Grid-interactive Efficient Buildings: Expanding Value Streams through Optimised Control of Flexible Building Technologies

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Agenda

- Introducing Grid-Interactive Efficient Buildings (GEBs)
- Types of Flexibility & Grid Services
- Analysis: ECM Overview & SCOUT
- Results: Technical Potential by Flexibility Type
- Conclusion & Next Steps

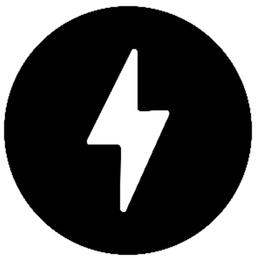
Research Question

» How can energy efficient technologies and buildings be enabled to offer flexibility services that bring value to grid service markets, and therefore to building owners and occupants?

U.S. Building Energy and Electricity Consumption

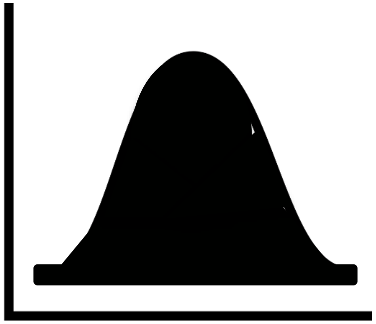
39%

of U.S. energy use



75%

of U.S. electricity use



80%

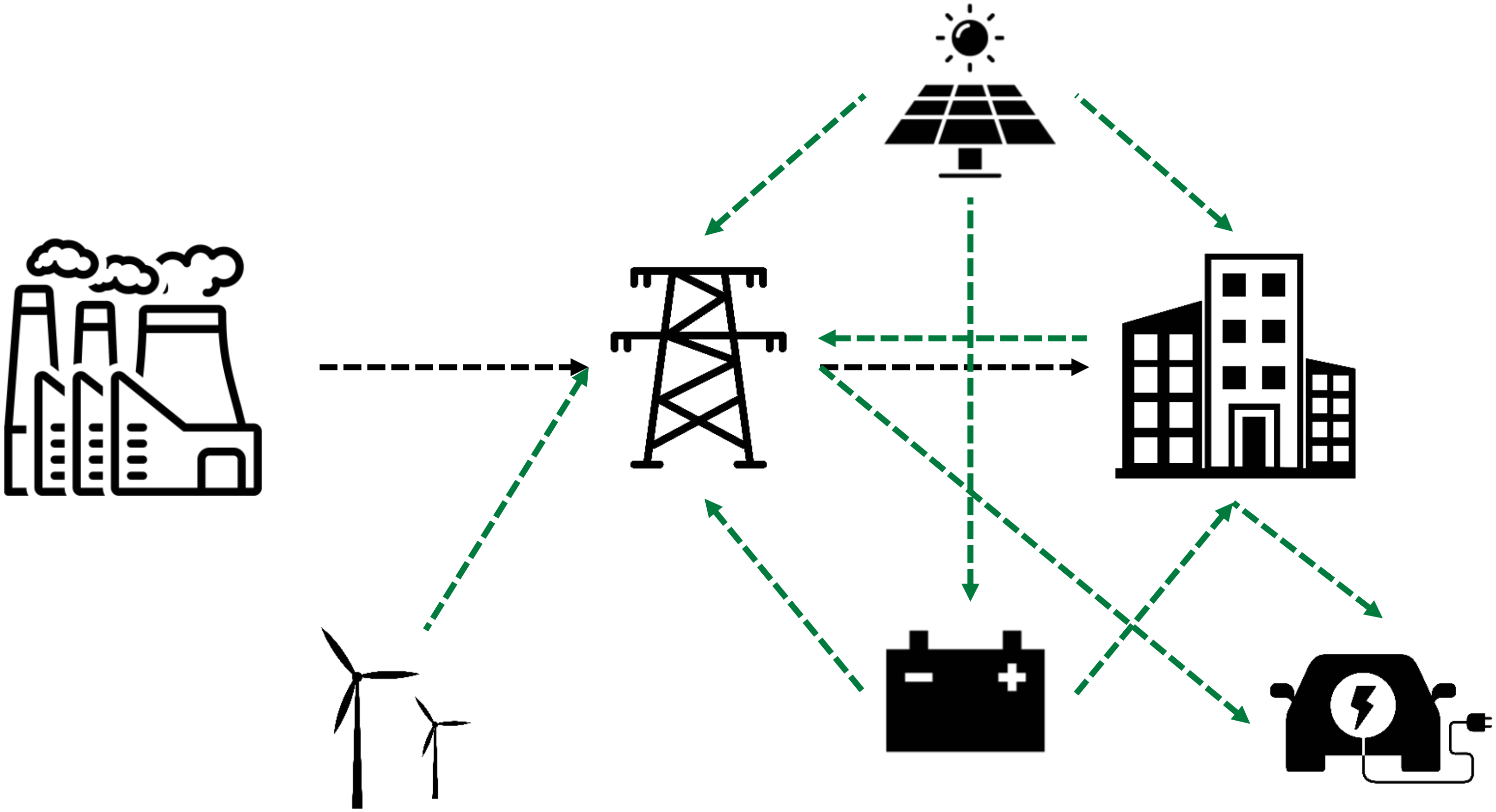
of electricity peak demand

$380B

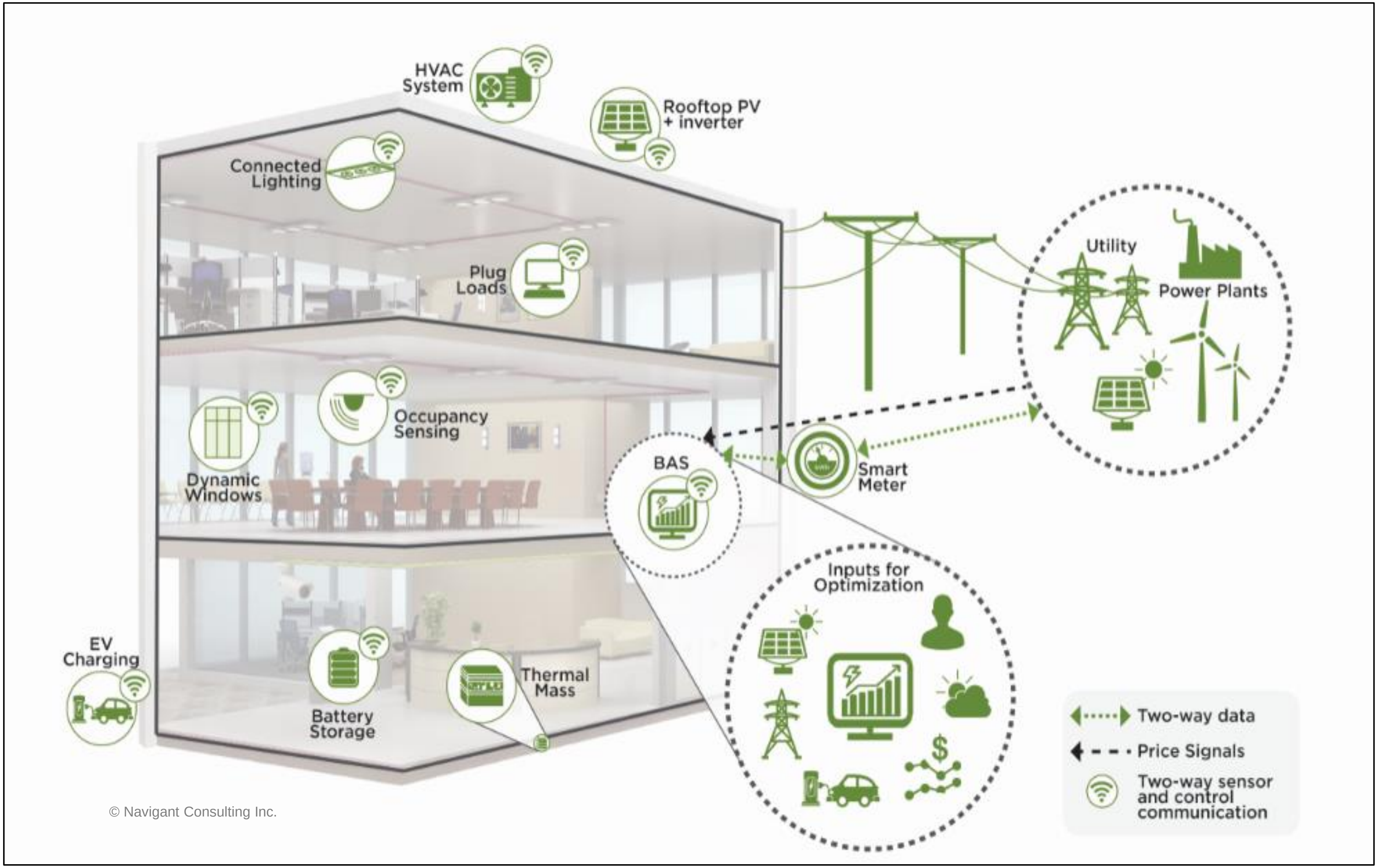
U.S. energy bill for buildings

Sources: US EIA, (Monthly Energy Review, Annual Energy Outlook 2017, Electric Power Monthly)

