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

Connected Communities Examples: Spotlight on Reynolds Landing

May 4, 2020

DOE Intends to Invest $42 Million into "Connected Communities"

Photo Courtesy of Patrick Schreiber via Unsplash

Connected Community:

A group of grid-interactive efficient buildings (GEBs) with diverse, flexible end use equipment that collectively work to maximize building and grid efficiency without compromising occupant needs and comfort

Funding opportunity would enable regional GEB communities to share research results and lessons learned on projects that increase grid reliability, resilience, security and energy integration well into the future.

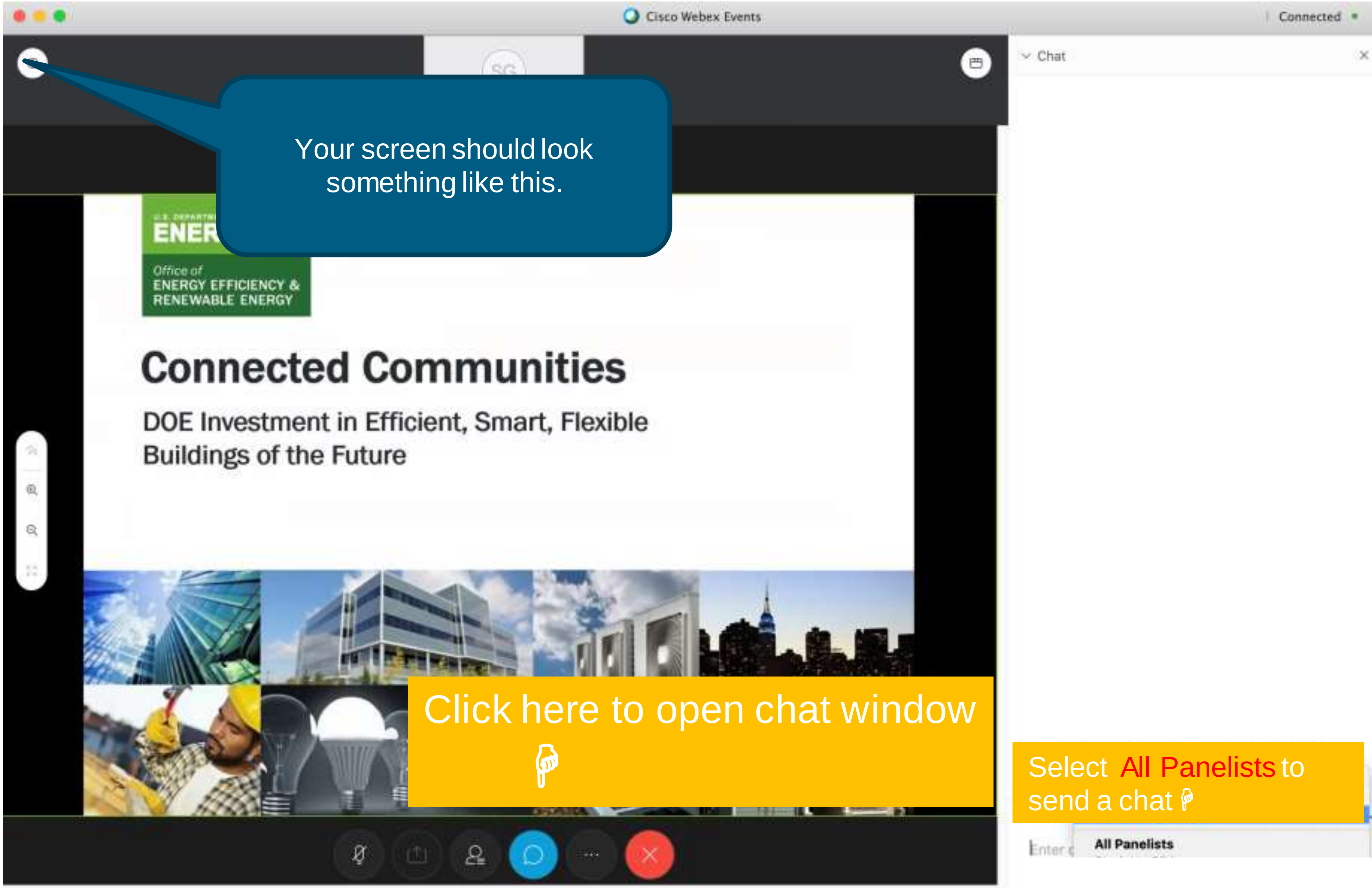
Demonstrate and evaluate the capacity of buildings as grid assets by **flexing load** in both **new developments and existing communities** across diverse climates, geography, building types and grid/regulatory structures

Share research results and lessons-learned on projects that improve energy affordability, increase grid reliability, resilience, security and energy integration

Webinar Agenda

- Welcome & Introductions
- Overview of Relevant Field Testing Projects
- Alabama Power Smart Neighborhoods
- Q&A

One note before we get started….



Current BTO Field Testing Projects

- Smart Neighborhoods: Birmingham, AL & Atlanta, GA
- Post House: Evansville, IN
- AI-Driven Smart Community: Basalt, CO
- Grid-interactive Water Heaters: Pacific Northwest
- Transactive Campus: Richland & Spokane, WA; Toledo, OH
- Economic Dispatch: New York
- GT-Flex: Atlanta, GA

Post House: Evansville, IN

Source: CenterPoint Energy

52 multifamily units in two mixed-use buildings (2nd building is control)

EE measures: Cold-climate heat pumps, Advanced air sealing, Connected water heater and appliances, LED lighting

DERs: Rooftop solar, EV chargers

Demand Flexibility Strategies

- Apartment units aggregated for load-shed DR program
- Response is optimized using HVAC, connected lighting, water heating, and smart appliance loads

Goals and Metrics

- Energy: Savings per unit and by measure type
- Load: Average and peak load reduction, DR snapback
- Occupant experience: Comfort, opt-out rate, satisfaction, and experience with smart home devices
- DER: PV/smart inverter performance
- Cost-effectiveness

AI-Driven Smart Community: Basalt, CO

Source: NREL

27 new-construction townhomes

EE measures: High-efficiency homes, Cold-climate heat pumps, Heat pump water heater, Connected thermostats

DERs: Rooftop PV, Battery storage, EV chargers, Virtual microgrid

Demand Flexibility Strategies

- Home energy management system uses model-predictive control of home load, responds to aggregator signals
- Community Aggregator module coordinates all the homes collectively; interacts with utility to get requests such as demand response

Goals and Metrics

- Energy: 35% better than code
- Load: Distribution feeder over-voltage reduction, 10% peak demand reduction, daily load shift
- Resilience: Days of operation with no net grid exchange
- Occupant comfort and experience: Indoor temperatures, satisfaction survey

Transactive Campus: Richland, Spokane WA; Toledo, OH

Source: PNNL

4-8 existing commercial buildings on 3 campuses; Pilot: tens of buildings in new EcoDistrict in Spokane, WA

EE measures: Agent-based transactive controls for existing HVAC, lighting

DERs: PV, battery and thermal storage, EV chargers

Demand Flexibility Strategies

- Efficiency optimization and fault diagnostics at individual building
- Transactive controls respond to grid prices and signals at campus or feeder level

