THE COMING AGE OF A SMART GRID AND SMART BUILDINGS

Dr. Tom Lawrence, PE, LEED-AP, F-ASHRAE
proftom@uga.edu

College of Engineering
UNIVERSITY OF GEORGIA

Copyright Materials

Course Description

The smart grid is arriving rapidly, and with new era buildings will be interacting even more with the electric utilities. The communication will be in both directions, as the the utility works to balance the grid supply and demand in collaboration with their customers through methods such as signaling requests for demand response measures, real-time price adjustments, etc. This is a new and evolving field and, while there are some differences in the need for and how a smart grid might function in the various regions of the world, there are some common factors as well. This seminar provides an overview of the smart grid particularly as it relates to buildings and their systems.

Learning Objectives

- Understand the concept of a smart grid and the purposes for why this is being developed
- Describe key methods on how a building can participate in electrical demand response programs
- Recognize how demand response measures are being incorporated into high-performance green building standards and rating systems
- Understand the role of HVAC systems in implementing demand response programs and some of the issues to watch for in demand response implementation.
- Identify some of the issues that building system designers need to consider in creating a smart building capable of interacting with a smart grid.

AIA/CES Registered Provider

ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Approved for: 1 LU/HSW by AIA   Course # Lawrence01

USGBC Education Partner

The Coming Age of a Smart Grid and Smart Buildings

by **ASHRAE**

GBCI cannot guarantee that course sessions will be delivered to you as submitted to GBCI. However, any course found to be in violation of the standards of the program, or otherwise contrary to the mission of GBCI, shall be removed. Your course evaluations will help us uphold these standards.

Approval date: **October 2018**

Course ID: **0920014297**

Approved for:

1

General CE hours

0

LEED-specific hours

LEED GREEN ASSOCIATE ☐

LEED AP BD+C ☐

LEED AP HOMES ☐

LEED AP ID+C ☐

LEED AP ND ☐

LEED AP O+M ☐

ASHRAE Will Give You the World

T
E
A
C
H

Give Back to ASHRAE

SHARE

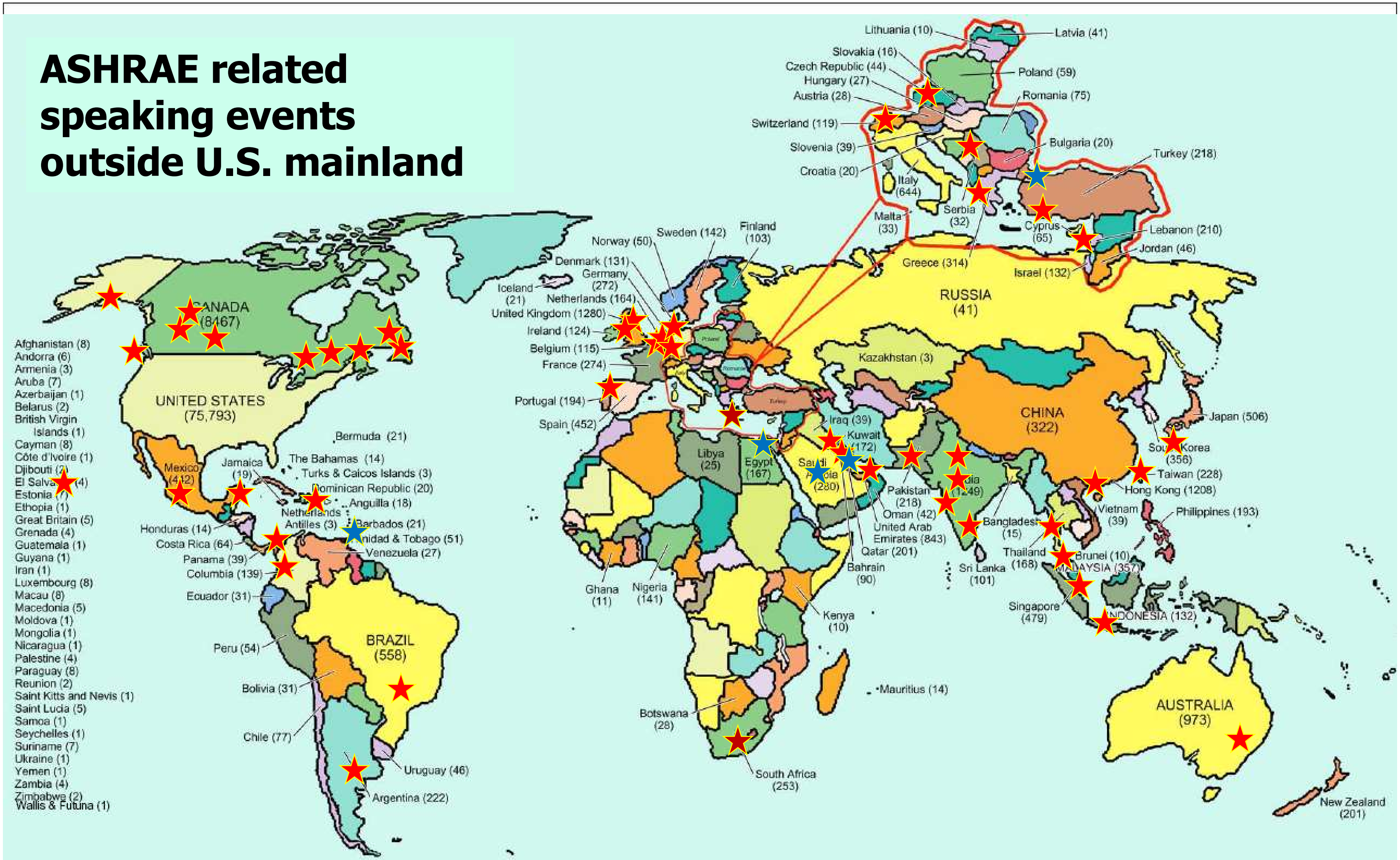
GROW

NETWORK

LEARN

This ASHRAE Distinguished Lecturer is brought to you by the Society Chapter Technology Transfer Committee

ASHRAE related speaking events outside U.S. mainland



High Performance Buildings and related topics are becoming a big focus around the globe

★ **Virtual chapter/section meeting**

Trivia Question

- What is significance to me for London and Windsor, Ontario?
- Answer:
  - My last in person ASHRAE chapter event as DL, February 24-25, 2020
    (although I did do Region IV CRC in Aug.)
- Since then have done ~20 ASHRAE events online (Chapters in 10 states and 5 foreign countries)

Topics Covered

- What is the smart grid and a smart building?
- The Grand Challenge of a smart grid integration
- Demand response and methods buildings can implement demand response
- Smart aspects that increase overall resilience
  - Smart buildings, fault detection & diagnostics
  - Microgrids
  - Renewable energy, distributed generation integration
  - Monitoring
  - A future “neural grid”?
- Other issues and observations

Smart Grid: Definition and Composition

What is the "Smart Grid"?

- Modernized electrical grid using information and technology to more efficiently produce, transmit and use electricity
- Each sector of the electricity supply chain has different goals and objectives for the smart grid
- A "smart grid" could also apply to other utility supplies (natural gas, fuel oil, gasoline, water) where smart controls can help alleviate disruptions

Why Should I Care?

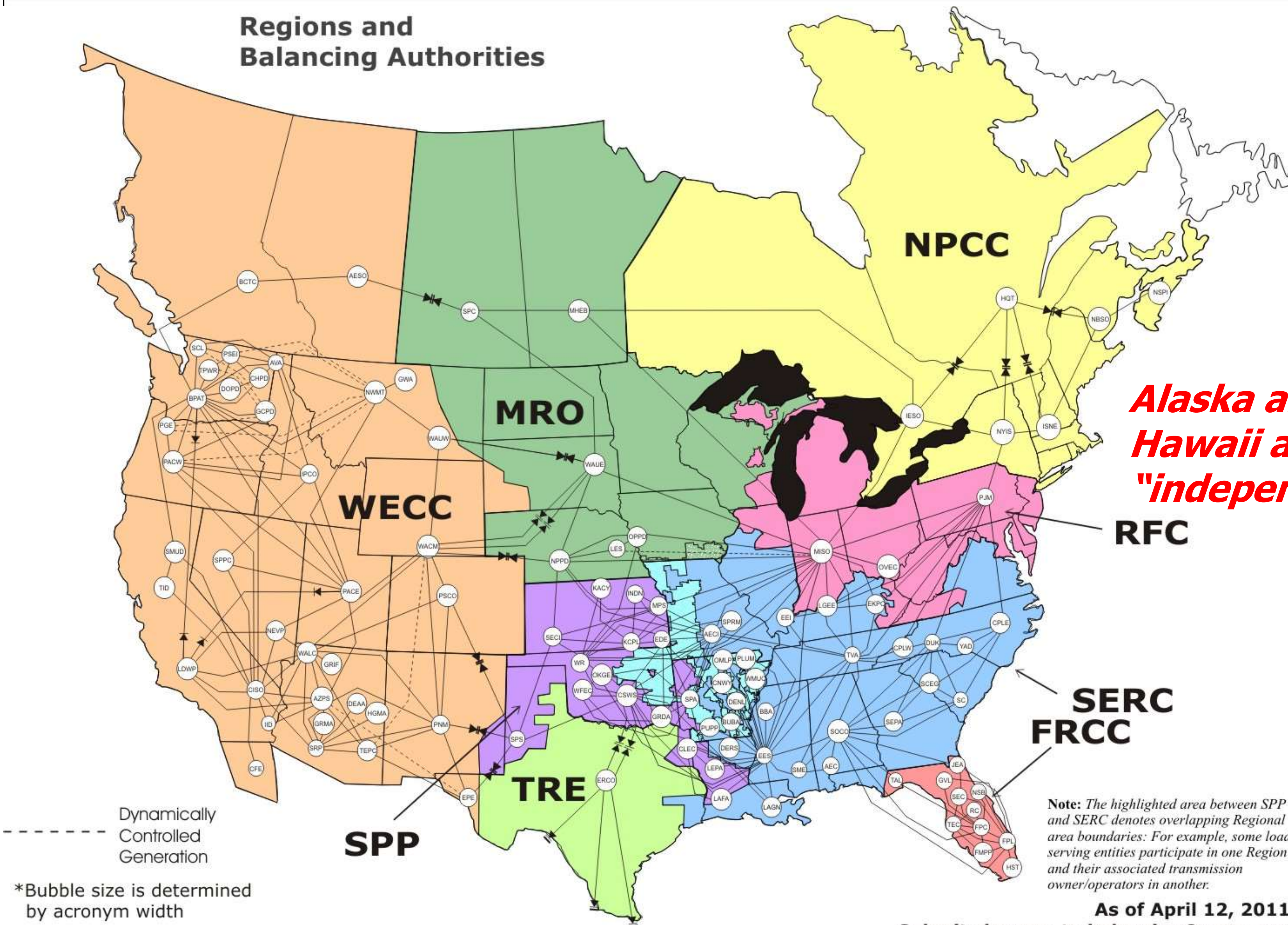
As an ASHRAE, CIBSE or related similar society member, this is important because…

