Harnessing the Power of Distributed Energy Resources: Quantifying Transactive Energy Economics

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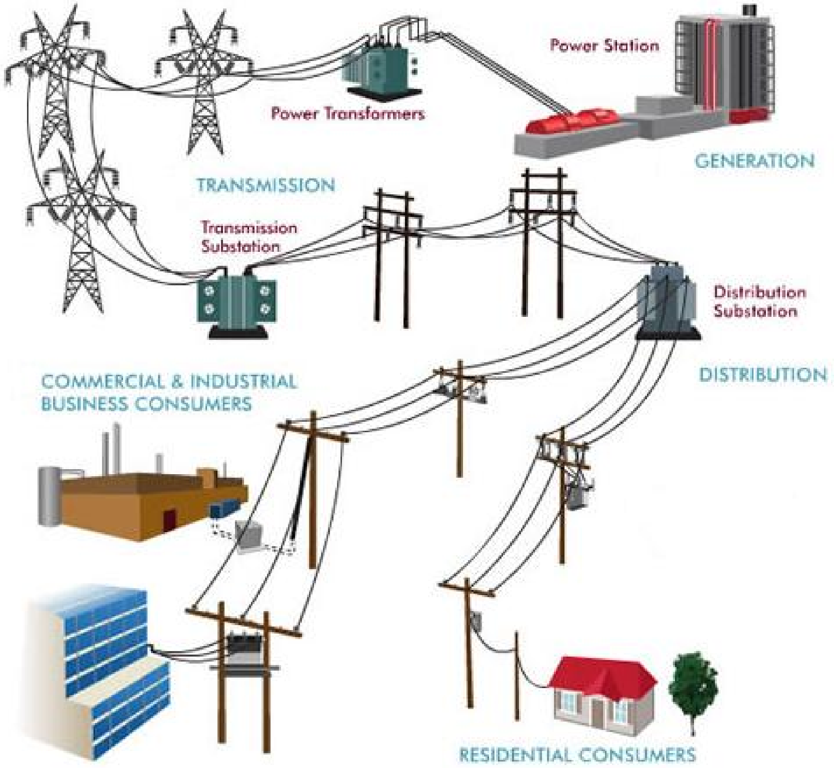
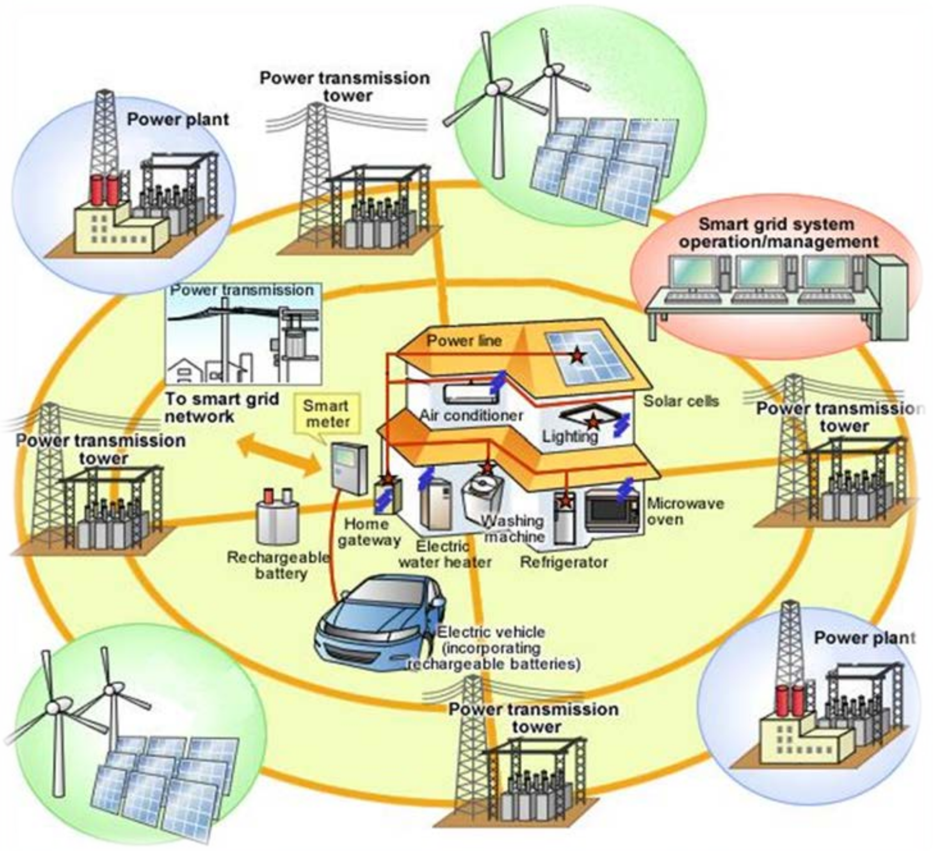
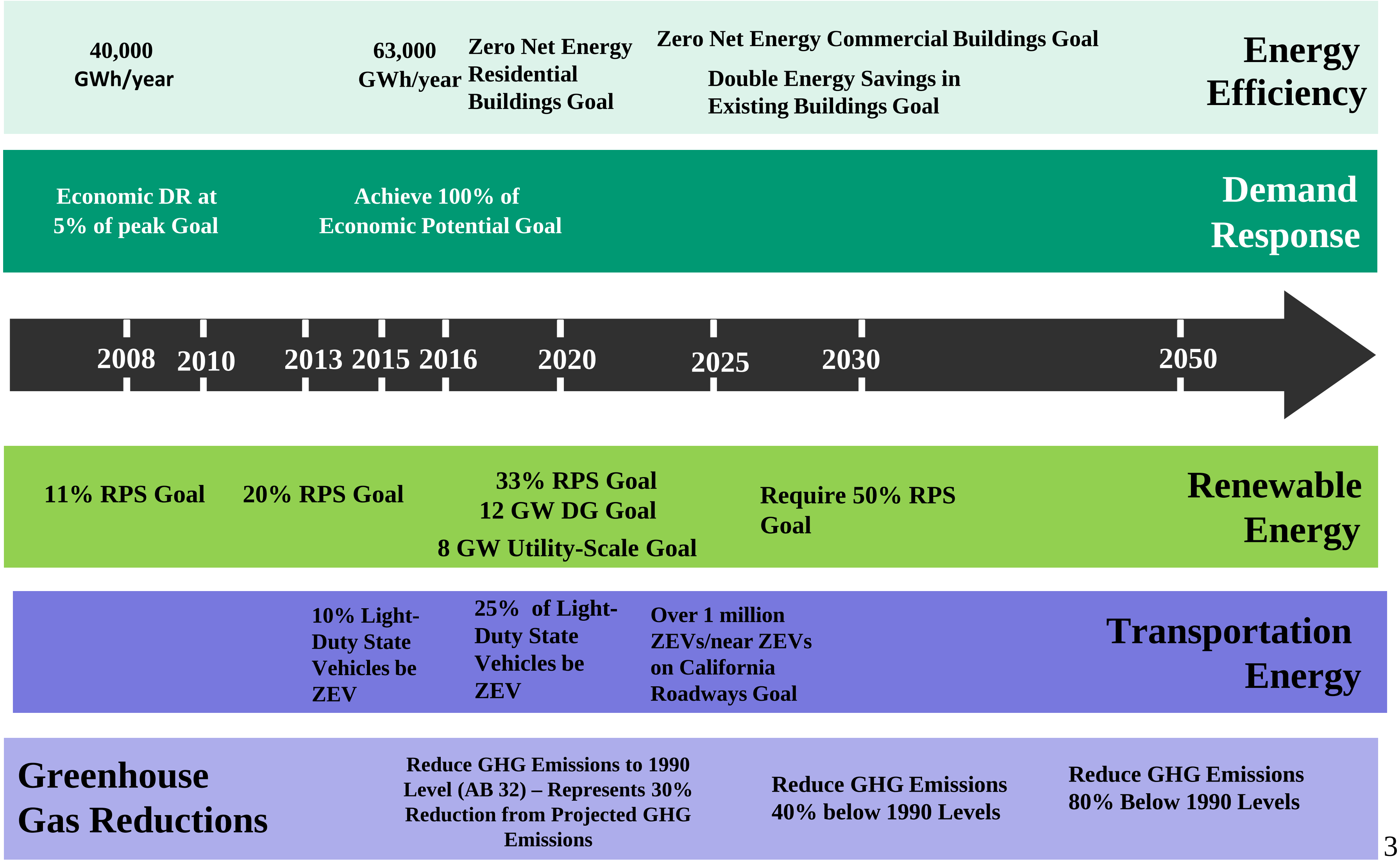
The Future Electric Grid in California





State Energy Policy Drives Energy RD&D Investments



Energy Efficiency

40,000 GWh/year

63,000 GWh/year

Zero Net Energy Residential Buildings Goal

Zero Net Energy Commercial Buildings Goal

Double Energy Savings in Existing Buildings Goal

Demand Response

Economic DR at 5% of peak Goal

Achieve 100% of Economic Potential Goal

2008 2010 2013 2015 2016 2020 2025 2030 2050

Renewable Energy

11% RPS Goal

20% RPS Goal

33% RPS Goal
12 GW DG Goal

8 GW Utility-Scale Goal

Require 50% RPS Goal

Transportation Energy

10% Light-Duty State Vehicles be ZEV

25% of Light-Duty State Vehicles be ZEV

Over 1 million ZEVs/near ZEVs on California Roadways Goal

Greenhouse Gas Reductions

Reduce GHG Emissions to 1990 Level (AB 32) – Represents 30% Reduction from Projected GHG Emissions

Reduce GHG Emissions 40% below 1990 Levels

Reduce GHG Emissions 80% Below 1990 Levels

Envisioning the Grid of the Future

Zero-Net Energy Affordable Multifamily Homes

Higher Mix of Renewable Energy Integration

Distributed Generation, a Significant Component of California's Electric System

Plug-In Electric Vehicles

Energy Efficiency Research

Lighting

HVAC

Plug Loads

Food Service

Commercial Laundry

Food Processing

Water

Data Centers

Renewable and Advanced Generation Research

Promoting Renewable-Based Communities

Integrating Renewables and Improving Grid Reliability at Camp Pendleton

Renewable Forecasting & Modeling

Advancing Combined Heat and Power Technologies

Converting waste to energy

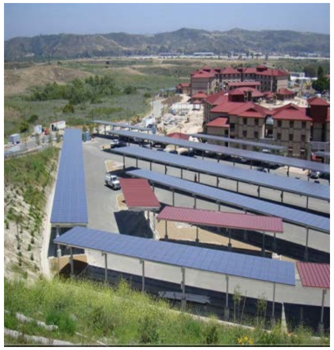
Thermal Energy Storage for Concentrated Solar

Microgrids Address Different Customers Needs

University Campus
Improve Reliability, Cost Savings,
Be an Environmental Leader

Santa Rita jail
Energy Resilience,
Cost Savings, GHG Reductions

Borrego Springs
Utility Grid Reliability Improvements,
Respond to Customer Outages Faster,
Integration of Renewables



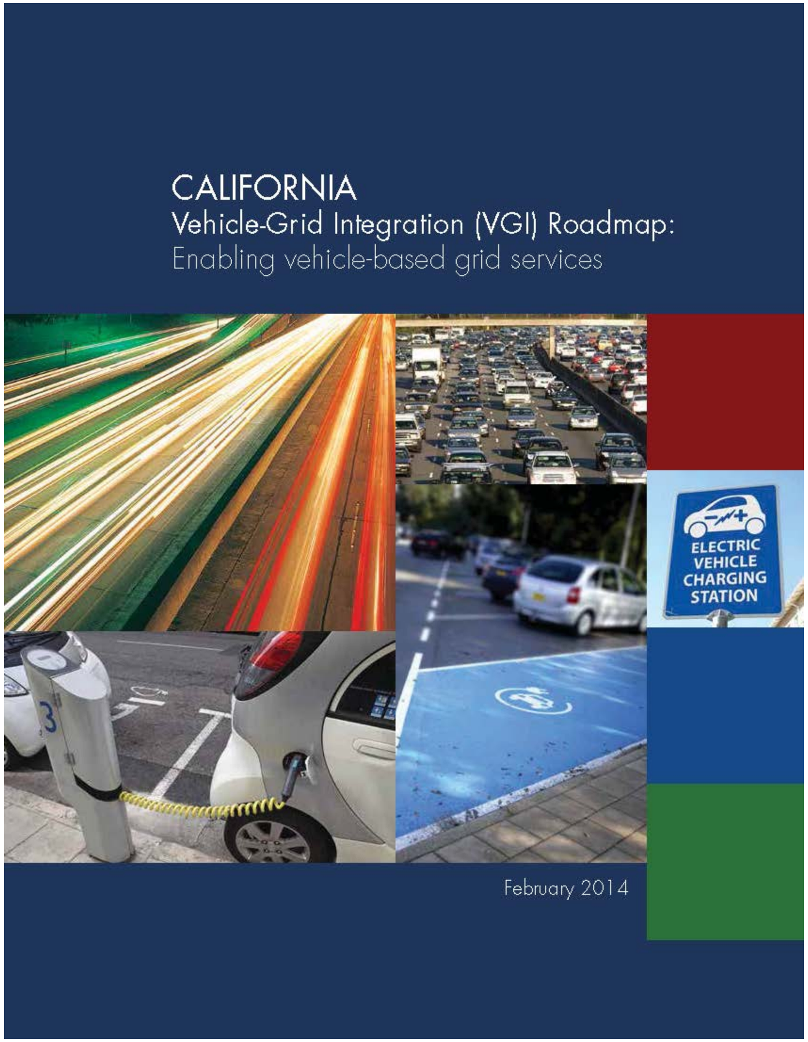
Military Base
Energy Resilience, Cost Savings,
Increased Renewables

Municipal Facility
Increase Reliability,
Compete in Grid Markets
Lower costs

Medical Hospital
Increase Reliability,
More Flexibility
Lower costs

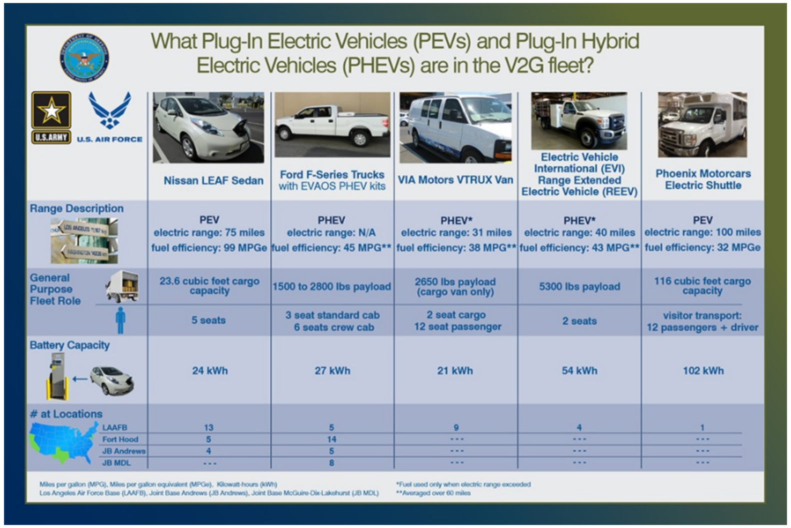
The Role of Energy Storage in the Future

The Role of Electric Vehicles in the Future



CALIFORNIA
Vehicle-Grid Integration (VGI) Roadmap:
Enabling vehicle-based grid services

February 2014



What Plug-In Electric Vehicles (PEVs) and Plug-In Hybrid Electric Vehicles (PHEVs) are in the V2G fleet?

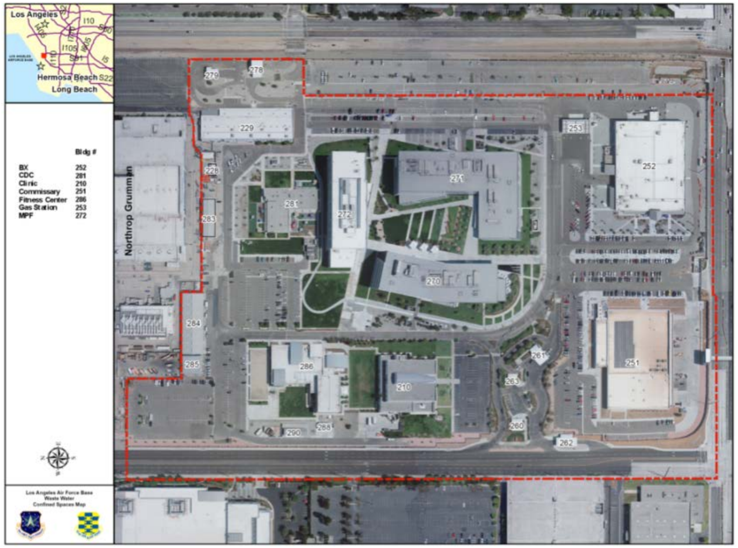
		Nissan LEAF Sedan	Ford F-Series Trucks with EVAOS PHEV kits	VIA Motors VTRUX Van	Electric Vehicle International (EVI) Range Extended Electric Vehicle (REEV)	Phoenix Motorcars Electric Shuttle
Range Description		PEV electric range: 75 miles fuel efficiency: 99 MPGe	PHEV electric range: N/A fuel efficiency: 45 MPG**	PHEV* electric range: 31 miles fuel efficiency: 38 MPG**	PHEV* electric range: 40 miles fuel efficiency: 43 MPG**	PEV electric range: 100 miles fuel efficiency: 32 MPGe
General Purpose Fleet Role		23.6 cubic feet cargo capacity	1500 to 2800 lbs payload	2650 lbs payload (cargo van only)	5300 lbs payload	116 cubic feet cargo capacity
		5 seats	3 seat standard cab 6 seats crew cab	2 seat cargo 12 seat passenger	2 seats	visitor transport: 12 passengers + driver
Battery Capacity		24 kWh	27 kWh	21 kWh	54 kWh	102 kWh
# at Locations	LAAFB	13	5	9	4	1
	Fort Hood	5	14	- - -	- - -	- - -
	JB Andrews	4	5	- - -	- - -	- - -
	JB MDL	- - -	8	- - -	- - -	- - -

Miles per gallon (MPG), Miles per gallon equivalent (MPGe), Kilowatt-hours (kWh)
Los Angeles Air Force Base (LAAFB), Joint Base Andrews (JB Andrews), Joint Base McGuire-Dix-Lakehurst (JB MDL)

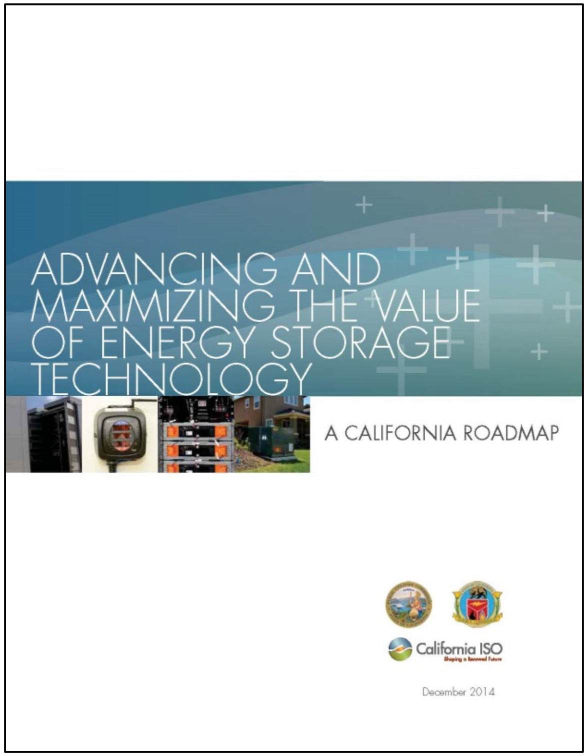
*Fuel used only when electric range exceeded
**Averaged over 60 miles

Electrification of the Transportation Sector: Los Angeles Air Force Base Vehicle-to-Grid Demonstration

- This is the first large-scale research project to demonstrate full V2G capability.
- The goal is for the base to use electric vehicles to co-optimize building load and participation in the California ISO’s ancillary services markets.
- These capabilities will be integrated and optimized using software also being developed through the project.
- This project will allow other entities to benefit from these advances and lessons, and will help improve the value proposition of owning electric vehicles.



Energy Storage and VGI Roadmaps

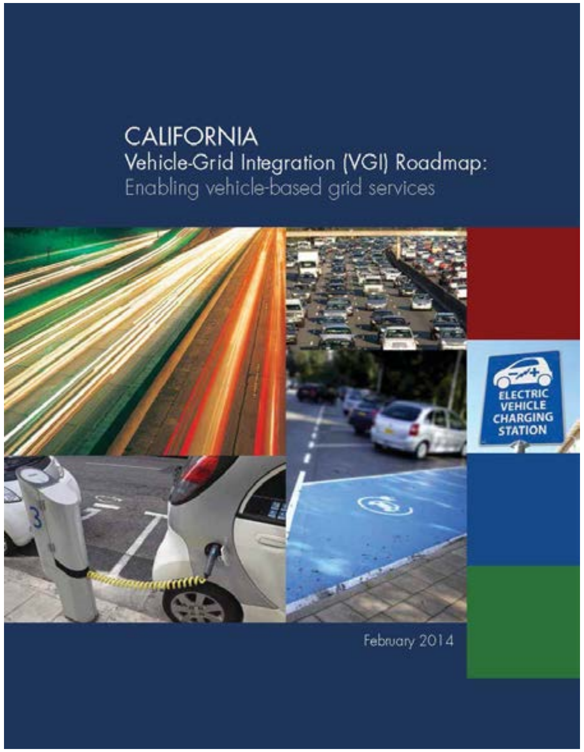


ADVANCING AND MAXIMIZING THE VALUE OF ENERGY STORAGE TECHNOLOGY

A CALIFORNIA ROADMAP

California ISO
Shaping a Renewed Future

December 2014



CALIFORNIA
Vehicle-Grid Integration (VGI) Roadmap:
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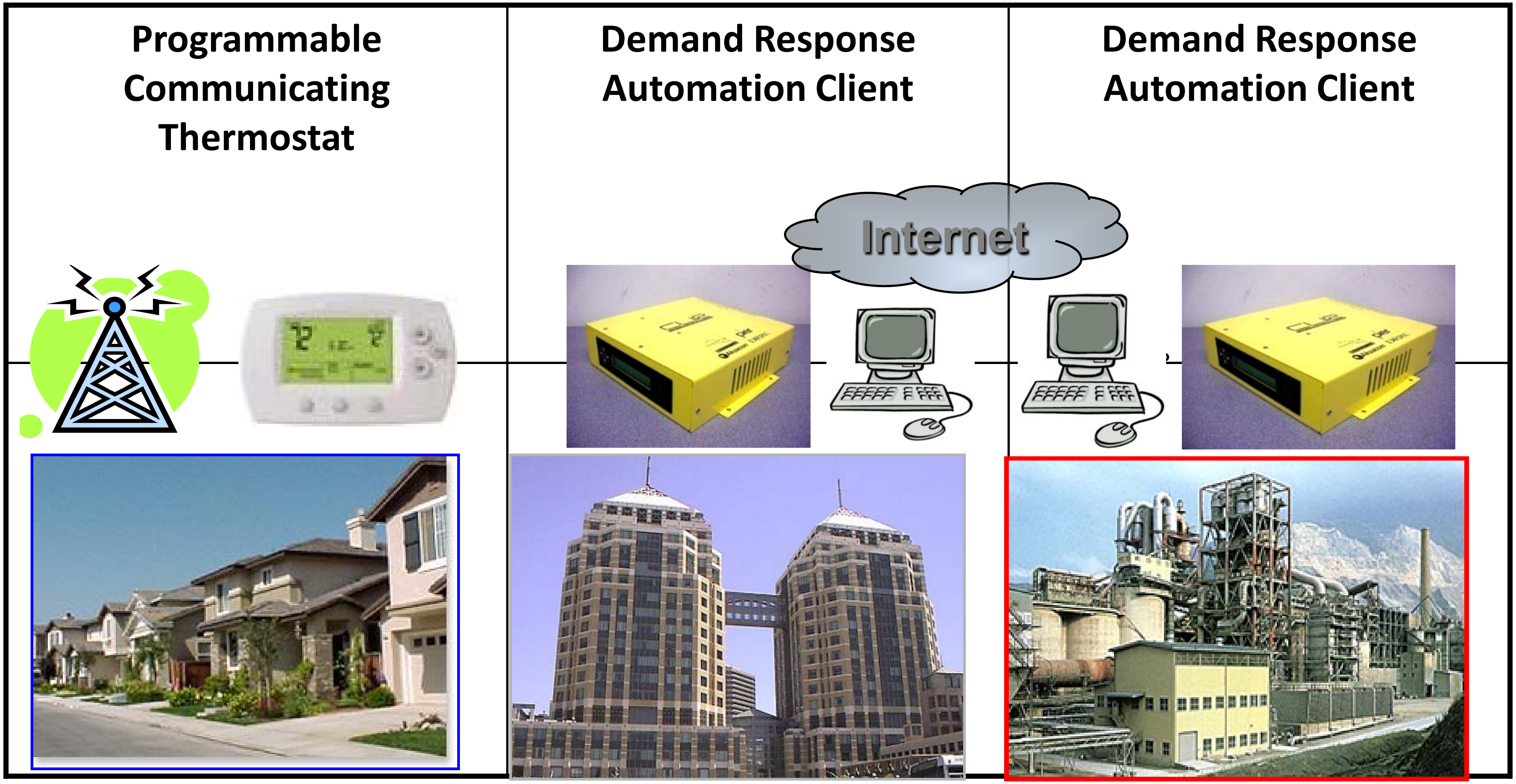
February 2014

