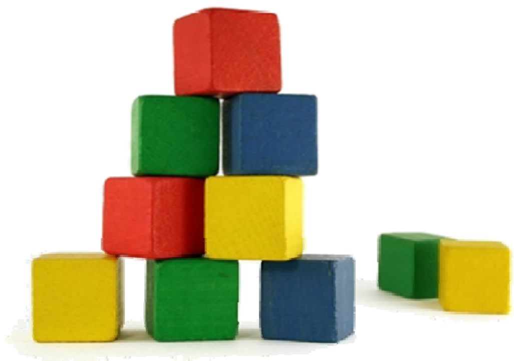

Microgrids – Designing Their Role in the Smart Grid

Steve Pullins, President

Horizon Energy Group

September 2012

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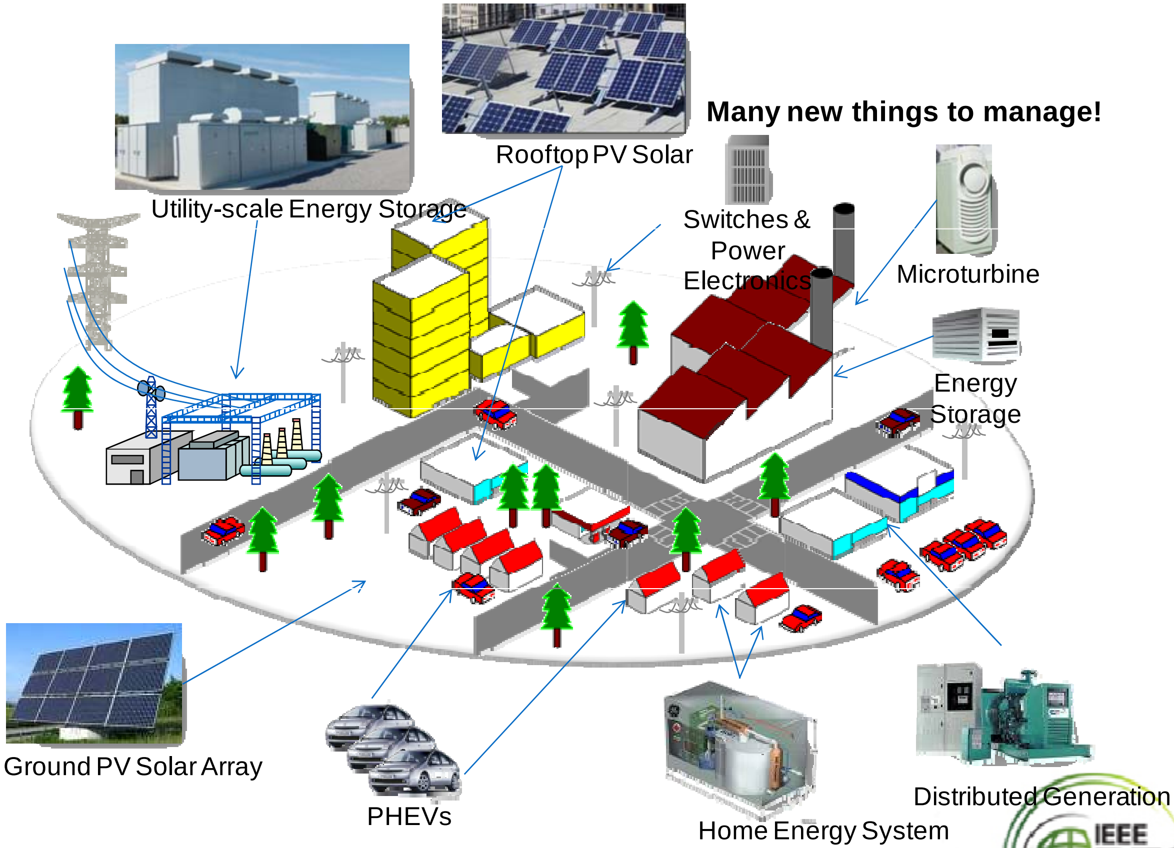
What is a Microgrid?

"A **microgrid** is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode."

DOE Microgrid Exchange Group, October 2010

There are federal and state incentives and tax credits for microgrids.



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Beach Cities Microgrid Project

- $15.2M project in Borrego Springs, 4.5 MW, 500 customers, 0.6 MW PV, heavy irrigation, 120^{o}F summer heat
- Funding: Sempra $4.2M, DOE $7.5M, CEC $2.8M, others ~$0.8M
- Involves Integration of five (5) technologies:
  - Distributed Energy Resource (DER) and VAr management
  - Feeder Automation System Technologies (FAST)
  - Advanced Energy Storage (AES)
  - Microgrid Controller & OMS/DMS
  - Price-Driven Load Mgmt (PDLM)
- Operations Testing for Optimization Scenarios
- First stage operational: Q3 2011, Final stage: Q4 2012
- Business Case and Multiple Microgrid Implementation Plan

What to expect in the future

THE CASE FOR MICROGRIDS

Electric and Gas Price Trends

Figure 60. Average annual U.S. retail electricity prices in three cases, 1970-2035 (2008 cents per kilowatthour)

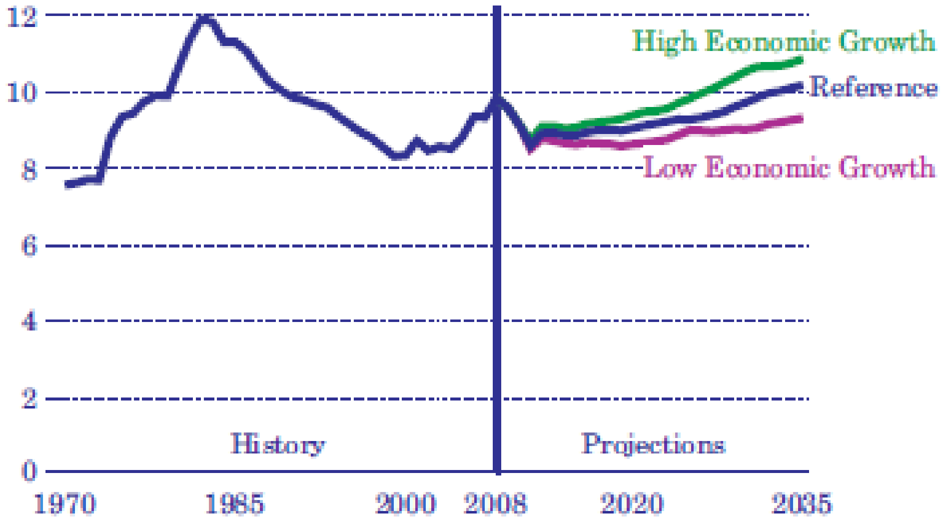
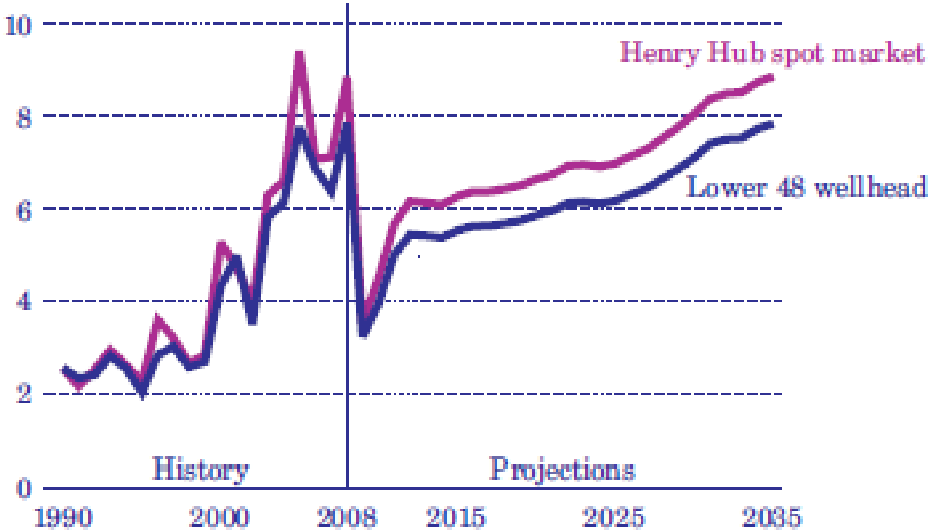


Figure 69. Annual average lower 48 wellhead and Henry Hub spot market prices for natural gas, 1990-2035 (2008 dollars per million Btu)

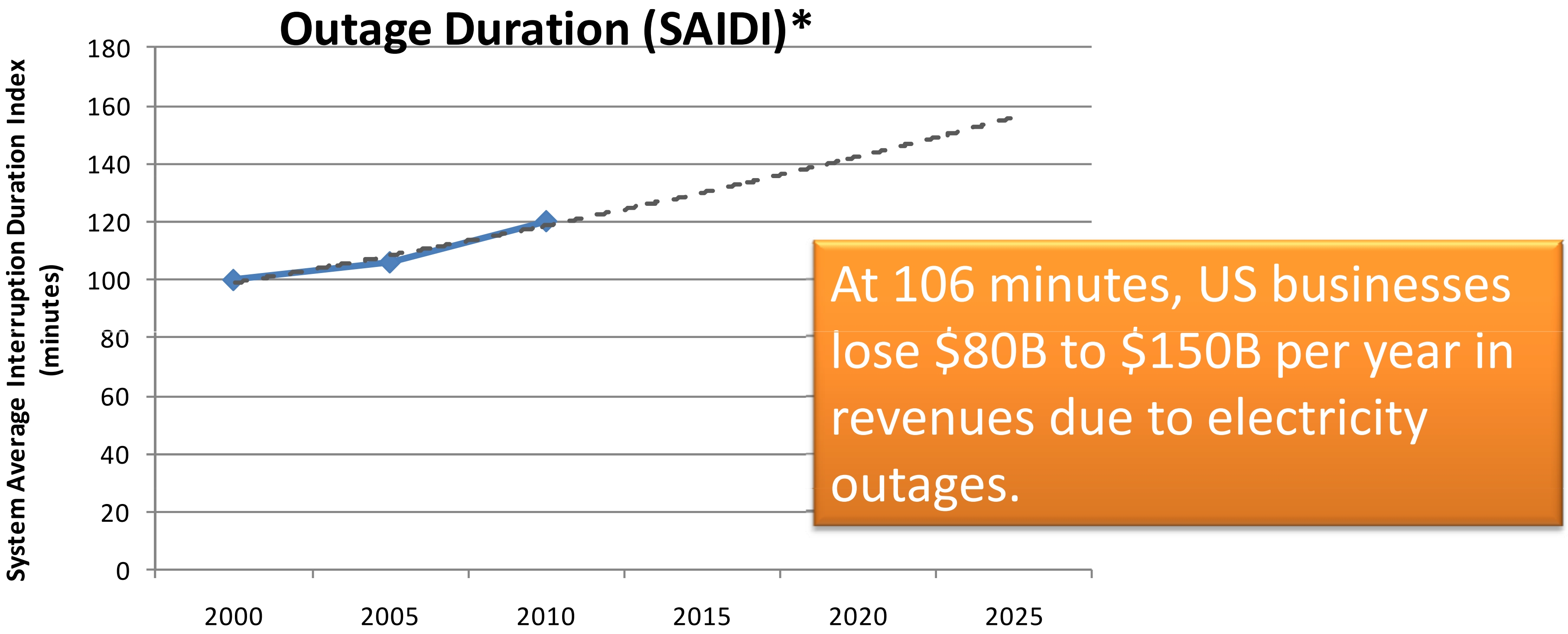


We can expect electric rates to increase 7% by 2020 and 15% by 2030.

We can expect natural gas rates to increase 56% by 2020 and 89% by 2030.

