U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Building Technologies Office (BTO)

# Sensor and Control Technologies R&D Overview

**Marina Sofos, Ph.D.**

**BTO Peer Review**

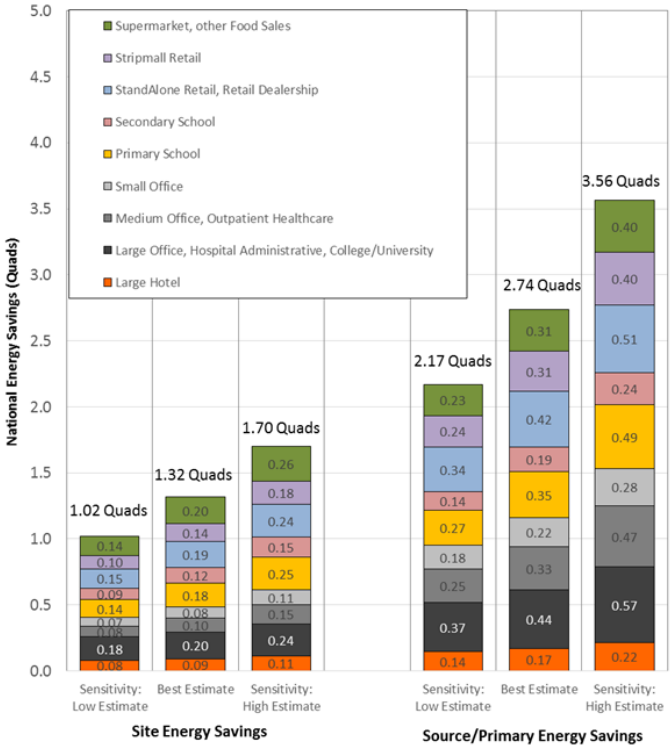
May 1, 2018

# Driving up efficiency of component technologies is not enough…

- **Sensors** monitor operating conditions of buildings and building equipment (e.g., temperature, air flow, and daylight levels), electronic **actuators** process these measurements, and device **controllers** initiate appropriate action (e.g., adjust temperature, air flow, light) to maintain operating conditions.

- An aggregated annual energy savings of 29%, or **~4-5% of total national energy consumption**, can be achieved through the implementation of efficiency measures using **current state-of-the-art sensors and controls** to optimize programmable settings and to detect and diagnose operational problems in the **commercial sector alone**.

- Most promising energy efficiency measures:
  - Optimize setpoints
  - Reduce minimum air flow rate through variable-air volume boxes
  - Limit space conditioning to most likely occupied periods




*N. Fernandez et al. "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction" PNNL Report 2017. http://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf*

## And that's just the beginning!

# Challenges for Sensor and Control Technologies in Buildings

Ensure savings by monitoring and correcting for faulty operation, as well as additional savings by tuning operations to match environmental conditions and occupancy patterns **(>20-30%)**, however,

Implementation of these savings, as well as incorporation of more sophisticated control methodologies for even greater savings are limited in the buildings sector:

- **Not considered an "operationally critical" application**
- **Adoption still not widespread** – 43% of commercial floor space (mostly large buildings > 50,000 sq. ft.) employ a building automation system and 41% of residential buildings have a programmable thermostat, but only 12% use the functionality
- **Not designed for energy efficiency** – simple, reactive for short-term thermal and ventilation needs
- **Fragmented systems** – HVAC separated from control of other building subsystems (e.g., lighting)
- **Labor intensive** – manual, hand-crafted installation and maintenance
- **High cost** – customized, not integrated into the building design process
- **Limited budgets** – for energy management
- **Limited interoperability** – across systems/vendors
- **Confusion in product offerings** – diversity of system configurations

