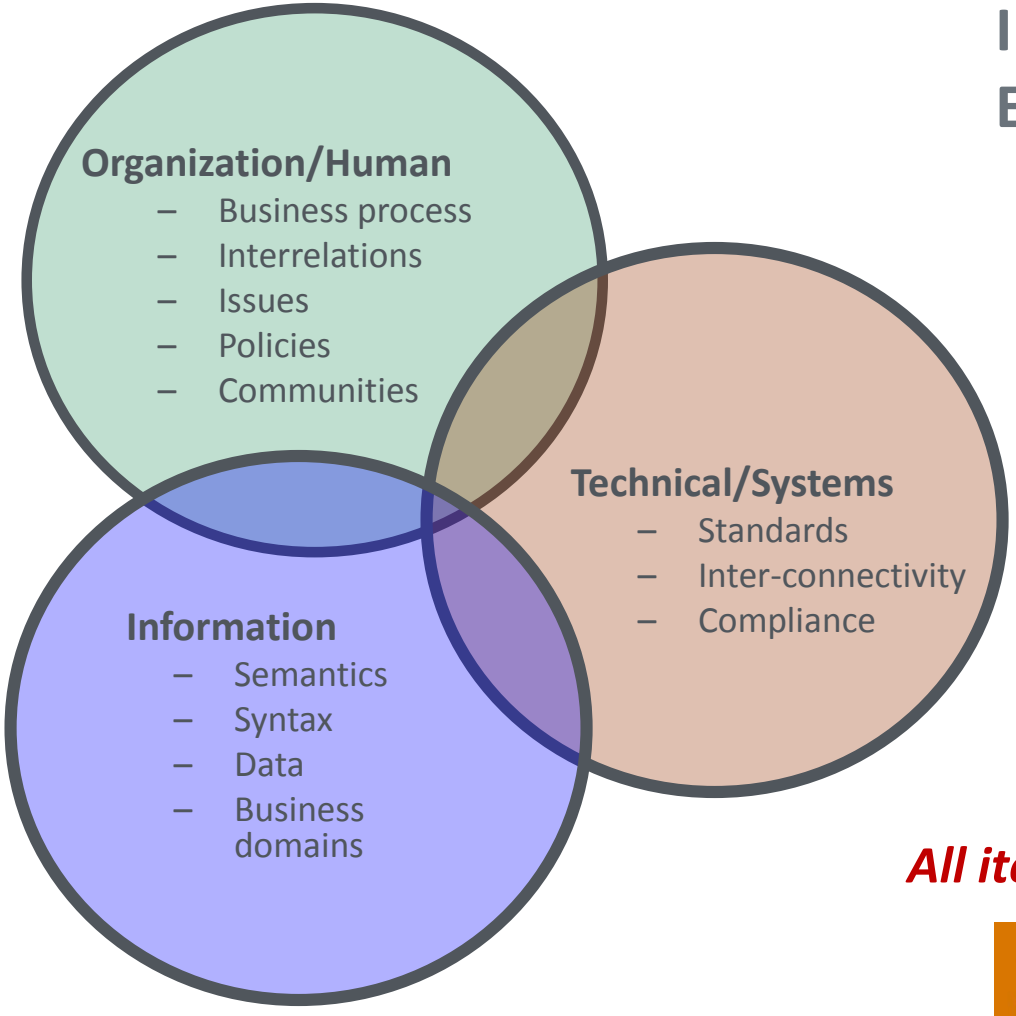
- **Building Energy Modeling** – Yesterday's Session
- **Interoperability, Data Standards, & Communication Protocols**
- **Cybersecurity**
- **Grid Integration**

– Grid Round Table Tomorrow Morning

- **Decision Science** – Workshop Tomorrow Afternoon; Bay Area in May 5
- **Technology Deployment Strategies** – Smart Thermostat Workshop Tomorrow

Interoperability is Essential for Information Exchange

* Connected equipment knows how it is performing, how it could perform, and is capable of communicating that to others.



