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

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

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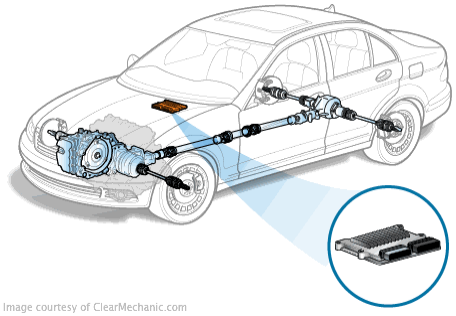
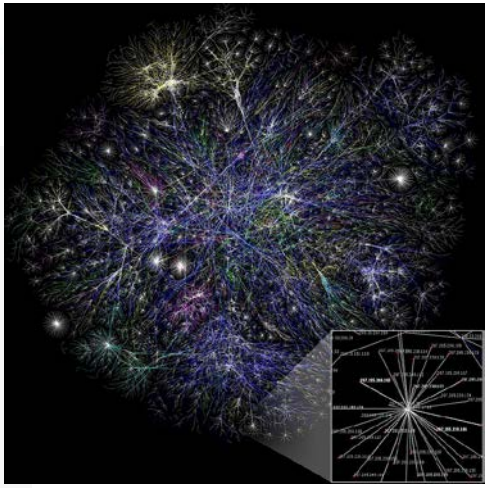
BTO Peer Review
March 15, 2017
Marina.sofos@ee.doe.gov

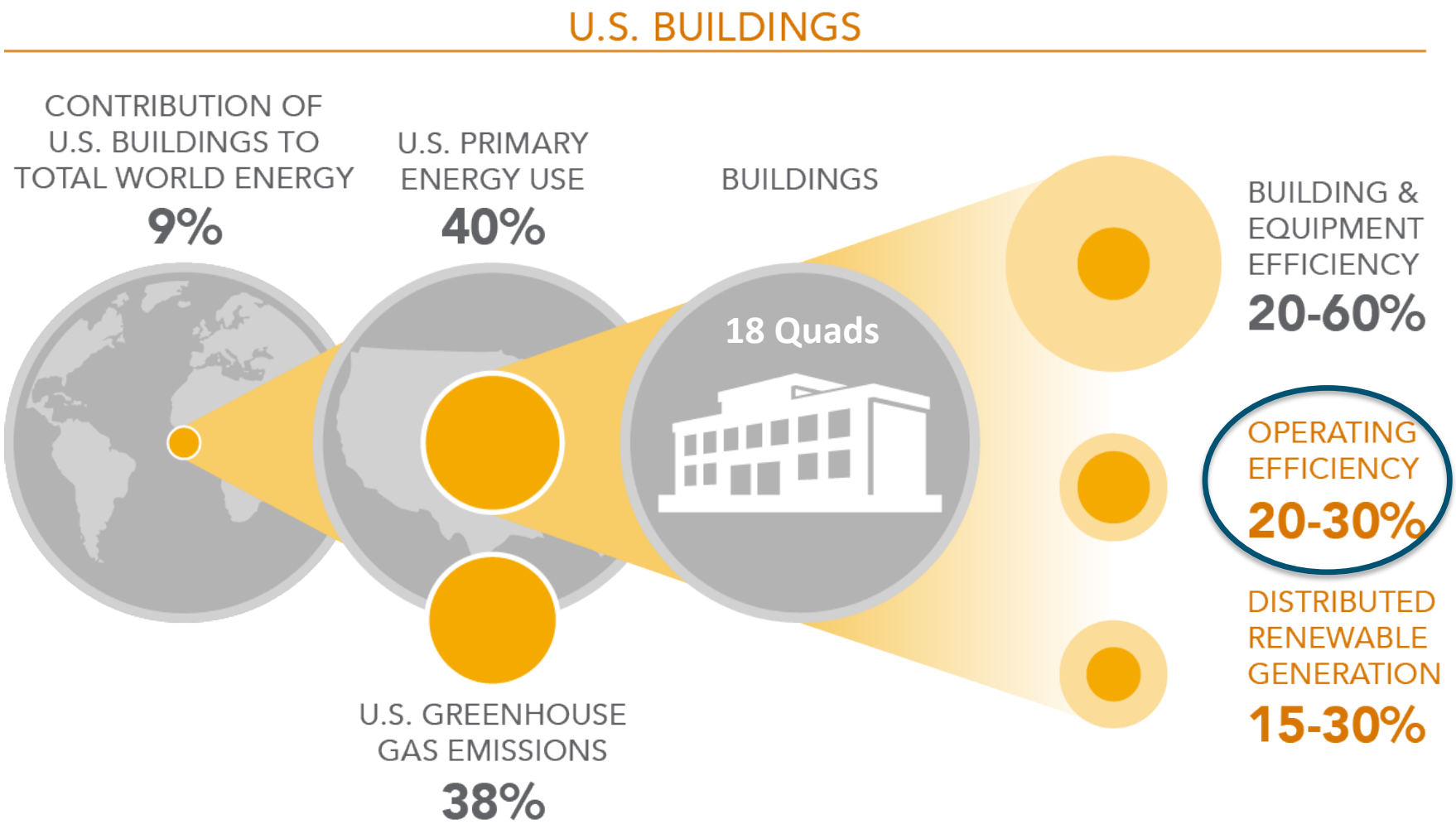
Sensors and Controls: Ubiquitous to Modern Technology

