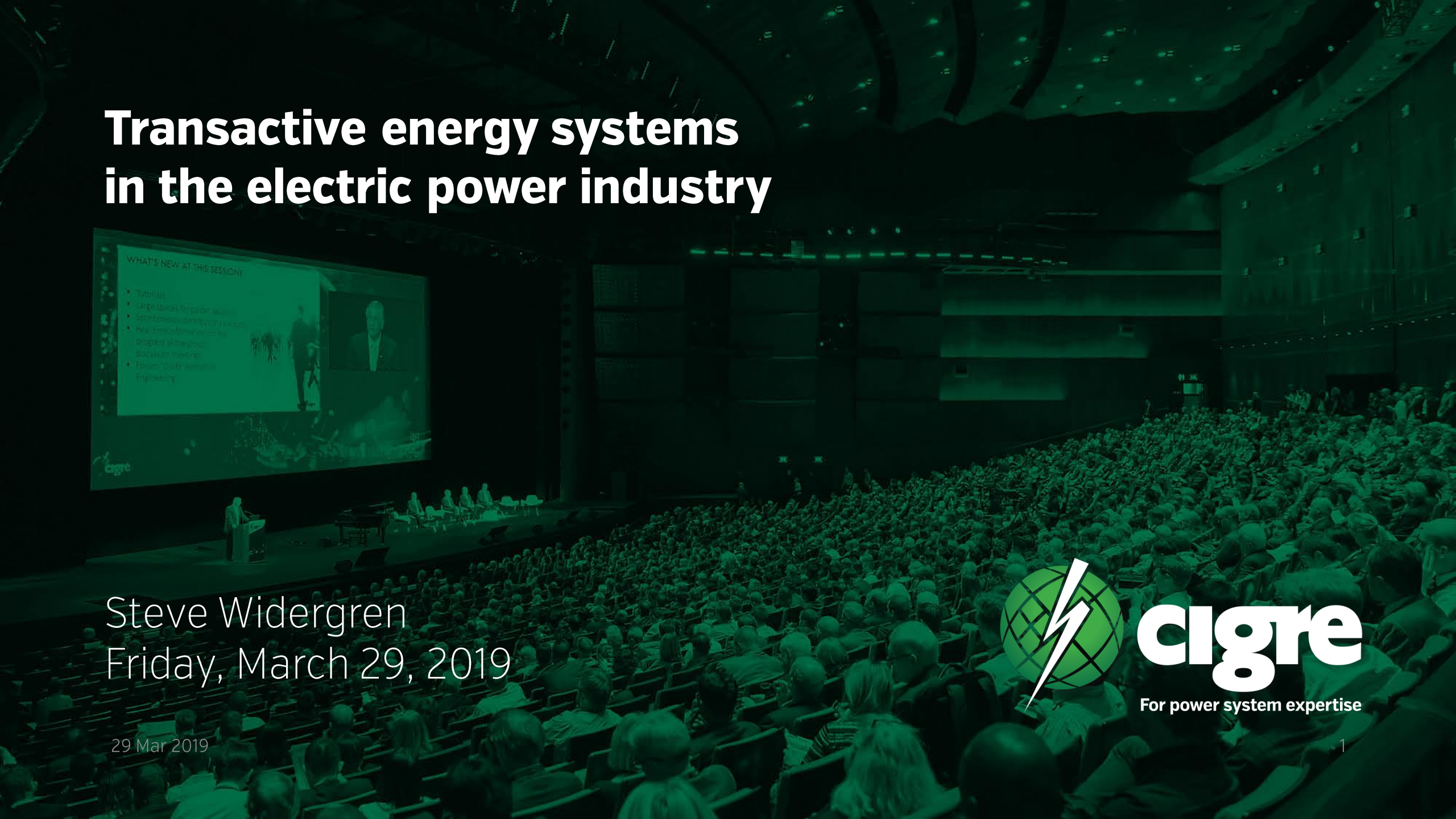
Transactive energy systems in the electric power industry



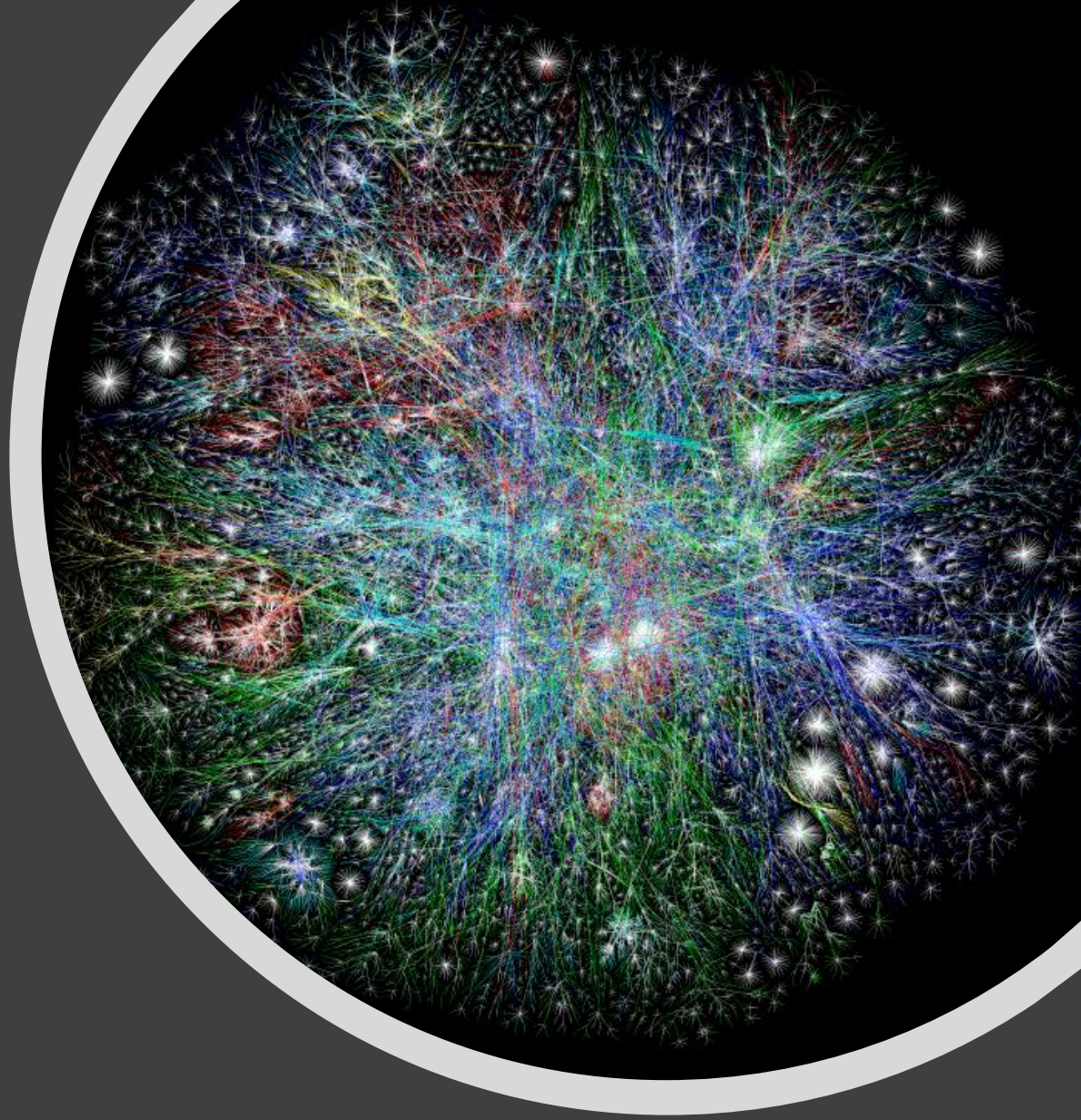
Steve Widergren
Friday, March 29, 2019

cigre
For power system expertise

Our world is more complex and growing faster than our control methods can handle

Complex systems

- Highly interconnected
- Heterogeneous device-human participation
- Extreme data
- Pervasive intelligence
- Increasing autonomy



Global energy goals cannot be met without changes in how we control complex systems

Energy systems

- Potential for substantial efficiencies in end-use systems with new controls
- More data and devices available
- New assets difficult to coordinate
- Existing controls antiquated

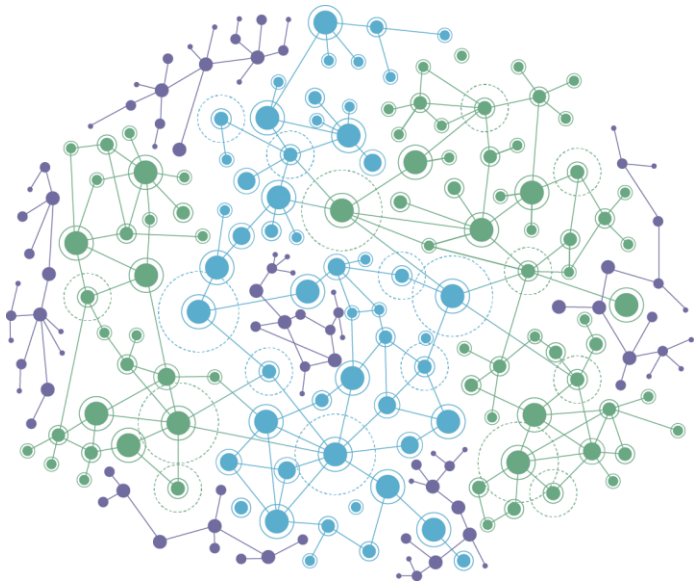
Cyber-physical systems

- Growing “edge” computing resources
- Cloud computing becoming paradigm
- Existing security models challenged

Traditional centralized control approaches are a common weakness

Distributed Controls Hypothesis

***Distributed** controls*



quick

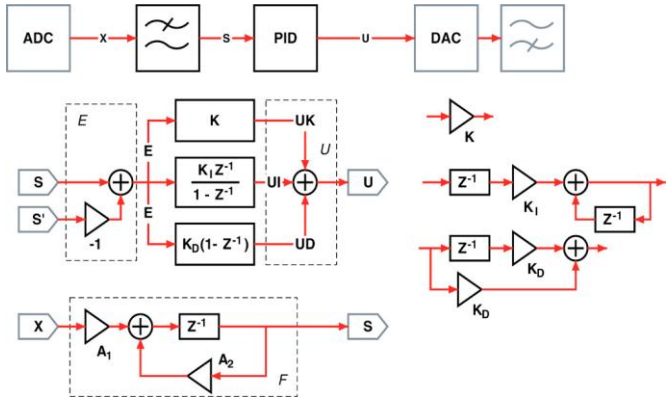
slow

Time to deployment

Hypothesis

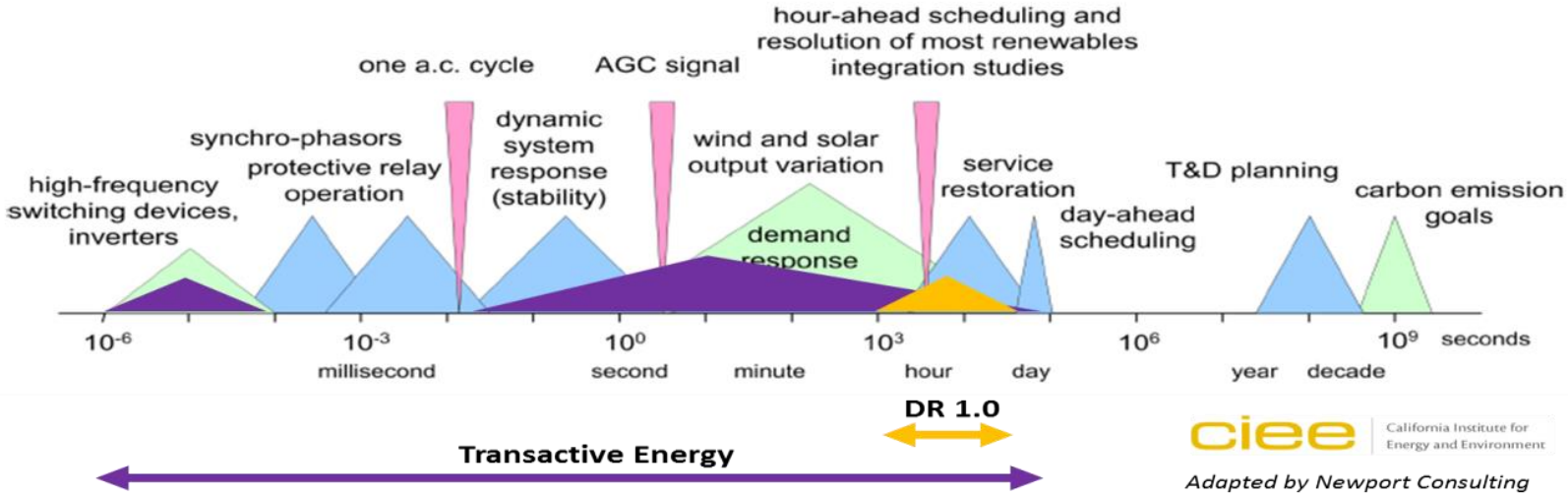
Distributed control approach is the fastest way to advance control theory to address the challenges posed by large-scale infrastructure systems

***Conventional** controls*



Negotiate Multiple Objectives with Distributed Control

- Some grid objectives
  - Reduce peak loads (lowers new capacity investments, enhances asset utilization)
  - Enhance efficiency of wholesale markets and production
  - Reduce impacts of transmission and distribution congestion
  - Provide ancillary services - reserves & balancing (especially w/ increased renewables)
- Some end-user objectives
  - Reduce energy bills
  - Maintain requirements for comfort and business
  - Increase net benefits of distributed generation and storage investments
- Some societal objectives
  - Mitigate impacts from disasters
  - Reduce environmental impact

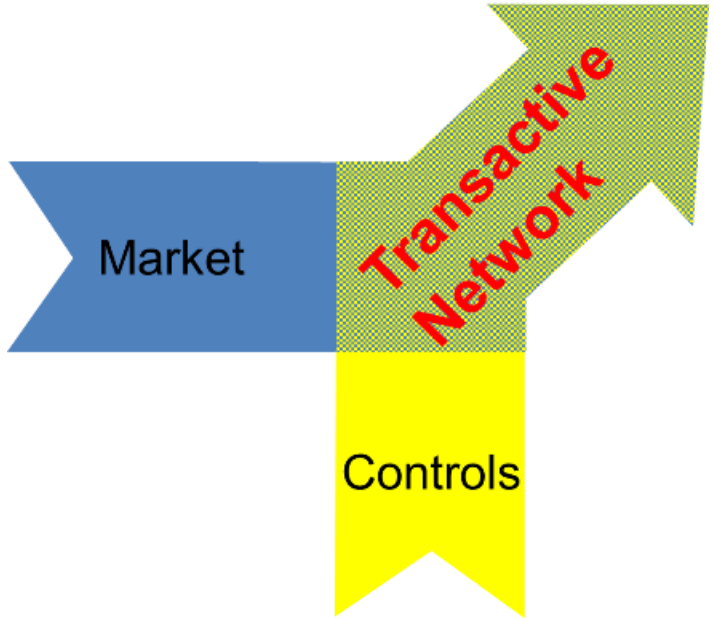


Transactive Energy – an approach to responding to our changing world…

"A set of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter."

