U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

GEB Technical Report Series: Water Heating, Appliances and Refrigeration

Building Technologies Office

June 9, 2020

Webinar Agenda

I. **GEB Overview**
   - Monica Neukomm, Senior Policy Advisor
     - Building Technologies Office

II. **GEB Water Heating, Appliances and Refrigeration Report**
   - Matt Guernsey, Associate Director
     - Guidehouse Consulting (Navigant)

III. **Water Heater, Appliances & Refrigeration Flexibility Metrics**
   - Nelson James, Science, Technology, and Policy Fellow
     - Building Technologies Office

IV. **Quantifying Flexibility Potential**
   - Nelson James, Science, Technology, and Policy Fellow
     - Building Technologies Office

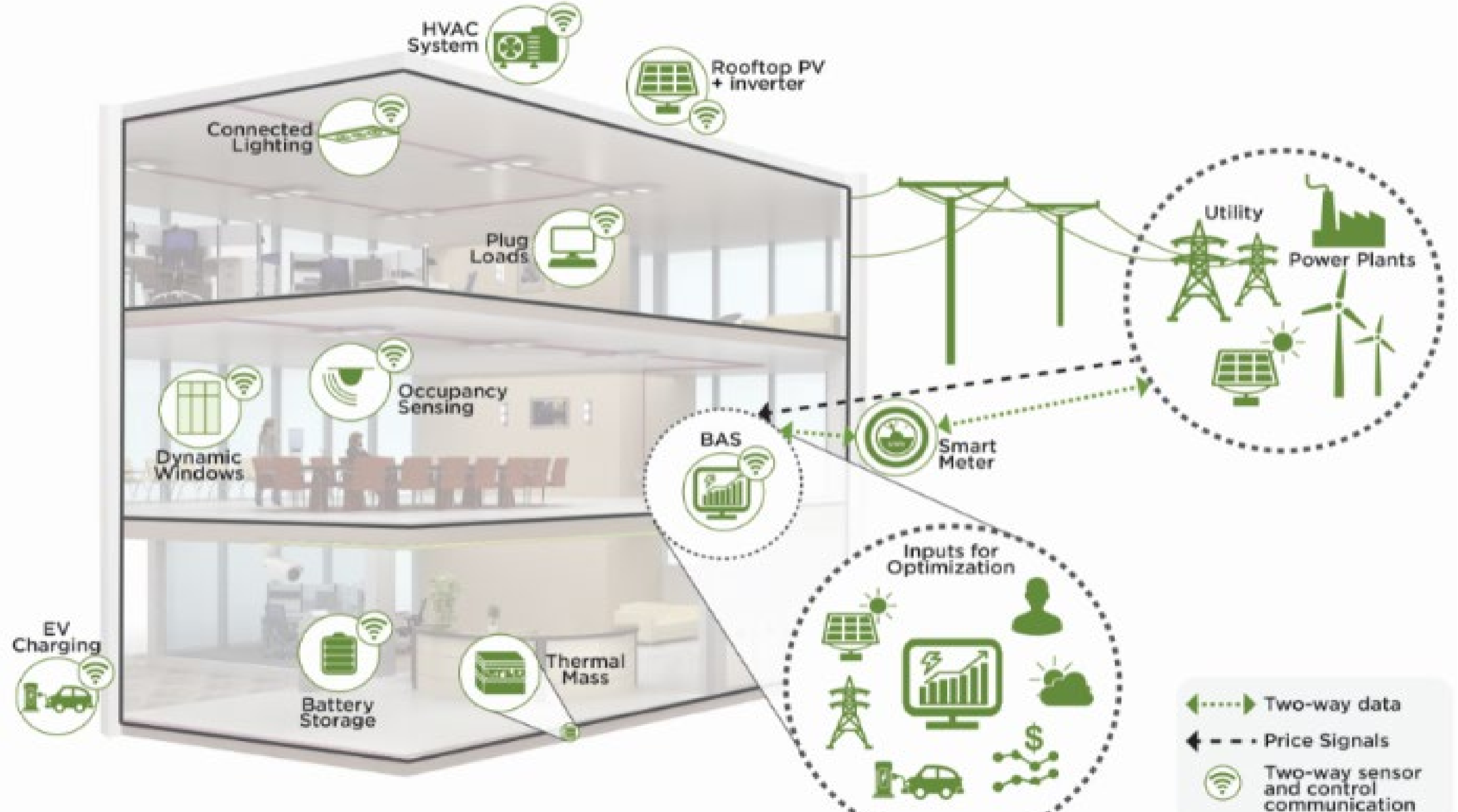
V. **Q&A Session**

GEB Technical Report Series Overview

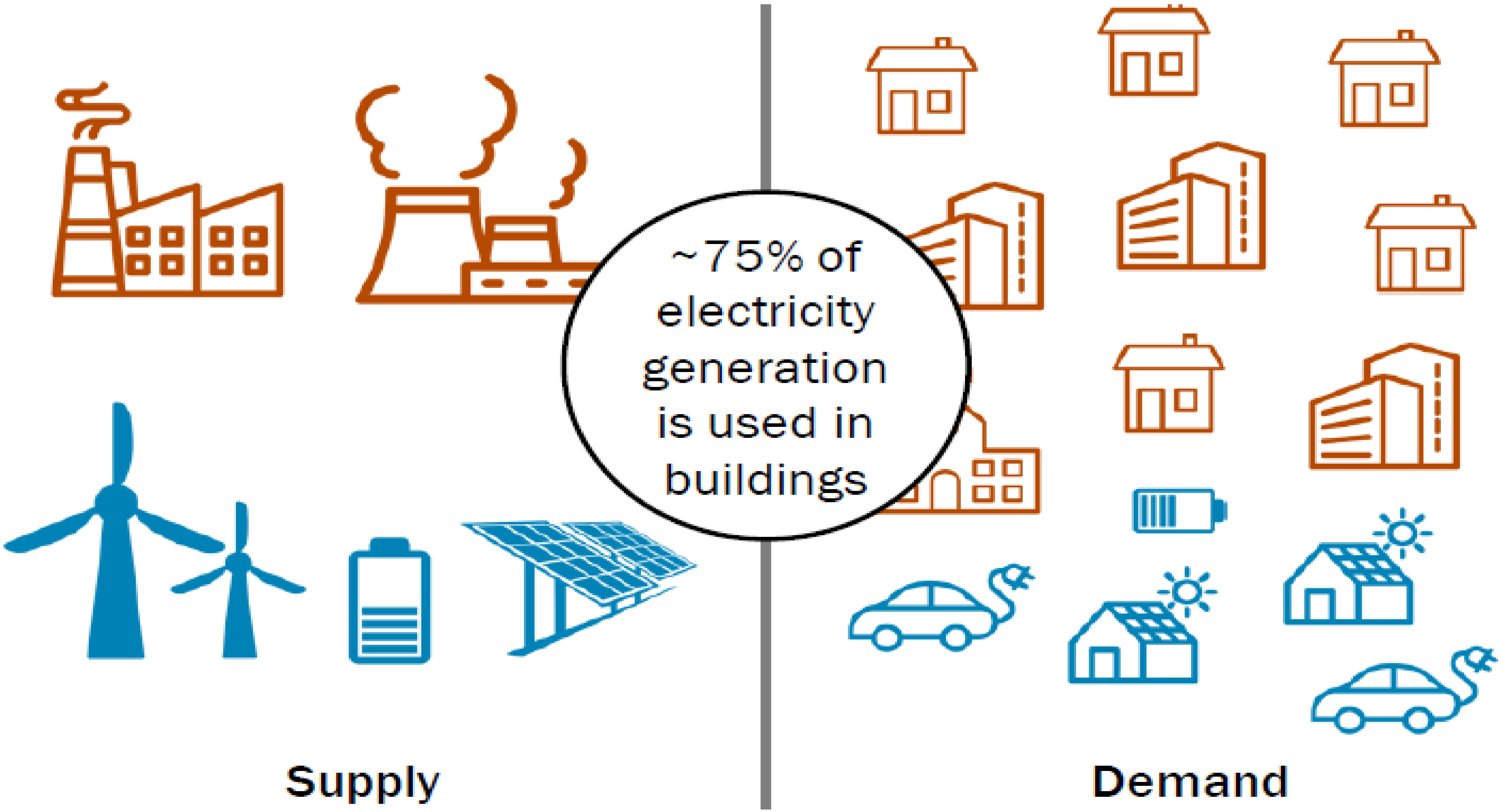
The GEB Technical Report Series outlines key demand flexibility opportunities across BTO's R&D portfolio:
http://energy.gov/eere/buildings/grid-interactive-efficient-buildings