# BTO Sensors and Controls R&D Sub-program

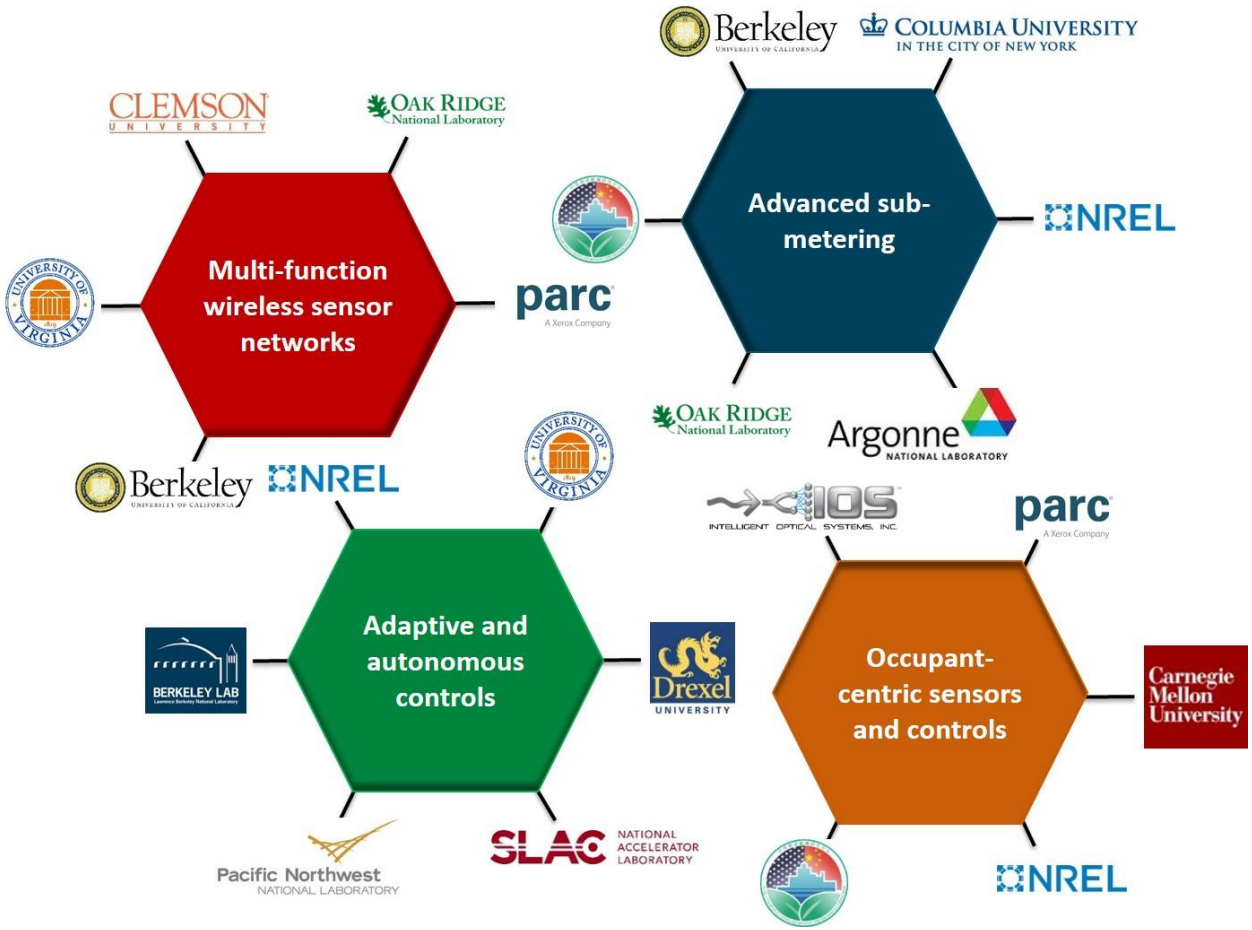
- **Vision:**
  Move beyond simple, reactive controls in buildings intended to meet short-term thermal ventilation needs to optimized controls designed to meet energy efficiency and occupant comfort requirements.

- **Objective:**
  Ensure energy savings (~30%) from efficient equipment through correct implementation of monitoring and control systems while achieving additional savings (>10%) from more sophisticated control strategies.

- **Strategy:**
  - **(1) Sensors and sub-meters** - reducing the cost and improving the long-term performance along with developing new sensing modalities (e.g., occupancy and building equipment health)

  - **(2) Controls** – developing and optimizing model-based and data-driven approaches over longer time periods (e.g., hours and days) and multiple spatial scales (e.g., occupant, whole-building), as well as incorporating additional inputs (e.g., occupancy patterns, weather forecasts)

# BTO Sensors and Controls Portfolio of Projects




**Cross-cutting strategies:**

- Advanced Materials and Manufacturing
- Virtual Sensing and Data Analytics
- Data Taxonomy, Models, and Mapping
- Building Energy Modeling