Interoperability - Expected Impact:

- **Reduces integration cost**
- **Reduces cost to operate**
- **Reduces capital IT cost**
- **Reduces installation cost**
- **Reduces upgrade cost**
- **Better security management**
- **More choice in products**
- **More price points & features**

All items provide compounding benefits

Pacific Northwest NATIONAL LABORATORY

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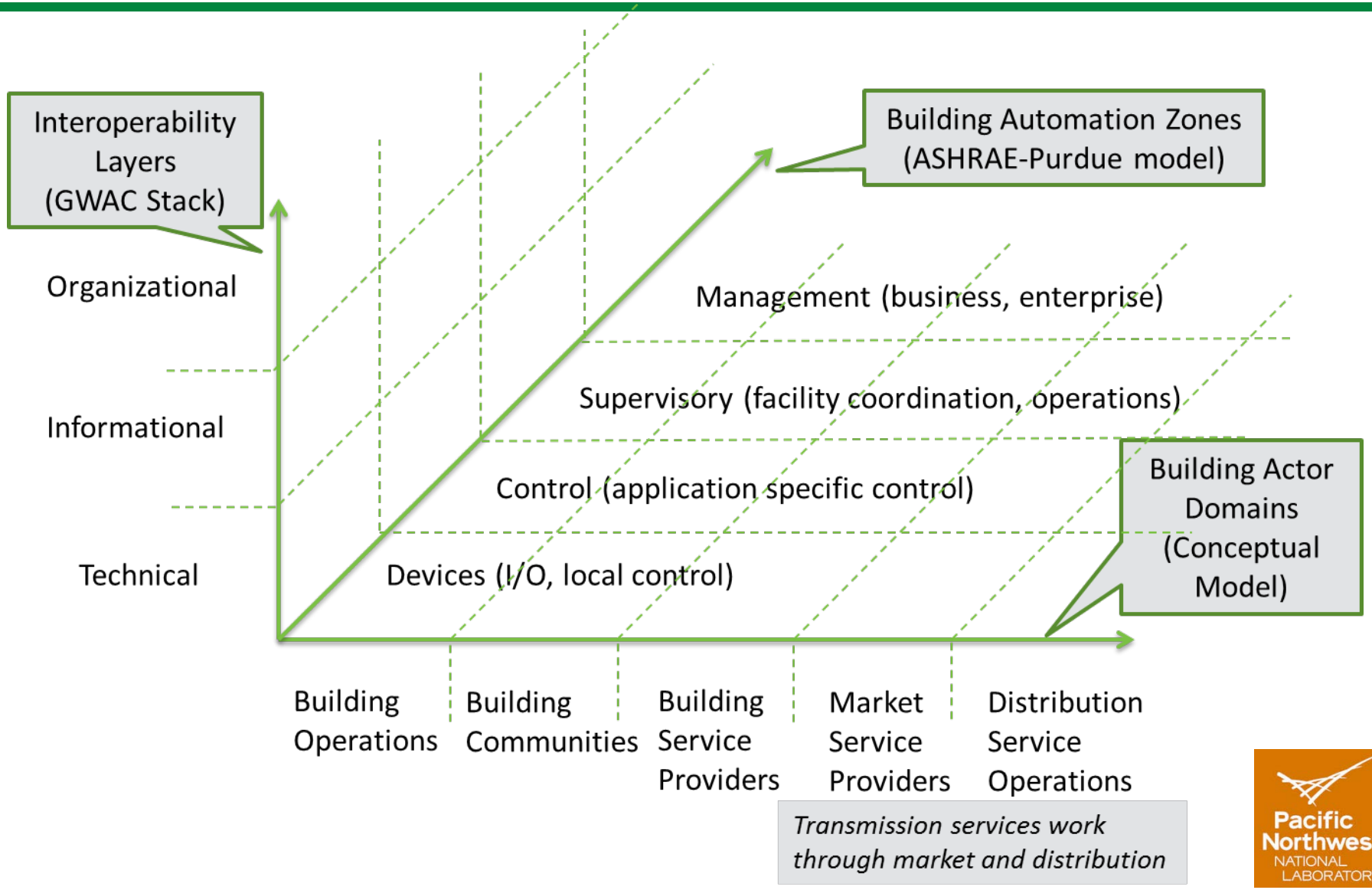
Buildings Interoperability Ecosystem