Goals and Metrics

- Energy: Consumption and bill savings, per building and for campus
- Load: Coincident and non-coincident peak load reduction, distribution feeder congestion reduction
- Indoor environmental quality: indoor temperature and illuminance
- Occupant satisfaction survey
- Scalability: Deployment and integration time and effort

GT-FLEX: Atlanta, GA

Source: GA Tech

12-18 existing education buildings on Georgia Tech campus

EE measures: Optimized controls for existing HVAC system, central plant upgrade (future)

DERs: Battery and thermal energy storage (future)

Demand Flexibility Strategies

- Efficiency optimization for individual buildings and central plant
- Pre-programmed strategies for optimal response for grid services (real-time pricing or demand response)

Goals and Metrics

- Energy: Utility bill savings, greenhouse gas reductions
- Load: Peak load reduction, load shift energy, for individual buildings and campus, DR program incentives
- Cost-effectiveness: return on investment

Common Project Characteristics

- Multiple buildings (20-50 residential buildings/units, 5-10 commercial buildings)
- Energy efficiency features (controls upgrade at minimum)
- Distributed energy resources (one or more)
- *Coordinated optimization for grid services*
- Metrics: Annual energy consumption, Non-coincident peak load reduction
- Data collected: Interval meter readings, smart tstat & appliance data, weather, DER generation/usage, customer/occupant perceptions

Differing Project Characteristics

- Building sector (residential/commercial/mixed)
- EE measure mix (controls and/or hardware)
- DER type and scale (e.g., individual vs. shared)
- Optimization algorithms & coordination methods
- Grid services provided (peak reduction for DR, load shift, distribution voltage support, etc.)
- Resiliency (presence of microgrid)
- Business model (which entities develop, own, and operate different parts of the project)
- Metrics: Customer energy bills, Ease of deployment, Cost-effectiveness, IEQ
- Data collected: Building end-use, Feeder load, Cost

What DOE is Looking For

- ✓ Teams of strategic stakeholders
- ✓ Sets of multiple buildings
- ✓ Multiple DER integration
- ✓ Ability and willingness to share data
- ✓ Diversity of projects (geography, building type, climate, vintage, regulatory)

What We Hope to Achieve

- Measured impact of building as grid assets
- Solutions that address diverse grid needs that can be scaled in size and in other communities
- Input from occupants on impact and comfort level
- Demonstrated new business models for demand flexibility and DER coordination and optimization
- Online solutions center on best practices

Request for Information on Connected Communities

Visit eere-exchange.energy.gov or Scan the QR Code for the Request for Information:

"DE-FOA-0002291: **Request for Information**: Funding Opportunity Announcement 2206: "Connected Communities"

Send RFI responses to: **CCPilotsRFI@ee.doe.gov**

Alabama Power Smart Neighborhood®

Research & Development

ORNL Team: Michael Starke, Heather Buckberry, Helia Zandi, Jeff Munk, Mahabir Bhandari, Chris Winstead, Robert Smith, Supriya Chinthavali, Varisara Tansakul, Joni Hall, Joe Hagerman, Ben Ollis, Drew Herron, Josh Hambrick, **Teja Kuruganti**, Ron Ott

Distributed Energy Resources

Southern Company
Jim Leverette
Chase Cortner
Justin Hill
Phil Markham
Pradeep Vitta
Greg Sewell
Prasad Avvaru
Che McNichols

Reynolds Landing

Alabama Power

SMART NEIGHBORHOOD®

Objective

Design and build a **first-of-a-kind connected community** to understand and prepare for evolving customer expectations and future grid needs

Scope

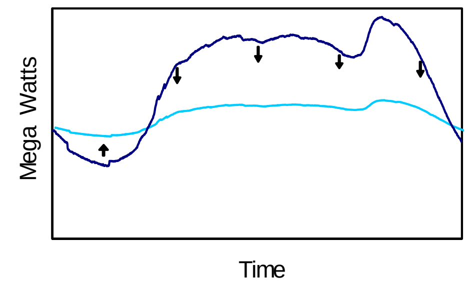
Demonstrate **distributed energy resource (DER)** use cases optimizing cost, reliability, and environmental impact with a **community-scale microgrid**

Demonstrate **62 high-performance homes with connected home technologies** providing an improved customer experience

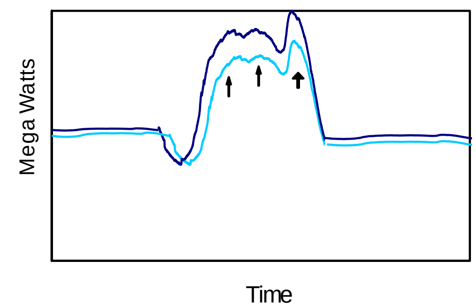
Demonstrate **buildings-to-grid integration** with real-time utility-to-customer interaction

Opportunity space

Facilities or large critical loads require microgrids to cost-effectively meet continuity of operations and resilience requirements	Existing electric grid lack methods for managing on-site generation low voltage (building), medium voltage (distribution), and high voltage (transmission) systems	Buildings have the potential to reduce their consumption by 20%-30% through advanced sensors and controls	Significant advantages in co-optimizing microgrid generation & neighborhood-scale consumption/residential loads	Significant need in scalable control and automation techniques for improving resilience and situational awareness



Reduce Energy Intensity and Increase Energy Efficiency



Increase Load Flexibility and Improve Grid Resiliency

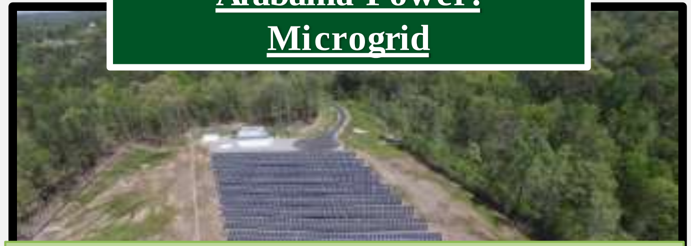
5.5 million commercial, 118 million residential, projected to be 80% of load growth through 2040

Overview (Centralized Theme, Alabama Power)