- The "smart grid" (in some form) is here regardless
- Buildings (commercial and residential), as well as industrial, will be affected in the future
- Building systems such as HVAC and lighting will be most involved with communicating energy use and adjusting demand based on the grid requirements
- It potentially opens up a new discipline specialty beyond just "energy efficiency" to "load management"
- Equipment and software suppliers already are converting their products

Smart Grid Components
(Already Here in Some Form)

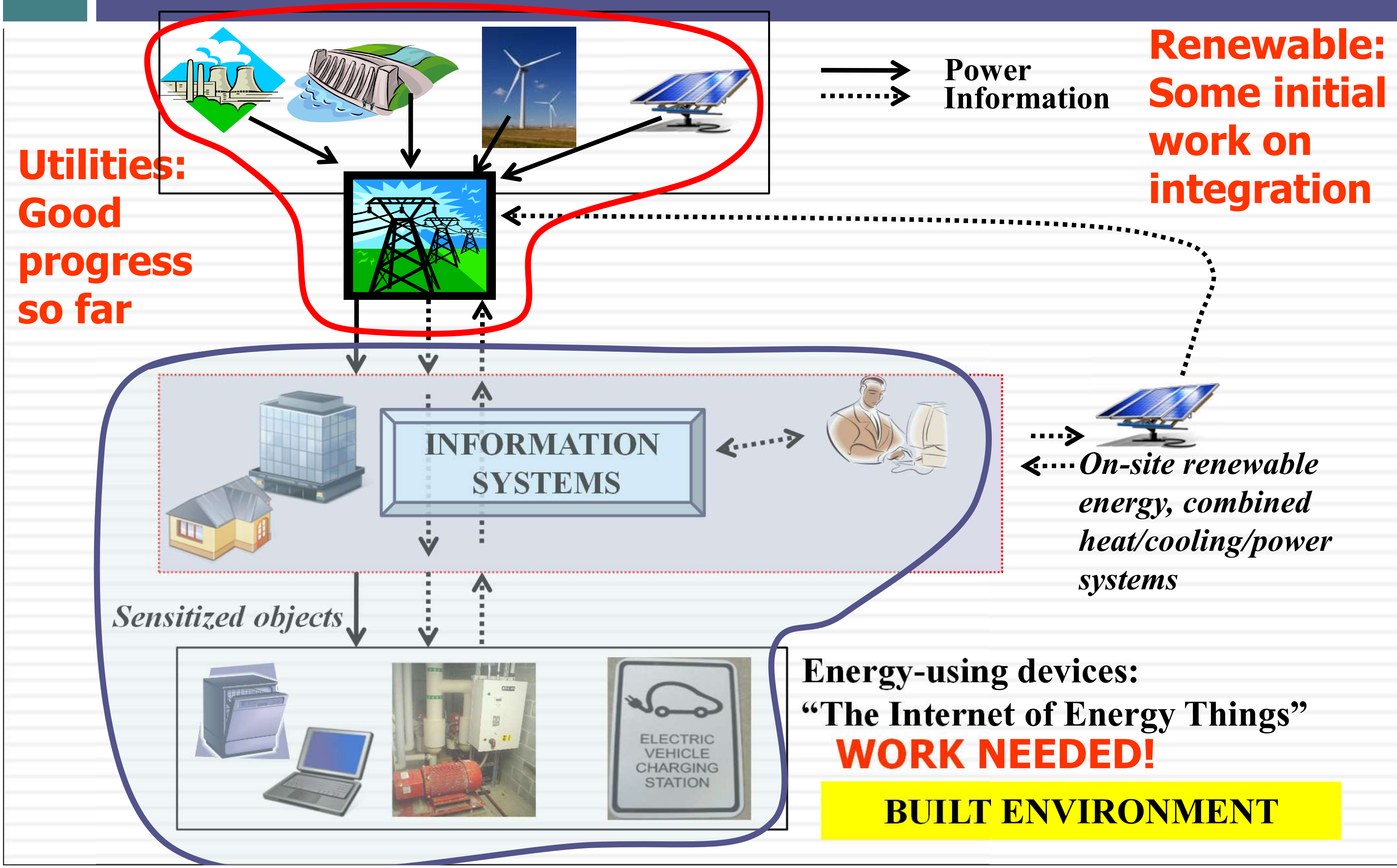
- Smart meters
- Two-way communication between utility and users (devices/buildings/industrial/transportation)
- Grid management logic and software
- Demand management logic and software
- Information flow, technology
- Load management through energy storage, use scheduling
- "Smart" end-use equipment or appliances

The U.S. and Canadian Electric Grid



Alaska and Hawaii are "independent"

The Grand Challenge



ASHRAE's Smart Grid Application Guide

Highlighting key parts of the Guide
More detailed aspects in remainder of the session

Demand Response and Management

Demand Response Scenarios

A. High Demand Relative to Supply:

- Reduce peak demand during high load conditions or grid "stress"
- Typically a summer cooling issue (occasionally in winter heating in some locations)

B. High or Variable Supply Relative to Demand:

- How to manage peak production from distributed generation systems (renewable, CHP)?
- Germany in June 2013 and continued this year
- Becoming more common in parts of U.S. (at night, wind)

C. Managing for Low Carbon Energy Production:

- An issue particularly for UK and EU now, others in future?
- Management of demand to match type of supply available

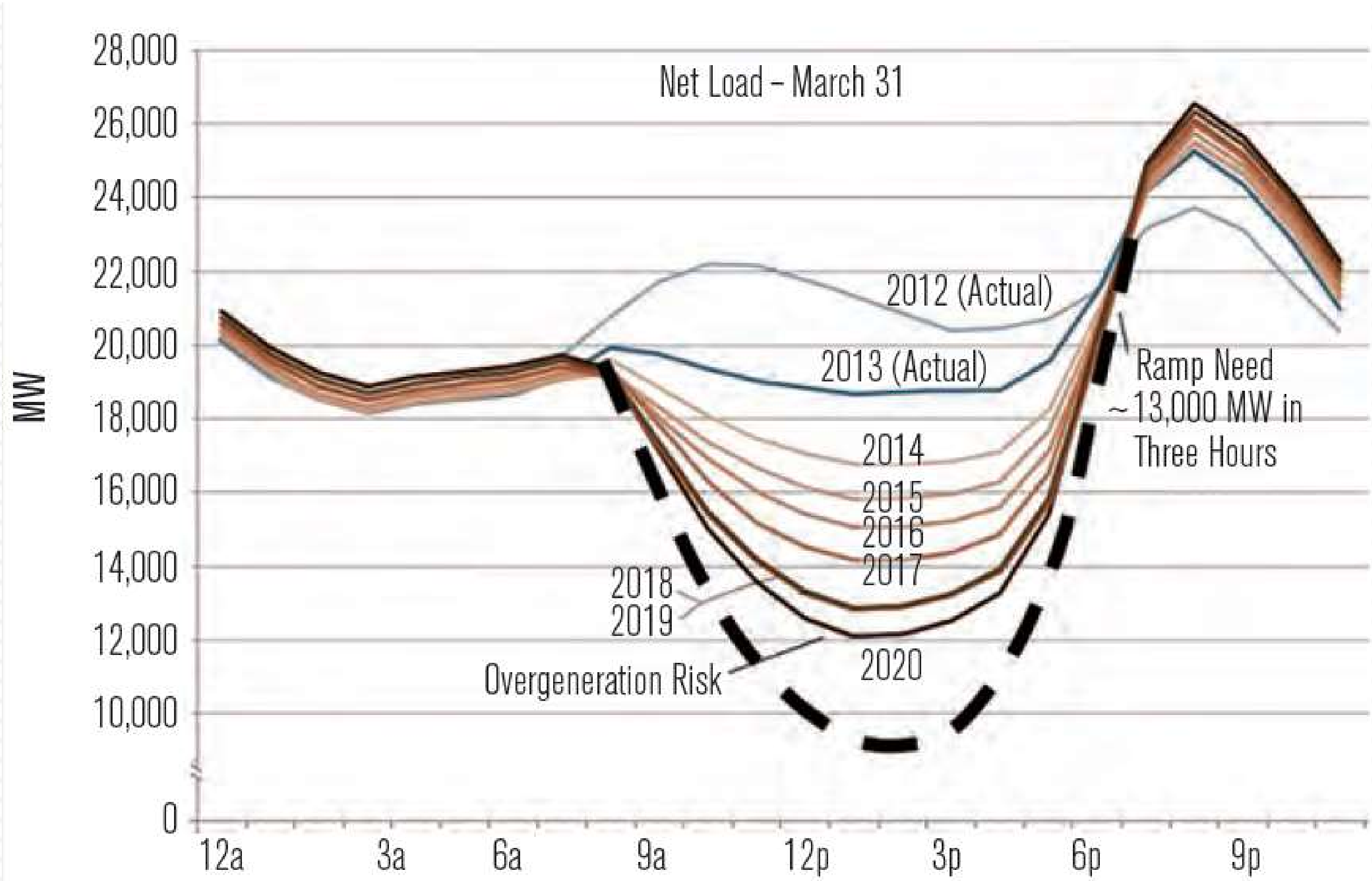
Common Types of Demand Response (DR) Programs

Price-based DR Programs: Higher prices used to induce demand reduction	
Time of Use (TOU) rates	Rates with fixed price blocks that differ by time of day.
Critical Peak Pricing (CPP)	Rates that include a pre-specified, extra-high rate that is triggered by the utility and is in effect for a limited number of hours.
Real Time Pricing (RTP)	Rates that vary continually (typically hourly) in response to wholesale market prices.
Incentive- or Event-based Programs: Incentives provided to induce demand reduction	
Direct load control	Customers receive incentive payments for allowing the utility a degree of control over certain equipment.
Demand bidding/buyback programs	Customers offer bids to curtail load when wholesale market prices are high or identify how much they would be willing to curtail at posted prices.
Emergency demand response programs	Customers receive incentive payments for load reductions when needed to ensure reliability, but curtailments are voluntary.
Capacity market programs	Customers receive incentive payments or rate discounts/bill credits for providing load reductions as substitutes for system capacity.
Interruptible/curtailable programs	Customers receive a discounted rate or bill credit for agreeing to reduce load upon request. If participants do not curtain when requested, they can be penalized.
Ancillary services market programs	Customers receive payments from a grid for ancillary services provided. Require that customers are able to adjust load quickly.