# BTO Sensors and Controls R&D Focus Areas and Goals

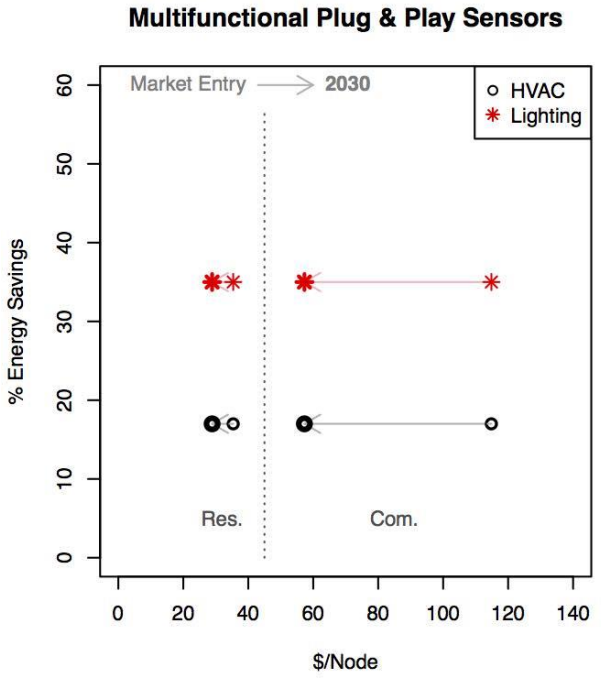
| Priority Focus Area | Energy Conservation Measure | Sector | Installed Cost Target[1] | | Energy Performance (HVAC, Lighting) | | 2030 Energy Savings Technical Potential |
|---|---|---|---|---|---|---|---|
| | | | Market Entry | 2030 Target | Market Entry | 2030 Goal | |
| Multi-functional Wireless Sensor Networks | Plug-and-play sensors self-powered with wireless communication | Residential[2] | $35/ node | $29/ node | 17%, 35% | | 1.14 quads |
| | | Commercial | $115/ node[3] | $57/ node | | | 0.99 quads |
| Advanced Sub-metering | AFDD incorporating sub-metered energy data | Commercial[4] | $0.14/ ft² floor | | 25%, N/A | 30%, N/A | 1.18 quads |
| Occupant-centric Sensors and Controls | Occupancy counting inputs | Residential[5] | $70/ occupant | | 15%, 15% | 30%, 40% | 2.31 quads |
| | | Commercial[6] | $36/ occupant | | | | 1.10 quads |
| | Occupancy comfort inputs | Residential | $92/ occupant | | 20%, 30% | 40%, 60% | 3.14 quads |
| | | Commercial | $49/ occupant | | | | 1.49 quads |
| Advanced and Autonomous Controls | AFDD | Commercial[7] | $0.12/ ft² floor | $0.14/ ft² floor | 20%, N/A | 30%, N/A | 1.18 quads |

# Multi-Functional, Plug-and-Play Wireless Sensor Networks

Enable low-cost approach to accurately detect and diagnose faults, failures, and resulting inefficiencies in building equipment and subsystems, while also allowing for optimal and localized whole-building control opportunities to improve occupant comfort along with reducing energy use.

**Technical Barriers**:

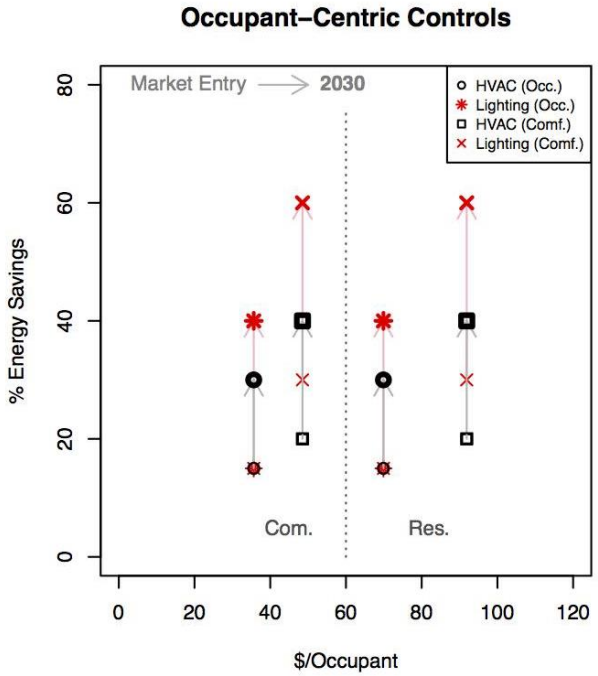
- Enhanced wireless communications
- Operational power lifetime
- Accuracy and reliability,
- Modular design and materials cost reduction,
- IT system expansion,
- Automated calibration, recognition and configuration,
- Flexible placement methods