Alabama Power: Neighborhood

62 Residential Buildings

Alabama Power: Microgrid



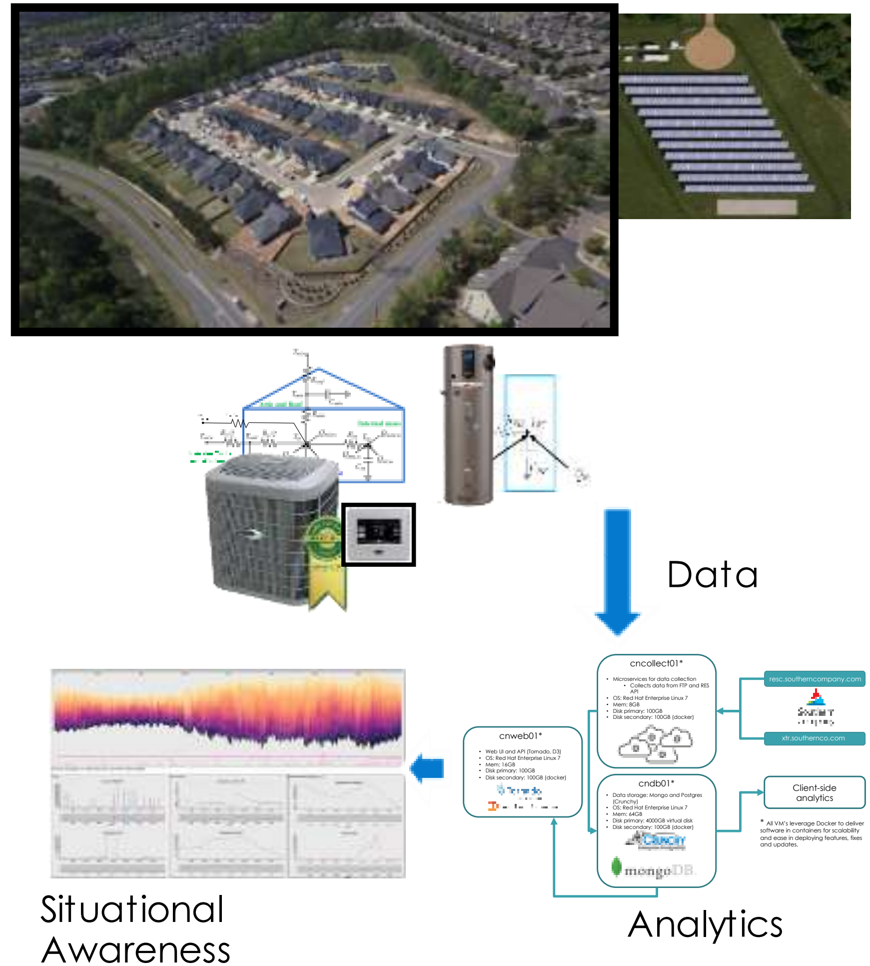
PV System: 420kW
Energy Storage System: 250kW, 681kWh
Generator: 400kW

Alabama Power: Timeline

- October 2017: Construction began
- December 2017: Entire Microgrid Completed
- May 2018: Entire Neighborhood Completed
- August 2018: Deployment of Full Neighborhood Water Heater Control
- October 2018: Deployment of Full Neighborhood HVAC Control
- November 2018: Integration of CSEISMIC Price Signal as Driver
- February 2019: Started running alternating on and off weekly against different study use cases.

Technical Approach

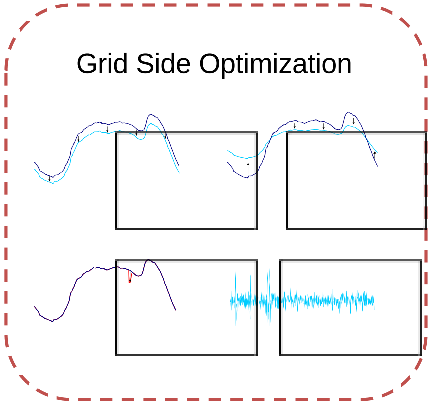
- Quantify the value to the grid of operating microgrid with controllable loads
- Develop and demonstrate control algorithms for generating macroscopic load shapes
- Evaluate price/incentive signal design with a microgrid and controllable loads.
- Develop scalable system-level architecture for performing control at-scale



Understanding homes are not primarily a grid asset

It is a balancing act to effectively manage resource efficiency and homeowner comfort

- **Changing philosophy on what supplies our generation**
  - Generation is moving from centralized plants to distributed
  - Integrating resources and coordinating resources is becoming more important (interoperability is a challenge)
  - Increased renewable generation
- **Increasing need for resilience of electrical system**
  - Establishing and utilizing residential building flexibility to support the grid.
  - Ensuring that customer privacy is maintained while supporting grid needs.
  - Improving system resiliency under threats of systems outages.



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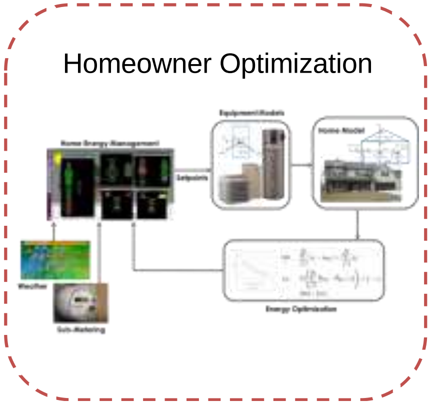
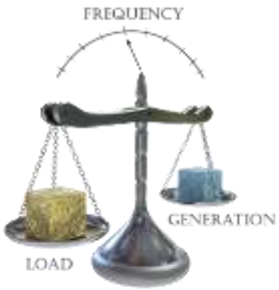
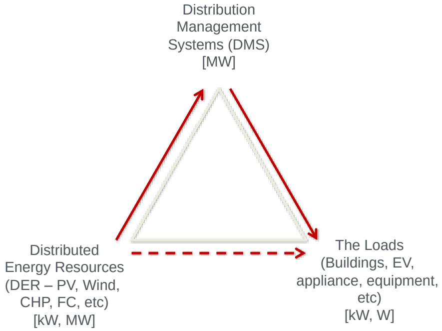






Multi-level of Optimization

Grid Level

Alabama Power Interval Pricing Signal

CSEISMIC

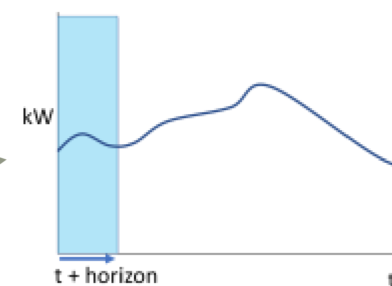
New Optimization Signal, Sent to Home Level Optimizer

Individual Home Level

External Data Inputs
- Weather
- Pricing Signal

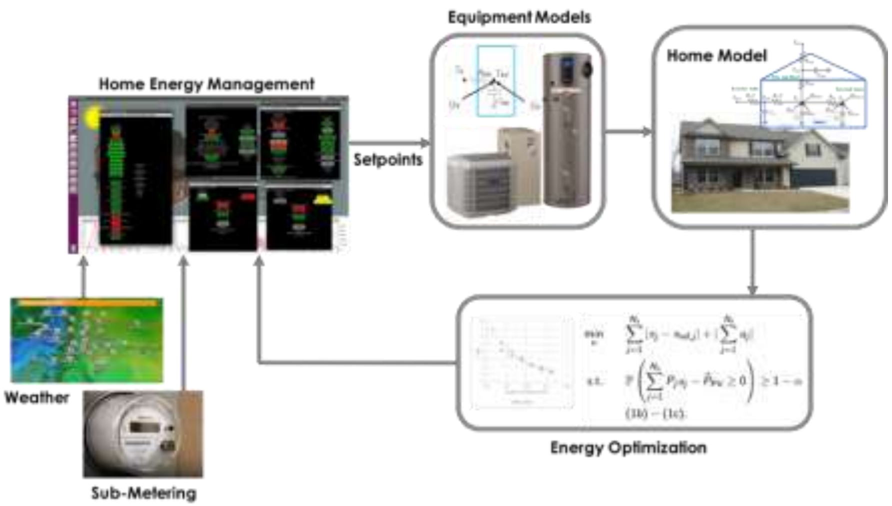
Learned/Built Inputs
- Simple Thermal model
- Comfort Constraints
- Equipment Performance