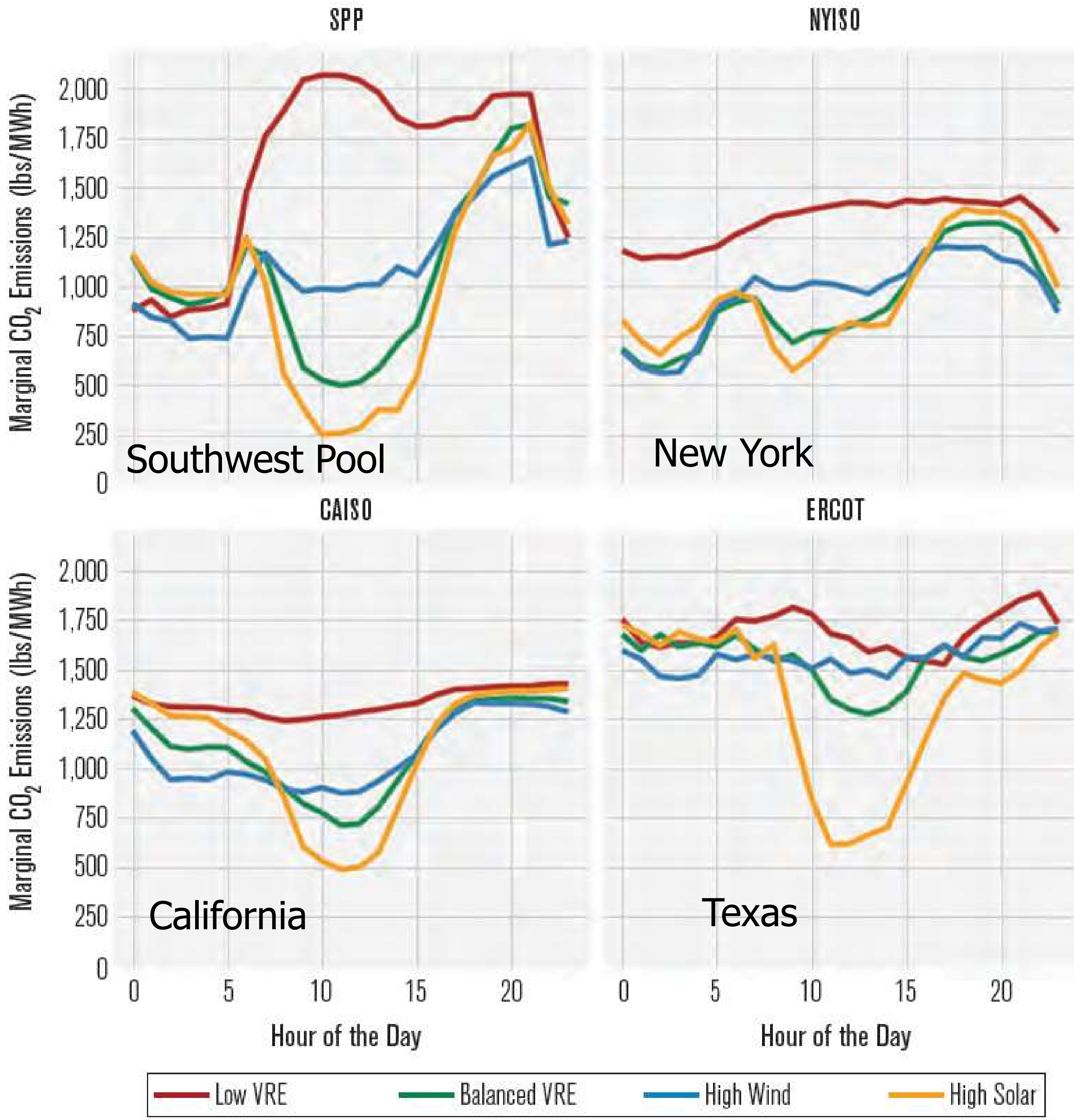
Goldman, C., M. Reid, R. Levy and A. Silverstein. 2010. *Coordination of Energy Efficiency and Demand Response*. LBNL-3044E, Lawrence Berkeley National Laboratory, Berkeley, CA.

The Future is Coming (or Here)

The "Duck" Curve of California's Energy Use ***(California ISO, in MW)***



D. Nall, 2018. "Grid Coordination for Net Zero Energy Projects", ASRHAE Journal Oct. 2018



CO2 Emissions Rate Varies with Renewable Energy Availability

(VRE = variable renewable energy)

Nall, 2018

New Trends with DR Management

- Increased distributed generation by buildings adds to the problem that utilities need to address
- Building energy storage in parallel with utility scale storage
- ***Communication of the utility with buildings will help alleviate the "duck curve" problems***

New Trends with DR (Cont'd)

- Utilities are now targeting DR in more disaggregated manner to offload congestion at specific points, rather than system wide
  - ***Zip code level***
  - ***Specific streets or locations***
- Fast-acting DR to provide more short-term responses
- "Reverse demand response" to increase load when it makes sense to avoid 'wasting' solar or wind generation

Demand Response for Buildings and Their Systems

Demand response becoming more a requirement (LEED, Std. 189.1, IgCC)

Implementing demand response in buildings: new and/or existing

Example of a test case

LEED v4 EA Credit: Demand Response

Building project can opt to pursue the following credit options ("Grid Harmonization")

- Case 1: Demand Response Program Available (2 pts)
  - Participate in the program through contract
  - Design system with capability for automate DR (Semi-automated allowed in practice)
  - Include DR in the commissioning
- Case 2: DR Program NOT Available (1 pt)
  - Provide infrastructure to take advantage of a future DR program, including meters and developing a comprehensive plan for load shedding of at least 10%

Demand Response is Becoming "Code" (IgCC/Standard 189.1)

- Automated demand response capability to allow communication with utility, to receive demand response signals and implement load adjustments to HVAC and lighting as appropriate.
- During automated DR
  - HVAC setpoints adjusted by minimum of 3° F
  - Ramp up and down logic to avoid rebound and large peak.
  - VFD controllers to 90% of maximum
  - Lighting adjustments by 15% for those with centralized control systems

California (Title 24)

SECTION 120.2 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

(h) **Automatic Demand Shed Controls.** HVAC systems with DDC to the Zone level shall be programmed to allow centralized demand shed for non-critical zones as follows:

1. The controls shall have a capability to remotely setup the operating cooling temperature set points by 4 degrees or more in all non-critical zones on signal from a centralized contact or software point within an Energy Management Control System (EMCS).
2. The controls shall have a capability to remotely setdown the operating heating temperature set points by 4 degrees or more in all non-critical zones on signal from a centralized contact or software point within an EMCS.
3. The controls shall have capabilities to remotely reset the temperatures in all non-critical zones to original operating levels on signal from a centralized contact or software point within an EMCS.
4. The controls shall be programmed to provide an adjustable rate of change for the temperature setup and reset.
5. The controls shall have the following features:

   A. Disabled. Disabled by authorized facility operators; and

   B. Manual control. Manual control by authorized facility operators to allow adjustment of heating and cooling set points globally from a single point in the EMCS; and

   C. Automatic Demand Shed Control. Upon receipt of a demand response signal, the space-conditioning systems shall conduct a centralized demand shed, as specified in Sections 120.2(h)1 and 120.2(h)2, for non-critical zones during the demand response period.

Building Electric Peak Demand Management

- Peak demand management and response are becoming more important in building systems and control
- May not have much impact on the individual building <u>total</u> energy use, but important for overall societal energy and environmental management
- Considerations go beyond just one building's energy cost and utilization

Implementing Demand Response in Buildings

- What types of actions are possible?
- Planning for a new building versus retrofitting in an old building
- Case study example
- Communication protocols needed

What "tools" are available for DR?