Source: DOE EIA Annual Energy Outlook 2010

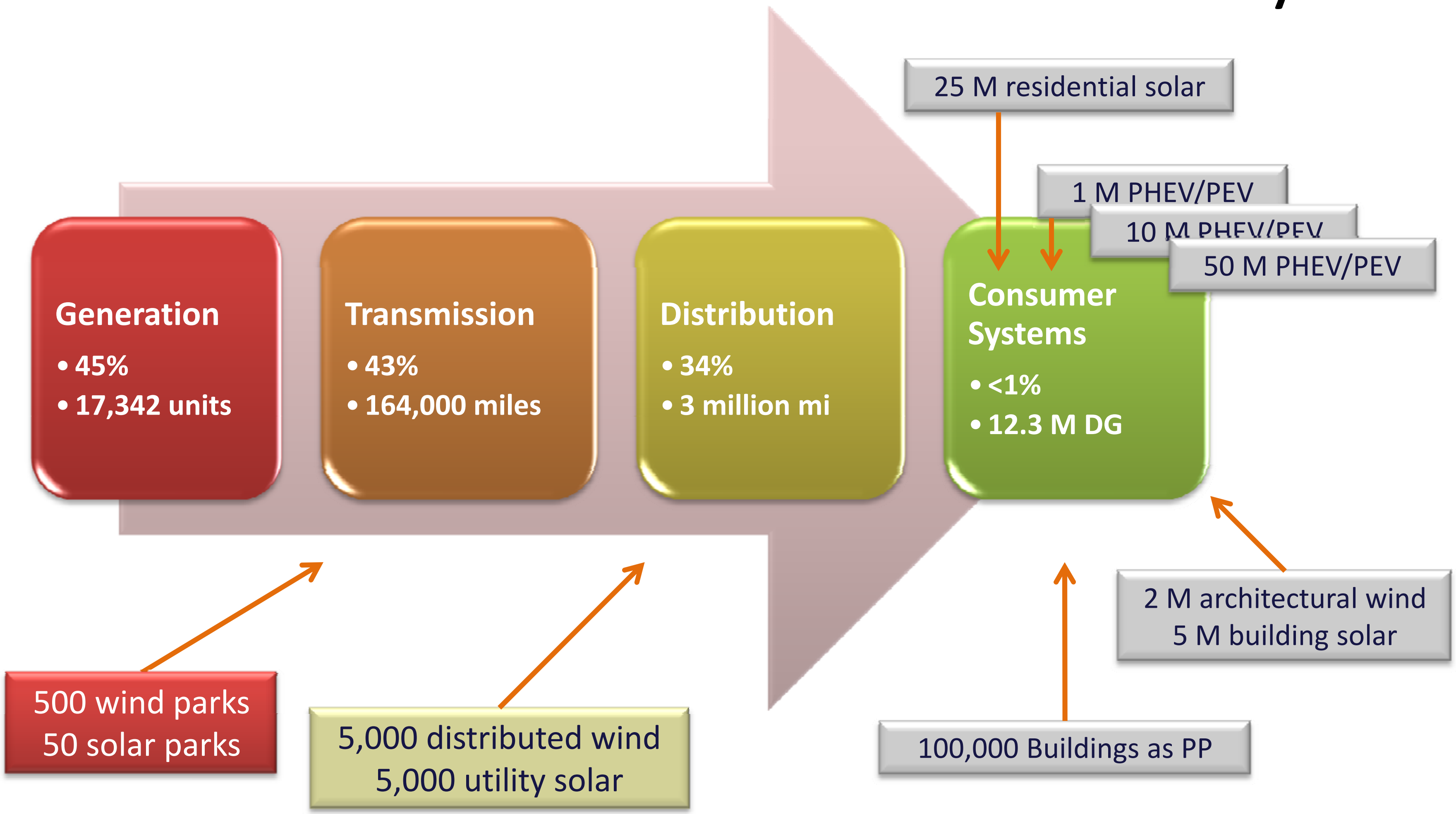
Electric System Reliability



*Reports on previous year's data

Sources: Lawrence Berkeley National Lab, IEEE 1366, EIA data, EPRI

From the 20th to the 21st Century



Continued increase in energy intensity

Prices increasing, in some regions faster than gasoline at the pump

Changeover to more and more digital loads

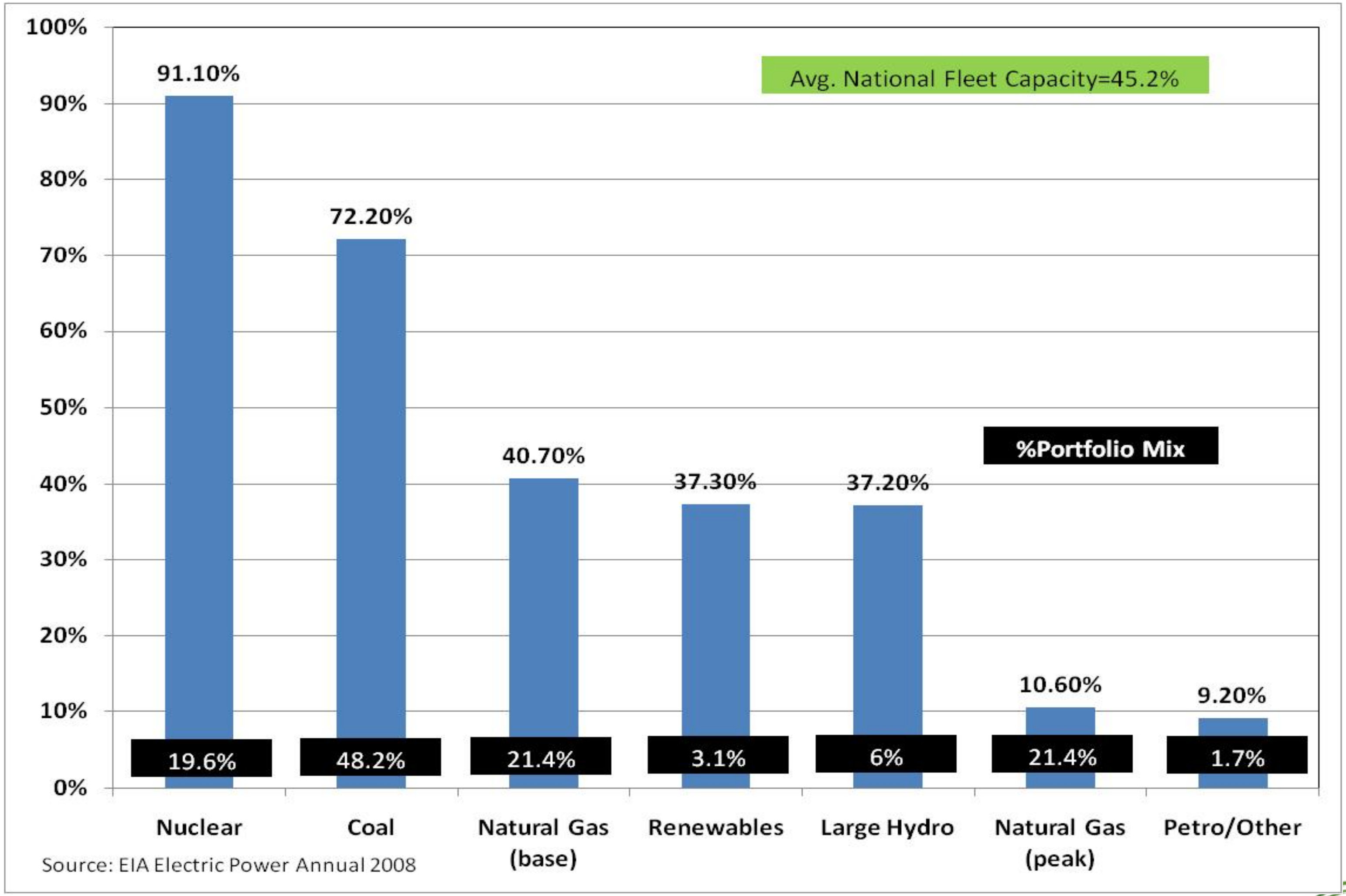
Consumer choices

Renewables Growth (2004* – 2008)

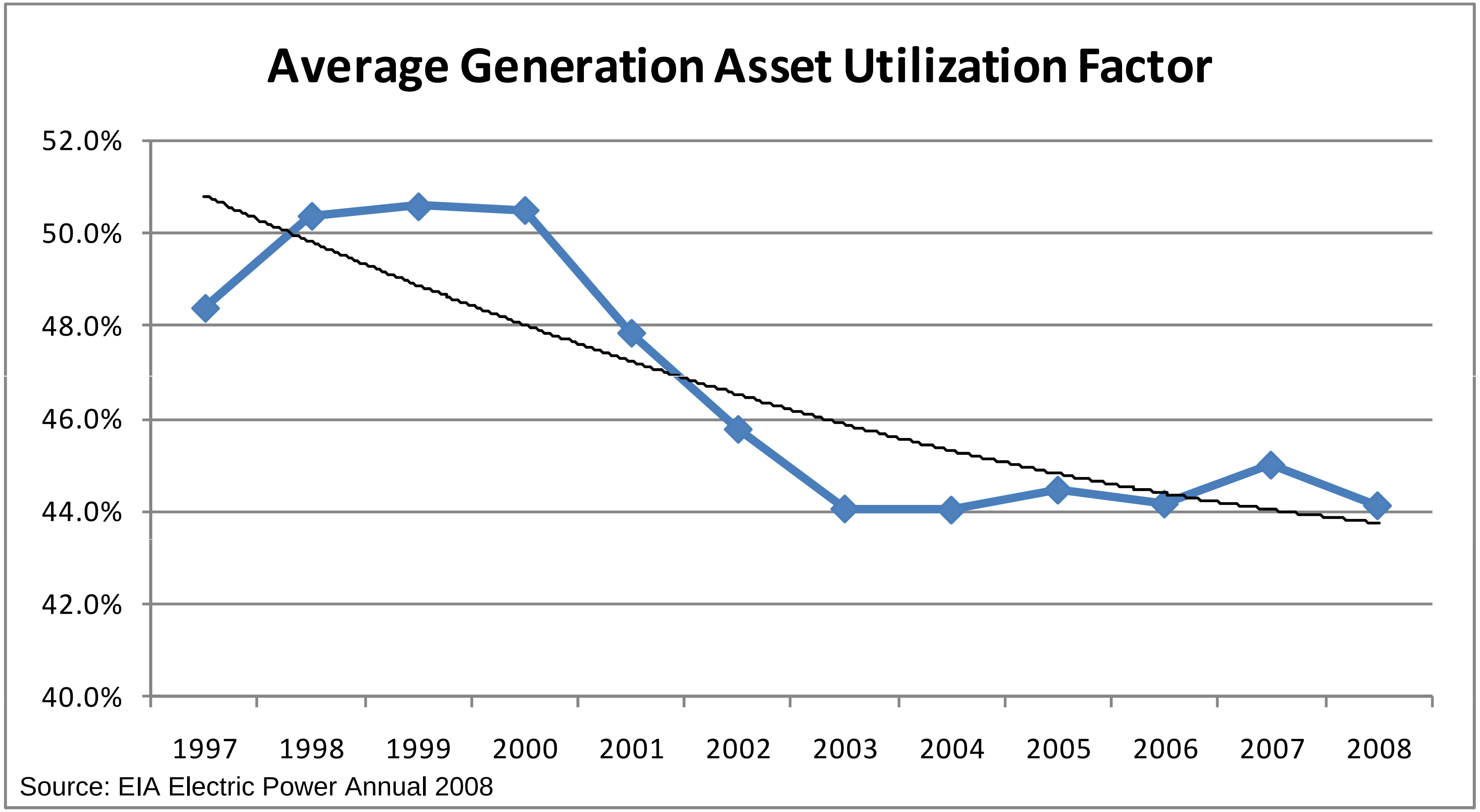
Renewables Global Status Report – 2009 Update (145 countries reporting)
** Baseline – Bonn Renewables Conference 2004*

- Grid connected PV now 13GW – 600% increase
- Wind now 121GW – 250% increase
- Total from all renewables now 280GW – 75% increase
  - Includes large increase in small hydro, geothermal, & biomass generation
- Solar heating now 145 GWth – 200% increase
- Biodiesel production now 12B liters/yr – 600% increase
- Ethanol production now 67B liters/yr – 200% increase
- Annual renewables investment in new capacity now $120B/year – 400% increase

Business As Usual Results



Trend in Central-Station Generation



Why would we think this will work tomorrow?

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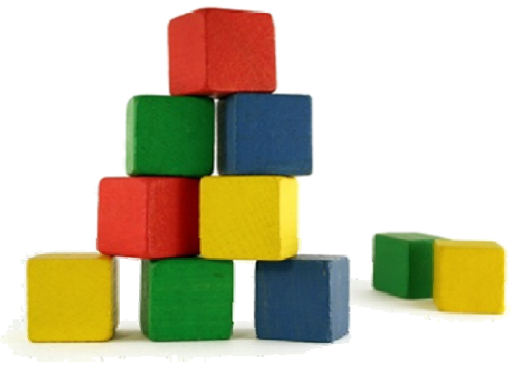
Simple Math

- To support consumption of 1 MW:

- Requires central-station production of ~1.2 MW
  - Line losses, transformation losses, congestion losses
- Requires central-station installation of ~2.2 MW
  - Average fleet capacity factor ~45%

- Requires distributed production of ~1 MW
- Requires distributed installation of ~1.4 MW



Design and engineering

CONSIDERATIONS

Microgrid vs Traditional Supplier Roles

Criteria	MEA/Shell	IIT/Exelon	Calpine[8]	NextEra[9]	US Avg.
Source Energy Intensity (mmBTU/MWh)	3.8	6.6	7.3	8.0	9.1
CO_2 Intensity (lbs/MWh)	610	0	870	650	1330
SO_2 Intensity (lbs/MWh)	0.3	0	0.0044	0.44	3.0
NOx Intensity (lbs/MWh)	0.3	0	0.12	0.33	1.4
Water Consumption (gallons/MWh)	>400*	240*	100	230	>400*
Solid Waste Recycled (waste recycled/total waste)	16%*	60%	0%*	28%*	65%
Renewable Energy Credits (bonus points)	6	0	0	0	N/A
PPI Rating Score (max 100)	**91**	**79**	**68**	**64**	**41**
Percent Renewable	**60%**	**40%**	**6%**	**13%**	**9%**

**Numbers estimated from available data*

Notes: Results adjusted for average system losses. MEA is the Marin Energy Authority contracting with Shell Energy. IIT is the Illinois Institute of Technology contracting with Exelon.

Table 3, Assessing Power Supply: Environment and Energy Efficiency, Perfect Power Institute, July 2012

[8] Calpine (2010). *Annual Report: A Generation Ahead, Today*. www.calpine.com/docs/CPN_Annual_Report.pdf

[9] NextEra Energy (2011). *Sustainability Report 2011*. http://www.nexteraenergy.com/pdf/sustain-report.pdf

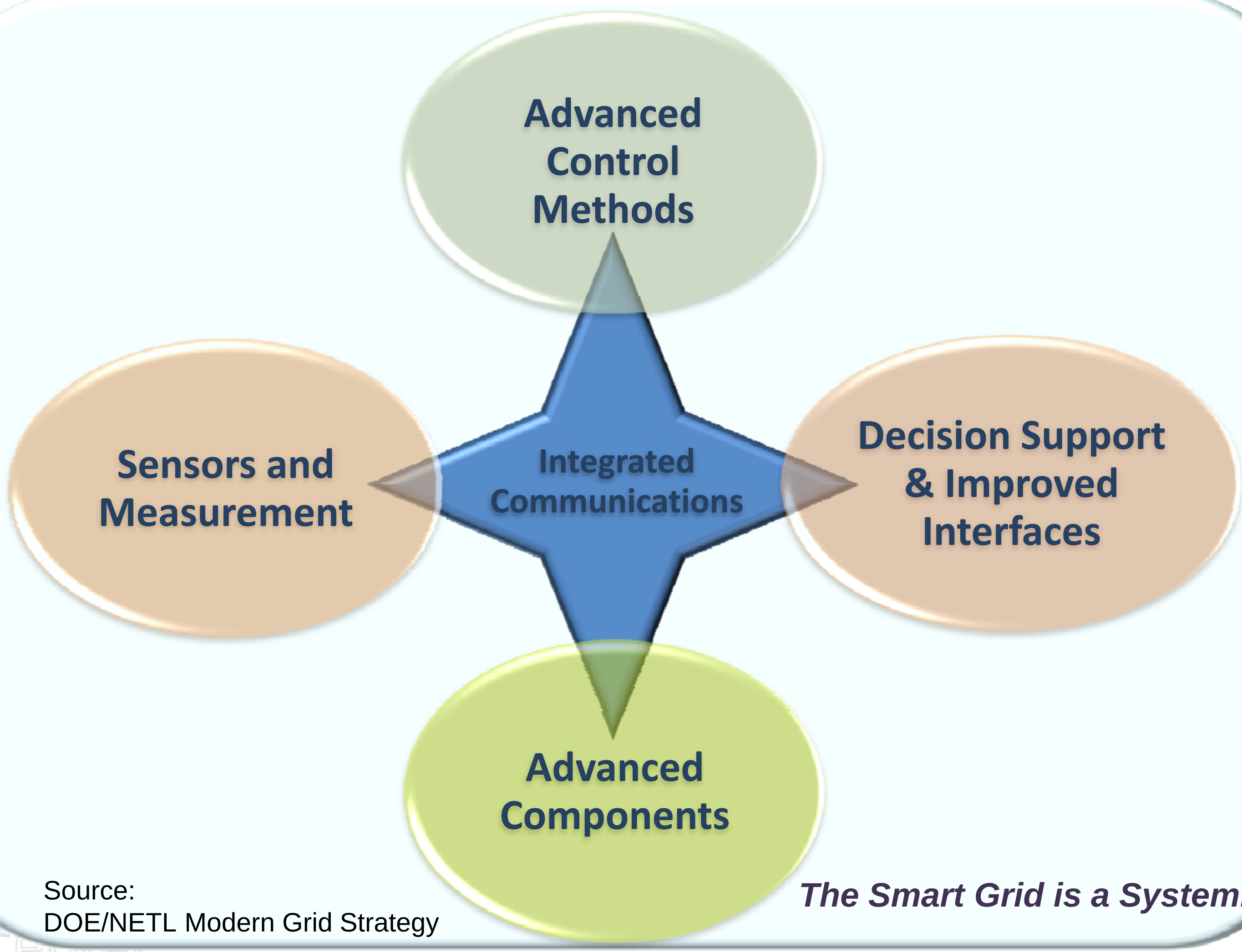
SG Characteristic Comparison

Characteristic	Microgrid	BAU Central Station Supply	DR, EE, Conservation	Renewables Standard
Enable active participation by consumers	X		X	
Accommodate all generation and storage options	X			X
Enable new products, services, and markets	X		X	
Provide power quality for the digital economy	X	X	X	
Optimize asset utilization and operate efficiently	X		X	
Anticipate & respond to system disturbances (self-heal)	X			
Operate resiliently against attack and natural disaster	X			

Why Microgrids?