Implement Control Strategy
- Create Schedules & Setpoints

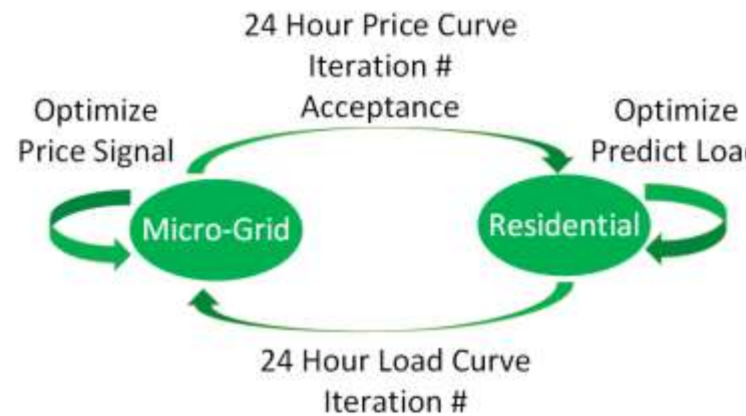


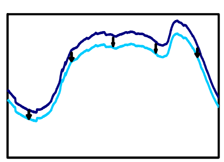
Models drive optimization

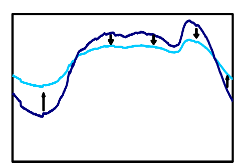
Residential-Level Optimization

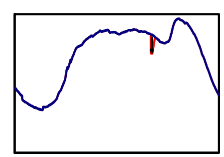


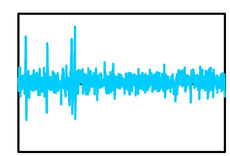
Neighborhood-Microgrid Optimization




Capacity Management

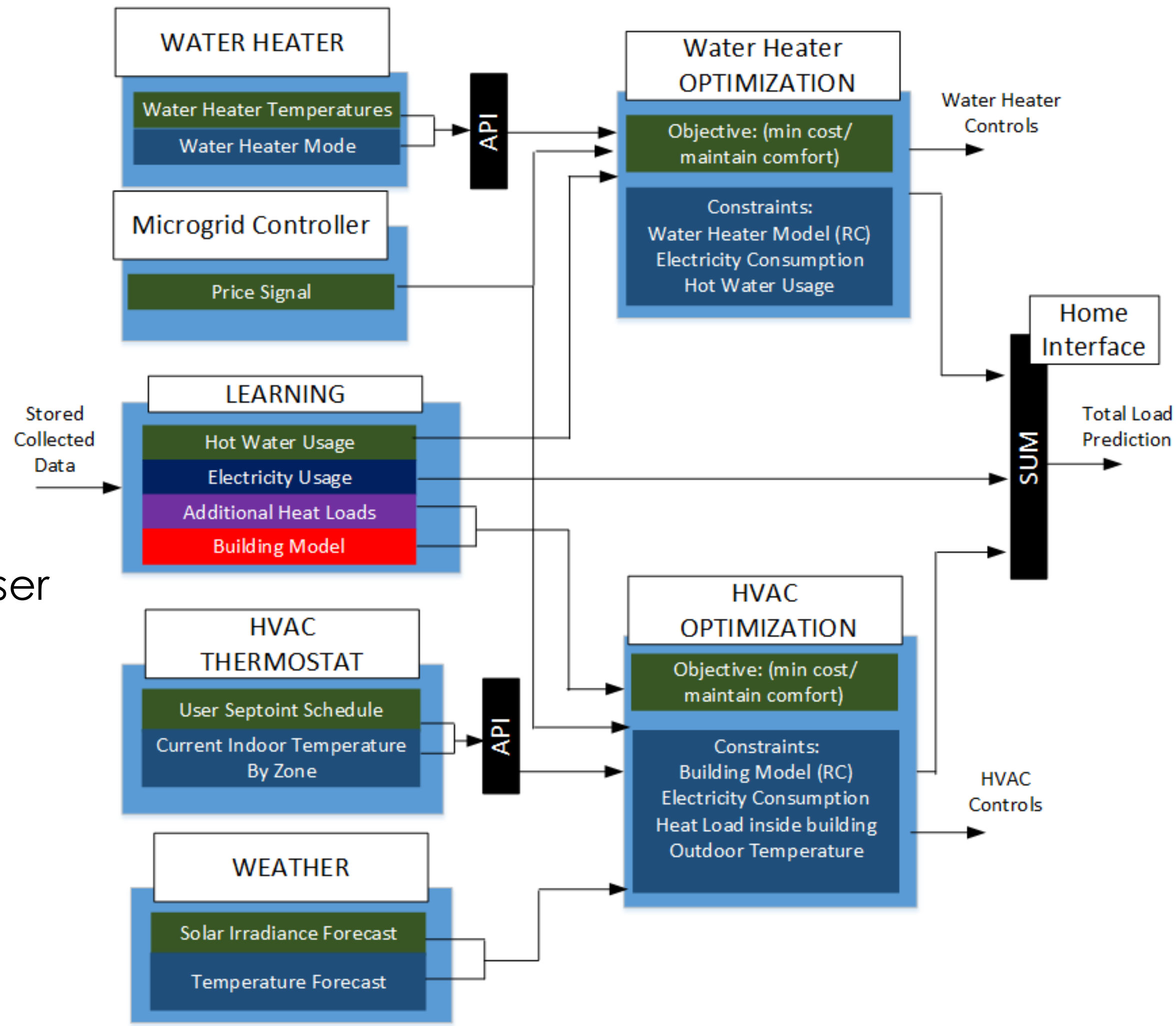

Adaptive Load Shape


Reliability response


Regulation response

Load Side Optimization

- Requires different data sources in near real-time:
  - Device measured data
  - Weather forecasting
  - Predicted behavior
- Optimization uses model predictive formulations for HVAC and water heater
- Comfort bands based on user input thermostat schedules and deadband.
- Driven by price signal from microgrid controller.
- Utilizes learning and predictions to assess future operations.