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





The Opportunity for Buildings



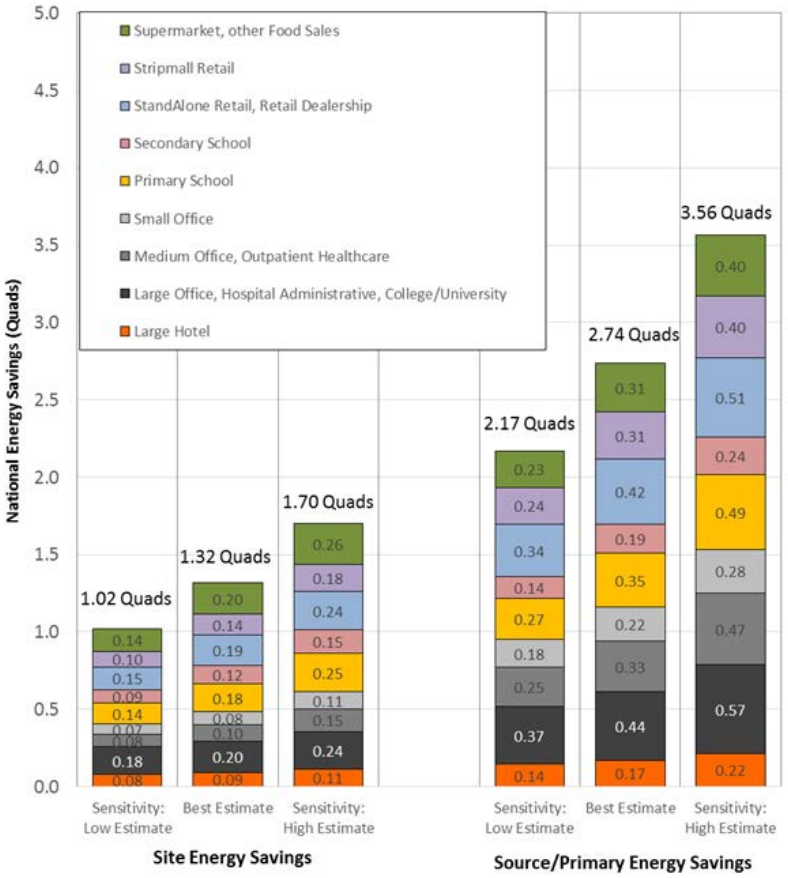
Motivation

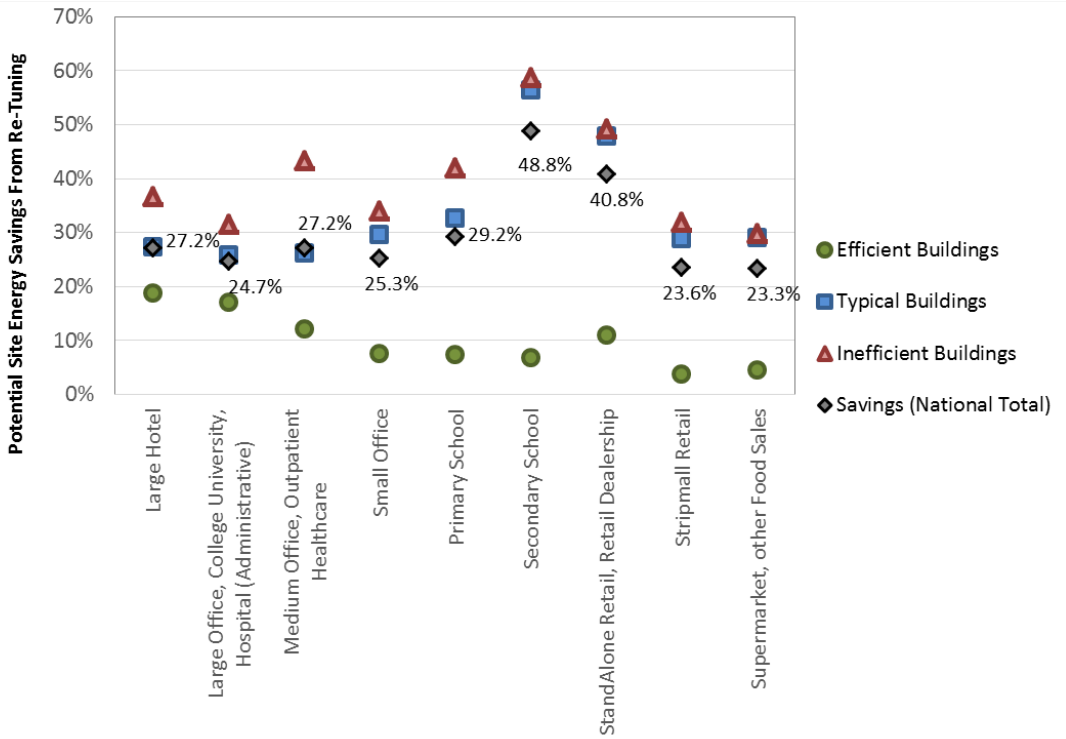
"The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is the automation applied to an inefficient operation will magnify the inefficiency." *- Bill Gates*

- Building efficiency is significantly degraded due to poor operation and maintenance practices resulting from:
  - Improper actions by operation and maintenance staff
  - Incorrect original installation of equipment and configuration of control
  - Lack of use of energy-savings control strategies
  - Other mistakes in operation often accompanied by overriding automatic control
  - Degradation of sensors and components over time, lack of good maintenance

Energy Savings and Peak Load Reduction Benefits

Aggregated among all building types, the annual building energy savings from "Re-tuning" is estimated to be 29%.





- Central/Best estimate:
  30% efficient, 50% typical, 20% inefficient
- Low Savings estimate:
  50% efficient, 40% typical, 10% inefficient
- High Savings estimate:
  10% efficient, 40% typical, 50% inefficient.

N. Fernandez et al, "Energy Savings and Peak Load Reduction Benefits from Building Controls Measures," PNNL Report, *Draft.*

Challenges Today for Building Management Systems

Fragmentation *of the businesses serving the buildings sector.*

- Multiple networks from multiple vendors
- Proprietary programming languages
- Too many systems to learn
- Limited integration capabilities

Lack of Reliable Information *on the energy use and efficiency of specific end uses.*

- Lack of granular data
- Inadequate elementary analytic tools

Performance Uncertainties *and the perceived risk of making significant investments in energy efficiency.*

- Complex troubleshooting
- Legacy user interfaces

Lack of Mechanisms *for establishing the market value of more energy-efficient properties.*

- Higher capital and operational expenditures

Split Incentives *between owners and occupants of rental properties in both the residential and commercial sectors.*

BTO R&D : Emerging Technologies

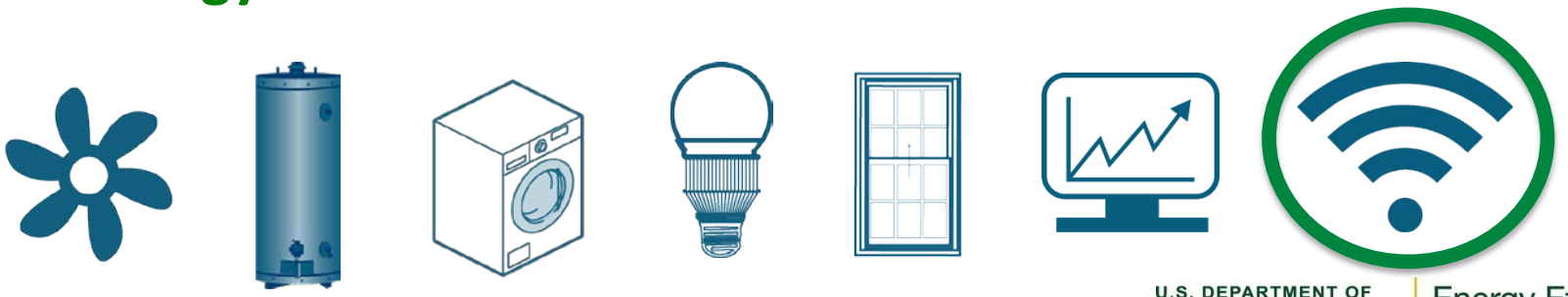
Goal

Develop cost-effective technologies capable of reducing a building's energy use per square foot by **45%** by 2030, relevant to 2010

Strategy

- Identify high-impact technologies with **Scout**, a building energy efficiency impact analysis tool
- **Fund R&D** through competitive solicitations (open to everyone) and direct funding to the DOE National Labs

Technology Areas



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Design Objectives are Common Across all Building Types

- Low-cost – installation and integration
- Scalable – across building types
- Interoperable – plug-and-play
- User-friendly
- Maintenance-free
- High accuracy

Achieve all six simultaneously!

BTO Sensors and Controls R&D Sub-program

Goal:

Improve building energy management and optimize building operating conditions (i.e., HVAC, lighting, and plug loads) through the development of low-cost and fully automated building sensors and controls systems that will improve data collection, monitoring, and optimization of building energy use, as well as effectively integrate building energy loads with the rest of the electric grid and support energy-related transactions outside the building envelope. The Sub-program is organized around the following areas:

(1) **Multi-function plug-and-play wireless sensors** – fully automated and self-powered sensing node packages that can be easily installed, operated, and maintained.

(2) **Occupant-centered and -comfort sensors and controls** – at the zone or sub-zone level to enable accurate, real-time feedback on individual and group-level occupant presence and/or comfort.

(3) **Whole-building sub-metering** – pervasive and granular sub-metering such that all equipment and plug loads are being metered with sufficient accuracy for unique identification and monitoring-based commissioning.

(4) **Adaptive and fault tolerant controls** – Ongoing, automated commissioning that compares top-level or sub-meter information about building energy consumption to an appropriate baseline to automatically identify and diagnose operational faults.

(5) **Auto-configurable and plug-and-play controls** -

BTO Sensors and Control R&D Goals

Sub-program Area	Metric	2020 Goal
Multi-function plug-and-play wireless sensors (Commercial)	% Primary Energy Savings	10%
	Installed cost premium ($/node)	$300 - $1000
Whole-building sub-metering	% Primary Energy Savings	2 %
	Installed cost premium ($/sq.ft. for commercial; $/home for residential)	$0.03-0.10 Commercial; $20-70 Residential
Automated Fault Detection and Diagnostics (Commercial)	% Primary Energy Savings	20%
	Installed cost premium ($/sq.ft.)	$0.1-0.4
Sub-program Area	**Metric**	**2025 Goal**
Occupant-centered and comfort sensors and controls	% Primary Energy Savings	25% Commercial; 21% Residential
	Installed cost premium ($/occupant)	$40-$100 Commercial; $20-$70 Residential

