March 3, 2015

Office of International Affairs

U.S. Progress on Smart Grids: Knowledge, Tools & Metrics

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Office of International Affairs
Office of International Climate and Clean Energy

Thanks to colleagues in DOE's Office of Electricity Delivery & Energy Reliability

Too much to cover!

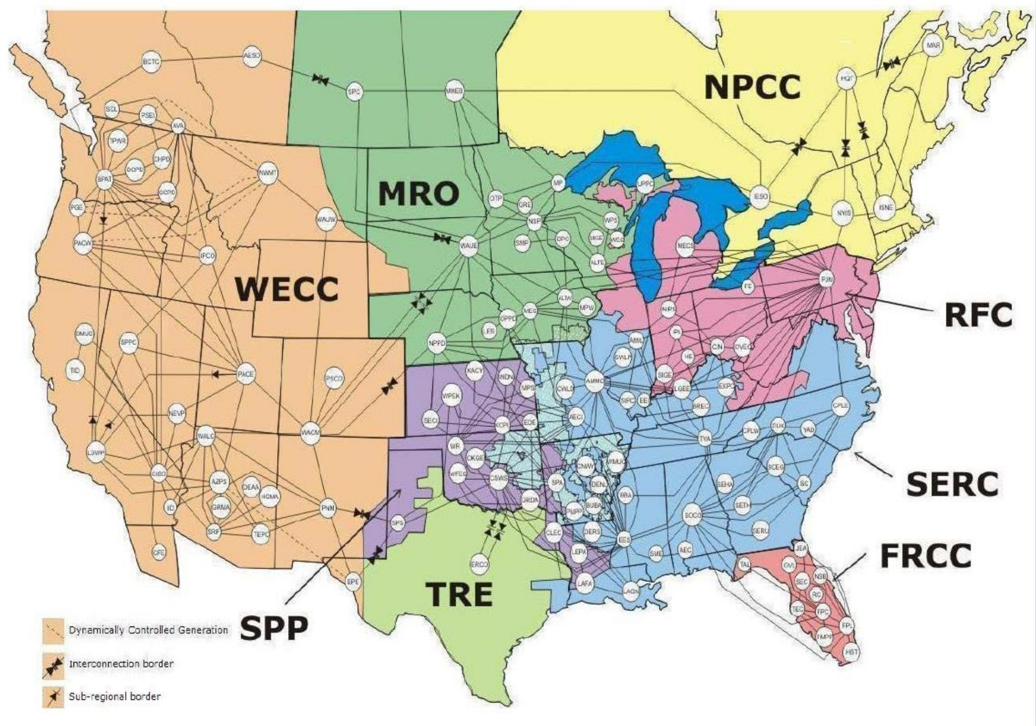
- The U.S. Department of Energy, its National Laboratories and its partners have a wide range of grid-related research tracks, models, tools, knowledge-sharing mechanisms, etc. underway
  - Many are highly relevant to India's smart grid development.

- I can't possibly cover all of them today, so I will cover some illustrative highlights from DOE's Office of Electricity Delivery and Energy Reliability

The North American Electric Grid

U.S. Figures

22% of world consumption



3 interconnects (Eastern, Western, ERCOT)

3,200 electric utility companies

17,000 power plants

800 gigawatt peak demand

165,000 miles of high-voltage lines

6 million miles of distribution lines

140 million meters

$1 trillion in assets

$350 billion annual revenues

Smart Grid

A smarter grid applies digital technologies with communications and IT infrastructure to improve the reliability, security, efficiency, and flexibility of the electric system.

