U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Grid-Interactive Efficient Buildings:

HVAC&R, Water Heating, Appliance, and Commercial Refrigeration Technologies

2019 Peer Review

Building Technologies Office

April 16, 2019

Agenda

1. Introduction
   a) Report Series Overview
   b) Background
   c) Scope
   d) Grid Services Definitions
   e) Load Shapes
2. Evaluation of Technologies
3. R&D Challenges and Opportunities

Please submit feedback and suggestions to:

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GEB Technical Report Series Overview

The GEB Technical Report Series will help inform and guide BTO's R&D portfolio and serve as a foundational resource for the larger building research community.

Reports will be published in Summer 2019 in partnership with

Navigant, NREL, PNNL

GEB Technical Report Series:

- Overview
- Heating, Ventilation, & Air Conditioning (HVAC); Water Heating; and Appliances
- Lighting
- Building Envelope & Windows
- Sensors & Controls, Data Analytics, and Modeling

1 Establish Frameworks

- Defines grid-interactive efficient buildings and demand flexibility
- Establishes potential grid services and some basic requirements for buildings to provide flexibility

2 Assess Flexibility Potential

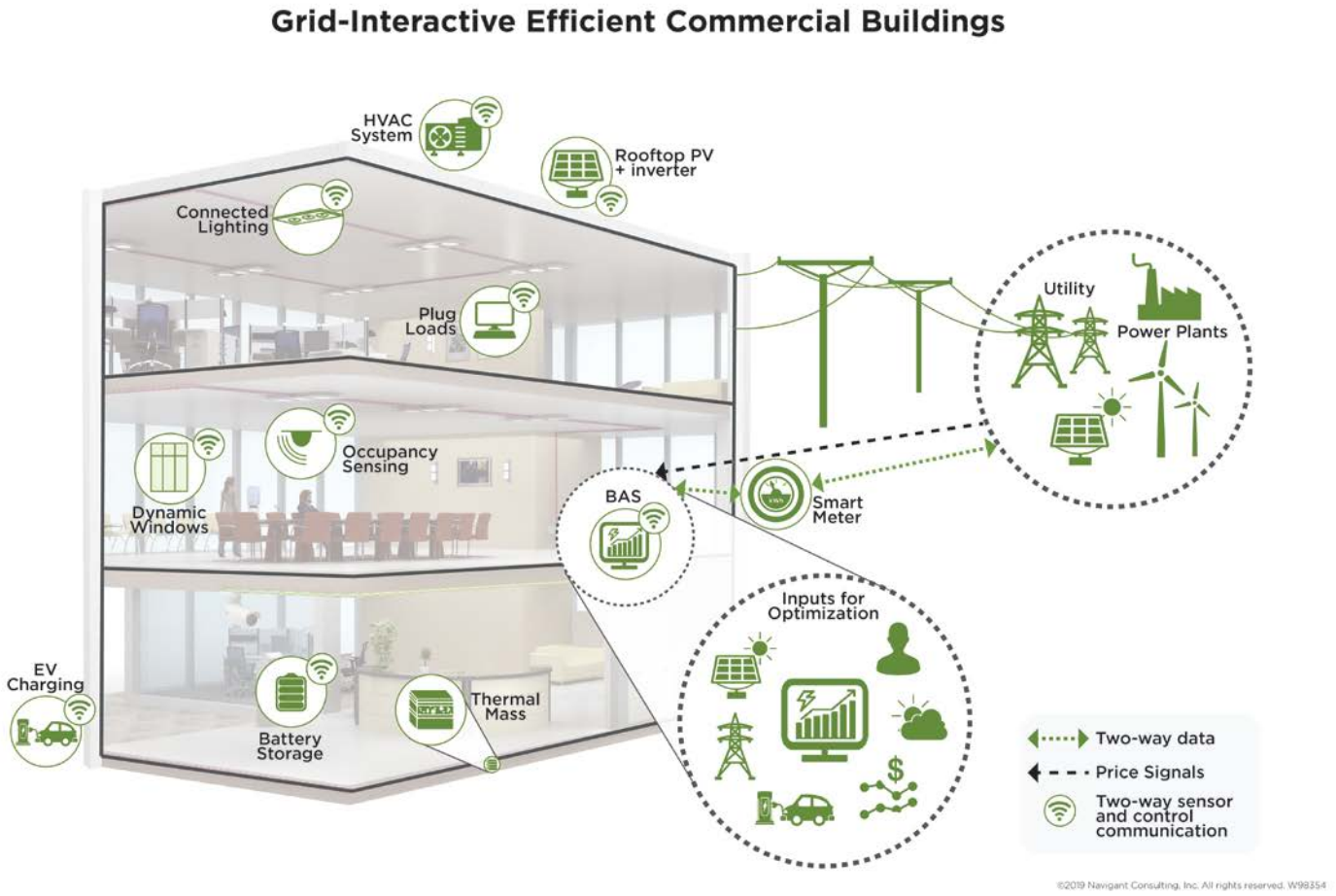
- Evaluate state-of-the-art and emerging building technologies based on ability to provide grid services
- Considers implementation attributes

3 Discuss Research Opportunities

- Identify major research challenges of technologies with significant potential for grid benefits and opportunities for additional technology-specific R&D.