GridWise® Architecture Council, Transactive Energy Framework

- Use market mechanisms to perform distributed optimization
  - Reflect value in exchangeable terms (price)
  - Effectively allocate available resources and services in real-time
  - Provide incentive for investment on longer time horizon
- Use communications and automation of devices and systems as real-time agents for market interaction
  - Agents convey preferences and perform local control actions
  - Engage in one or more markets to trade for services, e.g.,
    - Real-time energy, peak-shaving
    - System reserves



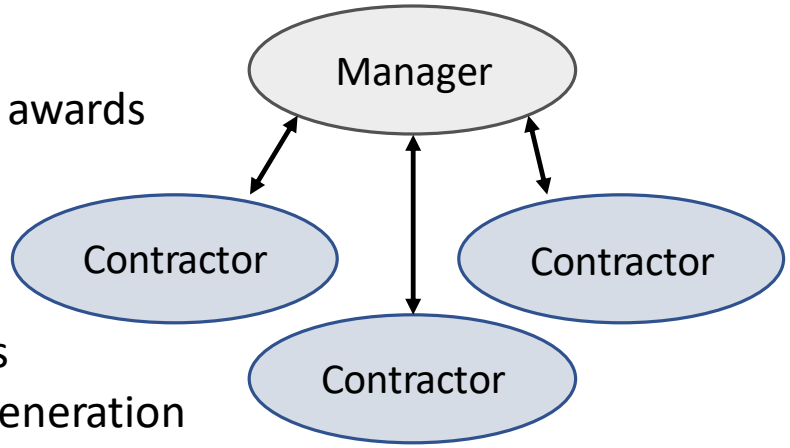
Topics

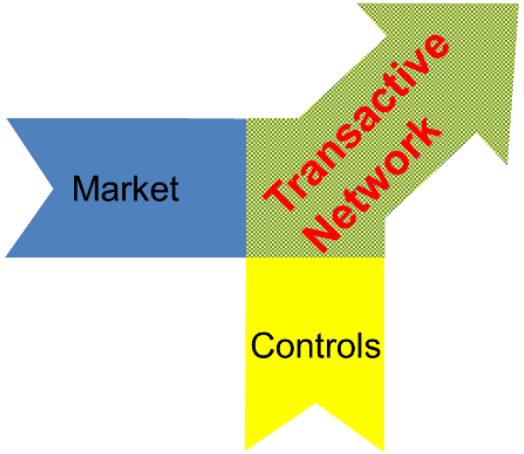
- Multi-agent contract-based systems
- Architectural coordination framework that accommodates multi-agent system (MAS) approaches
- The Energy Services Interface (ESI) concept – a gateway to MAS approaches for DER* integration
- Types of transactive systems and a general model for describing them
- Some transactive energy implementations
- Future directions for realizing transactive energy systems

* DER includes distributed generation, storage, and flexible load – e.g., PVs, batteries, HVAC, EVs, backup generators, lighting…)

Multi-agent Contract-based Systems

- Contract Net Protocol
  - Manager: posts a task for bid, receives contractor bids, verifies suitability, and awards contract
  - Contractor: reads posted task, evaluates suitability, bids and performs task
- Homeostatic Utility Control*
  - Balance supply within 5-10-minute period with frequency adaptive controllers
  - Spot-price energy markets for supply and demand to reflect current costs of generation and delivery
- Transactive Energy**
  - Use market mechanisms to perform distributed optimization
    - Reflect value in exchangeable terms to effectively allocate available resources and services in real-time and future time periods
  - Deploy communications and automation of devices and systems with real-time agents for market interaction
    - Agents convey preferences and perform local control actions, engage in one or more markets to trade for services, e.g., real-time energy, peak-shaving, system reserves





* Schweppe, FC, RD Tabors, JL Kirtley, Jr., HROuthred, FH Pickel, AJ Cox, " Homeostatic Utility Control," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99,No. 3 May/June 1980

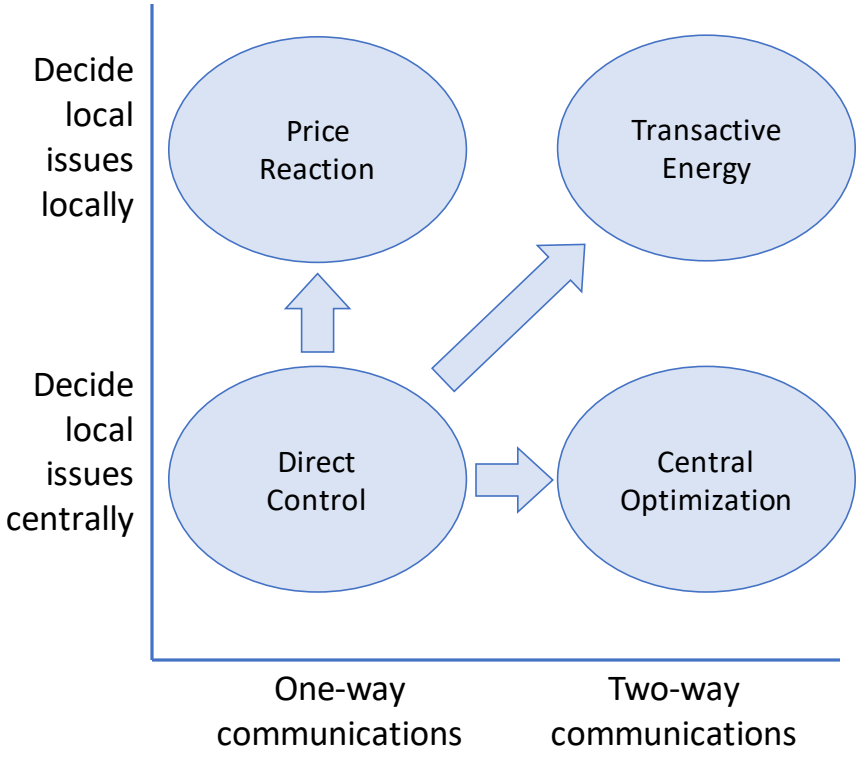
** See GridWise® Architecture Council, "Transactive Energy Framework," https://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf

Types of DER Coordination

- **Direct (Top-Down) Control**
  - Utility switches devices on/off remotely
  - No local information considered
- **Central Control/Optimization**
  - Optimization and control from a central point
  - Relevant local information must be communicated to central point

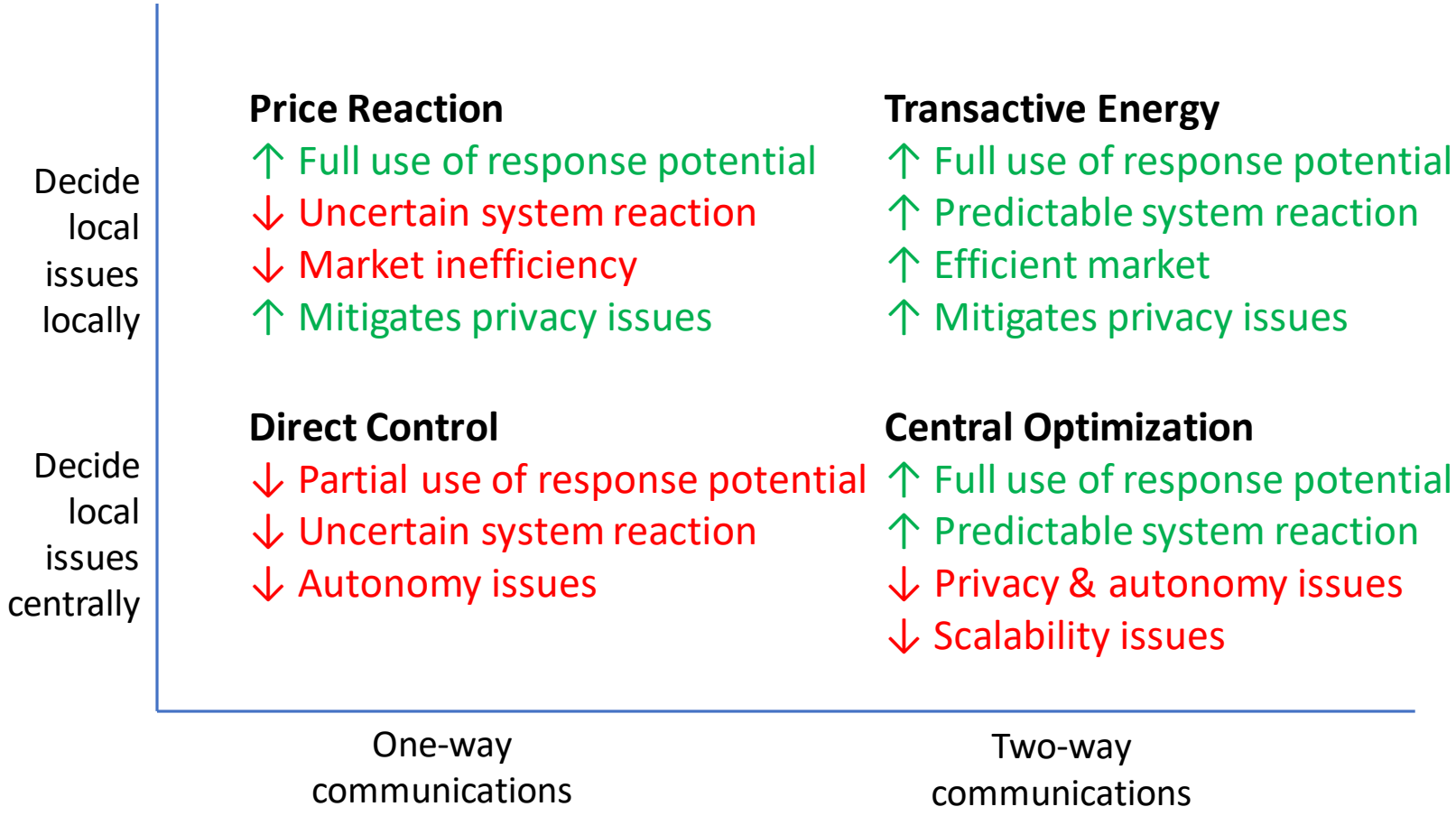
Agent Friendly

- **Price Reaction Control**
  - Prices signalled to customers and/or their automated devices
  - No communication of local information
- **Transactive Energy (TE)**
  - Automated devices engage in market interactions
  - Information exchange includes quantity (e.g., power, energy) and price



Slide produced with permission from Dr. Koen Kok, The PowerMatcher Smart Coordination for the Smart Electricity Grid, published by TNO, The Netherlands, 2013. www.tinyurl.com/PowerMatcherBook

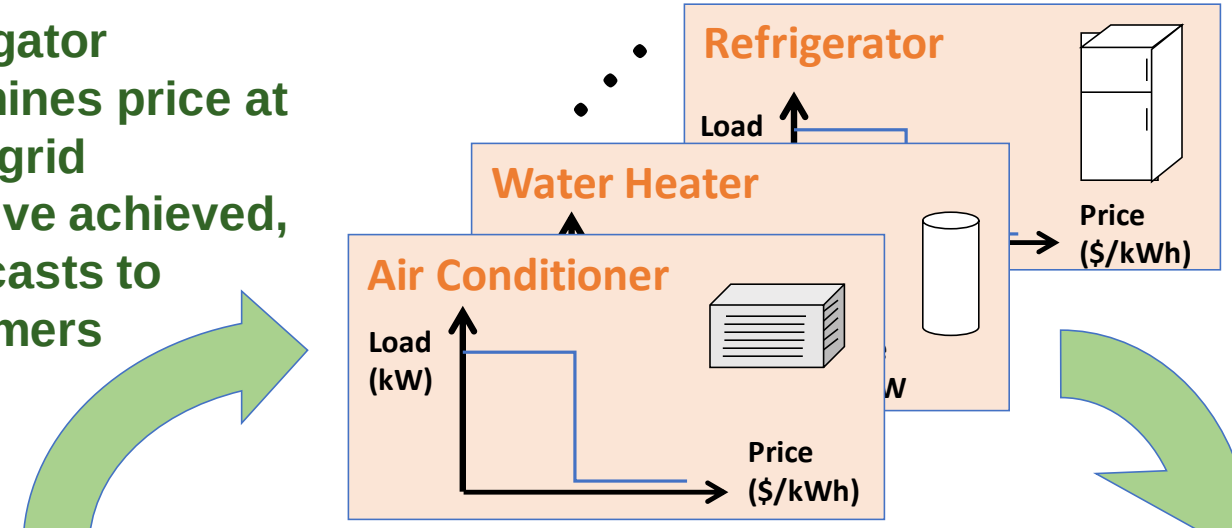
Smart Energy Management Matrix



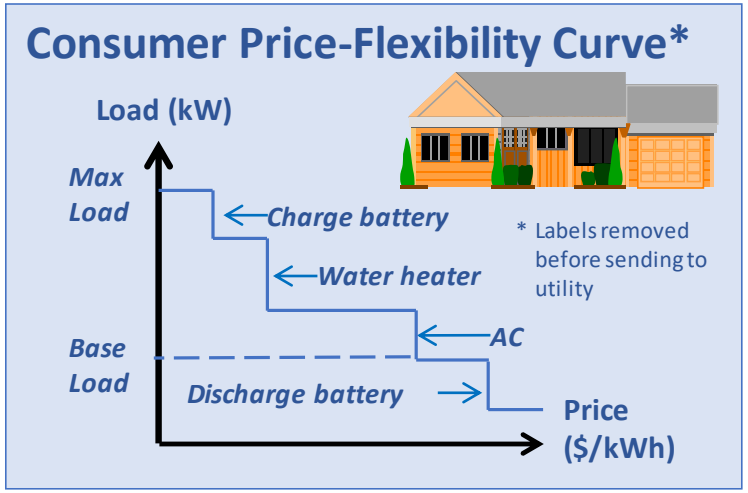
Slide produced with permission from Dr. Koen Kok, The PowerMatcher Smart Coordination for the Smart Electricity Grid, published by TNO, The Netherlands, 2013. www.tinyurl.com/PowerMatcherBook

Transactive Grid Overview

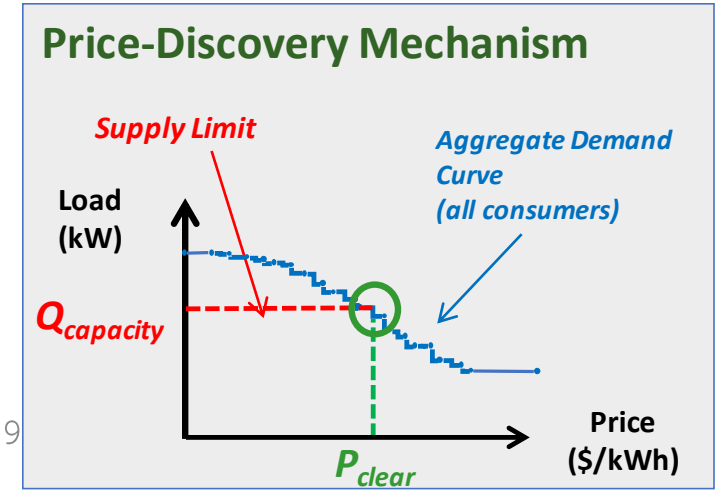
1. Automated, price-responsive device controls express consumer's flexibility (based on current needs)



2. Consumer system aggregates responses to form overall price flexibility curve



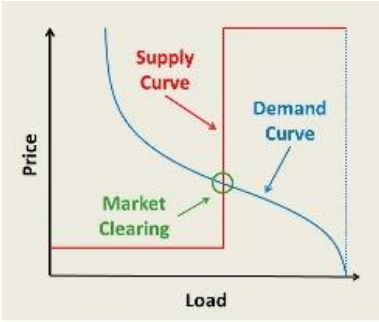
3. Service provider aggregates curves from all consumers

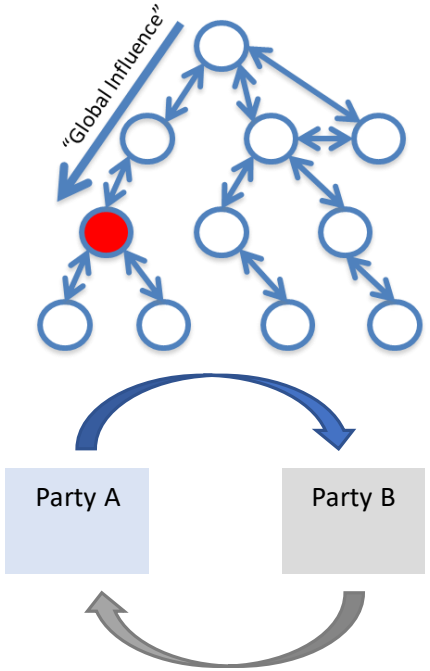


4. Aggregator determines price at which grid objective achieved, broadcasts to consumers

Types of Transactive Exchanges

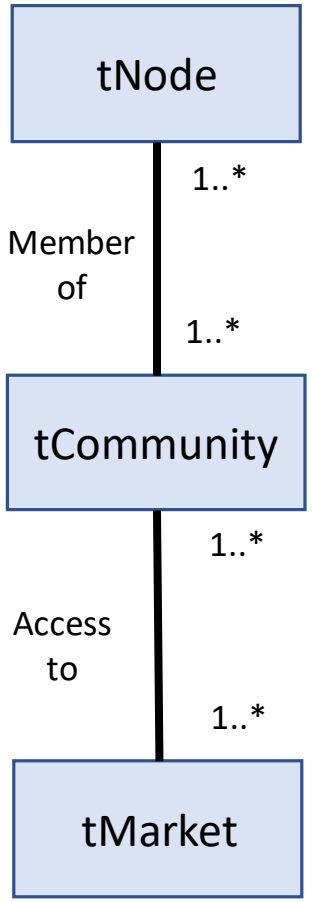
- Double auction markets
  - Nodes bid price/quantity curves to a retail market
  - Market clears with result broadcast to participants who enact controls
  - Measurement used for settlement
- Consensus exchanges
  - Nodes exchange price/quantity bids with electrically connected neighbors
  - Bids iterate based on differences with neighbor(s) until differences small
  - Measurement used for settlement
- Bilateral contracts
  - Suppliers/consumers offer to buy and sell blocks of scheduled energy
  - Establish contracts to supply and purchase scheduled energy along with electricity delivery reservations
  - Electric system operators manage delivery reservations
  - Measurement used for settlement