Technical Report Series:

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

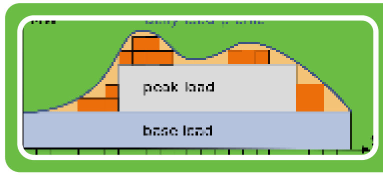


GEB is about enabling buildings to provide flexibility in energy use and grid operation



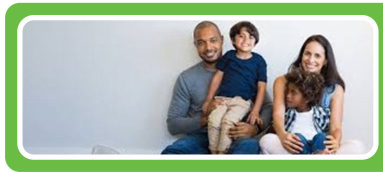
Potential Benefits of Flexible Building Loads

✓ Energy Affordability



✓ Improved reliability & resiliency

✓ Reduced grid congestion



✓ Enhanced services

✓ Environmental benefits

✓ Customer choice

Key Characteristics of GEBs

EFFICIENT

Persistent low energy use minimizes demand on grid resources and infrastructure

CONNECTED

Two-way communication with flexible technologies, the grid, and occupants

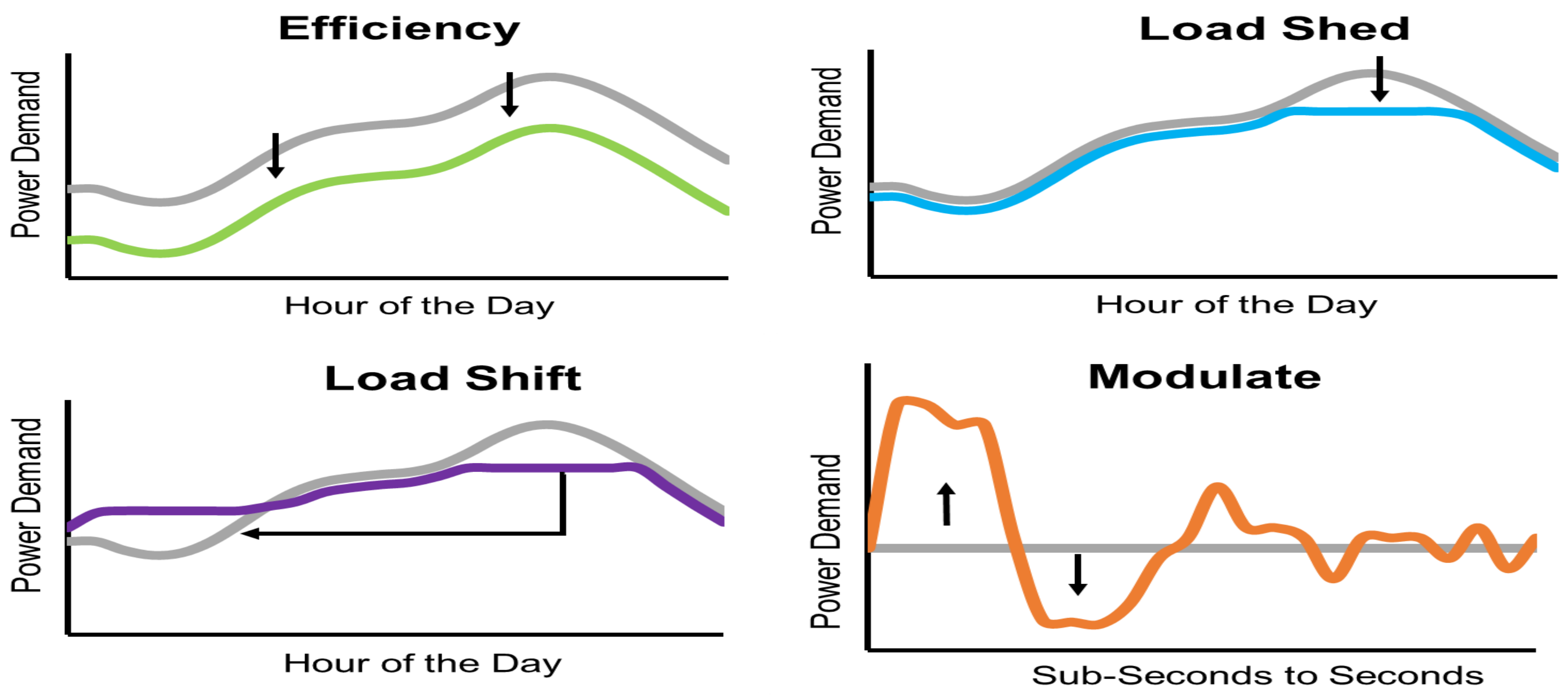
SMART

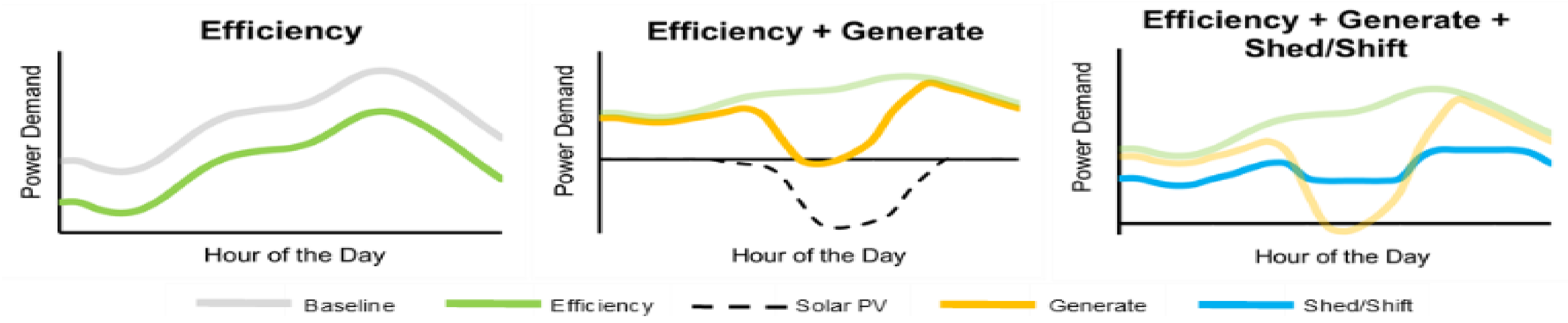
Analytics supported by sensors and controls co-optimize efficiency, flexibility, and occupant preferences

FLEXIBLE

Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use

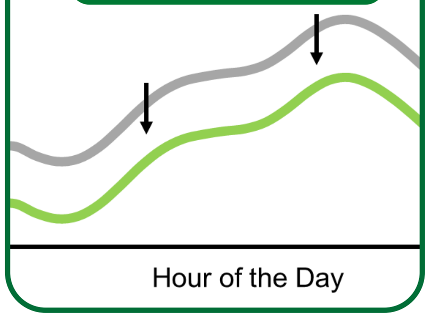
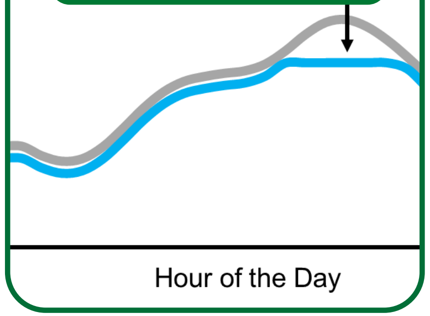
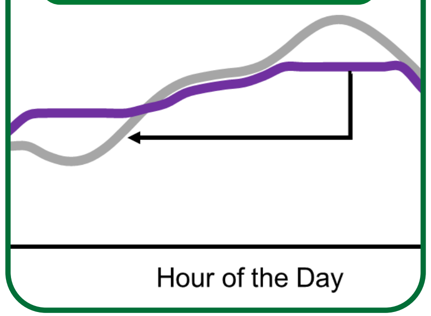
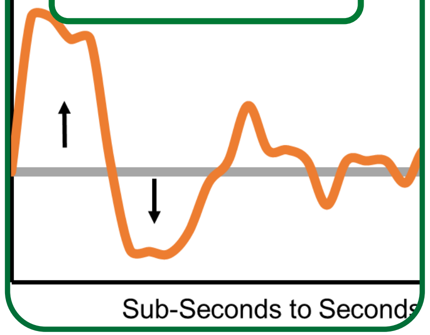
Demand Management Provided by GEB





Mapping Flexibility Modes and Grid Services

Buildings can provide grid services through 4 demand management modes.