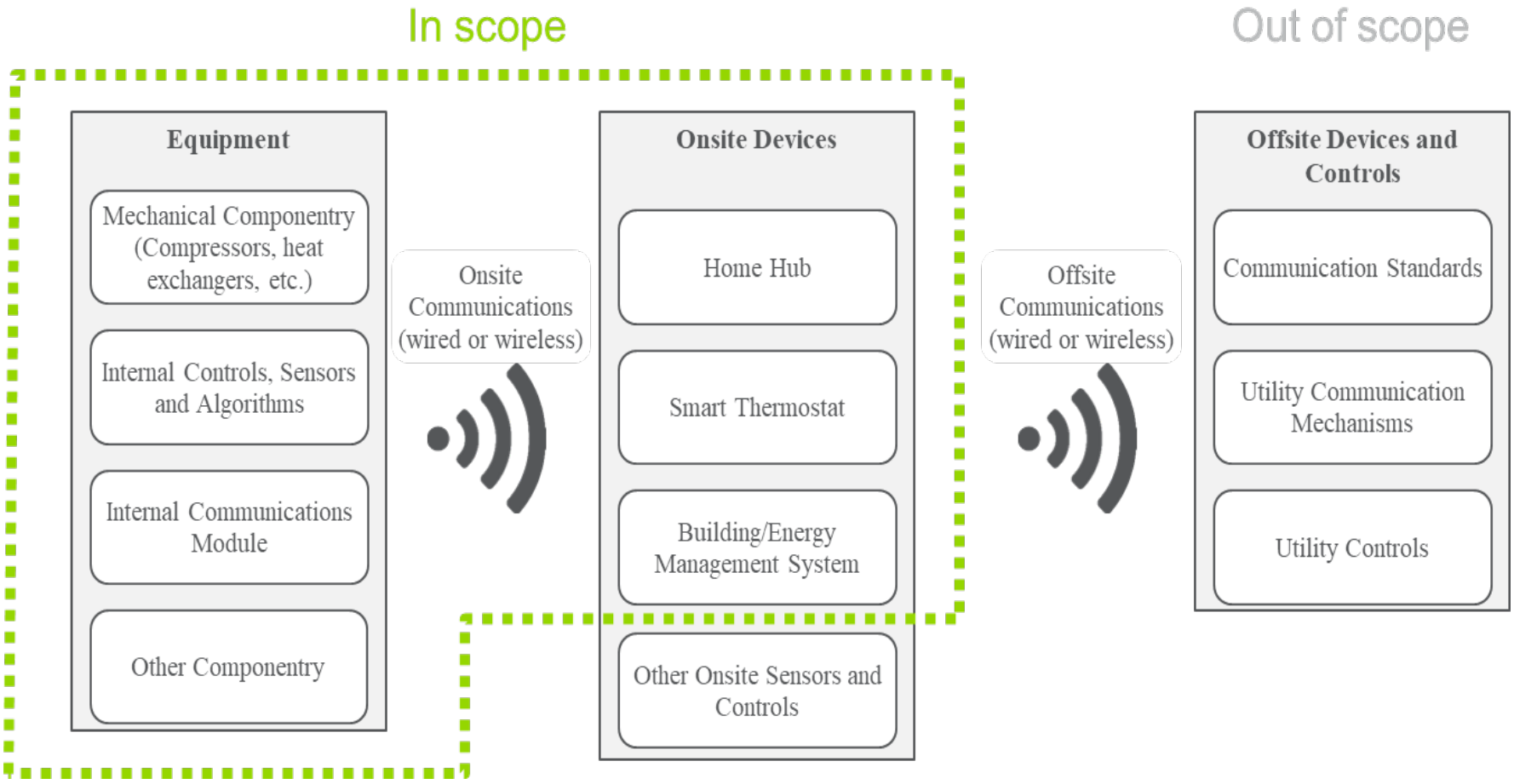
Grid-Interactive Efficient Buildings: Background

Grid-interactive efficient buildings (GEB): energy efficiency and flexibility to benefit occupants, owners and the grid.