Optimization and Control

$$objective = min\left(WP\sum_{t=0}^{t} Pelec(t) * Price(t) + WD\sum_{t=0}^{t} Discomfort(t)\right) \quad \begin{matrix} WD = 80 \\ WP = 1 \end{matrix}$$

$$Discomfort(t) \geq Twater(t) - Tmax(t)$$

$$Discomfort(t) \geq Tmin(t) - Twater(t)$$

$$Discomfort(t) \geq 0$$

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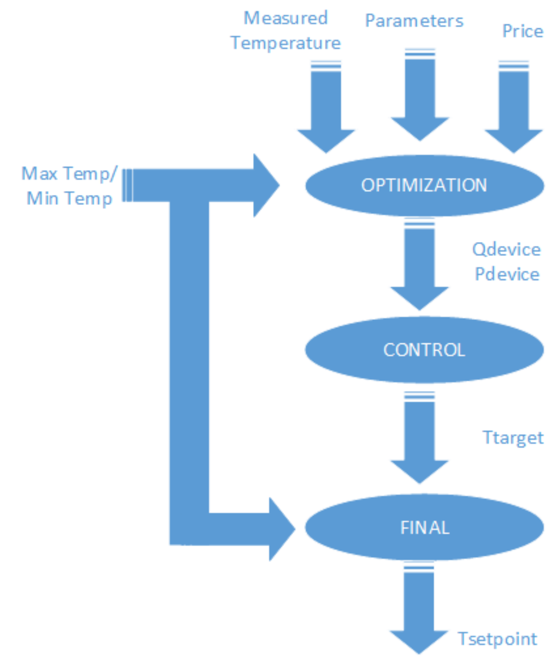
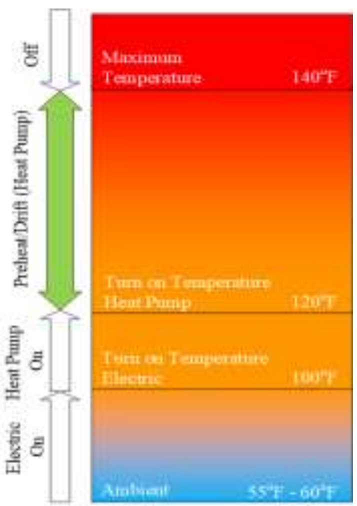
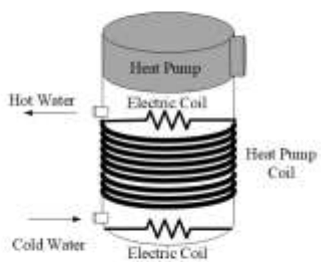


Water Heater Example in Detail





Objective Function:

$$\min \left(W_P \sum_{t=0}^{T} P_t^{WH} * \rho_t + W_{HP} \sum_{t=0}^{T} D_t^{HP} + W_{EL} \sum_{t=0}^{T} D_t^{EL} + W_{UP} \sum_{t=0}^{T} D_t^{UP} \right)$$

Constraints:

Heat Pump:

$$Q_t^{HP} = \begin{cases} \leq 1500 - 8.0 * T_t^W \\ \leq 3500 * b_t^{HP} \\ \geq 0 \end{cases}$$

$$P_t^{HP} = \begin{cases} \leq 3500 * b_t^{HP} \\ \leq 1190 * b_t^{HP} + 0.689 * Q_t^{HP} \\ \geq 0 \end{cases}$$

Electric:

$$Q_t^E = 5000 * b_t^E$$
$$P_t^E = 5000 * b_t^E$$

Total:

$$Q_t^H = Q_t^{HP} + Q_t^E$$
$$P_t^H = P_t^{HP} + P_t^E$$

Tank Model:

$$T_{t+1}^W = \frac{\left(\frac{T_t^e - T_t^W}{R_W} + Q_t^W + Q_t^H \right) \Delta t}{C_W} + T_t^W$$

Mode (On/Off) Options:

$$1 \geq b_t^E + b_t^{HP} + b_t^{OFF}$$

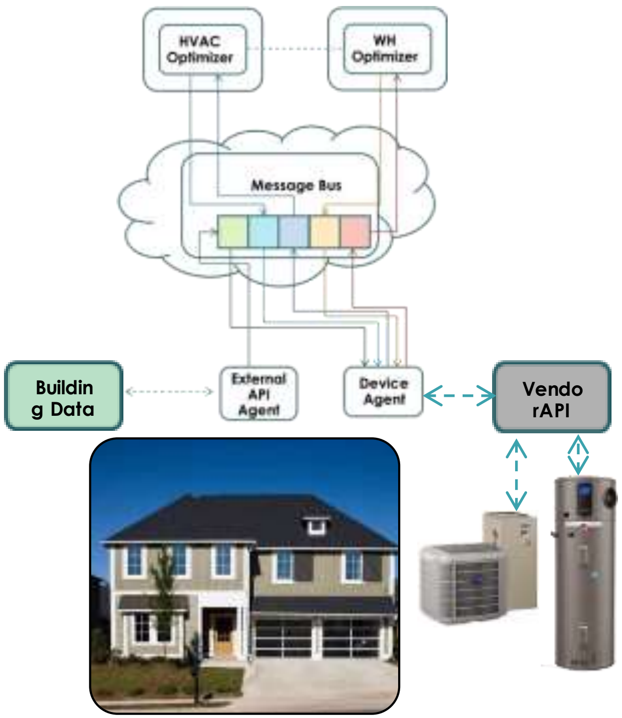
Comfort Model:

Aux Variables
$$\begin{cases} D_t^{HP} \geq T_{minHP} - T_t^W, D_t^{HP} \geq 0, heat\ pump \\ D_t^{EL} \geq T_{minE} - T_t^W, D_t^{EL} \geq 0, electric \\ D_t^{UP} \geq T_t^W - T_{max}, D_t^{UP} \geq 0, turn\ off \end{cases}$$

Output:
Mode
Setpoint

Agent Framework

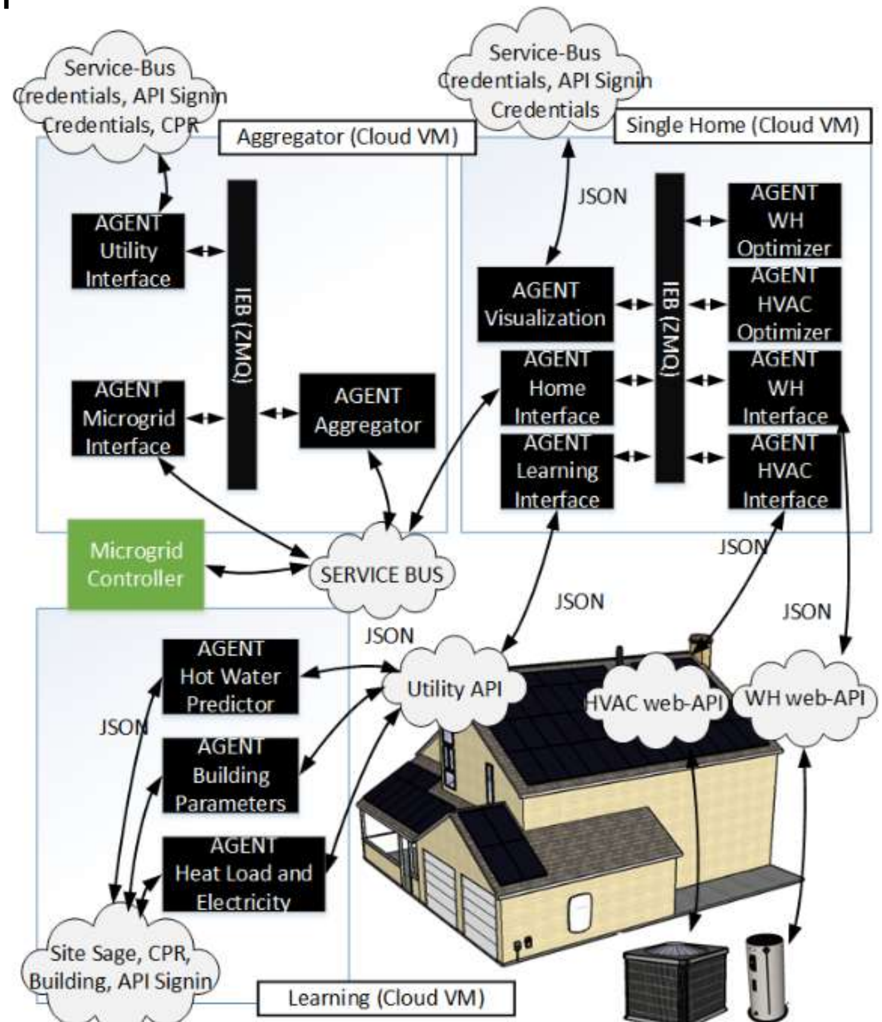
Agent based framework to support autonomous integration and negotiation of load resources with a microgrid controller