Efficiency	Load Shed	Load Shift	Modulate
			

Grid Services Provided

Efficiency	Load Shed	Load Shift	Modulate
• Generation: Energy & Capacity • Non-Wires Solutions	• Contingency Reserves • Generation: Energy & Capacity • Non-Wires Solutions	• Generation: Capacity • Non-Wires Solutions	• Frequency Regulation • Ramping

Examples

Efficiency	Load Shed	Load Shift	Modulate
• Daylighting with sensors & controls	• Reduce plug loads	• Precool with T-stat; preheat water heater	• Rapid dimming of lighting

GEB HVAC, Water Heating, Appliances and Refrigeration Report

Matt Guernsey
Guidehouse

Lead Authors

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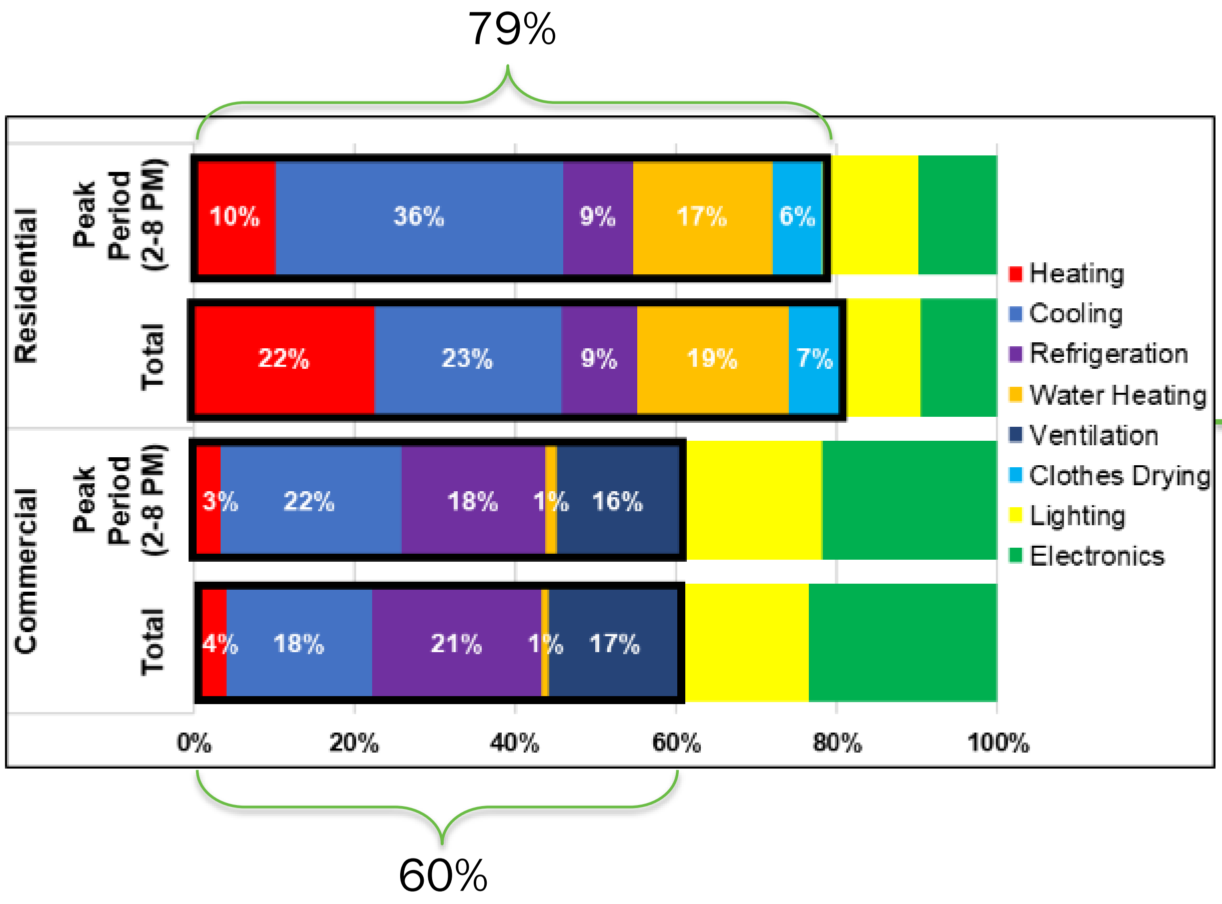
Significant Contributions

Jim Young, Guidehouse
Tim Savidge, Guidehouse

Importance of Water Heating and Appliances for GEB

U.S. 2018 Annual Electricity Use



Residential

- **Water Heating:** 19% of total annual use, slightly more at peak
- **Appliances:** 7% of total use for clothes drying
- **Refrigeration:** 9% of total use

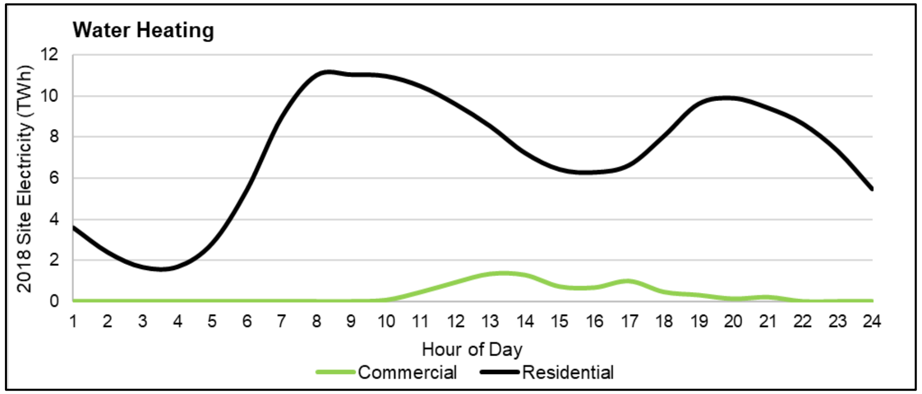
Commercial

- **Water Heating:**~1% of total annual use
- **Refrigeration:** 17% of total annual consumption and concentrated in a few building types

Value of Flexibility

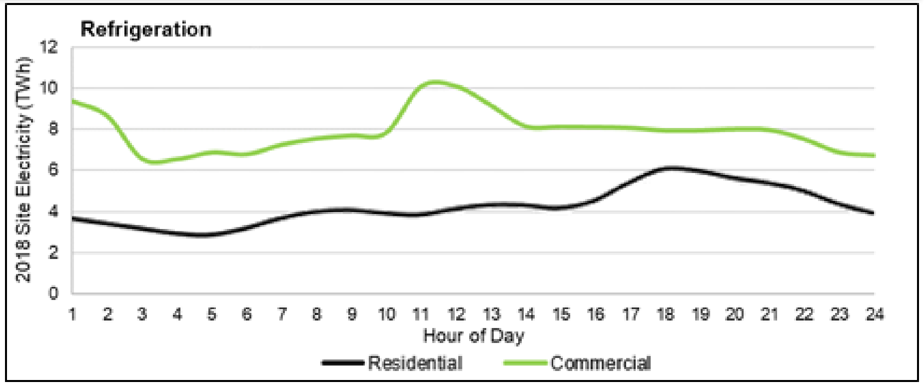
Water heating

- Residential: Two peaks – highest in the morning, but coincident peak in the afternoon nearly as large.
- Commercial: Power intensive load, especially for larger users (e.g., hotel), but few use electricity