- **Savings**: The microgrid portfolio of resources is tuned to the campus to provide economic savings
- **Sustainability**: The microgrid portfolio enables a hedge against fuel cost increases
- **Stewardship**: The microgrid enables deep penetration of renewables
  - Emissions reduction
  - Green marketing
- **Reliability**: The microgrid actively controls the network for better reliability

Microgrids and the 5 Key Technology Areas

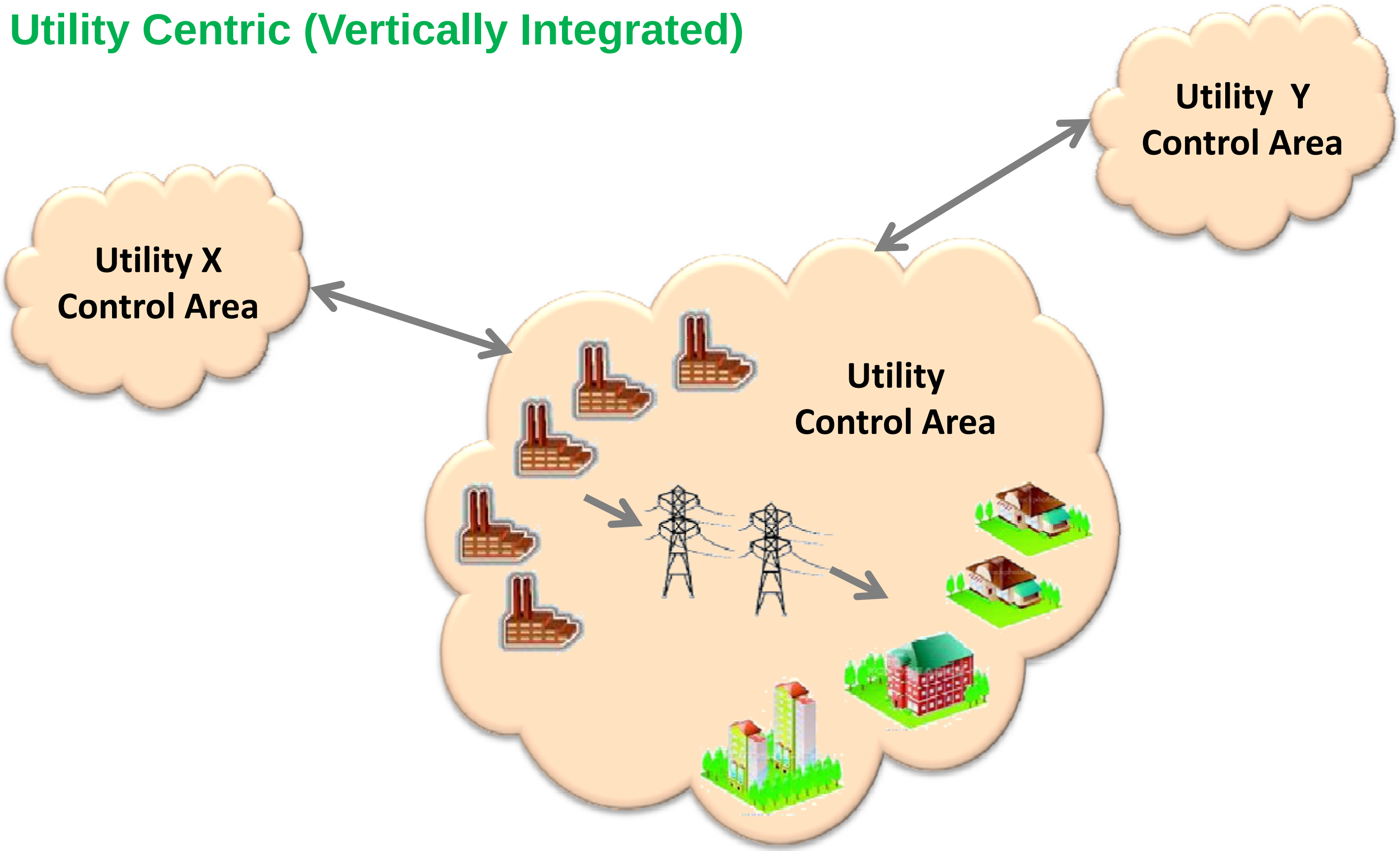


Source:
DOE/NETL Modern Grid Strategy

The Smart Grid is a System.

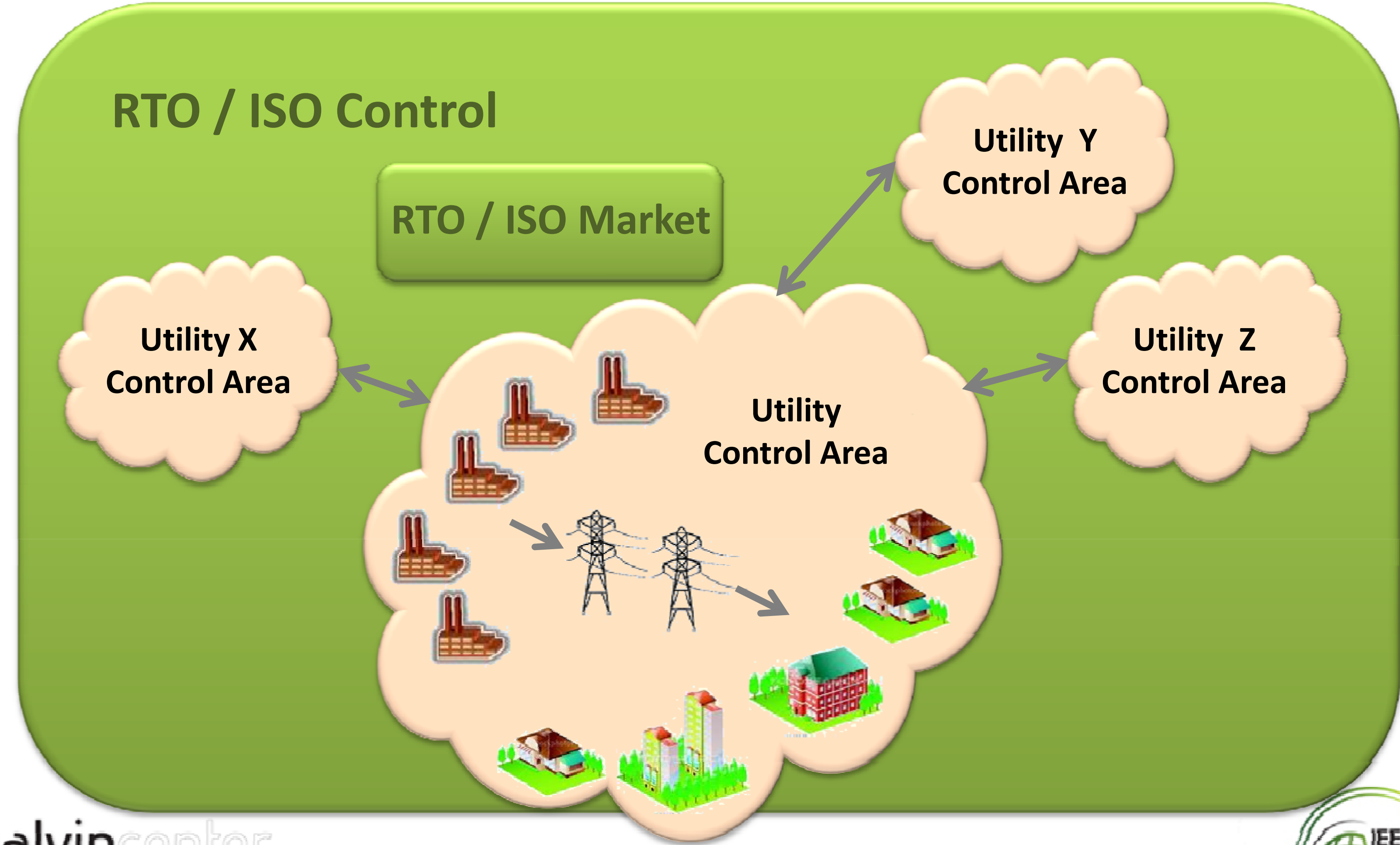
Generation Dispatch - Past

Utility Centric (Vertically Integrated)

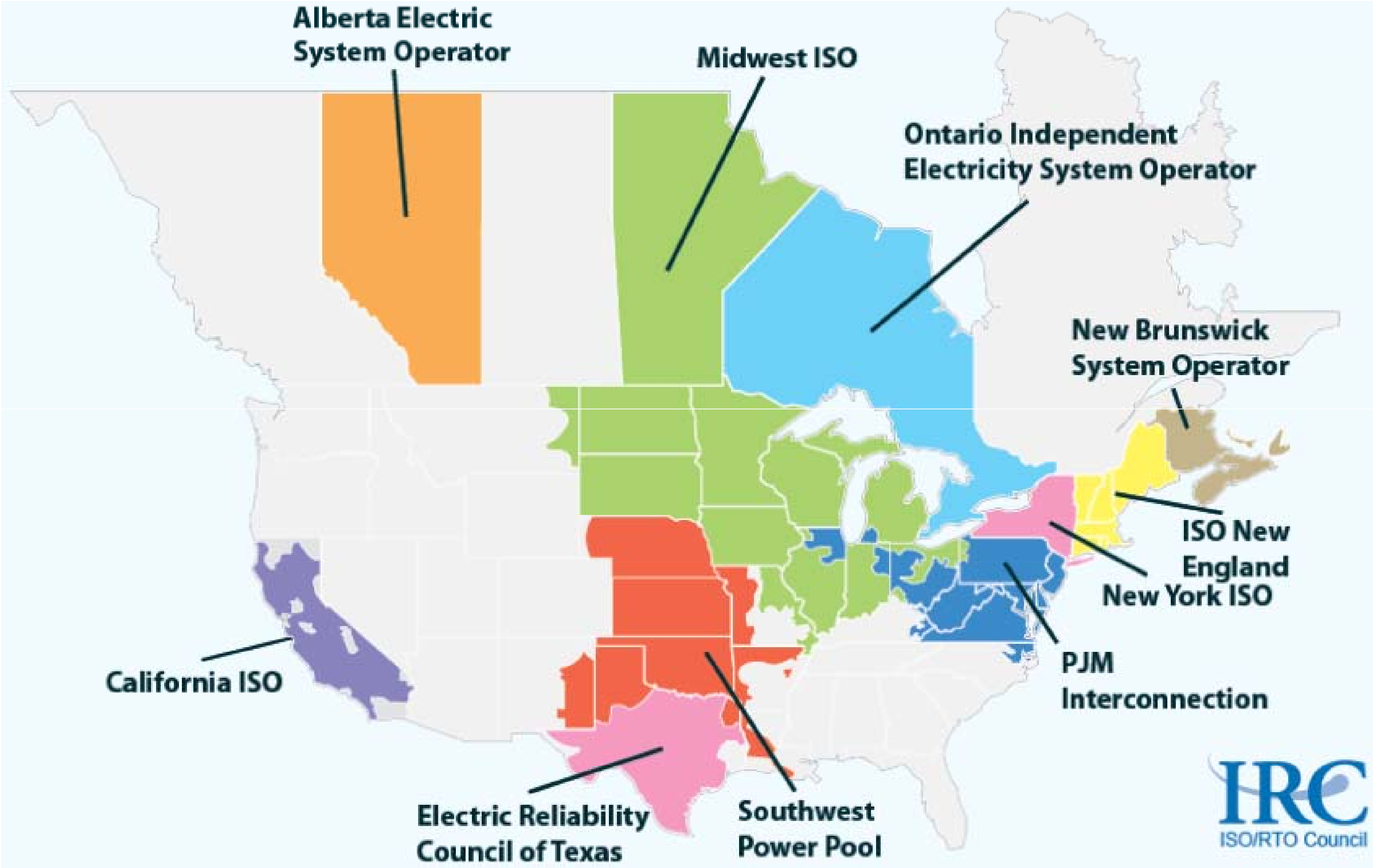


Generation Dispatch - Present

RTO/ISO Centric (Deregulated) – Security-Constrained Economic Dispatch



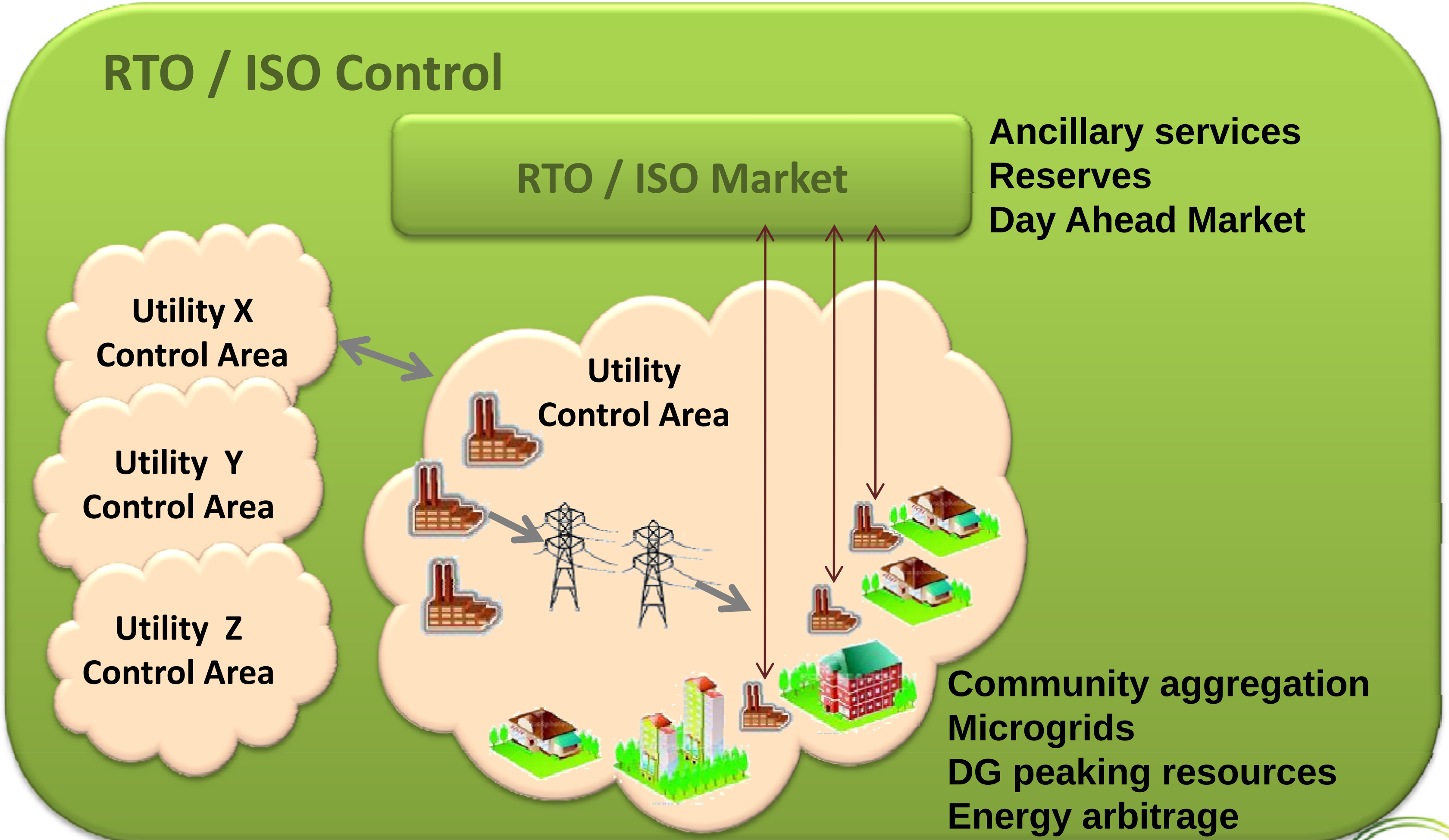
ISO / RTO Map



Alberta Electric
System Operator
Midwest ISO
Ontario Independent
Electricity System Operator
New Brunswick
System Operator
ISO New
England
New York ISO
PJM
Interconnection
California ISO
Electric Reliability
Council of Texas
Southwest
Power Pool
IRC
ISO/RTO Council