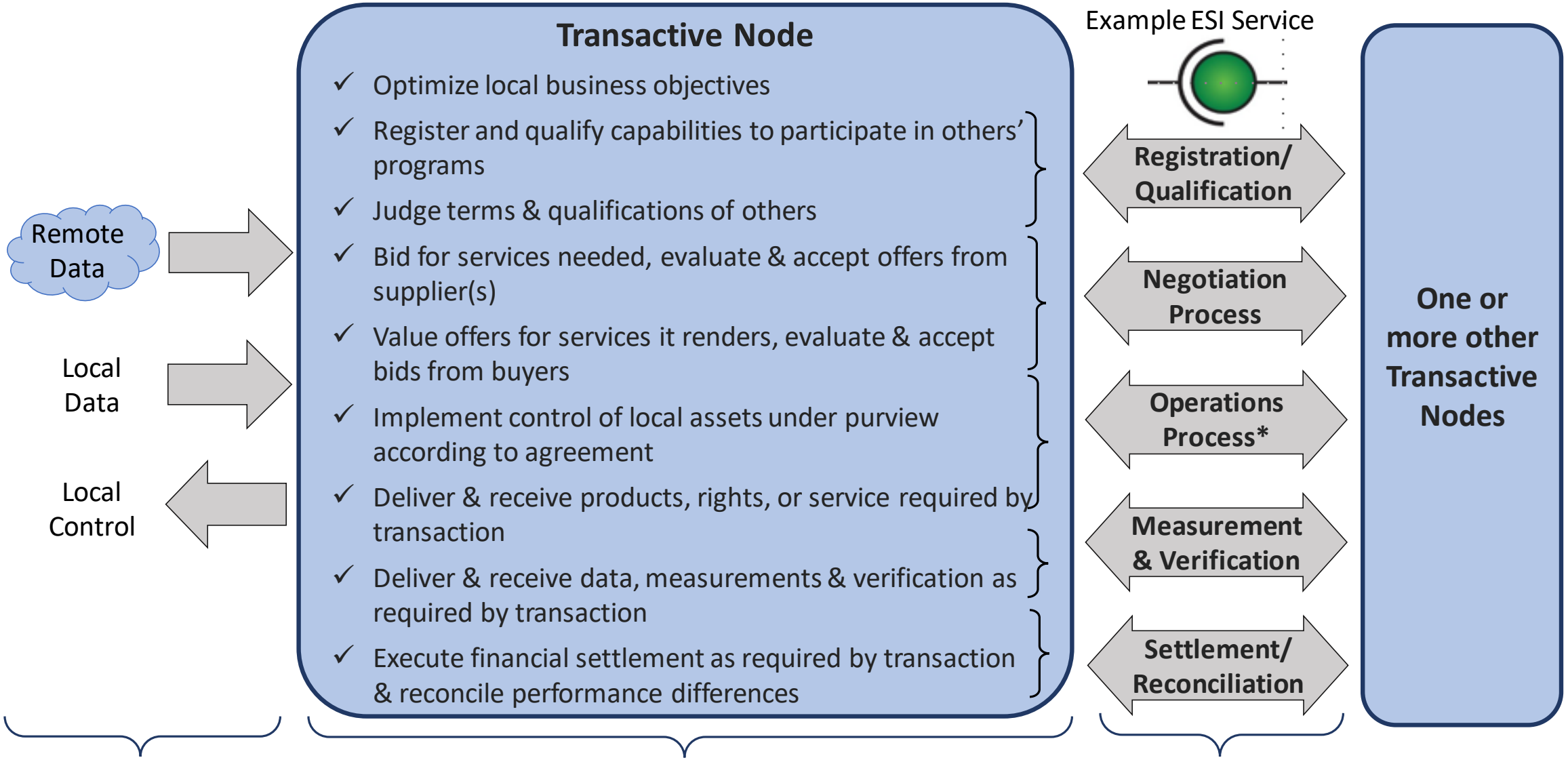


General Model for Transactive System

- **tNode: transactive node – an interacting agent in a community**
  - Specifies local business objectives
  - Identifies the electrical and communication networks' locations
  - Local and remote information monitoring
  - Operation of local devices and systems
  - Follows market rules for interactions with community
- **tCommunity: transactive community – a collection of interacting nodes**
  - Rules of membership and types of markets allowed
  - Double auction example: member nodes reside on same distribution circuit
  - Neighbor consensus example: communication only with electrical neighbor
- **tMarket: transactive market – the agent interaction rules**
  - Definition of services negotiated in a community
  - Mechanism for resolving the negotiation of services (i.e., double auction, consensus, or bi-lateral market rules)
  - Market negotiation intervals and timing rules
  - Registration/qualification rules
  - Operation, measurement, and settlement rules



Transactive Interaction Model

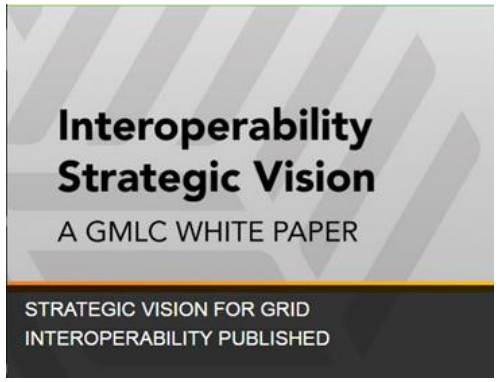


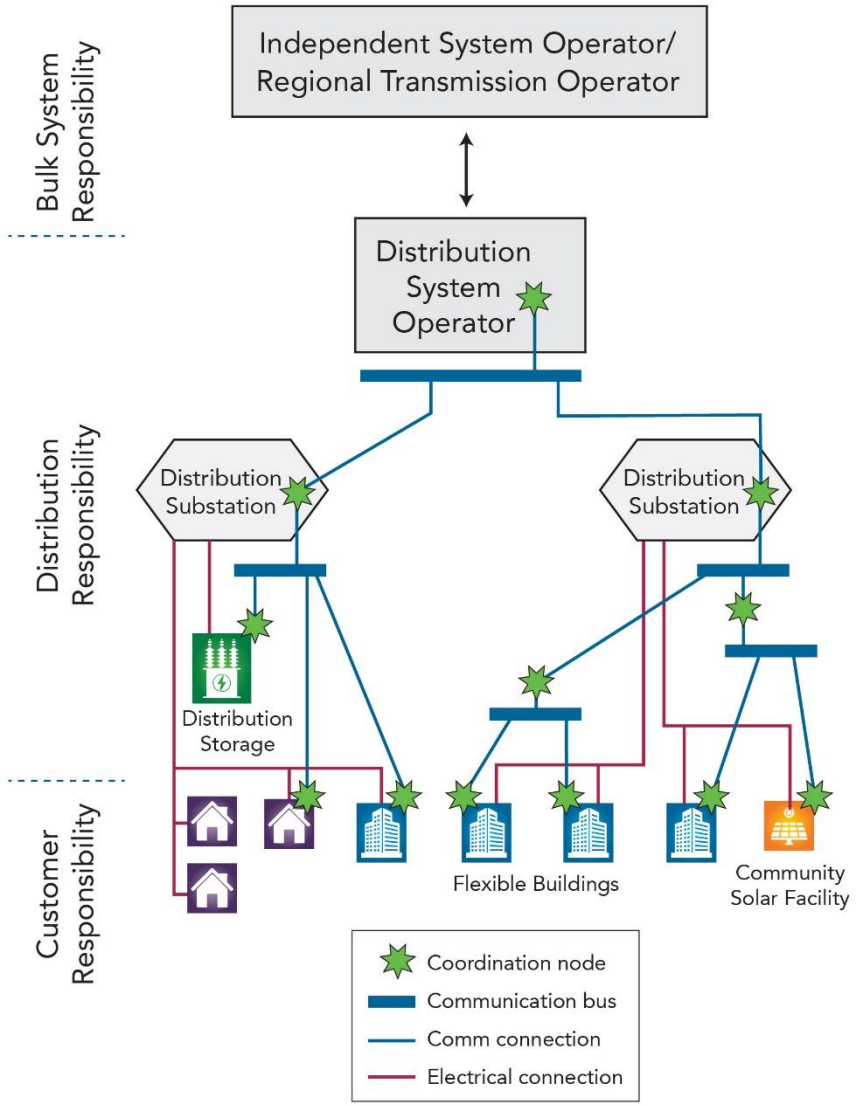
MAS and a Strategic Vision for Interoperability

- **Architecture** describes system concepts, components, structure, and organizing principles
- **Interoperability** drives simplicity of system integration
- Example: Architecture prescribes layered decomposition coordination framework, which defines interface points for interoperability

See Interop Strategic Vision GMLC whitepaper
https://gridmod.labworks.org/resources/interoperability-strategic-vision

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

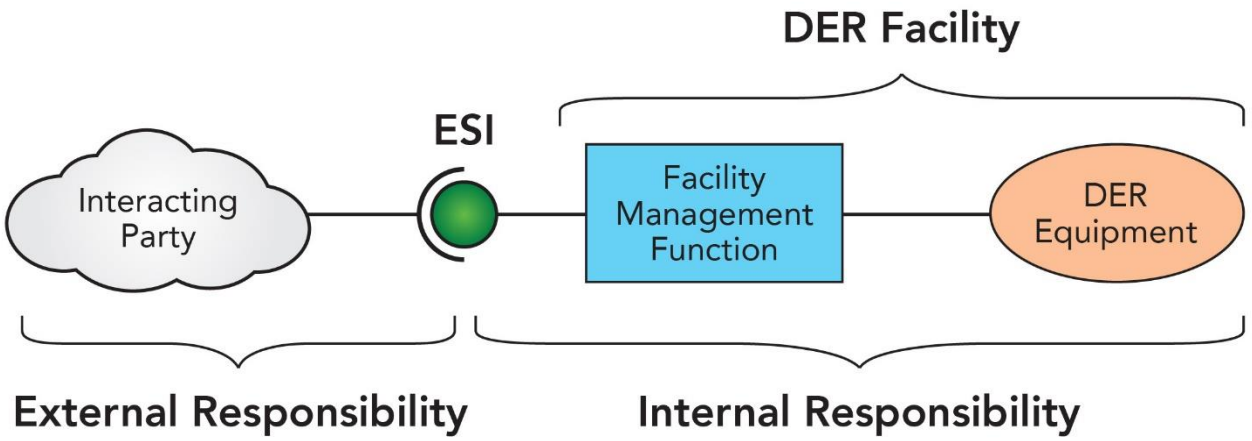




Taft, JD. 2016. *Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes.* PNNL-25480

Energy Services Interface Vision for DER

"An ESI is a bi-directional, *service-oriented*, logical interface that supports the secure communication of information between entities inside and entities outside of a customer boundary to facilitate various energy interactions between electrical loads, storage, and generation within customer facilities and external entities.“*



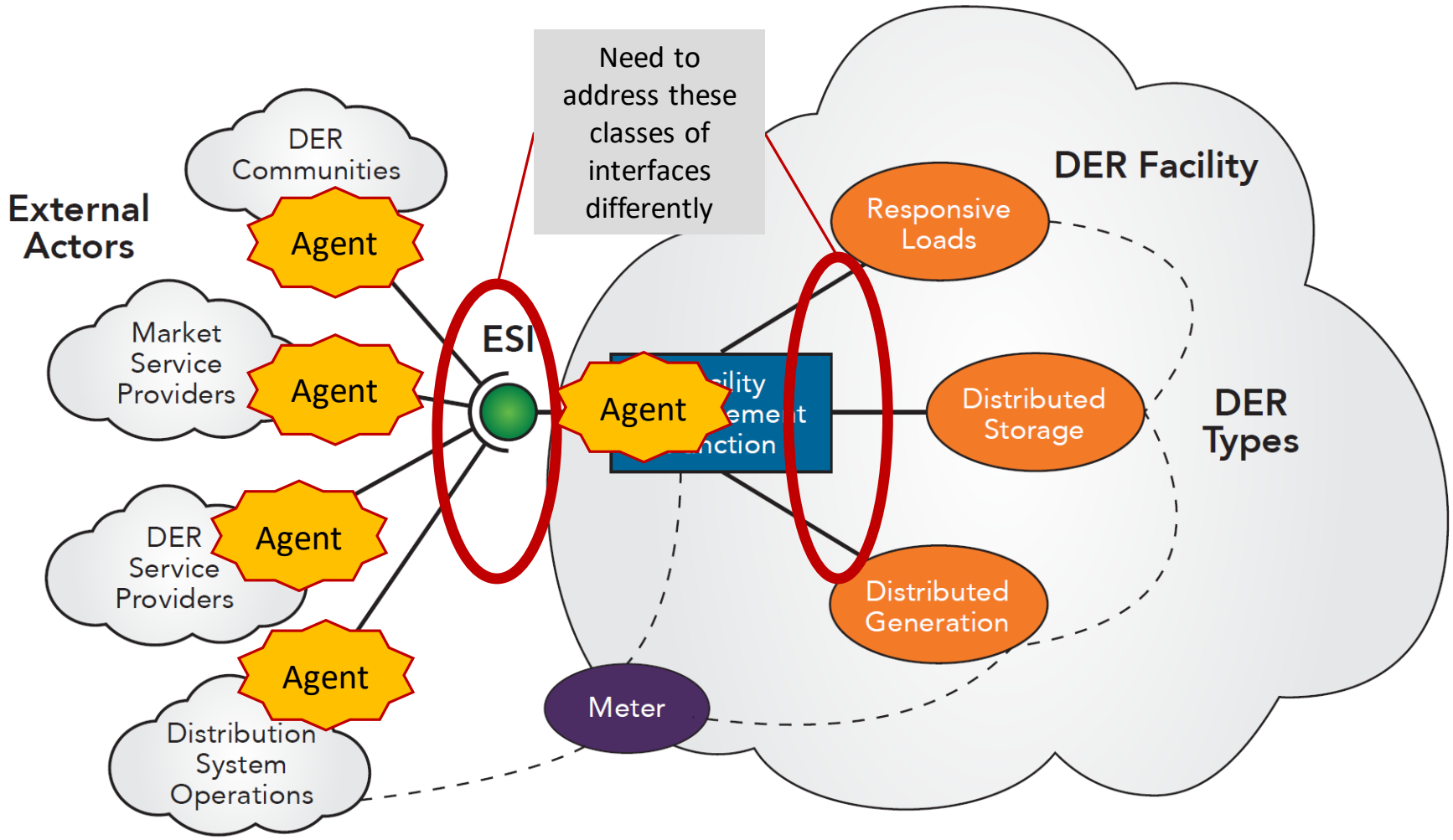
The ESI concept supports an agent-based approach to system design and operation

- Hardin et al: http://www.gridwiseac.org/pdfs/forum_papers11/hardin_paper_gi11.pdf .
  Note, the words “service-oriented” are added to the definition here.

PLUG & PLAY DER CHALLENGE

See http://plugandplayder.org/

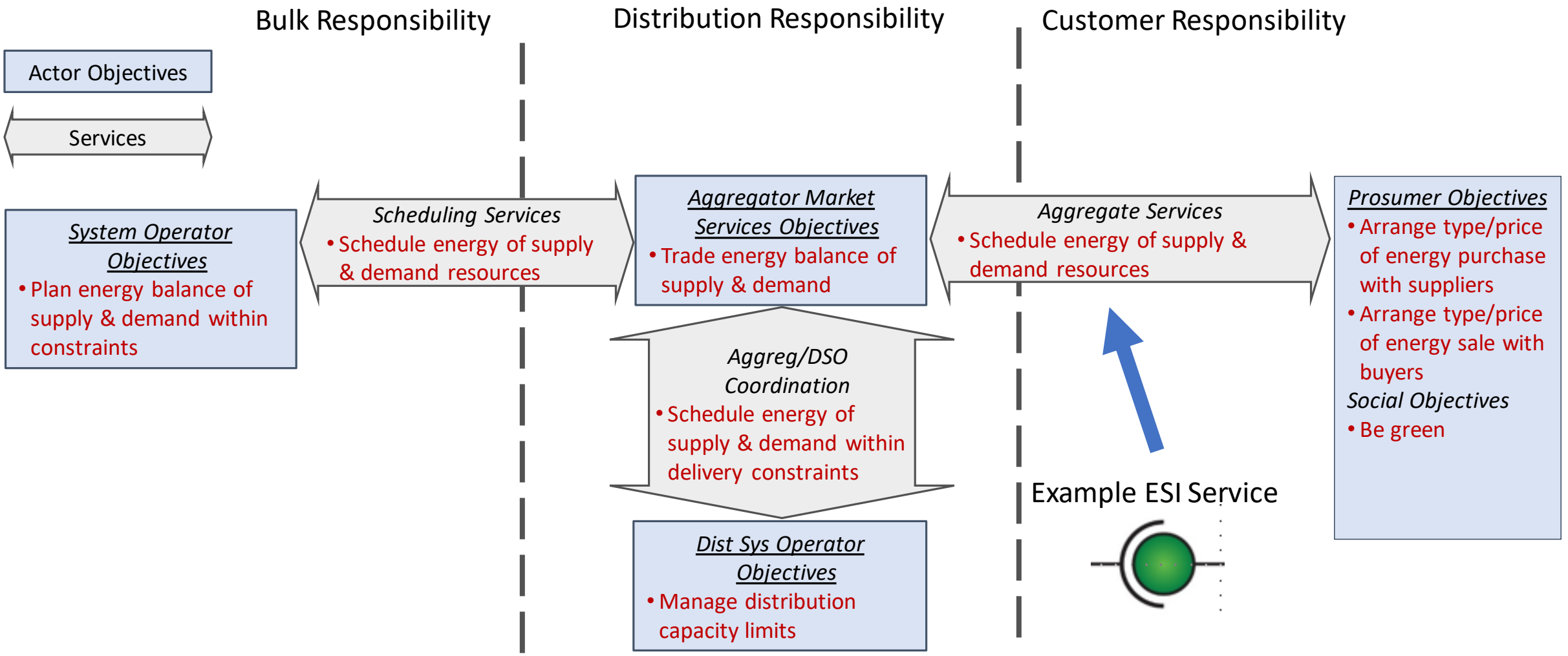
Vision: A General DER Facility Conceptual Model