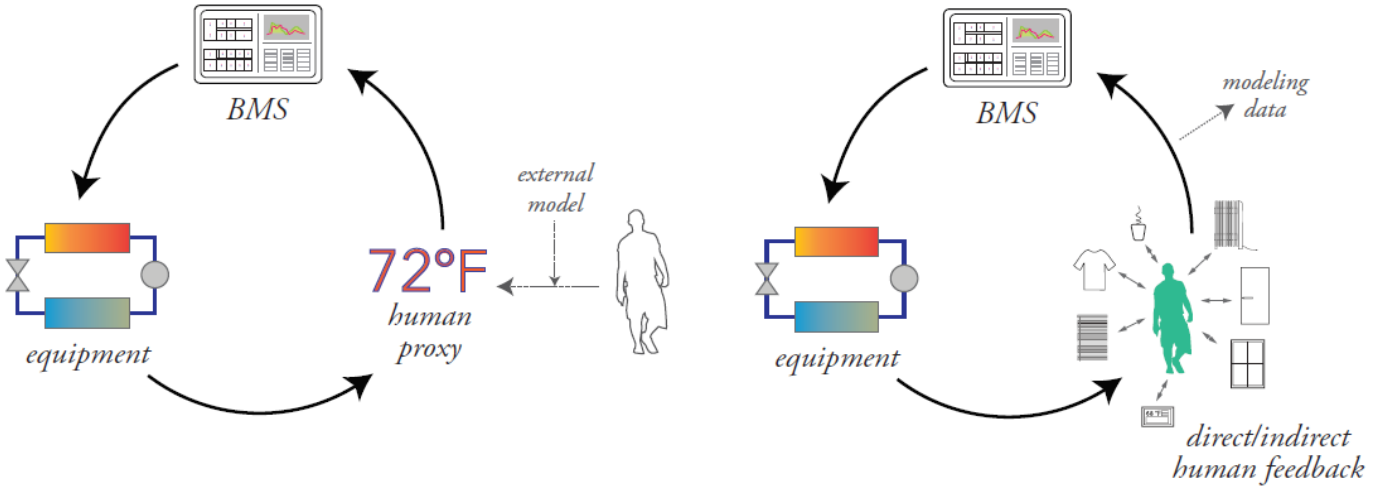


# The Role of the Occupant

**Technical Barriers:**

- Improved occupancy counting and comfort estimation and incorporation into control schemes
- Adaptive models and controls with near real-time response
- Long-term accuracy and calibration of indoor air quality variables (e.g., $CO_2$, humidity)
- Automated recognition and configuration with existing building automation infrastructure