Generation Dispatch - Future

Consumer Centric – Economic / Reliability / Environmental (ERE) Dispatch



Microgrid Architecture Considerations

Utility Network Management

Microgrid Master Controller

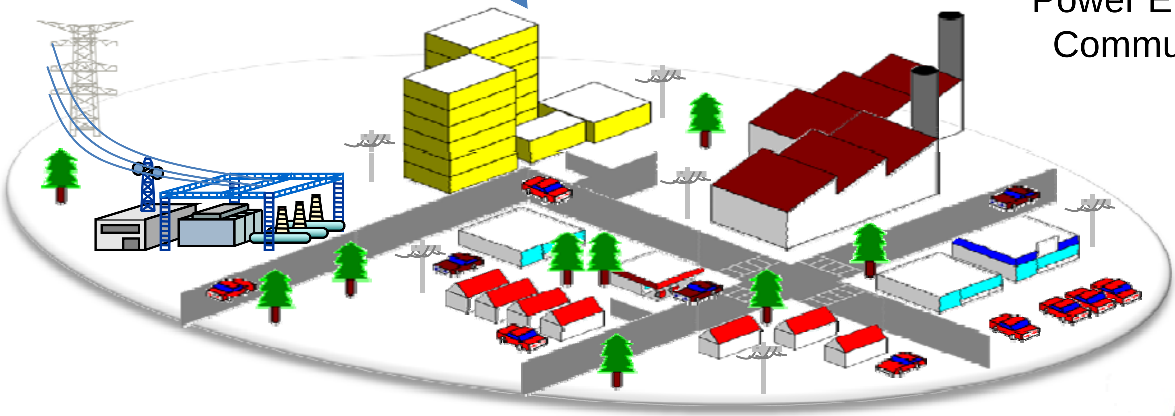
SCADA System

Microgrid Objectives
Take action to improve reliability
Take action to improve economics
Take action to manage renewables

Information
Electricity Pricing
DER status
Demand Response Programs
Network status
Community Objectives
Load and Resource Profiles

Grid Resources
Capacitor Banks
Voltage Regulators
Automated Switches
Power Electronics
Communications

Distributed Energy Resources
Utility-scale Energy Storage
Rooftop PV Solar
Micro-turbines
Building Energy Storage
Community Energy Storage
Distributed Generation
Home Energy System
PHEVs
Ground PV Solar Array



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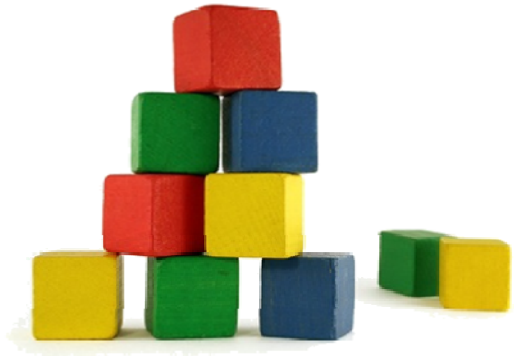

MICROGRID USE CASES

Use Case to Design

- Use Cases were first created in the software development community to bring order to defining requirements for development
- They represent an “actor using a function in a series of steps”
- Use Cases provide traceability between user objectives and requirements

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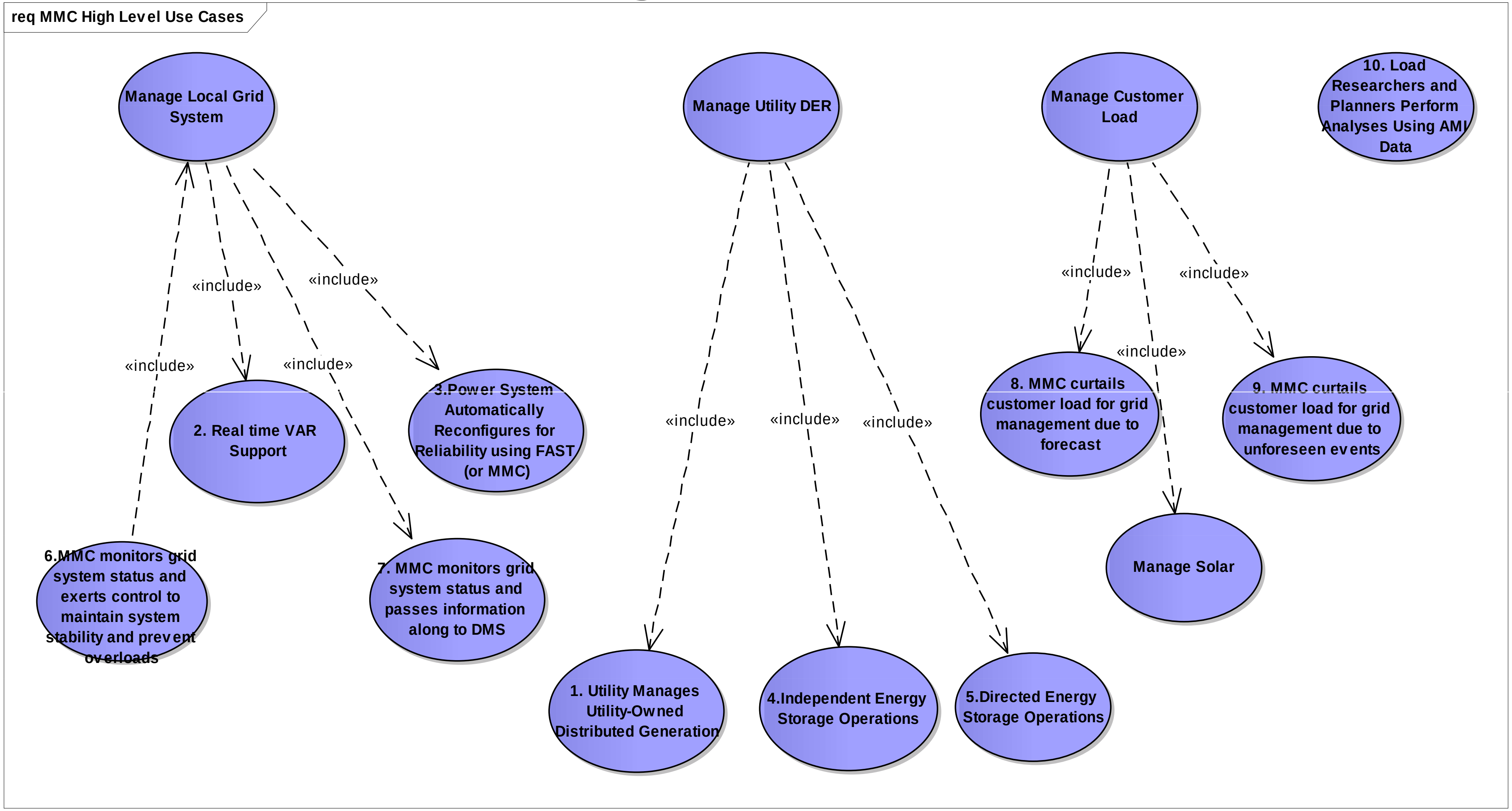
Functional Description (Use Cases)

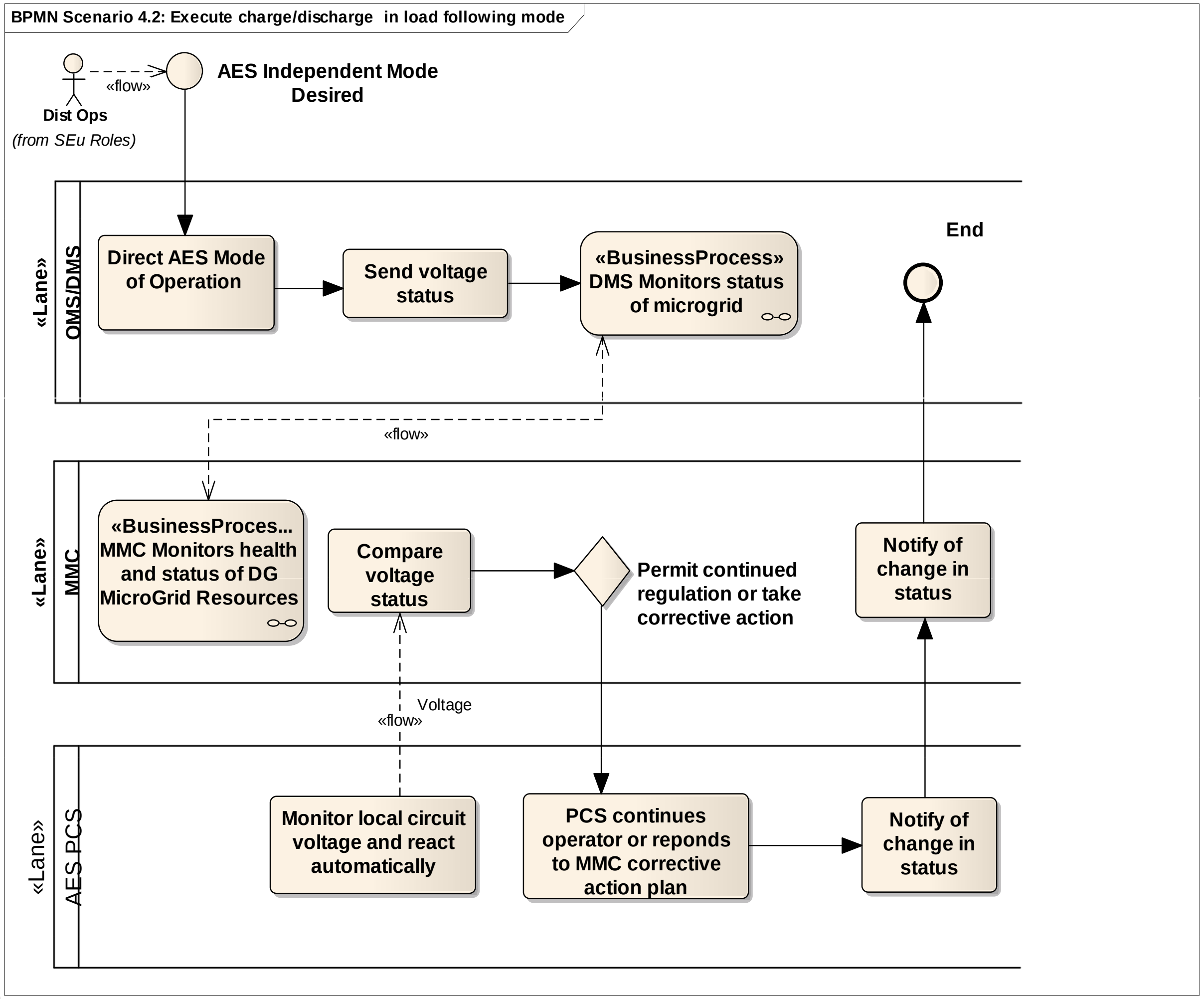
- Utility Manages Utility-Owned Distributed Generation
- Real-time VAR Support
- Power System Automatically Reconfigures for Reliability using FAST
- Independent Energy Storage Operations
- Directed Energy Storage Operations
- MMC monitors grid system status and exerts control to maintain system stability and prevent overloads
- MMC monitors grid system status and passes information along to DMS
- MMC curtails customer load for grid management due to forecast
- MMC curtails customer load for grid management due to unforeseen events
- Planners Perform Analyses Using Multiple Data Sources

Microgrid Use Cases



Example: Sparx EA Business Process Diagrams

Use Case 4.2: Independent Energy Storage Operations



Use Case Scenarios

1. Utility Manages Utility-Owned Distributed Generation
   - Scenario 1. Utility uses communications infrastructure to communicate with utility-owned distributed generation to start/stop generator in constant output mode.
2. Real-time VAR Support
   - Scenario 1. Capacitor reads Circuit VAR data real time and automatically turns on or off based upon prearranged setting. Change in status reported to DMS through SCADA.
   - Scenario 2. Capacitor reads line voltage and relays it to DMS through SCADA.
   - Scenario 3. Distribution operator places capacitor in Manual mode and manually turns capacitor on or off and MMC re-optimizes.

Use Case Scenarios (cont.)

3. Feeder Automation System Technology (FAST)
   - Scenario 1. Microgrid in island ops, a fault occurs inside microgrid.
   - Scenario 2. Microgrid island ops on DG only, a fault inside microgrid.
   - Scenario 3. Microgrid in island operation on AES with DG available, a fault occurs inside microgrid.
   - Scenario 4. Capacitor automatically comes online or offline as a result of FAST operation.
4. Independent Energy Storage Operations
   - Scenario 1. Energy storage executes charge/discharge sequence independent of DMS and MMC control as part of ongoing Peak Shaving Operations (similar to Cap Bank operations).
   - Scenario 2. Energy storage executes charge/discharge sequence in response to over volts or under volts on circuit (load-following mode).

Use Case Scenarios (cont.)

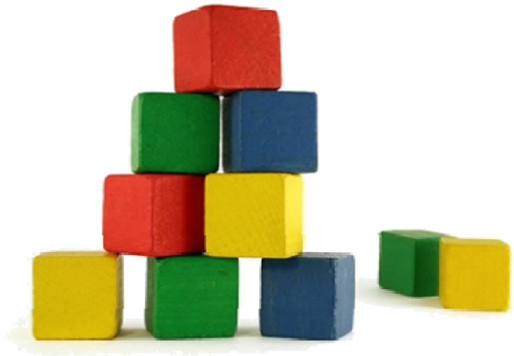
5. Directed Energy Storage Operations
   - Scenario 1. Energy storage executes basic charge/discharge sequence due to command from DMS/MMC.
   - Scenario 2. Energy Storage executes change in VAR flow during charge/discharge operations due to request from DMS/MMC.
   - Scenario 3. Utility uses energy storage for arbitrage (financial)
6. MMC monitors grid system status and exerts control to maintain system stability and prevent overloads
   - Scenario 1. MMC detects line outage, arms appropriate response, and executes
   - Scenario 2. Microgrid executes a planned transition to island ops
   - Scenario 3. Microgrid reconnects to the main grid
   - Scenario 4. MMC controls individual microgrid resources

Use Case Scenarios (cont.)

7. MMC monitors grid system status and passes information along to DMS
   - Scenario 1. MMC incorporates all system information into a status evaluation.
8. MMC curtails customer load for grid management due to forecast
   - Scenario 1. Forecast load expected to be subject to curtailment and pass to DMS.
   - Scenario 2. Execute curtailment in response to pre-scheduled pricing event on system.
   - Scenario 3. Customer opts out of curtailment for pre-scheduled event
   - Scenario 4. Load at the customer site is already below threshold

Use Case Scenarios (cont.)