Moving Towards the Grid of the Future



Grid-interactive Efficient Building (GEB)



Key Characteristics of GEB

EFFICIENT

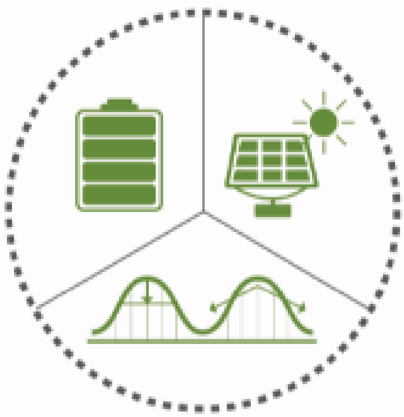
Persistent low energy use minimizes demand on grid resources and infrastructure

SMART

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

CONNECTED

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



FLEXIBLE

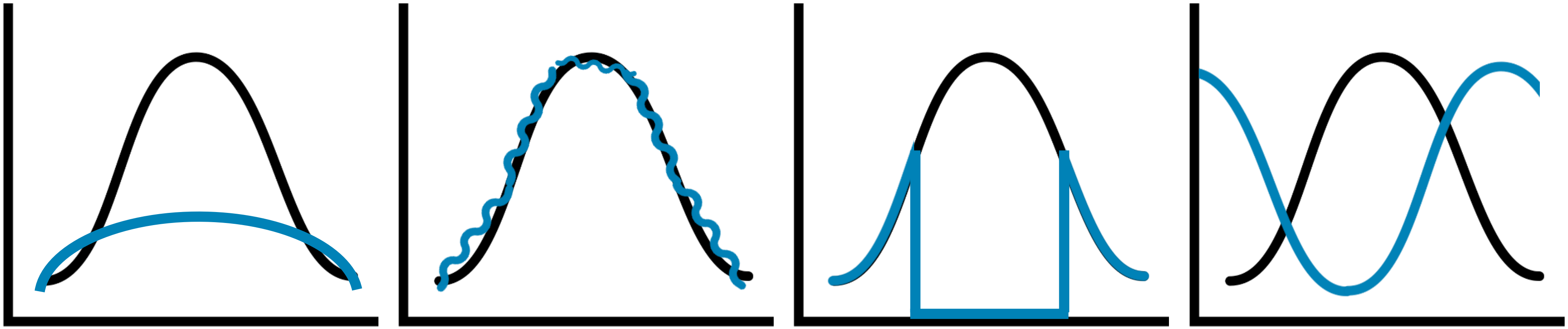
Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use

Flexibility & Grid Services

Flexibility Type	Load Change	Response Time	Example Technologies	Primary Grid Services
Flexible Efficiency	Adjustable efficiency performance allowing technologies to improve efficiency when electricity LMP is high (within occupant preferences).	~30 minutes	Dynamic facades, Smart / “eco- mode” appliances, Dimmable LEDs	Operating Reserves, Capacity Market Cost Reduction
Flexible Regulation	Adjustable power flow in response to 4-second grid signals to balance supply and demand.	~4 seconds	Electronically commutated motors (ECMs), variable frequency drives (VFDs), electrochemical storage, solar inverters	Frequency regulation, Voltage control
Flexible Power Source	Backup power supply for avoiding electricity when costs are high.	~10-30 minutes	Dual-fuel heat pumps, micro- combined heat and power (mCHP)	Operating Reserves, Capacity Market Cost Reduction
Flexible Power Timing	Capacity to pre-charge via energy storage or delay-start via appliances to coordinate power timing when controls suggest electricity is cheap.	~4 hours	Thermal storage, electrochemical storage, delay-start appliances	Operating Reserves, Capacity Market Cost Reduction

Flexibility Type Impacts Resultant Load

Theoretical impact on load shape:



Flexible Efficiency

Flexible Regulation

Flexible Power Source

Flexible Power Timing

Analysis Research Question

- How can energy efficient technologies and buildings be enabled to offer flexibility services that bring value to grid service markets, and therefore to building owners and occupants?
  - How can we quantifiably evaluate the technical potential of technologies to provide these services?
  - How should this information guide BTO's research?

Tool for ECM Analysis

U.S. DOE's Scout Tool assess the technical potential of energy conservation measures (ECMs) and estimates their energy, cost, and carbon impacts.

Applies ECMs across U.S. building stock to inform BTO research and development investment strategies.

Premise for Analysis

Immediate adoption of a **highly efficient, variable-speed electric cooling technology** across residential and commercial buildings in the US.