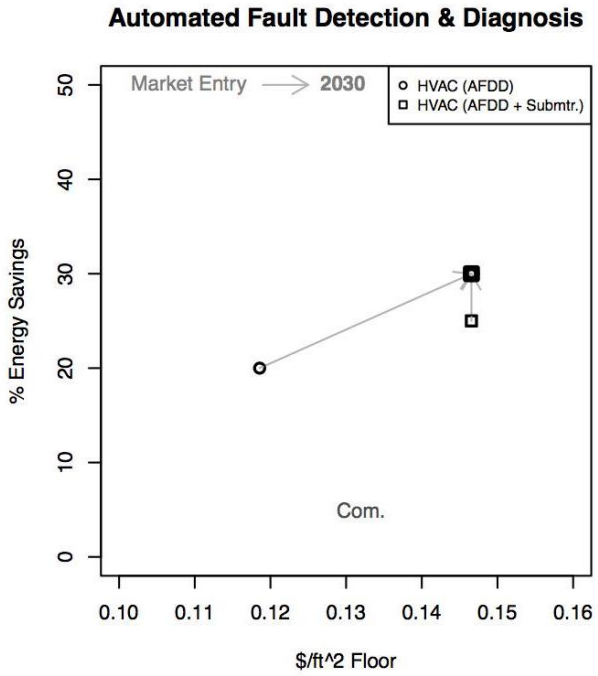


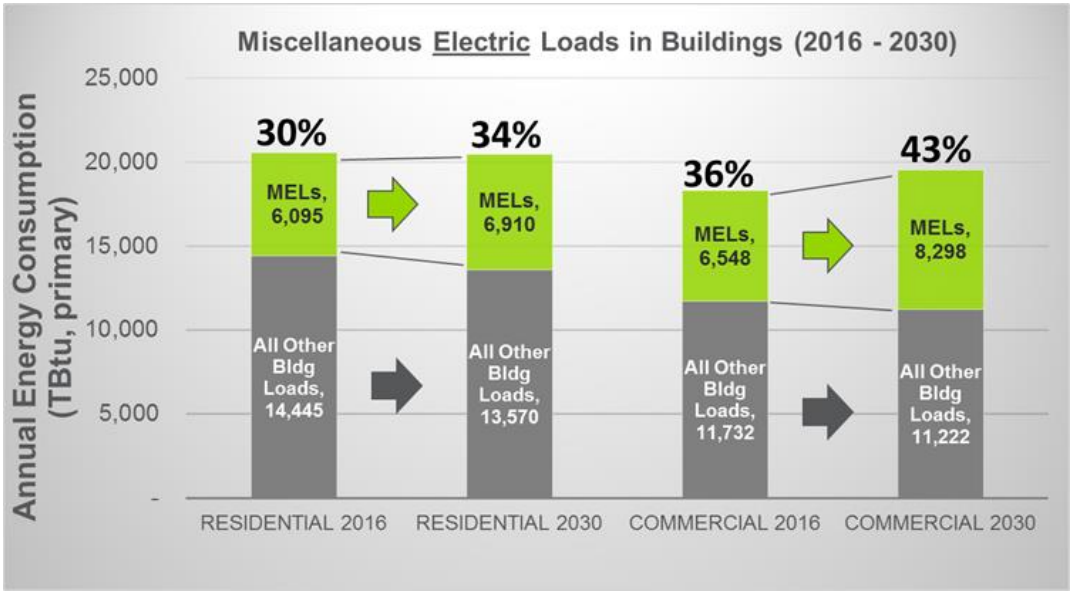
# Low-Cost Advanced Sub-metering

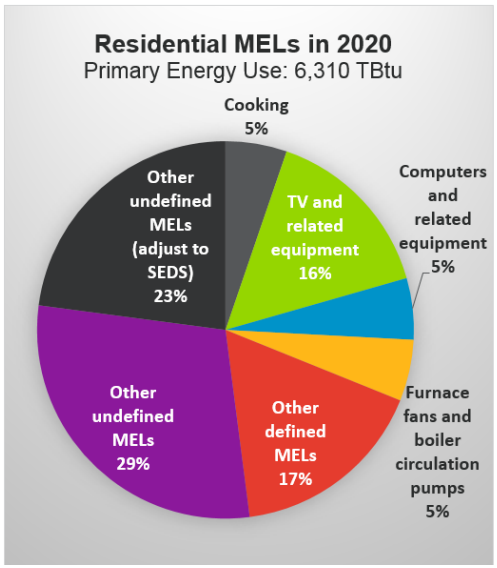
**Technical Barriers include:**

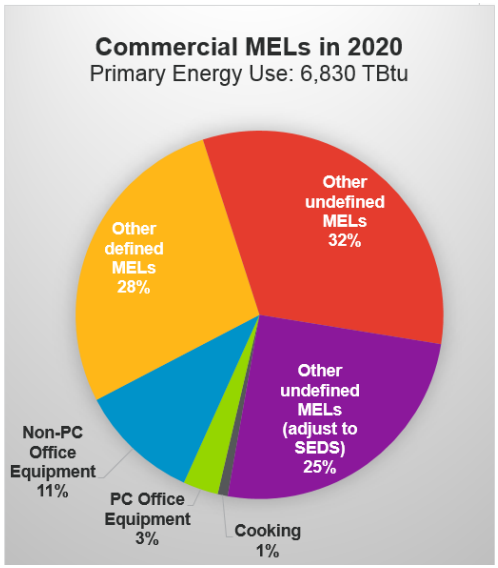
- High accuracy hardware
- Load disaggregation and non-intrusive monitoring techniques
- Automated configuration with existing or new building automation infrastructure
- Enhanced wireless communications
- Modular design and materials cost reduction
- Long-term accuracy calibration
- Occupant/operator engagement and feedback



# Extending Approaches to Miscellaneous Electric Loads




## Increase in portion of building energy consumption driven by:

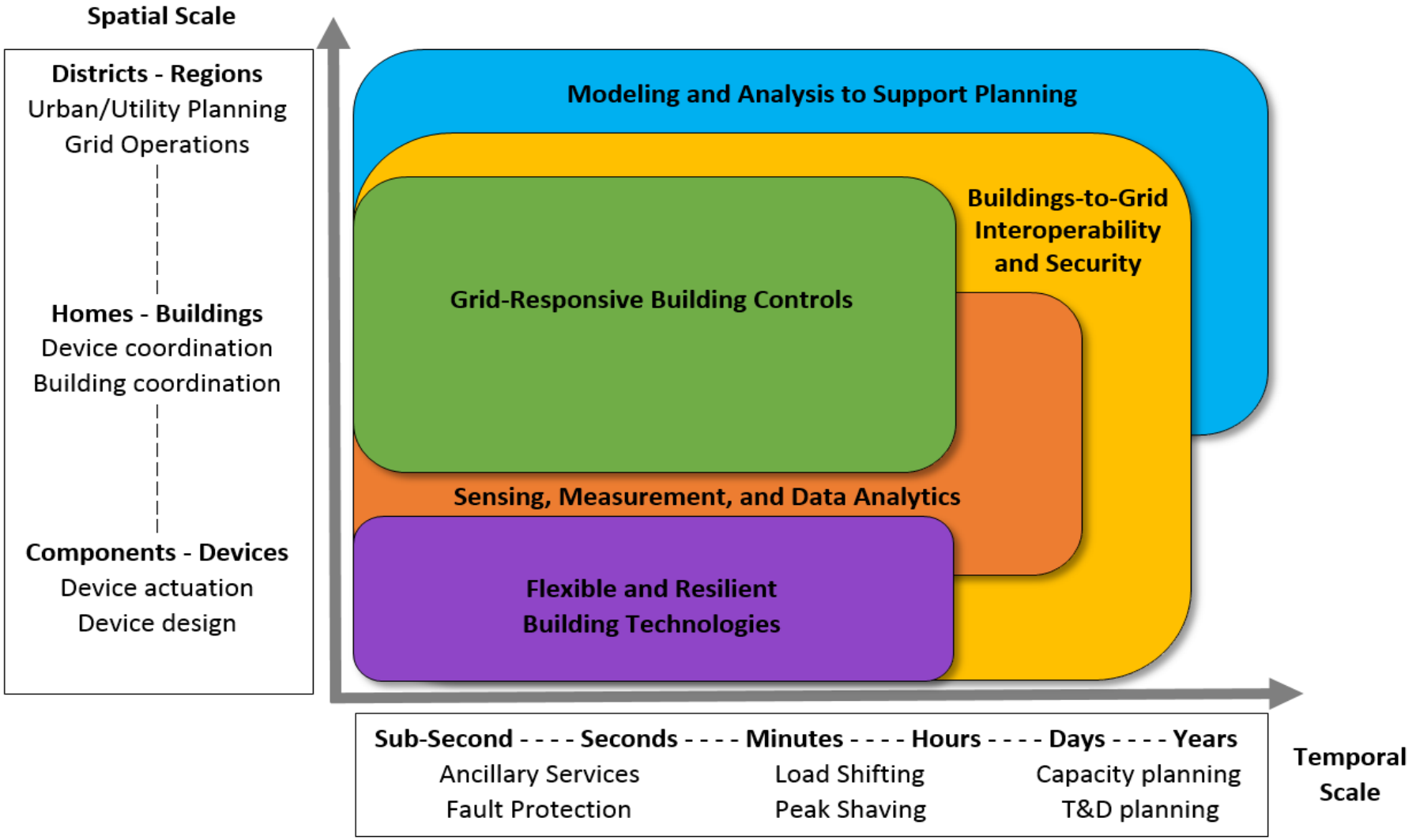
- Improved efficiencies of the major energy end use technologies
- Projected increase in primary energy consumption in residential and commercial buildings from MELs