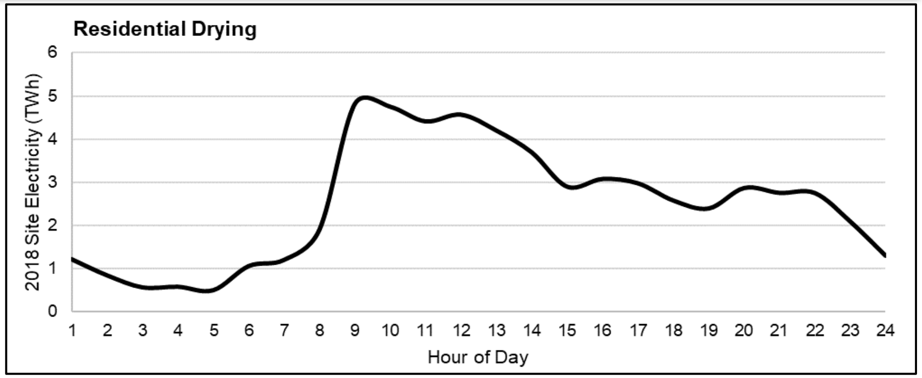
Refrigeration

- Homes – consistent, small load, means large volume needed to make impact
- Commercial – large load, high thermal mass, good load shift candidate



Drying

- Largest electric load in most homes aside from A/C and water heating
- Half the total US load at peak times vs. refrigeration



Broader Implications

- **Water heating and commercial refrigeration present shifting opportunities**
  - Leverage thermal storage to shift load "ahead" with minimal impact or "recovery"
- **Non-critical appliances with low duty cycles like washers, dryers, and dishwashers present a shifting "ahead" or "back" opportunity**
- **Common characteristics**
  - Weather and occupancy <u>in</u>dependent
  - Minimal physical interaction with space conditioning and other end-uses
- **Great flexibility in aggregation level: device, subsystem, end-use, building**
  - Performance vs. integration complexity trade-off

Report Objectives

- What technologies can provide grid services?
- Which have the highest potential?
- What R&D is needed to overcome current challenges inhibiting their performance and/or adoption?

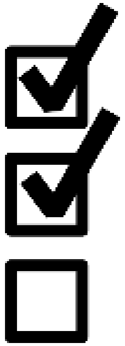
Process

Technology Evaluation

- Potential for shed, shift, and modulate

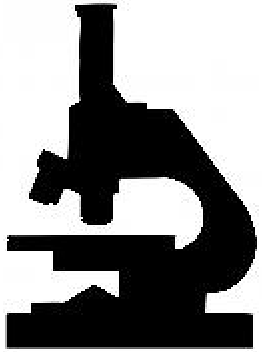
Technology Attributes

- Strengths, weaknesses, hurdles to market success



R&D Opportunities

- Needs and initiatives where DOE can add value



Technology Flexibility Analysis Results

	Water Heating	Appliance, Refrigeration, MELs
High Potential	• WH#1: Water Heaters with Smart, Connected Controls	• APP#1: Modulating, Advanced Clothes Dryers • APP#4: Advanced Controls for Commercial Refrigeration • APP#7: MELs: Water Heating
Medium Potential	• None	• APP#2: Advanced Dishwasher & Clothes Washer Controls • APP#5: MELs: Motors • APP#6: MELs: Water Circulation • APP#8: MELs: HVAC • APP#9: MELs: Refrigeration
Low Potential	• WH#2: Dual-Fuel Water Heater	• APP#3: Connected Refrigerator and Freezer Advanced Controls

Evaluation of Technologies

We used 3 criteria to evaluate the technologies in the context of 4 demand management strategies: Efficiency, Load Shed, Load Shift, Modulate

1. **Capability Rating for demand side management (DSM) strategy**
   – Based on Grid Services Technical Requirements

Capability Ratings							
	Not Applicable		Low Capability		Medium Capability		High Capability

2. **Number of demand-management strategies provided**
3. **Weighting of demand-management strategies**
   – Efficiency and peak reductions (shed/shift) higher value than frequency regulation, voltage support, ramping (modulate)

Water Heating Technologies Evaluated

WH#1: Water Heaters with Smart, Connected Controls

Flexibility	Capability
Efficiency	◑
Shed	◑
Shift	●
Modulate	◐
OVERALL	**HIGH**

Technology

- Integrated or add-on connected, smart controls that enable remote, two-way communication for operator-controlled dispatch and programmable setbacks

Flexibility

- Programmed or dispatched load shifting, including fast-response services

Source: Rheem.com

WH #2: Dual-Fuel Water Heaters

Flexibility	Capability
Efficiency	○
Shed	●
Shift	○
Modulate	○
OVERALL	**LOW**

Technology

- Gas/propane/oil burner + electric resistance or heat pump; highest grid-value systems would use electricity with delivered fuel (oil/propane) as backup

Flexibility

- Provide load shedding by temporarily switching fuels

Source: rheem.com

Appliance and Refrigeration Technologies Evaluated

APP#1: Modulating, Advanced Clothes Dryers

Flexibility	Capability
Efficiency	◐
Shed	◑
Shift	◐
Modulate	●
OVERALL	**HIGH**

Technology:

- Greater precision of heating control enable efficiency and slow or fast-response modulation

Flexibility:

- Load shifting; modulation via control of heat element

APP#2: Advanced Dishwasher & Clothes Washer Controls

Flexibility	Capability
Efficiency	○
Shed	○
Shift	●
Modulate	○
OVERALL	**MED**

Technology:

- Products with delayed start controls; once cycle starts, flexibility is more limited

Flexibility:

- Load shifting via delayed start

APP#3: Refrigerator & Freezer Advanced Controls

Flexibility	Capability
Efficiency	○
Shed	○
Shift	◐
Modulate	○
OVERALL	**LOW**

Technology:

- Potential for pre-cooling or simply recovery after curtailment

Flexibility:

- Load shifting

APP#4: Advanced Controls for Comm. Refrigeration

Flexibility	Capability
Efficiency	◐
Shed	◑
Shift	●
Modulate	○
OVERALL	**HIGH**

Technology:

- Advanced controls enable pre-cooling with minimal change in functionality

Flexibility:

- Load shifting

MELS Technologies Evaluated

#5: Motors

Flexibility	Capability
Efficiency	◐
Shed	◐
Shift	◑
Modulate	◐
OVERALL	**MED**

Examples:

- Fans, pumps, small kitchen appliances, and refrigeration

Flexibility:

- Variable speed modulation

#6: Water Circulation

Flexibility	Capability
Efficiency	◑
Shed	◑
Shift	●
Modulate	◑
OVERALL	**MED**

Examples:

- Pumps for pools, boilers, condensate, hot tubs

Flexibility:

- Variable flow rates

#7: Water Heating

Flexibility	Capability
Efficiency	●
Shed	◑
Shift	●
Modulate	○
OVERALL	**HIGH**

Examples:

- Portable electric spas and pool heaters

Flexibility:

- Load shifting

#8: HVAC

Flexibility	Capability
Efficiency	◑
Shed	◐
Shift	●
Modulate	○
OVERALL	**MED**

Examples:

- Dehumidifiers, ceiling fans, furnace fans, kitchen vent.

Flexibility:

- Load shifting

#9: Refrigeration

Flexibility	Capability
Efficiency	◑
Shed	◐
Shift	◐
Modulate	○
OVERALL	**MED**

Examples:

- Lab fridge & freezer, coolers & cooler-fridge combos

Flexibility:

- Load shifting

Cross Cutting Technologies Evaluated

CC#1. Thermal Energy Storage (TES)

Flexibility	Capability
Efficiency	◐
Shed	◐
Shift	●
Modulate	◐

Technology

- TES may be stand-alone or be embedded within other equipment. Examples:
  - Heating/Cooling: Water/Ice or phase change materials (PCMs) in tanks
  - Gas absorption: Separate storage of the sorbent and refrigerant mid cycle for long-term, no-loss, storage

Flexibility

- Off-peak recharging enables load shifting

https://www.bradfordwhite.com/

CC#2. Modulating Vapor Compression

Flexibility	Capability
Efficiency	●
Shed	◐
Shift	◐
Modulate	◐

Technology

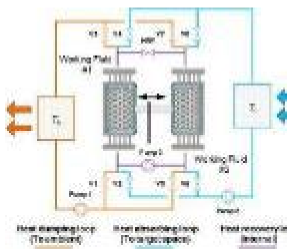
- Modulating allows for more granular control than provided by single-speed systems.