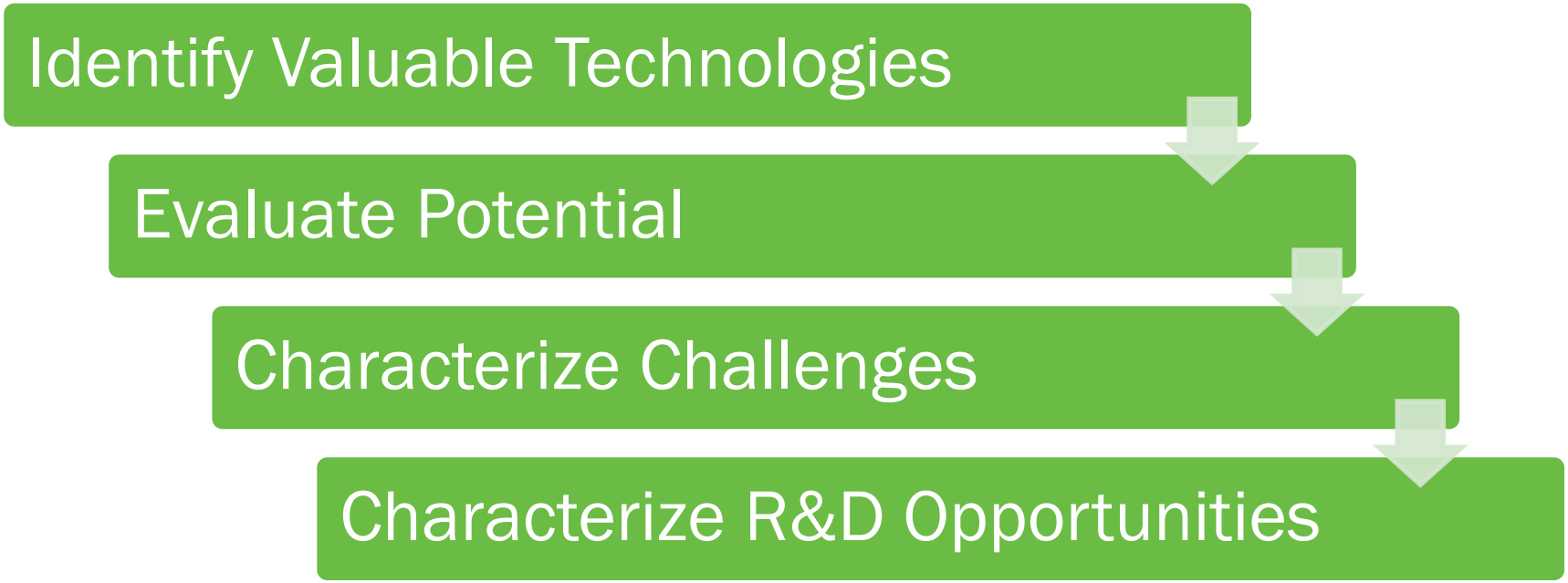
Scope

- HVAC&R, water heating, appliances, comm. refrigeration
- Equipment and related, onsite controls