## 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/*

# S&C in the Future: Enabling Key GEB Focus Areas



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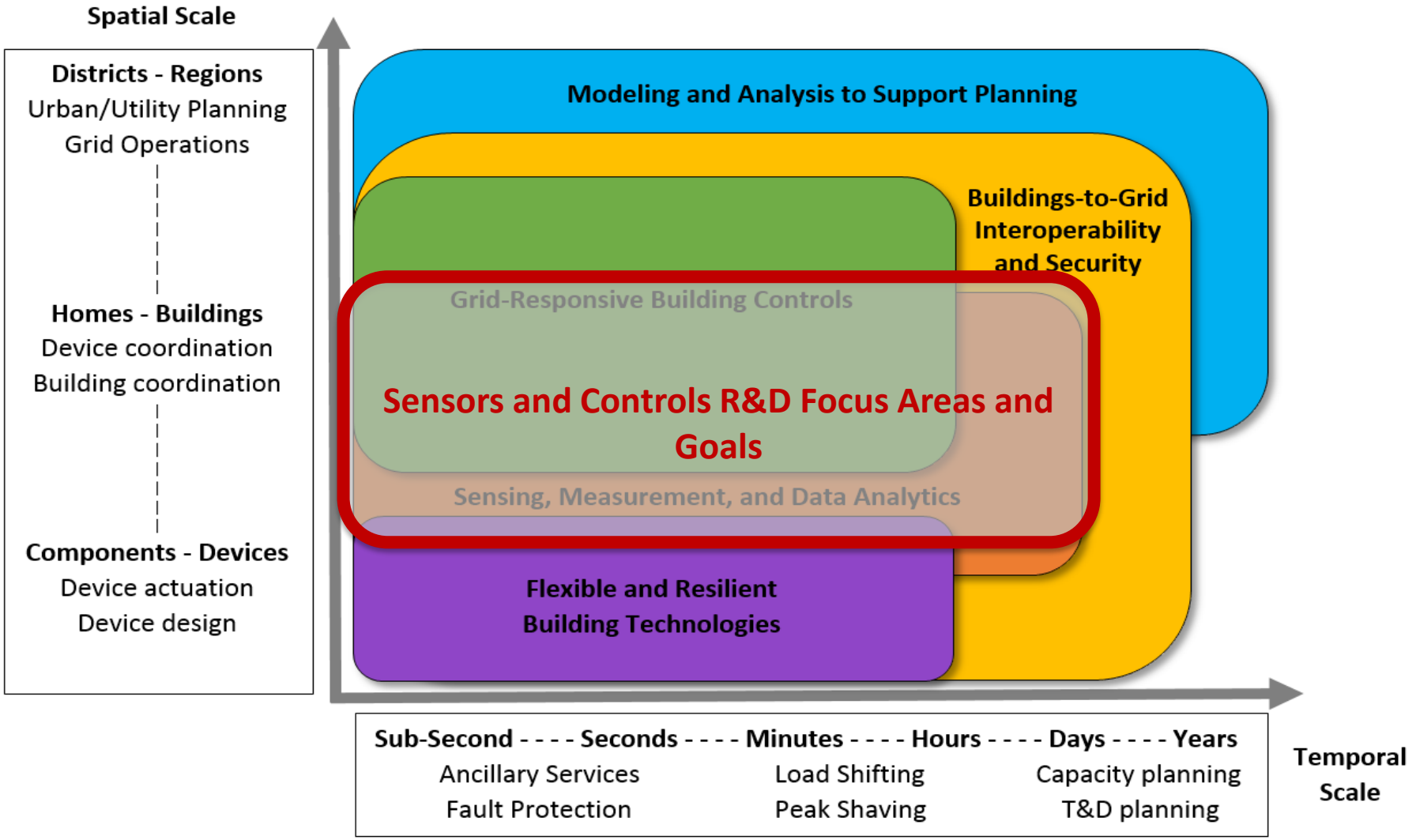