- The obvious first choices:
  - HVAC systems
    - Setpoints
    - Thermal energy storage
  - Lighting
- Perhaps you have considered:
  - Plug load management
  - General overall energy conservation effects
- Other more unique considerations
  - Non-traditional thermal energy storage

Execution of Demand Response

- Buildings typically contain both deferrable and non-deferrable electric loads for the same end-users.
- Key questions to answer:
  - What to curtail?
  - How long?
  - How to verify (and who does the verifying)?
  - Comfort considerations
  - Safety, security concerns
  - Control and monitoring
- Externally generated versus internally created events:
  - External by utility or outside agent
  - Internal at owner's discretion (demand limiting or peak shaving) - May be more effective

Davis, P. "Smart Grid and Building Operations," ASHRAE Journal 55(11):B23-B25, November 2013

Example: Implementing Demand Response in an Existing Campus

- Project goals: Study how could automated demand response measures be implemented in existing campus of buildings with wide range of technologies available and real-time price tariff
- First example of test case: Saturday 7 June 2014 (low occupancy, limited 'risk')
  - Changed zone set points by +3° F
  - Changed supply air set point also +3° F
  - Changed upper limit for AHU fan speed from 100% to 90% of maximum (when possible)
  - Thermal comfort survey

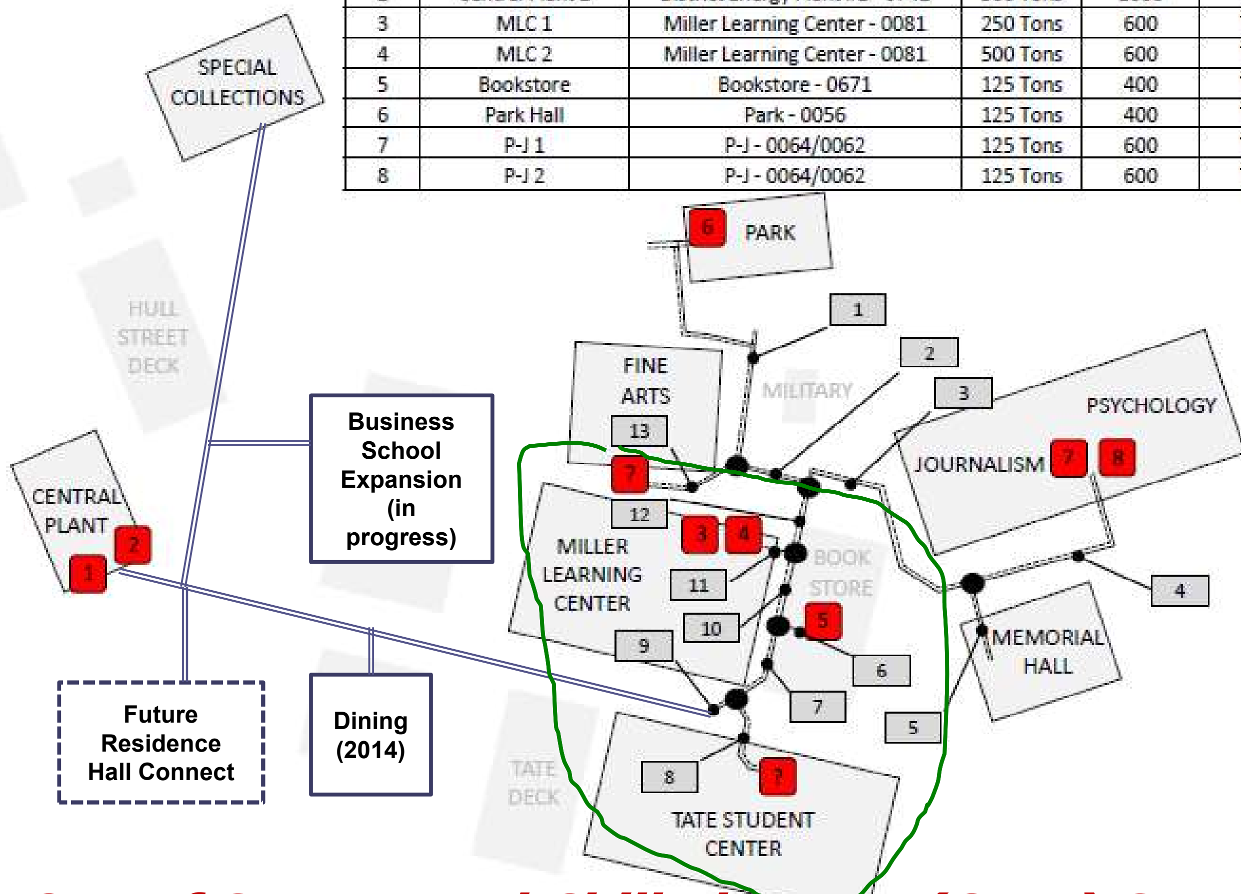
District Chilled Water Loop #1

Central District - Chiller Table

Dwg #	Chiller	Location	Rated Capacity	CT Size (Amps)	Staging	Heat Exchanger (y/n)
1	Central Plant 1	District Energy Plant #1 - 0741	420 Tons	1000	TBD	TBD
2	Central Plant 2	District Energy Plant #1 - 0741	500 Tons	1000	TBD	TBD
3	MLC 1	Miller Learning Center - 0081	250 Tons	600	TBD	TBD
4	MLC 2	Miller Learning Center - 0081	500 Tons	600	TBD	TBD
5	Bookstore	Bookstore - 0671	125 Tons	400	TBD	TBD
6	Park Hall	Park - 0056	125 Tons	400	TBD	TBD
7	P-J 1	P-J - 0064/0062	125 Tons	600	TBD	TBD
8	P-J 2	P-J - 0064/0062	125 Tons	600	TBD	TBD

Central District - Chilled Water Piping

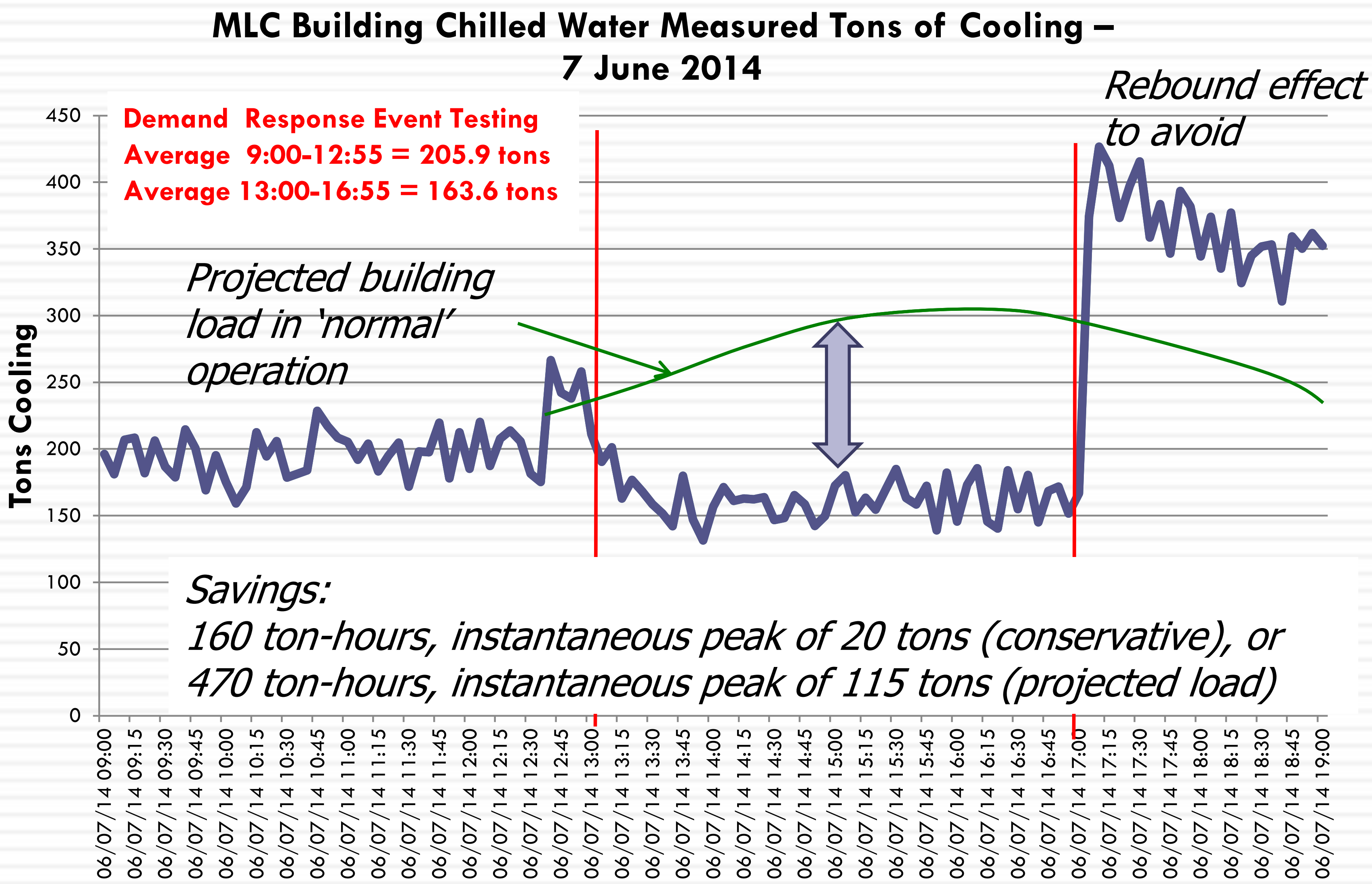
Pipe Segment Number	Pipe Dia. (in)	Approx. Length (ft)
1	8	600
2	10	130
3	10	420
4	10	400
5	6	150
6	6	35
7	18	165
8	10	165
9	20	10
10	18	135
11	8	60
12	16	125
13	6	190