BTO Sensors and Controls R&D Funding Mechanisms

1. Directed National Laboratory Efforts

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

b) Industry Partnerships: CRADAs and SBV

c) DOE Grid Modernization Lab Consortium

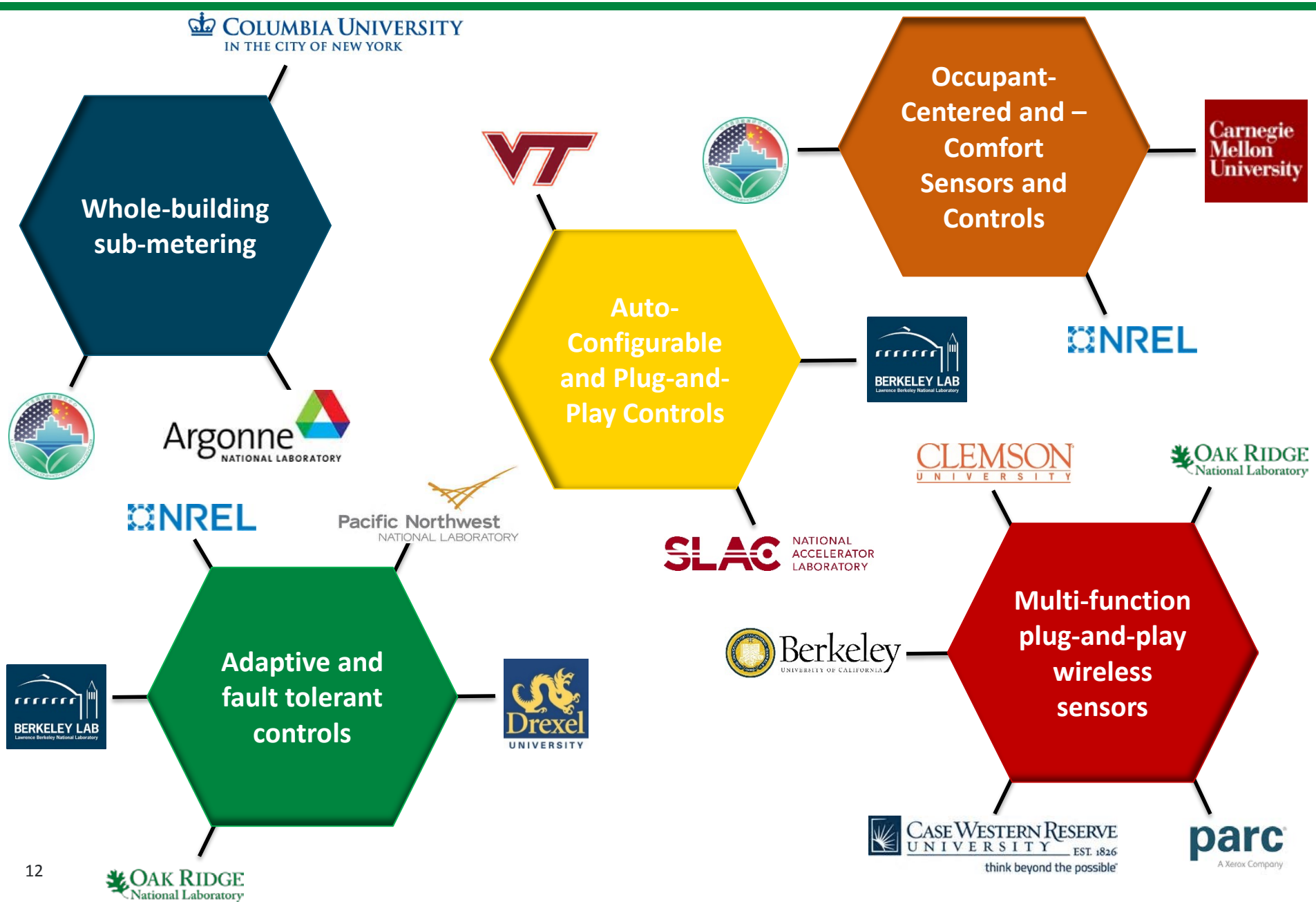
2. Awarded by Funding Opportunity Announcements to Industry, Academia or National Labs

a) FOAs: FY13 Turn-Key, FY14 BENEFIT, FY15 BUILD and FY16 BENEFIT

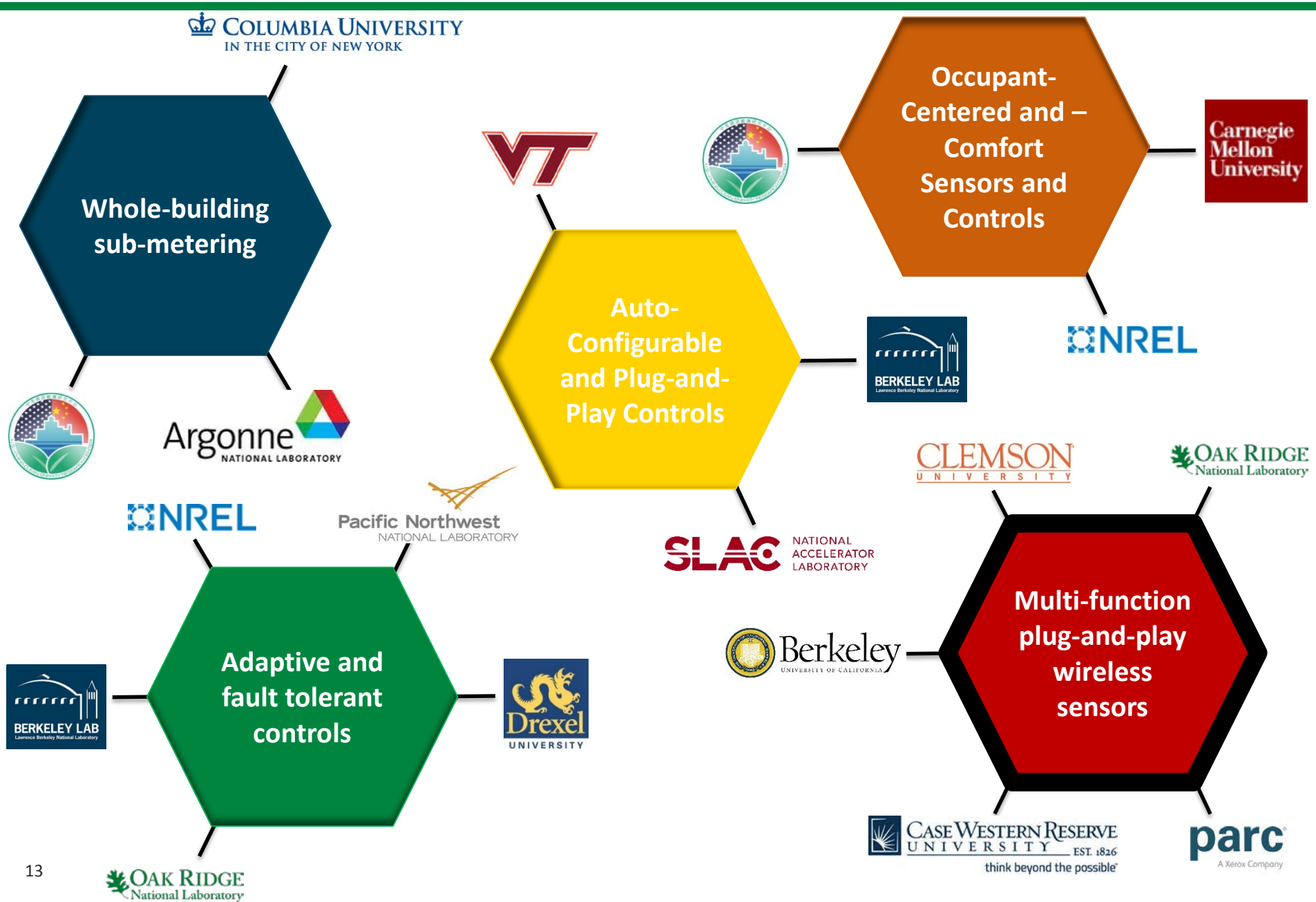
b) Consortia: US-China CERC, US-India CBERD