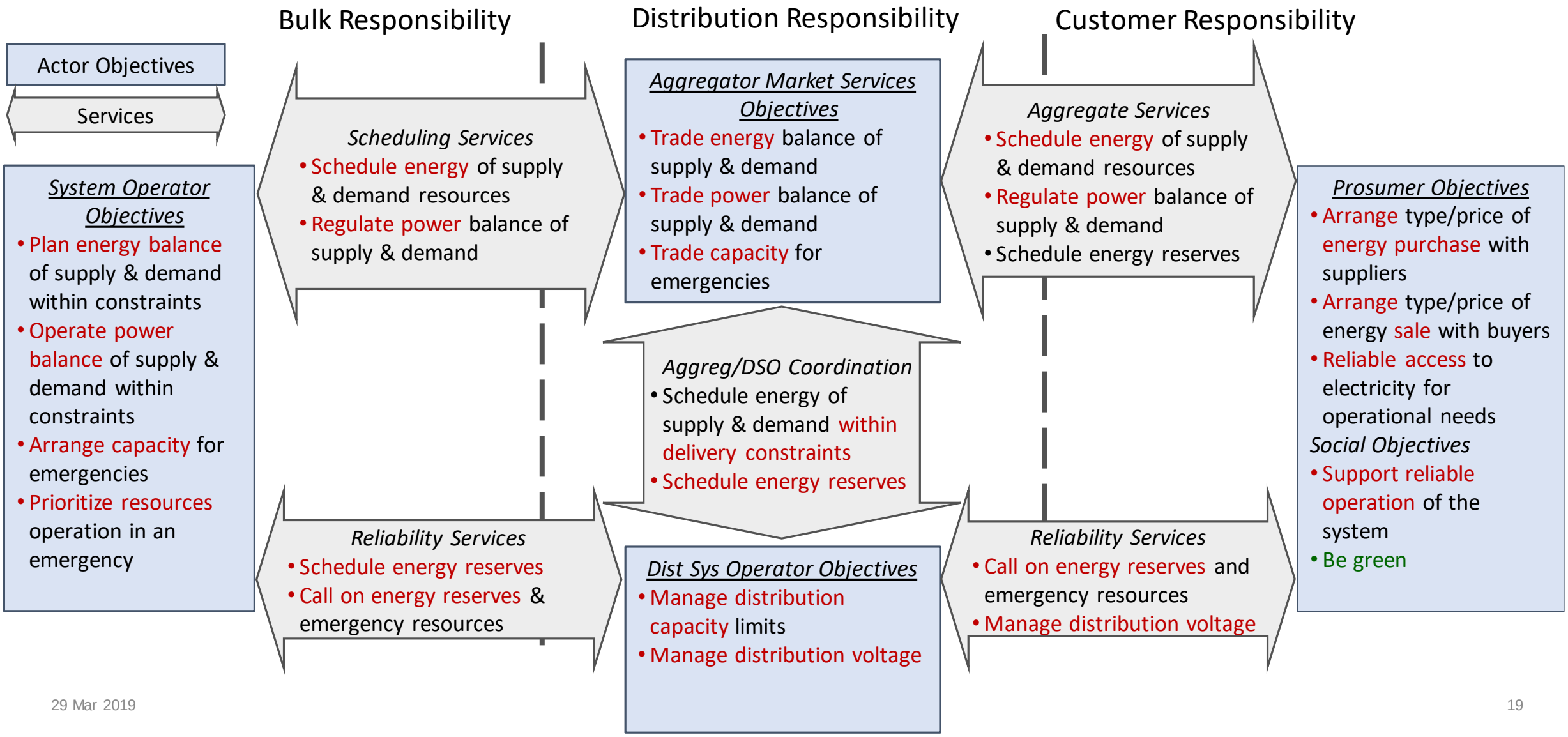
ESI = Energy Services Interface

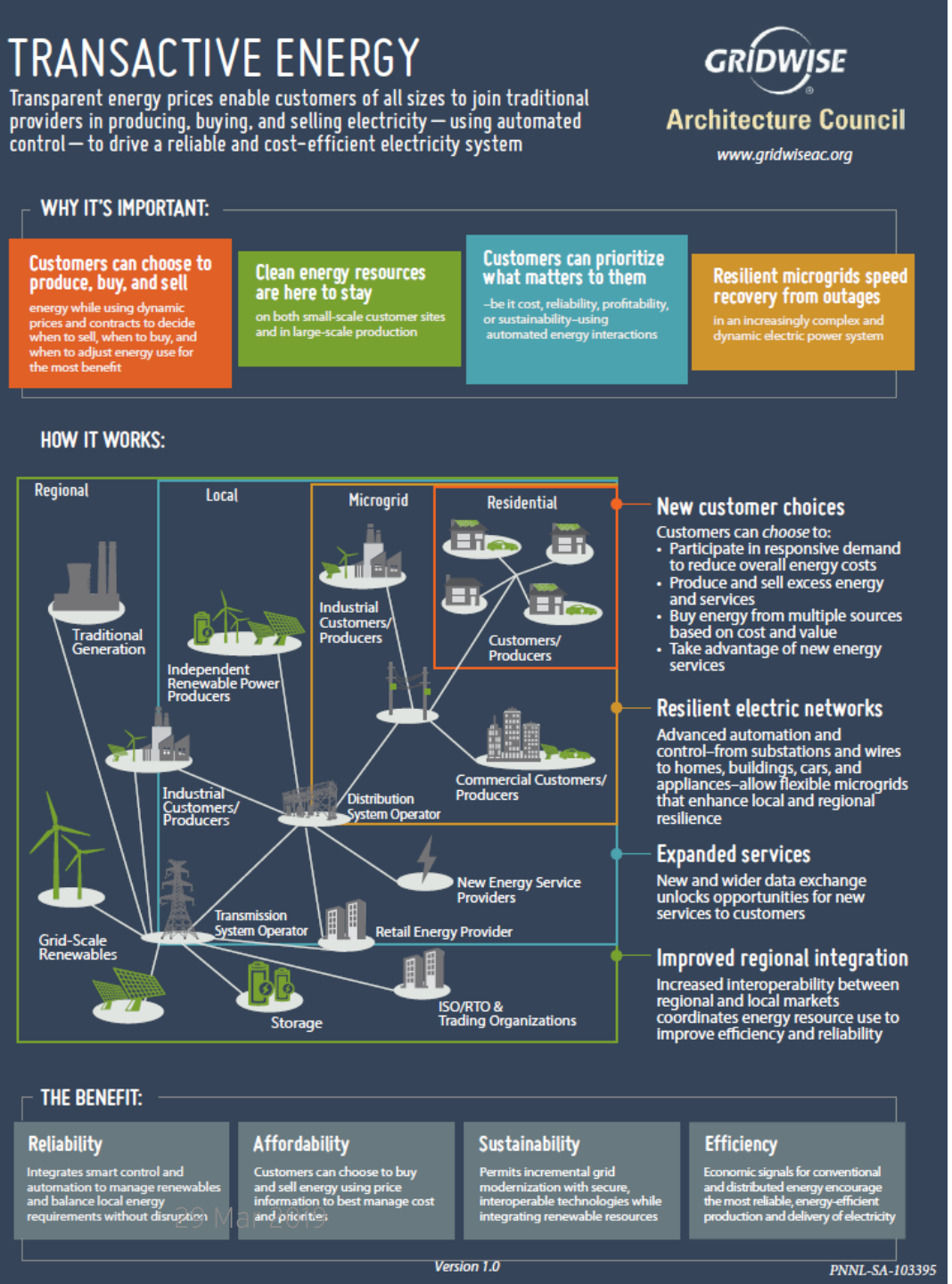
The sets of arrows and dotted lines represent areas of focus for discussing interoperability issues

Separating Actor Objectives and Service Interactions: An Energy Scheduling Example



Imaging an Agent-based Vision for DER Coordination





TE Framework - GWAC

It's not…

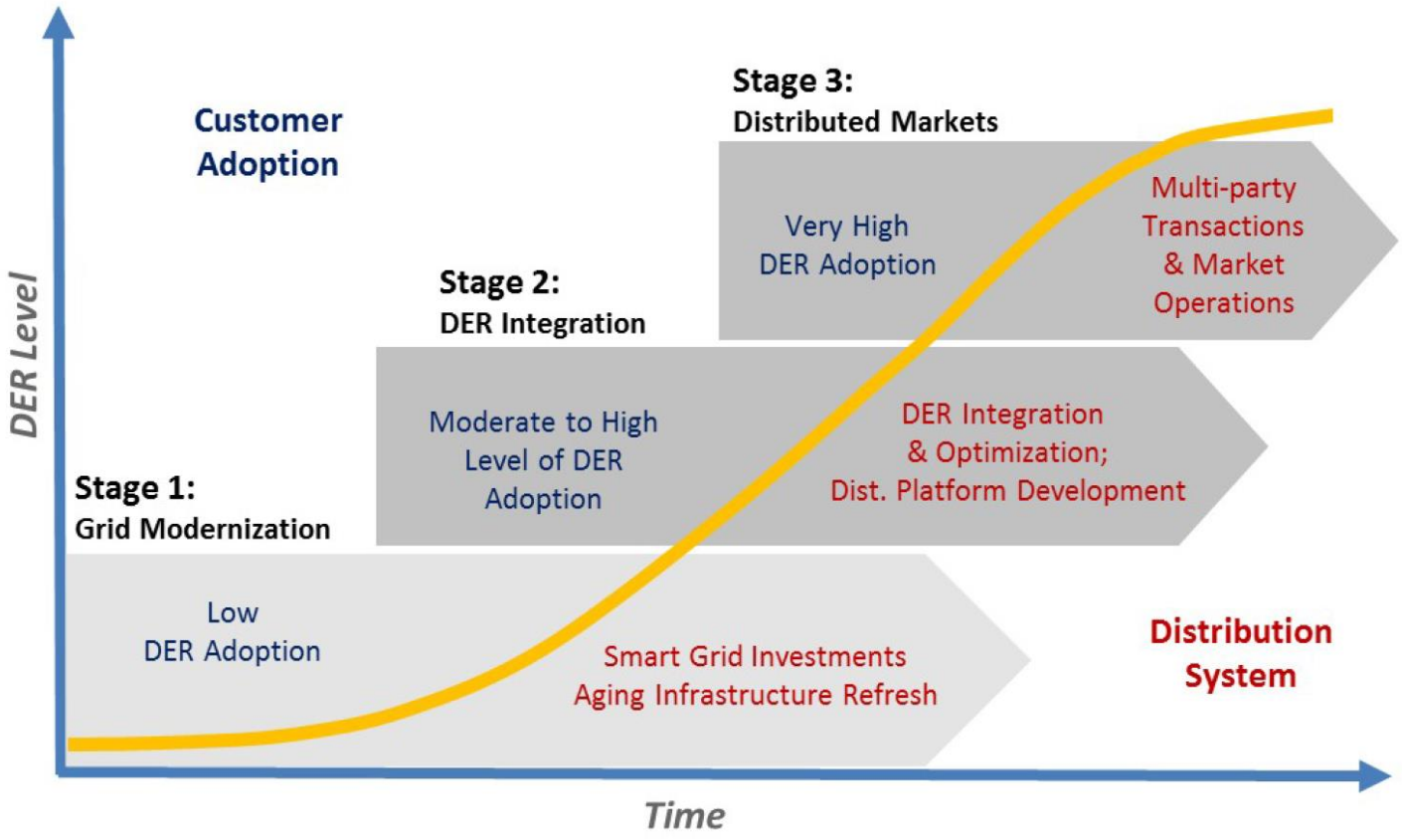
An architecture or the standards for Transactive Energy.

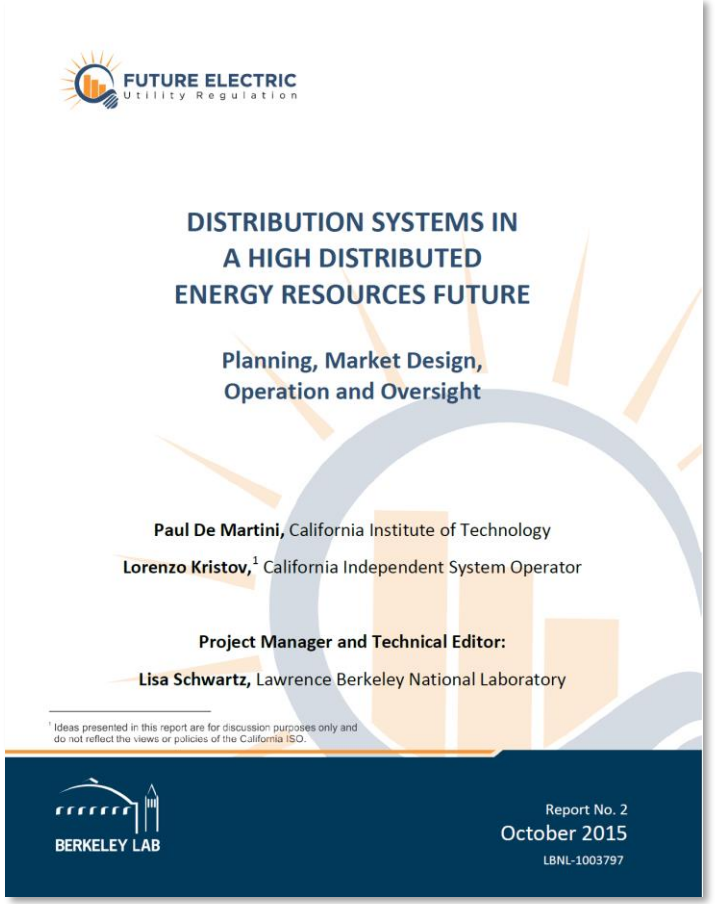
It is…

A frame of reference that allows for a set of supporting tools that can be used for

- Promoting discussion
- Comparing different approaches
- Identifying research and development needs

TE Roadmap Stages





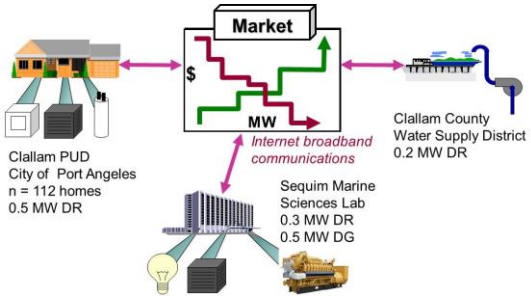
Example TE Implementations

PNNL Transactive Energy Field Experience

Olympic Peninsula, 2006-07

Established viability of transactive, decision-making

- Peak load, distribution constraints, wholesale prices
- Double auction market
- Residential, commercial, & water pumping loads, DG



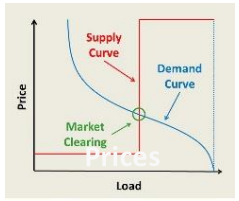
AEP gridSMART®, 2010-14

PUC-approved RTP tariff developed

- Dynamic, real-time incentive to respond
- Real-time prices from PJM energy market
- Manages AEP T&D constraints and peak load

Home energy management system

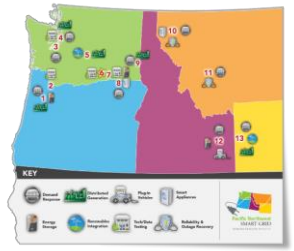
Real-time feeder double-auction market



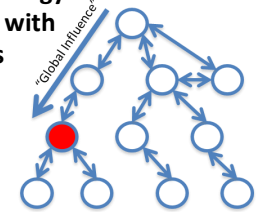
Pacific NW Smart Grid, 2010-15

Key advancements made by PNWSGD

- Wind balancing
- Consensus-based look ahead signals
- Formalized definition of transactive node
- Integrated legacy direct load control systems within a transactive network



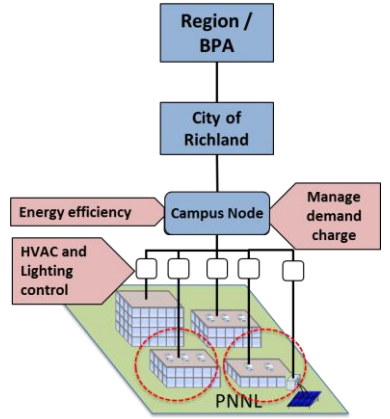
Real-time & forward energy exchange with neighbors



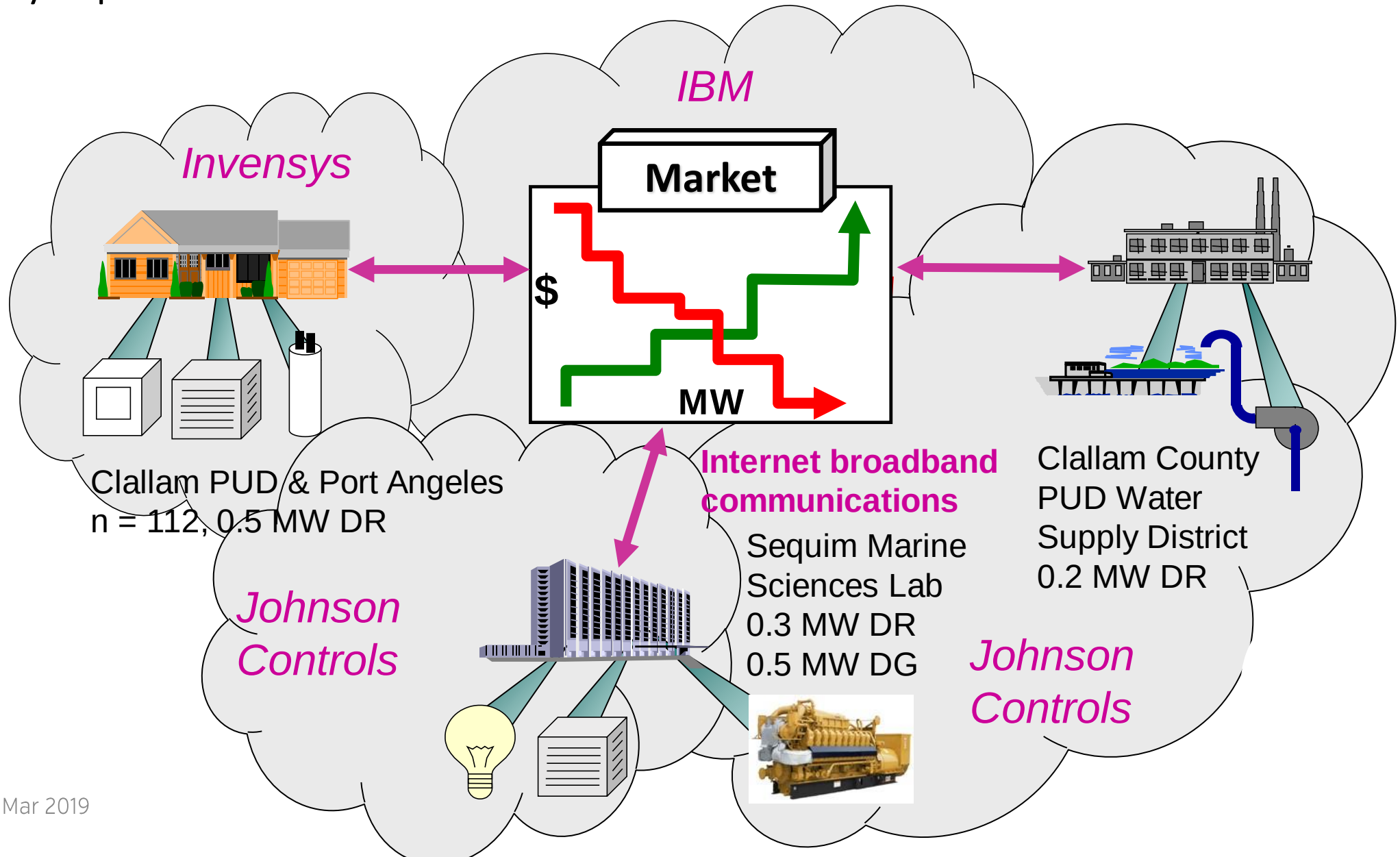
Transactive Campus, present

Flexibility in buildings, storage, and generation

- Manage peak demand charges, smooth local PV generation
- Enhance energy efficiency
- 3 research locations: PNNL, WA State Univ, Univ of Toledo, OH