Building Stock Type	Typical Installed Electric Cooling System Performance	Applied Instantaneous Adoption of Electric Cooling System Performance*
Residential Buildings (SEER)	SEER 10 – 13	SEER 18
Commercial Buildings (EER)	11.2 – 11.6 EER	13 EER
Commercial Buildings (COP)	1.2 – 1.6 full-load COP	4.1-11.5 part-load COP (depending on best available by type)

***Technology chosen for broad applicability across the various analysis scenarios, not because it is necessarily the best technical solution.**

- Results: 31% cooling energy savings in residential buildings, 22% in commercial buildings
- Impact:
  - 240 TWh (0.86 XJ) in annual energy savings
  - 38 MtCO2 reduced each year
  - $10.8 B (€9.6 B) in energy cost reduction (using median time-of-use rates)

No flexibility, controls, interoperability, cybersecurity needed for these results

Apply Flexibility Strategies *On Top* of Efficiency

Efficiency first!

Then, model impact of flexibility strategies through assumed integration of intelligent controls and other features as needed.

Flexibility Strategy	Enabling Technologies
Flexible Efficiency	PID controls, interoperable grid communication
Flexible Regulation	PID controls, interoperable grid communication, quick reaction time
Flexible Power Source	PID controls, interoperable grid communication, dual-fuel power infrastructure
Flexible Power Timing	Model-predictive controls, interoperable grid communication, thermal or electrochemical energy storage

Modeled Implementation

- Applied each flexibility strategy individually on top of efficient cooling to assess additional potential impacts of each strategy
- Applied each flexibility from 14:00 to 20:00 between May and September, a proxy for when locational marginal price (LMP) is high & cooling demand is high

Results Overview

Savings Measure / Flexibility Strategy	Technologies Required	Estimated Energy Savings (May-Sept.)	Estimated Cost Savings (May- Sept. TOU rates)	Estimated Emissions Savings (marginal emissions)
Improved Cooling Efficiency Performance	SEER 18 (res.); EER 13 (sm. comm.); part-load COP 4.5 - 11.1 (lg. comm.)	240 TWh	€9.6 B ($10.8 B)	38 MtCO2
Flexible Efficiency	PID controls or model-predictive controls & grid interoperability	+ 48 TWh	+ €2.3 B ($2.6 B)	+ 7 MtCO2
Flexible Regulation	PID controls & grid interoperability	+ 0 TWh	+ ~€0.3 B ($0.3 B)	+ 0 MtCO2
Flexible Power Source	Rule-based or model-predictive controls, grid interoperability, dual fuel capability	+ 172 TWh	+ €10.1 B ($11.4 B)	+ 24 MtCO2
Flexible Timing	Model-predictive controls, grid interoperability, battery storage	+ 0 TWh	+ €5.5 B ($6.2 B)	+ (-8 MtCO2)

Table 3. Seasonal energy, cost, and emissions savings estimates for efficiency and flexibility measures. Each of the flexibility strategies are in addition to the first savings measure, “Improved Cooling Efficiency Performance.”

Technical Potential: Flexible Efficiency

Savings Measure / Flexibility Strategy	Technologies Required	Estimated Energy Savings (May-Sept.)	Estimated Cost Savings (May- Sept. TOU rates)	Estimated Emissions Savings (marginal emissions)
Flexible Efficiency	PID controls or model-predictive controls & grid interoperability	+ 48 TWh	+ €2.3 B ($2.6 B)	+ 7 $MtCO_2$
Total Impact Efficiency + Flexible Efficiency		288 TWh	€11.9 B ($13.4 B)	45 $MtCO_2$

The Good

» Relatively low barriers to deployment

The Bad

» Can negatively impact occupant comfort

The Ugly

» Not as reliable from a grid services perspective; compromises value

The Future

» Building autonomously opts-in, reducing needs for behavior change

Technical Potential: Flexible Regulation

Savings Measure / Flexibility Strategy	Technologies Required	Estimated Energy Savings (May-Sept.)	Estimated Cost Savings (May- Sept. TOU rates)	Estimated Emissions Savings (marginal emissions)
Flexible Regulation	PID controls & grid interoperability	+ 0 TWh	+ ~€0.3 B ($0.3 B)	+ 0 MtCO2
Total Impact Efficiency + Flexible Regulation		240 TWh	€9.9 B ($11.1 B)	38 MtCO2

The Good

» Essentially no impact on occupants, yet derives value

The Bad

» Current market size is small, does not reduce energy use

The Ugly

» Risk of reduced lifetime of technology being used (e.g., motors)