c) SBIR

Sensors and Controls Subprogram Project Portfolio

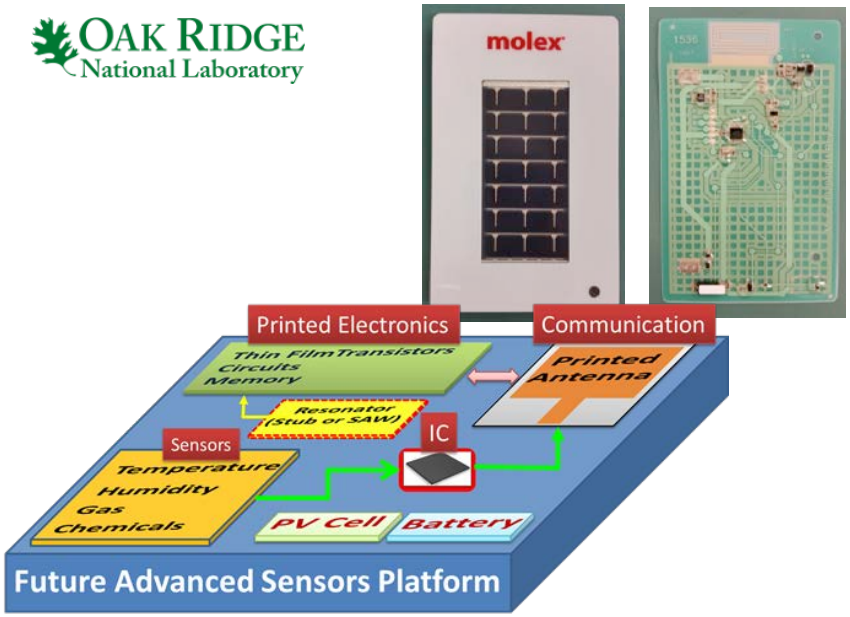


Sensors and Controls Subprogram Project Portfolio



Multi-functional Plug-and-Play Wireless Sensor Systems

OAK RIDGE National Laboratory



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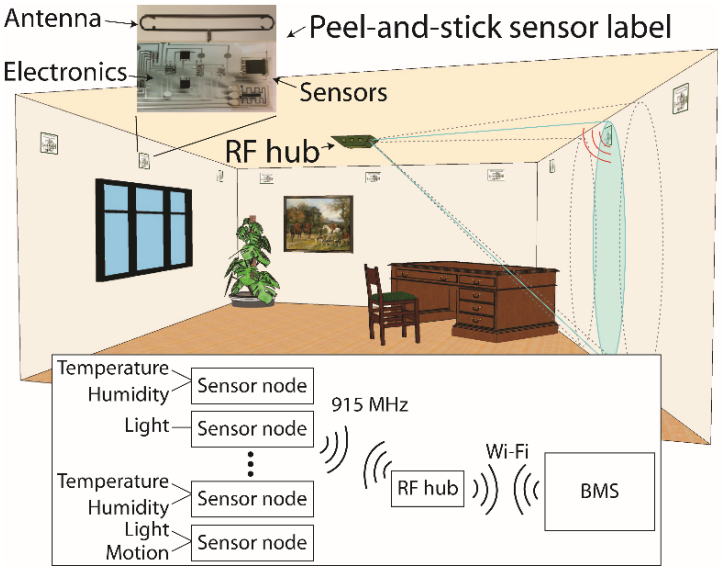
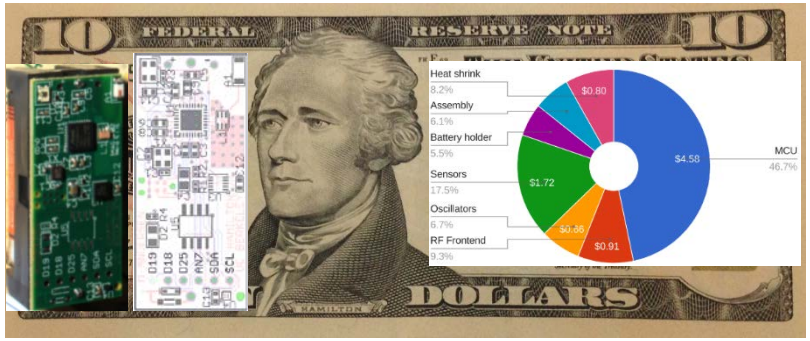
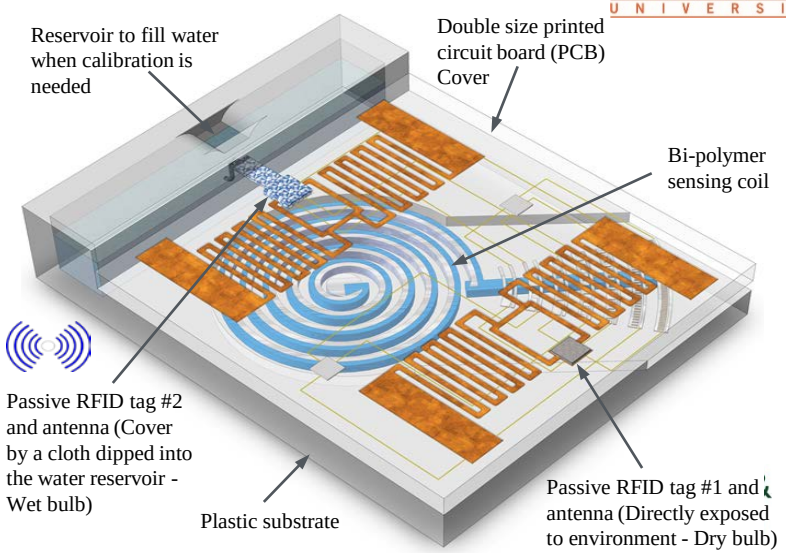
A Xerox Company



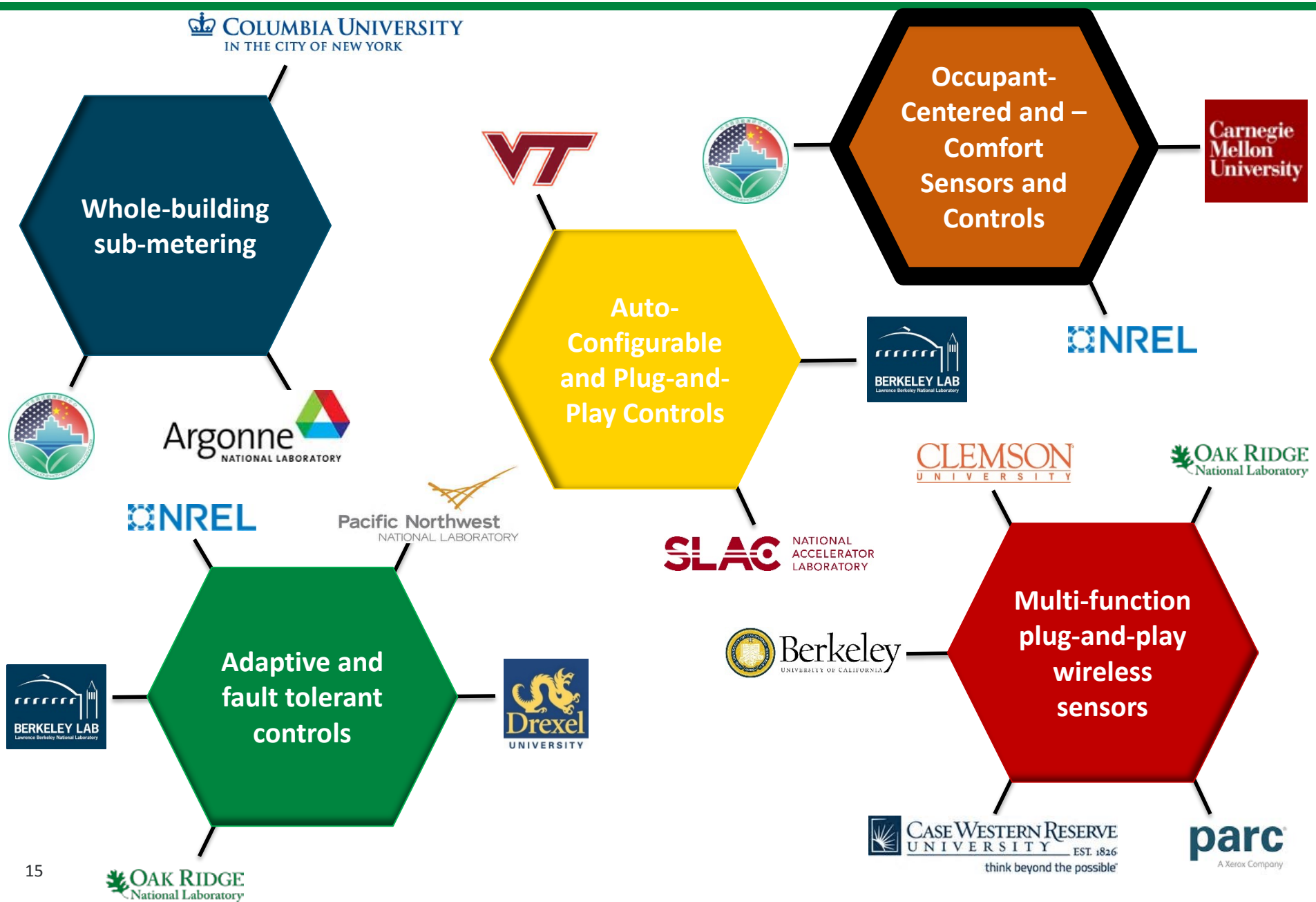
Berkeley
UNIVERSITY OF CALIFORNIA



CLEMSON UNIVERSITY



Sensors and Controls Subprogram Project Portfolio



Challenges for Occupant-Centered R&D

1. Defining Occupant-Centered Measures

2. Obtaining Supporting Data

3. Communicating Outputs

kWh $/occupant
Net Present Value % energy savings
% uncomfortable work performance
Predicted Mean Vote EUI

Incorporating occupancy counts & thermal comfort preferences into controls

Technical Summary

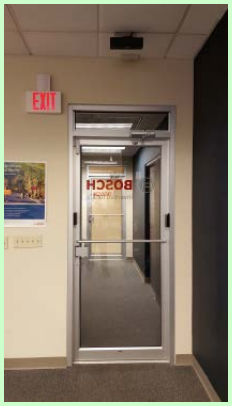
- Depth-based sensing technology utilized to perform fine-grained occupancy estimation in an area while requiring almost no training, not being as invasive as RGB cameras, and working even in a completely dark environment.
- Leverages body shape information and occupancy prediction for context-aware human-in-the-loop controller to save energy as well as improve occupant comfort.
- Design, implement, and evaluate a human-in-the-loop sensing and control system for energy efficiency of HVAC and lighting systems, which takes into account occupant comfort.

Deliverables

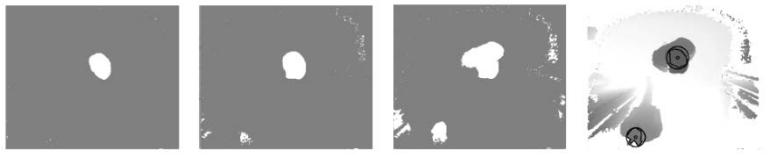
- Comfort model integration with human-in-the-loop control, embedded prototype development, and VOLTTRON integration
- Hardware prototype that consumes < 25W on average, and has a BOM cost of < $200 per unit with average accuracy above 97%.
- Context aware human-in-the-loop controller that can switch between different modes depending on occupancy context and weather condition.