Agent	Purpose
Home Interface	Data Pass through and collector of optimization and electrical consumption projections for Aggregator agent
HVAC Interface	Translates HVAC decisions and status to vendor API
Water Heater Interface	Translates Water Heater decisions and status to vendor API
HVAC Optimizer	Utilizes building specifications, forecasted weather data, building parameter data, price forecast, and HVAC status data to optimally schedule HVAC and provide expected electrical consumption.
Water Heater Optimizer	Utilizes predicted water consumption, price forecast, and Water Heater status data to optimally schedule Water Heater and provide expected electrical consumption.
SoCoInterface	Pulls data from Southern Company API which includes weather, building specifications, historical load measurements by circuit, device credentials, and historical data.
Learning	Utilizes data collected from SoCo stored data to perform predictions on hot water usage, internal heat loads, building parameters, etc.

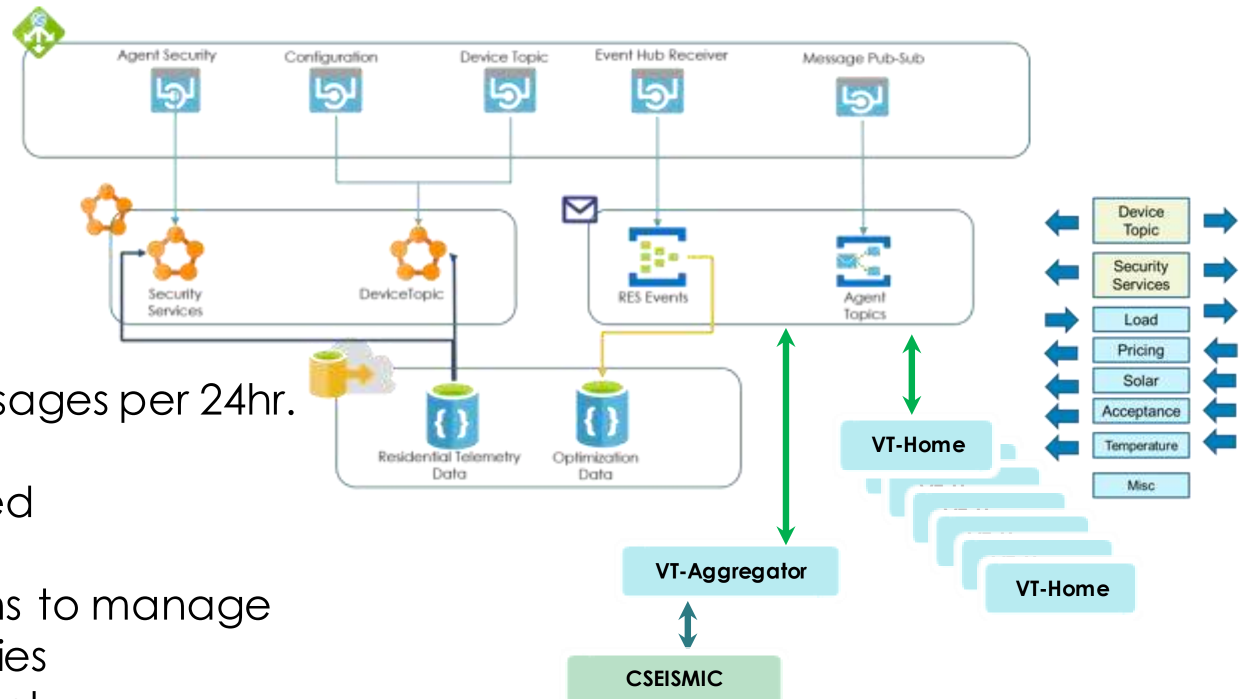
Enterprise-scale Deployment

- An integrated system interacting with vendor API, SoCo API, and VOLTTRON Agents
- VOLTTRON allocates price signals to resources (loads) which optimize and provide total load projection
- This process iterates until Microgrid controller meets minimum convergence criteria.
- Real-time optimization driven by measurements and forecasts
- Optimizing and dispatching WH and HVAC units 62 homes



Integration with RES API

- API Managed by central gateway
- Several individually managed backend resources
- Gateway provisioned to handle 1M Requests/day



- RES Processes ~3M messages per 24hr. Period
- 14 API sets for REST based communications
- 4 Categories of functions to manage various backend activities
  - Security Management
  - Data capture
  - Data provisioning
  - Configuration management
- All external interactions managed through centralized API Gateway

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Southern Company

Phased Testing Approach

Laboratory

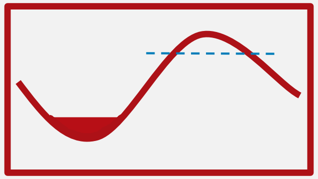
- Simulation-based Testing
- Software as Deployed

ORNL Yarnell Station

- Unoccupied Research Home in West Knoxville
- Development Testing

Southern Company Idea Home

- Southern Company Development Environment
- Unoccupied Research Home at Reynold's Landing