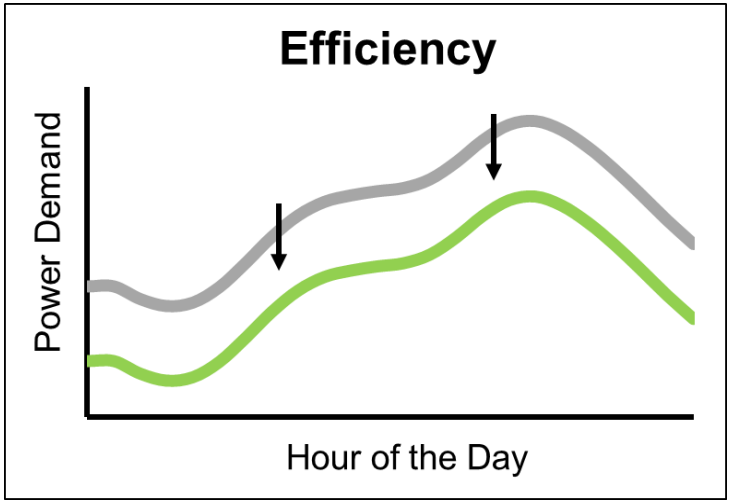
Methodology

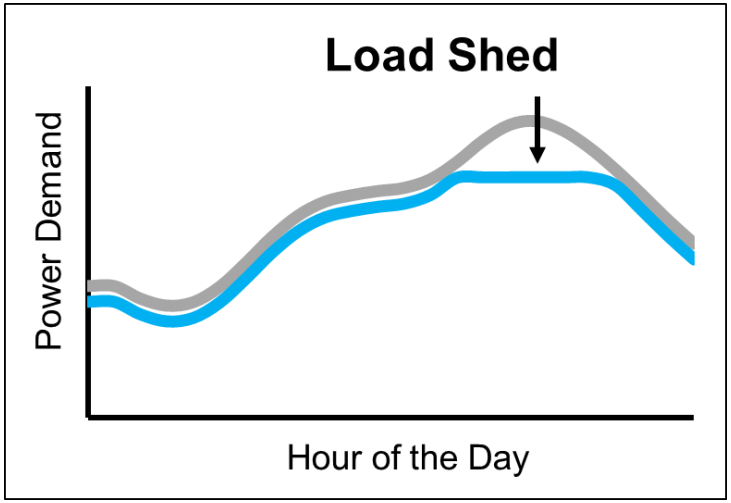
The GEB analysis followed four steps

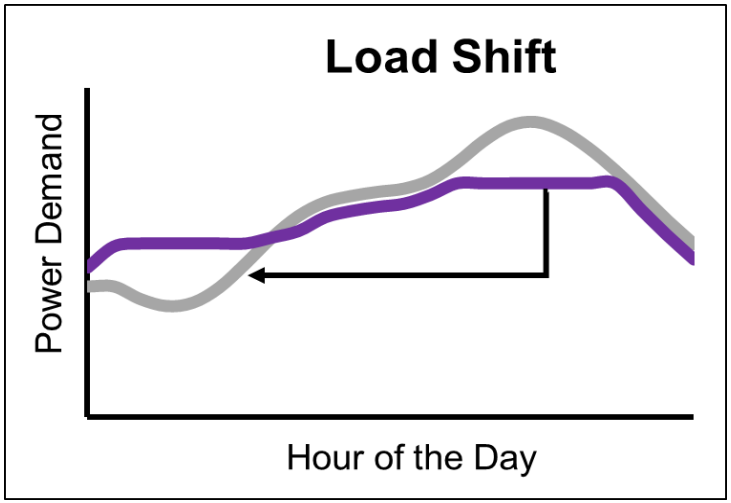


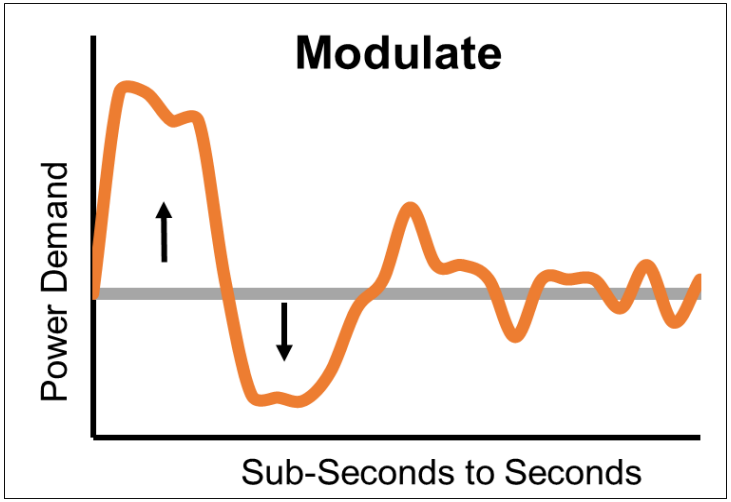
Methods for Buildings to Provide Services

Four primary ways buildings providing grid value:





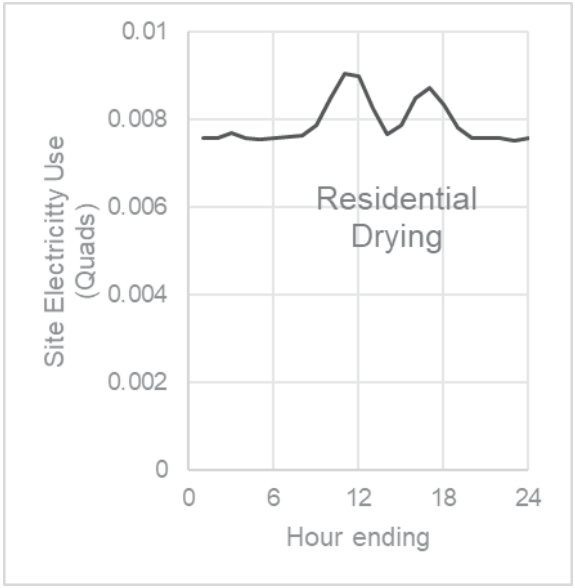


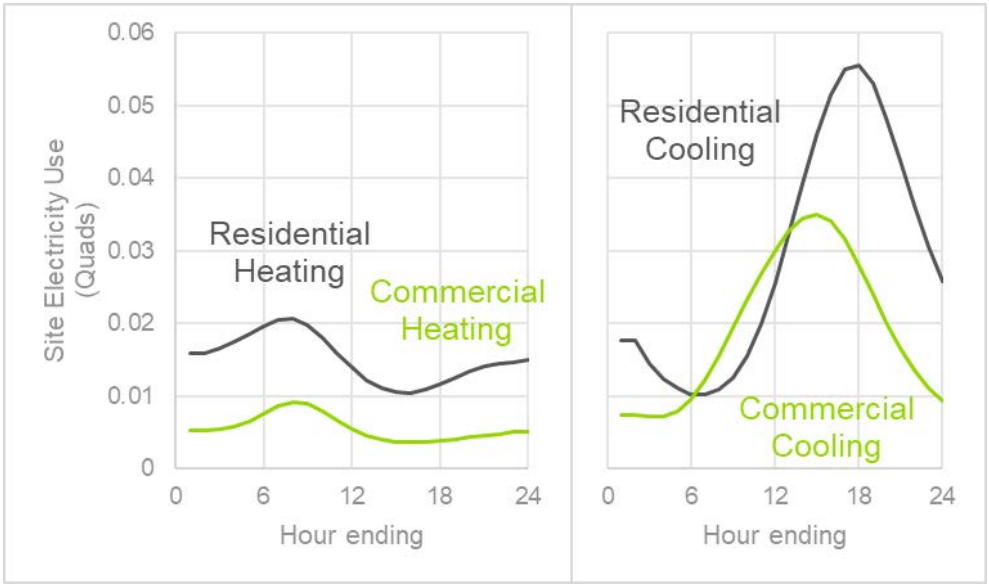


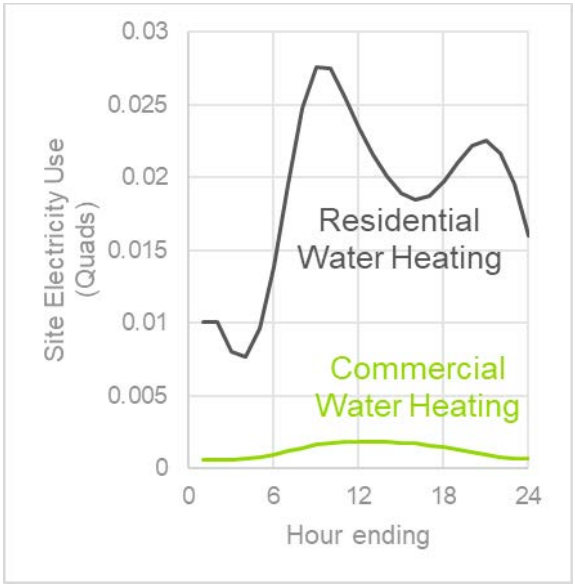
Load Shapes: Electric

Well-suited loads for grid services:

- Dryers, clothes washers and dishwashers – finite operation cycle
- Space conditioning – easy to pre-cool/heat
- Water heating – easy to pre-heat