Approximate Building Footprint
Approximate Chiller Location

One of Seven Total Chilled Water (CHW) Systems on Campus

Initial Test in 2014: Demand Reduction Potential

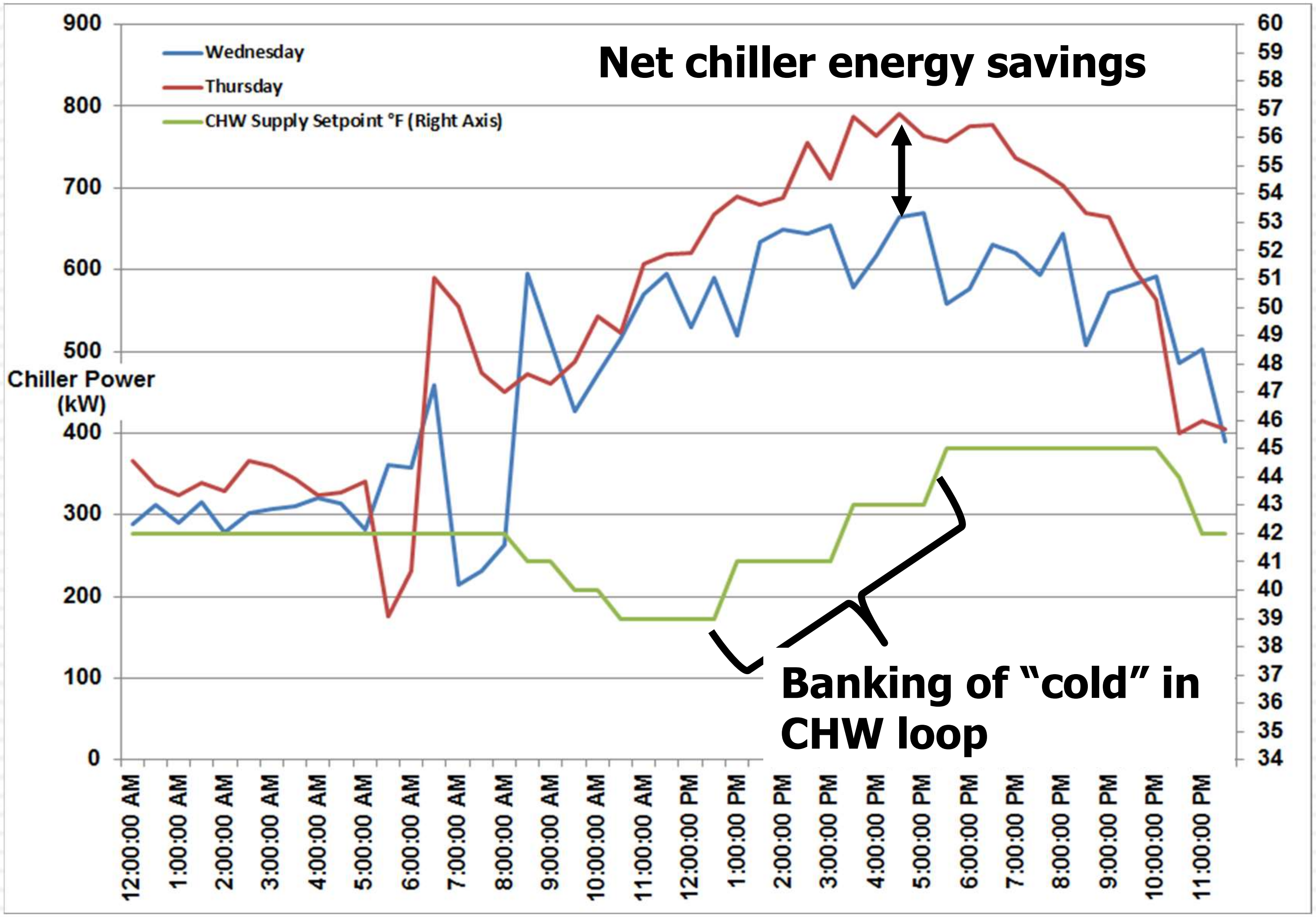


Thermal Comfort Survey Results

- *No real difference in perceived thermal comfort (both cases were 'good'); statistically 'close'*

June 7 (ADR Test Date)				June 19 (Control)		
PREDICTED MEAN VOTE ESTIMATOR				**PREDICTED MEAN VOTE ESTIMATOR**		
"COMFORT"	**#Votes**	**Score**		**"COMFORT"**	**#Votes**	**Score**
Cold	1	-3		Cold	2	-6
Cool	0	0		Cool	0	0
Slightly Cool	0	0		Slightly Cool	0	0
Neutral	20	0		Neutral	51	0
Slightly Warm	0	0		Slightly Warm	0	0
Warm	0	0		Warm	0	0
Hot	6	18		Hot	5	15
Total	27	15		Total	58	9
	PMV=	**0.555556**			**PMV=**	**0.1551724**
	PPD =	**11.5%**			**PPD =**	**5.5%**

Combined CHW and Air Side Test



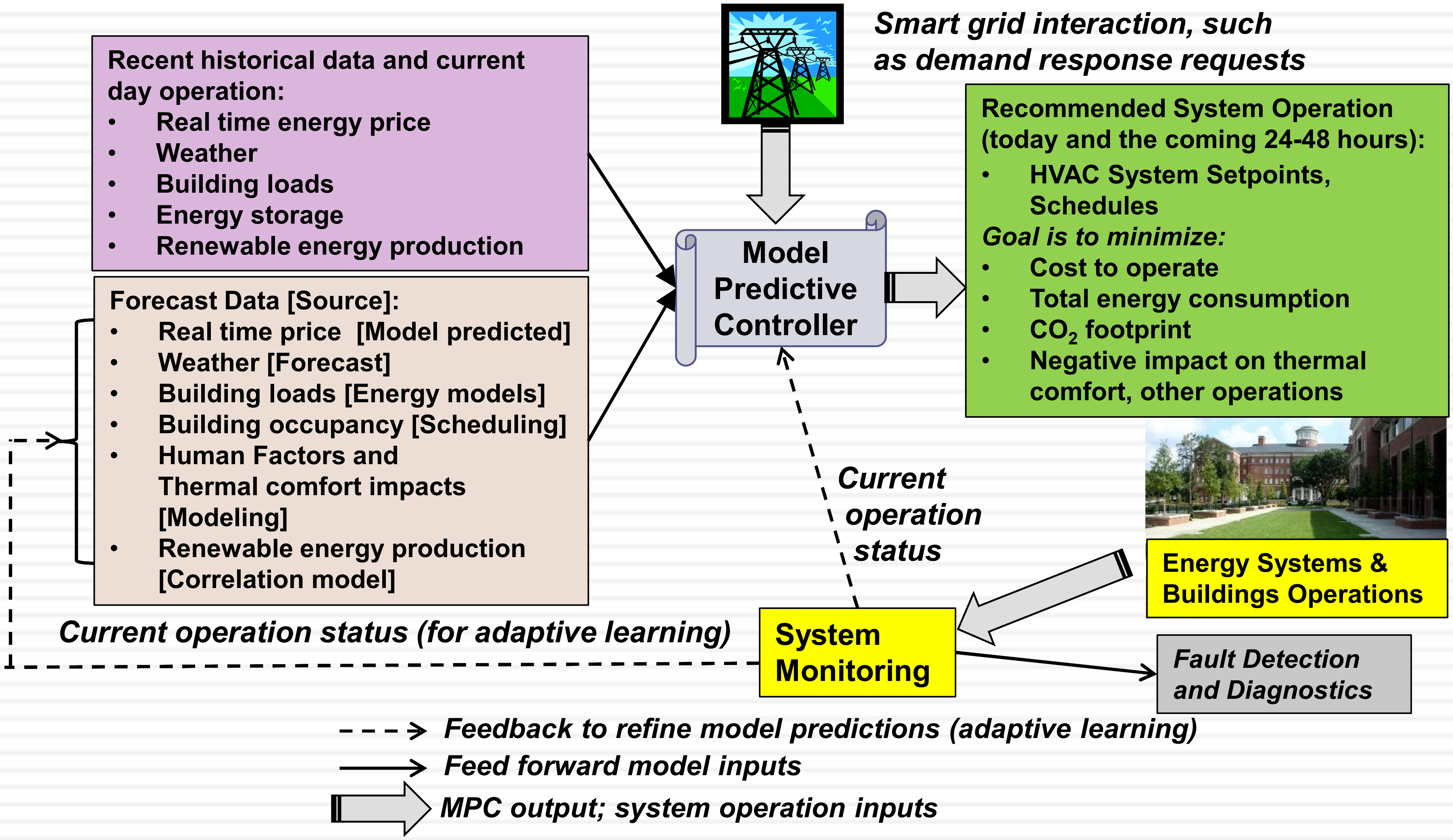
August 26-27, 2015

			% Compared to Test Day		
Day	Total kWh	Peak kW	Total kWh	Peak kW	High T (ºF)
Monday	42,507	2,447	129.0%	128.0%	92.6
Tuesday	36,109	2,211	109.6%	115.7%	90.0
Wednesday	32,939	1,911	-	-	86.9
Thursday	36,584	2,132	111.1%	111.5%	87.0

Lessons Learned from this Test

- Perhaps temperature setpoints overall could be altered, or at least during higher cost time periods?
- Timing and scheduling
  - What are the optimal setpoint changes?
  - What times to start and stop?
  - How to avoid the rebound effect ('soft-start')?
- Most difficult… Need to be adaptable to the technologies in place
  - How to implement with automation and controls not designed for 'automated' demand response