High Performance Homes

Changing Load Shapes

Tighter envelope

Advanced Building Energy Systems

Managing Behind the Meter Assets

Energy Use Optimization

Buildings as a resource

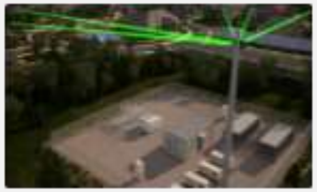
Create load shapes

Identifying Revenue & Rate Design Impacts

Informed Load Forecasting

New building codes & standards

How to price energy in IoT future



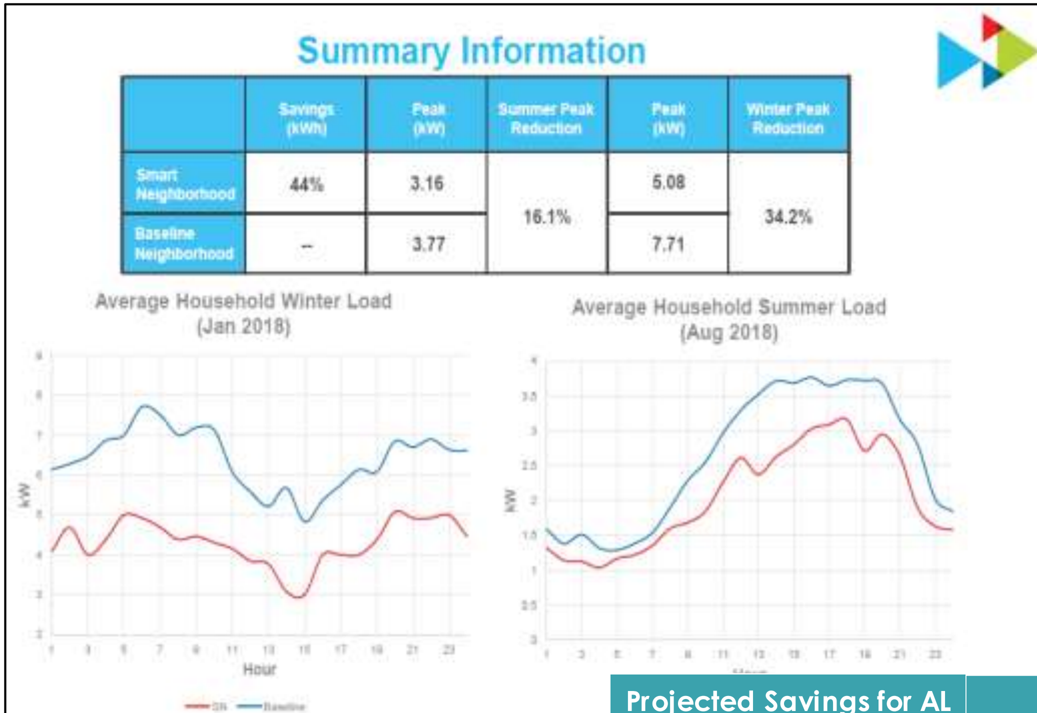
Understanding Renewable Energy Grid Integration

Help meet 2050 Low-to-No Carbon Goal

New infrastructure needs

Balance grid & customer benefits

Smart Neighborhoods Are Energy Efficient (reduce annual energy usage (kwh))



Slide from Southern Company Presentation to International Home Builders Show (2019)

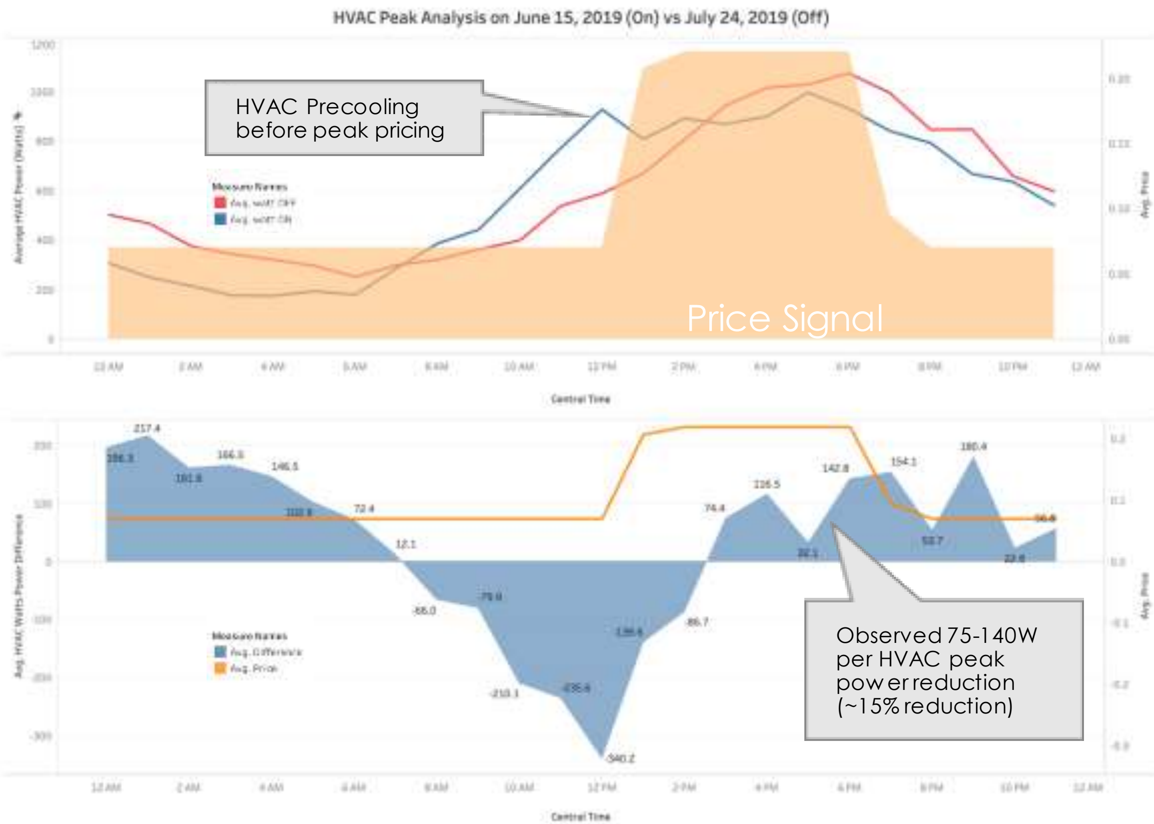
- Homes have been measured against the HERS Index:
  - AL Code Minimum Homes (e.g., 2015 IECC) achieve a HERS 70
  - Neighborhood Homes achieved HERS 45
  - **Therefore, the Smart Neighborhood Homes are ~35% More Energy Efficient Than AL's Code Minimum Homes.**
- The conversion of the entire AL Residential Sector into Efficient Smart Construction will achieve significant energy and carbon savings.

Extrapolated Across All of AL

Projected Savings for AL Residential Conversion	EE Savings	CO_2 Tons/Yr/Home Avoided	CO_2 Tons/Yr Avoided	Equivalent cars removed from the road
Predicted from homes at HERS 45	35%	0.65tn	~820,000tn	~164,000 cars
Actual, measured home usage (from AMI Meter)	44%	0.79tn	~1,000,000tn	~200,000 cars