Impact

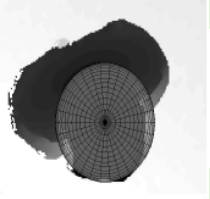
- Reduce significant energy waste (i.e. target 20% energy savings) by accurately estimating occupants in an area to overcome current HVAC systems operation which assumes maximum occupancy in each room.



Placement of a Kinect at a ceiling, Kinect for Xbox One, Embedded computer Odroid-XU4

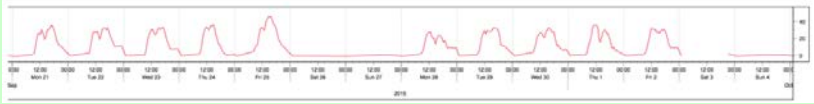


Head detection by multilevel scanning



Head verification

Shoulder verification



Occupancy estimation of two weeks at a Bosch office

Carnegie Mellon University BOSCH

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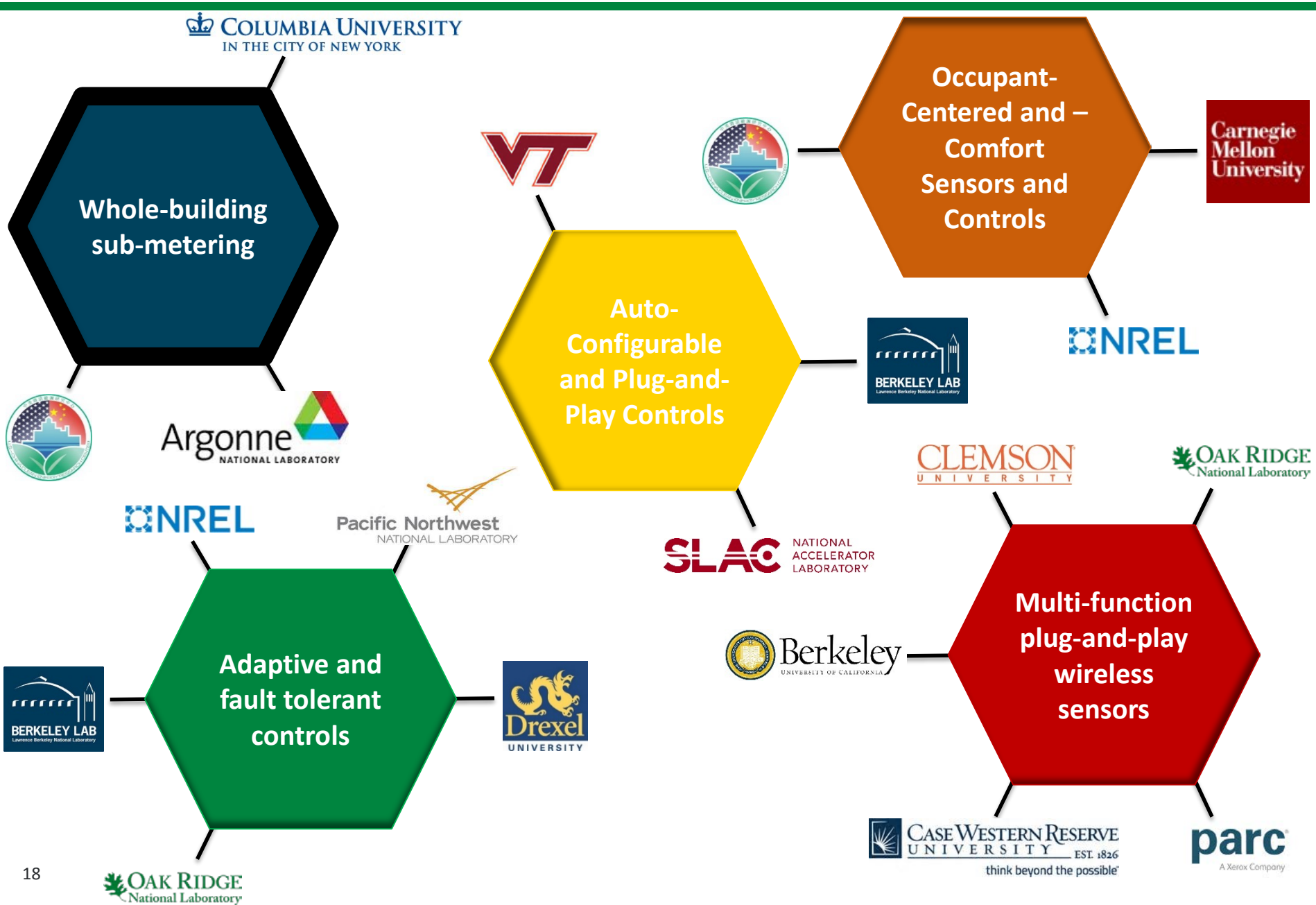
Sensors and Controls Subprogram Project Portfolio



Revenue Grade Sub-metering Strategy

Challenge:

- Essential for separating electricity bills of tenants, monitoring specific end uses for rate purposes, or monitoring local power generation for resale to or M&V by utility.
- Low cost sensing methods needed that can easily be incorporated into low power microcontrollers and interface circuits.
  - Single phase meters (2% accuracy) < $100 (not including communication connectivity hardware or software).
  - Revenue grade meters (0.2% accuracy) > $300 (not including any connectivity).

Approach:

- Coreless differential flux gate magnetometer (DFGM) current sensor and matched compact signal conditioning solution for closed loop current measurements.
- Minimize component count and connectivity by combining several required measurement and control features into a single compact chip to reduce required chip count and board size.

Goal:

0.2% accuracy, $10/ phase

Argonne NATIONAL LABORATORY

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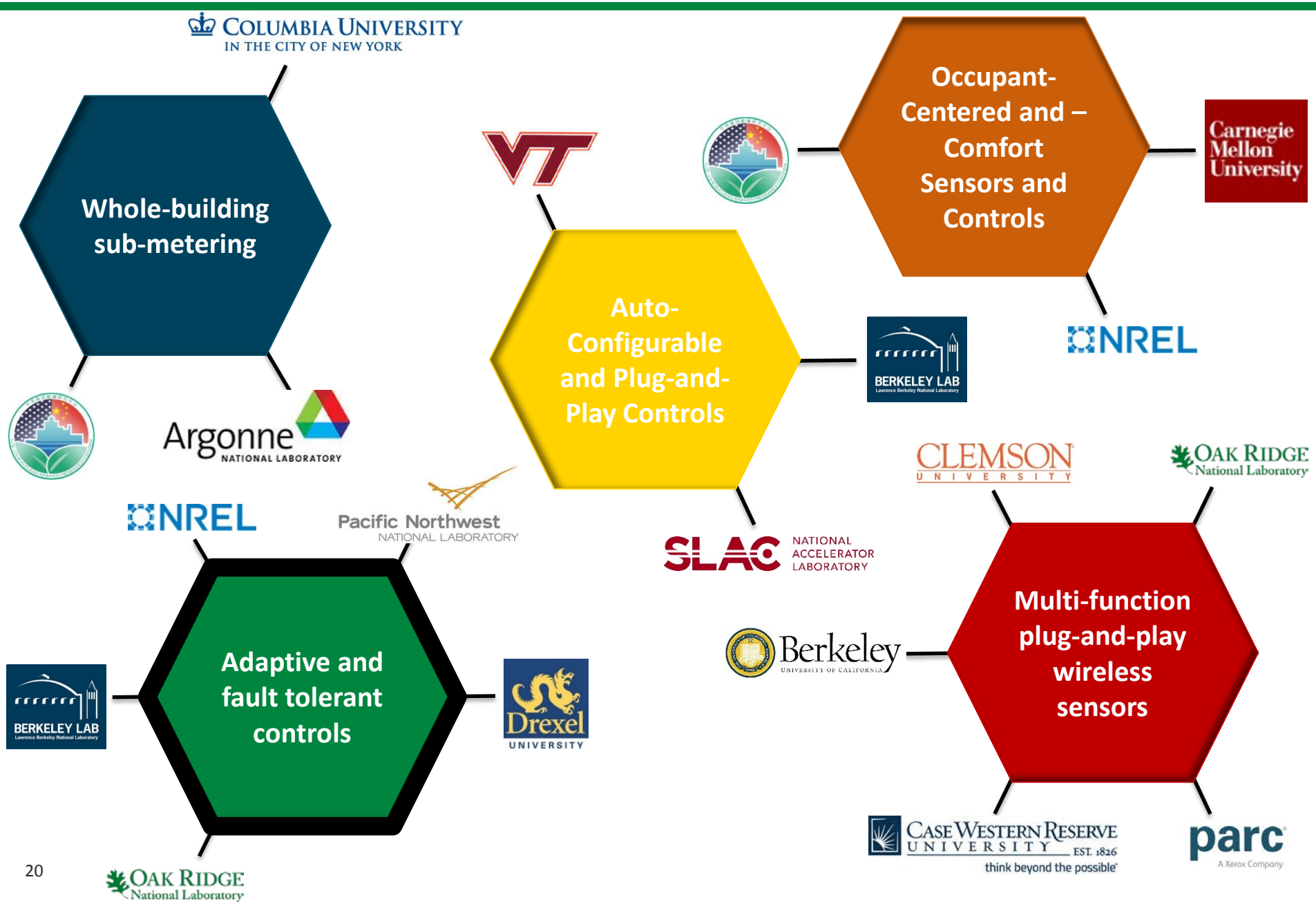
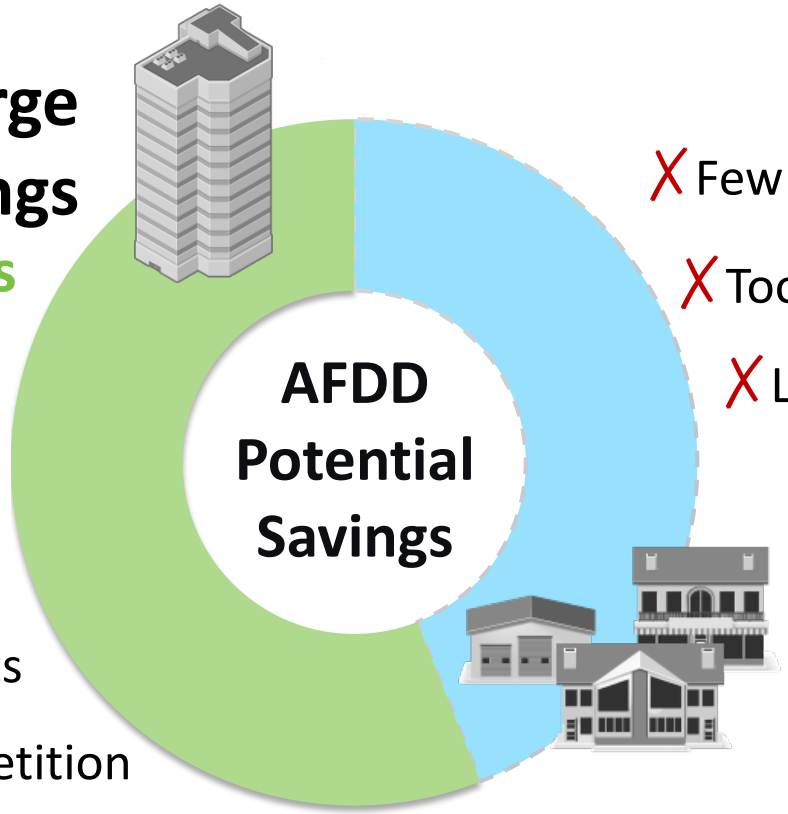
Sensors and Controls Subprogram Project Portfolio