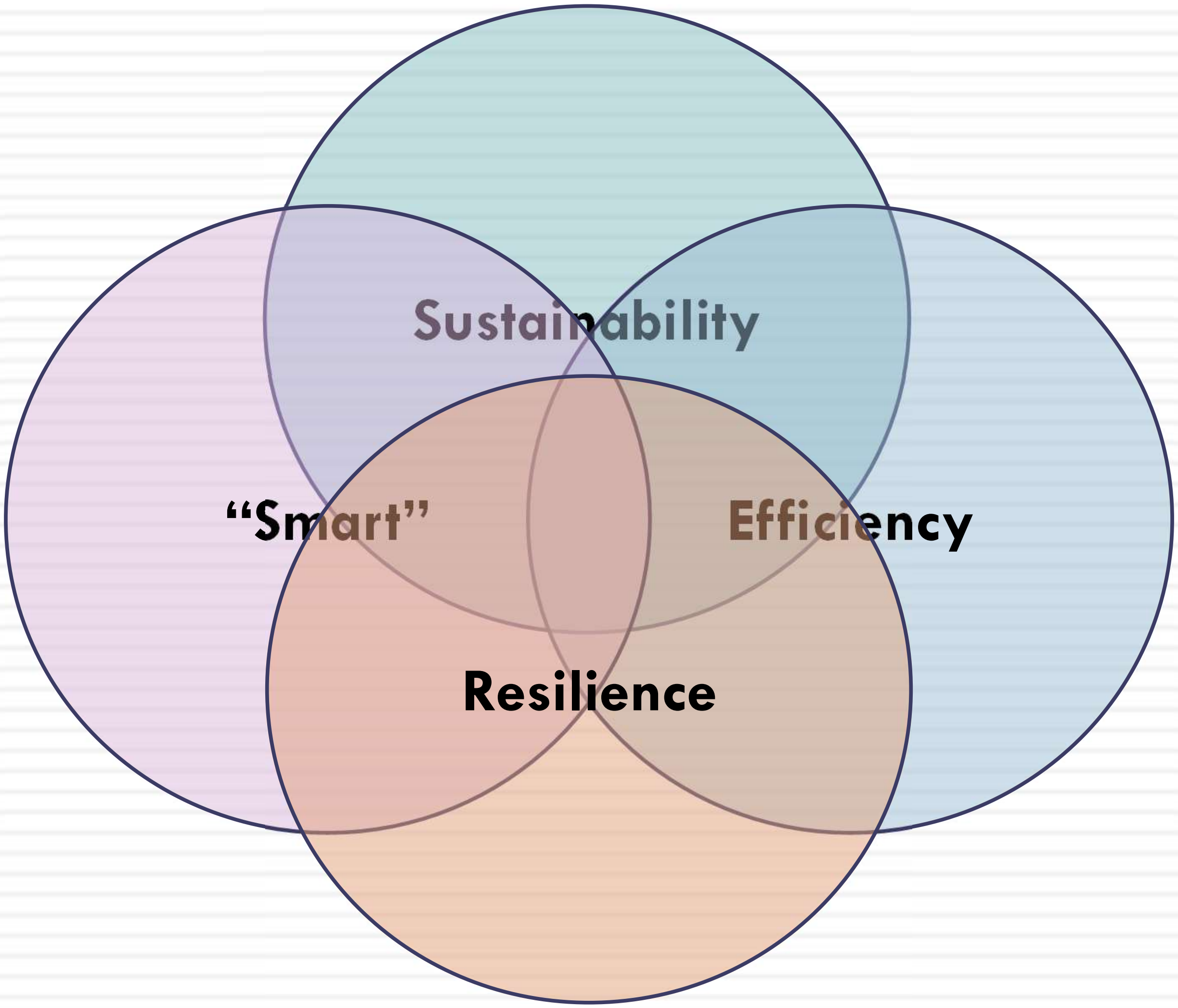
Vision for Model Predictive Control



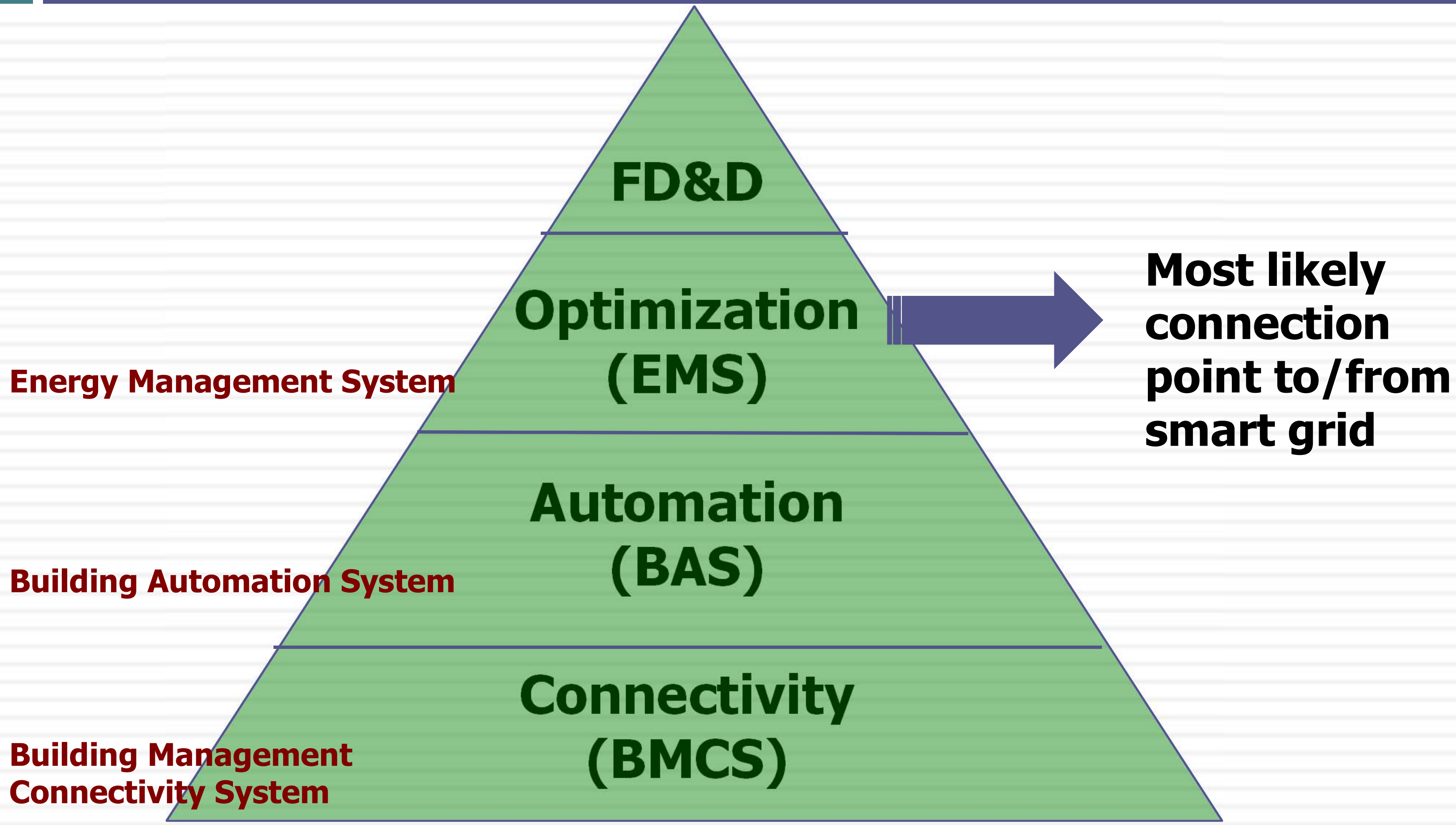
A Smart Grid Increases Resilience of the Built Environment

- Smart buildings and their equipment
- Microgrids
- Distributed generation (CHP, renewables)
- Energy storage
- Grid monitoring and control
- Smart grid to neural grid evolution

Sustainability, Resilience, Efficiency and "Smart" – The Interrelationship



Building Controls Pyramid Featured in Operation and Interactions with Grid



ASHRAE Digital Lighthouse and Industry 4.0

- Smart buildings integrated to a smart grid relates well to the presidential theme of Chuck Gulledge, ASHRAE president 2020-2021
  - Workflow inefficiencies
  - Information and data are not captured
  - Shackled to the analog age
  - Adapt new technologies such as virtual design and construction, computational fluid dynamics, digital twins, drones, LIDAR point cloud maps of as built conditions, augmented reality

https://www.youtube.com/watch?v=Pz4iSCDDiG0

Smart Buildings 4.0

- My personal observations:
  - 1.0 Hot … open the window! (up to early 20th century)
  - 2.0 We have air conditioning! (mid-20th century)
  - 3.0 Integrated controls, BAS (circa 1980's, BACNet in 1995)
  - 4.0 OpenADR, smart technology, digital twins, Internet of Things, data analytics

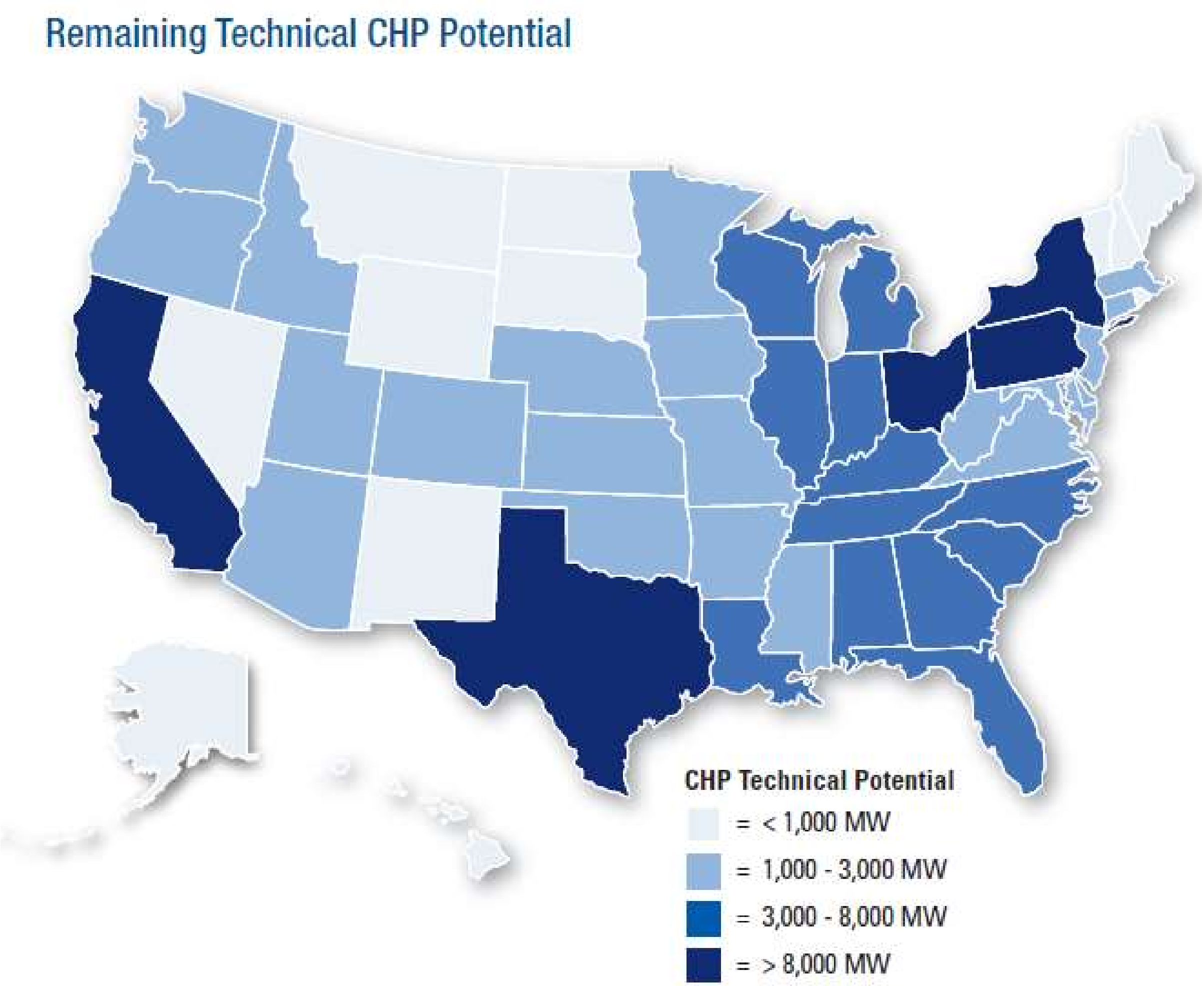
Microgrids are a Natural Outgrowth from Traditional “Standby Generator”

- Serve multiple buildings
- Good candidates for consideration are a medical complex, university or large corporate campus, and military bases
- Can be integrated with multiple generation sources of traditional and renewable energy
- Well suited for combined heat-cooling-power systems

Microgrid Types

- Microgrid operation modes:
  - Local generation (when grid is operational or not)
  - Local load management (demand response, etc.)
  - Parallel operation with grid/market interaction (possibly sending excess power to grid depending on real-time market conditions)
  - Island mode (allows independent operation if grid down for long period of time)
- Types:
  - Grid-tied utility distribution microgrids (UDMs)
  - Direct current microgrids (DC)
- A key to future growth is with greater creativity in both the public policy and business model arenas.