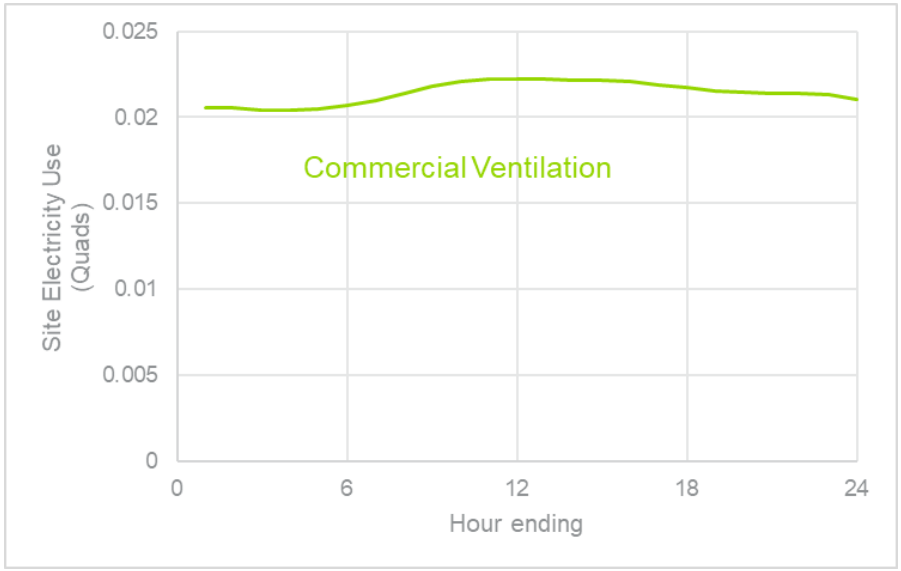


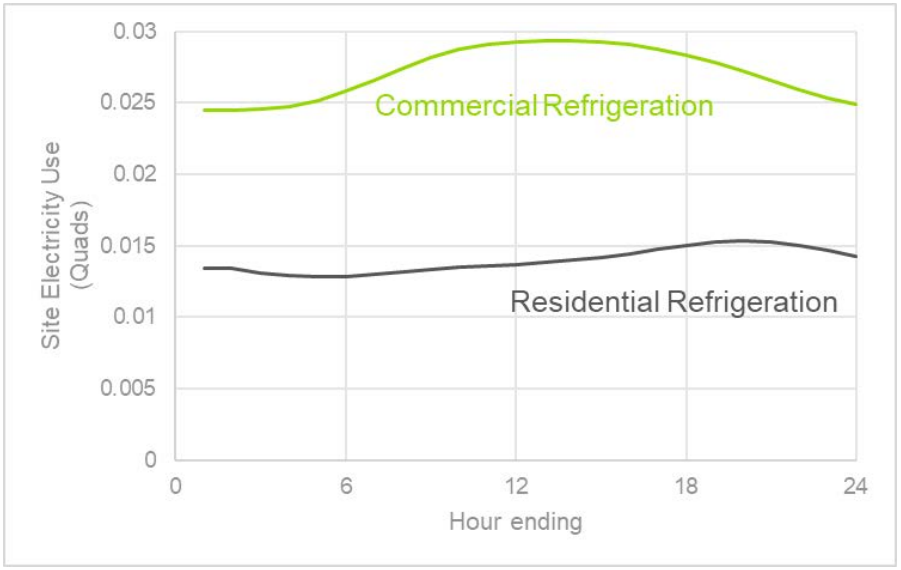


Load Shapes: Electric cont.

Less-ideally-suited loads for grid services:

- Ventilation and refrigeration
  - Maintain conditions continually – somewhat less flexible
  - Careful planning and design to provide grid value safely