Flexibility

- Modulation increases load-control precision for load shifting and improves efficiency.

https://climate.emerson.com/en-us

CC#3. Non-Vapor Compression (NVC) Systems and Materials



Flexibility	Capability
Efficiency	●
Shed	◐
Shift	●
Modulate	◐

Technology

- Multiple types: may use unique material properties or new architectures. Examples:
  - Solid-state NVC: thermoelectric, magnetocaloric, electrocaloric
  - Other: Membrane, thermoelastic, Stirling, liquid desiccant, thermoacoustic

Flexibility

- Modulating capacity, separate sensible/ latent controls, and energy storage.

https://www.energy.gov/eere/buildings/downloads/non-vapor-compression-hvac-technologies-report

Poll

Based on potential grid flexibility impact and likelihood of adoption, of the evaluated technologies, select the two that you think DOE should prioritize :

- Smart, Connected Water Heaters
- Dual-Fuel Water Heaters
- Smart, Connected Home Appliances and MELs
- Smart, Connected Commercial Refrigeration
- Cross-Cutting Technologies (e.g., Thermal Energy Storage)

Challenges & Opportunities: All Connected Technologies

	Challenge	Opportunity
• All Connected Technologies	• Interoperability	• Standardized semantic and syntactic specifications for connected devices and software systems
	• Cybersecurity	• Secure system architectures and cybersecurity best practices
	• Cost	• New manufacturing processes with low capital cost or use of existing manufacturing equipment
		• New materials and technologies compatible with scalable manufacturing methods

Challenges & Opportunities Cont.

	Challenge	Opportunity
• WH#1: Water Heaters with Smart, Connected Controls	• Lower heat-pump-only preheat capabilities from HPWH vs. elec. resistance	• Evaluate the optimal approach for hybrid electric resistance/heat pump water heaters (HPWHs) for curtailment • Develop low-GWP refrigerant-based (e.g., carbon dioxide [CO2]) HPWHs for higher-temperature capabilities
• APP#7: MELs: Water Heating • APP#2: Dish & Clothes Washers • APP#3: Fridges • APP#4: Comm. Refrigeration	• Lack of nonpremium products with grid-interactive functionality	• Develop inexpensive retrofit grid-interactive packages
• APP#1: Modulating, Advanced Clothes Dryers	• High product cost (heat pump models)	• Conduct cost-reduction R&D for heat pump clothes dryers

Challenges and Needs – Controls, Sensing, Modeling Report

- **End-use prioritization**
  - Develop methods of establishing priorities and valuations of different end-uses
- **Control coordination and resource allocation**
  - Develop frameworks for distributed resource allocation
  - Integrate HVAC, generation, and electrical storage into these frameworks
- **Multiple grid services**
  - Determine degree of interaction between shedding and shifting, energy neutral modulation, and non-energy neutral modulation in devices that can provide more than one of these services
  - Determine viability of providing both fast and slow services from one control domain

Poll

Select the 2 highest priority areas to improve the flexibility potential provided building appliances and equipment.

- Advanced controls, connectivity, and communications
- Interoperability and cybersecurity
- Occupant behavior and ensuring utility for customers
- Improved individual equipment flexibility
- Development of flexibility-specific equipment (e.g., energy storage)

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Flexibility Metrics for Water Heating, Appliances, & Refrigeration

Nelson James
Building Technologies Office

Water Heater Efficiency Metrics

A variety of metrics have been traditionally used to quantify the performance of residential and commercial water heaters. These can allow for the direct comparison of systems with one another.

Metric	Description
UEF	Uniform Energy Factor: Measure of water heater overall efficiency. The higher the UEF value is, the more efficient the water heater.
FHR	First Hour Rating: An estimate of the maximum volume of hot water in gallons that a storage water heater can supply within an hour that begins with the water heater fully heated.
SL	Standby Losses: The average hourly energy, expressed in Btu per hour, required to maintain the stored water temperature based on a 70°F temperature differential between stored water and ambient room temperature.
COP	Coefficient of Performance: The dimensionless ratio of the rate of useful heat transfer gained by the water, expressed in Btu/h, to the rate of electrical power consumed during full input rate operation, expressed in Btu/h.
TE	Thermal Efficiency: The ratio of the heat energy (Btu/hr) transferred to the water flowing through the water heater to the amount of energy (Btu/hr) consumed by the water heater during full-firing rate, steady-state operation.

Appliance Efficiency Metrics

Similarly metrics have been developed to quantify and compare the energy performance of various appliances.

Metric	Description
CEF (Dryers)	Combined Energy Factor is the quotient of the test load size, 8.45 lbs for standard dryers and 3 lbs for compact dryers divided by the sum of the machine electric energy use during standby and operational cycles
IMEF (Washer)	Integrated Modified Energy Factor is the quotient of the capacity of the clothes container divided by the total clothes washer energy consumption per cycle
EF (Dishwasher)	Energy Factor is expressed in cycles per kWh; so the greater the EF, the more efficient the dishwasher is. EF is the reciprocal of the sum of the machine electrical energy per cycle plus the water heating energy consumption per cycle.
IEF (Dehumidifier)	Integrated Energy Factor is measure of energy efficiency of a dehumidifier that expresses the amount of water the dehumidifier can remove with a given energy input under test conditions

Potential Equipment Flexibility Metrics

- The ability of water heaters, appliances, and refrigerators to provide flexibility depends simultaneously on equipment capabilities and occupant behavior
- In a similar manner to efficiency, metrics are needed to compare the ability of various systems to provide grid flexibility.

Appliances

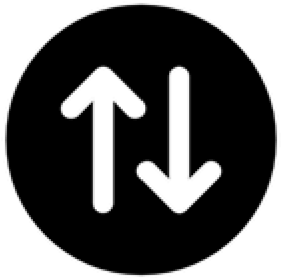
- Load Change During Event
- Load Shift Capacity
- Reliability of Response

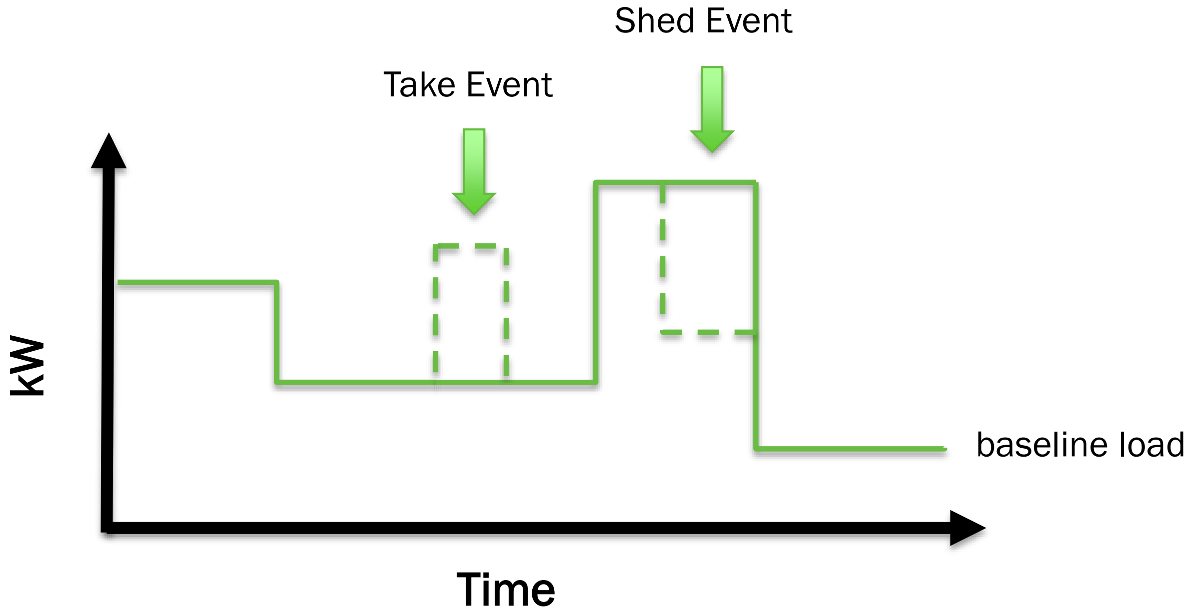
- Resolution of Control
- Load Shift Efficiency
- Lifetime Impacts