Demand Response Automation



Programmable Communicating Thermostat

Demand Response Automation Client

Demand Response Automation Client

Overview of Energy Commission GFO 15-311

Advancing Solutions That Allow Customers to Manage Their Energy Demand Through The Use of Transactive Signals

Development and Use of Transactive Signals

- Focus of this solicitation was to first develop a set of transactive signals and then test how various DR projects respond to such signals
  - Specifically,
    - the technical aspects of this communication and response
    - to identify, inform and develop strategies for overcoming technical, institutional and regulatory barriers to expanding DR participation in California
    - to fund applied research and development projects that test and assess how groups or aggregations of distributed resources respond to current, planned and potential price signals.
- Awards were made in Three Categories

Category 1: DR as supply-side in CAISO Markets

- BMW of North America, LLC
  - Total Charge Management: Advanced Charge Management for Renewable Integration $3,999,900

- Center for Sustainable Energy
  - Meeting Customer and Supply-side Market Needs with Electrical and Thermal Storage, Solar, Energy Efficiency and Integrated Load Management Systems $3,960,805
- OhmConnect, Inc.
  - Empowering Prosumers to Access Wholesale Energy Products $3,995,028

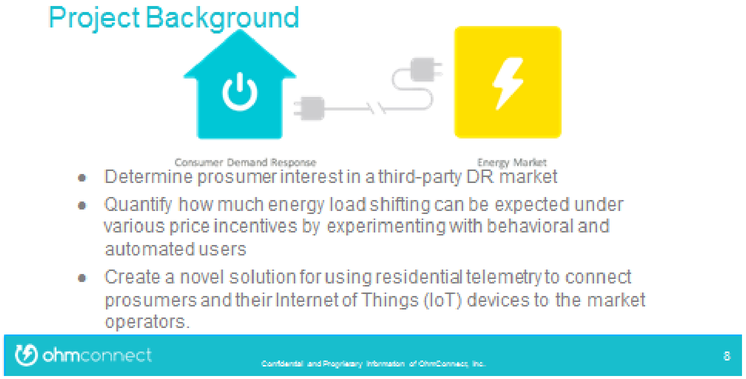
Category 2: DR as Demand Side Resources

- Electric Power Research Institute, Inc. (EPRI)
  - Customer-centric Demand Management using Load Aggregation and Data Analytics $3,998,587
- Alternative Energy Systems Consulting, Inc. (AESC)
  - Residential Intelligent Energy Management Solution: Advanced Intelligence to Enable Integration of Distributed Energy Resources $3,996,597

- The Regents of the University of California (Berkeley)
  - Customer-controlled, Price-mediated, Automated Demand Response for Commercial Buildings $4,000,000
- Universal Devices, Inc.
  - Complete and Low Cost Retail Automated Transactive Energy System (RATES) $3,187,370
- The Regents of the University of California (UCLA)
  - Identifying Effective Demand Response Program Designs for Small Customer Classes $2,007,875

Category 3: Development of Transactive Signal

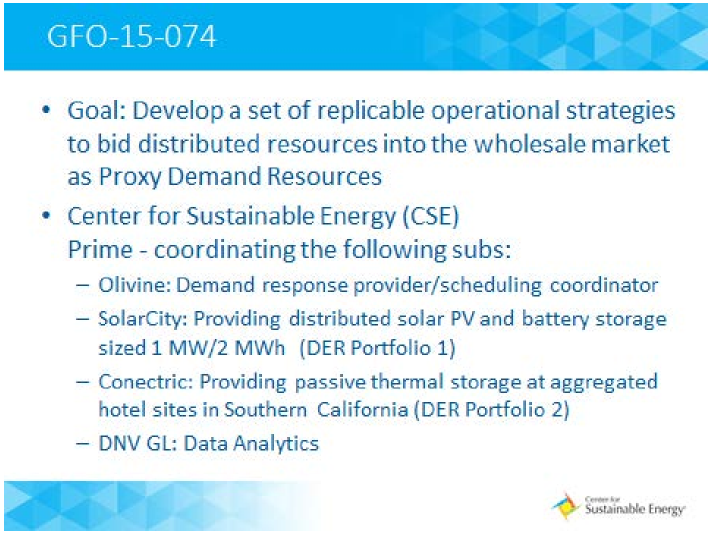
- Electric Power Research Institute, Inc.
  - Transactive Incentive Signals to Manage Electricity Consumption (TIME): A System for Transactive Load Management $499,997
  - This being the actual set of signals to be sent, received and evaluated for customer response by the other grant recipients



Project Background

- Determine prosumer interest in a third-party DR market
- Quantify how much energy load shifting can be expected under various price incentives by experimenting with behavioral and automated users
- Create a novel solution for using residential telemetry to connect prosumers and their Internet of Things (IoT) devices to the market operators.

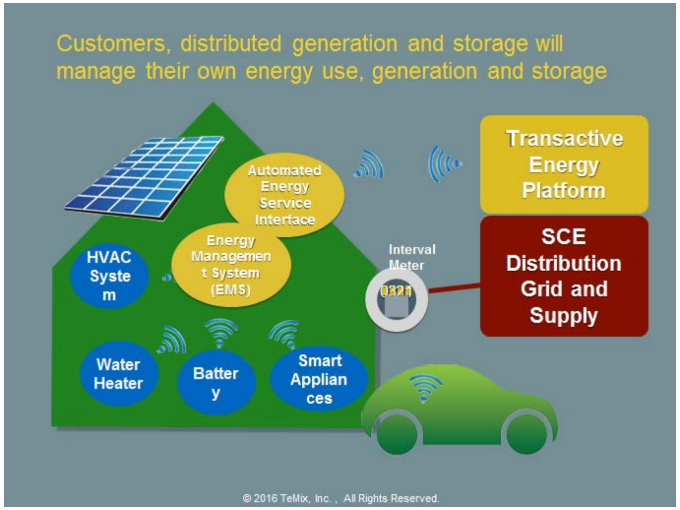
ohmconnect Confidential and Proprietary Information of OhmConnect, Inc. 8



GFO-15-074

- Goal: Develop a set of replicable operational strategies to bid distributed resources into the wholesale market as Proxy Demand Resources
- Center for Sustainable Energy (CSE) Prime - coordinating the following subs:
  - Olivine: Demand response provider/scheduling coordinator
  - SolarCity: Providing distributed solar PV and battery storage sized 1 MW/2 MWh (DER Portfolio 1)
  - Conectric: Providing passive thermal storage at aggregated hotel sites in Southern California (DER Portfolio 2)
  - DNV GL: Data Analytics

Center for Sustainable Energy



Customers, distributed generation and storage will manage their own energy use, generation and storage

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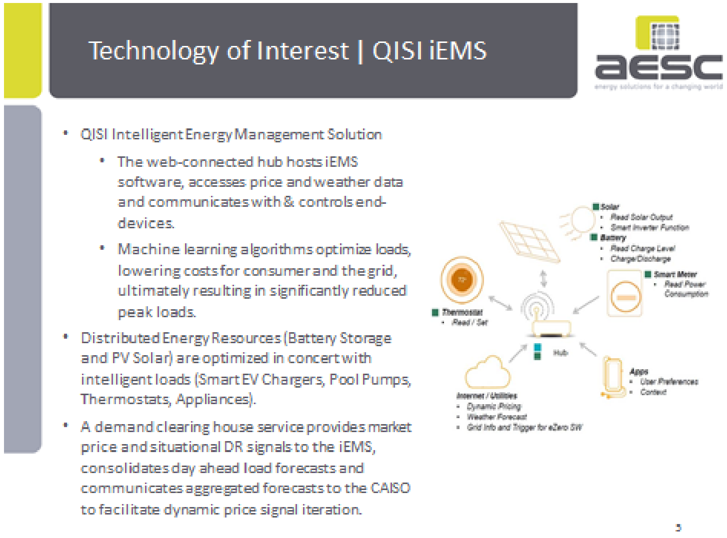


Technology of Interest | QISI iEMS

aesc

- QISI Intelligent Energy Management Solution
  - The web-connected hub hosts iEMS software, accesses price and weather data and communicates with & controls end-devices.
  - Machine learning algorithms optimize loads, lowering costs for consumer and the grid, ultimately resulting in significantly reduced peak loads.
- Distributed Energy Resources (Battery Storage and PV Solar) are optimized in concert with intelligent loads (Smart EV Chargers, Pool Pumps, Thermostats, Appliances).
- A demand clearing house service provides market price and situational DR signals to the iEMS, consolidates day ahead load forecasts and communicates aggregated forecasts to the CAISO to facilitate dynamic price signal iteration.

5

Questions?

NIST Transactive Energy Challenge

Modeling and simulation for the transactive Smart Grid

David Holmberg

TE Challenge Lead, Engineering Laboratory
NIST Smart Grid Program

San Jose Workshop
October 20, 2016

TE Challenge Goals

1. **Simulation tools and platforms**
    1. Demonstrate how different TE approaches can improve reliability and efficiency of the electric grid to address today’s grid challenges
    2. Make use of Phase I-developed co-simulation platform, reference grid, scenarios and metrics to allow comparable results.
    1. Develop a repository of co-simulation platform components.
2. **Collaboration**—promote collaboration among industry stakeholders.
3. **Progress**—work toward implementation of TE applications.
4. **Communication**—provide a stage for teams to present the exciting work they’ve accomplished.

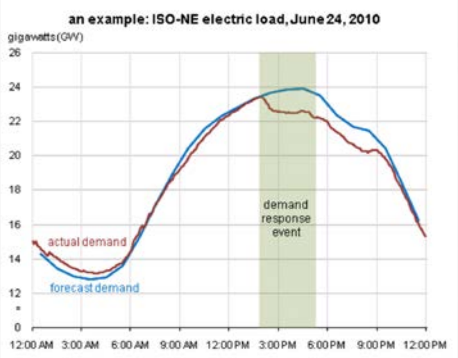
→ Deliver value to utilities, regulators, policy makers and other stakeholders in understanding, testing, and applying TE to meet today’s grid challenges.

Timeline

- September 2015: Launch of Phase I and formation of 7 teams
- Summer 2016: Completion of Phase I team efforts, development of Co-simulation platform architecture
- September 20: Phase I Capstone meeting
- Fall 2016
  - Implementation of basic components of a co-simulation platform tool set.
  - Outreach meetings in San Jose, and NYC
- Early 2017 TE Simulation Challenge Phase II Launch.
  - Focus on TE simulation based on co-simulation platform tools, in addition to
  - Collaboration, demonstration, understanding and communication
- Collaboration site: https://pages.nist.gov/TEChallenge/ gives access to the latest documents
  - JOIN US!

TE Application Landscape Scenarios

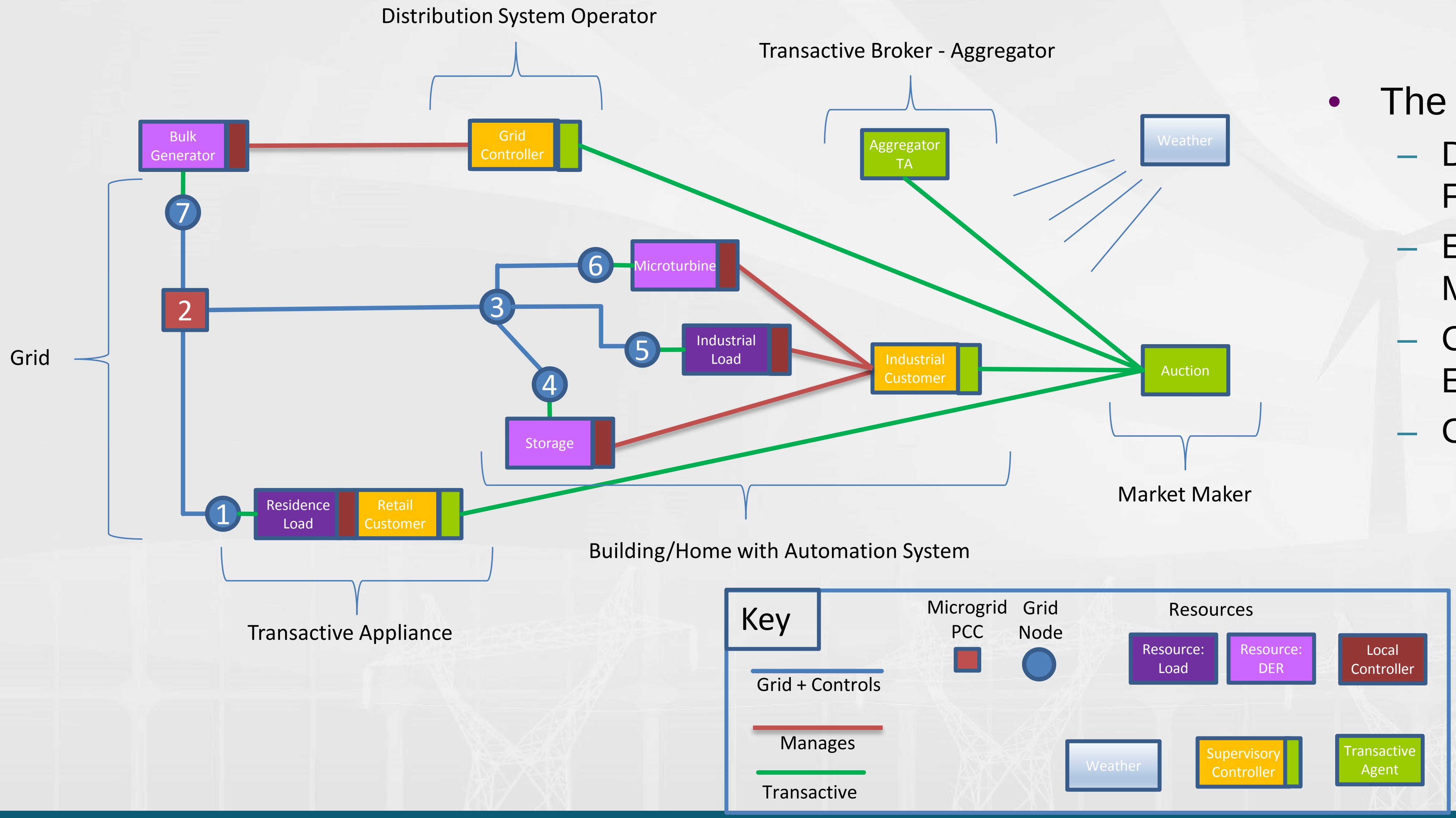
- TE use cases (in pre-read)
  - Cover the landscape of TE applications—how we think TE can support grid operations.
  - To be combined with reference grids, environmental conditions, objectives.
  - 6 use cases:
    1. Peak-day DR
    2. Wind energy balancing reserves
    3. Voltage control for high-penetration distribution circuits
    4. Concentrated EVs
    5. Islanded microgrid energy balancing
    6. System constraint resulting in mandatory curtailment



TE Landscape Scenarios paper abstract

- This paper presents an analysis of the transactive energy (TE) application landscape, specifically examining the ***transactive process***, ***business functions***, ***actors*** in different smart grid (SG) application domains, and ***time scales*** as dimensions of the landscape.
- Six high-level, operational scenarios are presented which cover the TE dimensions, and which can collectively be used to explore TE interactions.
- The paper also reviews the process that was used to analyze the TE landscape, including use case analyses, TE mind map, and a transactive agent interaction model.
- Paper is available on the SGIP.org website (white papers).

Summer progress on Co-simulation Platform



Distribution System Operator

Transactive Broker - Aggregator

Bulk Generator

Grid Controller

Aggregator TA

Weather

7

6

Microturbine

2

3

5

Industrial Load

Industrial Customer

Auction

Grid

4

Storage

1

Residence Load

Retail Customer

Market Maker

Building/Home with Automation System

Transactive Appliance

Key

Microgrid PCC

Grid Node

Resources

Resource: Load

Resource: DER

Local Controller

Grid + Controls

Manages

Transactive

Weather

Supervisory Controller

Transactive Agent

- The Results
  - Draft Technical Framework
  - Extensible Component Model
  - Canonical Experiment/Simulation
  - Core Analytics

Phase I work as input to Phase II simulations

- **Phase I was about foundational elements** in preparation for a more **simulation based research focus in Phase II**.
  - 2 of the Phase I teams were focused on modeling and simulation framework and reference components to allow comparison of simulations.
- Phase I teams also included "**what's working**":
  - Business and Regulatory Models team looking at what is being done or considered today in CA, NY and elsewhere.
  - Common Transactive Services (CTS) team examining minimal set of TE services based on what's used in for established financial markets.
    - TransactiveADR team looking to add these transactive services to the industry standard OpenADR.
  - 2 TE implementations: Microgrids and Virtual PowerMatcher demo teams.
- 11 Background questions are about what works for the customer and how we measure and validate performance of systems.
  - We discover the answers to these questions by examining what has worked and is working
  - Also by modeling and simulation

Connect with the TE Challenge

Go to the TE Challenge collaboration website to get more information on the team efforts and participants, and to get access to work products

Consider joining/forming a team to participate in our TE Challenge Phase II. Let us know how you want to be involved – techallenge-info@nist.gov

Thank you.

NIST Smart Grid Program

Buildings and the Smart Grid

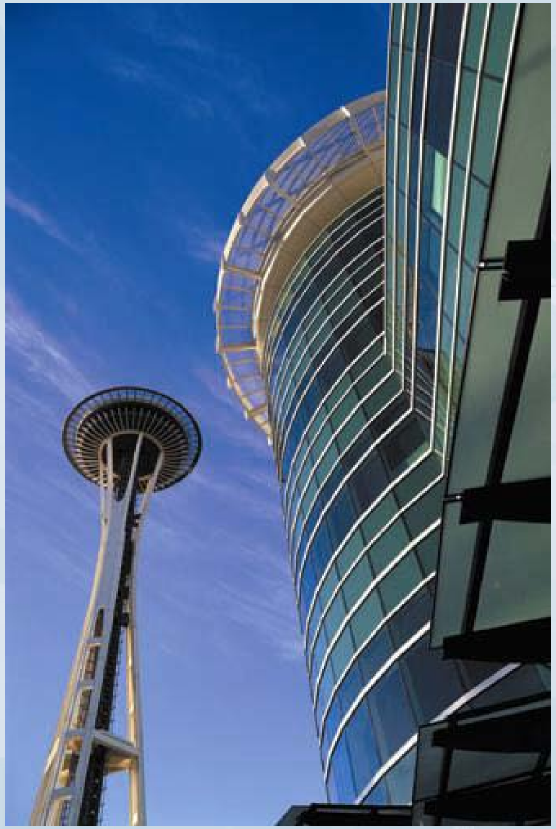
Steven T. Bushby
Group Leader, Engineering Laboratory
NIST Embedded Intelligence in Buildings Program

Harnessing the Power of Distributed Quantifying Transactive Energy Resources: Quantifying Transactive Energy Economics
October 20th 2016

National Institute of Standards and Technology
U.S. Department of Commerce

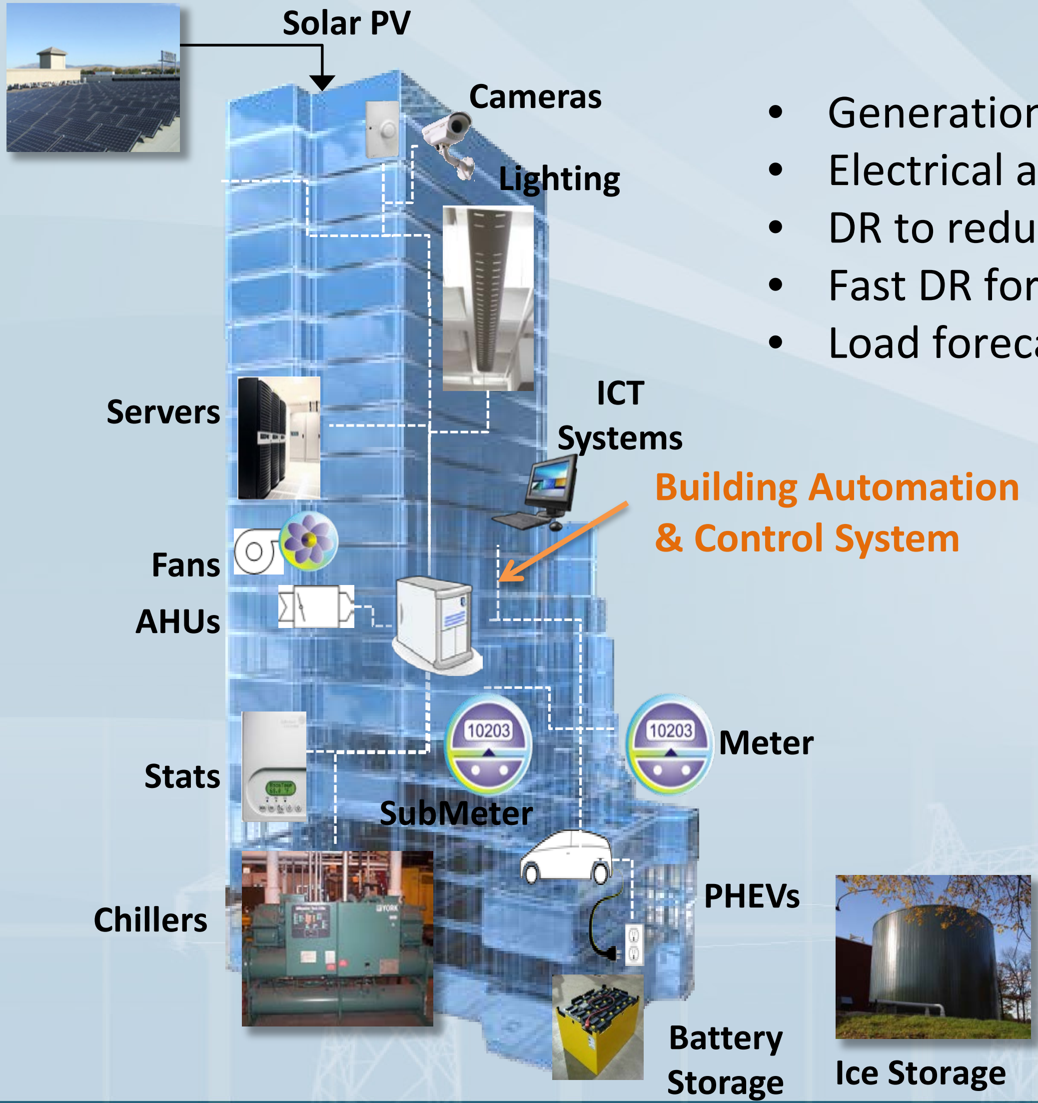
There is no Smart Grid without Smart Buildings!

- 72% of electricity is consumed in buildings (40% commercial, 32% residential)
- As we approach national goals of net-zero energy buildings, renewable generation sources connected to buildings will become increasingly important
- As the nation migrates to electric vehicles, they will be plugged in to buildings



Buildings will no longer be a dumb load at the end of the wire. They will become an integral part of the grid.