9. MMC curtails customer load for grid management due to unforeseen events
   – Scenario 1. Execute emergency curtailment in response to load on system
   – Scenario 2. Customer opts out of curtailment for Grid Management (same as scenario 1)
   – Scenario 3. Customer already operating at DR commitment level (same as scenario 1)
10. Planners Perform Analyses Using Multiple Data Sources
   – Scenario 1. Planners perform studies with data from a designated subset of meters

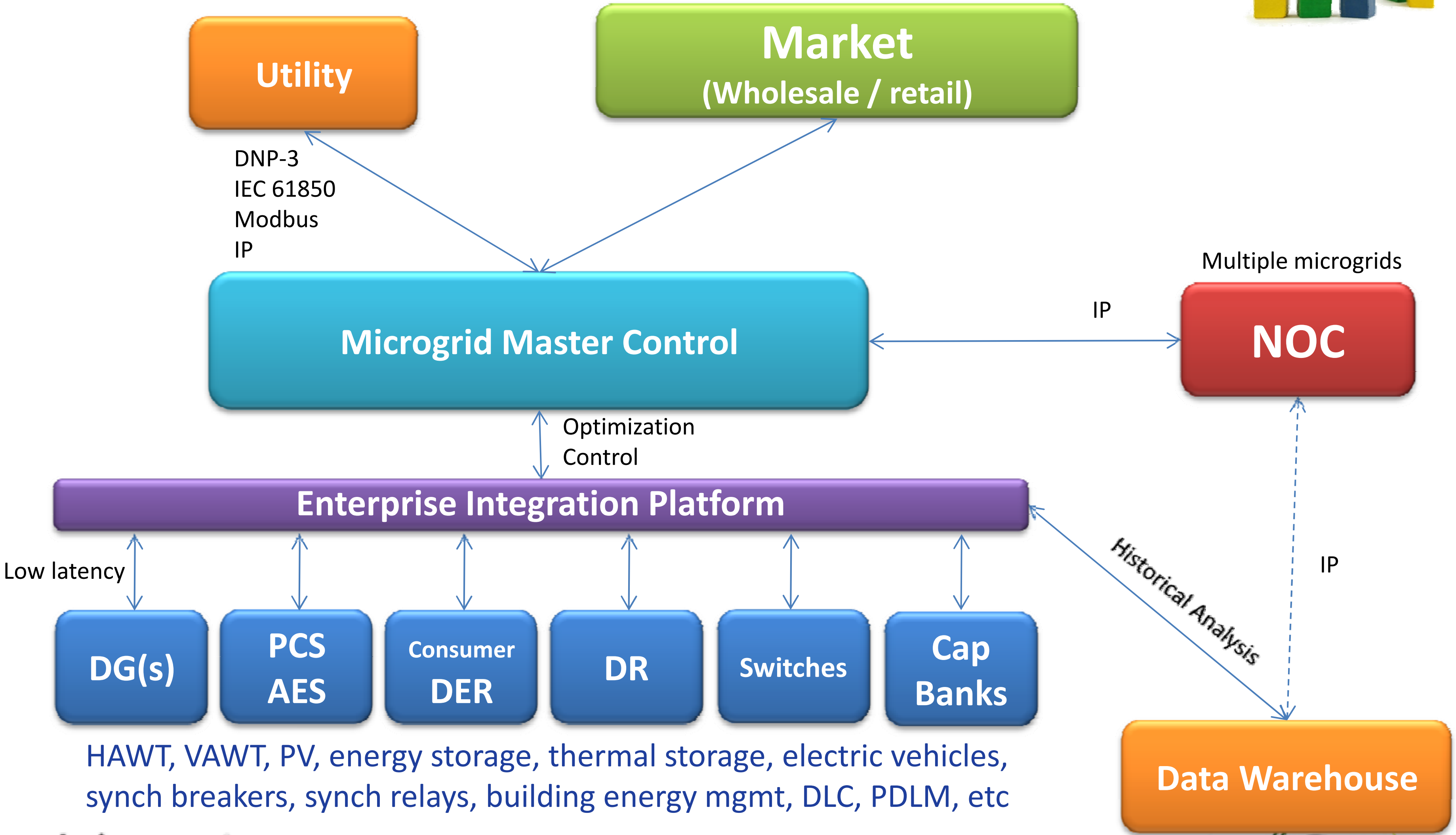


TECHNICAL ARCHITECTURE

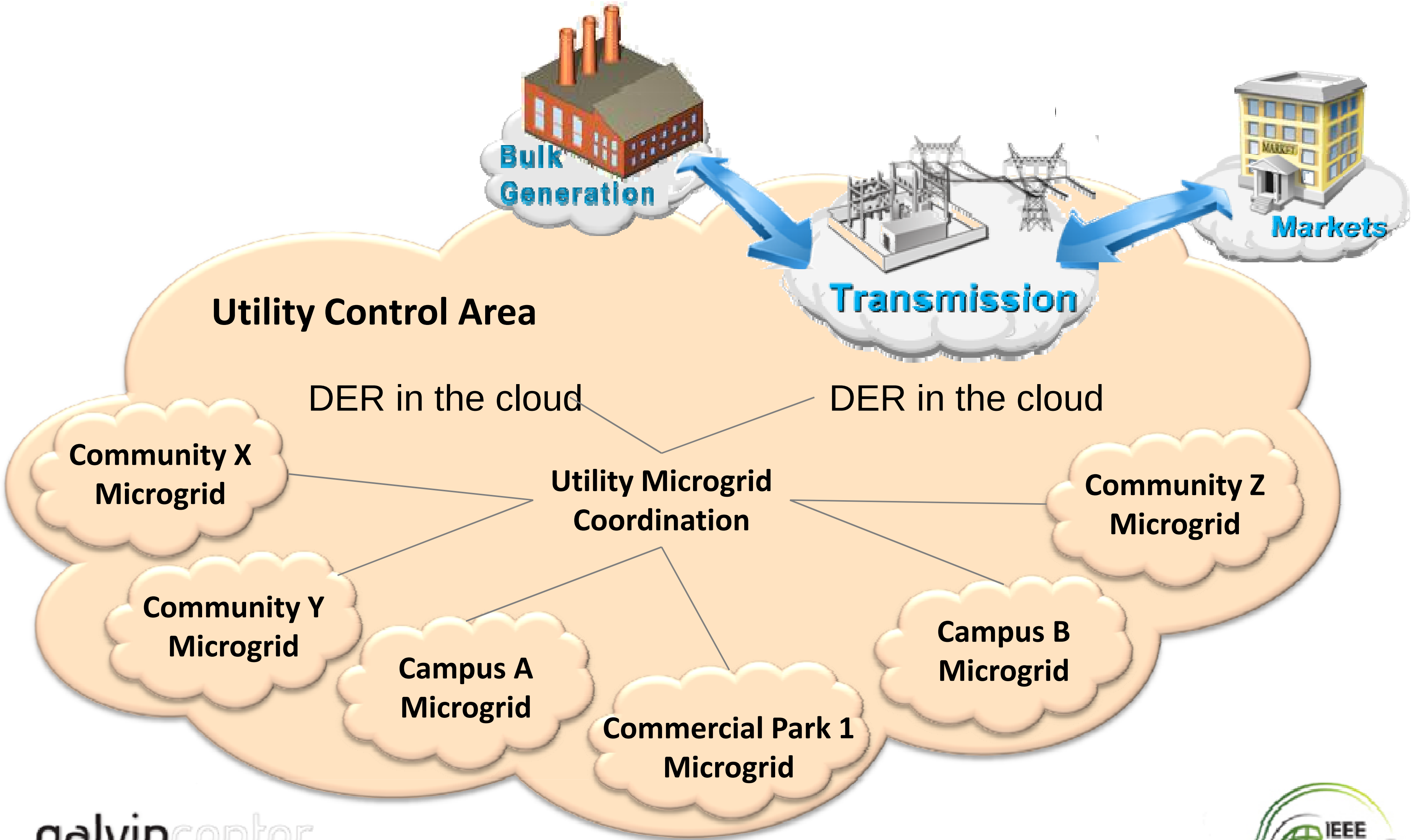
Architectural Significance

- Resource integration
- Volt, VAR, variability (VVV) management
- Control modes and signal design
- Distributed control
- Sharing information in real-time (two-way)
- Market influences
- Recognize the microgrid mostly performs in parallel with main grid – ability to seamlessly island and reconnect

Microgrid Architecture Overview

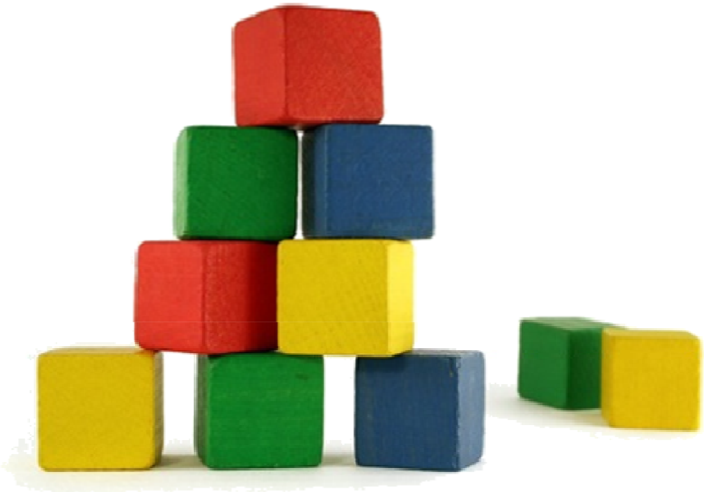


Future Distribution Architecture



Essential Role of Microgrids

- Address local reliability challenges
- Address local economic issues (community objective)
- Enable energy arbitrage (community objective)
- Aggregate control of multiple sources (DG, storage, consumer DER, DR, switches, Cap Banks, DA, etc.)
- Be a good grid citizen



MICROGRID DESIGN

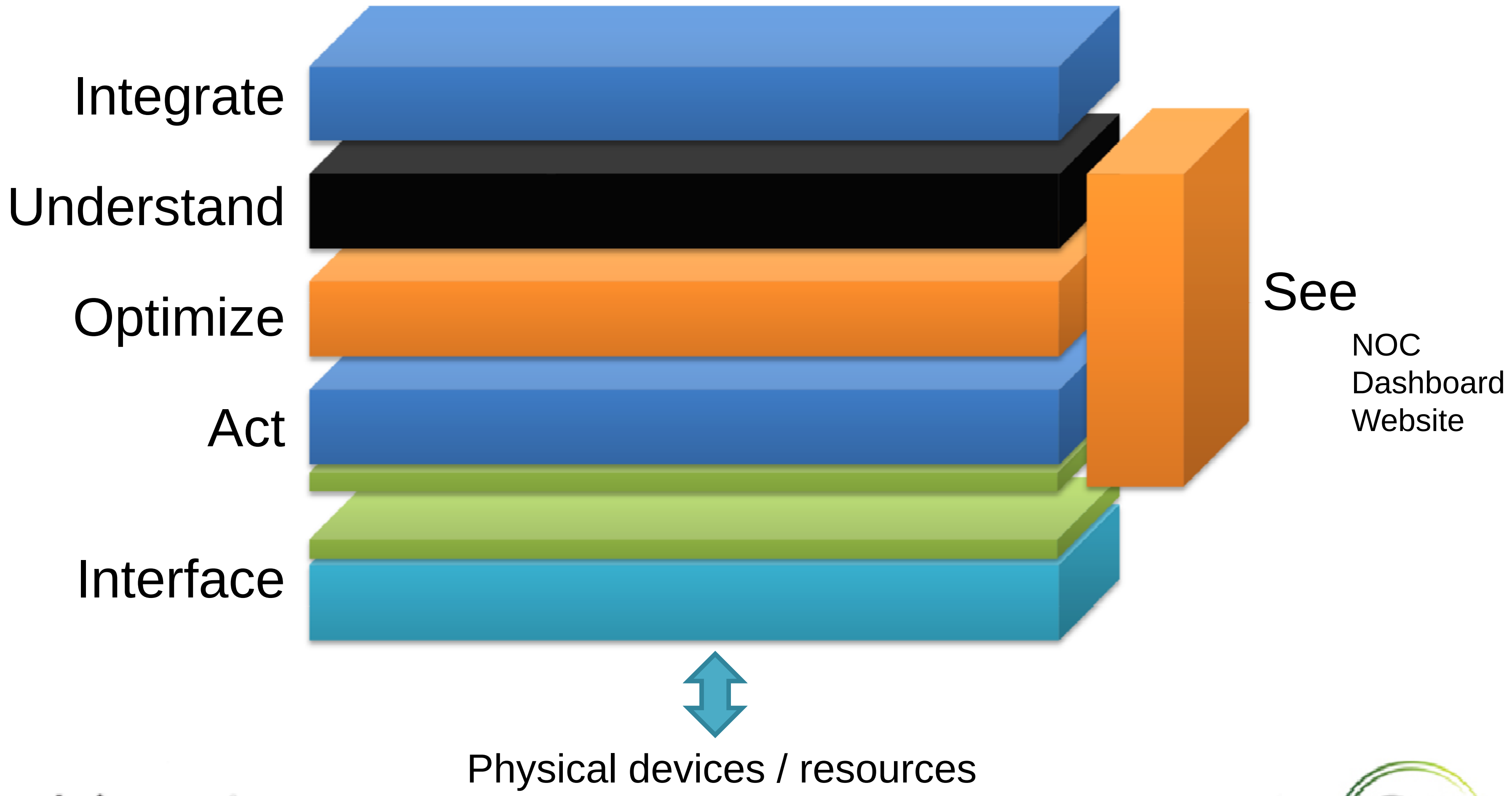
Active Monitor and Control

- Optimize variable aspects: load, wind, solar, storage
- Continuously monitor and trend health of all system components
- Base the energy market purchases and sales on hourly forecasts
- Leverage resources into the energy market on local non-peak days
- Island (i.e. disconnected or zero net electric import) when needed or advantageous

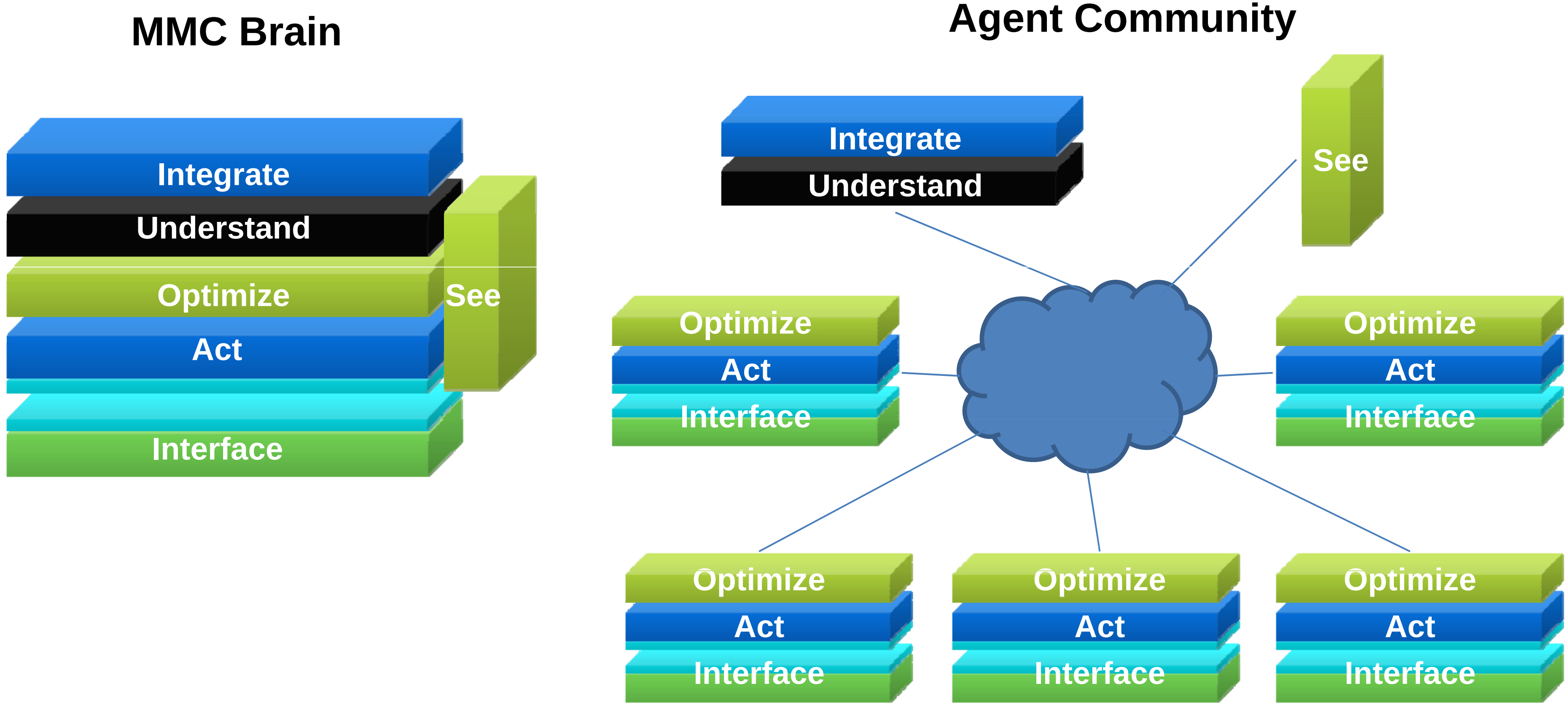
Microgrid Master Controller

- Microgrid master controller (MMC) – the brain – actively control electric supply and consumption 24/7
- Objectives
  - Optimize economics
  - Optimize reliability
  - Reduce carbon footprint
- Based on a significant Use Case requirements process developed on the San Diego microgrid under SDG&E, DOE, and CEC funding

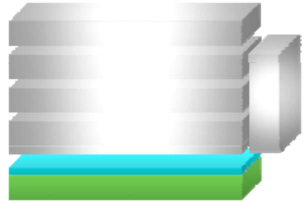
Successful Microgrid Design



MMC – Two Designs



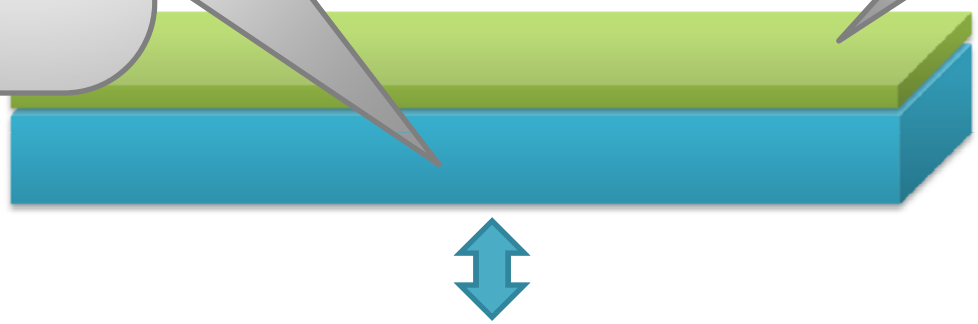
MMC Design – Interface



- Distribution resources
  - Wind
  - PV
  - Storage / PCS
  - Grid devices
  - DG base
- Consumer resources
  - Wind
  - PV
  - Storage
  - DG peak
  - Load

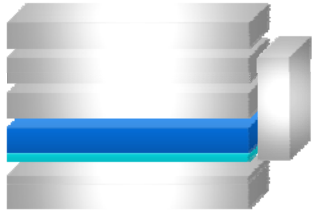
This layer provides the interface to all resources and devices in the microgrid network.