Water Heating and Refrigeration

Load Change During Event

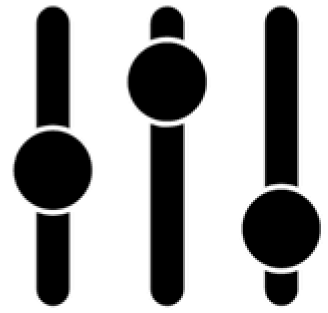
- **Equipment can be required to increase load when for example renewable energy is abundant and reduce load when the grid is constrained**
- **Quantification of how much the load can change in response to a signal.**
  - Percentage change of rated load [%]
  - Load increase or decrease [kW]

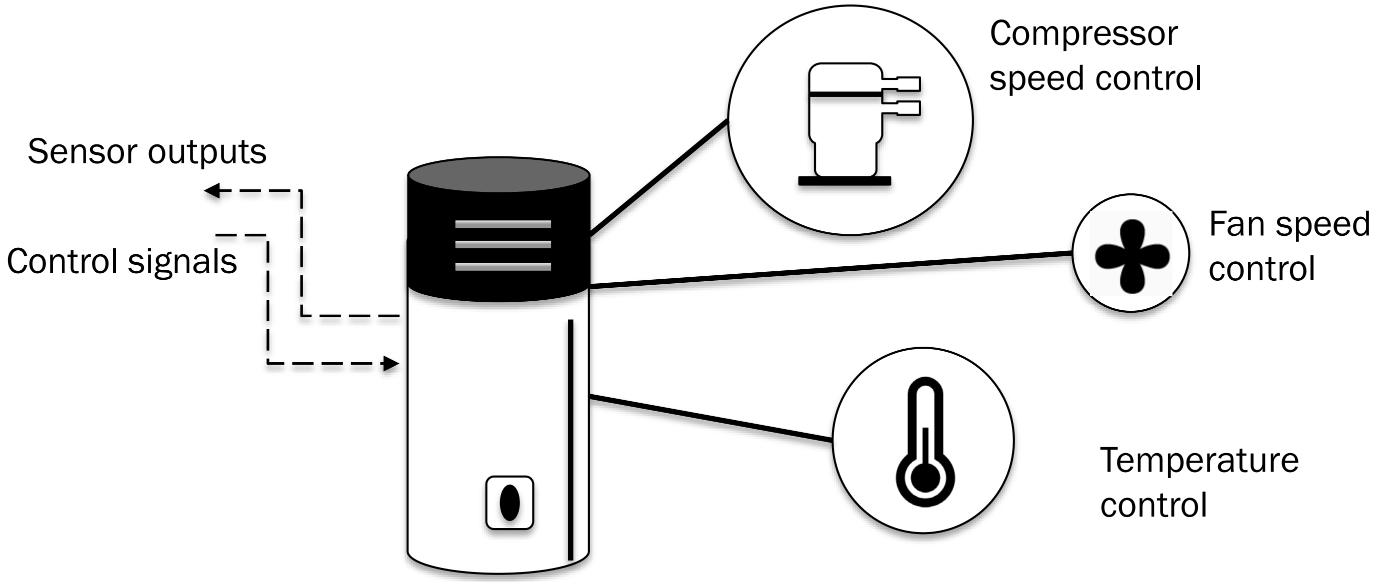




Resolution of Control

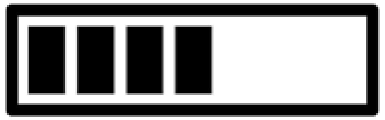
- **Control interfaces are needed for communication with automation systems and grid signals**
- **Additionally being able to operate at multiple power draws could increase options for flexibility**
  - Number of modes of control [-]

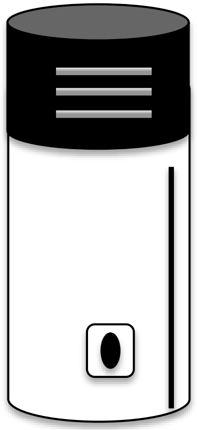




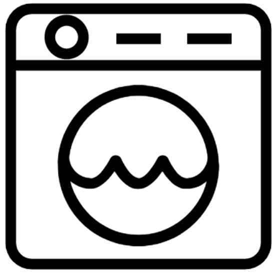
Load Shift Capability

- Measure of how much energy can be stored for shifting energy usage from the grid
- Dependent on thermal mass of equipment and energy usage characteristics
- Includes not only quantity of energy, but how quickly that energy can be utilized
  - – Load Shift Capacity [kWh]
  - – Load Shift Power [kW]

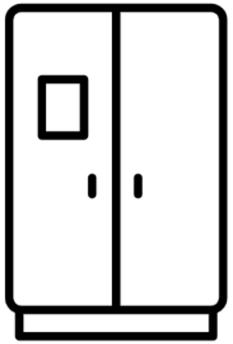




Tank size and Temperature Setpoint



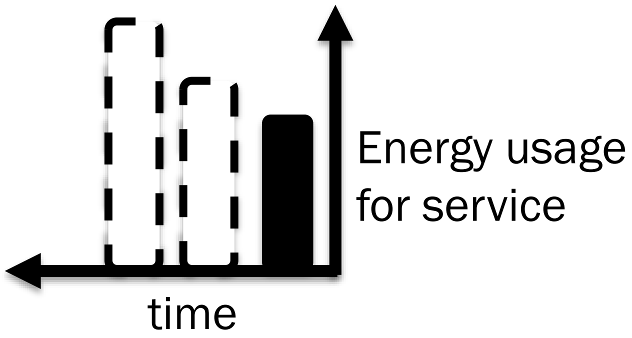
Appliance Performance and Usage Patterns

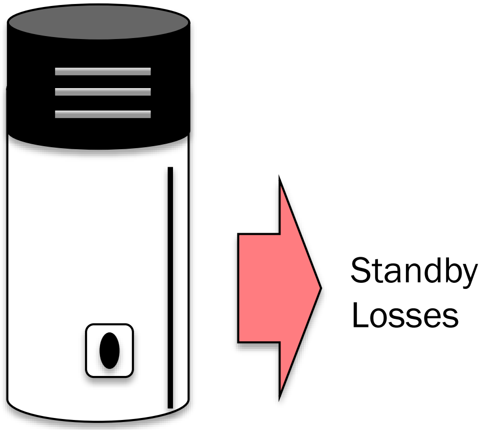


Refrigerator content and Temperature Setpoint

Load Shift Efficiency

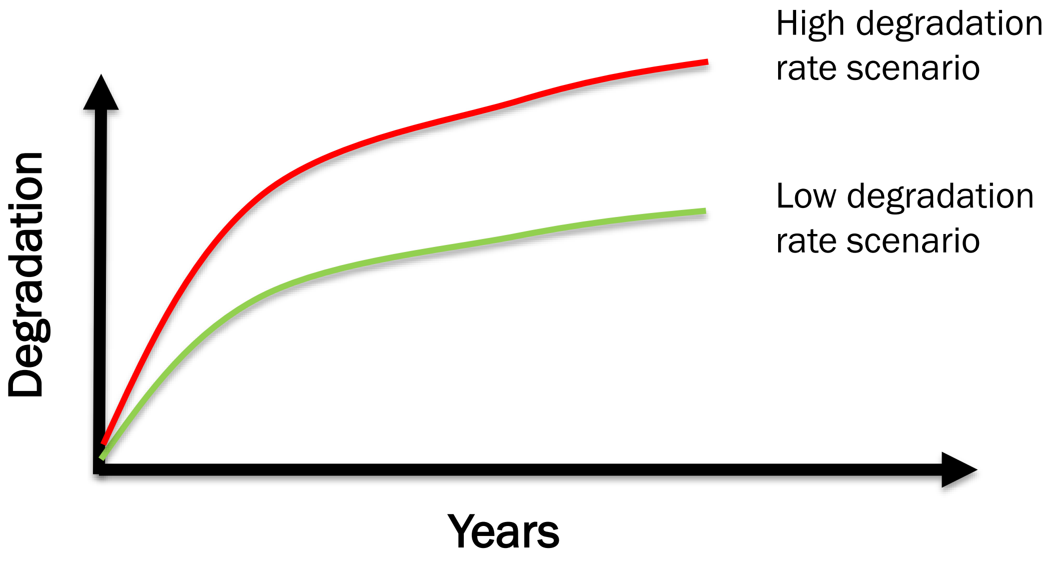
- **If energy is stored for shifting, inefficiencies of the storage and extraction process can lead to increase energy consumption**
- **Potential losses include heat gain or loss from the storage medium and thermal resistances between the storage medium and the equipment**
  – Storage efficiency [%]
  – Energy usage increase [kWh]