Building Resources Potentially Available to the Grid

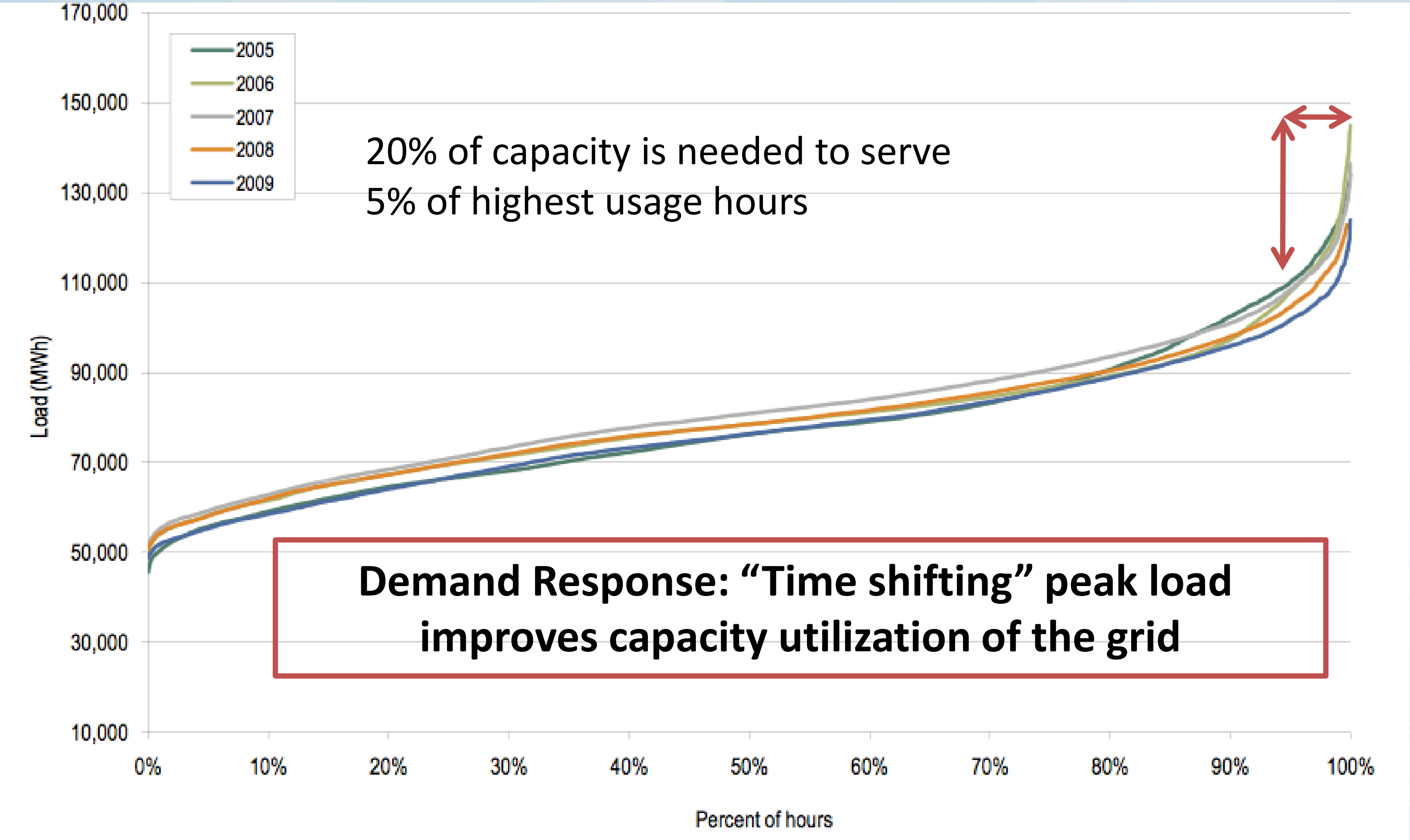


- Generation
- Electrical and thermal storage
- DR to reduce peaks
- Fast DR for some ancillary services
- Load forecasts to improve planning

The scale in homes is much smaller but there are many of them.

Buildings Can Improve Capacity Utilization

PJM Real Time Load Duration

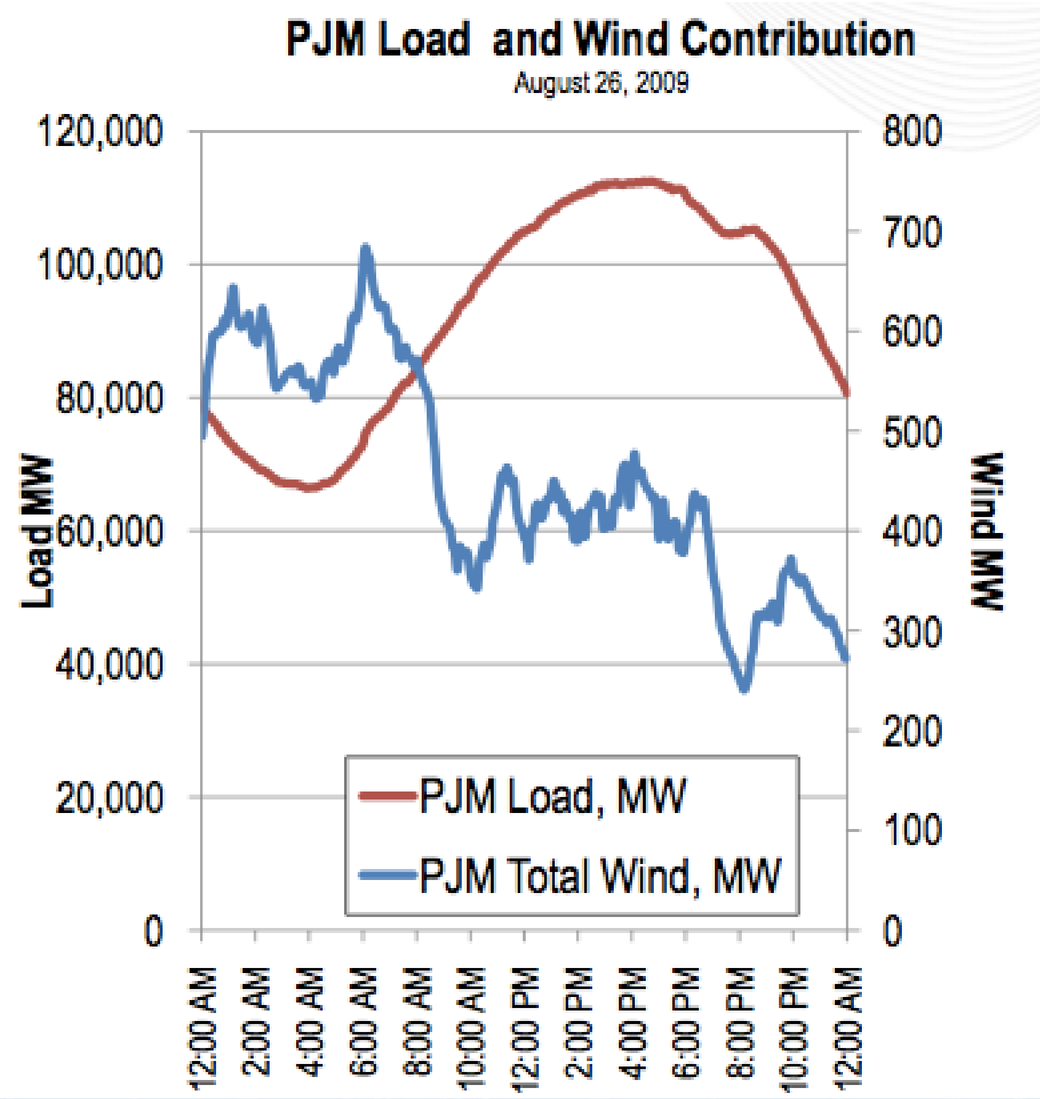


20% of capacity is needed to serve 5% of highest usage hours

Demand Response: "Time shifting" peak load improves capacity utilization of the grid

Source: PJM (a Regional Transmission Organization part of the Eastern Interconnection grid)

Buildings Can Help Integrate Renewables



Renewable sources have their own challenges

- Intermittency
- Need for storage
- Need for power conditioning, quality, conversion systems
- Not all renewables are equally “green”

Today’s Automation and Control Technology

- Industrial – Ubiquitous, mature, capable but generally not configured to support grid needs
- Large Commercial –
  - Installed base slow to change (20 year life)
  - BACnet the dominant technology being installed today
  - Strong trend towards greater system integration and more sophisticated control strategies
- Small Commercial
  - Limited automation and control – mostly thermostats
- Residential
  - Limited automation and control – mostly thermostats

Control System Trends

ASHRAE
NEMA
FSGIM
Facility Smart Grid Information Model
Standard 201

PURPOSE: The purpose of this standard is to define an abstract, object-oriented information model to enable appliances and control systems in homes, buildings, and industrial facilities to manage electrical loads and generation sources in response to communication with a “smart” electrical grid and to communicate information about those electrical loads to utility and other electrical service providers.

ASHRAE NEMA

FSGIM

Facility Smart Grid Information Model

Standard 201

The model will support a wide range of energy management applications and electrical service provider interactions including:

(a) on-site generation,
(b) demand response,
(c) electrical storage,
(d) peak demand management,
(e) forward power usage estimation,
(f) load shedding capability estimation,
(g) end load monitoring (sub metering),
(h) power quality of service monitoring,
(i) utilization of historical energy consumption data, and
(j) direct load control.

How Do You Model Device Energy Management?

Imagine modeling all devices behind the ESI as either an energy manager, energy meter, energy generator, or energy load.

Generator

Load

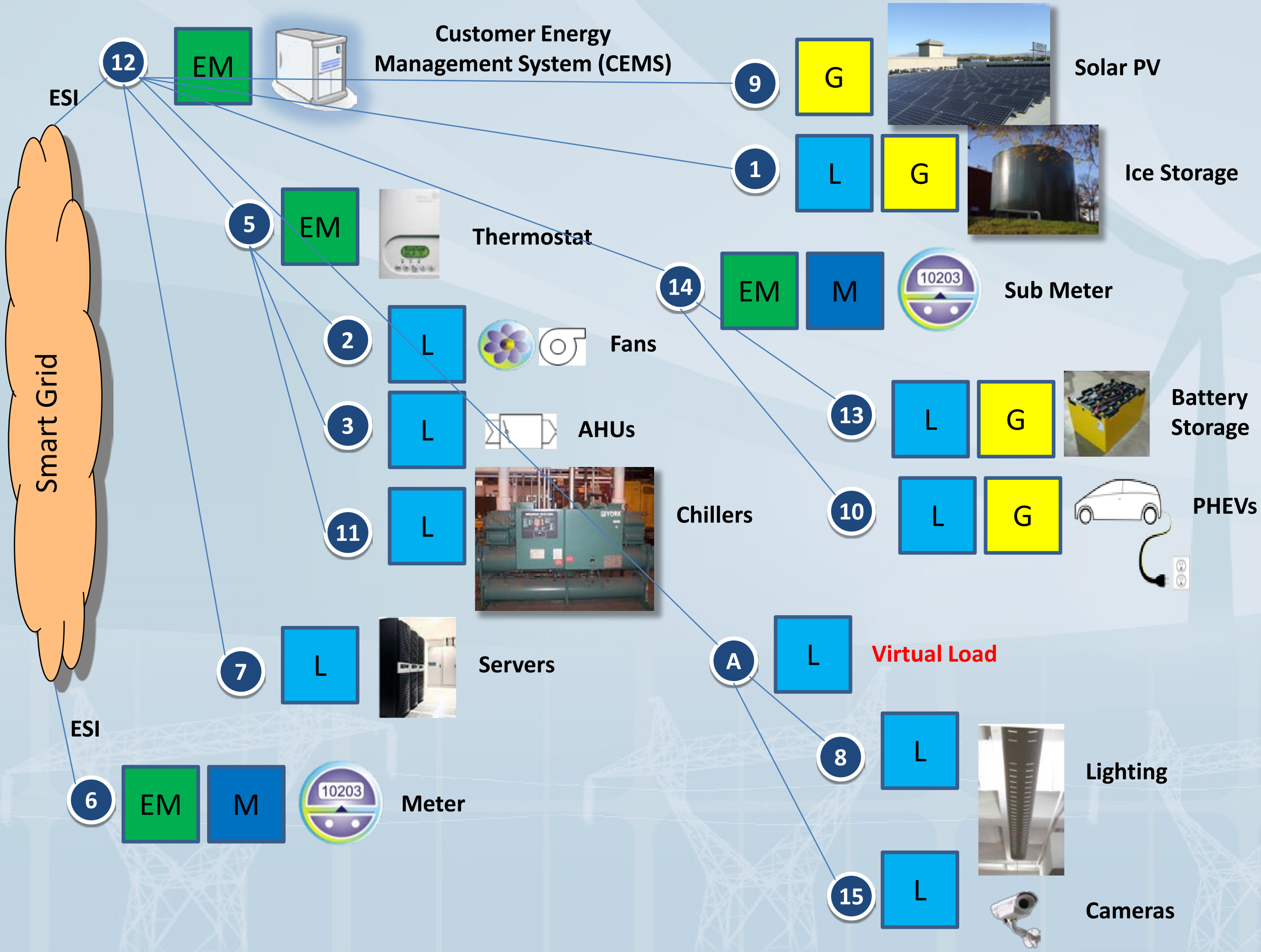
Meter

Energy Manager

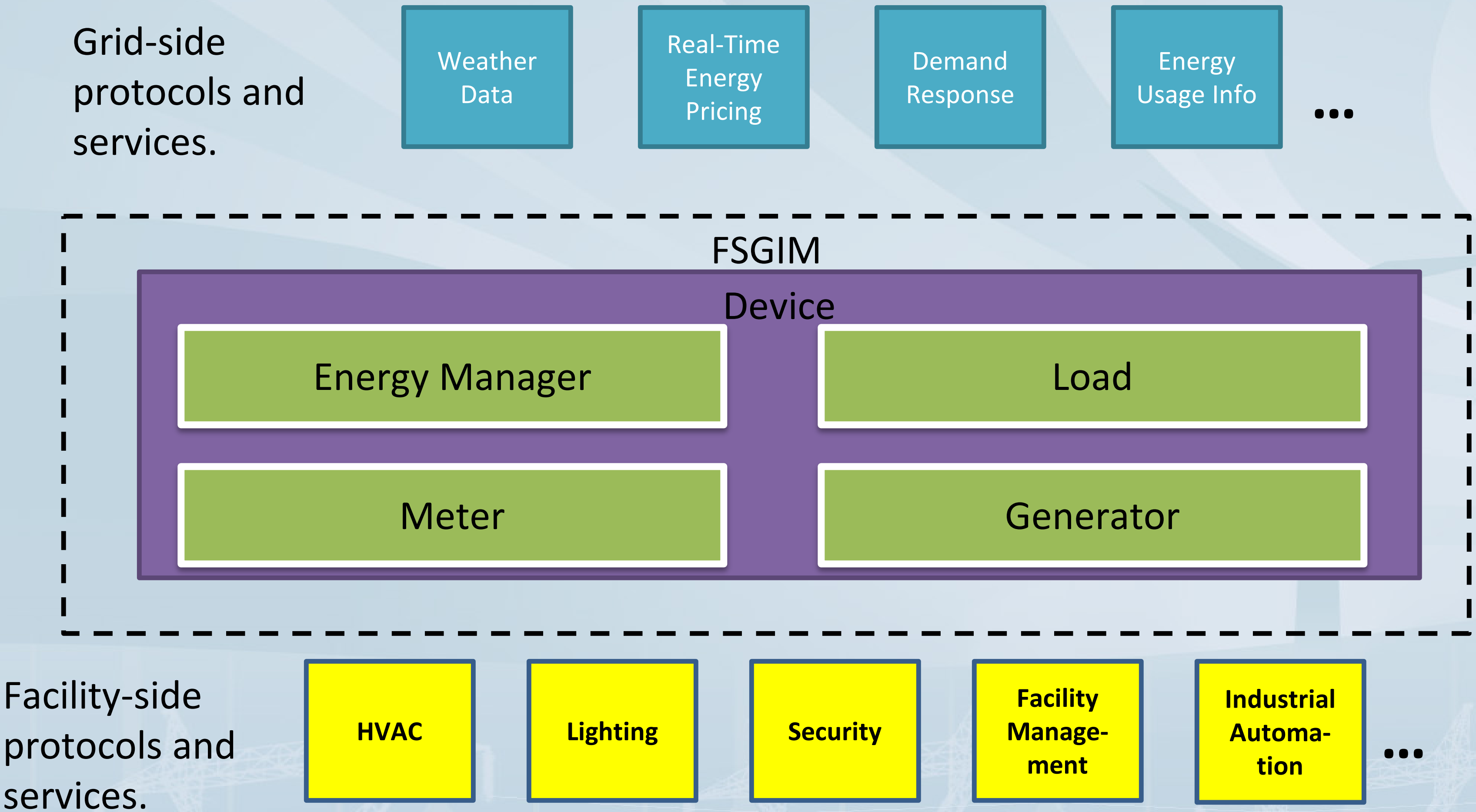
Examples might be:

EMS = Energy Manager
Smart Appliance = Energy Manager + Load
Battery = Generator + Load
Premise sub-meter = Meter

Composition of Devices from Components



FSGIM Overview



Grid-side protocols and services.

Weather Data

Real-Time Energy Pricing

Demand Response

Energy Usage Info

…

FSGIM

Device

Energy Manager

Load

Meter

Generator

Facility-side protocols and services.

HVAC

Lighting

Security

Facility Management

Industrial Automation

…

Impact of the FSGIM

- Compatible with Green Button, OpenADR and weather information services
- Provides standard aggregations that will work in a multi-vendor environment
- Can represent load curves for predicting energy and power consumption or selecting control points

Control technology standards groups are beginning to develop technology specific implementations of the FSGIM

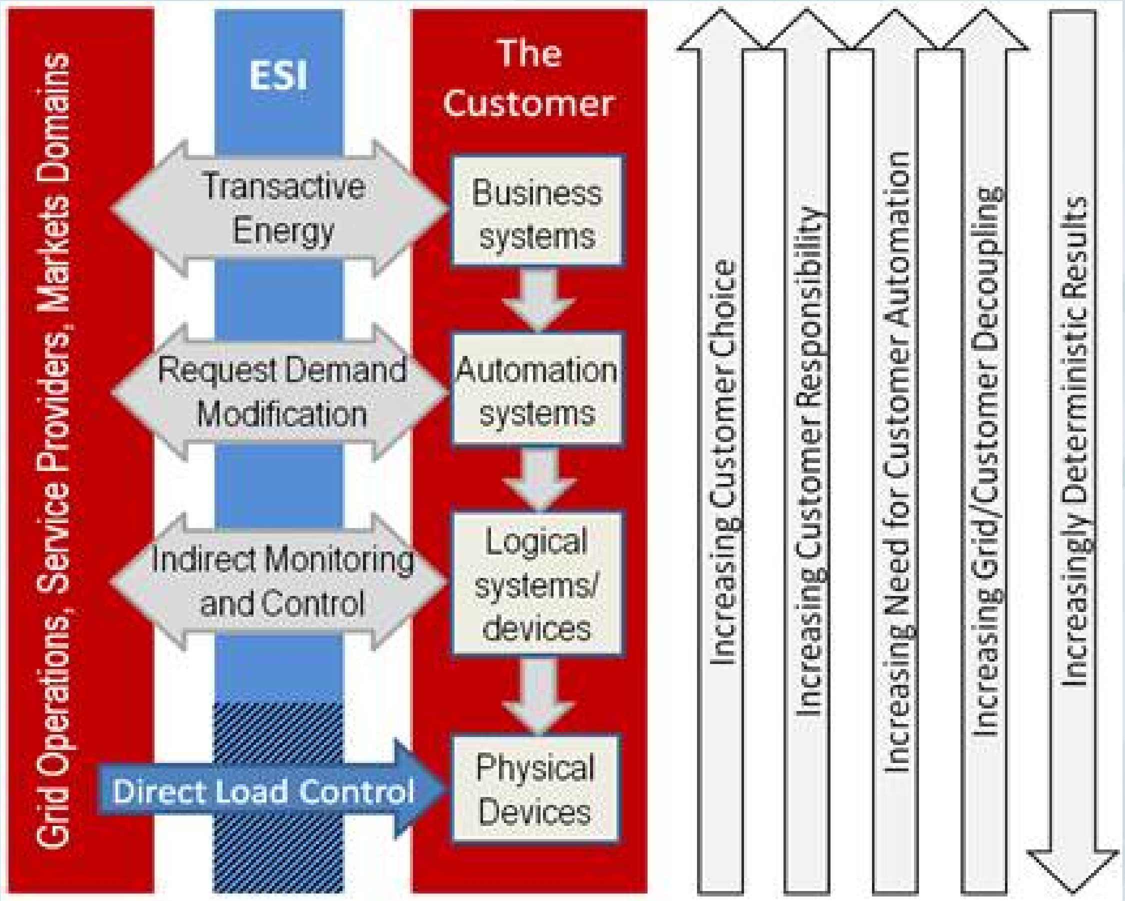
The Evolution of Control Technologies and TE Services Will be Driven by Market Forces

Program Type	Latency	Which Market	Automation
Frequency regulation	Less than 1 second	Day ahead	Required
Voltage support services	Less than 1 minute	Day ahead	Required
Energy support	Less than 5 minutes	Day ahead	Recommended
Demand adjustment	15 minutes	Real time	Recommended
Market Adjustment	Hour ahead	Hour Ahead	Not required
Price Management	Day ahead	Day ahead	Not required

Focus Question Part 1:

How do DER services fit with conventional market structures?

Spectrum of Possibilities for Delivering TE Services to the Grid



Focus Question Part 2:

How are DER services best delivered to the grid?

Ensuring the Availability and Delivery of Transactive Energy Services Across Markets

Lorenzo Kristov, Ph.D.
Principal, Market & Infrastructure Policy

NIST Workshop:
Harnessing the Power of Distributed Energy Resources
October 20, 2016, San Jose

Ideas in this presentation are offered for discussion purposes only, and do not reflect the views or policies of the California ISO.

Growth of DER and distribution-level transactive markets call for an updated whole-system grid architecture.

- The electric industry – at state, national and global levels – is undergoing comprehensive transformation characterized by
  - Shift to renewable energy resources and away from conventional fossil-fuel generation at all scales
  - “Grid edge” adoption of diverse distributed energy resources (DER) and a trend toward decentralized power systems (e.g., microgrids)
  - Decline of the traditional centralized, one-way power flow paradigm and associated revenue models & rate structures
  - Potential for distribution-level “peer-to-peer” transactive markets
  - New roles for distribution utilities or new independent entities as distribution system operators (DSOs)
- First and foremost, the next system must be reliable and meet 21st century objectives for sustainability, resilience & efficiency
- Crucial to success will be the design of the DSO and coordination between transmission & distribution systems & markets

The DER+TE transformation is driven from the bottom up.

- DER growth is driven by customer demand & adoption
  - Customers want flexibility, control, energy services customized to their needs, resilience to disturbances, cost effectiveness
  - Local jurisdictions adopt climate action plans, pursue synergies among municipal services, seek to boost local economy, extend renewable energy and EV to less affluent communities
  - Powerful new technologies make it all feasible & economic
- The new paradigm features
  - Substantial local supply to meet local demand
  - Multi-directional, reversible flows on distribution system
  - New challenges for distribution operations, planning & interconnection
  - Multi-use DER provide services to customers, D and T systems
  - Potential for low-cost, resilient islanding & “grid defection”
  - Desire for transactive peer-to-peer markets at the grid edge
  - Bottom-up autonomous adoption => less top-down policy control

DER business models look to provide & earn revenues from services at multiple levels of the system.

- “DER” = all energy resources connected at distribution level, on customer side or utility side of the customer meter
  - Plus communications & controls to aggregate & optimize DER
- Behind the end-use customer meter
  - Time of day load shifting, demand charge management, storage of excess solar generation
  - Service resilience – smart buildings, microgrids, critical loads
- Distribution system services
  - Deferral of new infrastructure
  - Operational services – voltage, power quality
- Transmission system & wholesale market
  - ISO spot markets for energy, reserves, regulation
  - Resource adequacy capacity
  - Non-wires alternatives to transmission upgrades
- Bilateral energy contracts with customers, DSO & LSEs
- Peer-to-peer transactions, via distribution-level transactive markets

CAISO has several market participation models for DER.

- Demand Response (“Proxy Demand Resource” or PDR)
  - May incorporate behind-the-meter (BTM) devices such as energy storage, but can only reduce load, cannot inject energy to the grid
  - Relies on baselines to measure performance
  - Allows sub-metering of BTM storage device for DR measurement
  - Visible to CAISO only when it bids in and is dispatched
  - Future: CAISO ESDER2 initiative developing rules for bi-directional dispatch and provision of regulation service
- “Non-Generator Resource” (NGR)
  - Designed for a resource like storage that will consume or inject energy at different times; can provide regulation service
  - Visible to CAISO and settled 24x7 (comparable to a generator)
  - Does not use baselines
- Distributed Energy Resource Provider (DERP)
  - Allows aggregator to create a virtual resource of mixed DER types
  - Resource will utilize NGR model

High DER penetration requires rethinking distribution system operation and T-D interface coordination.

- ❖ Diverse end-use devices & resources with diverse owners/operators will dramatically affect key operational features:
  - o Net end-use load shapes, peak demands, total energy
  - o Direction of energy flows, voltage variability, phase balance
  - o Variability & predictability of net loads & grid conditions
- ❖ High DER penetration has operational impacts in two directions:
  - o From D to T: DER services to customers & DSO & P2P transactions affect the transmission grid => need for accurate RT forecasting and local management of DER variability
  - o From T to D: ISO market sees DER at T-D substations, has no visibility to distribution grid conditions or impacts
- ❖ DER growth also affects infrastructure planning, utility business models, ratemaking, regulatory frameworks, interconnection, …
- ❖ Central design question: What is the relationship between ISO and DSO, between wholesale market and retail transactive market?