Challenges for Fault Detection and Diagnostics R&D

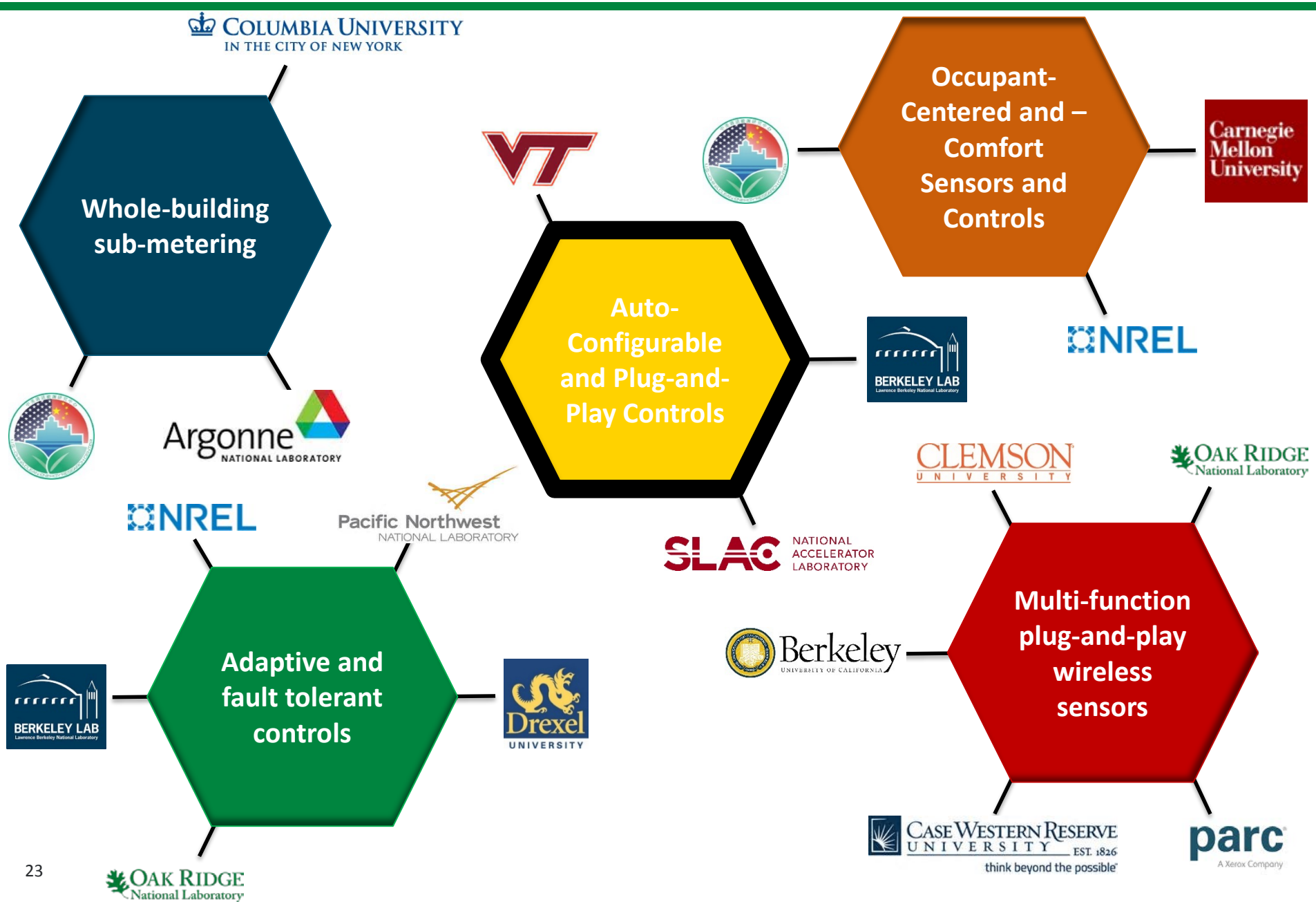
- Commercially available analytics products represent one of fastest growing markets in technologies for building control and operations

- New algorithms continuously developed – no means for users, research community to compare/contrast, benchmark performance



Fault Detection and Diagnosis – Multi-Pronged Approach

Sensors and Controls Subprogram Project Portfolio



OpenBuildingControl: Simulation, Specification and Verification of Control Sequences

Technical Summary

- Process and integrated set of tools for design, deployment and end-to-end quality assurance of control sequences.
- Relies on open digital specification of control sequences—BACnet : communication :: OpenBuildingControl : specification
- **For design**: tool configures control sequences and their functional tests (i.e., set of inputs that exercises control sequence) for a particular project (e.g., setpoints, number of zones, equipment layouts) and assess their performance via simulation.
- **For implementation**: tool translates control sequence to platform specific implementation (e.g., BACnet/VOLTTRON, proprietary).
- **For commissioning:** tool translates functional test to platform specific implementation.