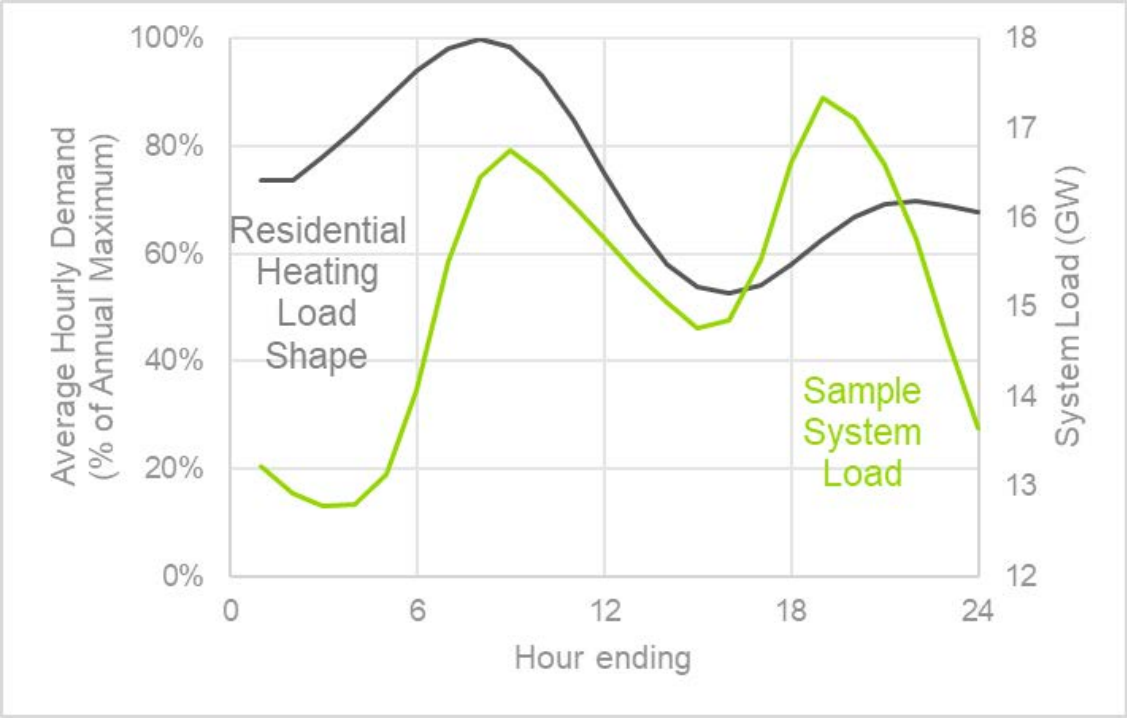




Load Shape: Natural Gas

Natural Gas demand response (DR) is of increasing interest

- Network under strain during cold spells
- DR alleviates strain via shifting/shedding
- Fuel switching DR must consider electric grid impact



Technology Evaluation Overview

- Evaluated technologies based on grid value
- Considered market limitations to assess Overall GEB Potential

High Potential	Medium Potential	Low Potential
• [HVAC] Smart Thermostats • [HVAC] Liquid Desiccant Thermal Energy Storage • [HVAC] Thermal Energy Storage • [Water Heating] Smart Connected Water Heater Controller • [Cross-Cutting] Building Energy Management Systems (BEMS) • [Cross-Cutting] Home Hubs • [Cross-Cutting] Plug-and-Play GEB Equipment • [Cross-Cutting] Grid-Sensing, Self-Dispatching Equipment	• [HVAC] Modulating HVAC • [HVAC] Advanced Controls for HVAC Equipment with Embedded Thermostats • [Appliances] Modulating Low-Power Mode Clothes Dryer • [Appliances] Advanced Dishwasher /Clothes Washer Controls • [Appliances] Connected Refrigerator /Freezer Advanced Controls • [Comm. Refrigeration] Commercial Refrigeration Thermal Storage • [Comm. Refrigeration] Advanced Controls for Commercial Refrigeration • [Cross Cutting] Embedded Batteries	• [HVAC] Hybrid Evaporative Cooling • [HVAC] Dual-Fuel HVAC • [Water Heating] Dual-Fuel Water Heaters • [Cross-Cutting] DC Buildings/Equipment
• [Natural Gas] Thermal Energy Storage • [Natural Gas] Smart Water Heater Controllers • [Natural Gas] Smart Thermostats		• [Natural Gas] Dual-Fuel HVAC • [Natural Gas] Dual-Fuel Water Heaters

Technology Evaluation: HVAC

HVAC Technologies	Efficiency	Shed Load	Shift Load	Modulate Load	Overall GEB Potential
Smart Thermostats	✓	✓	✓		High
Liquid Desiccant Thermal Energy Storage	✓		✓		High
Thermal Energy Storage for Heating/Cooling			✓		High
Modulating HVAC	✓	✓	✓	✓	Med
Advanced Controls for HVAC Equipment with Embedded Thermostats		✓	✓		Med
Hybrid Evaporative Cooling		✓	✓		Low
Dual-Fuel HVAC		✓			Low

Technology Evaluation: Water Heating & Appliances

Water Heating Technologies	Efficiency	Shed Load	Shift Load	Modulate Load	Overall GEB Potential
Smart Connected Water Heater Controller		✓	✓	✓	High
Dual-Fuel Water Heater		✓			Low

Appliance Technologies	Efficiency	Shed Load	Shift Load	Modulate Load	Overall GEB Potential
Modulating Low-Power-Mode Clothes Dryer	✓		✓	✓	Med
Advanced Dishwasher/Clothes Washer Controls			✓		Med
Connected Refrigerator/Freezer Advanced Controls			✓		Med

Technology Evaluation: Comm. Refrig., & Natural Gas

Commercial Refrigeration Technologies	Efficiency	Shed Load	Shift Load	Modulate Load	Overall GEB Potential
Commercial Refrigeration Thermal Storage			✓		Med
Advanced Controls for Commercial Refrigeration	✓		✓		Med

Natural Gas Technologies	Efficiency	Shed Load	Shift Load	Overall GEB Potential
Thermal Energy Storage for Heating/Cooling			✓	High
Smart Connected Water Heater Controller		✓	✓	High
Smart Thermostats	✓	✓	✓	High
Dual-Fuel HVAC		✓		Low
Dual-Fuel Water Heaters		✓		Low

Technology Evaluation: Cross-Cutting

Cross-Cutting Technologies	Efficiency	Shed Load	Shift Load	Modulate Load	Overall GEB Potential
Building Energy Management Systems (BEMS)	✓	✓	✓		High
Home Hubs	✓	✓	✓		High
Plug-and-Play GEB Equipment		✓	✓		High
Grid-Sensing, Self-Dispatching Equipment				✓	High
Embedded Batteries		✓	✓		Med
DC Buildings/Equipment	✓				Low