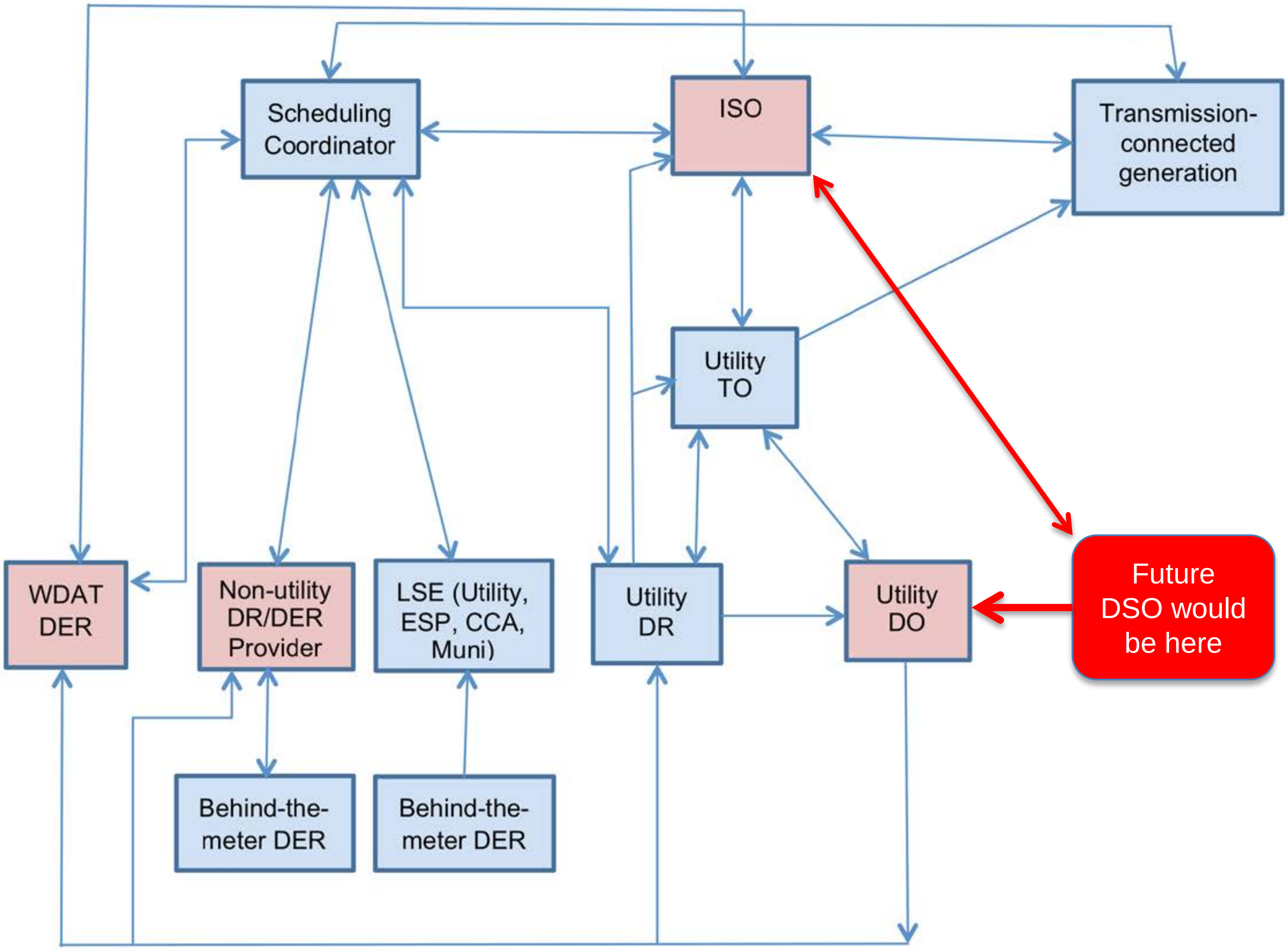
Each entity's objectives & responsibilities drive needed tools, information & procedures.

- ISO's primary DER concern is at the T-D interface or p-node
  - Predictability/confidence re DER responses to ISO dispatch instructions
  - Short-term forecasts of net interchange at each T-D interface
  - Long-term forecasts of DER T-D impacts for transmission planning
  - May not need to know details below T-D interface with a "total" DSO …
- DSO's concern starts with reliable distribution system operation
  - Visibility/predictability to current behavior of DER
  - Ability to modify behavior of DER via instructions or controls as needed to maintain reliable operation
  - Long-term forecasts of DER system impacts for distribution planning
  - May take on much greater responsibilities as a "total" DSO …
- DER provider/aggregator is concerned with business viability
  - Ability to participate, in a non-discriminatory manner, in all markets for which it has the required performance capabilities
  - Ability to optimize its choice of market opportunities and manage its risks of being curtailed for reasons beyond its control

System components (boxes) & structures (arrows) will determine system behavior and qualities.

Relationships of red boxes are crucial for T-D coordination with High DER.

Today the ISO and Utility DO do not exchange information or coordinate activities for real-time operation.



New T-D coordination framework for high DER & TE must address several essential areas & functions.

Area of Activity	Challenges of High-DER	What's Needed
System operations	• Diverse DER behaviors & energy flows, esp. with aggregated virtual resources • Hard to forecast impacts at T-D interfaces • DSO is not in the loop on DER wholesale market transactions • Multi-use DER may receive conflicting dispatches/signals (from DSO and ISO)	• Distribution grid real-time visibility • Real-time forecasting of DER impact at each T-D substation • Coordination procedures between ISO, DSO and DER re wholesale DER schedules & dispatches • Dispatch priority re multiple uses
T & D infrastructure planning	• Long-term forecasting of DER growth & impacts on load (energy, peak, profile) • DER seek to offset T&D upgrades • Distribution grid modernization needs	• Align processes for T&D planning and long-term forecasting • Specify required performance for DER to function as grid assets • Modernize grid in logical stages for "no regrets" investment
System reliability & resilience	• High DER may make traditional top-down paradigm obsolete	• Develop new approaches to "layer" responsibilities for reliability
Market issues: • Wholesale v retail • Monopoly v competition	• When does DER volume in wholesale market become too costly? • Unclear boundary between competitive v. utility services, while utilities & insurgents pursue new business models	• Explore "Total DSO" aggregation of DER wholesale market transactions • Consider optimal scope of regulated distribution monopoly with high DER

Who knows what today? What is needed for market DER?

Information Type	ISO	DO/DSO	ISO participating DER/DERP
DER/DERP bids to ISO market	X	Add ?	X
DER installed capacity		X	X
T system topology & conditions	X		X
D system topology & conditions		X	DSO inform DER
DA & RT forecasts of load + non-ISO participating DER	Add	Add	
ISO DA market schedules	X	Add	X
ISO RT market dispatches	X	Add	X
T feasibility of ISO schedules & dispatches	Ensured by ISO optimization		Ensured by ISO optimization
D feasibility of ISO schedules & dispatches		DSO assess & inform DER	DSO inform DER
Revenue meter data	X		X
Generation/DER telemetry	X	X	
System telemetry	T system	D system	

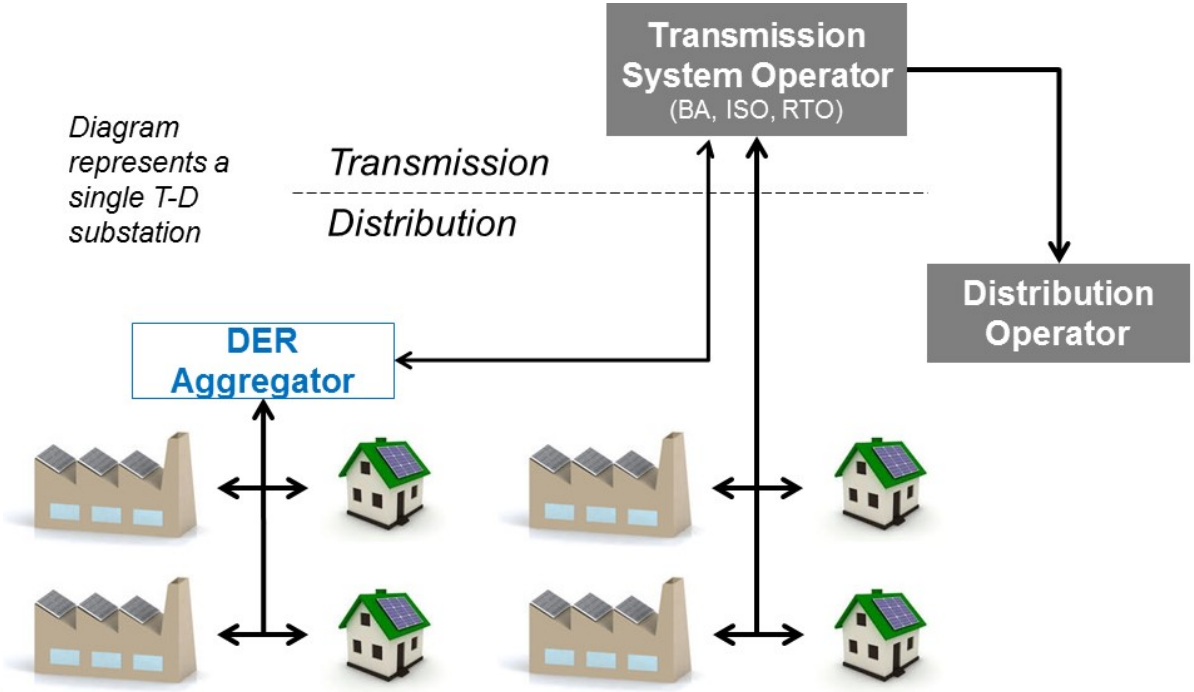
The design of ISO-DSO coordination for high DER is inseparable from design of the future DSO.

- ❖ Bookend A: Current Path or “Minimal DSO”
  - – DSO maintains current distribution utility role, with enhancements only as needed to ensure reliability with high DER volumes
  - – Large numbers of DER & DER aggregations participate in ISO market
  - – DER engage in “multiple-use applications” (MUA) providing services to end-use customers, DSO and wholesale market
- ❖ Bookend B: “Total DSO”
  - – DSO expands its role to include
    - Operation of distribution-level transactive markets
    - DER aggregation for wholesale market participation
    - Optimizing local DER to provide transmission grid services
    - Balancing supply-demand locally
    - Manage DER variability to minimize impacts at T-D interface
  - – DSO provides a single aggregated bid to ISO at each T-D interface
  - – Multi-use applications are simplified because DSO manages DER response to ISO dispatch

“Minimal DSO” retains current distribution utility role – reliable operation & planning – for for high DER & TE.

ISO directly integrates all DER for both transmission and distribution system operations. Requires ISO to incorporate distribution grid network model and have complete real-time distribution grid state information.

This approach is not advised due to complexity & scaling risks



Transmission System Operator (BA, ISO, RTO)

Diagram represents a single T-D substation

Transmission

Distribution

Distribution Operator

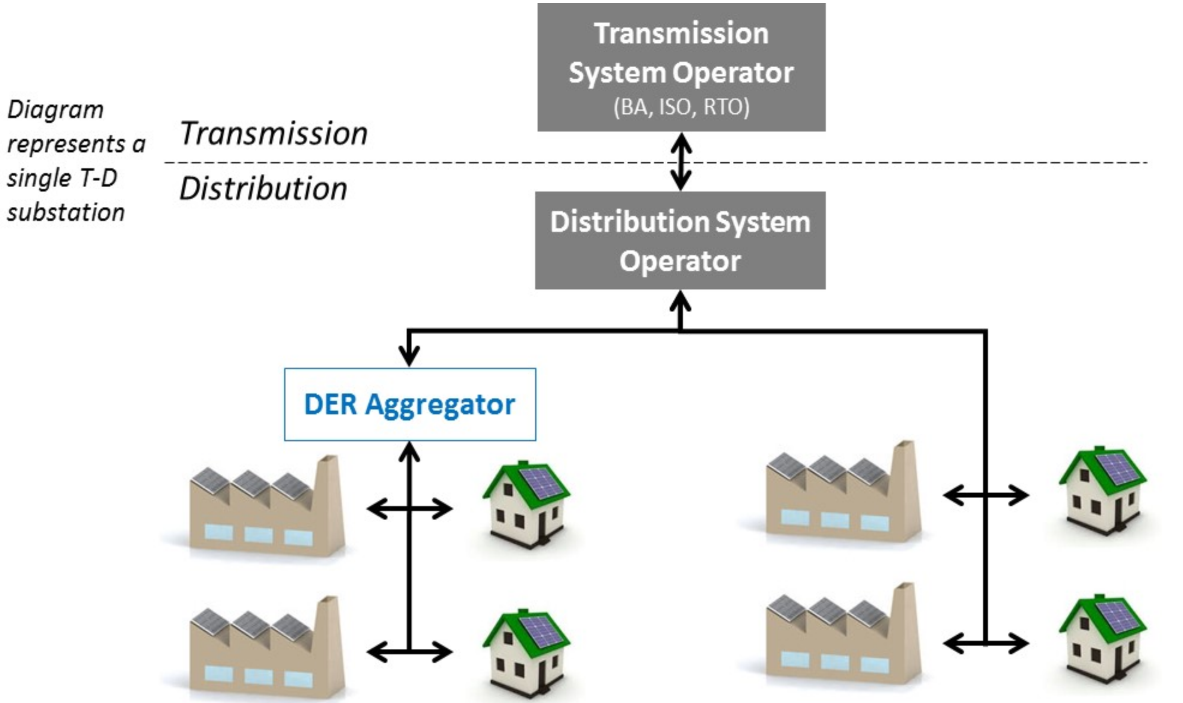
DER Aggregator

Source: De Martini & Kristov, Distribution Systems in a Highly Distributed Energy Resources Future, LBNL, 2015

“Total DSO” – similar to an ISO at distribution level – is the most robust & scalable model for TE.

DSO directly integrates all DER for Local Distribution Area for each T-D Interface (e.g., LMP pricing node) and coordinates T-D interchange with TSO, so that ISO sees only a single resource at each T-D interface and does not need visibility to DER. DSO manages all intra-distribution area transactions, schedules and energy flows.

DSO coordinates a single aggregation of all DER at each T-D interface



Source: De Martini & Kristov, Distribution Systems in a Highly Distributed Energy Resources Future, LBNL, 2015

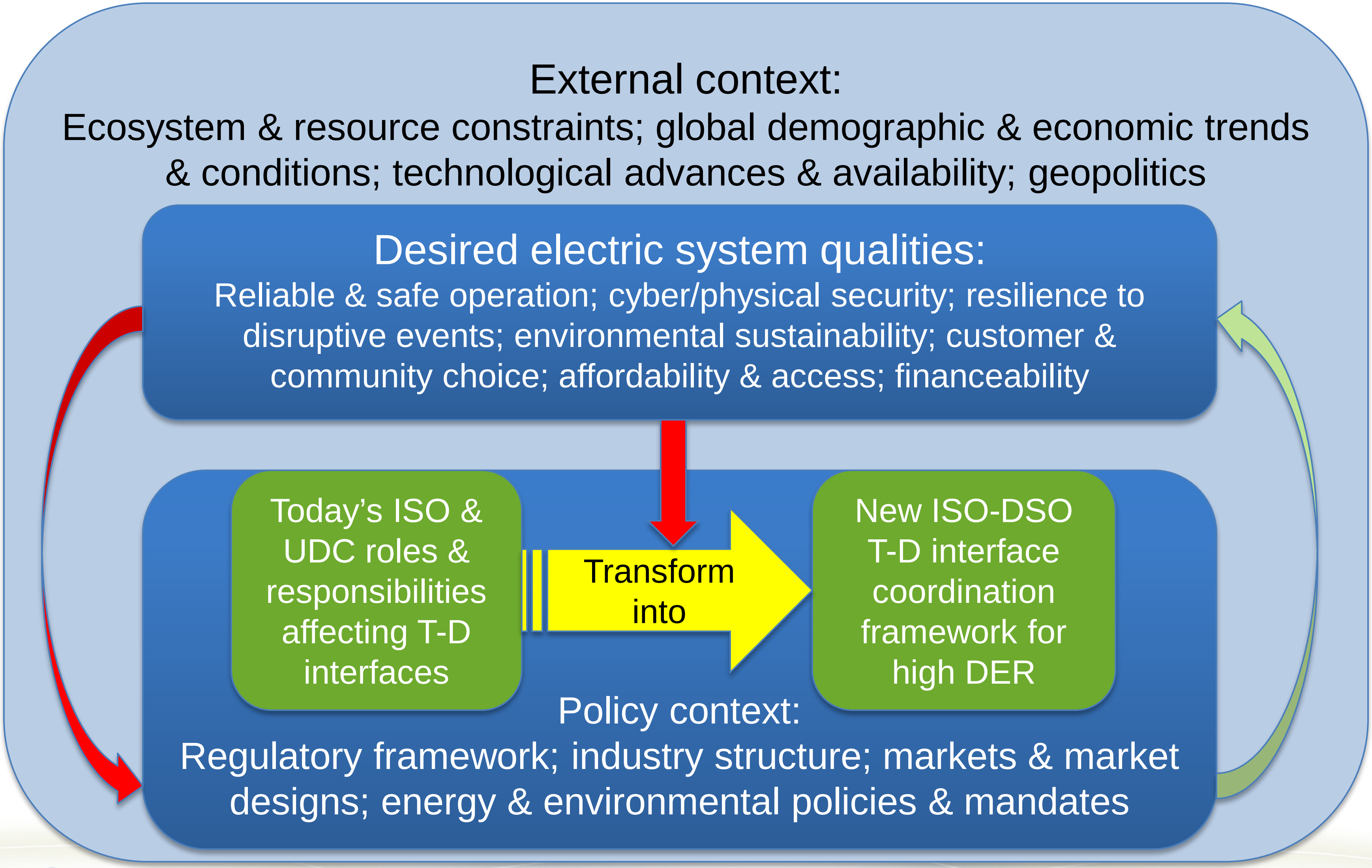
The choice of DSO model implicates several key power system design elements.

Design Element	Minimal DSO	Total DSO
Market structure	Central market optimization by ISO with large numbers of participating DER	DSO optimizes local markets at each T-D substation; ISO market sees a single virtual resource at each T-D interface
Distribution-level energy prices	Locational energy prices based on LMP plus distribution component (e.g., LMP+D)	Based on value of DER services in local market, including LMP for imports/exports
Resource/capacity adequacy	As today, based on system coincident peak plus load pocket & flexibility needs; opt-out allowed for micro-grids	Layered RA framework: DSO responsible for each T-D interface area; ISO responsible to meet net interchange at each interface
Grid reliability paradigm	Similar to today	Layered responsibilities; e.g., DSO takes load-based share of primary frequency response
Multiple-use applications of DER (MUA)	DER subject to both ISO and DSO instructions Rules must resolve dispatch priority, multiple payment, telemetry/metering issues	DER subject only to DSO instructions, as DSO manages DER response to ISO dispatches & ancillary services provision
Regulatory framework	Federal-state jurisdictional roles similar to today	Explore framework to enable states to regulate distribution-level markets
Comparable to existing model	Current distribution utility roles & responsibilities, enhanced for high DER	Total DSO is similar to a balancing authority

DER growth & TE trigger other design & policy questions for optimal whole-system performance.

- Open-access structure for distribution system operators (DSOs)
  - Non-discrimination in distribution services, resource interconnection, infrastructure investment, real-time re-dispatch as needed
  - Is an independent DSO needed? Or can today's utility DO be effectively firewalled into a regulated "wires & markets" operator and competitive affiliate offering retail services?
- Possible new boundary definition for federal-state jurisdiction
  - Could states regulate "sales for resale" that occur within a local transactive market without using transmission?
- Could reliability responsibilities be layered?
  - "Total DSO" aggregates all DER & customers below a T-D substation and submits a single virtual resource to ISO at the interface
  - ISO responsible for system reliability only to the T-D interface
  - DSO responsible from T-D interface to the customer meter
  - A micro-grid takes responsibility for its own reliability, and will island if grid supply is limited or interrupted

Grid architecture tools enable a whole-system approach to electric system transformation.



External context:

Ecosystem & resource constraints; global demographic & economic trends & conditions; technological advances & availability; geopolitics

Desired electric system qualities:

Reliable & safe operation; cyber/physical security; resilience to disruptive events; environmental sustainability; customer & community choice; affordability & access; financeability

Today's ISO & UDC roles & responsibilities affecting T-D interfaces

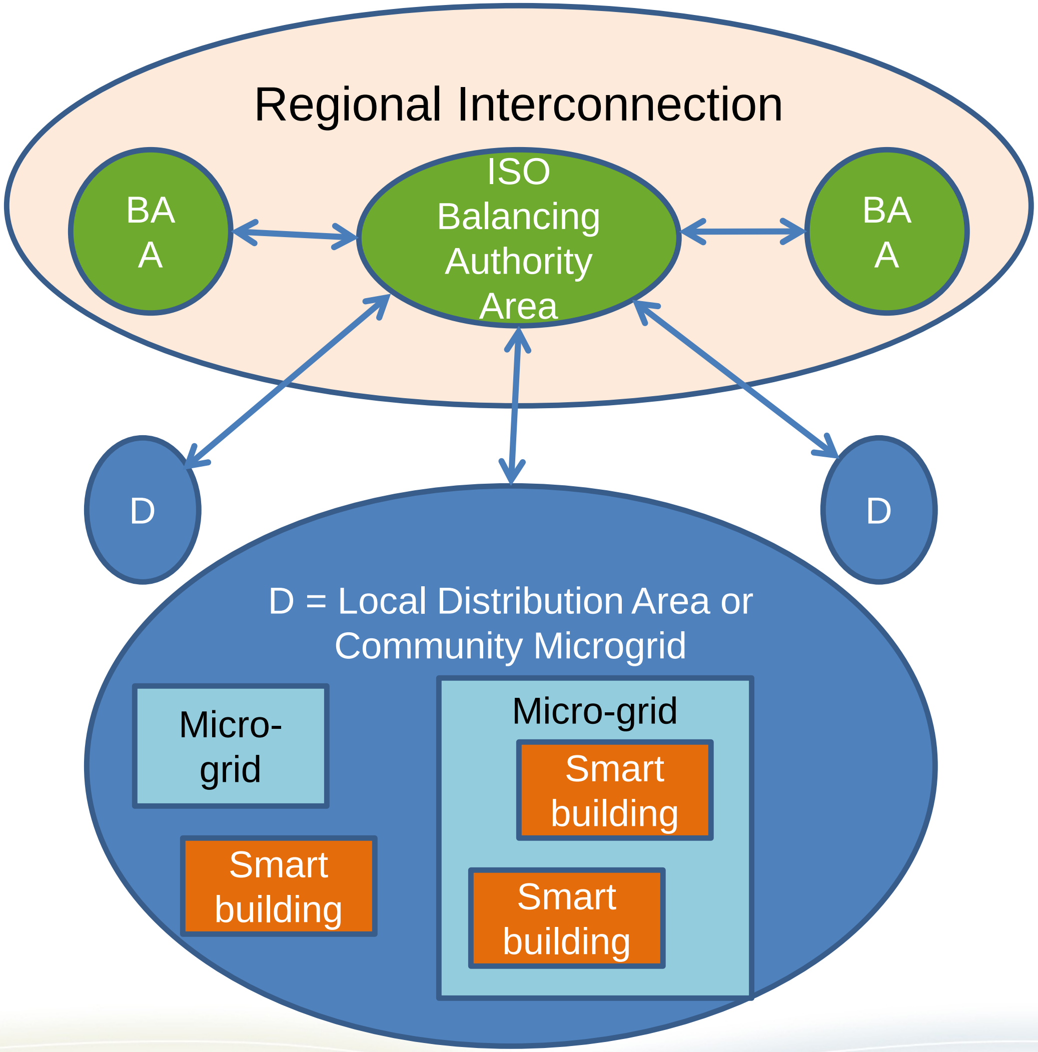
Transform into

New ISO-DSO T-D interface coordination framework for high DER

Policy context:

Regulatory framework; industry structure; markets & market designs; energy & environmental policies & mandates

The future grid may be a layered hierarchy of optimizing sub-systems.



- Each tier only needs to see interchange with next tier above & below, not the details inside other tiers
- ISO focuses on regional bulk system integration while distribution utility coordinates DERs
- Layered control structure reduces complexity, allows scalability, and increases resilience & security
- Fractal structure mimics nature's design of complex organisms & ecosystems.

Additional resources

- L. Kristov, P. De Martini, J. Taft(2016) “Two Visions of a Transactive Electric System” (IEEE Power & Energy Magazine, May-June 2016): http://resnick.caltech.edu/docs/Two_Visions.pdf

- P. De Martini & L. Kristov (2015) “Distribution Systems in a High Distributed Energy Resources Future: Planning, Market Design, Operation and Oversight” (LBNL series on Future Electric Utility Regulation):https://emp.lbl.gov/sites/all/files/FEUR_2%20distribution%20systems%2020151023.pdf

- L. Kristov (2015) “The future history of tomorrow’s energy network” (Public Utilities Fortnightly, May 2015): http://www.fortnightly.com/fortnightly/2015/05/future-history-tomorrows-energy-network?page=0%2C0&authkey=afacbc896edc40f5dd20b28daf63936dd95e38713e904992a60a99e937e19028

- L. Kristov & P. De Martini (2014) “21st Century Electric Distribution System Operations”: http://smart.caltech.edu/papers/21stCElectricSystemOperations050714.pdf

- JD Taft and A Becker-Dippmann, Pacific Northwest National Laboratory, Grid Architecture, January 2015, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24044.pdf

Thank you.