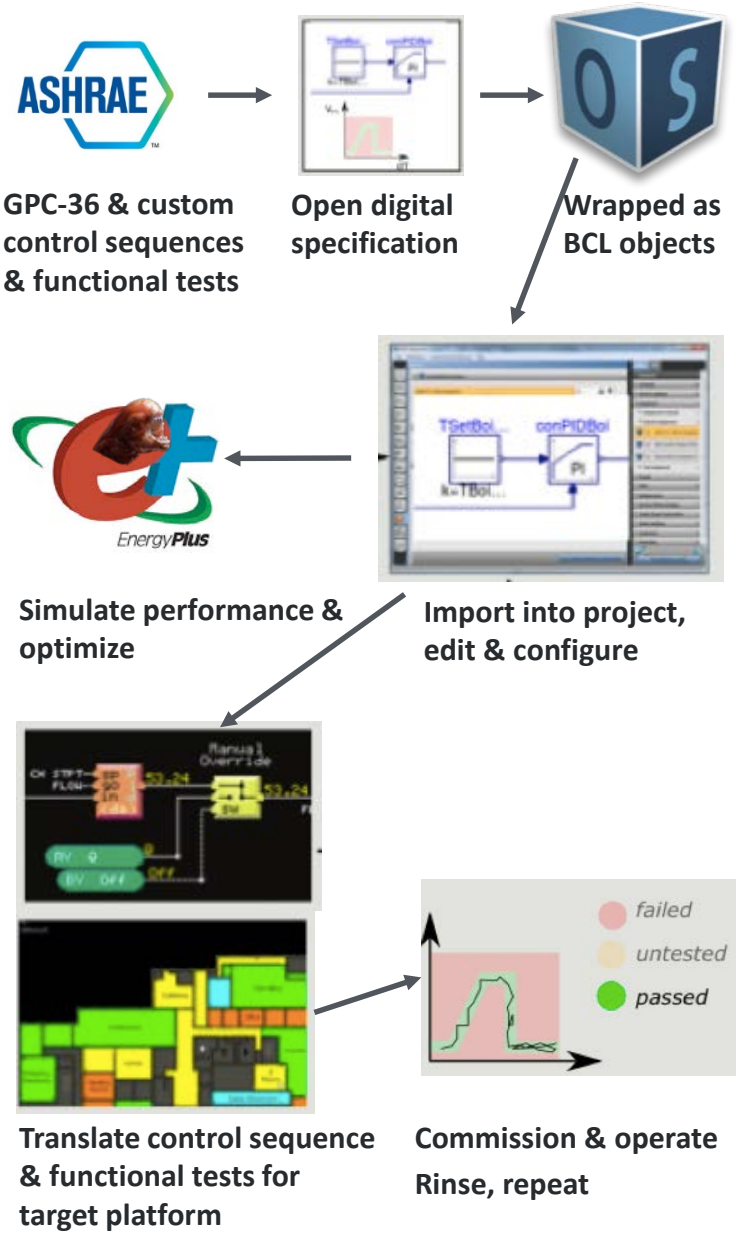
Impact

- Reduce effort, cost & error of designing, testing, and deploying control sequences.
- Provide industry with formal process to test and evaluate control sequences.
- Narrow performance gap between design and operation through correct implementation and verification of controls.

Deliverables

- Library of high-performance control sequences in open digital form.
- Implementation translator framework for open and proprietary systems.
- Integration with BTO simulation and control execution workflows.
- Large scale demonstration.

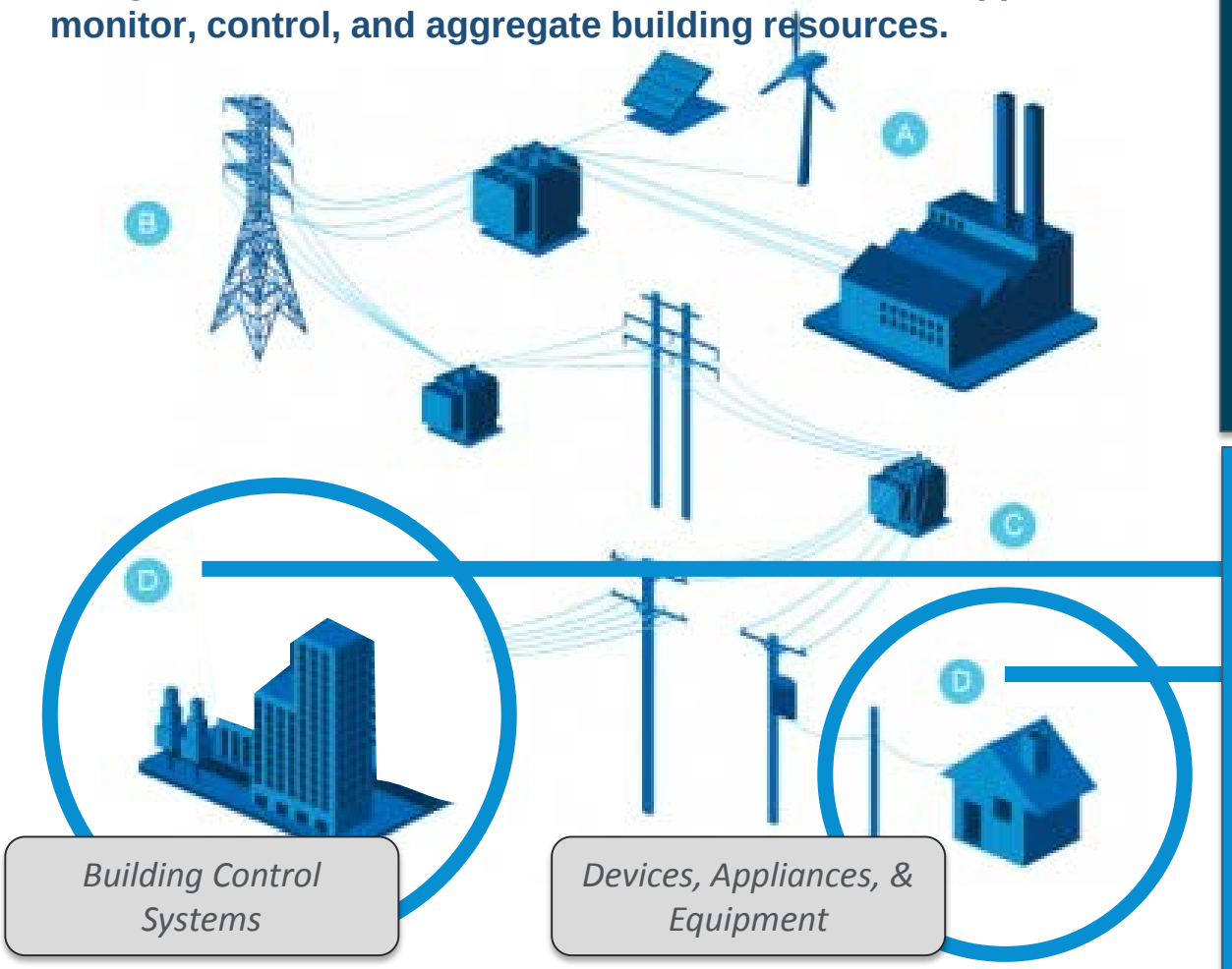
Partners: Continual, BIG, Arup, Oracle, Integral Group, Stanford, kW Engineering, CEC



How does S&C interface with ‘smart’ buildings and the grid?

“Smart” Building Ecosystem

Comprehensive, interoperable integration of devices, buildings, and grid with Transactive Controls utilizes software applications to monitor, control, and aggregate building resources.

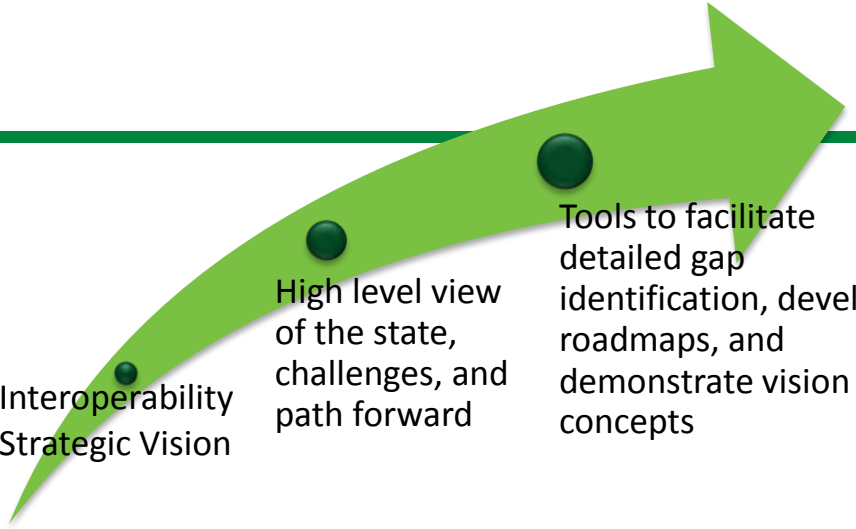


Goal:
Transact with the Electric Grid to Enable Greater Penetration of Renewables