- Common Interface
- SOA / Web svcs
- Likely wireless

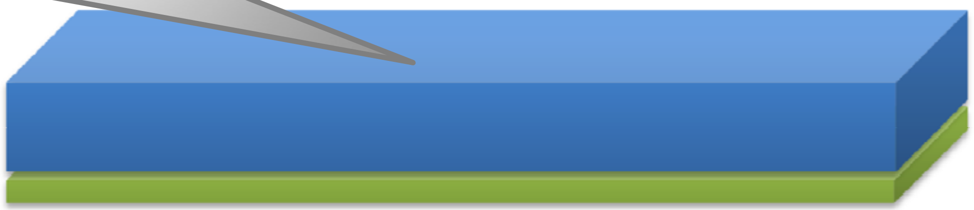


Physical devices / resources

MMC Design – Act

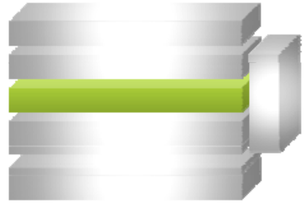


- Volt, VAR, Variability Management
- Economic, Reliability, Environmental Dispatch
- Resources Integration
- Real-time State Measurement
- Status & Health Monitoring
- Response / Corrective Action
- Cold Load Pickup



This layer provides the actions or decision-making that are needed in real-time.

MMC Design – Optimize



- Optimization Module
- Comparison Algorithm
- Cost Optimization Algorithm
- Price-Driven Load Management
- Anticipatory Algorithm

This layer provides the primary means of continuously optimizing the microgrid network for all inputs and variables.

It operates in near-real-time to support the Act layer.

MMC Design – Understand

This layer provides the more computationally-intensive decision services that support Optimization but are not needed in real-time.

- Risk Evaluation Module
- Simplified Rules Engine
- Energy Arbitrage Algorithm
- Day-Ahead State Estimation
- Market Influences Algorithm
- Demand Response Estimator
- External Inputs Engine
- Two-way Information Sharing Interface
- Reporting Tools

MMC Design – Integrate

- Financial Module
  - billing, market clearing, settlements, AP, AR, rates engine
- Design Tools
  - DER balance, Market PDLM, VVV, ERE Dispatch
- Wholesale Power Buy Module
- Weather / Environment

This layer provides access to complex engines that support the overall microgrid operations or network design but are not needed in real-time.

MMC Design – See

This layer provides presentment of key information to operators, management, maintenance, and customers. Some information is in real-time while most is in near-real-time.

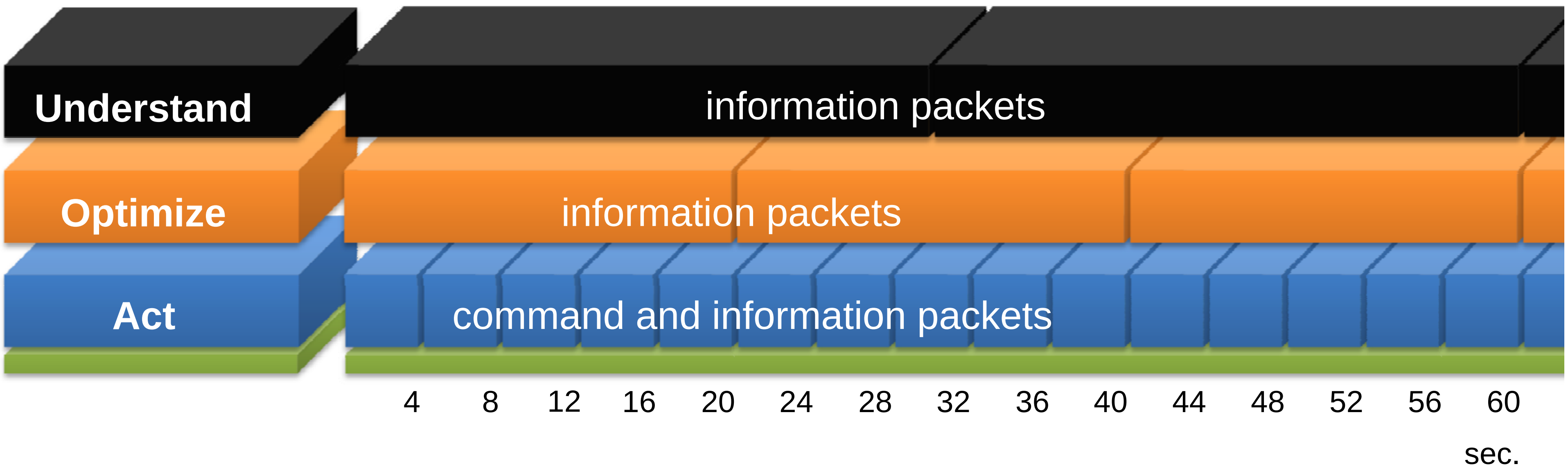
- Network Operations Center
- Dashboards
    - HMS
    - Owner/operator
    - Maintenance support
    - Customers
- Websites

MMC Design - Embedded

- There are several key elements embedded in multiple areas of the design
  - Interoperability standards
  - Common information model
  - Cyber security
  - Service-oriented architecture

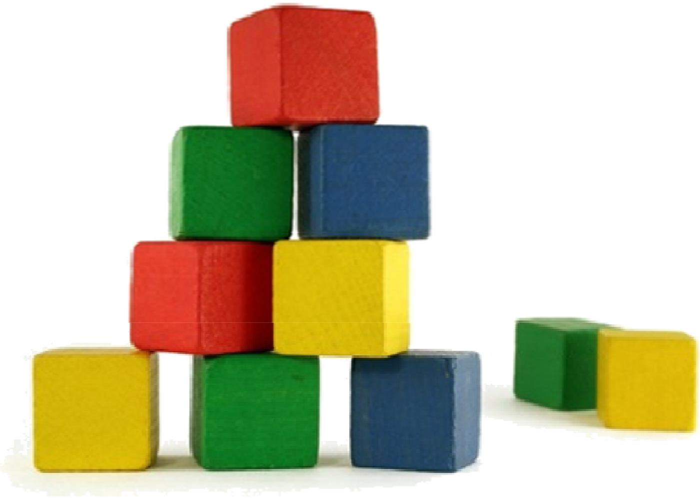
MMC Sequence of Operations

These layers operate in different time regimes based on capabilities and needs. Shorter time regimes require “thinner” computations.



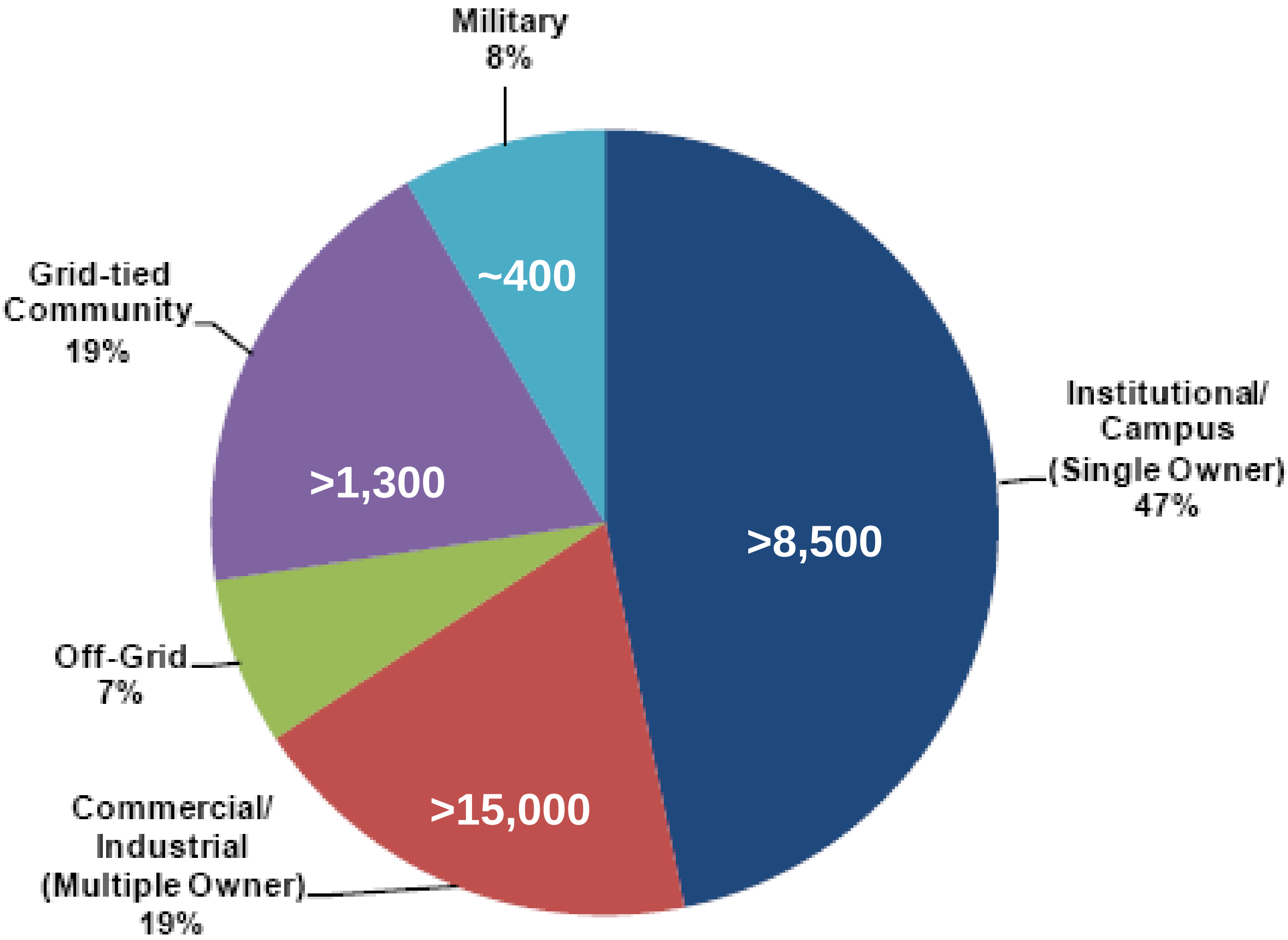
Design Conclusions (So Far)

- The MMC is complex, but necessary to properly manage the network complexity from multiple resources and loads that are variable in nature.
- The Use Cases, and subsequent functional requirements, developed with utility experts provides a sound foundation for the architecture and design.
- The organization of the MMC around those modules that require real-time computation and action, and those that do not is essential for the MMC to meet its timing requirements in operation.