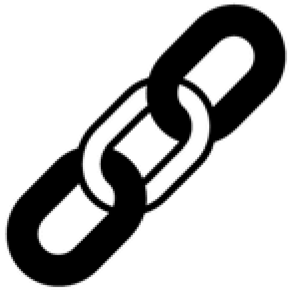
Lifetime Impacts

- **Extent to which providing services could impact equipment life from cycling, or running in non-standard operation**
  - Maintenance cost [$]
  - Maintenance intervals [hrs]
  - System life [yrs]



Reliability of Response

- Depending on the severity of the impact on occupant services from a flexibility measure, the rate at which customers opt out of programs could vary
- Building characteristics and occupant behavior can influence the reliability at which a desired flexibility response is provided
  - Percentage of Opt-Outs [%]



Poll

- **Six metrics were presented:**

Appliances + Water Heaters + Refrigeration

1. Load Change During Event
2. Load Shift Capacity
3. Reliability of Response

Water Heaters + Refrigeration

4. Resolution of Control
5. Load Shift Efficiency
6. Lifetime Impacts

Do you have recommendations for additional metrics, or changes to the current metrics?

Quantifying Flexibility Opportunity of Water Heaters, Appliances, and Refrigeration

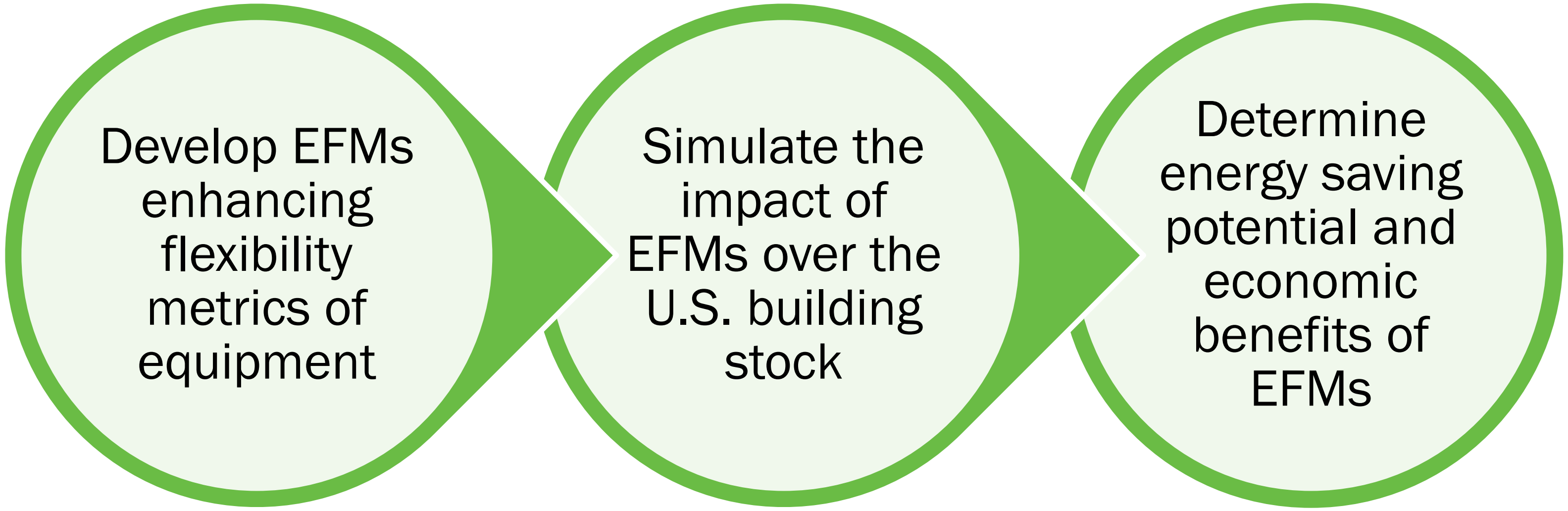
Nelson James
Building Technologies Office

Researchers

Jared Langevin, Lawrence Berkeley National Laboratory
Handi Putra, Lawrence Berkeley National Laboratory
Elaina Present, National Renewable Energy Laboratory
Andrew Speake, National Renewable Energy Laboratory
Chioke Harris, National Renewable Energy Laboratory
Rajendra Adhikari, National Renewable Energy Laboratory
Eric Wilson, National Renewable Energy Laboratory

Quantifying Flexibility Opportunity

- **A consistent framework is needed to assess the impact of energy flexibility measures (EFMs) on the ability of residential and commercial buildings to provide load flexibility**
- **Using this framework, energy savings and cost targets can be associated with respective flexibility enhancements**



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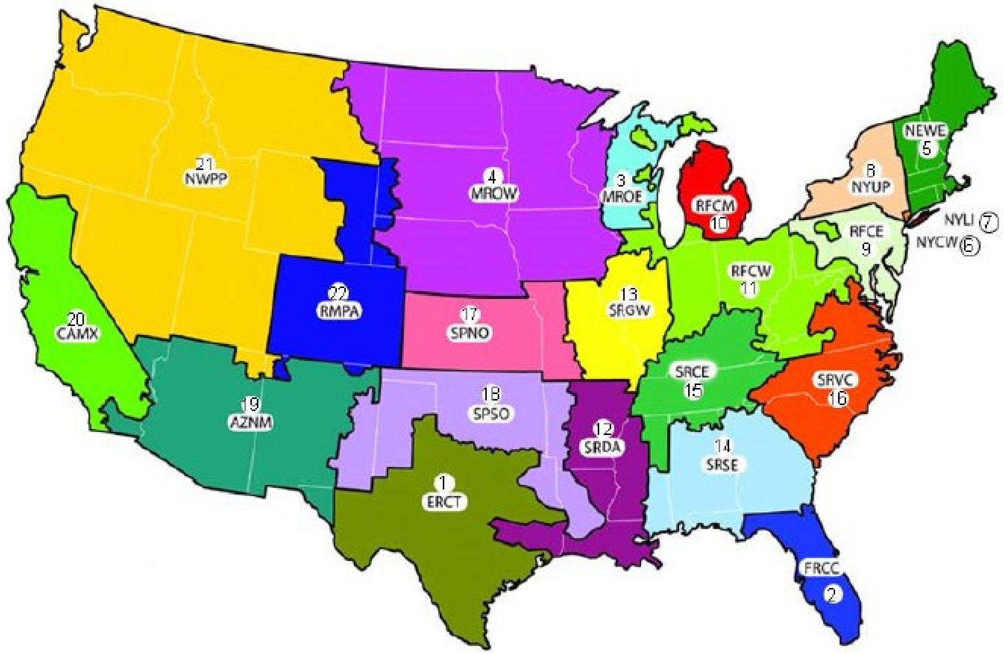
DOE Tools and Resources

eia	EIA provides a wide range of information and data products covering energy production, stocks, demand, imports, exports, and prices. The Electricity Market Module represents the capacity planning, generation, transmission, and pricing of electricity, subject to various factors including electricity load shapes and demand.
ResStock	A high level of granularity used to represent the diversity of housing stock characteristics and climates across the contiguous United States. The ResStock framework brings together the use of large public and private data sets, statistical sampling, detailed sub-hourly building energy simulations, and high-performance computing resources.
OpenStudio	OpenStudio® is a cross-platform collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance. OpenStudio is an open source (LGPL) project to facilitate community development, extension, and private sector adoption.
scout U.S. DEPARTMENT OF ENERGY	Scout is a tool for estimating the energy and carbon impacts of various energy conservation measures (ECMs) on the U.S. residential and commercial building sectors