The Future

» VRE deployment & other technology will increase market size

Technical Potential: Flexible Power Sourcing

Savings Measure / Flexibility Strategy	Technologies Required	Estimated Energy Savings (May-Sept.)	Estimated Cost Savings (May- Sept. TOU rates)	Estimated Emissions Savings (marginal emissions)
Flexible Power Source	PID or model-predictive controls, grid interoperability, dual fuel capability	+ 172 TWh	+ €10.1B ($11.4B)	+ 24 MtCO2
Total Impact Efficiency + Flexible Power Source		412 TWh	€19.7 B ($22.5 B)	62 MtCO2

The Good

» Largest emission, cost, and energy savings of all strategies

The Bad

» Reductions dependent on specific grid mix and fuel cost

The Ugly

» Not responsive to changing trends in VRE deployment

The Future

» Leverage existing infrastructure to minimize impacts today & tomorrow

Technical Potential: Flexible Power Timing

Savings Measure / Flexibility Strategy	Technologies Required	Estimated Energy Savings (May-Sept.)	Estimated Cost Savings (May- Sept. TOU rates)	Estimated Emissions Savings (marginal emissions)
Flexible Timing	Model-predictive controls, grid interoperability, battery storage	+ 0 TWh	+ €5.5 B ($6.2 B)	+ (-8 $MtCO_2$)
Total Impact Efficiency + Flexible Timing		240 TWh	€15.1 B ($17.0 B)	26 $MtCO_2$

The Good

» Largely autonomous, big market for small occupant impacts

The Bad

» Does not reduce energy use, significant technology needs

The Ugly

» With current grid mix, this could increase emissions

The Future

» Appropriate deployment will enable VRE growth

Key Conclusions & Next Steps

- **Flexibility in building technologies already have potential to save energy, dollars, and emissions**
  - This potential is expected to grow over time
- **If deployed poorly, flexibility strategies do not always achieve benefits**
  - Some U.S. grid regions may be ready for storage and electrification, but not all yet
- **Research on cyber-secure control strategies, interoperable systems, and transactional protocols is vital across all flexibility strategies**

Thank you!

Questions?

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Appendix A: Types of Controls

- **Rule-based & On/Off Control**
  - Simple if-then control logic, common in residential HVAC
- **Proportional-Integral-Differential (PID) Feedback Control**
  - Uses continuous measurement of the output that is trying to be controlled (e.g.: temperature) to continuously tune the appropriate position for an actuator (e.g.: ventilation damper)
  - Common control system used with building automation systems
- **Model Predictive Control (MPC)**
  - Emerging methodology using a physical or empirical model of the building to predict how it will respond to changes made to a given system
  - Critical for use in capacity markets and furthering impact of demand response and grid services in buildings

Type of control is specified for each flexibility analysis.

Appendix B: Types of Ancillary Grid Services

Grid Service	Load Change	Response Time	Avoided Cost
Frequency Regulation (Up, Down, and Combined)	Modulate power demand in response to 4-second signals from the grid operator to balance electricity supply and demand. Maintain grid frequency at 60 Hz.	~4 seconds	Power plant fuel, operation, maintenance, and opportunity costs associated with providing frequency regulation (e.g., not selling power in order to be ready for up-regulation).
Distribution Voltage Support/Solar Integration	Modulates rate of active and/or reactive power draw to control distribution system voltage.	~4 seconds	Avoided costs for distribution voltage control equipment (e.g. capacitor banks, transformer tap changes); reduced costs for distributed solar hosting capacity (Nistor et al. 2015).
Operating Reserves (spinning, non-spinning, & supplemental)	Reduce power demand within 10-30 minutes of a signal from the grid operator to make up for a shortfall in electricity supply.	~10-30 minutes	Power plant fuel, operation, maintenance, and opportunity costs associated with providing operating reserves.

Appendix C: Types of Capacity Market Grid Services

Grid Service	Load Change	Response Time	Avoided Cost
Reduced Peak Generation Capacity Costs	Reduce or shift demand during generation annual peak demand period(s).	Years	Fixed operation and maintenance costs for power plants and capital costs for new generating facilities.
Reduced Generation Operating Costs	Reduce or shift electricity demand during high-cost periods. Improve utilization of low-cost generation.	Years	Power plant fuel, operation, maintenance, and start-up and shutdown costs.
Reduced Transmission Upgrade Costs	Reduce or shift demand at a time that reduces local transmission delivery constraints.	Years	Capital costs for transmission equipment upgrades.
Reduced Distribution Upgrade Costs	Reduce or shift demand at a time that reduces local distribution delivery constraints.	Years	Capital costs for distribution equipment upgrades.