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Market & Infrastructure Policy

Breakout #2:
Ensuring Availability & Delivery of TE Services

Avi Gopstein

Smart Grid Program Manager, NIST

Harnessing the Power of Distributed Energy Resources

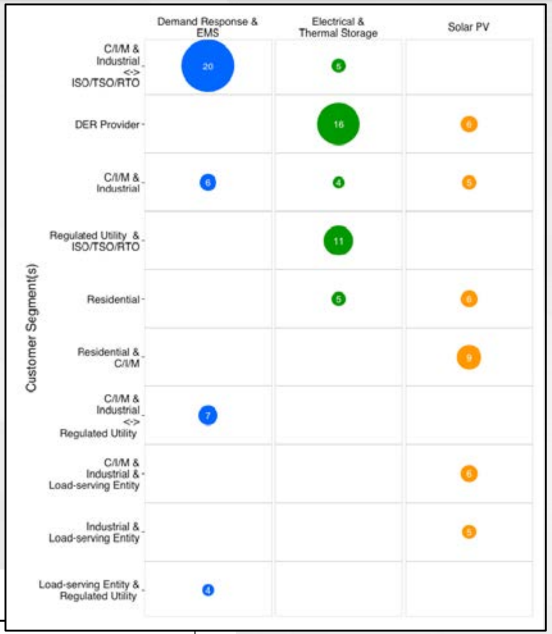
October 20, 2016

National Institute of Standards and Technology
U.S. Department of Commerce

Many applications, many customers

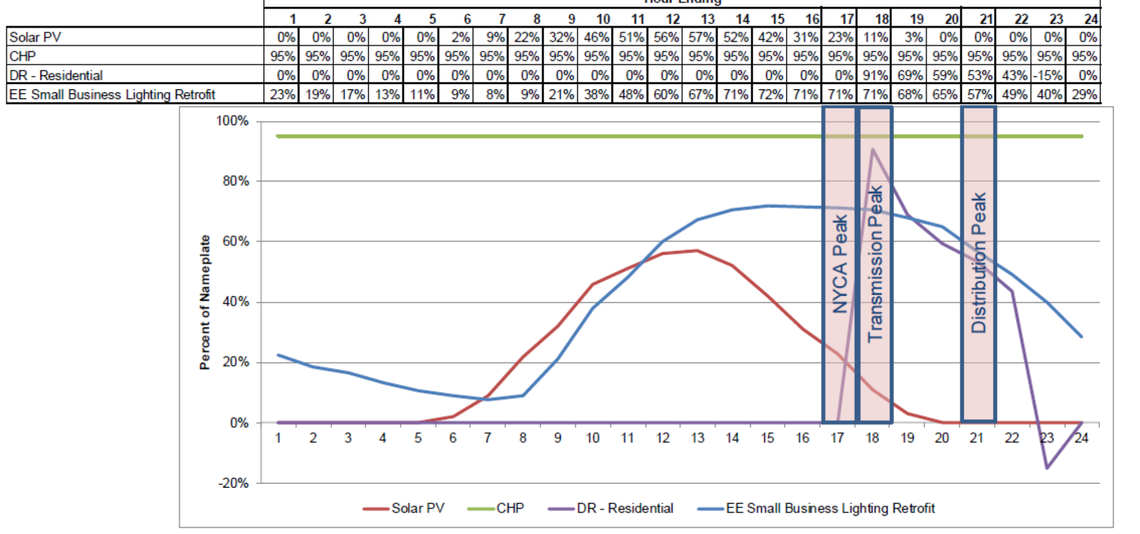
TE Challenge Use Case	Value Proposition
Peak Day	ISO, DGO, Customer, IPP, Aggregators
Balancing/Ramping	ISO, Hydro, IPP, Merchants, DER, Aggregators
PV + Voltage Control	DGO, DER, Customer
EV Load	DGO, Customer
Islanded Microgrid	Local DGO, Customers
Inadequate Supply	ISO(RC), DGO, Customers

Source: *NIST TE Challenge*



Source: *MIT, 2016*

Figure 5-1. Illustrative Example of Coincidence Factors



	Hour Ending																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Solar PV	0%	0%	0%	0%	0%	2%	9%	22%	32%	46%	51%	56%	57%	52%	42%	31%	23%	11%	3%	0%	0%	0%	0%	0%
CHP	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
DR - Residential	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	91%	69%	59%	53%	43%	-15%	0%
EE Small Business Lighting Retrofit	23%	19%	17%	13%	11%	9%	8%	9%	21%	38%	48%	60%	67%	71%	72%	71%	71%	71%	68%	65%	57%	49%	40%	29%

Source: *ConEdison Benefit Cost Analysis Handbook, June 2016*

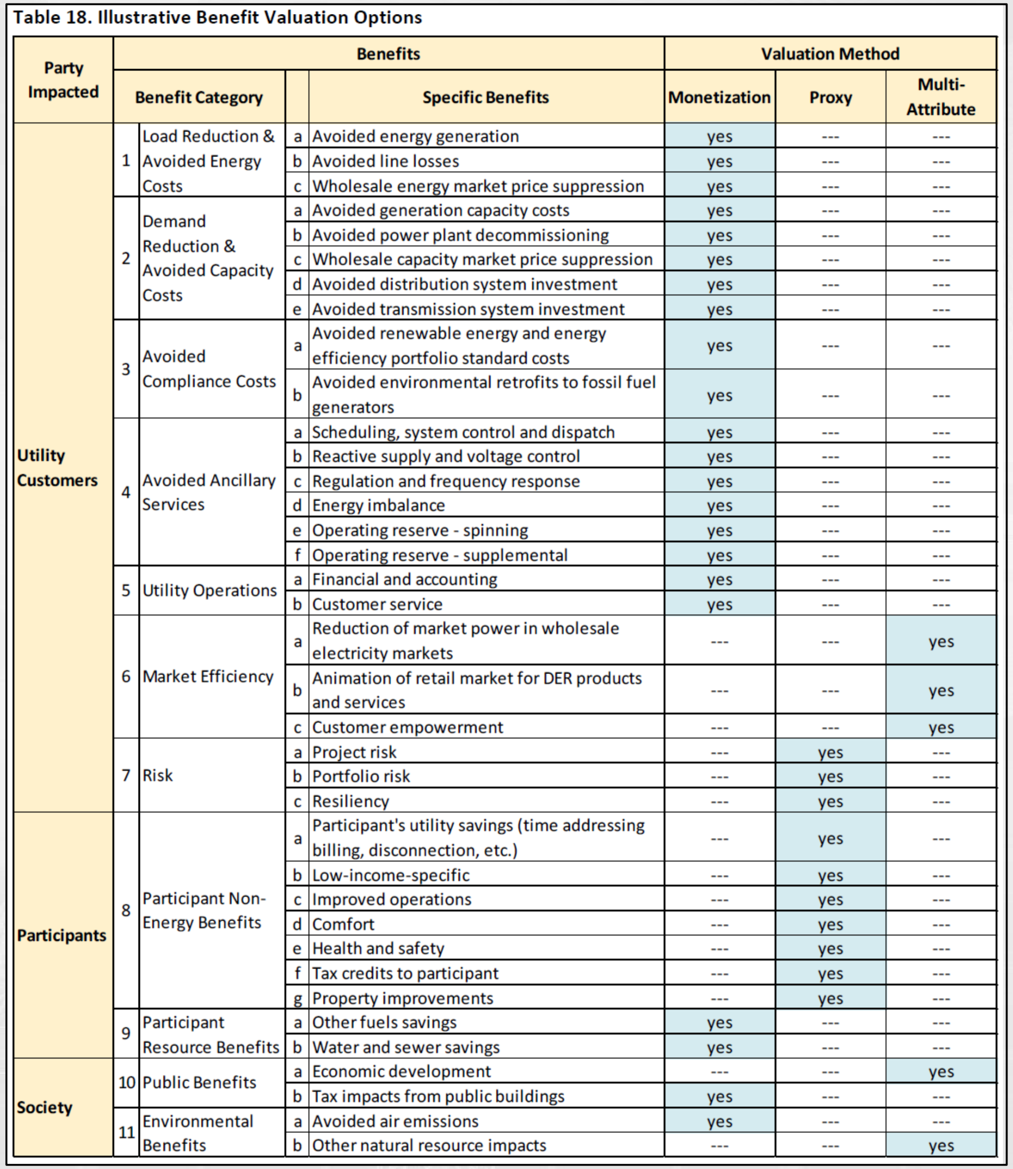
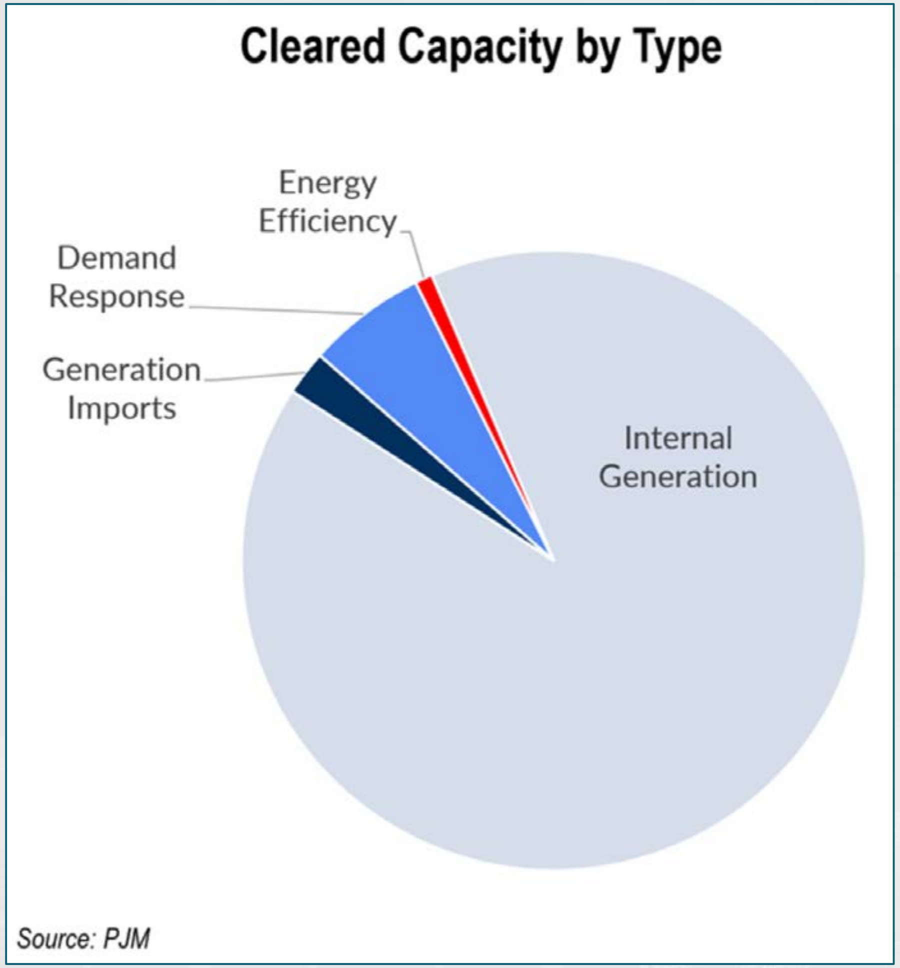


Table 18. Illustrative Benefit Valuation Options

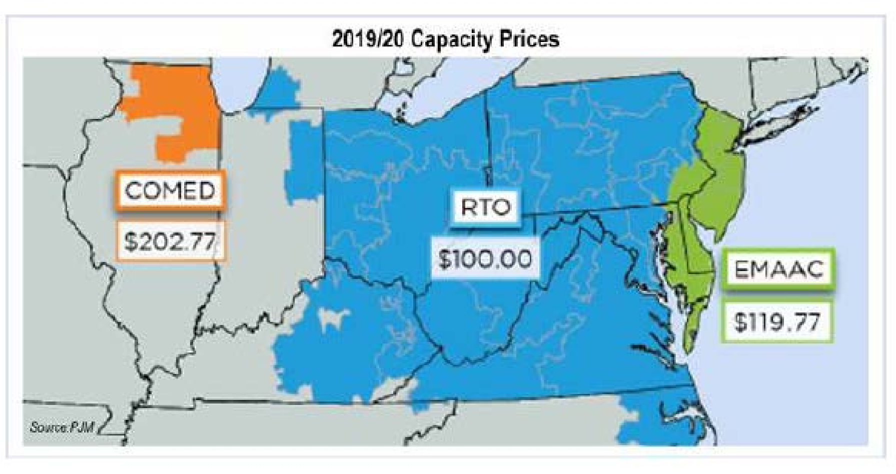
Party Impacted	Benefits				Valuation Method		
	Benefit Category			Specific Benefits	Monetization	Proxy	Multi-Attribute
Utility Customers	1	Load Reduction & Avoided Energy Costs	a	Avoided energy generation	yes	---	---
			b	Avoided line losses	yes	---	---
			c	Wholesale energy market price suppression	yes	---	---
	2	Demand Reduction & Avoided Capacity Costs	a	Avoided generation capacity costs	yes	---	---
			b	Avoided power plant decommissioning	yes	---	---
			c	Wholesale capacity market price suppression	yes	---	---
			d	Avoided distribution system investment	yes	---	---
			e	Avoided transmission system investment	yes	---	---
	3	Avoided Compliance Costs	a	Avoided renewable energy and energy efficiency portfolio standard costs	yes	---	---
			b	Avoided environmental retrofits to fossil fuel generators	yes	---	---
	4	Avoided Ancillary Services	a	Scheduling, system control and dispatch	yes	---	---
			b	Reactive supply and voltage control	yes	---	---
			c	Regulation and frequency response	yes	---	---
			d	Energy imbalance	yes	---	---
			e	Operating reserve - spinning	yes	---	---
			f	Operating reserve - supplemental	yes	---	---
	5	Utility Operations	a	Financial and accounting	yes	---	---
			b	Customer service	yes	---	---
	6	Market Efficiency	a	Reduction of market power in wholesale electricity markets	---	---	yes
			b	Animation of retail market for DER products and services	---	---	yes
			c	Customer empowerment	---	---	yes
	7	Risk	a	Project risk	---	yes	---
			b	Portfolio risk	---	yes	---
			c	Resiliency	---	yes	---
Participants	8	Participant Non-Energy Benefits	a	Participant's utility savings (time addressing billing, disconnection, etc.)	---	yes	---
			b	Low-income-specific	---	yes	---
			c	Improved operations	---	yes	---
			d	Comfort	---	yes	---
			e	Health and safety	---	yes	---
			f	Tax credits to participant	---	yes	---
			g	Property improvements	---	yes	---
	9	Participant Resource Benefits	a	Other fuels savings	yes	---	---
			b	Water and sewer savings	yes	---	---
Society	10	Public Benefits	a	Economic development	---	---	yes
			b	Tax impacts from public buildings	yes	---	---
	11	Environmental Benefits	a	Avoided air emissions	yes	---	---
			b	Other natural resource impacts	---	---	yes

Source: *AAE Institute & Synapse Energy Economics, 2014*

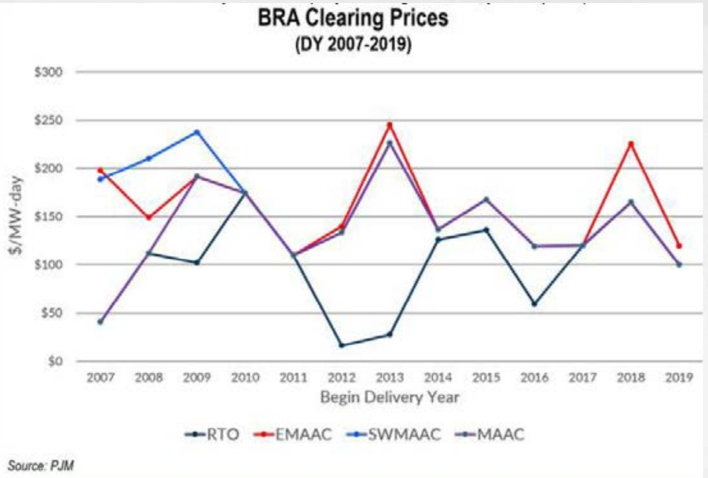
Market drivers & impacts can be volatile



Source: PJM



Source: PJM



Source: PJM

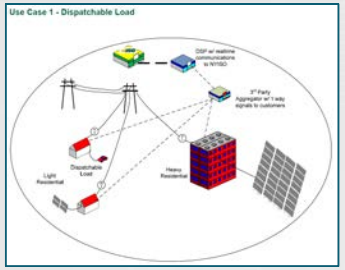
2019/20 PJM Capacity Performance market (second auction)

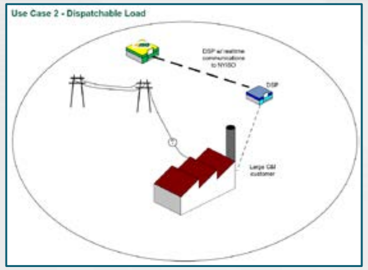
- RTO prices fell 39%
- Eastern MAAC prices fell 47%
- ComEd fell 6%
- Base capacity $20/MW-day below RTO

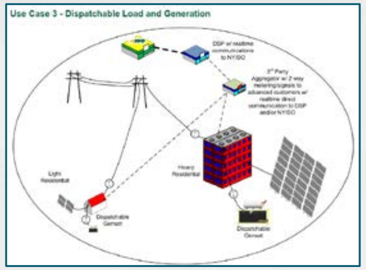
84 MW new DR, but just 6% of DR resources qualified as CP

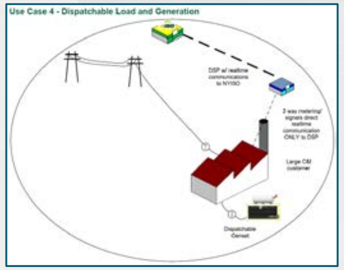
Source: *RTO Insider, May 24, 2016*

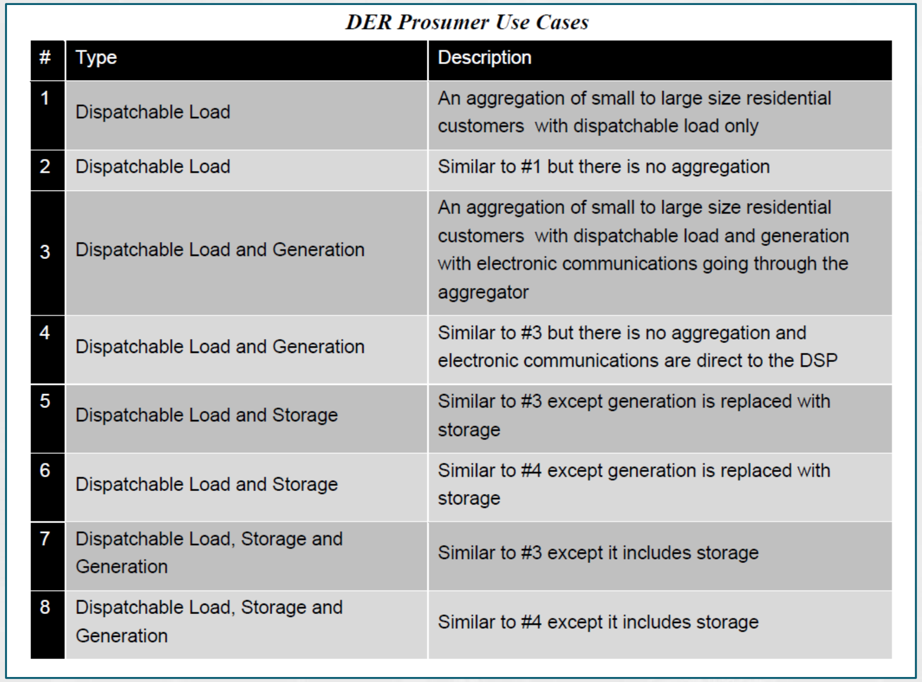
Multiple value streams for every asset


Use Case 1 - Dispatchable Load

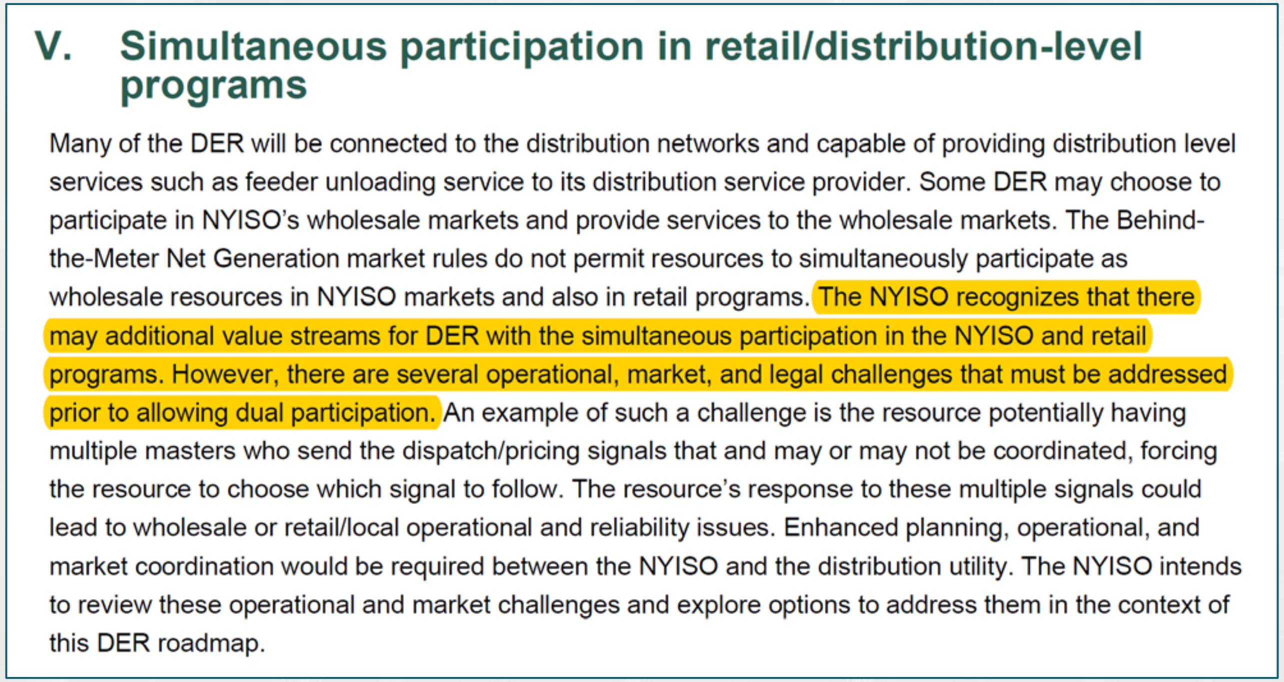

Use Case 2 - Dispatchable Load


Use Case 3 - Dispatchable Load and Generation

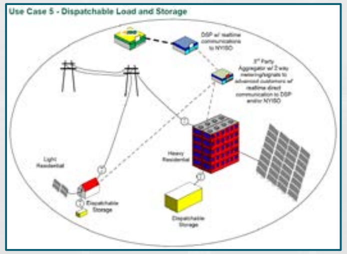

Use Case 4 - Dispatchable Load and Generation

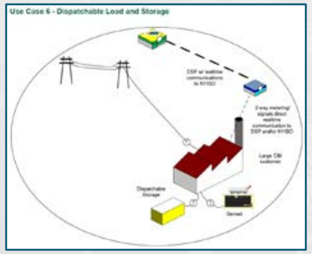

DER Prosumer Use Cases

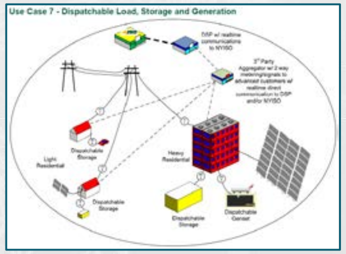
#	Type	Description
1	Dispatchable Load	An aggregation of small to large size residential customers with dispatchable load only
2	Dispatchable Load	Similar to #1 but there is no aggregation
3	Dispatchable Load and Generation	An aggregation of small to large size residential customers with dispatchable load and generation with electronic communications going through the aggregator
4	Dispatchable Load and Generation	Similar to #3 but there is no aggregation and electronic communications are direct to the DSP
5	Dispatchable Load and Storage	Similar to #3 except generation is replaced with storage
6	Dispatchable Load and Storage	Similar to #4 except generation is replaced with storage
7	Dispatchable Load, Storage and Generation	Similar to #3 except it includes storage
8	Dispatchable Load, Storage and Generation	Similar to #4 except it includes storage

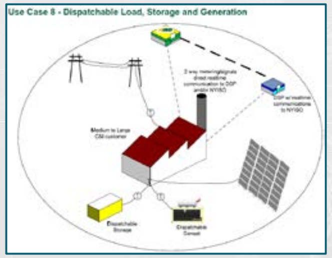

V. Simultaneous participation in retail/distribution-level programs

Many of the DER will be connected to the distribution networks and capable of providing distribution level services such as feeder unloading service to its distribution service provider. Some DER may choose to participate in NYISO's wholesale markets and provide services to the wholesale markets. The Behind-the-Meter Net Generation market rules do not permit resources to simultaneously participate as wholesale resources in NYISO markets and also in retail programs. The NYISO recognizes that there may additional value streams for DER with the simultaneous participation in the NYISO and retail programs. However, there are several operational, market, and legal challenges that must be addressed prior to allowing dual participation. An example of such a challenge is the resource potentially having multiple masters who send the dispatch/pricing signals that and may or may not be coordinated, forcing the resource to choose which signal to follow. The resource's response to these multiple signals could lead to wholesale or retail/local operational and reliability issues. Enhanced planning, operational, and market coordination would be required between the NYISO and the distribution utility. The NYISO intends to review these operational and market challenges and explore options to address them in the context of this DER roadmap.


Use Case 5 - Dispatchable Load and Storage


Use Case 6 - Dispatchable Load and Storage


Use Case 7 - Dispatchable Load, Storage and Generation


Use Case 8 - Dispatchable Load, Storage and Generation

Source: NYISO, August 2016
Distributed Energy Resource Roadmap for New York's Wholesale Electricity Markets (Draft)

Planning + monetizing DER remain limiters

Figure 32. Mapping market places, actors, planning horizon and flexibility provision.