CHP as Distributed Generation



Nearly 9% of total U.S. generation capacity is in the form of CHP systems

Source: "COMBINED HEAT AND POWER: Effective Energy Solutions for a Sustainable Future" Oak Ridge National Lab, ORNL/TM-2008/224, December 2008

CHP Integrated with Renewable Energy Provides Layers of Resilience

Source: US DOE Better Buildings Dist. Energy Resources Disaster Matrix

Ranking Criteria

Four basic criteria were used to estimate the vulnerability of a resource during each type of disaster event. They include the likelihood of experiencing:

1. *a fuel supply interruption,*
2. *damage to equipment,*
3. *performance limitations, or*
4. *a planned or forced shutdown*

○ *indicates the resource is unlikely to experience any impacts*

◒ *indicates the resource is likely to experience one, two, or three impacts*

● *indicates the resource is likely to experience all four impacts*

Table 1. Matrix of DER Vulnerability to Weather Events

Natural Disaster or Storm Events	Flooding	High Winds	Earthquakes	Wildfires	Snow/Ice	Extreme Temperature
Battery Storage	◒	○	◒	●	○	◒
Biomass/Biogas CHP	◒	◒	◒	●	○	○
Distributed Solar	○	◒	◒	●	◒	◒
Distributed Wind	○	◒	◒	◒	◒	◒
Natural Gas CHP	○	○	◒	◒	○	○
Standby Generators	◒	○	◒	●	◒	○

Resilience and Reliability

- ***Resilience*** – The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events[1] (natural or human caused)
  - Could be result of acute shocks or chronic stresses
  - Aging grid infrastructure mean more vulnerability
- ***Reliability*** – Minimized number of power outages, duration of an outage and overall recovery time

[1]Source: ICC. Building Codes: Driving Growth through Innovation, Resilience and Safety. https://www.iccsafe.org/professional-development/safety2/resiliency/.

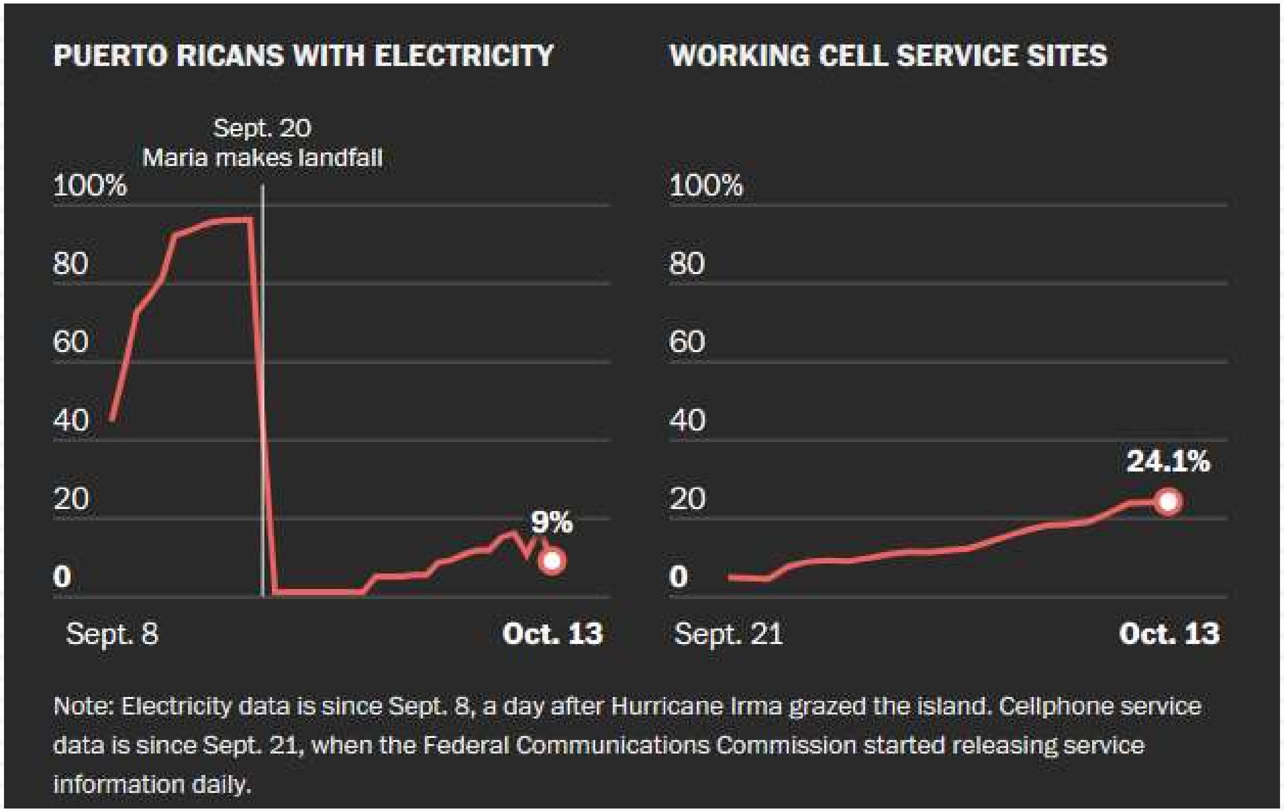
Distinguishing Chronic Versus Acute

- ***Chronic*** stress or problems
  - In a person: diabetes, heart disease, etc.
  - For the grid:
    - Changing climate and increased temperatures → increased grid demand
    - Fuel availability and bottlenecks (e.g., natural gas used for power generation)
- ***Acute*** shock examples
  - In a person: heart attack or stroke
  - For the grid:
    - Extreme weather events (hurricanes, etc.)
    - Human induced, such as cyber attacks

Lessons from Puerto Rico

- The island was devastated by Hurricane Maria on September 20, 2017 (also damaged earlier by Irma on September 8)
- Essentially entire island power grid down (>85%); very slow recovery, estimated at least six months

Puerto Rico One-Two Punch and Recovery



Source: Washington Post. 2017. https://www.washingtonpost.com/graphics/2017/national/puerto-rico-hurricane-recovery/?utm_term=.876578f45c89.

Rebuild a Better Way?

- Why rebuild to the old, outdated standard a grid that did not function well to begin with?
- Desired to rebuild new with:
  - Distributed generation (solar and wind)
  - Microgrids
  - Energy storage
- Only 2% of island-wide generation from renewables in FY 2017
- New legislation set targets for 100% renewables by 2050 and ramping up energy efficiency

Monitoring in Smart Grid can Improve Recovery

- Utilities can detect and address grid outages faster

New Smart Grid Means Fewer Outages For Georgia Power Customers

Georgia Power announced investments in "smart grid" technologies which can help avoid 17 million minutes of potential power outages.

By De Castillo (Patch Staff) - Updated August 31, 2016 2:50 pm ET

My house after Trop. Storm Irma, Sept. 11, 2017

Energy Storage

The Need for Energy Storage

"Storage will be critical

for large scale implementation

of sustainable energy."

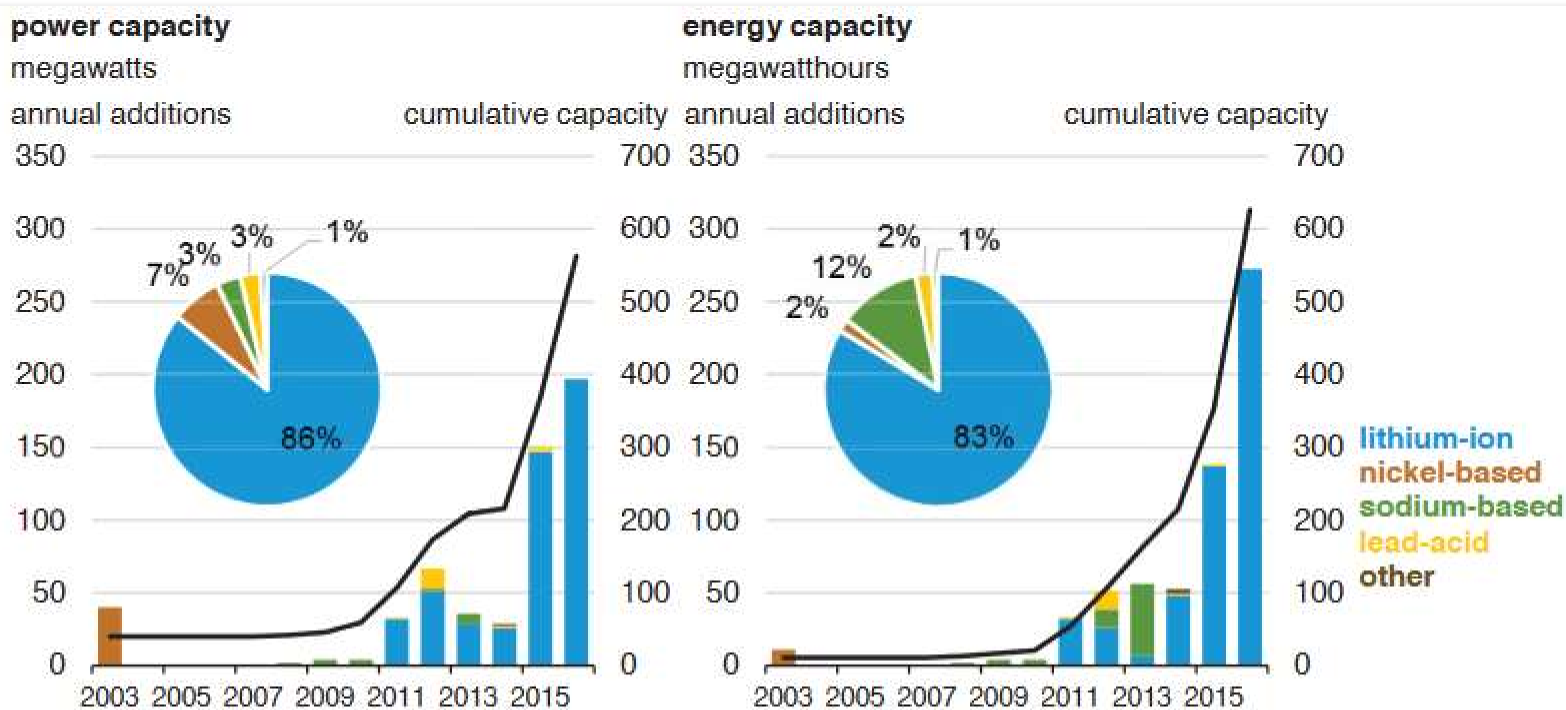
– The November 2007 California ISO report "Integration of Renewable Resources"