MICROGRID MARKETPLACE

North American Microgrid Market 2015

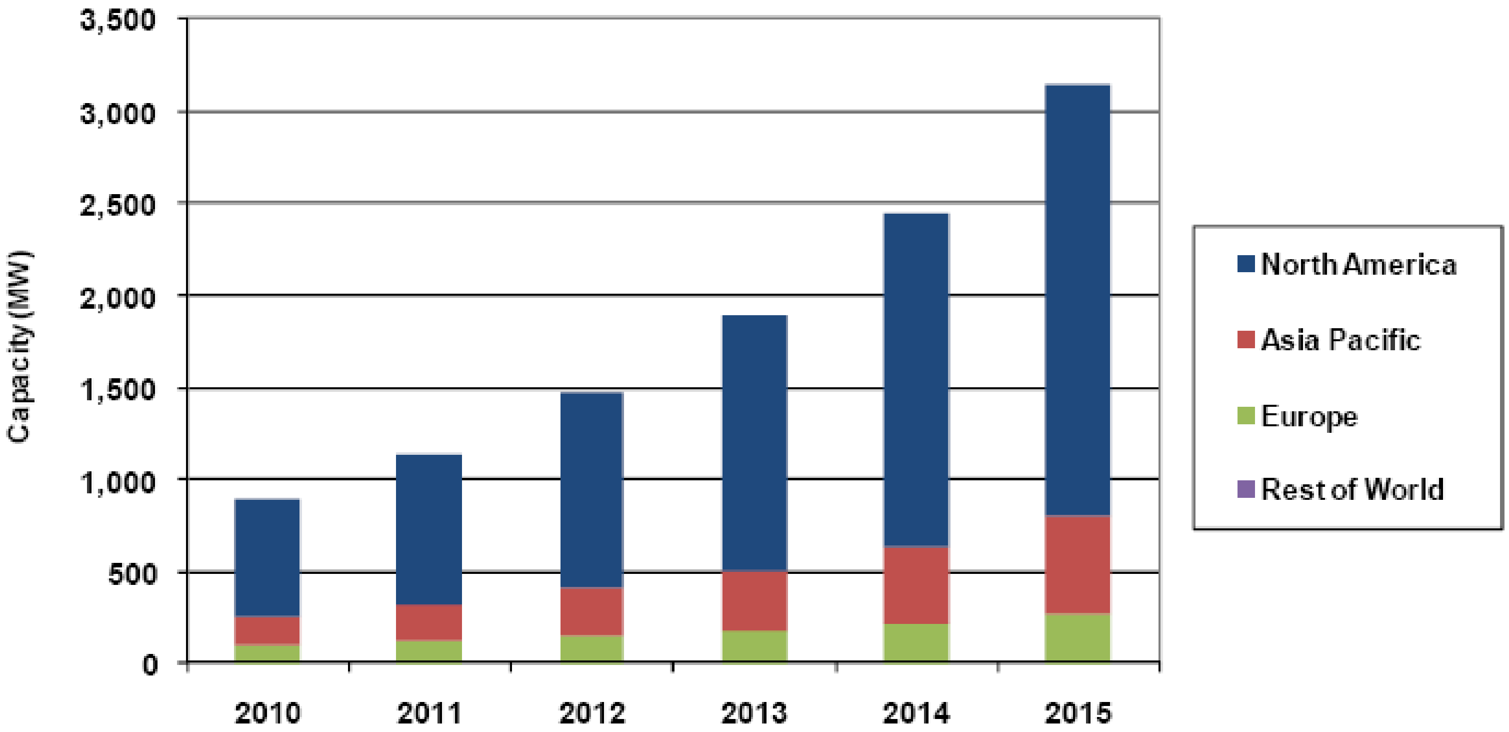


Source: Pike Research

Market Size

2,000 US microgrids by 2015
- Pike Research, Dec 2009

Microgrid Capacity, World Markets: 2010-2015

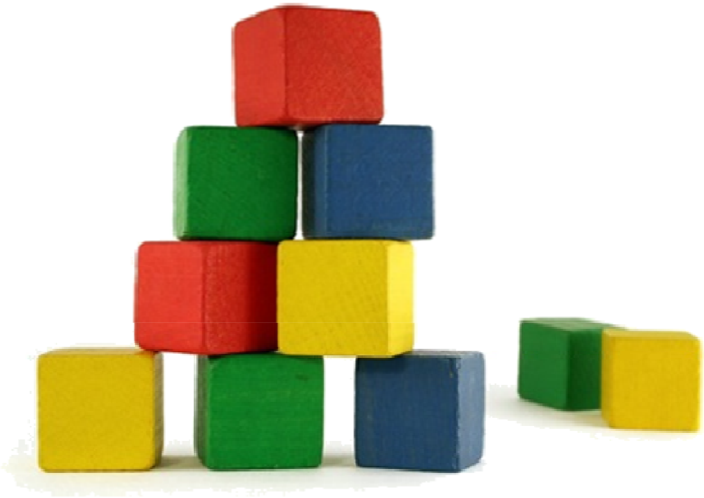


Source: Pike Research

~$2B annual US market by 2015
- Pike Research, Dec 2009

Regulatory Risk

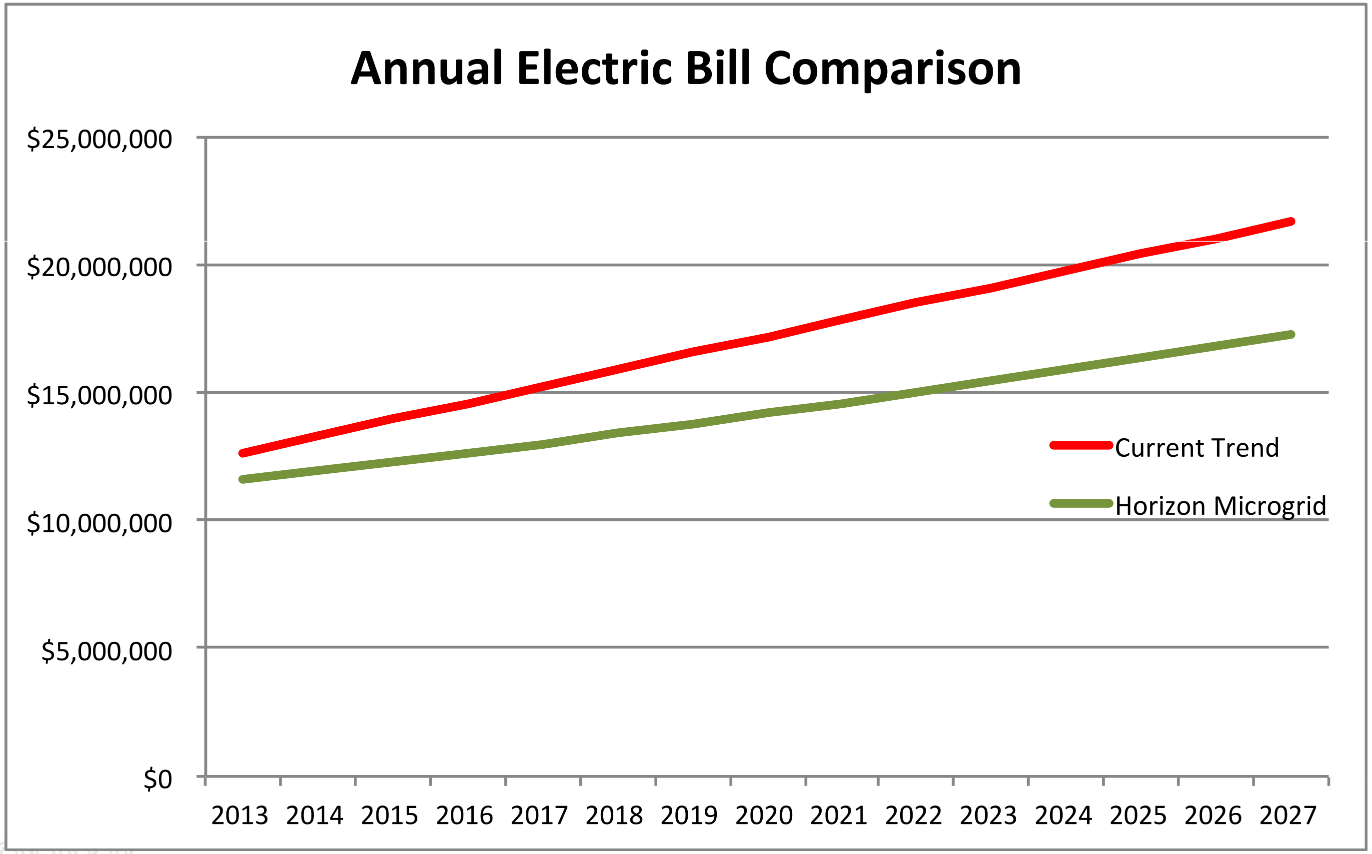
- State regulators will have little to no authority in the campus, commercial / industrial park, and military markets.
- For municipalities with an existing municipal utility, the city commission regulates the electric service – good long-term economics rule.
- For municipalities currently served by an investor-owned utility, the microgrid may require the municipality to charter its own utility – several in CA, FL, and Northeast are already doing this for cost and reliability reasons.
- For utilities, the state regulator would get involved if the utility expected customers to pay for the microgrid – not our business model.
- State commissions who are promoting active grid participation by customers (CA, TX, FL, MA, CT, OH, IL,…) could lead to microgrid incentives tied to better economics, better reliability, and reduced CO2 footprint.



EXAMPLE MICROGRIDS

Project 1: 11 MW Shipyard

Shipyard will save ~$23 million in the first 10 years of the microgrid operations.



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Project 2: Campus Project

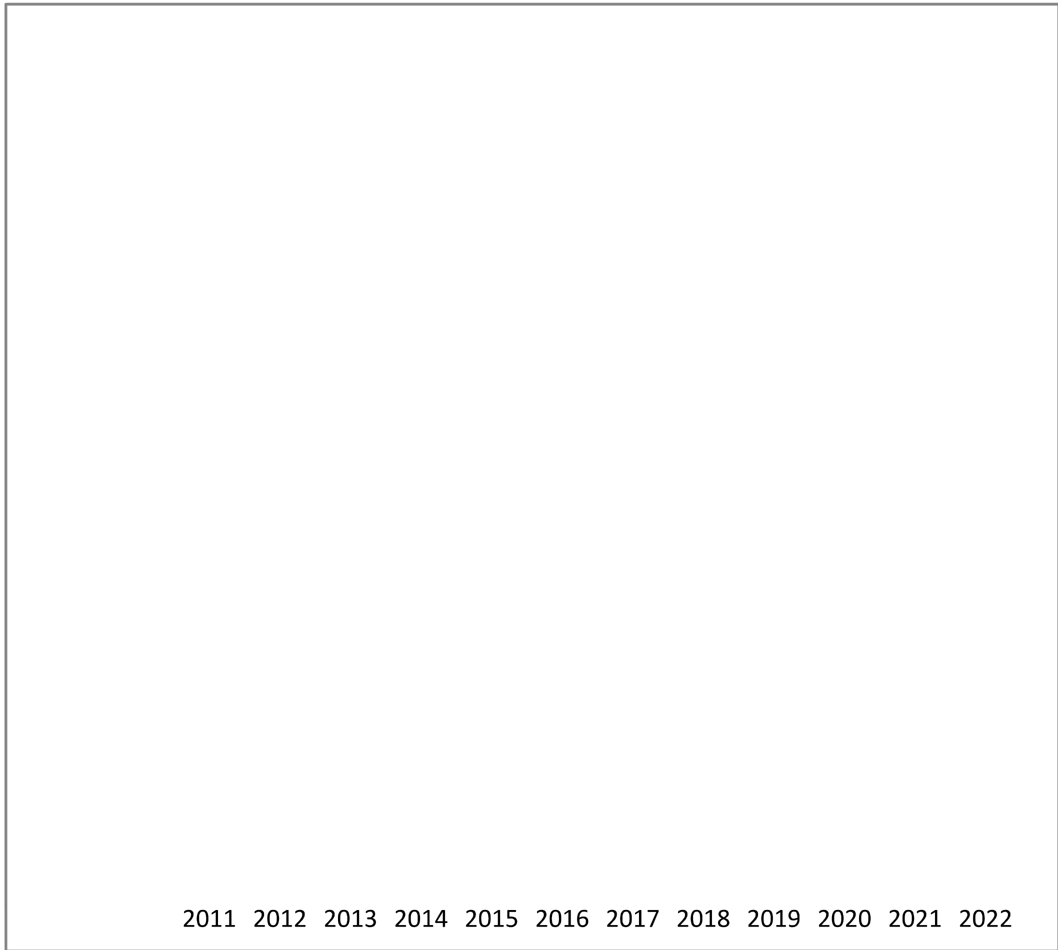
- Engineering Campus
- 3.5 MW projected average summer day demand
- 750,000 sq ft
- 3,200 engineers

Executive Summary

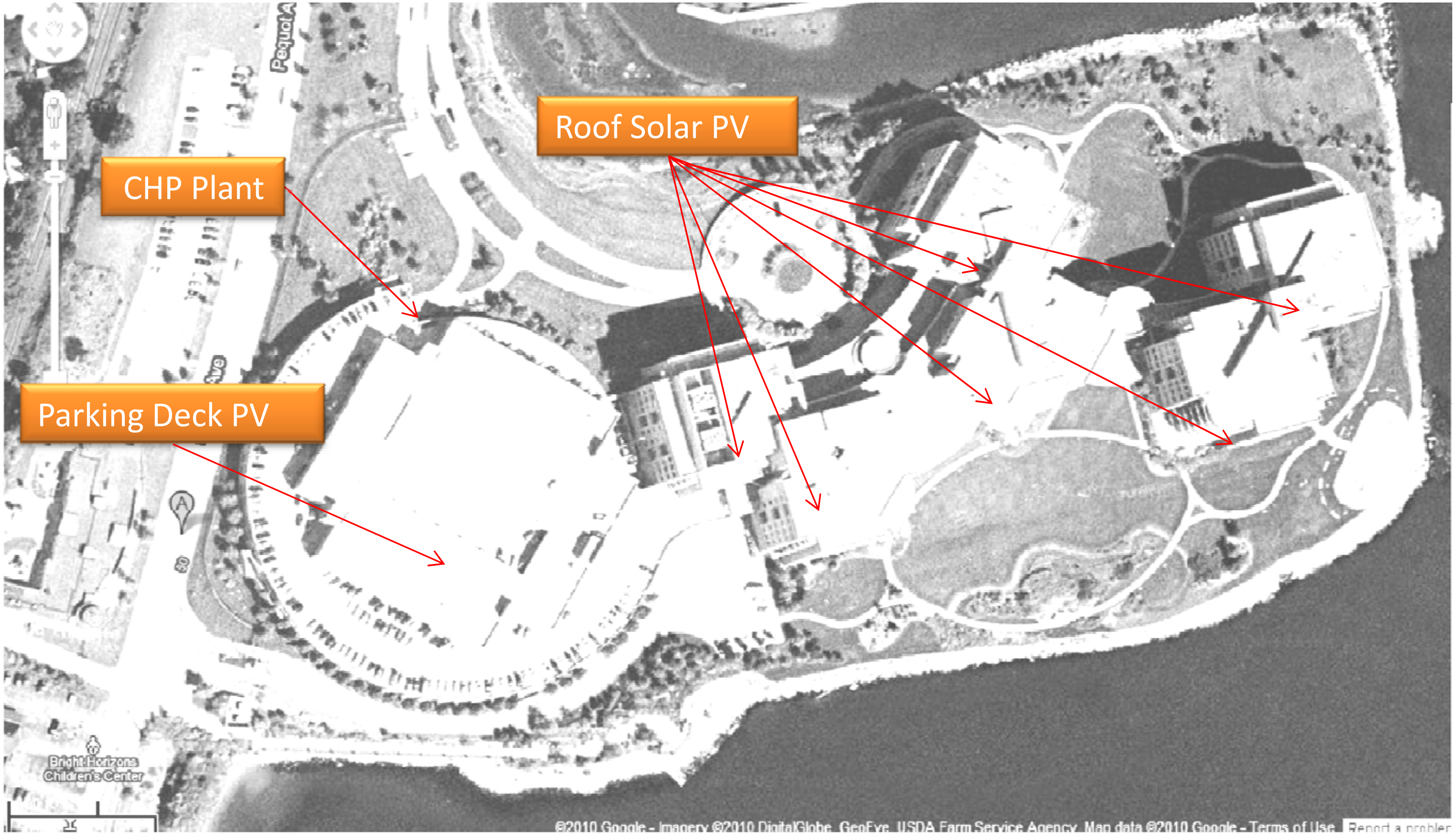
- Microgrid – sustainable, reliable active 24/7 control of supply and load
- Sustainability Objectives
  - Reduce annual energy cost by > 15% for the long-term
  - Reduce carbon footprint by 1,530 Tons over 10 yrs
  - Increase reliability and reduce the risk of an outage
  - Sustainability leadership among peers
- Not replacing the utility grid (still connected), but replacing much of the utility supply to be more cost effective & reliable
- Increased renewables

Project 2: Electric Bill Savings

The campus will save almost $10M in the first 10 years of the microgrid operations



Renewables Footprint – Campus



Resources Modeled

Resource	Capacity (kW)	Hours / Year
PV	144	1563
Wind	0	5840
DG Base	600	2088
DG Peak	200	200
CHP	2846	7884
Energy Storage	1884	2190

Horizon has also modeled a 11,200 ft^2 Solar Thermal system to offset space and water heating. This would be co-located with the roof PV arrays.