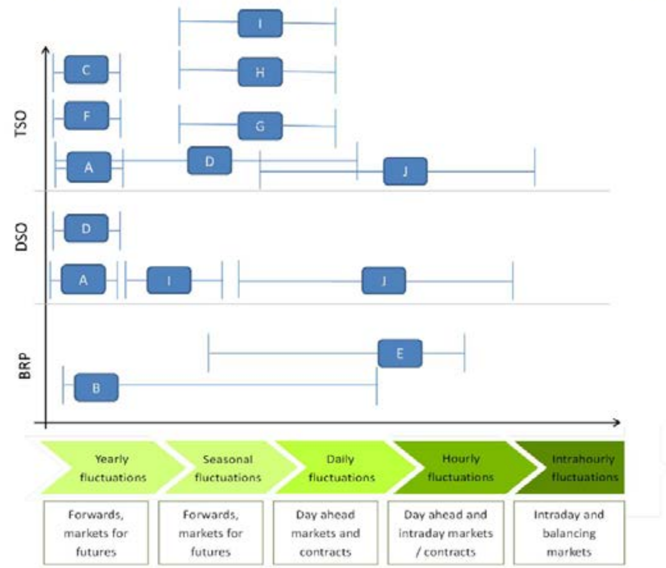
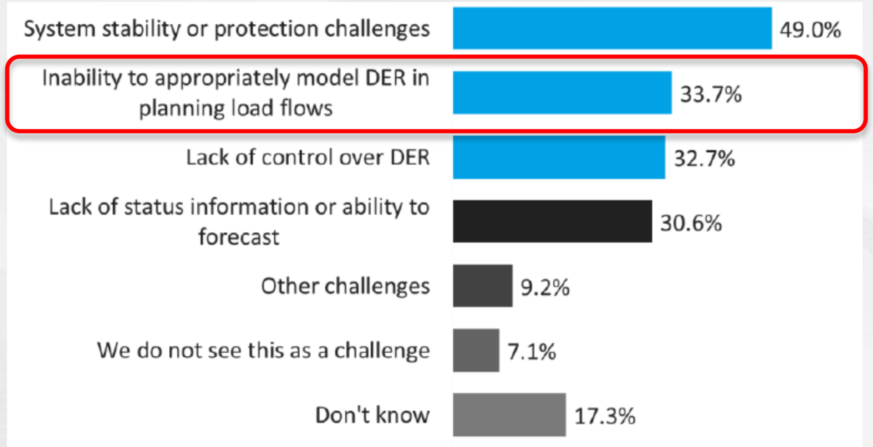


Table 8. List of abbreviations used in Figure 32 above.

Abbreviation	Name	Buyer
A	Peak shifting, long-term congestion management	DSO, TSO
B	Peak shifting, portfolio optimization	BRP
C	Peak shifting, generation capacity adequacy	TSO
D	Demand adjustments, short-term congestion management	TSO/DSO
E	Demand adjustments, portfolio optimization	BRP
F	Demand adjustments, generation capacity adequacy	TSO
G	Balancing services, frequency control	TSO
H	Balancing services, frequency control	TSO
I	Generation adjustments, short term congestion management	TSO/DSO
J	Generation adjustments, short term congestion management	TSO/DSO

Source: *Report to the European Commission, 2015*

Most significant Challenges to supporting high penetration of DERs

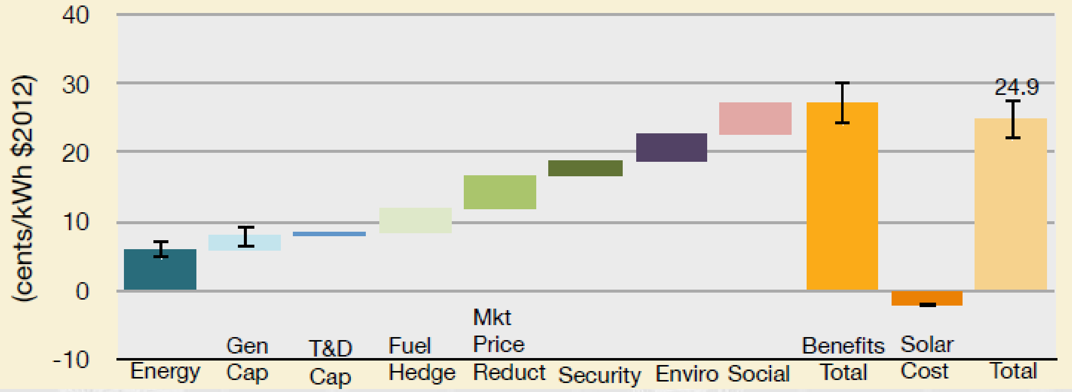


Source: *Black & Veatch & SEPA, 2016*

> *To realize their full value while ensuring power quality and reliability for all customers, DER must be included in distribution planning and operation, just as central generation resources are included in transmission planning and operation.*

Source: *EPRI, 2014*

Value of solar PV alone crosses customers, markets, societies, planet

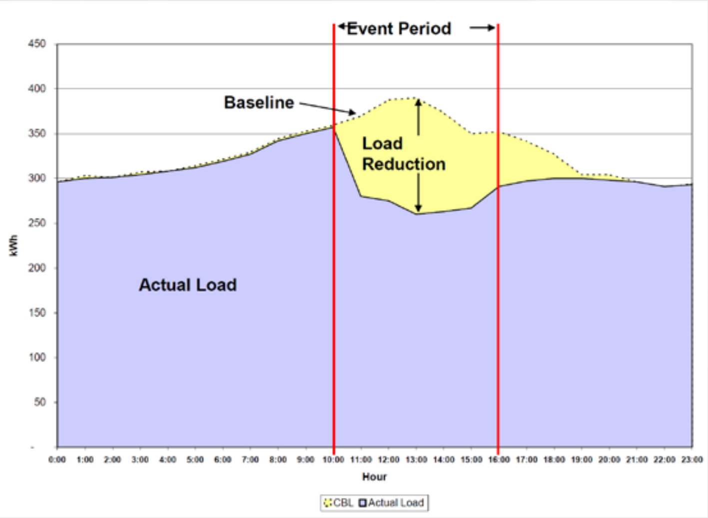


Source: *Rocky Mountain Institute, 2013*

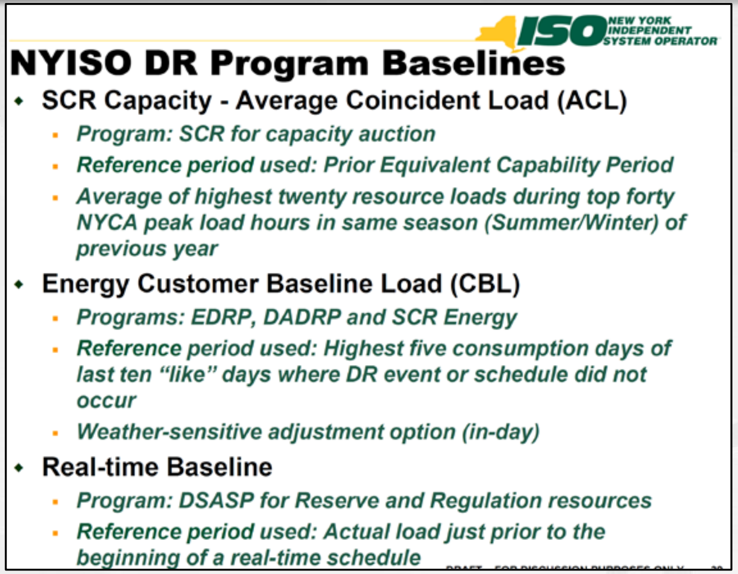
M&V a challenge for non-supply resources

Source: *NYISO, 2016*

Quantifying Demand Response



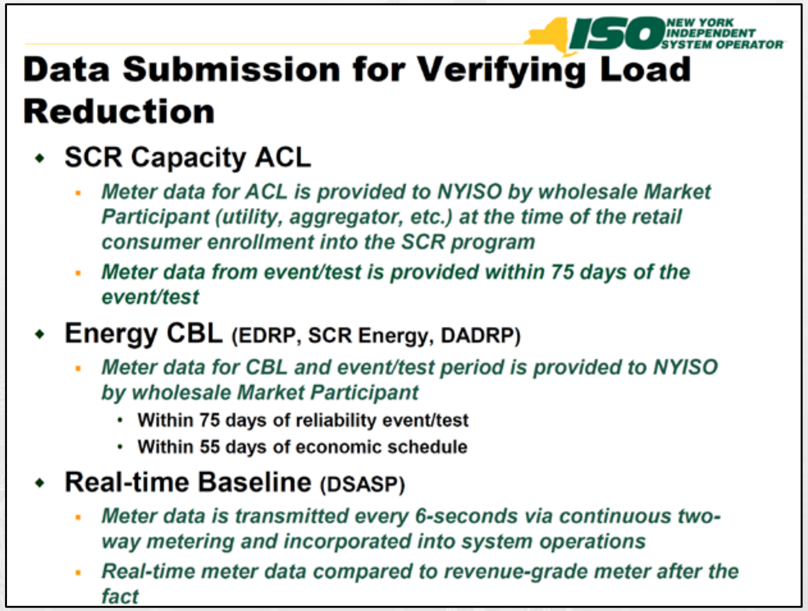
Determine Baseline



NYISO DR Program Baselines

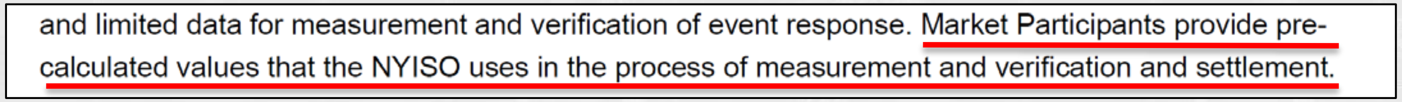
- SCR Capacity - Average Coincident Load (ACL)
  - *Program: SCR for capacity auction*
  - *Reference period used: Prior Equivalent Capability Period*
  - *Average of highest twenty resource loads during top forty NYCA peak load hours in same season (Summer/Winter) of previous year*
- Energy Customer Baseline Load (CBL)
  - *Programs: EDRP, DADRP and SCR Energy*
  - *Reference period used: Highest five consumption days of last ten "like" days where DR event or schedule did not occur*
  - *Weather-sensitive adjustment option (in-day)*
- Real-time Baseline
  - *Program: DSASP for Reserve and Regulation resources*
  - *Reference period used: Actual load just prior to the beginning of a real-time schedule*

Validate Performance (months later)

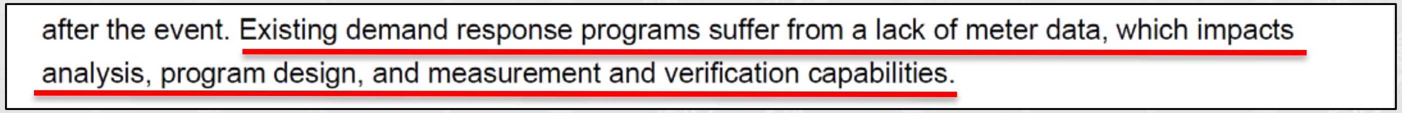


Data Submission for Verifying Load Reduction

- SCR Capacity ACL
  - *Meter data for ACL is provided to NYISO by wholesale Market Participant (utility, aggregator, etc.) at the time of the retail consumer enrollment into the SCR program*
  - *Meter data from event/test is provided within 75 days of the event/test*
- Energy CBL (EDRP, SCR Energy, DADRP)
  - *Meter data for CBL and event/test period is provided to NYISO by wholesale Market Participant*
    - Within 75 days of reliability event/test
    - Within 55 days of economic schedule
- Real-time Baseline (DSASP)
  - *Meter data is transmitted every 6-seconds via continuous two-way metering and incorporated into system operations*
  - *Real-time meter data compared to revenue-grade meter after the fact*



and limited data for measurement and verification of event response. Market Participants provide pre-calculated values that the NYISO uses in the process of measurement and verification and settlement.



after the event. Existing demand response programs suffer from a lack of meter data, which impacts analysis, program design, and measurement and verification capabilities.

Breakout 2 Question:

Part 1:
What are the best practices for measuring and validating the provision of energy services to one or more markets?

Part 2:
Where are the gaps in measuring and validating the provision of energy services to one or more markets?

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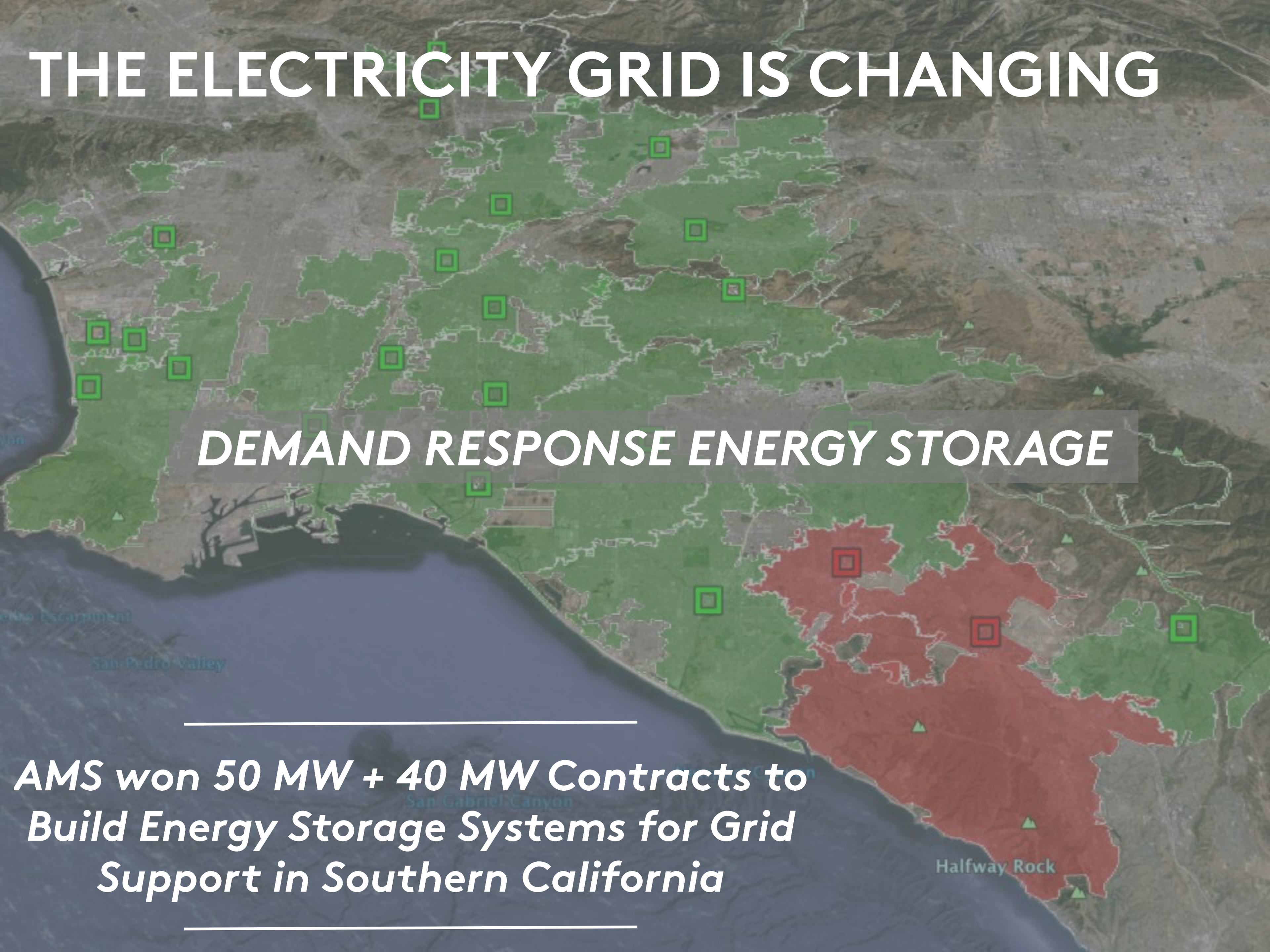
Tomorrow's Energy Grid

NIST Workshop:
Harnessing the Power of
Distributed Energy Resources

A Model for
Transactive Energy

Audrey Lee, Ph.D.
Vice President, Analytics and Design
October 20, 2016

THE ELECTRICITY GRID IS CHANGING



DEMAND RESPONSE ENERGY STORAGE

AMS won 50 MW + 40 MW Contracts to Build Energy Storage Systems for Grid Support in Southern California

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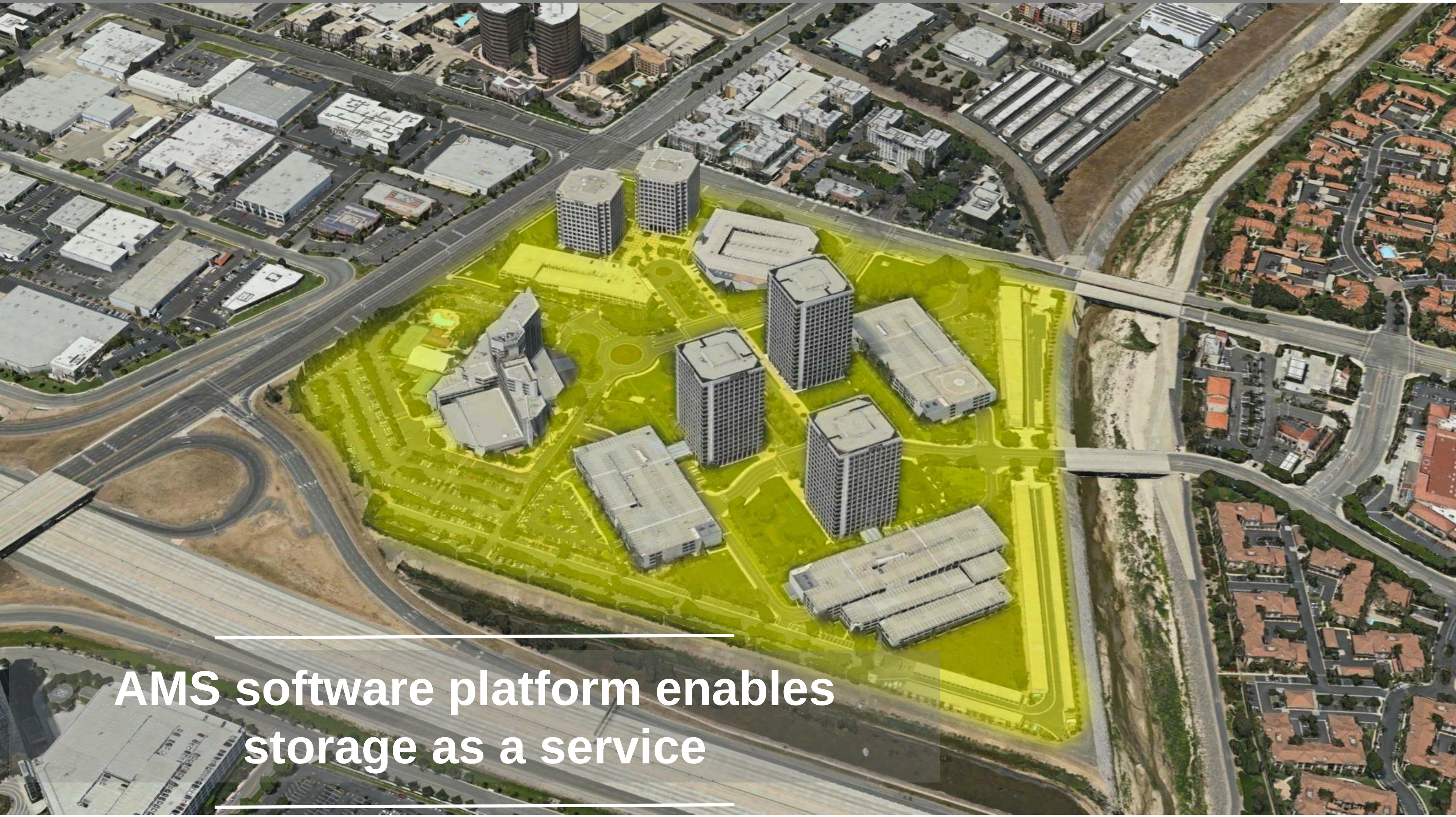
AMS TARGETS LOAD CLUSTERS



AMS software platform enables storage as a service

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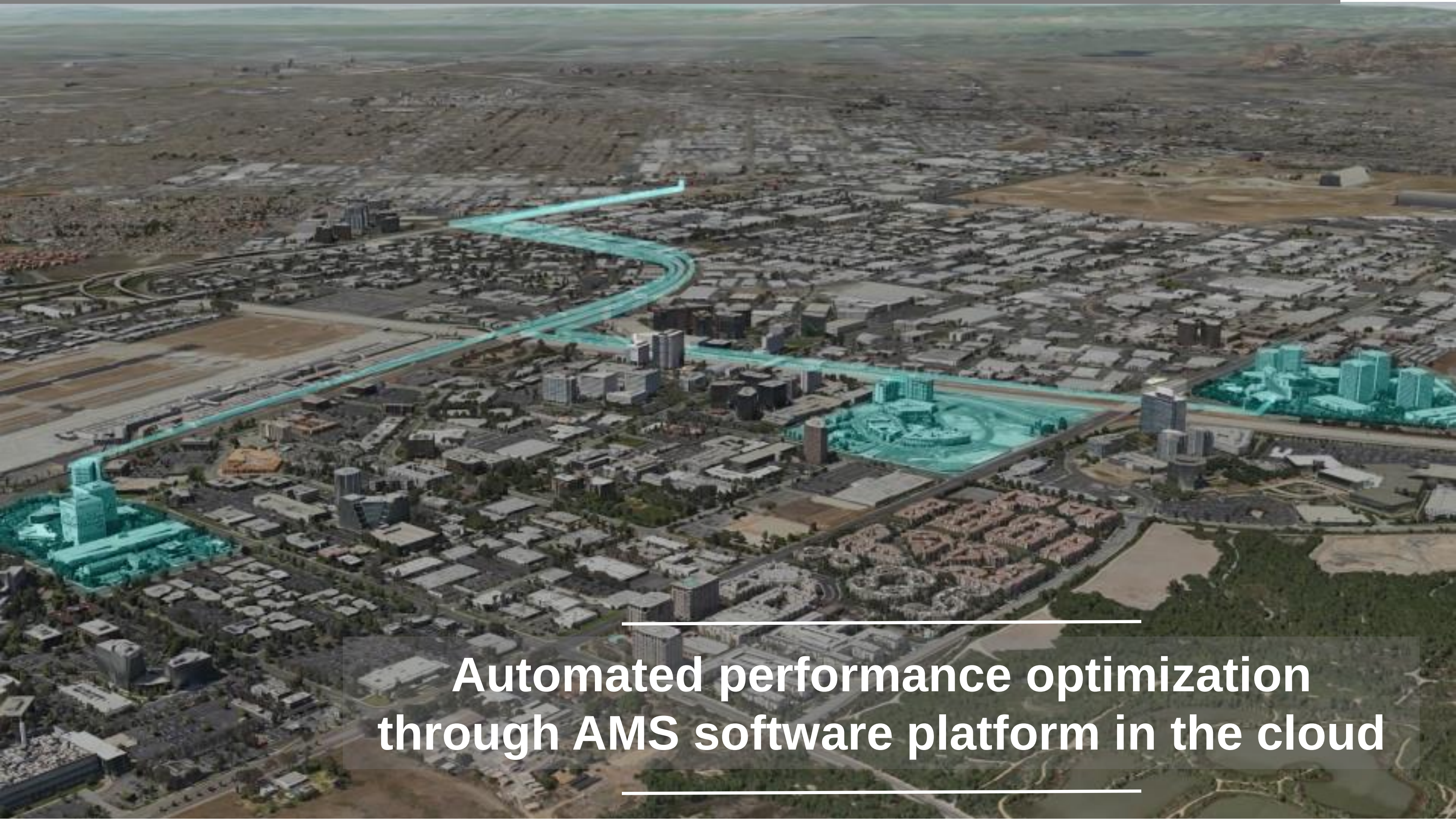
AUTOMATED DISPATCHABLE LOAD REDUCTION