Principle Challenges for Energy Storage Growth

- Cost competitive technology needed
  - Life-cycle cost and overall performance (efficiency, energy density, cycle life, etc.)
- Validated reliability and safety
- Equitable regulatory environment
  - Reducing institutional and regulatory hurdles to similar that of other grid resources
- Industry acceptance
  - Must have confidence that it can be deployed as expected and it delivers as promised
- **Some of that storage can/could/should be imbedded into building systems**

U.S. Grid Related Energy Storage in Rapid Growth Mode

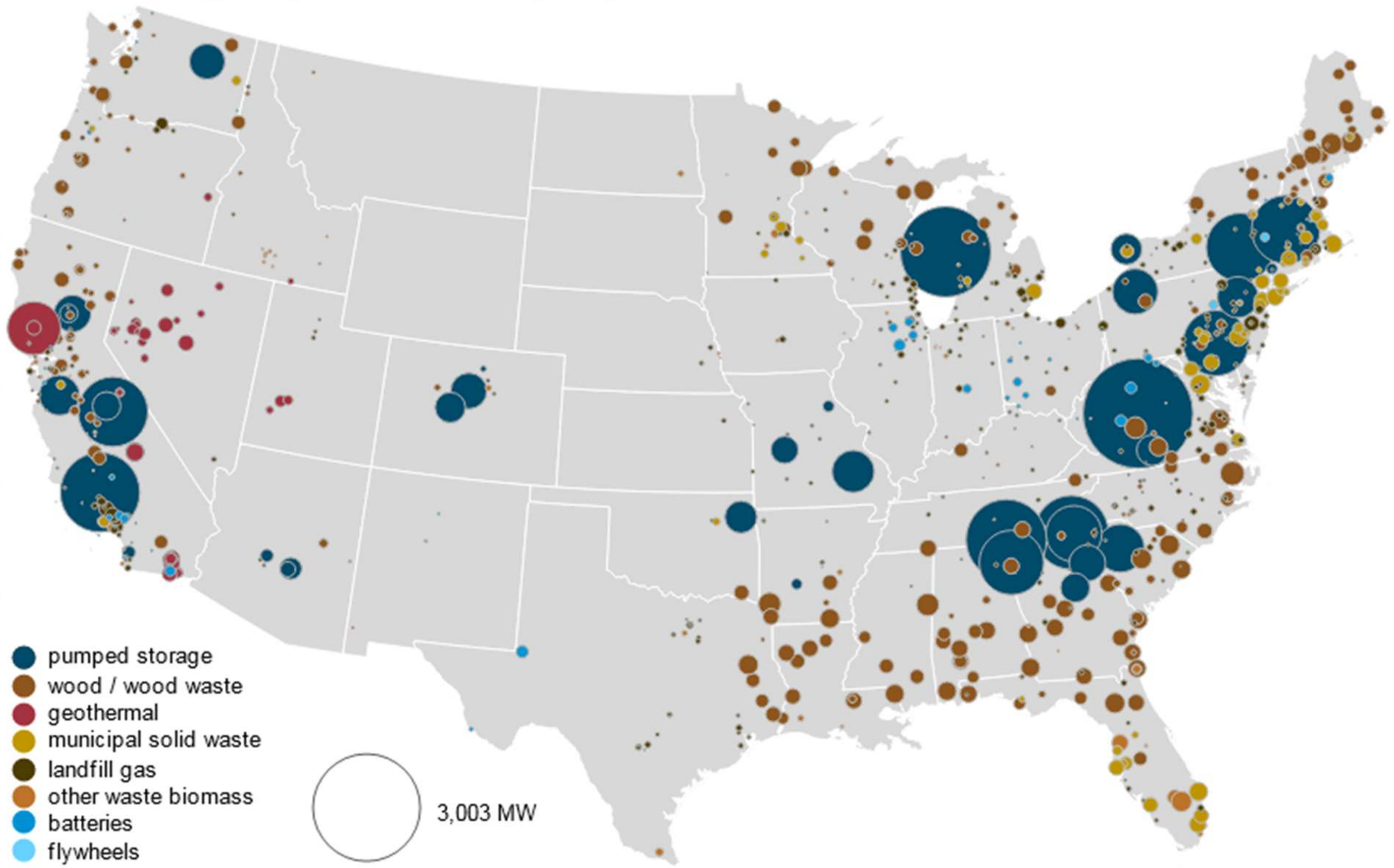
- Only 10% in 2014 was "behind the meter", but by 2019 expected to be 45%
- Mostly thus far in PJM (13 states and D.C.) and California
- Europe and Japan have higher fractions of the total grid capacity as storage



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Regional Variations in U.S.

Distribution of energy storage and other renewable power plants in the Lower 48 states



Other Methods for Energy Storage as Supplement to Grid Energy

- Potential for chilled water or hot water to be used as a means to supplement grid electrical storage *similar to thermal energy storage systems for buildings:*
  Defined as "**Grid Interactive Thermal Storage**"
- Integrating electric vehicles into the grid

Energy Storage at Residential Scale

- Salt River Project in Arizona, test case with 4,500 houses coordinated by NREL

https://www.nrel.gov/news/program/2018/arizona-utility-and-nrel-launch-home-energy-storage-study.html

Observations on Energy Storage

- Will energy storage negate the need for demand response measures?
- Increased emphasis on resilience will be a big driver for energy storage
- Utility scale grid storage or distributed (building scale) storage?

From Smart Grid to a Neural Grid?

- Smart Grid 1.0
  - Some pockets of connectivity
- Currently evolving into Smart Grid 2.0
  - Widespread connectivity, communication and automation (building systems evolving in parallel)
- Future neural grid (and buildings?)
  - “Everything Belongs”
  - Distributed energy assets and generation, storage
  - Cloud based AI evaluation, control
  - Self-healing and learning

The Impact of Buildings' Distributed Generation and Storage Capacity

- Increased distributed generation by buildings adds to the problem that utilities need to address
- Building energy storage in parallel with utility scale storage
- ***Communication of the utility with buildings will help alleviate the duck curve problems***

The Future?: "Autonomous Energy Grids (AEG)"

- A concept proposed from NREL
- The AEG effort envisions a self-driving power system—a very "aware" network of technologies and distributed controls that work together to efficiently match bi-directional energy supply to energy demand
- Fractalized group of microgrids, adjusting to local and current conditions

Source: T&D World, 12 Sept 2019
https://www.tdworld.com/distributed-energy-resources/bottom-designing-decentralized-power-system

(Another) Future Big Question/Issue

- Transition to all electric buildings and localities?

New York Times, Feb. 4, 2020

‘All-Electric’ Movement Picks Up Speed, Catching Some Off Guard

As cities across the nation embrace electric power as a cleaner alternative to natural gas, developers are scrambling to keep up.

Why Do This?

- Berkeley California banned natural gas hookups in new buildings July 2019
  - Purpose: Wean developers off natural gas and fossil fuels, reducing carbon emissions
- The idea 'went viral', under consideration by Los Angeles, San Francisco and Seattle (but also 'banned' by some states)
- Not surprisingly, somewhat controversial…

But There is an Alternative Approach: Power to Gas

- Renewable energy generated hydrogen (via electrolysis), potential use for:
  - Energy storage during periods of lower energy demand than production (more efficient/effective than batteries)
  - Fuel cells (stationary or vehicles)
  - Injected into natural gas lines (reduces carbon intensity)
- Early implementation for excess energy storage
  - 100 kW system for NREL
  - EnergiePark Mainz, 6 MW initial phase
  - Proposed North Sea 700 MW wind farm supplement

Other Issues, Observations

The Need for Cybersecurity

- The 800 pound (400 kg) gorilla in the room …

Building Designers Need to Now Consider …

- System considerations:
  - On-site renewable energy
  - Other distributed generation (CHP, etc.)
  - Advanced building automation systems
  - Integrated system concepts
  - Energy measurement and metering
  - Electric vehicle charging stations
  - Ease of use, interoperability with existing technologies
- Demand response adaptations:
  - HVAC control and operation strategies

Human Factor Considerations

- Thus far, development of smart grid, smart buildings has focused on larger industrial or commercial scale technologies
- But it is human beings who will interact and control this technology
- Smart grid concepts are also coming (or could be coming) to developing countries as well, without the evolutionary aspects as in U.S.
- Next slide provides insight into the human factor considerations

Thank You!

- Other comments, questions, concerns, advice …

Dr. Tom Lawrence, P.E., LEED-AP

proftom@uga.edu