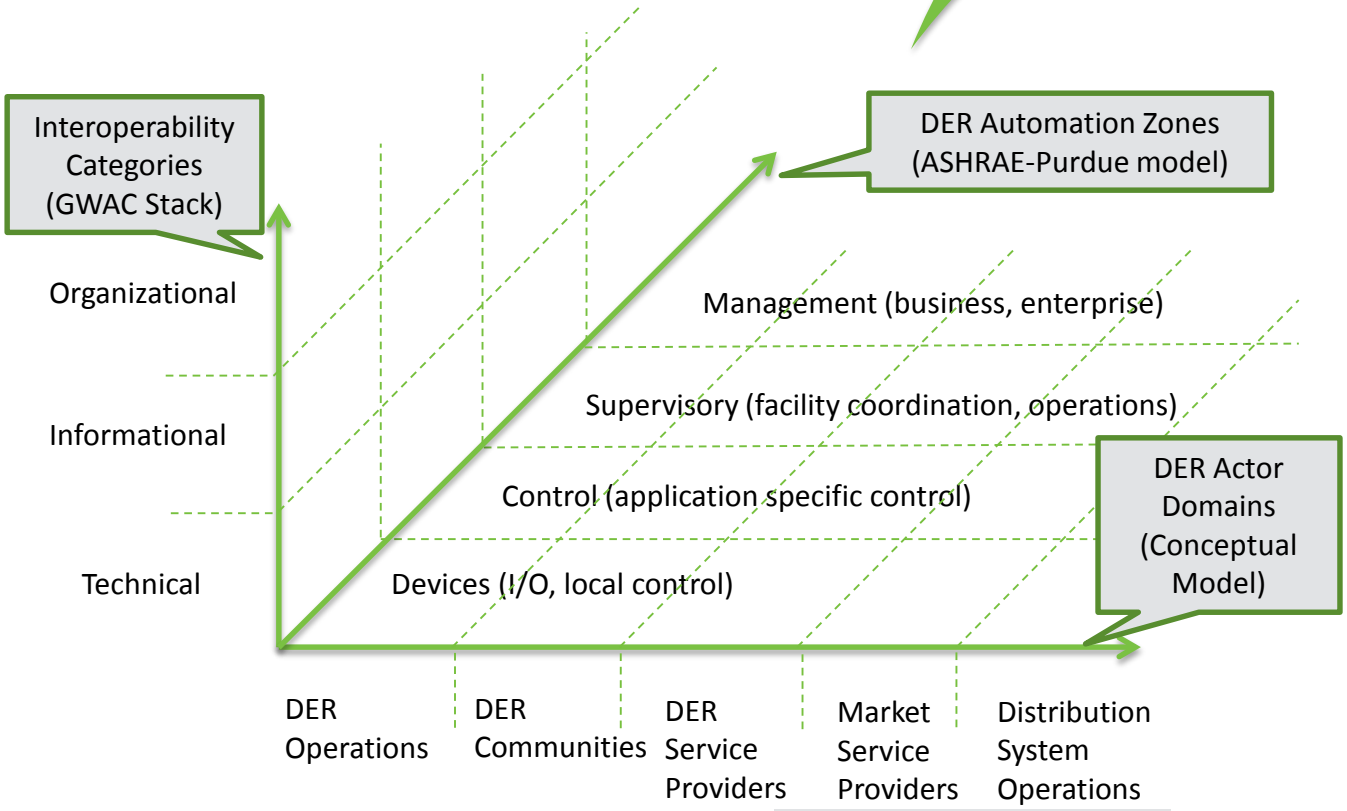
Goal:
Reduce Energy Usage to Enable Greater Energy Savings

Sensors & Controls for Building Efficiency
(behind the meter - within the customer premises)

Interoperability Ecosystem



DER Connectivity Framework



Transmission services work through market and distribution

Pacific Northwest NATIONAL LABORATORY

MODERNIZATION INITIATIVE
U.S. Department of Energy

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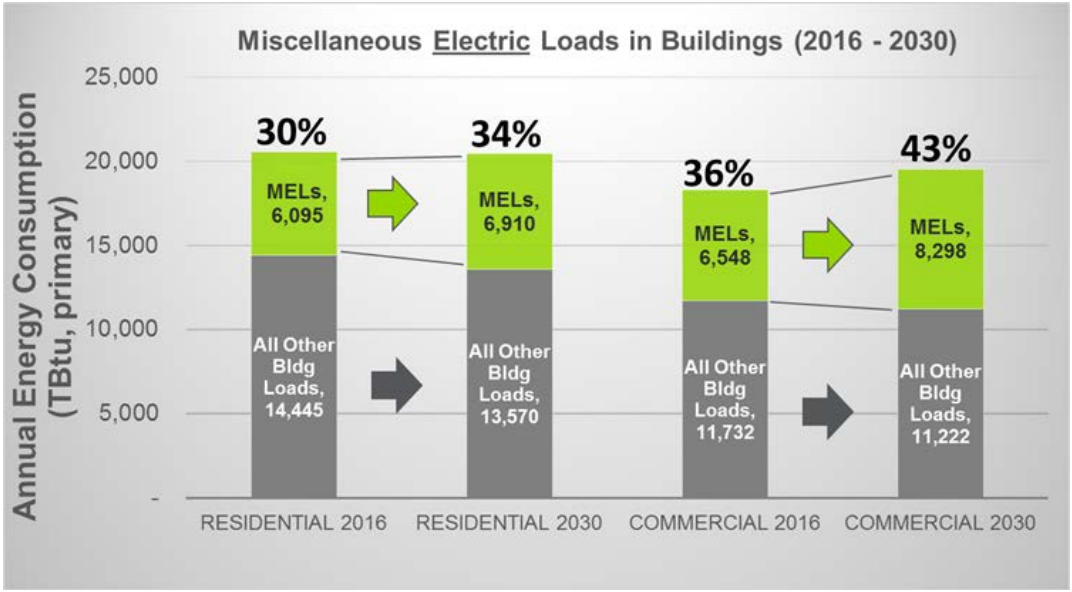
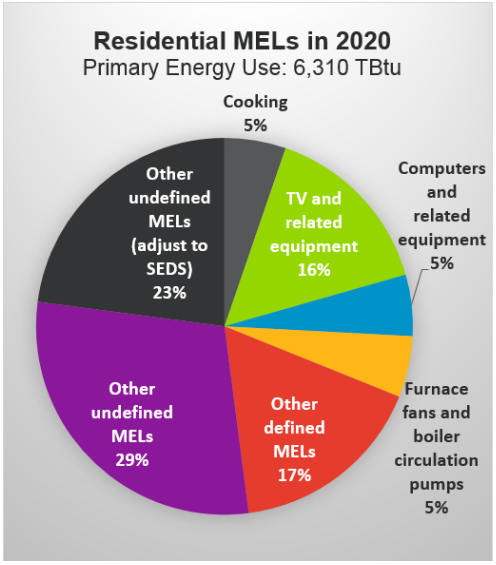
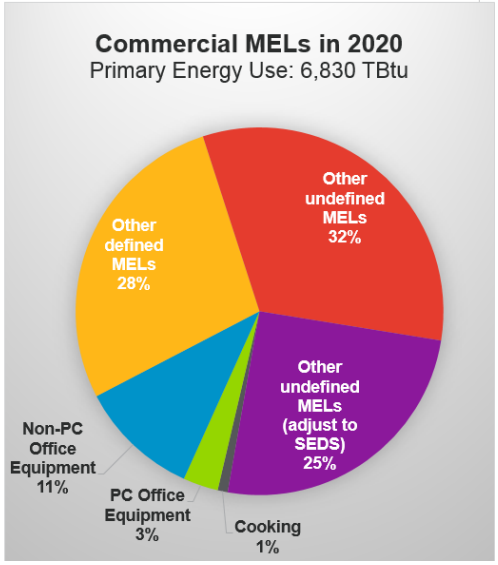
Our next challenge – the "other"







Increase in portion of building energy consumption driven by:

- Improved efficiencies of the major energy end use technologies
- Projected increase in primary energy consumption in residential and commercial buildings from MELs

Reducing consumption poses a unique challenge due to:

- Total consumption projected to increase significantly by 2030 under current business-as-usual trends
- Significant portion (i.e. the majority) is comprised of undefined loads not yet attributed to individual devices
- Comprise a wide variety of distinct electric loads (e.g., televisions, set-top boxes, office equipment, etc.) that individually consume a relatively small amount of energy

EIA Annual Energy Outlook, 2015. http://www.eia.gov/forecasts/archive/aeo15/

Today's Agenda

Time	Session/Speaker	Project/Topic
2:30 pm – 3:00 pm	Marina Sofos (DOE/BTO)	Sensors & Controls Subprogram Overview
3:00 pm – 3:30 pm	Dane Christensen (NREL)	Home Battery System (BPA Initiative)
3:30 pm – 4:00 pm	Break	
4:00 pm – 4:30 pm	Michael Brambley (PNNL)	NorthWrite Small Business Voucher Project
4:30 pm – 5:00 pm	Jin Wen (Drexel)	VOLTTRON Compatible Whole Building root-Fault Detection & Diagnosis
5:00 pm – 5:30 pm	Saifur Rahman (Virginia Tech)	Building Energy Management Open-Source Software Development (BEMOSS)
5:30 pm – 6:00 pm	REVIEWERS AND STAFF ONLY	Sensors and Controls Wrap-up

How to Get Involved

Funding Opportunity Announcements:

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

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)**
- **Participate in National Laboratory Technical Advisory Groups (TAGs) and other stakeholder outreach through funded projects**

"We all need people who will give us feedback. That's how we improve." - *Bill Gates*

Thank You!

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Mike Atsbaha (AST)
Mia Casabona (AST)
Adam DeDent
Carla Dunlap (CSRA)
Robert Fares (AAAS)
Michael Geocaris (AST)
Joe Hagerman
Mary Hubbard
Amy Jiron
Mohammed Khan
Gina Lynch (AST)
Ryan McCleary
Jared Langevin (LBNL)
Julia Moody
Jim Payne
Samuel Petty (AST)
Amir Roth
Karma Sawyer
Geoff Walker
Michael Wofsey (AST)