R&D Challenges and Opportunities

We considered the following attributes to identify barriers:

- Reliability
- Resiliency
- System readiness
- Usability
- Manufacturability
- Human Health
- Environment
- Cost-Effectiveness

R&D Challenges and Opportunities

Identified areas for R&D include:

Product costs	Self-dispatching equipment	Installation costs	Appliance retrofits
Embedded batteries	Battery control algorithms	High-density thermal storage	Refrigeration DR algorithms
Smart algorithms for GEB controls	Active power factor management	Heat pump water heaters for DR	

R&D Challenges and Opportunities

Reduce GEB Product Costs

- **Challenge:**
  - Cost premium
- **Opportunities (for all tech):**
  - Develop novel materials and manufacturing processes
  - Support standardization of communications and controls

Develop Self-Dispatching Equipment for Stable Grid Control

- **Challenge:**
  - Issue detection delay increases with distance from the source, leading to desynchronized equipment response
- **Opportunities (for self-dispatching equipment):**
  - Evaluate and model grid impacts
  - Develop control strategies

R&D Challenges and Opportunities

Reduce Installation Cost for GEB Equipment

- **Challenge:**
  - High cost installation due to commissioning/setup labor
- **Opportunities (for all tech):**
  - Support development of a standard data model for utility tariffs and schedules for equipment programming
  - Develop plug-and-play connectivity for new buildings or retrofits

Enable Plug-and-Play GEB Appliance Retrofits

- **Challenge:**
  - Only new (select) appliances are Plug-and-Play GEB capable
- **Opportunities (for appliances):**
  - Develop inexpensive retrofit Plug-and-Play GEB packages for appliances

R&D Challenges and Opportunities

Support Embedded Battery Technology Development for GEB Services

- **Challenge:**
  - Embedded battery potential is poorly characterized
- **Opportunities (for embedded batteries):**
  - Determine technical requirements for embedded batteries
  - Investigate alternative electric storage technologies
  - Conduct techo-economic analysis

Support the Development of Battery Control Algorithms

- **Challenge:**
  - Batteries control optimization is key to effective GEB dispatch
- **Opportunities (for embedded batteries):**
  - Develop control algorithms for batteries

R&D Challenges and Opportunities

Support Development of High-Density Thermal Energy Storage

- **Challenge:**
  - Large space requirements for storage
- **Opportunities (for thermal energy storage technologies):**
  - Improve thermal energy storage density
  - Develop ways to package thermal energy storage solutions

Develop Algorithms to Control Demand Response in Refrigeration

- **Challenge:**
  - Refrigerated food may be negatively impacted by load shifting/shedding
- **Opportunities (for refrigeration control technologies):**
  - Support the development of refrigeration control algorithms

R&D Challenges and Opportunities

Develop and Evaluate Smart Algorithms for Centralized GEB Controls

- **Challenge:**
  - Limited capabilities of centralized controls to optimize building response to grid signals
- **Opportunities (for BEMS, home hubs and smart thermostats):**
  - Research smart algorithms for centralized controllers
  - Research artificial intelligence applications to improve control algorithms performance

Voltage Support via Power Factor Management

- **Challenge:**
  - Poorly characterized algorithms and potential for voltage support from buildings
- **Opportunities (for BEMS):**
  - Investigate BEMS-based control strategies to provide voltage support

R&D Challenges and Opportunities

Heat Pump Water Heaters for Demand Response

- **Challenge:**
  - Heat pump water heater performance degrades at high temps (and temps may be limited)
- **Opportunities (for smart connected water heater controllers):**
  - Model and test optimal approaches for hybrid electric resistance/heat pump water heaters to provide demand response
  - Develop high-temp-capable HPWH

Questions/Discussion

Please submit feedback and suggestions to:

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Appendix

Grid Services

Grid Services		Potential Avoided Power/Grid Cost
Generation	Generation: Energy	Generation variable operating costs; startup/shutdown costs
	Generation: Capacity	Capital costs for new generating
Ancillary	Contingency Reserves[1]	Generation variable operating costs and opportunity costs associated with providing contingency reserves
	Frequency Regulation	Generation variable operating costs and opportunity costs[2] associated with providing frequency regulation
	Ramping	Generation variable operating costs; startup/shutdown costs
Delivery	Non-wires Alternatives	Capital costs for transmission & distribution equipment upgrades
	Voltage Support	Capital costs for voltage control equipment

[2] E.g., not selling power in order to be ready for up-regulation