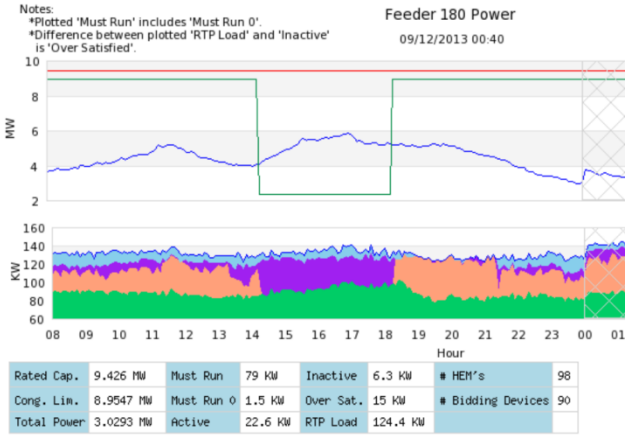


Olympic Peninsula Demonstration



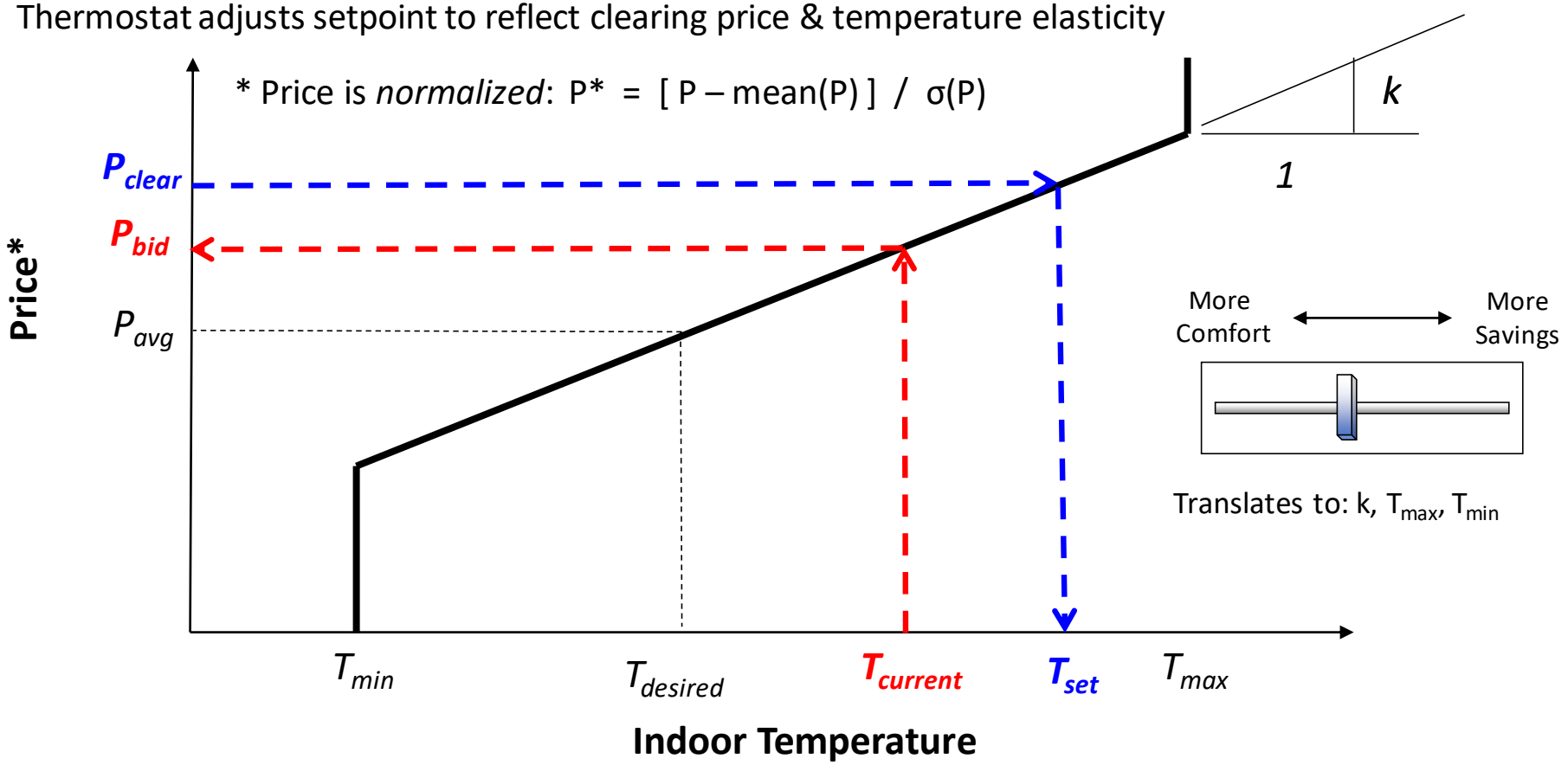
gridSMART® RTPda Demo

- First real-time market at distribution feeder level with a tariff approved by the PUC of Ohio
- Value streams
  - Energy purchase benefit: function of PJM market LMP
  - Capacity benefits: distribution feeder and system gen/trans limitations, e.g., peak shaving
  - Ancillary services benefits: characterized, but not part of the tariff
- Uses market bidding mechanism to perform distributed optimization – transactive energy
  - ~200 homes bidding on 4 feeders
  - Separate market run on each feeder
  - "Double auction" with 5 minute clearing
- HVAC automated bidding
  - Smart thermostat and home energy manager
  - Homeowner sets comfort/economy preference
  - Can view real-time and historical prices to make personal choices

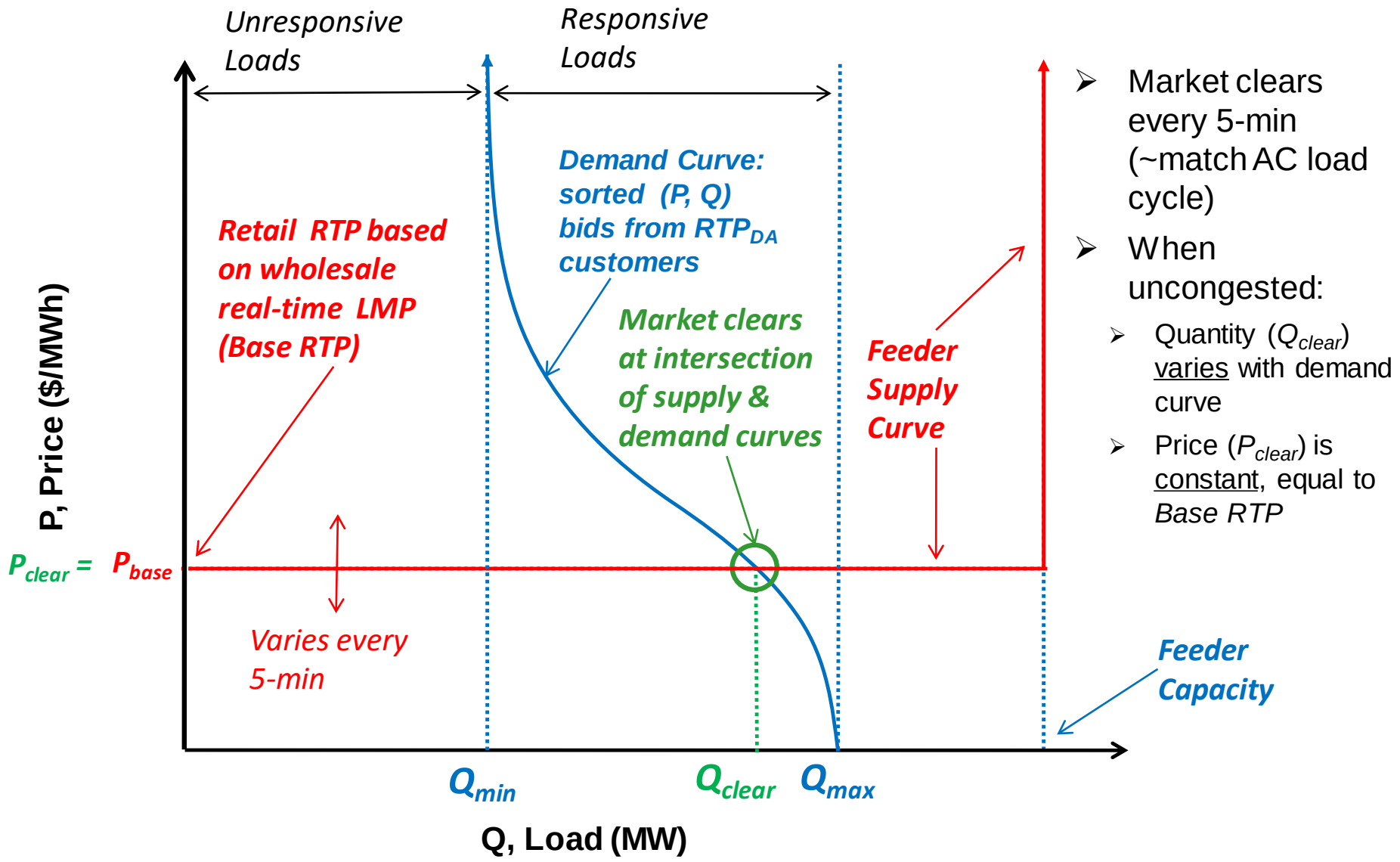


Transactive Thermostat Generates Demand Bid Based on Customer Settings *(Cooling Example)*

- User's *comfort/savings* setting implies limits around normal setpoint ($T_{desired}$), *temp. elasticity* (k)
- Current temperature used to generate bid price at which AC will "run"
- AMI history can be used to estimate bid quantity (AC power)
- Market sorts bids & quantities into demand curve, clears market returns clearing price
- Thermostat adjusts setpoint to reflect clearing price & temperature elasticity



RTP Market Uncongested Conditions

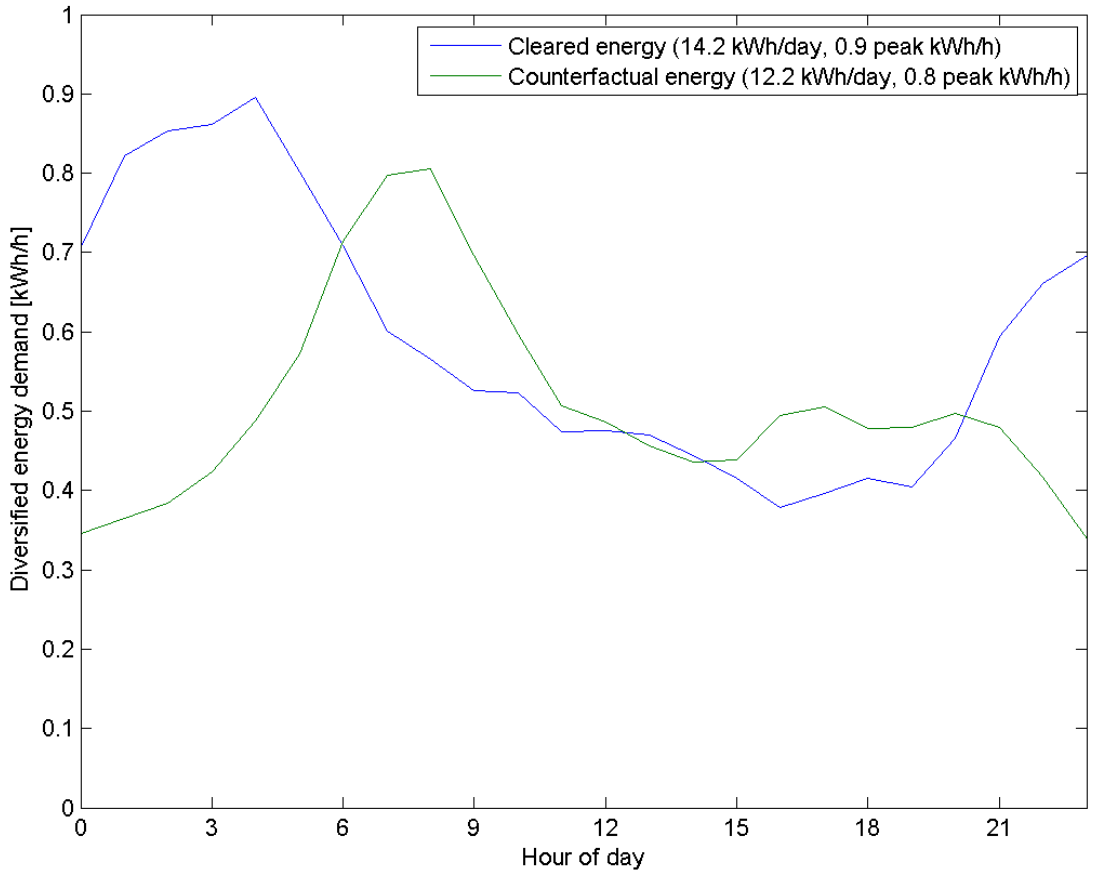


- Market clears every 5-min (~match AC load cycle)
- When uncongested:
  - Quantity (Q_{clear}) <u>varies</u> with demand curve
  - Price (P_{clear}) is <u>constant</u>, equal to *Base RTP*

Olympic Peninsula Demo: Key Findings

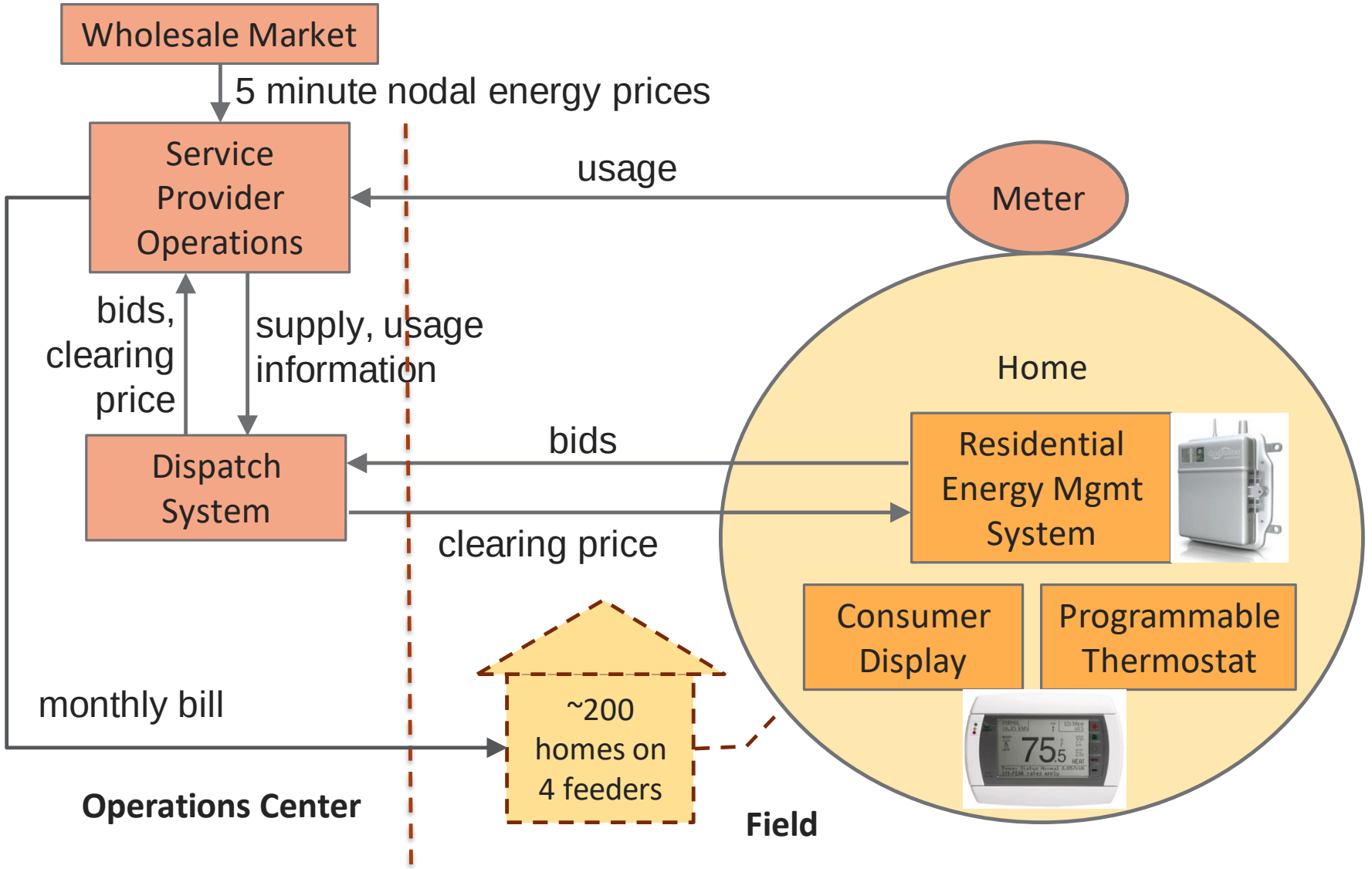
Significant demand response was obtained:

- 15% reduction of peak load
- Up to 50% reduction in total load for several days in a row during shoulder periods
- Response to wholesale prices + transmission congestion + distribution congestion
- Able to cap net demand at an arbitrary level to manage local distribution constraint
- Short-term response capability could provide regulation, other ancillary services adds significant value at very low impact and low cost)
- Same signals integrated commercial & institutional loads, distributed resources (backup generators)