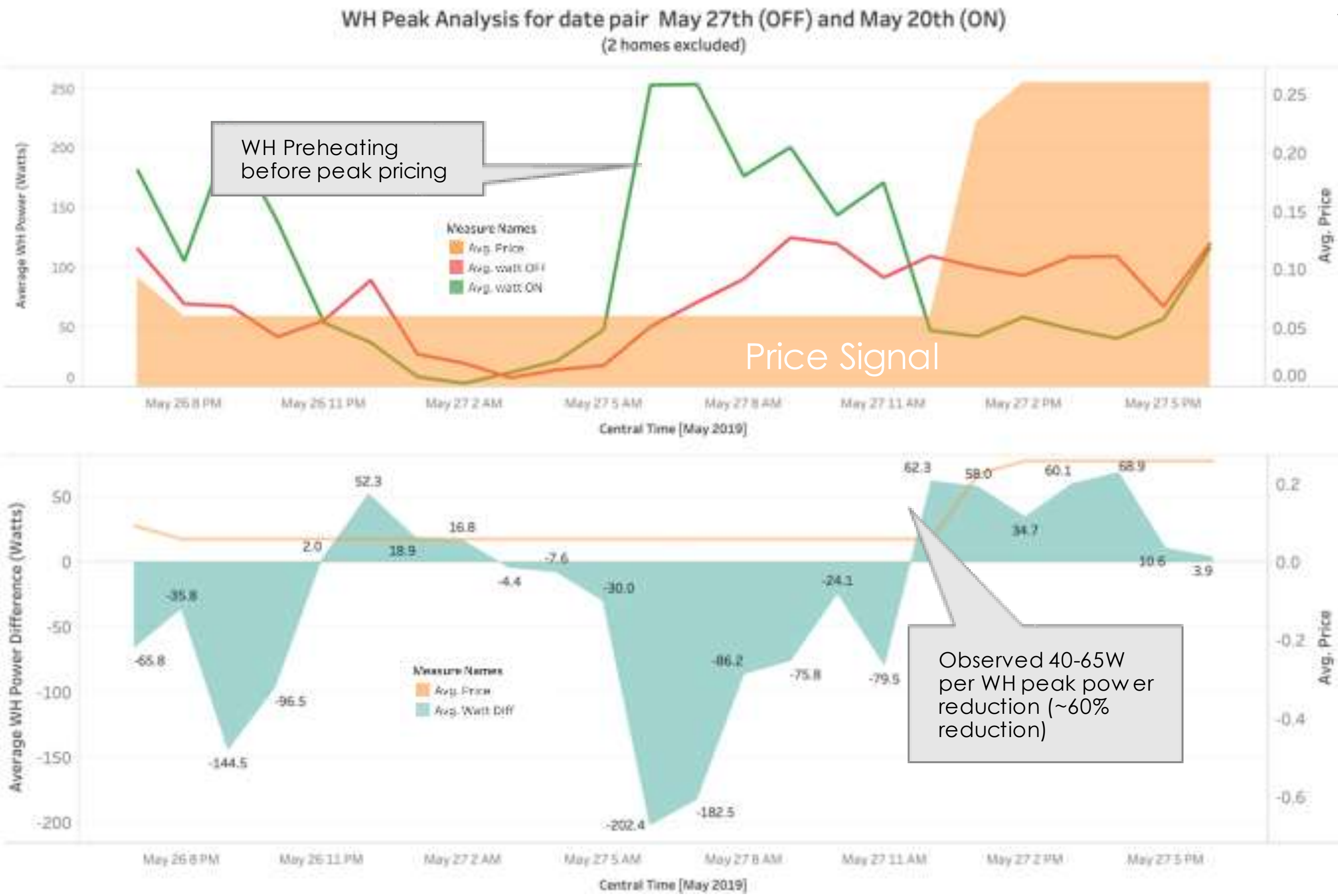
This data is derived from using EPA's AVERT.

HVAC Peak Analysis



- With only 2°F flexibility of indoor temperature, **the optimization of HVAC can't pre-cool to ride through a 6-hr peak.**
  - We are exploring shorter peak pricing events for increased grid benefits from HVAC peak reduction.
  - Water heaters may be better suited for longer duration events.
- Additional Observations:
  - Homeowners interact with their HVAC thermostat more frequently than WHs resulting in optimization being disabled more frequently.
  - ~50% of homeowners operate their smart thermostat in manual mode instead of using a programmed schedule

WH Peak Analysis – Summer 2019



- Water heaters are better suited for longer duration events.

Additional Observations:

- **Water draw forecast is based on generalized, conservative patterns that vary significantly from actual usage** (see notes for more information).
- We observed that the water heaters ran in hybrid mode (e.g., **electric resistant mode**) more frequently than the simulations.
- Water heater energy consumption is higher due to maintaining higher water temperature and more aggressive heating **to ensure occupants did not run out of hot water.**

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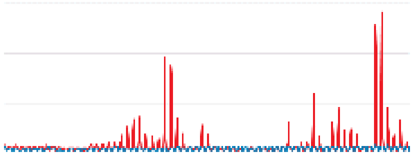
Southern Company

Quantify Grid Service Capability

Determine the additional value of continuous optimization vs. event driven DR

Ability to predict Homeowner Comfort/Convenience/Productivity

Forecasting Day-Ahead Cost is like predicting the weather



Planning tools use average data, which removes value

Device Capabilities enabled in APIs

Alabama – Significant Lessons Learned

- Significant load flexibility is available from residential loads
  - A coordinated control framework and customer education key to success
  - Reducing computational footprint is needed for seamless deployment
  - Potential exists for improvement – Current control settings are conservative
- Design of control-related application identified new requirements
  - Clouds-in-the-loop
  - Latency and Reliability
  - Data security and authentication
  - Format or content changes of the data from manufacturers' APIs can cause disruption in operation.
- Training is required to educate homeowners on how to interact with their thermostat to achieve the best results (i.e., adjust the programmed schedule instead of setting a manual hold on the temperature) - Many users do not utilize schedules (HVAC) and as a result optimization is difficult
- Simultaneous Development, Deployment, and Data Analysis
- Energy and demand savings are not the same – shifting demand often requires using additional energy in the form of pre-heating or pre-cooling
- Shorter and/or more specific peaks allow for more significant demand impacts

Alabama – Significant Lessons Learned (Cont'd)

- Need for developing innovative rates or price structures to align customers and utilities
  - Dual-benefit for homeowners and utility
- Opportunities to scale these systems across utility for large-scale, aggregate impacts
  - A rich understanding of requirements - design, automation, deployment
- Differences in how these results translate into the existing housing stock with very different thermal and equipment characteristics
  - Automatic commissioning and learning of the energy usage
- What frequency of control is optimal to minimize impacts to the customer while providing grid benefits? (hourly, daily, etc)
  - Understanding customer adoption

Southern Company Smart Neighborhood Initiatives

Understanding tomorrow's home today

Two first of a kind smart home communities at the intersection of energy efficiency, distributed energy resources & buildings to grid integration and the traditional utility model

Georgia Power Smart Neighborhood™

- 46 townhomes
- Atlanta, Georgia
- Homeowner owned solar + storage
- Grid integration of solar, storage, HVAC, water heating & EV charging

Alabama Power SMART NEIGHBORHOOD®

- 62 single-family homes
- Birmingham, Alabama
- Utility owned, grid-connected microgrid
  → 330 kW solar
  → 680 kWh storage
  → 400 kW NG generator
- Grid integration of microgrid, water heating & HVAC

Major Research Partners
Electric Power Research Institute and U.S. Department of Energy's Oak Ridge National Laboratory

Key Vendor Partners
LG Chem, Delta, Carrier, ecobee, Rheem, SkyCentrics, Flair, Vivint, Pulte Homes, Signature Homes

Key Results
Homes are 30 40% more efficient
EV makes up 15 20% of total usage
Successful microgrid islanding
New business opportunities deployed

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