Automated performance optimization through AMS software platform in the cloud

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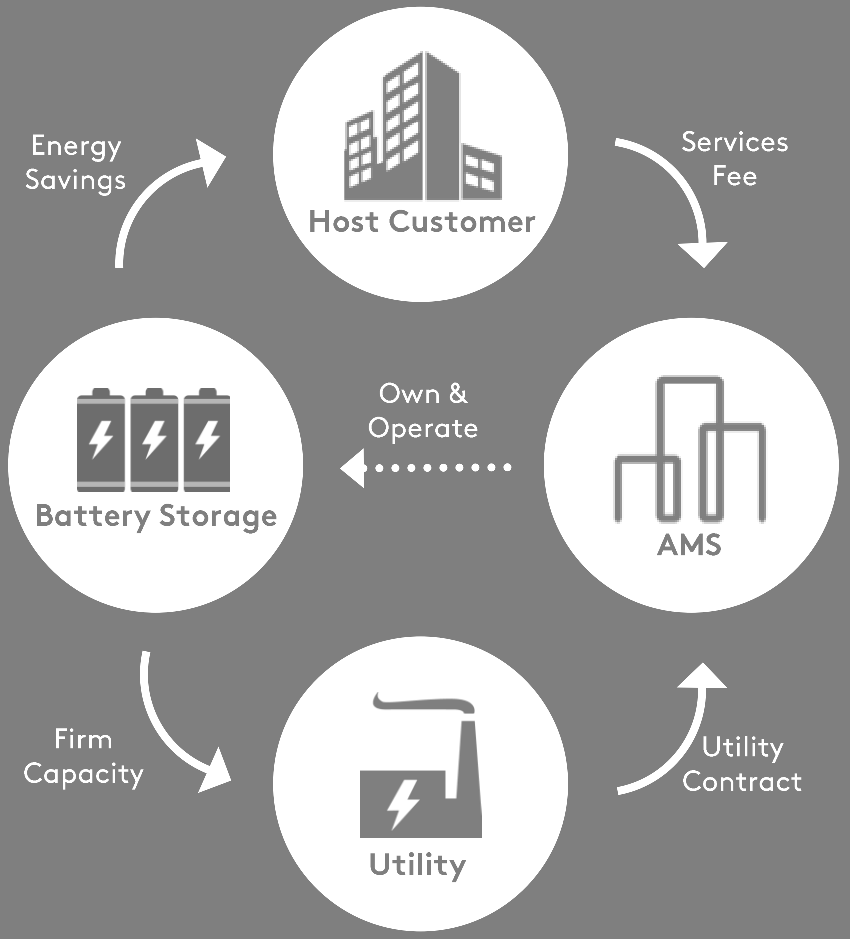
STORAGE AS A SERVICE

- Host customers receive cost savings, operational efficiencies and market revenues with no capital outlay and no technology risk

- Utilities receive firm, dispatchable energy products that are clean, flexible and competitively priced – and keep their customers happy

- AMS recruits the host customers, negotiates the utility agreements, and manages the assets

- AMS finances the projects with a combination of fixed services fees from hosts, utility revenues, incentives and/or grants



Host Customer

Services Fee

AMS

Own & Operate

Battery Storage

Energy Savings

Firm Capacity

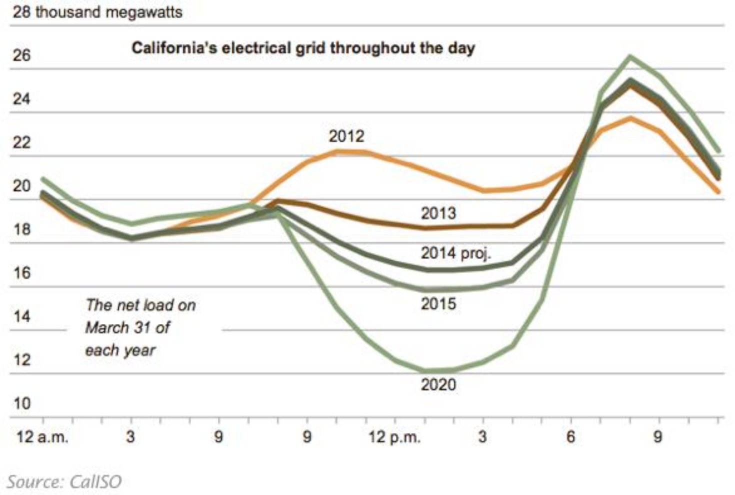
Utility

Utility Contract

BUSINESS MODEL

PROBLEM

Distribution grid is stressed from plant closures, capacity constraints and adoption of renewable energy



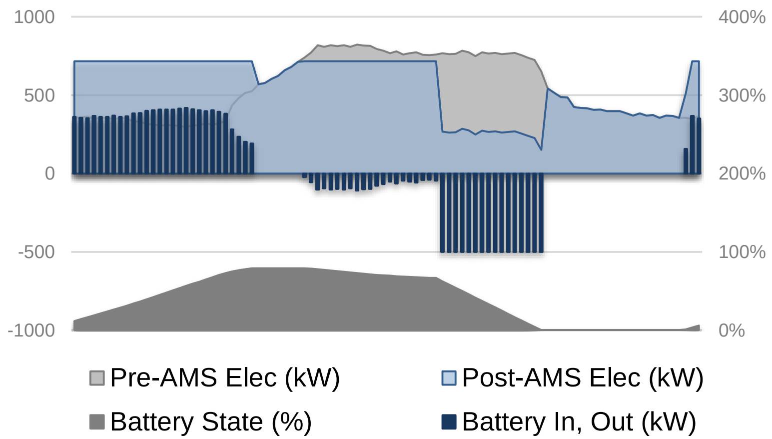
Source: CallSO

Customers bear costs of the current grid:

- Utilities face high investment in grid infrastructure
- Host customers face high demand charges

SOLUTION

Energy storage is the keystone technology for managing the modern distribution grid



AMS provides solutions to customers:

- Clean, dispatchable load reduction to utilities on constrained utility circuits
- Lower host customer energy expenses

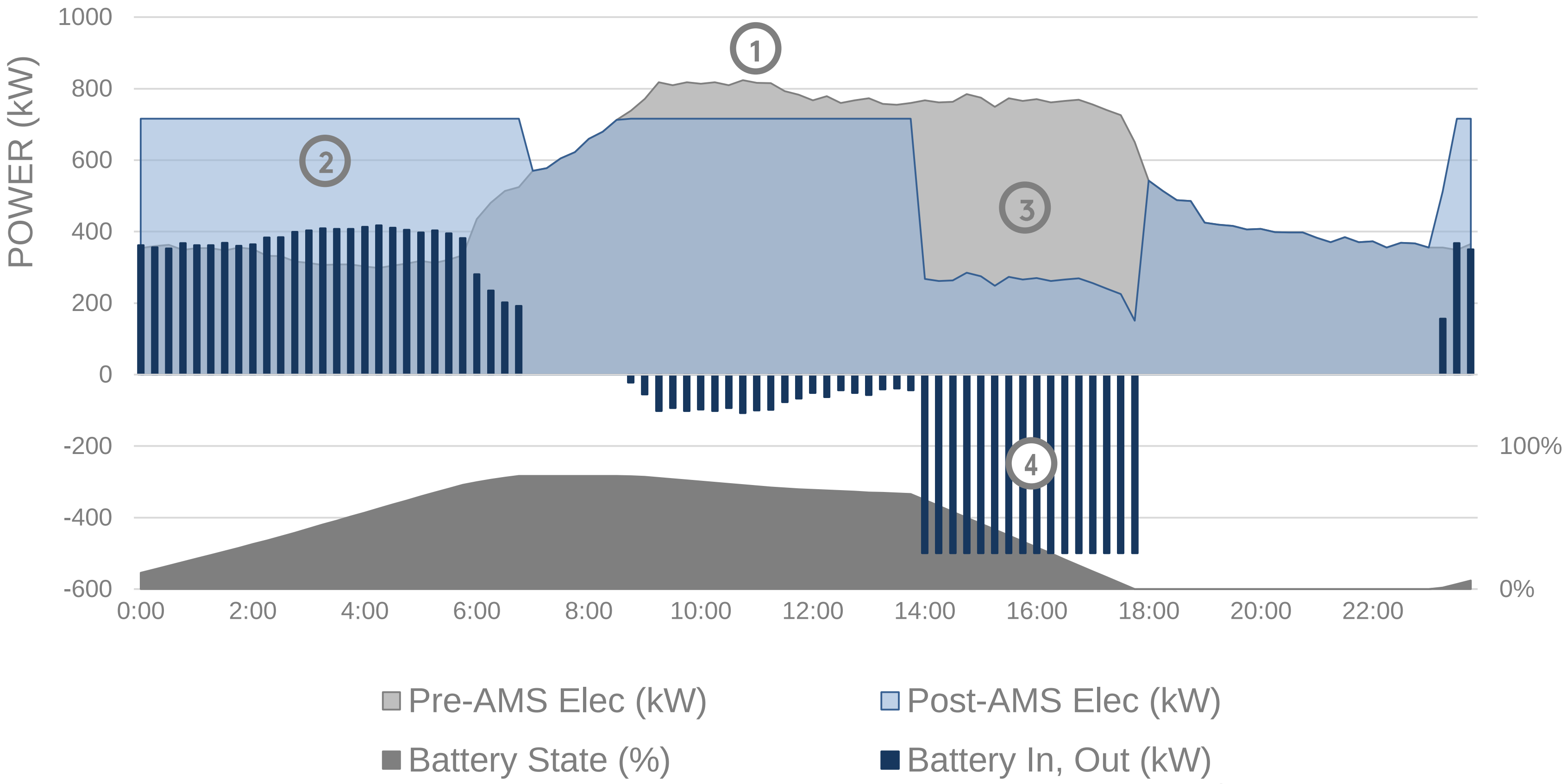
OPTIMIZED DEMAND MANAGEMENT

① DEMAND MANAGEMENT

② LOAD SHIFTING

③ UTILITY SERVICES

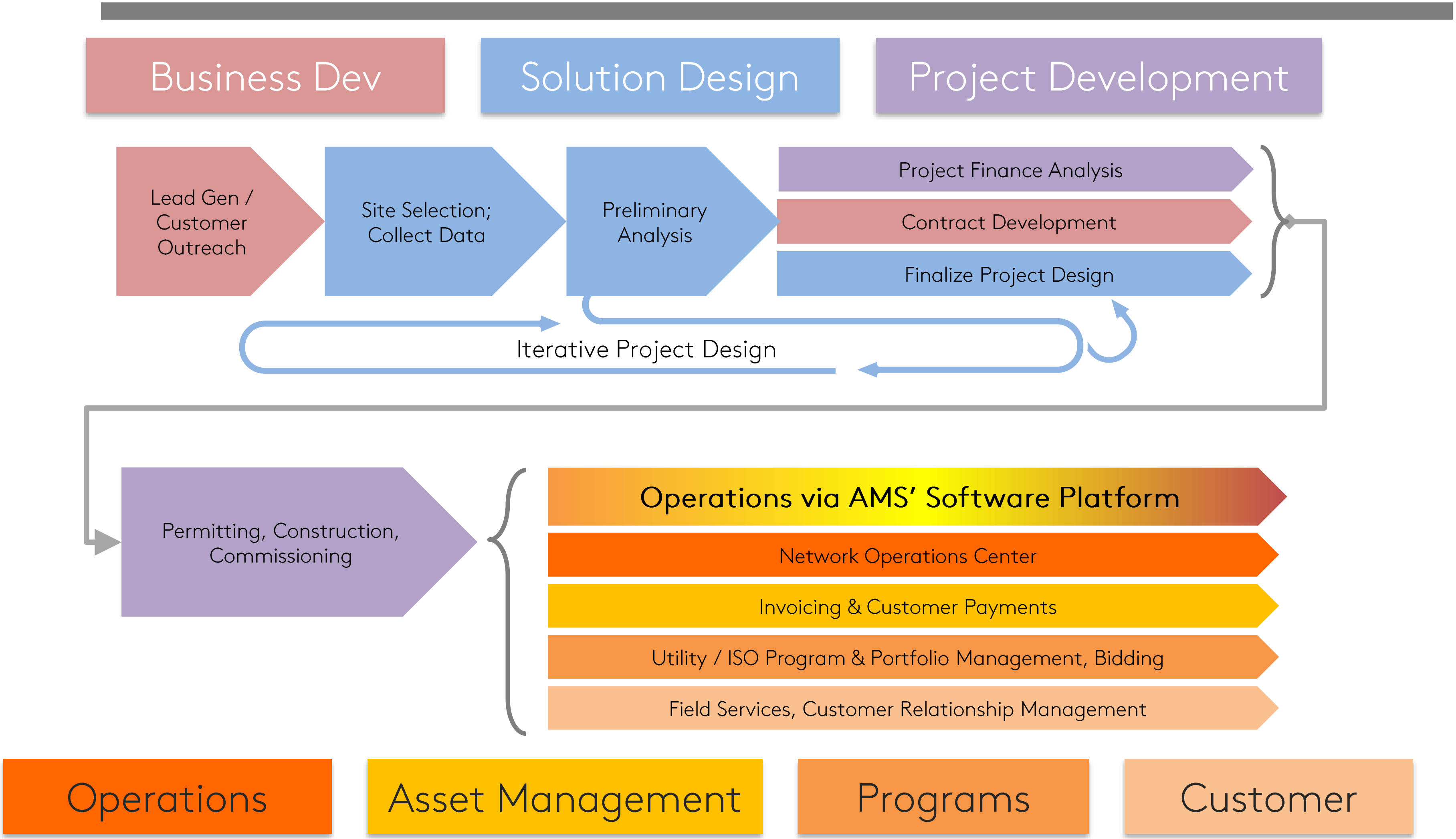
④ BATTERY ACTIVITY



Confidential and Proprietary

ANALYTICS AND DESIGN PROCESS

From Lead to Close to Operations



Business Dev

Solution Design

Project Development

Lead Gen / Customer Outreach

Site Selection; Collect Data

Preliminary Analysis

Project Finance Analysis

Contract Development

Finalize Project Design

Iterative Project Design

Permitting, Construction, Commissioning

Operations via AMS' Software Platform

Network Operations Center

Invoicing & Customer Payments

Utility / ISO Program & Portfolio Management, Bidding

Field Services, Customer Relationship Management

Operations

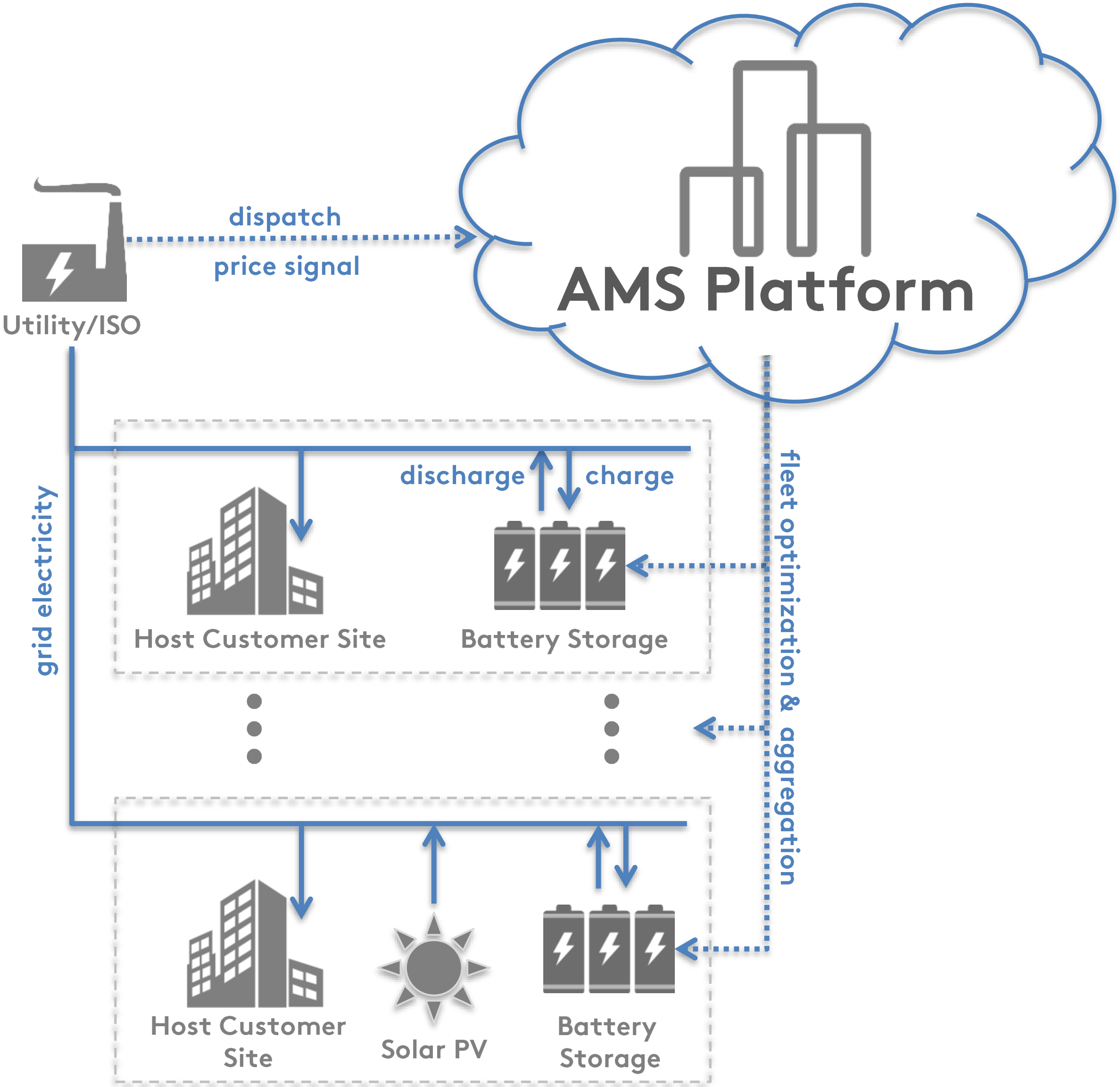
Asset Management

Programs

Customer

AMS Software Platform

Enables and Optimizes Revenue Streams



Inland Empire Utilities Agency
A MUNICIPAL WATER DISTRICT

- 6 Industrial water pumping and treatment facilities
- Optimization of grid and renewable generation assets
  - 3.75 MW energy storage
  - 3.5 MW solar
  - 1 MW wind
  - 3 MW biogas
  - 2.8 MW fuel cell
- 5-10% reduction in annual energy costs(~$550,000)
- Complex tariffs: RES-BCT, Standby, Direct Access, NEM
- Custom designed

HYBRID ELECTRIC BUILDING™

IRVINE COMPANY
Since 1864

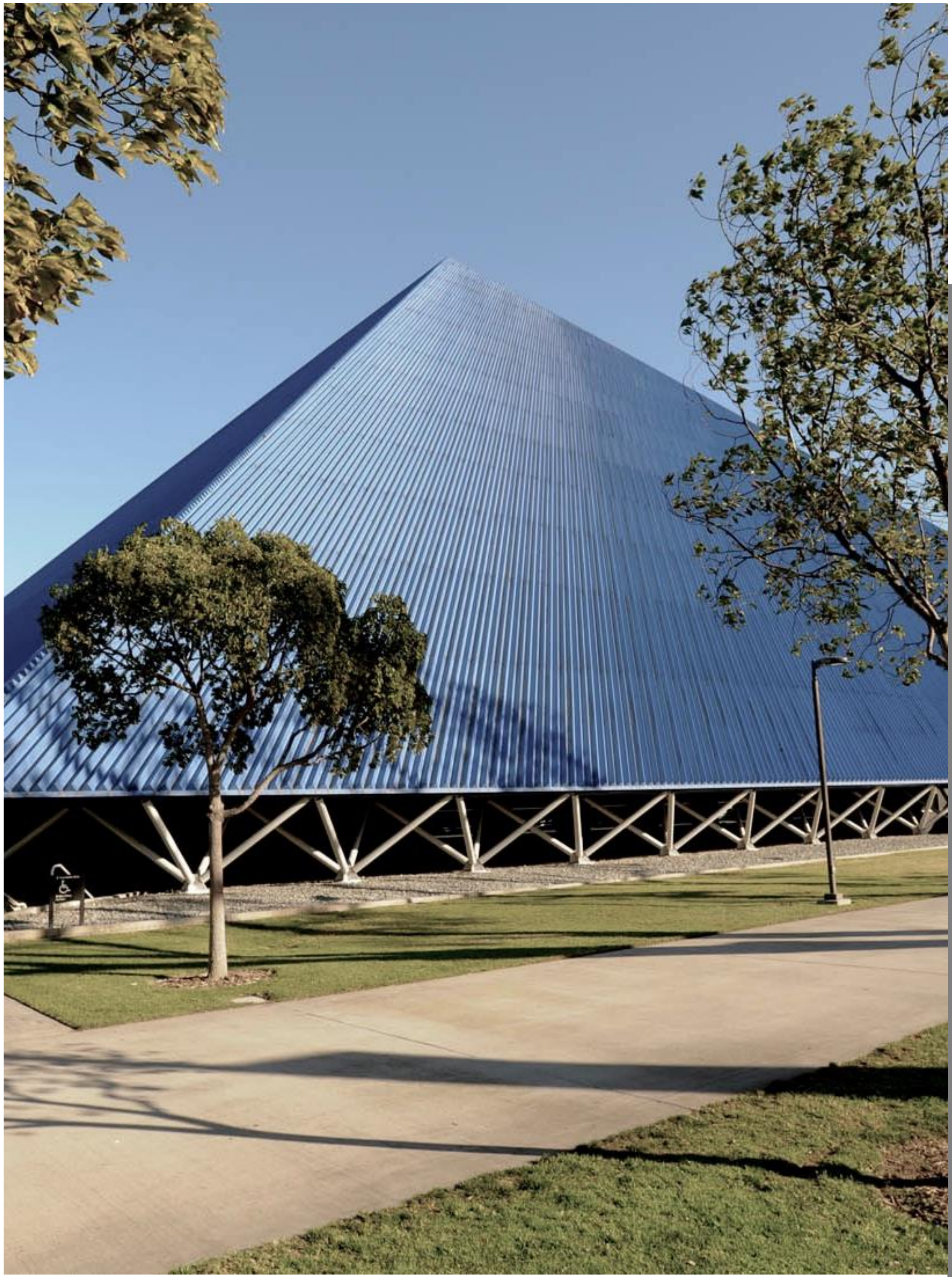
- 10 MW Fleet of Hybrid-Electric Buildings
- 22 class A commercial office buildings
- 10 MW of firm, dispatchable capacity to the utility
- No distribution upgrades
- Carbon neutral, zero emissions

CUSTOM-FITTED WITH ENERGY STORAGE

Irvine Ranch Water District

- World's largest energy storage project with public water agency
- 7.5 MW / 35 MWh Advanced Energy Storage Network
- 11 state-of-the-art water treatment facilities:
  - Water Recycling
  - Deepwater Aquifer Treatment
  - Wastewater Treatment
  - Desalter Facility
  - Pumping Stations
- 6 MW Firm Capacity to SCE

Treatment basins for cutting-edge membrane bio-reactor process at Michelson Water Recycling Plant.