Recent Funding Opportunities

- **BENEFIT (BENEFIT = Building ENergy Efficiency Frontiers and Innovation Technologies) FY16 DE-FOA-0001383**

  - **Topic 2: Human-in-the-Loop Sensor and Control Systems (Innovations)**
    Move building control schemes beyond the typically over-simplified representation of occupant comfort and actions (e.g., static group-level occupancy schedules and comfort proxies) to enable real-time feedback on individual-level occupant presence and/or comfort via a local sensing infrastructure.

  - **Topic 4: Plug-and-Play Sensor Systems (Frontiers)**

Table 4.1. Technical Targets

ID	Category	Value
4.1.1	Operational lifetime of power source	
	(a) Mean time to replacement (for batteries)	≥ 10 years
	(b) Mean time between charging (for energy harvesters)	≥ 72 hours
4.1.2	Calibration (lifetime duration of accurate sensor operation)	≥ 5 years
4.1.3	Positional Accuracy (distance from true node location)	≤ 2 feet
4.1.4	Nodes Correctly Located	≥ 90 %
4.1.5	# of Sensed Variables/Node	≥ 1

Required concept papers were due Feb. 5, 2016

Recent Funding Opportunities (cont.)

- **SBIRs (Small Business Innovation Research)**
  - **Humidity Sensors:**
    New humidity sensors with the ability to remain accurate within ±5% with a long-term stability of ±1% for a period of at least 10 years at installed costs similar to that of current commercially available sensors.

    Full applications were due Feb. 16, 2016

- **Lab-directed Merit Review FY17 BTOLMR0001719**
  - **Topic 1: Occupant-driven Sensing and Controls**
    Improved occupancy detection and counting-based sensors, incorporation of such sensors to optimize control strategies, or a combination thereof.
  - **Topic 2: Building Equipment Sub-metering**
    Solutions for all building equipment, systems, and plug loads that will enable monitoring-based commissioning to optimize building operations.
  - **Topic 3: Adaptive and Fault Tolerant Controls**
    Self-correcting control solutions through data-driven or model-driven adaptive controls that will optimize building operation in response to environmental changes or the manifestation of faults and failures in building operation or equipment.

    Full applications were due March 7, 2016

How to Get Involved

Funding Opportunity Announcements:

- **BENEFIT FOA (BENEFIT = Building ENergy Efficiency Frontiers and Innovation Technologies) FY17**
- **SBIRs (Small Business Innovation Research)**

Workshops, Roadmaps, Technical Reports

- **Request for Information (RFI): Provide feedback on soon to be released Sensors & Controls Roadmap**

Website: http://energy.gov/eere/buildings/emerging-technologies

Email List: http://www1.eere.energy.gov/buildings/newsletter.html

- **Apply to a FOA!**
- **Volunteer to be a Reviewer!** (send CV to BTOreviewer@ee.doe.gov)
- **We're Hiring!** Post-doc Fellow (US citizenship required) to support Sensors & Controls program

Thank You!

Marina Sofos
Sensors & Controls Technology Manager
Emerging Technologies Program
Marina.sofos@ee.doe.gov

Michael Geocaris
Joe Hagerman
George Hernandez
Stephanie Johnson
Mohammed Khan
Jared Langevin
Brent Nelson
Jim Payne
Pat Phelan
Michael Wofsey