# R&D Funding Mechanisms

1. **Directed National Laboratory Efforts – Annual Operating Plan (AOP)**
   a) 1-3 Year Sensor and Controls Lab Call Merit Review Awards: FY17-19
   b) Consortia: DOE Grid Modernization Lab Consortium (GMLC)
   c) Industry Partnerships: CRADAs and Small Business Voucher (SBV)

2. **Awarded by Funding Opportunity Announcements (FOA) to Industry, Academia or National Labs**
   a) FOAs: FY15 BUILD, FY16 BENEFIT, and FY17 BENEFIT
   b) Consortia: US-China Clean Energy Research Center (CERC)
   c) Small Business Innovation Research (SBIR)

# Sub-program Evolution: Relevant Solicitations

***2015***

FOA

**Building University Innovators and Leaders Development (BUILD)-2015, DE-FOA-0001167 (Nov 11, 2014)**

- University-based teams (both undergraduate and graduate students led by faculty sponsor) with a minimum 50% direct project costs supporting undergraduates in innovative building energy efficiency technologies

***2016***

FOA

**Small Business Innovation Research (SBIR)- 2016 Phase 1 Release 2, DE-FOA-00011417 (Nov 30, 2015)**

- Technologies for Sensing and Managing Indoor Air Quality in Buildings – Accurate, stable humidity sensors

FOA

**Building Energy Efficiency Frontiers and Innovation Technologies (BENEFIT)-2016, DE-FOA-0001383 (Dec 15, 2015)**

- Open Topic for Energy Efficiency Solutions for Residential & Commercial Buildings
- Human-in-the-Loop Sensor & Control Systems
- Plug-and-Play Sensor Systems

***2017***

AOP

**Building Technologies Offices FY2017 National Laboratory Call for Proposals & Merit Review, BTO-LMR-0001719 (Feb 3, 2016)**

- Building Equipment Sub-metering
- Adaptive and Fault Tolerant Building Controls

FOA

**Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) – 2017, DE-FOA-0001632 (Nov 30, 2016)**

- Open Topic for Energy Efficiency Solutions for Residential & Commercial Buildings
- Miscellaneous Electric Loads Research and Development (R&D)

***2018***

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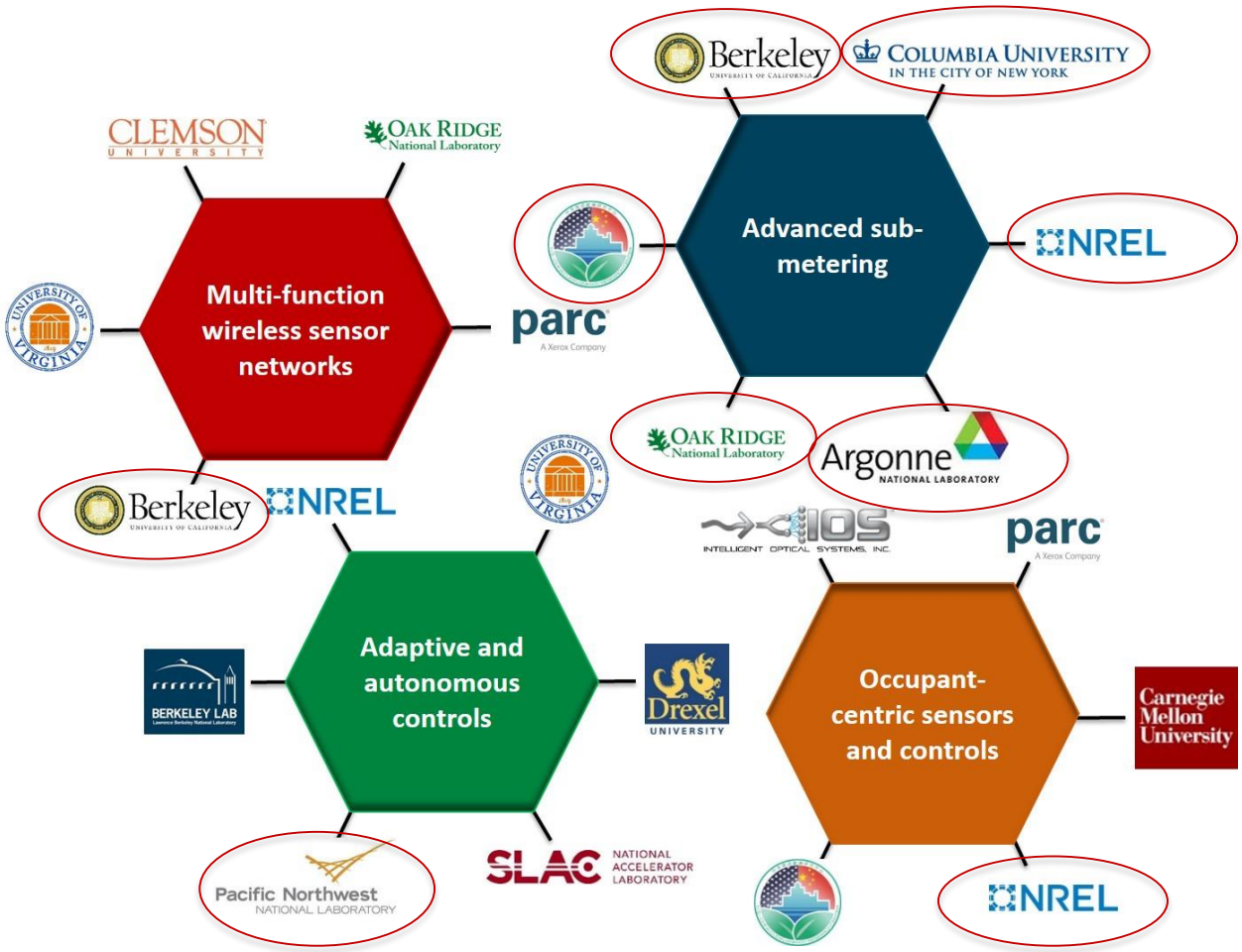
***2018***