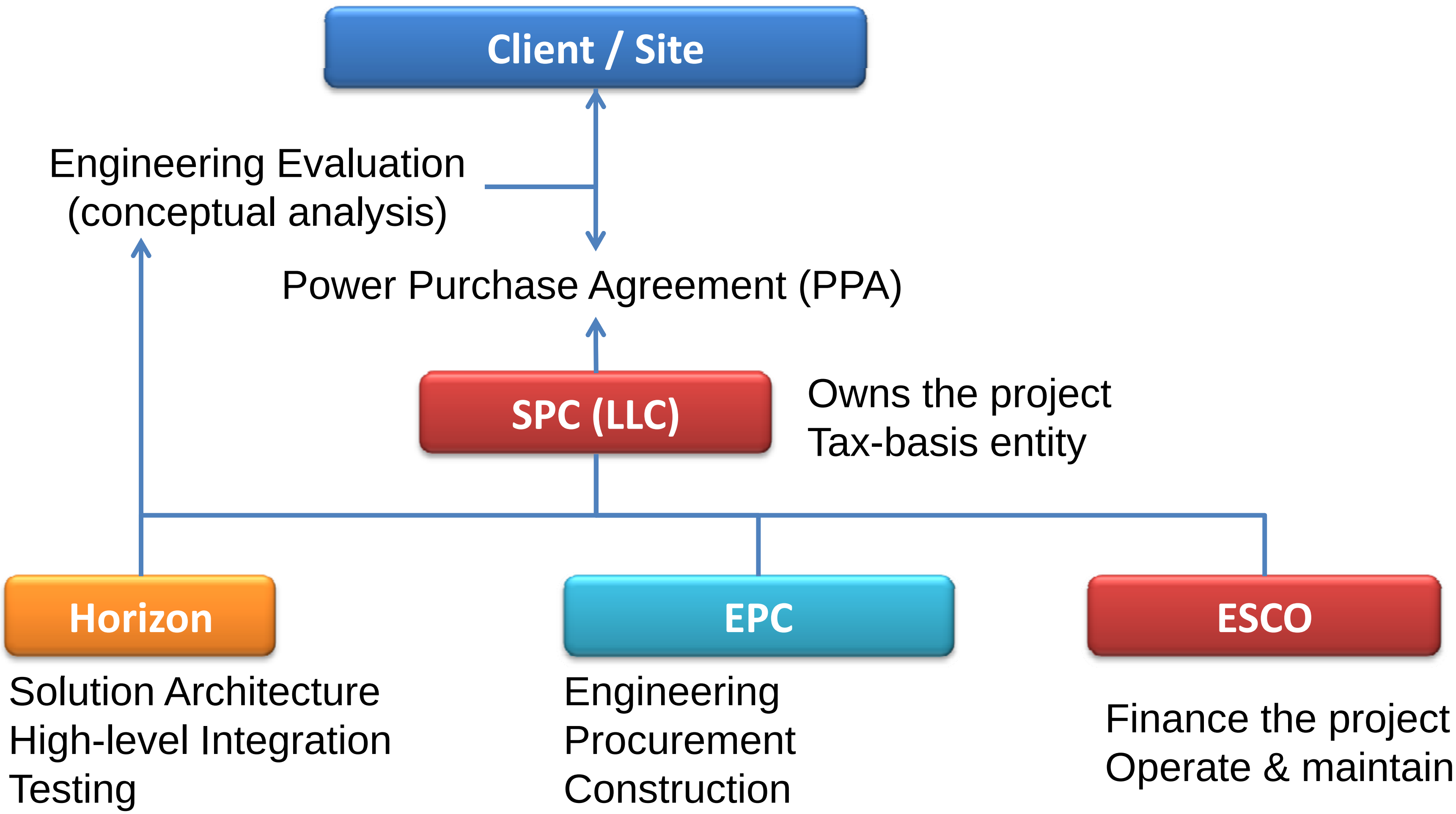
Keys to Success

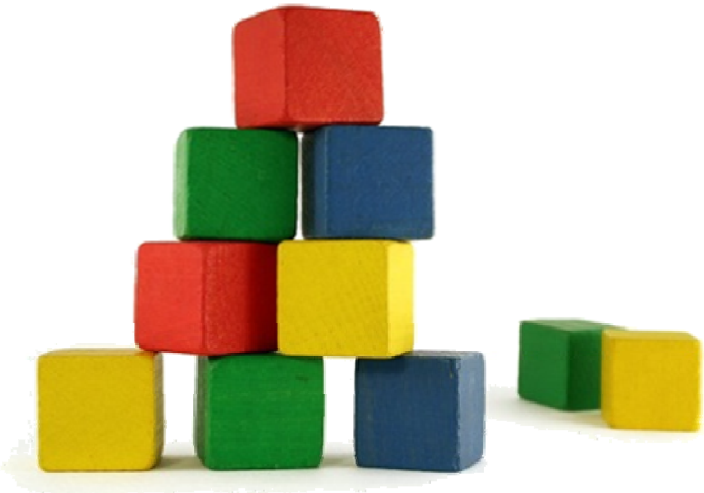
- Portfolio mix of resources (high efficiency and renewables)
- ISO-NE market participant
- Integration of resources
- Gaining approval for State and Utility Incentives
- MMC Control to optimize operations (economics, reliability, and environmental considerations)

The Project

- Estimated $10.3M total development cost after incentives and tax credits
  - Before Incentives and Tax Credits: $19.6M
  - Equity: $2.0M
  - Total Incentives: $9.3M
    - Federal ITC: $3.3M
    - State Incentives: $4.6M
    - Utility Incentives: $1.4M
  - Financing: $8.3M @ 6.00%

Horizon Microgrid Business Model

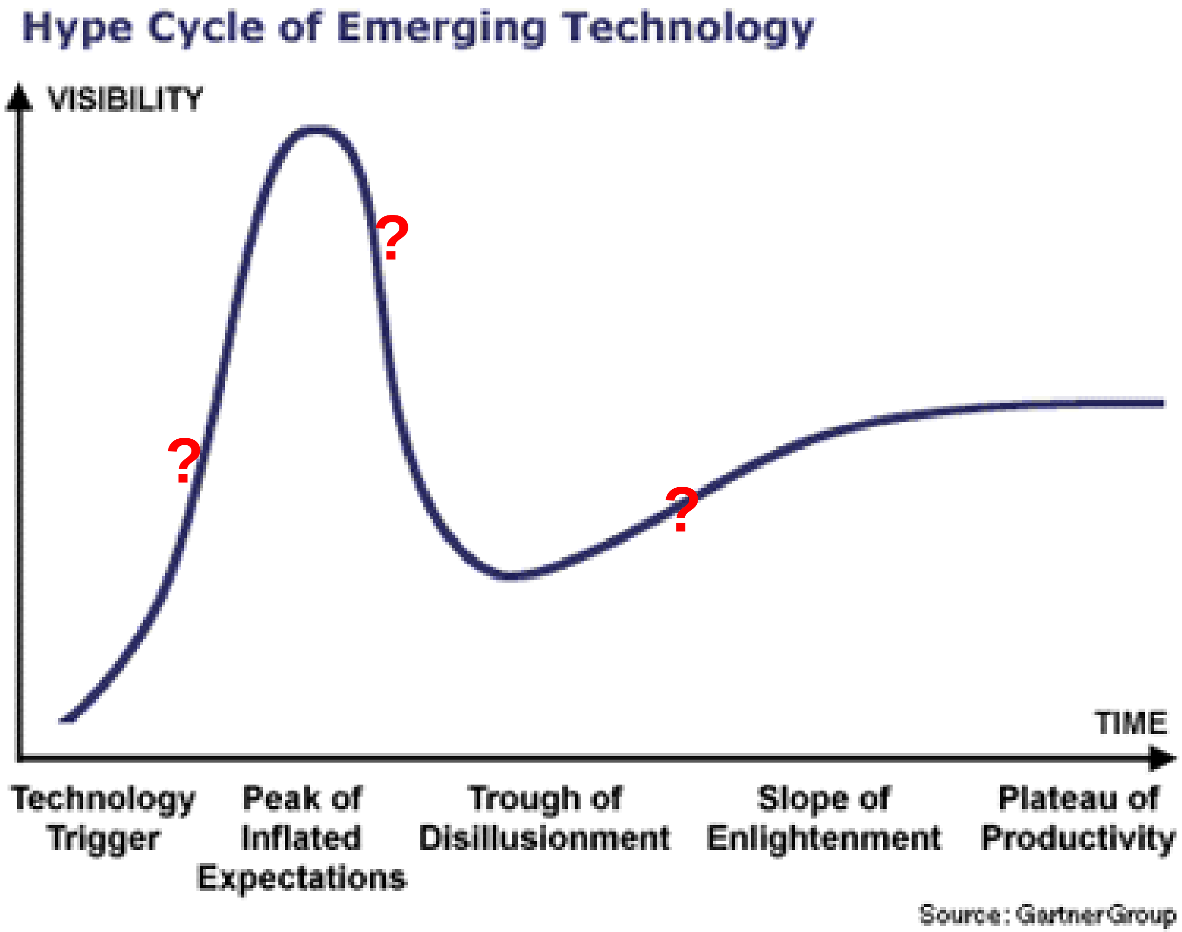




Where does the microgrid revolution lead?

CONCLUSIONS

Probable Future State?



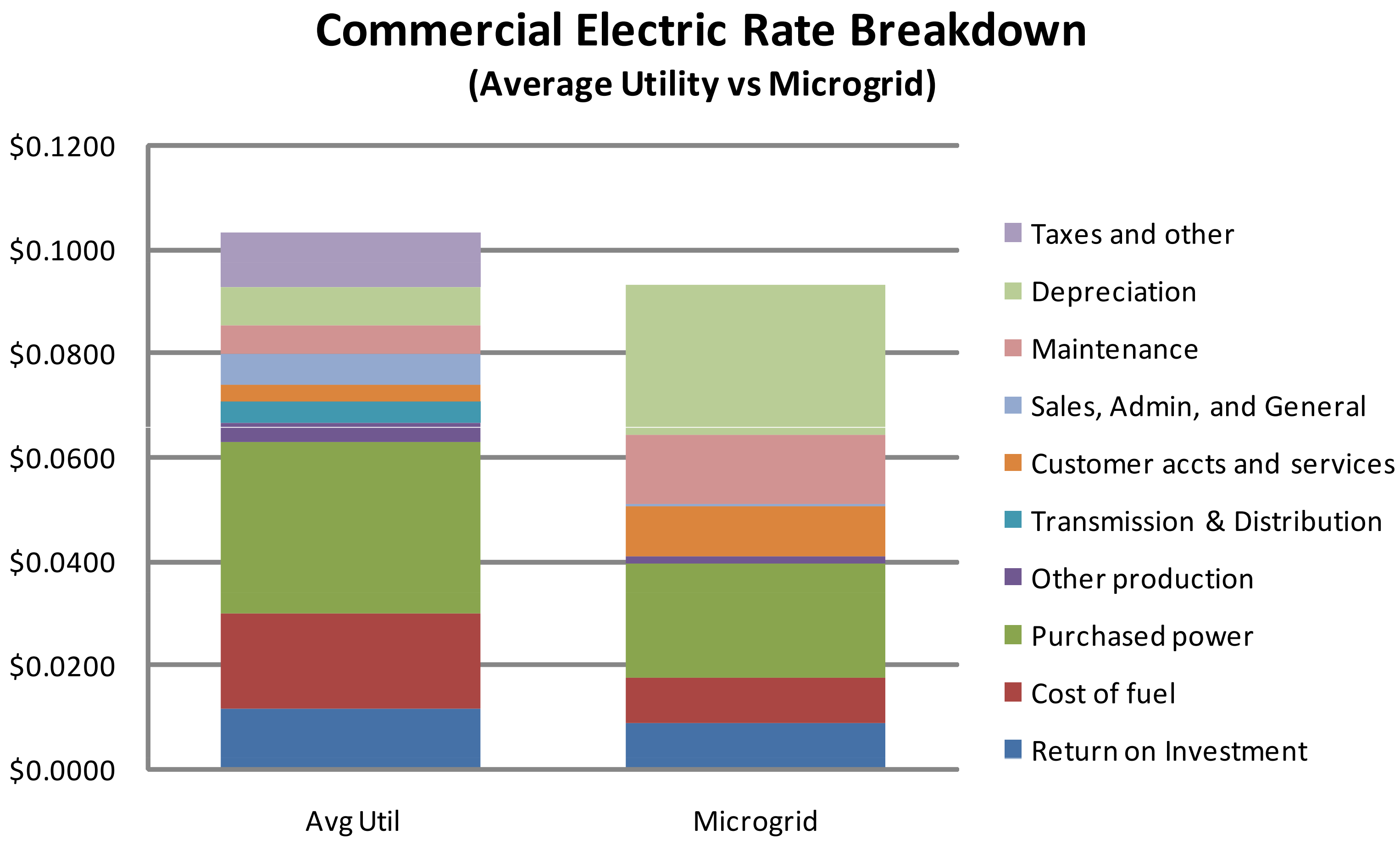
What are the realities of building microgrids?

Do we understand the barriers?

Are microgrids broadly applicable?

What is our learning vector?

Rate Comparison – Avg Utility vs Microgrid

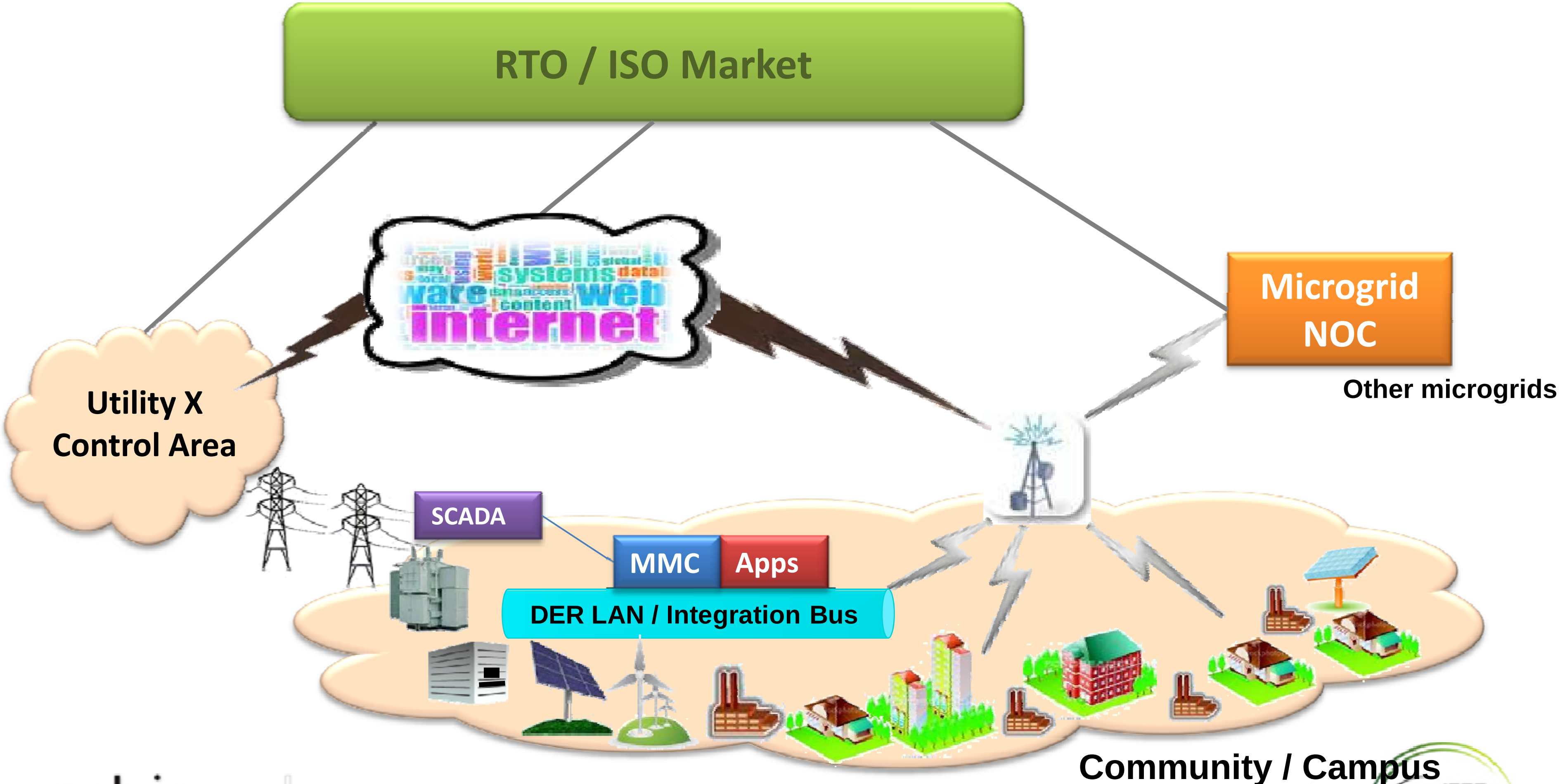


- Avg Util data is based on EIA Electric Power Annual 2008, published Jan 2010
- Microgrid data is based on Horizon microgrid model of typical Smart Grid 2020 City

Emerging Design Elements

- State estimation (day ahead)
- State measurement (real-time)
- Economic, reliability, environment (ERE) dispatch tools
- Objective functions and algorithms for most of the design (Design Overview)
- Anticipatory and response/corrective algorithms
- Energy arbitrage algorithms
- MMC – enterprise vs distributed; brain vs agent community

Typical Campus Microgrid Architecture



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Conclusions

- Business As Usual will damage the US economy by 2030
- Microgrids will be essential to deep distributed renewables penetration
- It is likely to get worse before it gets better
- The microgrid market will be defined by electricity consumers not utilities or regulators
- Microgrids are the likely building block of the future electric system defined by the Smart Grid environment

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Horizon Energy Group named in 2008 as a Company to Watch in the book, "Perfect Power" by former Motorola Chairman, Bob Galvin, and former EPRI CEO, Kurt Yeager.

Horizon listed in 2009 as one of the "Top 100 Movers and Shakers in the Smart Grid Movement" by GreenTech Media.