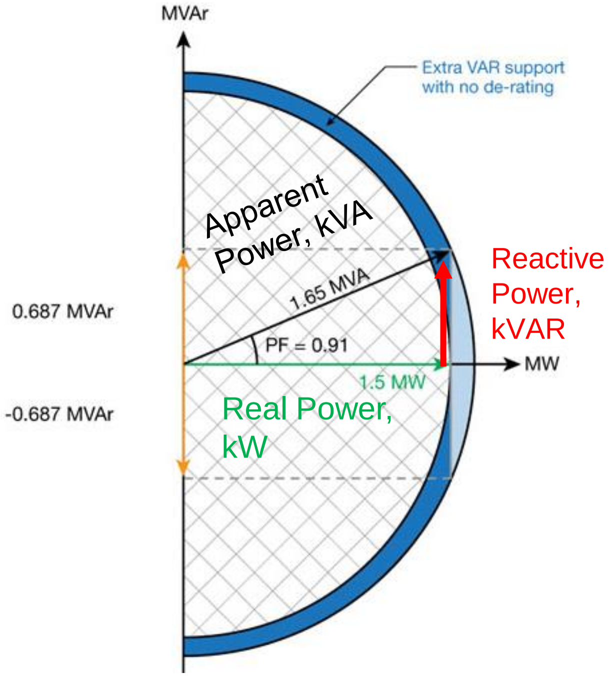


CSU The California State University

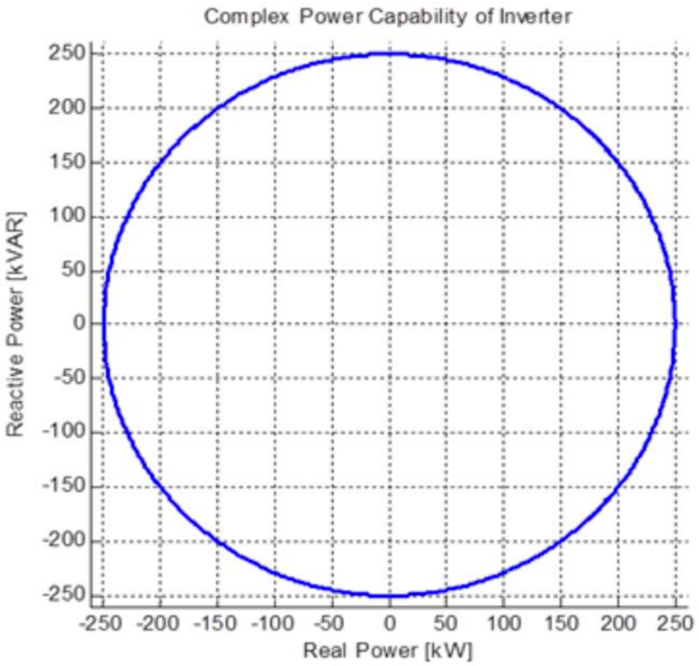
- Launches flagship system-wide CSU battery storage program
- Phase I projects:
  - CSU Long Beach
  - CSU Fullerton
  - Chancellor's Office
- Initial deployment: 4 MW of firm, dispatchable load reduction to SCE
- Expedited for grid support

BEYOND REAL POWER: VOLT/VAR OPTIMIZATION

- Battery Inverters are 4-quadrant inverters → can provide both **real** and **reactive** power
- Reactive power can help with voltage support (CVR) as well as manage site power factor

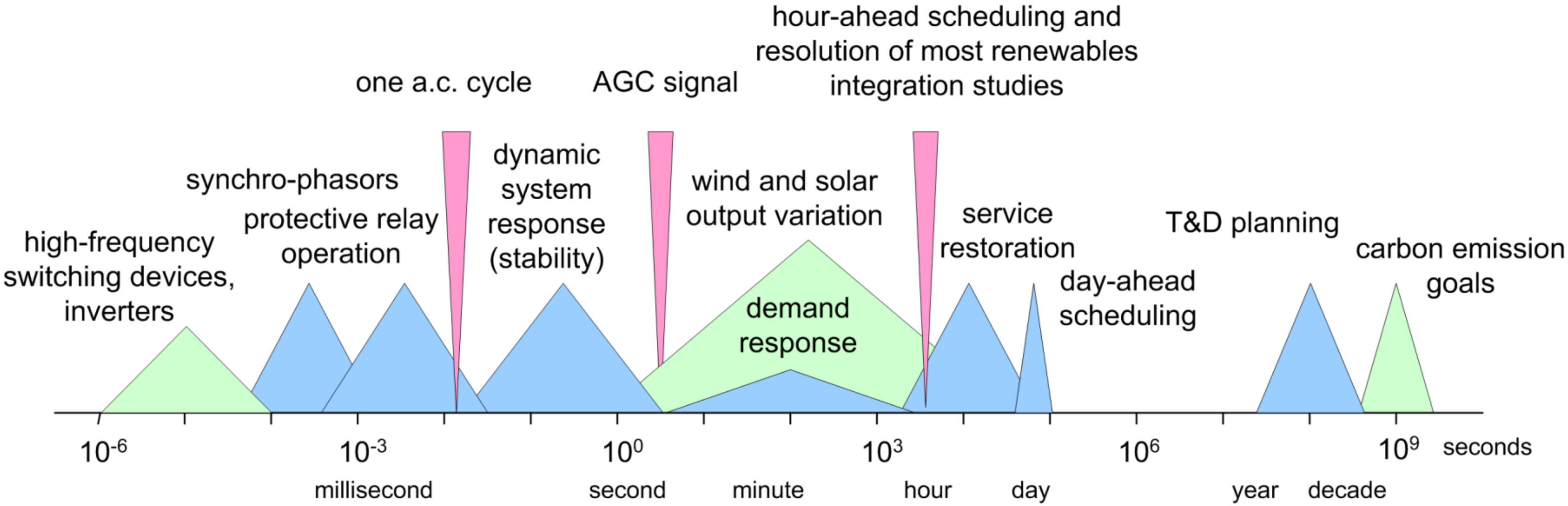


Eaton Solar Inverter



Tesla Battery Inverter

TIME SCALES IN ELECTRIC OPERATIONS



uc-ciee.org

AGGREGATION UNLOCKS FUTURE VALUE OPPORTUNITIES

UTILITIES / GRID OPERATORS

GRID SERVICES

Firm, Dispatchable Capacity

Dynamic Load Management

Transmission Congestion Relief

Distribution Deferral

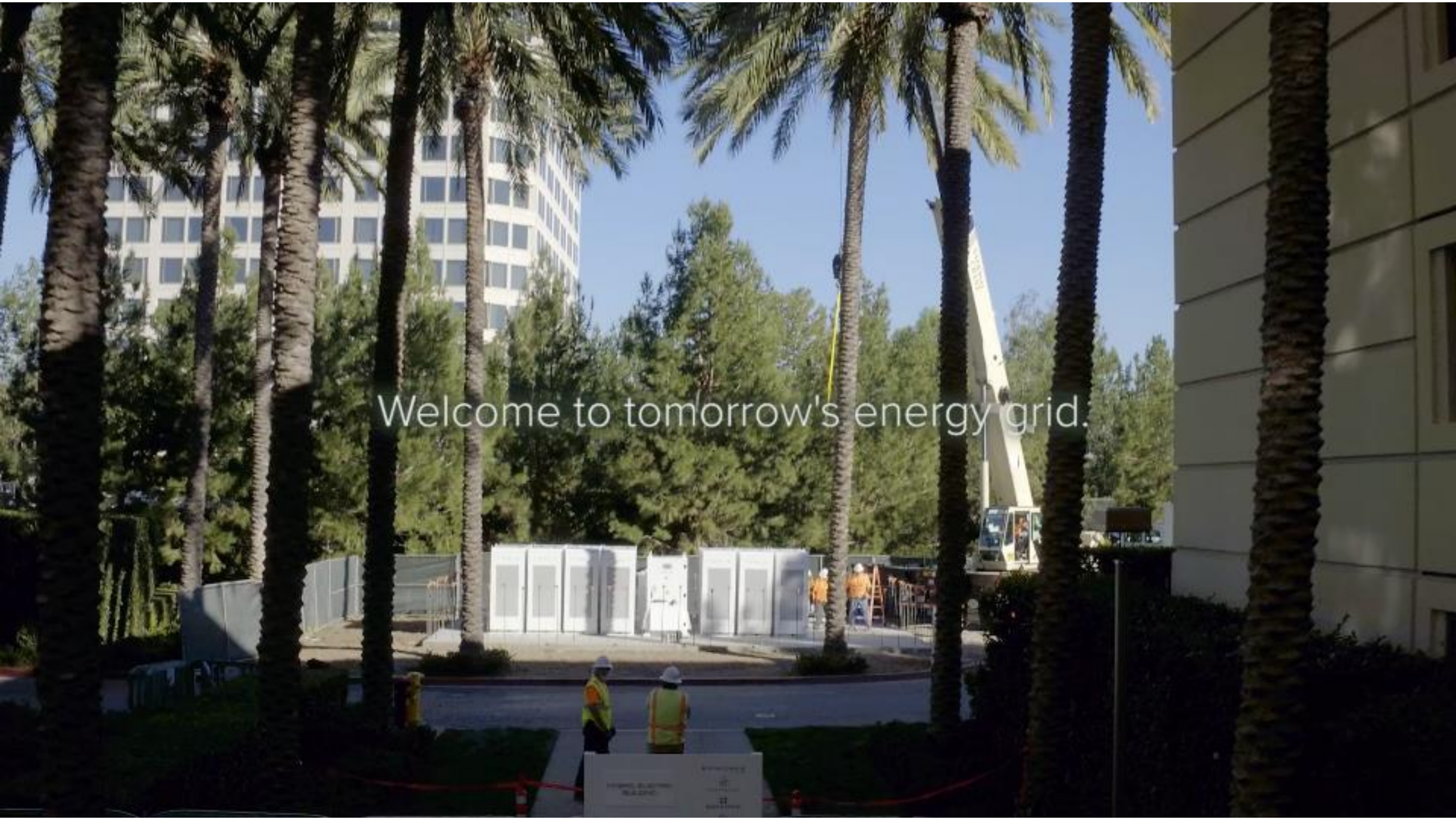
Volt/VAR Optimization

Local Frequency Response

Black Start

Wholesale Market Products:

- Frequency Regulation
- Spin / No Spin Reserves
- Day Ahead, Real Time



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AMS EXECUTIVE TEAM

SUSAN KENNEDY
Founder and CEO

Chief of Staff, CA Gov. Arnold Schwarzenegger
Commissioner, CA Public Utilities Commission
Cabinet Secretary, CA Gov. Gray Davis

KELLY WARNER
President

CEO, KEMA | CEO, Deerpath Energy | CEO, Xenergy
Developed one of the first retail energy service companies in the United States

JACKALYNE PFANNENSTIEL
Co-Founder and Director

Asst. Secretary of Energy, US Navy
Chairman, CA Energy Commission
Corporate Officer, Pacific Gas & Electric

KATHERINE RYZHAYA
Chief Commercial Officer

Dir. of Structured Transactions, Evolution Markets
Contract Origination, Pacific Gas & Electric
RBC Capital Markets | UBS Warburg

MARK THOLKE
VP Development

VP EDF Renewable Energy, West Region
GE Wind | Eurus | Green Mountain Energy

AUDREY LEE, PHD
VP Analytics & Design

Advisor CPUC Pres., Smart Grid, Energy Data & Storage
Fellow, US Department of Energy
International Energy Agency

ALAIN STEVEN
Chief Technology Advisor

CTO & Co-Founder, Viridity Energy
President and CEO, Alstom ESCA Corp.
CTO, PJM Interconnection

MANAL YAMOUT
VP Policy and Markets

Dir. Government Affairs, NextEra Energy
Renewable Energy Advisor, CA Gov. Schwarzenegger
Assistant Secretary of International Trade, CA

STACY LOVELACE
VP Finance and Legal

VP Finance and Legal, Sensage
VP Finance and Legal, Altius Education
Senior/Special Counsel, Sprint

WEST OWENS
VP Finance and Strategy

VP Structured Finance, SolarCity
Finance Manager, AES Solar
US Renewables Group | Mascoma Corporation

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Validating the Models for Transactive Energy

Dr. Martin J. Burns

Electronic Engineer, Engineering Laboratory
NIST Smart Grid Program

Harnessing the Power of Distributed Quantifying Transactive Energy Resources: Quantifying Transactive Energy Economics
October 20th 2016

TE Challenge Co-Simulation Framework

- Reason for Tiger Team Effort
- The Participants:
  - PNNL
  - Vanderbilt
  - CMU/MIT
- The Results
  - Draft Technical Framework
  - Extensible Component Model
  - Canonical Experiment/Simulation
  - Core Analytics

Why do we need a "Common Platform" for TE Simulations?

Platform Goal: *to be able to understand, evaluate, compare and validate transactive energy approaches, grid operations and controls.*

- Design a common platform that has well-defined interfaces and semantics such that stakeholders can use it to evaluate in their own contexts and may even plug-in their own [proprietary/confidential] models and components.
- As part of the platform we envision a library of tools & models that will be available for users to leverage existing great work from the open-source domain.
- Three collaborators may implement the common specification providing three equivalent testbeds for TE evaluations

Progression of Simulation Platform Usage

Baseline Reference Scenario Demonstrates the Model

- Simple Grid Model
- 30 Houses
- Simple market based on price curve bidding

What scale / type of grid model will meaningfully demonstrate your technology?

- Scale to achieve meaningful analysis
- Radial vs Mesh grid
- How many nodes/customers

How might you use the common platform to distinguish your capabilities?

- Compare different grids
- Compare different market models
- Compare discrete event physics and ODEs

What significant timescales should be studied?

- Capitalization impacts
- Grid stability
- Market stability/complexity -- time of use ... dynamic bidding ... aggregation pools

TE Challenge Common Platform Specification

- A detailed technical specification that can be faithfully implemented on one or more simulation platforms comprising:
  - A set of model components with specific minimum interfaces
    - Any interface can be extended as needed for any TE Challenge Case
    - Core components can be combined and hide internal interfaces
  - A canonical simulation that allows the set of components to be orchestrated in a simulation
    - Minimal or extended models can be substituted for any component(s) and can simulated by the same experiment controller
  - A reference grid and scenario
    - A defined set of grid nodes, resources, controllers, and transactive agents and market simulation to provide a baseline for comparison
  - A minimum core set of analytics based on the data provided through the canonical simulation

Baseline Reference Scenario

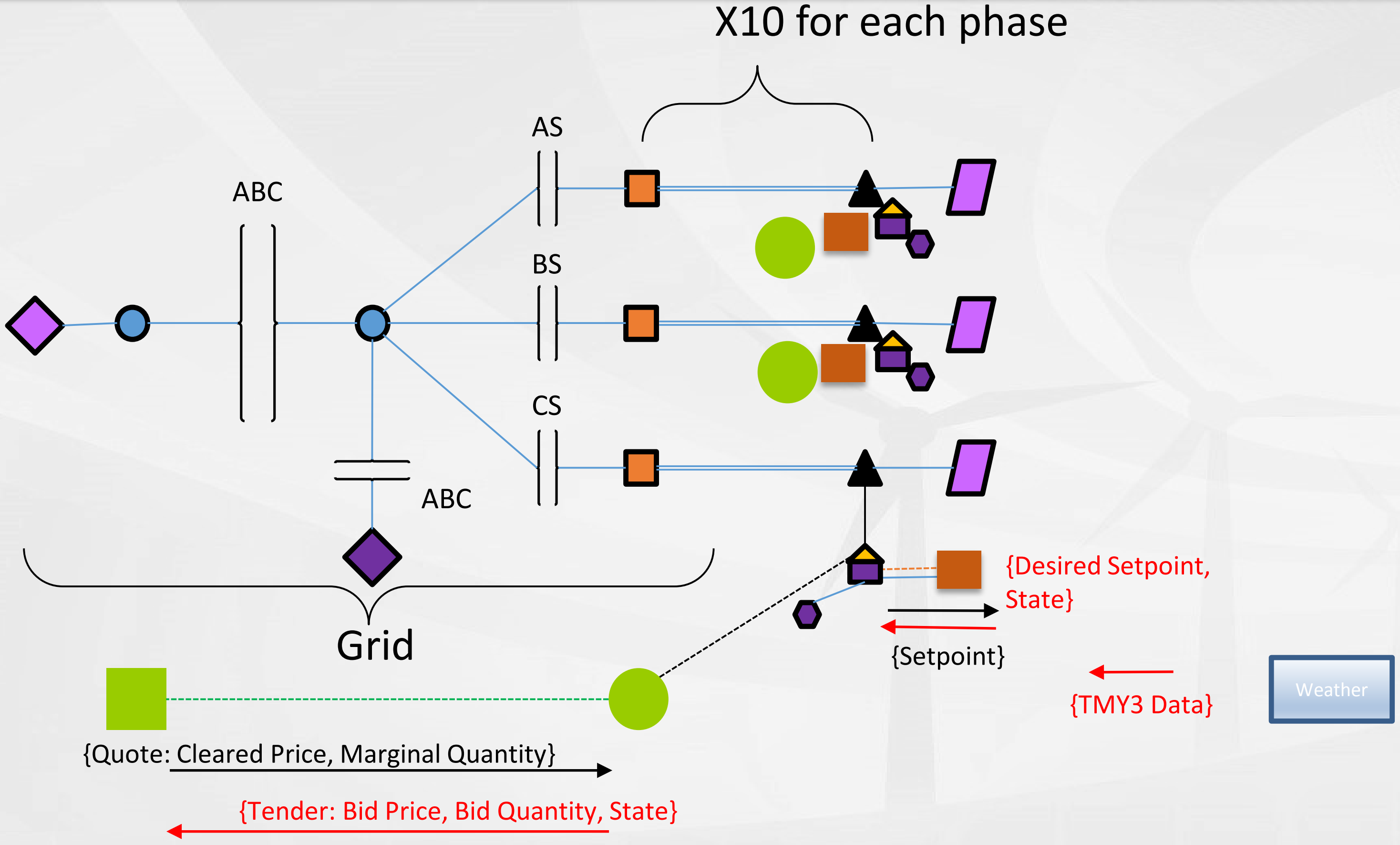
30 houses divided among three phases on one distribution transformer.

The distribution system has one uncontrollable load (Resource) and one source of bulk power (Resource).

There is a weather feed of TMY3 Data for a single locale (Weather).

Each house has:

- A solar panel (Resource)
- A controllable load – HVAC (Resource)
- A non-controllable load (Resource)
- A home automation system (SupervisoryController)
- A thermostat (LocalController)
- A transactive agent (TransactiveAgent)



Resources
▱ PV Panel (+inverter)
◆ Bulk Power
◆ Dummy Grid Load
▬ Controllable Load (HVAC)
⬢ Uncontrollable Load

Nodes
▲ Meter (triplex)
■ Node (triplex)
● Node (three-phase)

Links
‖ Transformer
═ Triplex cable

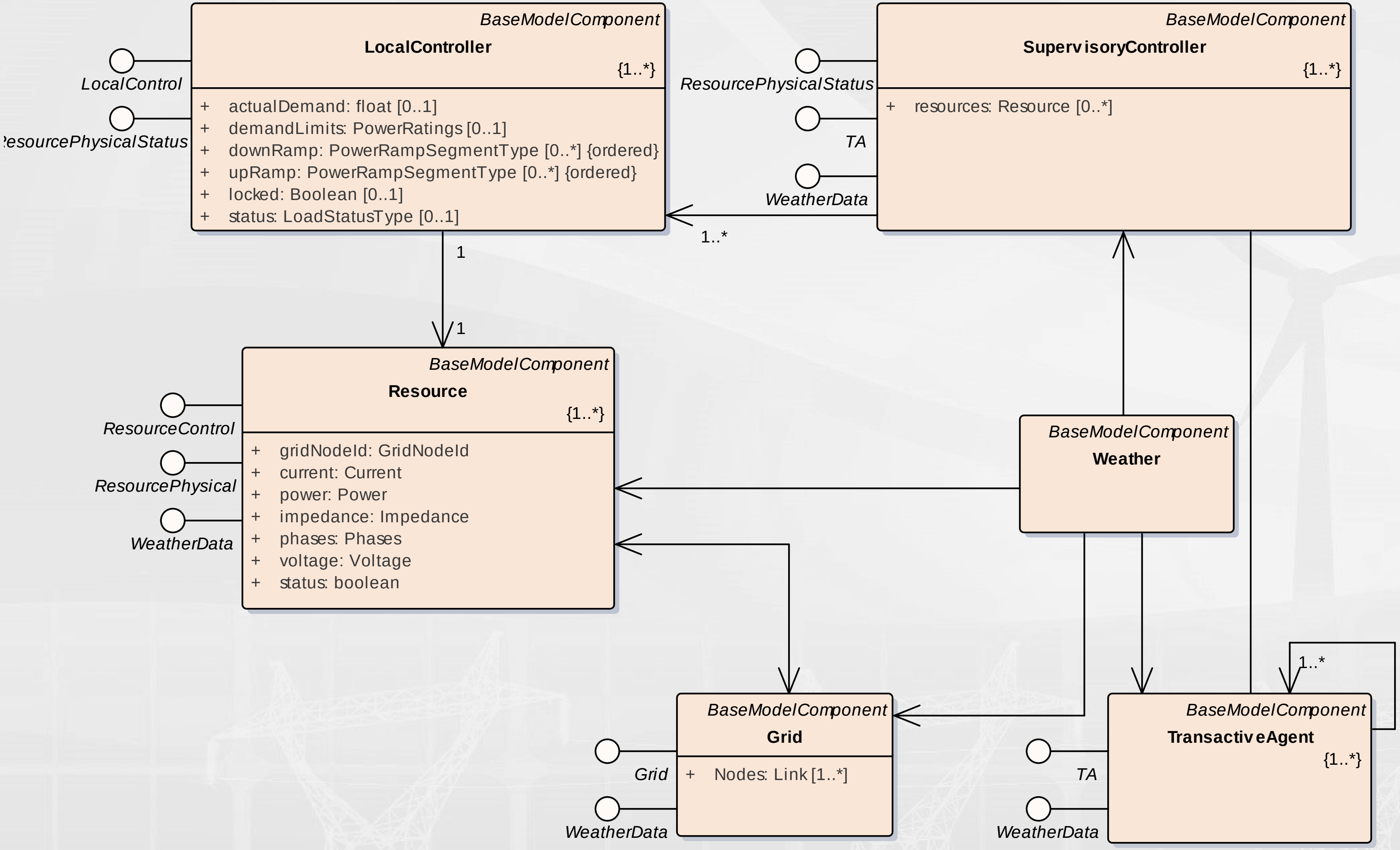
Logical Connectors
— Power Flow
- - - Data

LocalController
■ Thermostat

SupervisoryController
▲

Transactive Agents
● Bidding Controller
■ Auction
Weather

Core Modeling Components of Common Platform


BaseModelComponent
LocalController
{1..*}
- + actualDemand: float [0..1]
- + demandLimits: PowerRatings [0..1]
- + downRamp: PowerRampSegmentType [0..*] {ordered}
- + upRamp: PowerRampSegmentType [0..*] {ordered}
- + locked: Boolean [0..1]
- + status: LoadStatusType [0..1]

BaseModelComponent
SupervisoryController
{1..*}
- + resources: Resource [0..*]

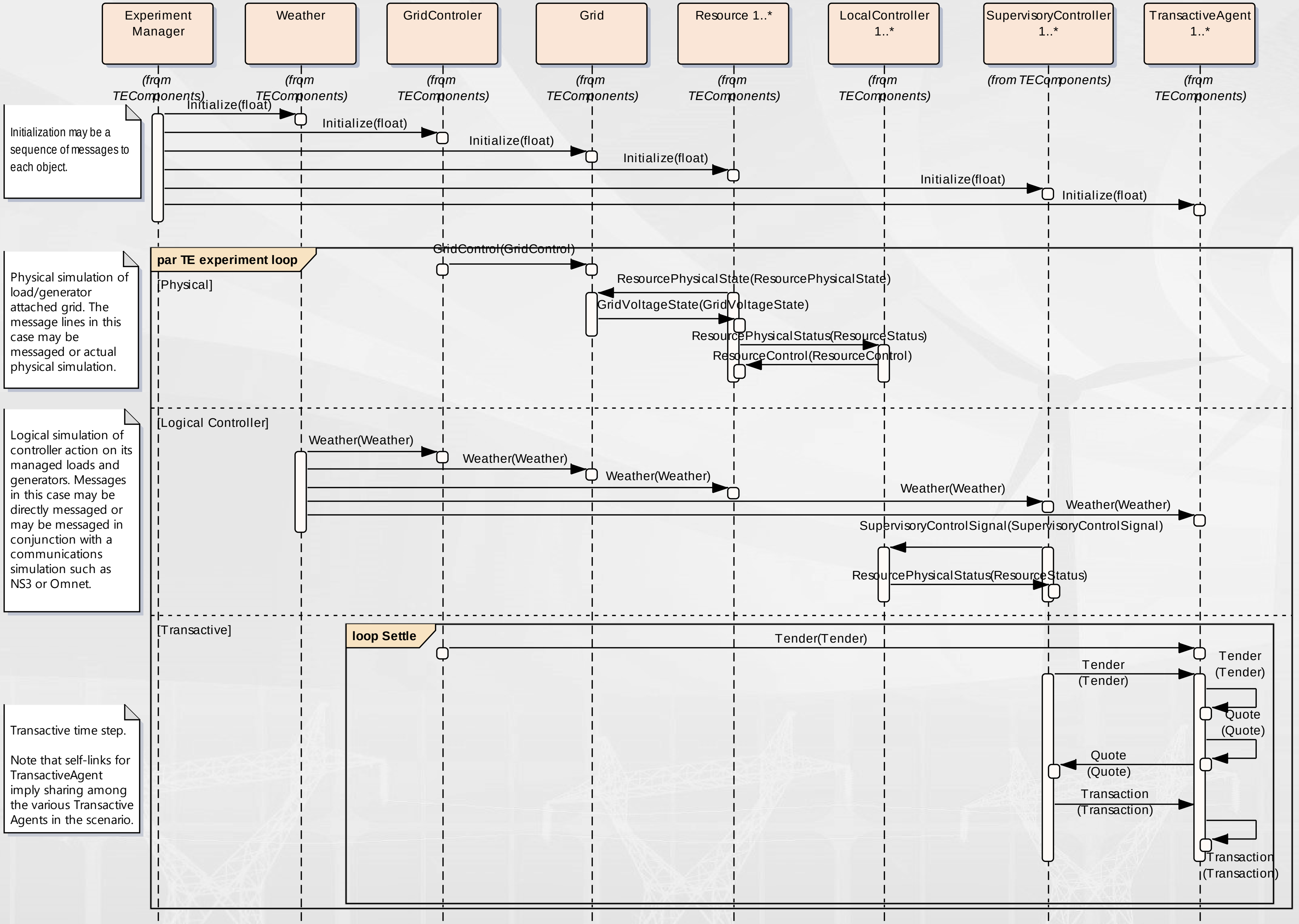
BaseModelComponent
Resource
{1..*}
- + gridNodeId: GridNodeId
- + current: Current
- + power: Power
- + impedance: Impedance
- + phases: Phases
- + voltage: Voltage
- + status: boolean

BaseModelComponent
Weather

BaseModelComponent
Grid
- + Nodes: Link [1..*]

BaseModelComponent
TransactiveAgent
{1..*}

Common Platform Canonical Simulation


Initialization may be a sequence of messages to each object.

Physical simulation of load/generator attached grid. The message lines in this case may be messaged or actual physical simulation.

Logical simulation of controller action on its managed loads and generators. Messages in this case may be directly messaged or may be messaged in conjunction with a communications simulation such as NS3 or Omnet.

Transactive time step.

Note that self-links for TransactiveAgent imply sharing among the various Transactive Agents in the scenario.

Metrics that can be Extracted by Analytics Component

Through the course of the experiment/simulation the following data can be extracted from the message exchange:

- Grid power flow and voltage states
- Load profile as consumed by all loads
- Generation profiles as produced by all solar panels
- Aggregated loads by household
- Price negotiations and exchanges
- Realized pricing coordinated by loads and generators