# BTO Sensors and Controls Portfolio of Projects



# Today's Agenda – May 1, 2018

| Time | Session/Speaker | Project/Topic | Solicitation |
|---|---|---|---|
| 10:45 – 11:00 am | Marina Sofos (DOE/BTO) | Sensors & Controls Subprogram Recap | |
| 11:00 – 11:30 am | Rich Brown (LBNL) | Direct Current (DC) Buidlings and Smart Grid | CERC FY16 |
| 11:30 – 12:00 pm | Stephen Frank (NREL) | Energy Design and Scoping Tool for DC Distribution Systems | BENEFIT FY17* |
| 12:00 – 12:30 pm | Robert Fares (AAAS)/ Alan Meier (LBNL) | Improving Characterization of Miscellaneous Energy Loads in Residential and Commercial Buildings | AOP FY18* |
| 12:30 – 1:30 pm | Lunch Break | | |
| 1:30 – 2:00 pm | Prabal Dutta (UC-Berkeley) | Low-Cost Identification & Monitoring of Diverse MELs in Residential and Commercial Buildings with PowerBlade | BENEFIT FY17* |
| 2:00 – 2:30 pm | David Culler (UC-Berkeley) | Hamilton: Flexible, Open Source $10 Wireless Sensor System for EE Building Operation | BENEFIT FY16 |
| 2:30 – 3:00 pm | Ted Bohn (ANL) | Low Cost Sub-metering | Lab Call FY17 |
| 3:00 – 3:30 pm | Som Shrestha (ORNL) | Experimental Validation of a New Cost-Effective and Non-Intrusive BTU Meter | SBV CRADA FY17 |
| 3:30 – 4:00 pm | Break | | |

*not formally peer reviewed today

# Today's Agenda – May 1, 2018 (cont.)

| Time | Session/Speaker | Project/Topic | Solicitation |
|---|---|---|---|
| 3:30 – 4:00 pm | Break | | |
| 4:00 – 4:30 pm | Christoph Meinrenken (Columbia) | Reducing plug-load electricity footprint of residential buildings through low-cost, non-intrusive sub-metering and personalized feedback technology | BENEFIT FY16 |
| 4:30 – 5:00 pm | Srinivas Katipamula (PNNL) | Economic Dispatch – Transactive Whole Buildings | GMLC FY16 |
| 5:00 – 5:30 pm | Dane Christensen (NREL) | Home Battery System | CRADA FY16 |
| 5:30 – 6:00 pm | REVIEWERS AND STAFF ONLY | Sensors and Controls Wrap-up | |

# Thank you!

Mike Atsbaha
Adam DeDent
Carla Dunlap
Christina Dunn
Dr. Robert Fares
Michael Geocaris
Mary Hubbard
Amy Jiron
Mohammed Khan
Marc LaFrance
Dr. Jared Langevin
Gina Lynch
Ryan McCleary
Mary Murray
Valerie Nubbe
Sam Petty
Dr. Janet Reyna
Dr. Amir Roth
Antonio Ruiz
Dr. Karma Sawyer
Dr. Mike Specian
Geoff Walker

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**"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*