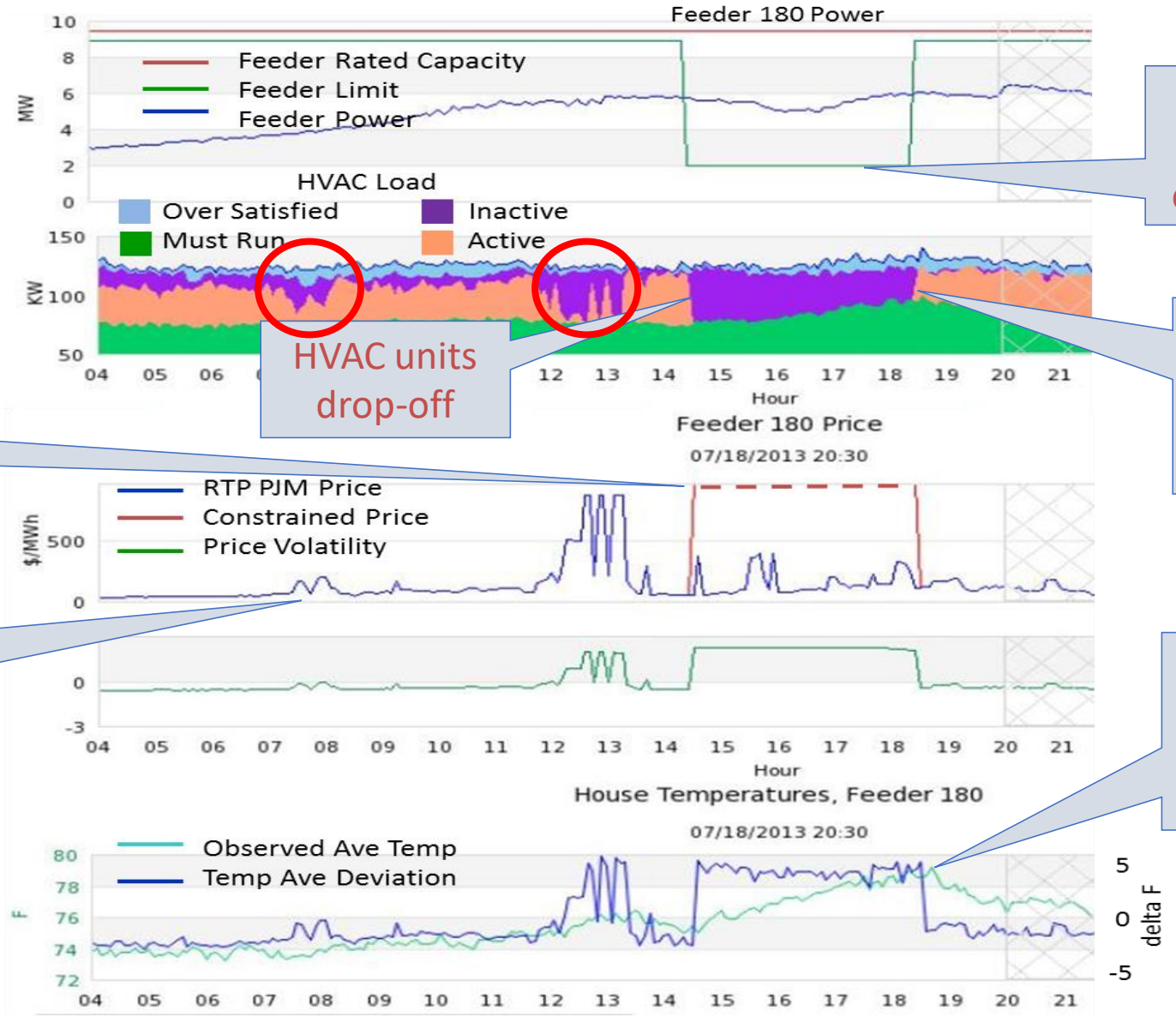


Winter peak load shifted by pre-heating

gridSMART® RTP System



TE Use Cases in Action



Reduce feeder capacity to engage end-use

HVAC units drop-off

Units rebound when capacity returns to normal

Price rises to price cap

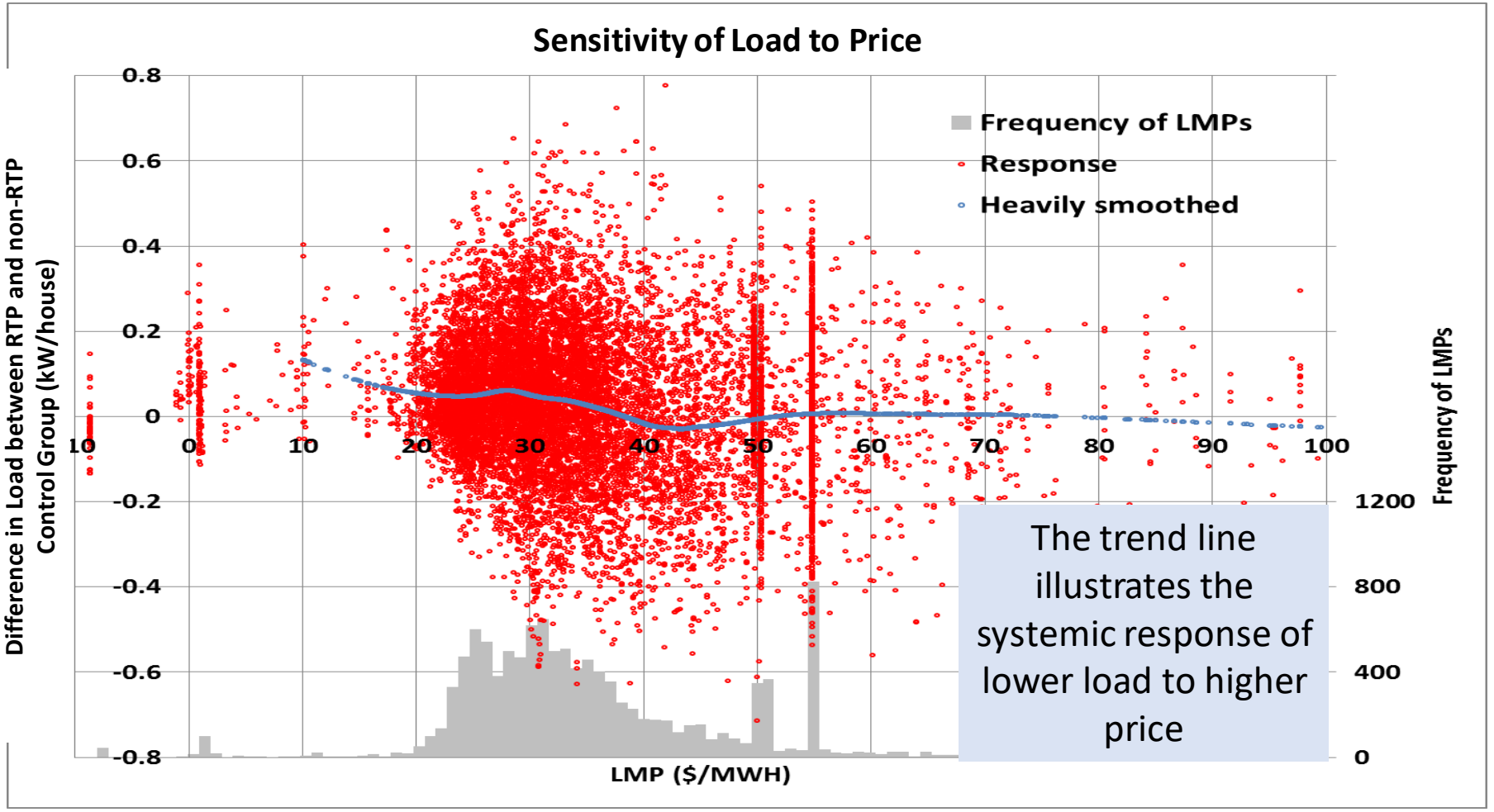
Devices respond to price fluctuations

Average indoor temp rises ~4°F over 4 hours

Summary of RTP Demo Analysis

- Experiments analyzed Jun – Sep 2013
- Electric system impacts
  - Wholesale purchases: energy use and cost reduced by ~5%
  - System peak shaving: ~6.5% peak load reduction at 50% simulated RTP household penetration
  - Feeder peak management: ~10% peak feeder load reduction at 50% simulated household penetration
- Household impacts
  - Bills: ~5% average reduction (includes peak management incentive)
  - Thermostat overrides over 4-month duration
    - 70 - 2 hr events: ave 1-2% household overrides/event, max < 5%
    - 26 - 4 hr or greater events: ave ~3%, max < 10%
  - Customer satisfaction
    - Over 75% satisfied (40% very satisfied)
    - Perceived monthly bill impact: 51% savings, 39% same, 10% increase

Swarm of Responses to Price



Actual load response versus LMP for about 12,000 5-min data points covering the period June–September 2013
Bottom shows histogram of the frequency of LMPs up to $100/MWh

Pacific Northwest Smart Grid Demonstration Project

What:

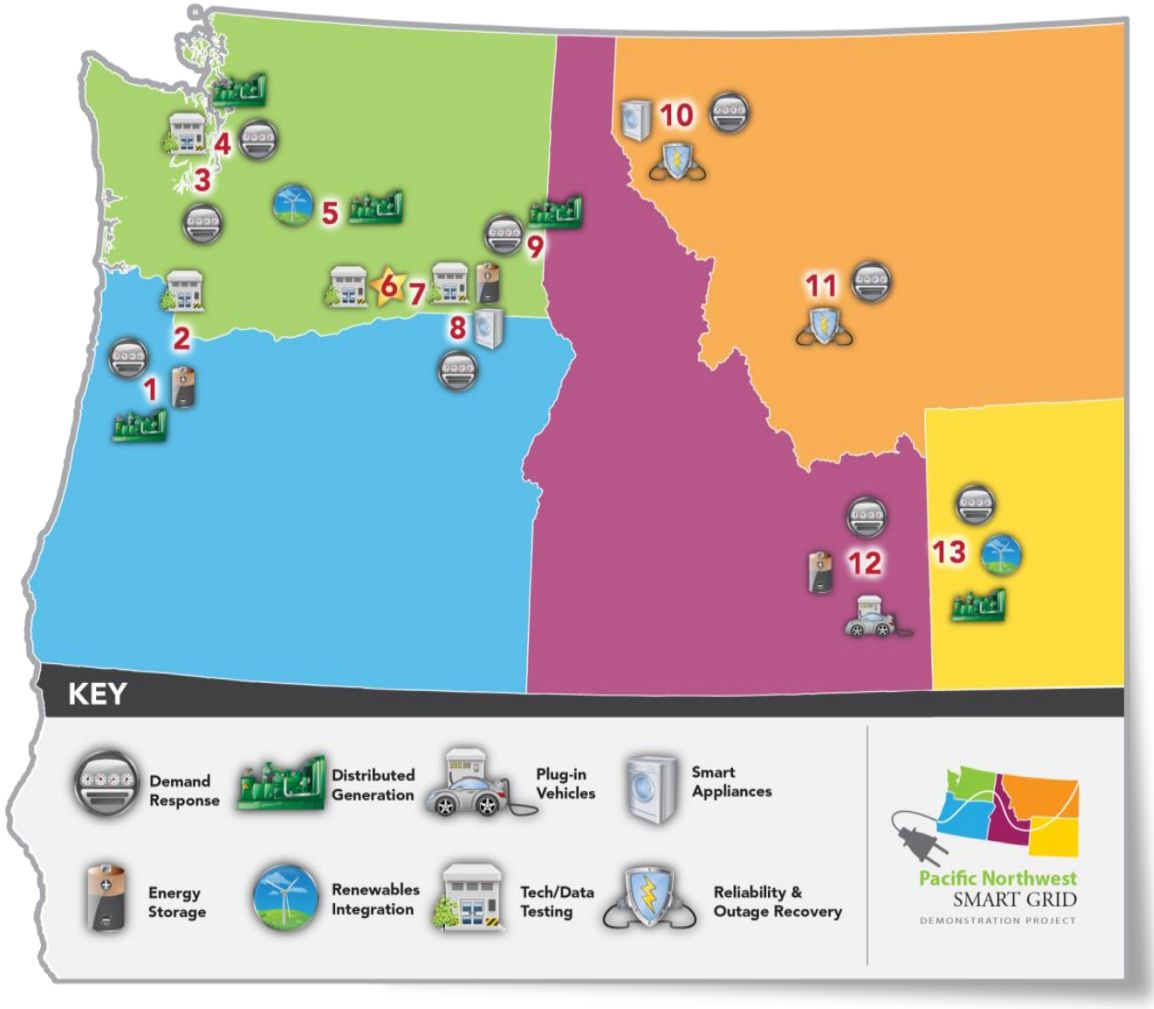
- $178M, ARRA-funded, 5-year demonstration
- 60,000 metered customers in 5 states

Why:

- Develop communications and control infrastructure using incentive signals to engage responsive assets
- Quantify costs and benefits
- Contribute to standards development
- Facilitate integration of wind and other renewables

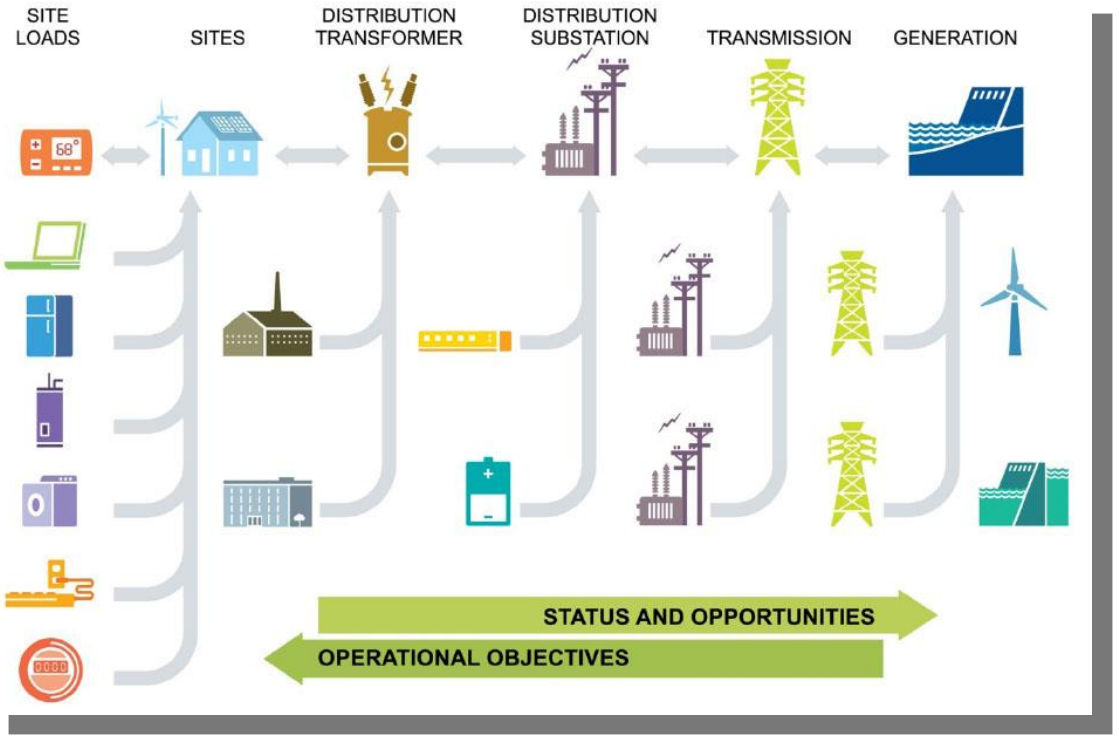
Who:

Led by Battelle and partners including BPA, 11 utilities,
2 universities, and
5 vendors