Proposed Analysis Process

- **Establish baseline grid load shapes**
  - For each of 22 EIA Electric Market Module (EMM) regions, determine how electricity demand varies over the year



U.S. EIA EMM regions

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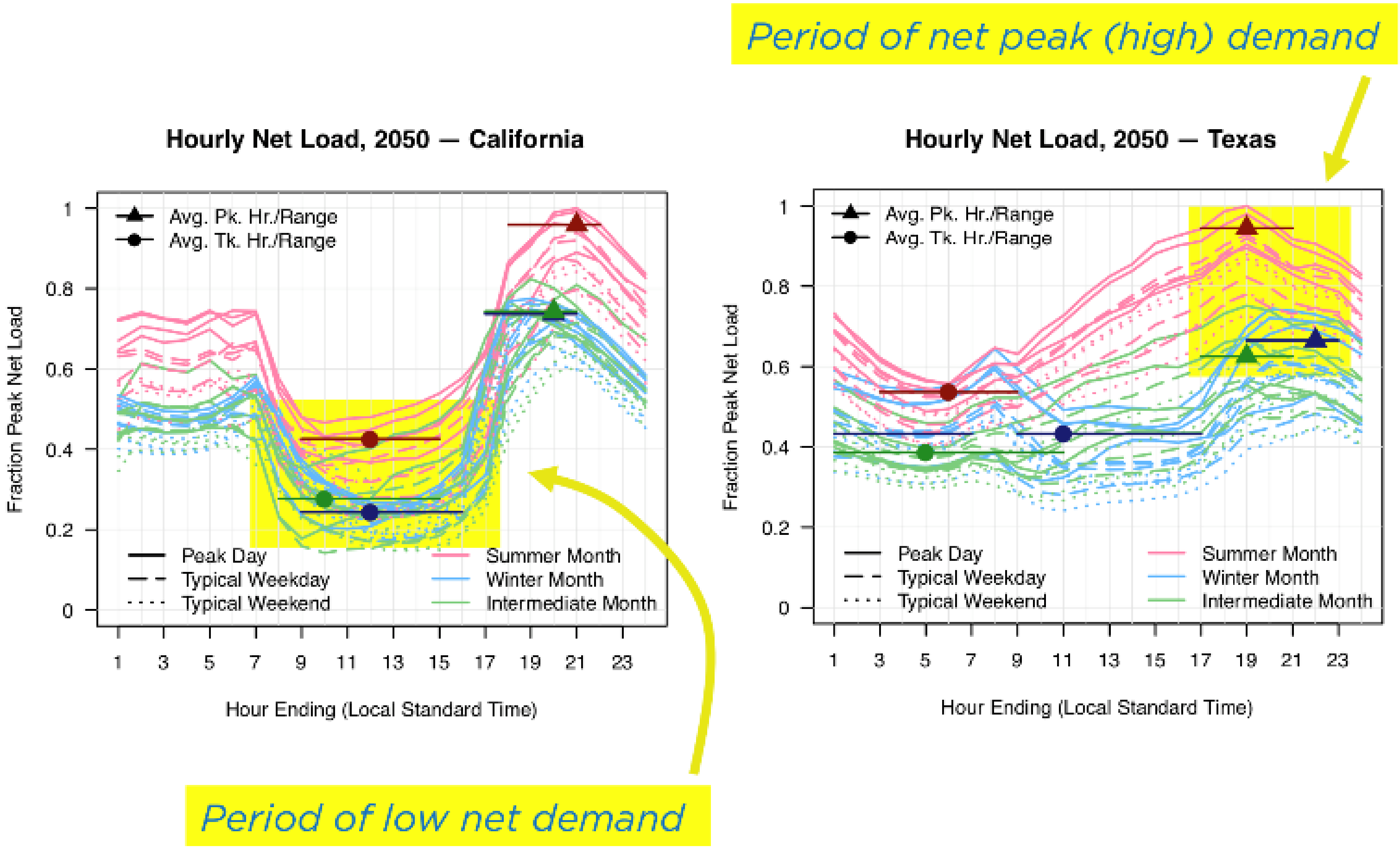
Proposed Analysis Process

- **Define windows for peak demand and low demand periods**

  - Based on seasonal load shapes, define windows of time where it could be beneficial to increase or decrease load
  - Peak demand windows currently set at 4 hours
  - Low demand windows based on when load is below a threshold percentage of the peak



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Proposed Analysis Process

- **Specify flexibility measures**
  – How equipment will response to provide flexibility during the peak demand and low demand periods

Measure	Description
Grid-responsive water heater	Increase temperature setpoint at beginning of take period, decrease setpoint at beginning of peak period.
Grid-responsive washer/dryer	Shift washer/dryer cycles to off-peak hours
Grid-responsive refrigerator	Decrease temperature setpoint at beginning of take period, return setpoint to normal at beginning of peak period.

⋮

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Proposed Analysis Process

- **Simulate measures across climate zones**
  - Using ResStock and commercial prototype building models, determine 8760 end-use building loads
  - Implement the flexibility measures in EnergyPlus to determine demand impacts while maintaining comfort constraints
  - Utilize peak demand and low demand definitions for respective EMM region
  - Determine EFM savings fraction relative to baseline

ResStock

EnergyPlus

OpenStudio

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Proposed Analysis Process

- **National assessment using scout**
  - Use Scout to assess the regional and national impacts of EFMs across future years
    - Energy savings
    - CO_2 savings
    - Cost Savings
    - EFM price premiums

scout
U.S. DEPARTMENT OF ENERGY

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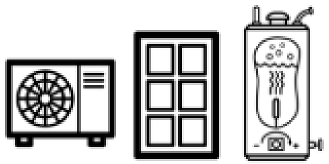
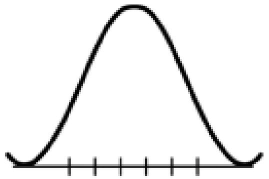
Proposed Analysis Process

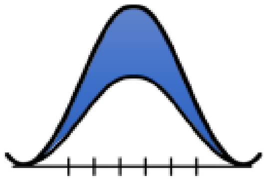
1. Define energy efficiency (EE), demand flexibility (DF), and EE + DF measure portfolios



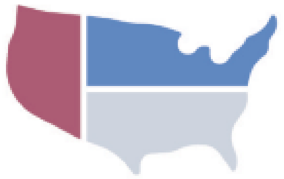
2. Develop 8760 hourly fractions of annual baseline load by climate, building type, and end use



3. Develop bottom-up EnergyPlus measure simulations and 8760 savings fractions based on regional system needs



4. Translate measures to Scout and assess regional/national portfolio potential, annually and sub-annually (2015-2050)



Analysis Inputs

- EMM load shapes
- Cambium hourly electricity pricing
- Cambium hourly CO_2 emission rates
- Energy flexibility measures

Building Simulations

- Generate baselines for commercial and residential buildings
- Simulate impacts of EFMs
- Generate EFMs saving fractions relative to baselines

Analysis Outputs

- Develop national and regional impacts with Scout
  - Energy savings
  - CO_2 savings
  - Cost savings
  - EFM price premiums

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Poll

Does the analysis framework presented create a reasonable path to quantifying and comparing the capabilities of Water Heaters, Appliances, and Refrigerators to provide grid flexibility?

- Yes, the approach should be adequate to quantify the flexibility potential of the equipment
- Almost, additional inputs are required in the analysis
- Almost, improvements are needed in EFM simulation approach
- Almost, relevant outputs are missing from the analysis
- No, analysis framework needs to be significantly altered

Q&A

Use the question feature to ask a question or provide a comment.

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