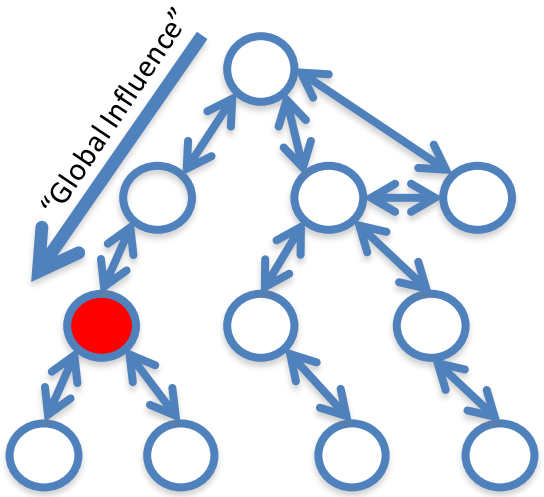


Operational Objectives

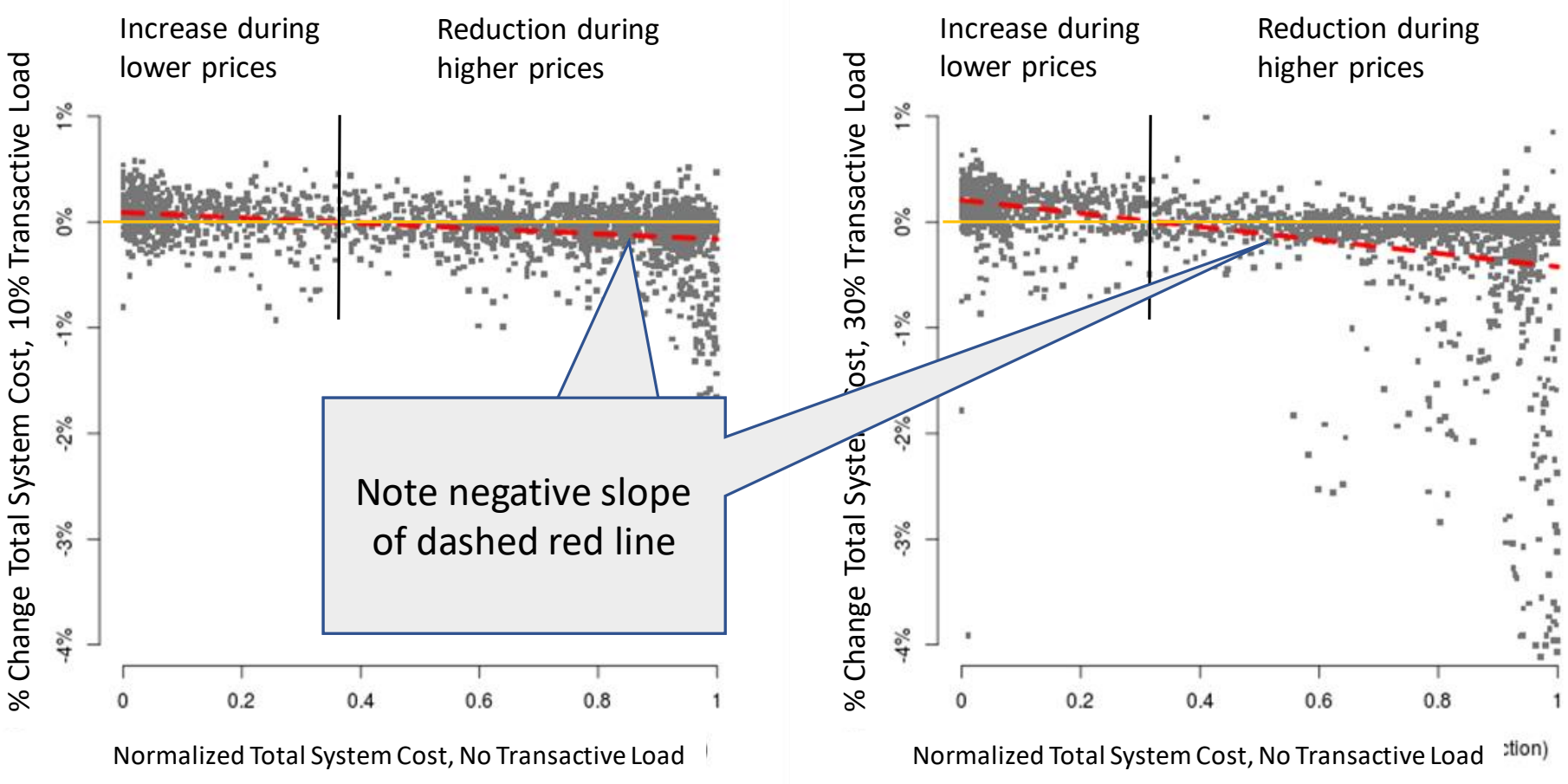
- Manage peak demand
- Facilitate increase of renewable resources
- Address constrained resources
- Improve system reliability and efficiency
- Select economical resources (optimize the system)



Aggregation of Power and Signals Occurs Through a Hierarchy of Interfaces



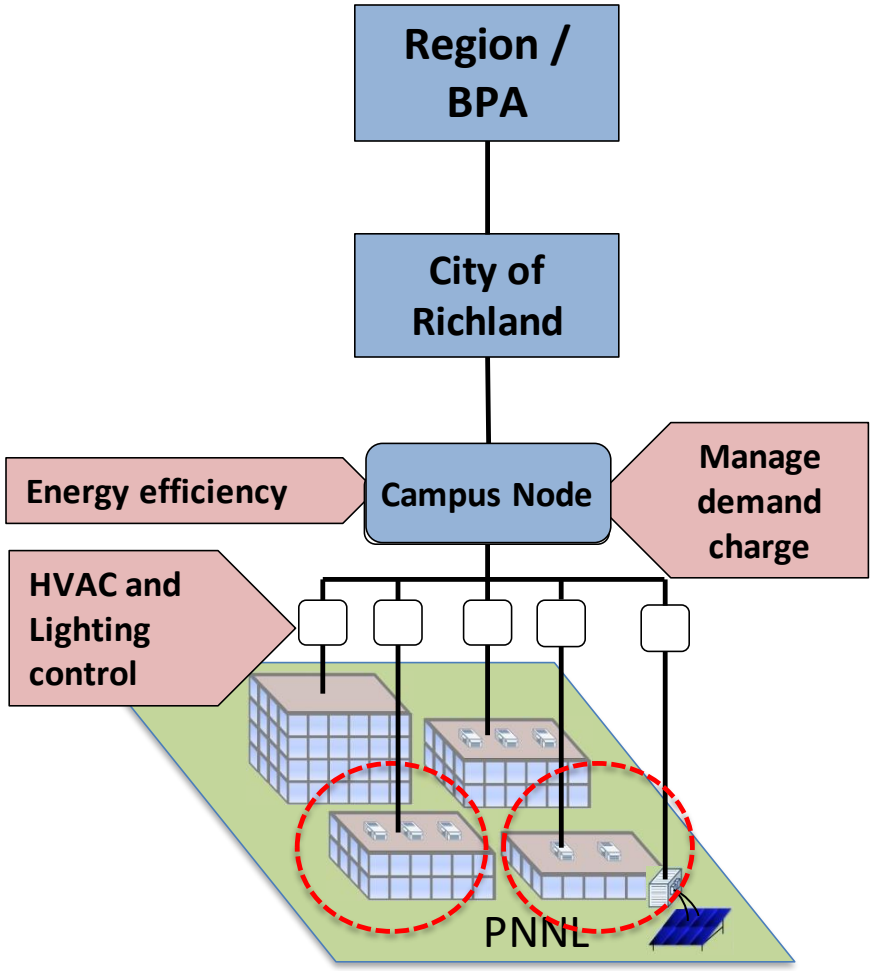
Transactive Load Responsiveness*



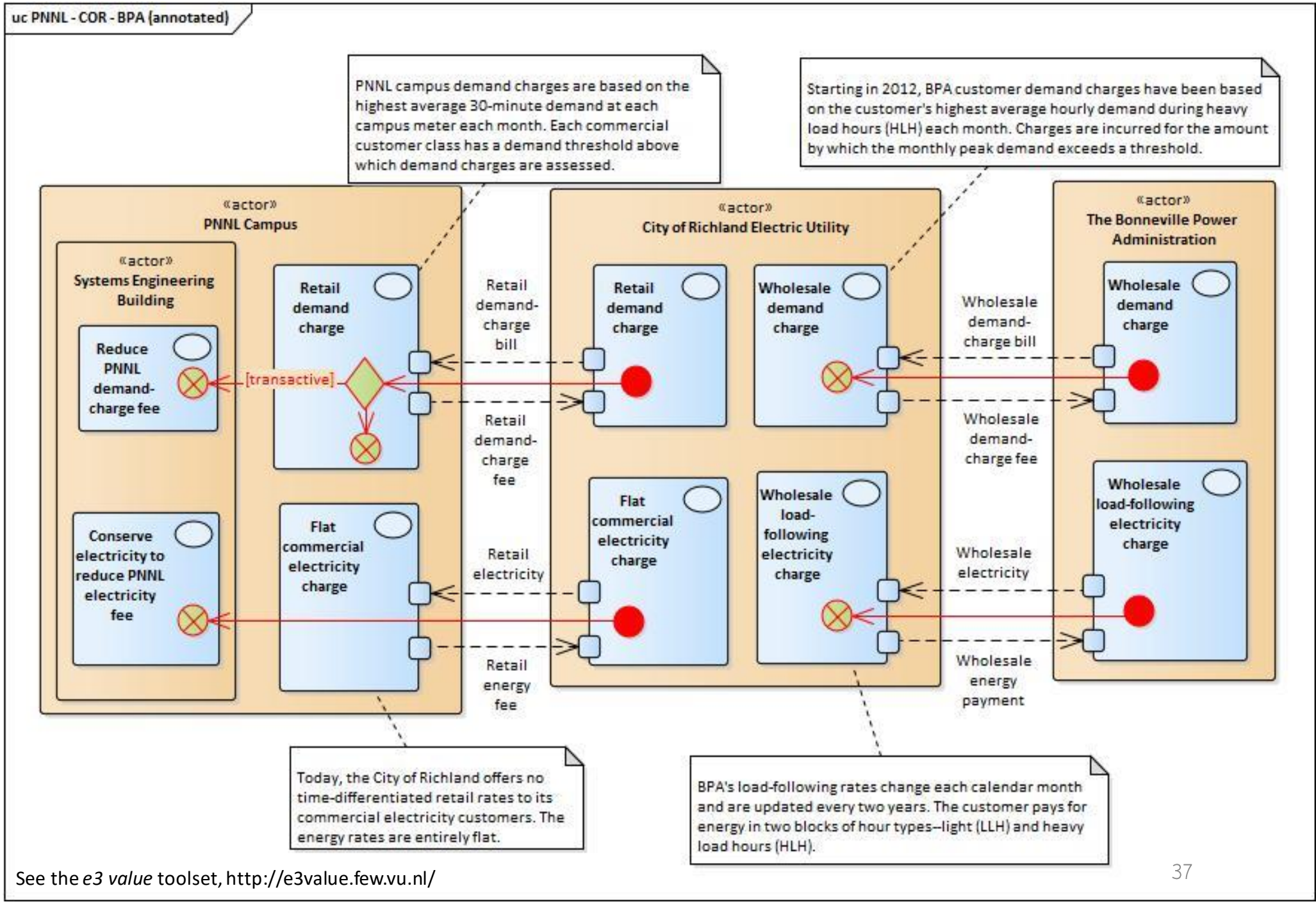
* From IBM, TJ Watson Research Center computer simulations using field transactive control node designs
Ghosh, S. et al, 2015, *Simulation Analysis of the Pacific NorthWest Smart Grid Demonstration Transactive System*

PNNL Transactive Campus Actors & Objectives

- Region / Bonneville Power Authority (BPA)
  - Balance supply/demand
    - High renewable variability
    - Variability of demand
  - Manage congestion
- City of Richland
  - Manage BPA peak demand charges
  - Manage potential future wholesale dynamic prices
- PNNL campus
  - Manage Richland peak demand charges
  - Maximize use of local PV generation
  - Enhance energy efficiency

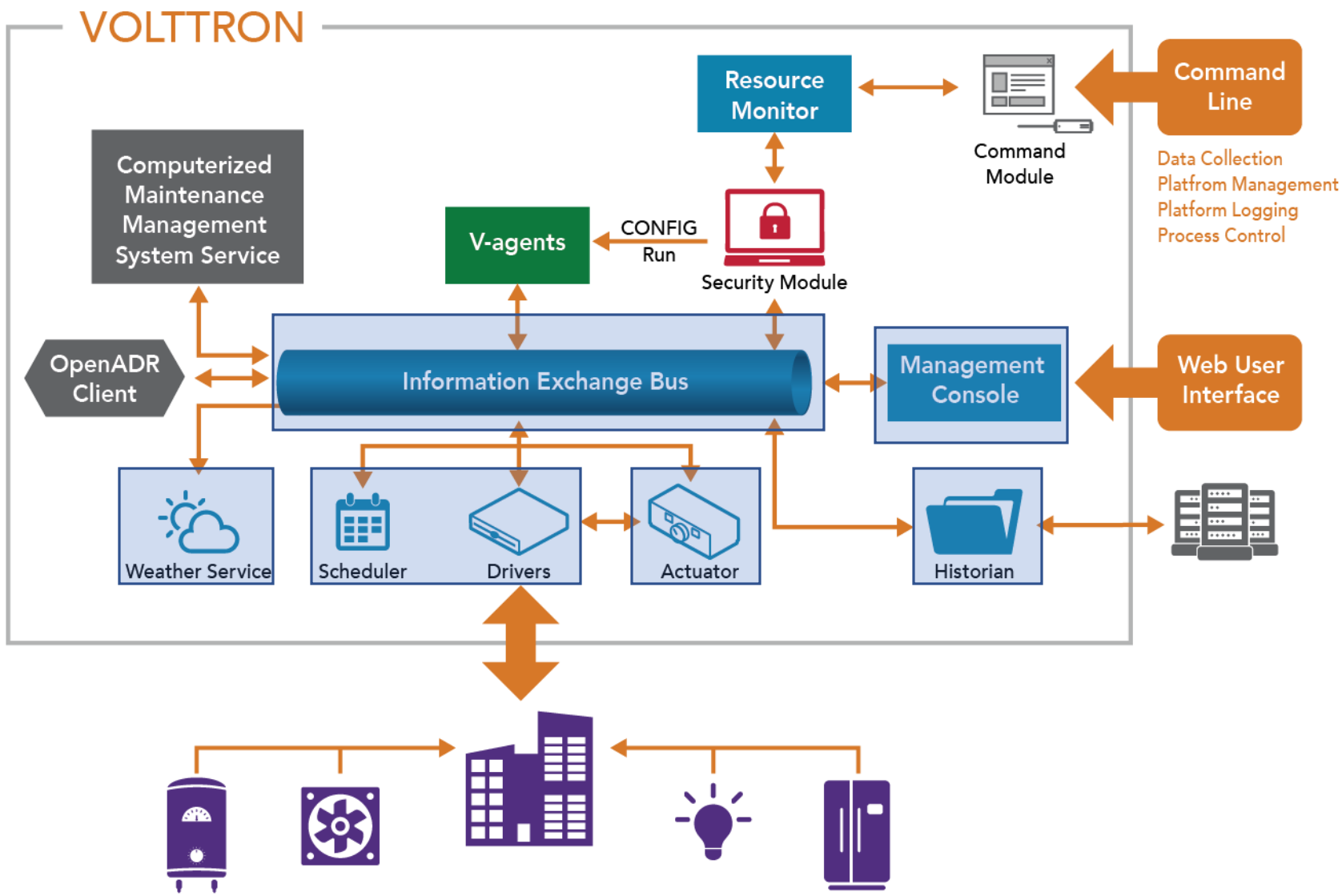


e-3 Value Diagram

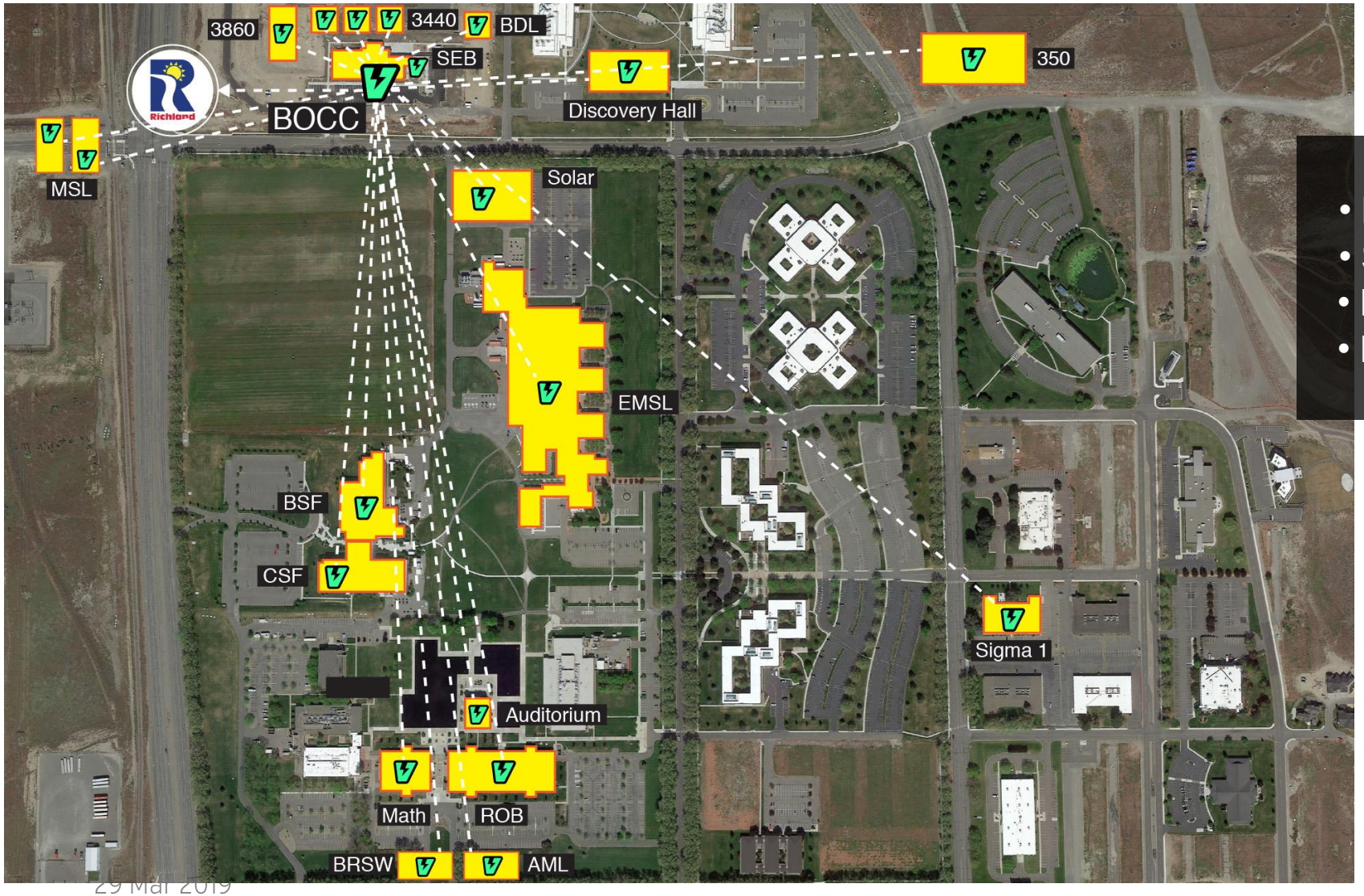


See the *e3 value* toolset, http://e3value.few.vu.nl/

Multi-Agent Campus Platform



Platform Deployment on PNNL Campus



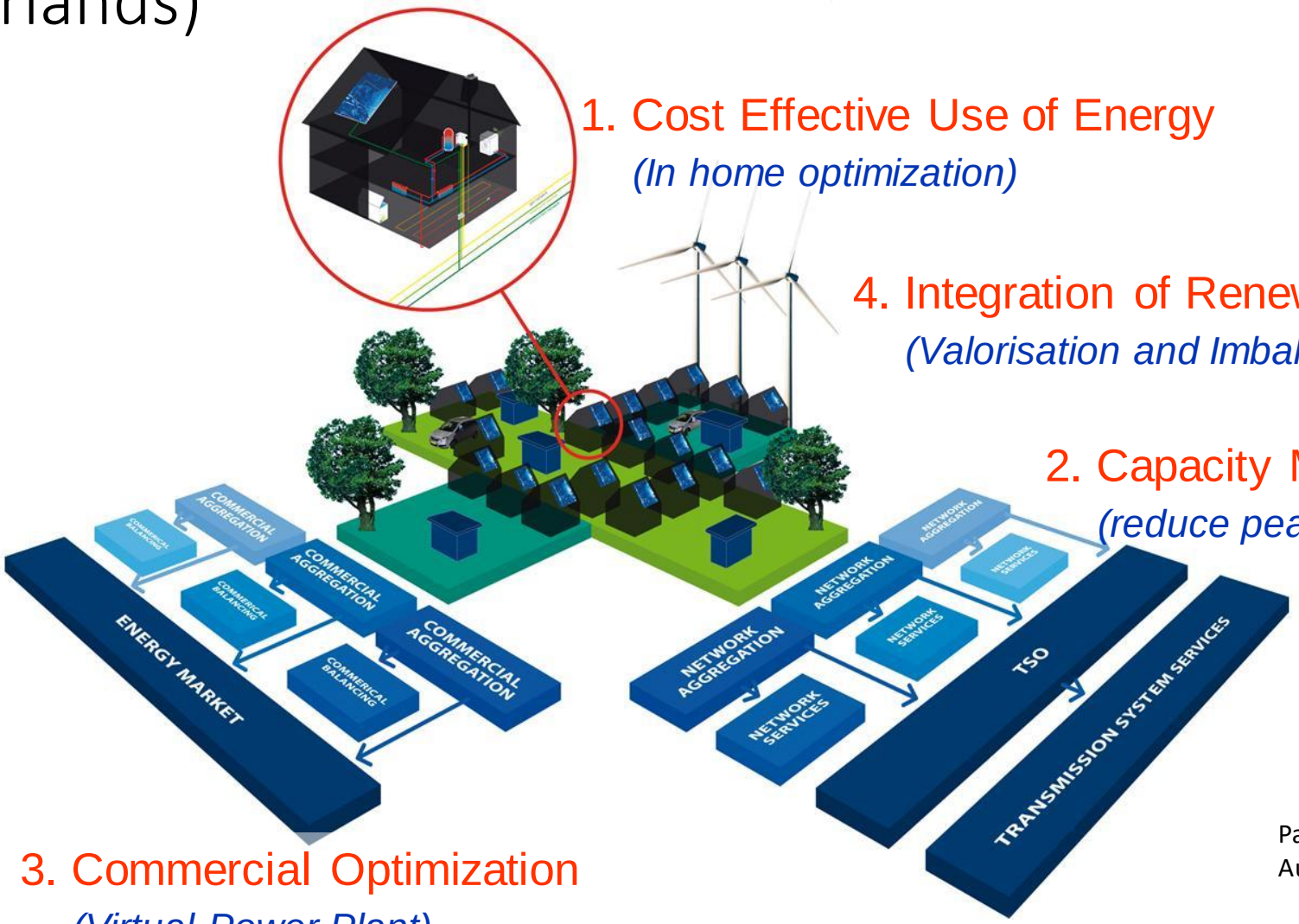
- **Buildings:** 16
- **Sensor Points:** >10,000
- **Daily Data:** ~14,000,000
- **Records to Date: >20,000,000,000**

Multiple functions of the system – Multiple Goals (Netherlands)

1. Cost Effective Use of Energy
(In home optimization)

4. Integration of Renewable Energy
(Valorisation and Imbalance Reduction)

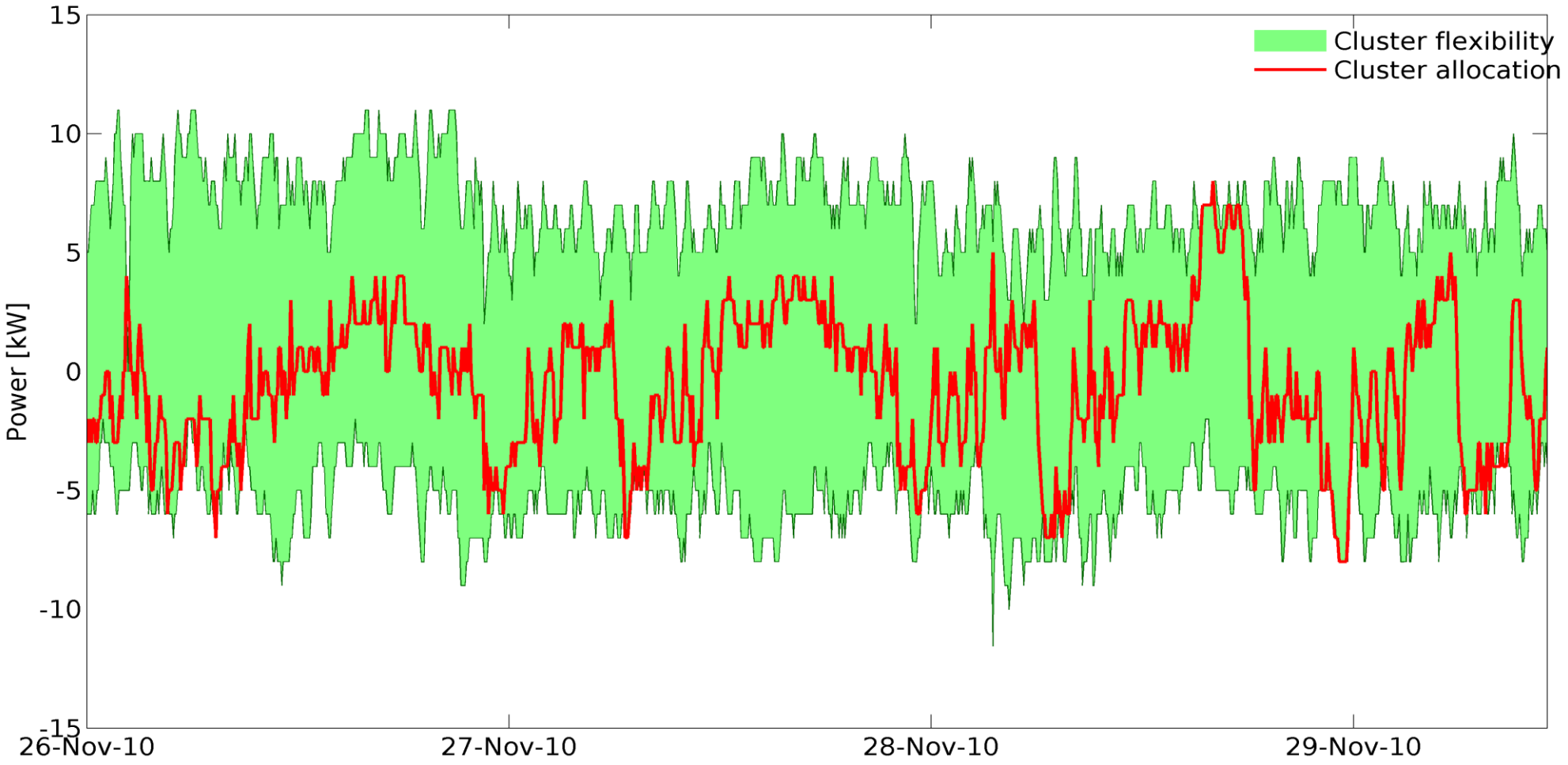
2. Capacity Management
(reduce peak loads)



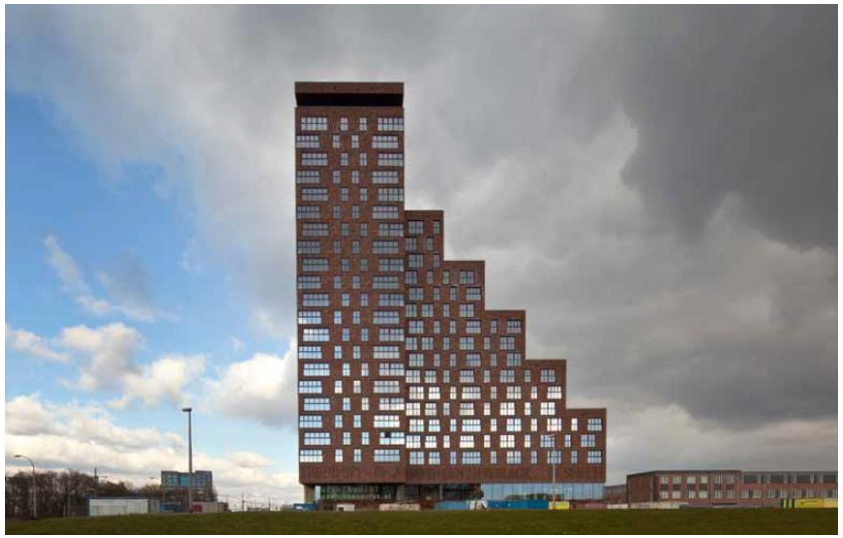
3. Commercial Optimization
(Virtual Power Plant)

Partners: Enexis, Essent, Gasunie, ICT Automation, DNV GL & TNO.

Flexibility Bandwidth



The Couperus Smart Grid Project – I (Netherlands)



Largest operational PowerMatcher-based smart grid so far with ~300 energy efficient heat pumps in apartment complex Couperus Ypenburg

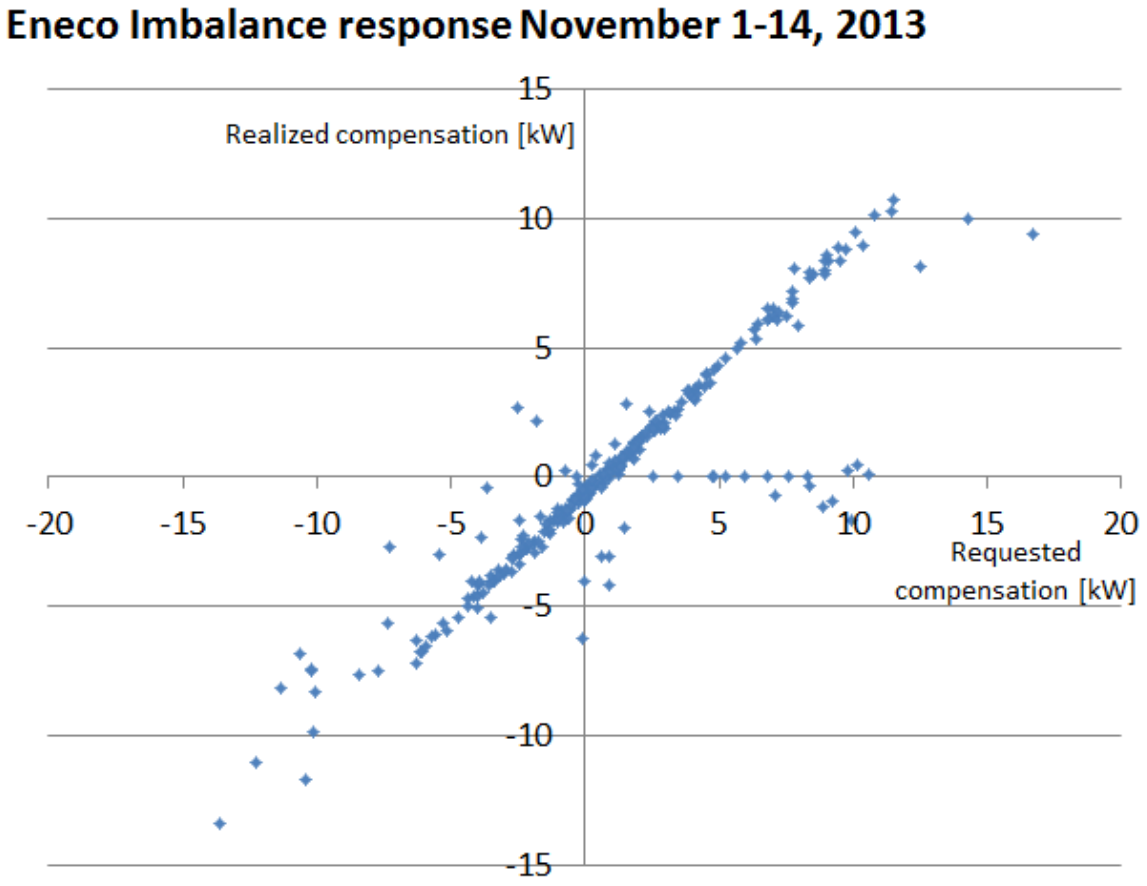
Partners:
Stedin, Eneco, ITHO Daalderop, SWY/Vestia, IBM, TNO & Province of Zuid Holland.

Wind Power Imbalance Reduction:
The HP Cluster compensates for the imbalance of a nearby wind turbine park without user comfort infringement.

The demo system also performs congestion management.

Couperus Smart Grid Project, NL

The Couperus Smart Grid Project - II



Results from test with 150 apartments:

For Energy Supplier Eneco: 80% imbalance reduction achieved

Couperus Smart Grid Project, NL

Bilateral Trading Platforms Emerging

TeMix: Retail Automated TE System (RATES)

- Agents on devices using trading platform for scheduled energy
- Includes delivery reservations to manage distribution constraints
- https://rates.energy/

Blockchain-based trading platforms

- LO3 Energy
  - Brooklyn Microgrid (USA)
    - Photovoltaic community trading using a distributed ledger
    - No apparent coordination with distribution system operations
  - Other projects: Enexa (Australia), Allgau Microgrid (Germany)
- Swytch Utility Token
  - Decarbonization platform to provide energy tokens for verified carbon displacement
  - Unknown coordination with distribution system operations

Wrap-up

Challenges and New Research

- Articulate the objectives of the grid and each edge resource (customers/prosumers), then define grid services to exchange value based on these objectives
  - Difficulty of common grid services definition across regions
  - Need standardized mechanisms to support regional specialization
- Forecasting and planning needed to address risk and uncertainty
  - All participants can contribute forecasted needs – particularly better models for planning energy use
  - Forward markets and associated risk hedging strategies hold promise
- Information technology standards to support multi-agent interactions lacking
  - Direct control paradigm dominates existing standards
  - A service interaction paradigm that is performance-based is immature

Realizing Transactive Energy

Purpose

- Transactional frameworks are established to incentivize and coordinate the response of millions of smart energy assets

Characteristics of a Good Solution

- Privacy, free will, and cyber-security concerns are mitigated
- Simple cyber-interaction paradigm, applicable at all levels of the system and supported by standards
- Offers a viable transition path that co-exists with traditional approaches
- Smooth, stable, predictable, and graceful failure

Necessary Outcomes

- Accepted by business and policy decision-makers as a cost-effective, valid, equitable, and advantageous revenue/investment recovery mechanism
- Vibrant vendor community supplies transactional products and services, e.g., operating systems and system & device-level controls

Summary: Characteristics of Transactive Energy Systems

- Engenders the voluntary collaboration of end-user assets though incentives
- Incentives must reflect actual grid values and constraints, to offer the end user an equitable deal
- Decision-making to respond is kept at the end-user, participant level
- Automation conveniently takes care of the details
- Uses decentralized decision-making – scalable and sensitive to privacy
- “Virtual control” – negotiation feedback loop provides smooth, stable, predictable response required by grid operators
- Allows end-user assets to compete on a level playing field, with each other and traditional grid assets

Some References

For further information please see,

- Olympic Peninsula: Pacific Northwest GridWise™ Testbed Demonstration Projects
  - http://www2.econ.iastate.edu/tesfatsi/OlympicPeninsulaProject.FinalReport_pnnl17167.pdf
- AEP Ohio gridSMART® Final Technical Report on SmartGrid.Gov
  - https://www.smartgrid.gov/project/aep_ohio_gridsmartsm_demonstration_project
- Pacific Northwest Smart Grid Demonstration
  - www.pnwsmartgrid.org
- GWAC Transactive Energy Framework
  - http://www.gridwiseac.org/about/transactive_energy.aspx
- NIST TE Challenge
  - http://www.nist.gov/smartgrid/techallenge.cfm
- PowerMatcher
  - www.PowerMatcher.net
- Flexiblepower Alliance Network (FAN)]
  - www.flexiblepower.org

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About us

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Welcome to the world of CIGRÉ

- Founded in Paris as the *Conseil International des Grands Réseaux Électriques*, CIGRÉ is translated to the “International Council on Large Electric Systems”
- Since 1921, CIGRÉ is one of the world’s most foremost sources for power system expertise
- CIGRÉ is a collaborative global community committed to the world's leading knowledge development program for the creation and sharing of power system expertise
- CIGRÉ United States is the National Committee, and the local representative organization of CIGRÉ
- The U.S. Next Generation Network (NGN) is a CIGRÉ network for early career professionals and students in the power industry. The NGN seeks to facilitate a successful transition into the power systems industry by providing technical resources and networking opportunities

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- Community experts and CIGRÉ bodies define strategic focus
- Focused on key strategic themes based on key challenges, trends and issues
- Applied to CIGRÉ's 16 domains of work
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- Involving thousands of power system professionals
- 59 National Committees & 15,000 members globally
- 1,200+ organizations from around the world

16 DOMAINS OF WORK

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- Limitations to build new transmission infrastructures
- Architecture of networks and systems
- Maintaining the existing power systems
- Transmission of large amounts of power over long distances
- Cybersecurity
- Intermittency of renewable power generation

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24-28 August 2020

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- The world's #1 global power system event, unique for its thought leadership

Paris Session at a glance

3500+ delegates
5000 industry participants
94+ countries
Massive trade exhibit
160+ working meetings
30+ Study Committee sessions

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