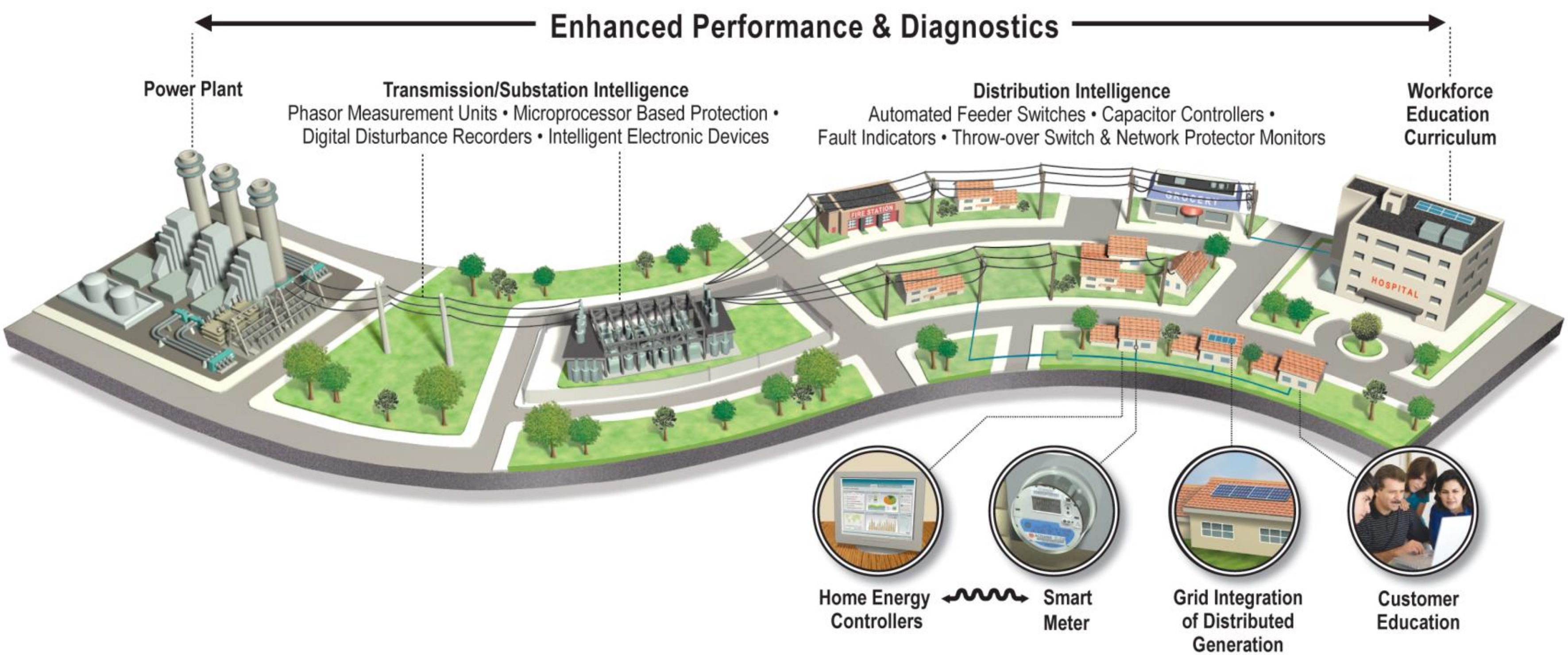
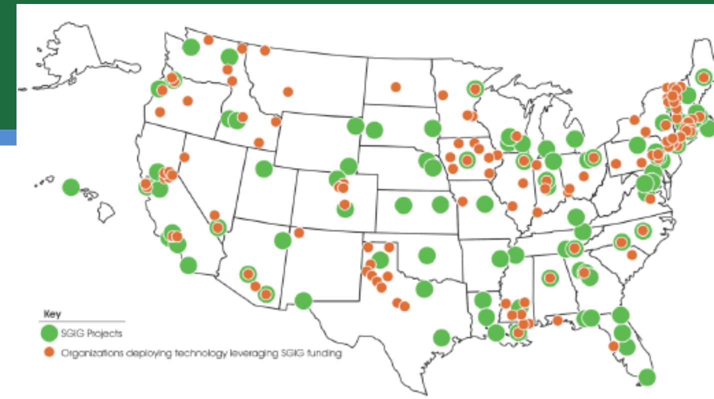
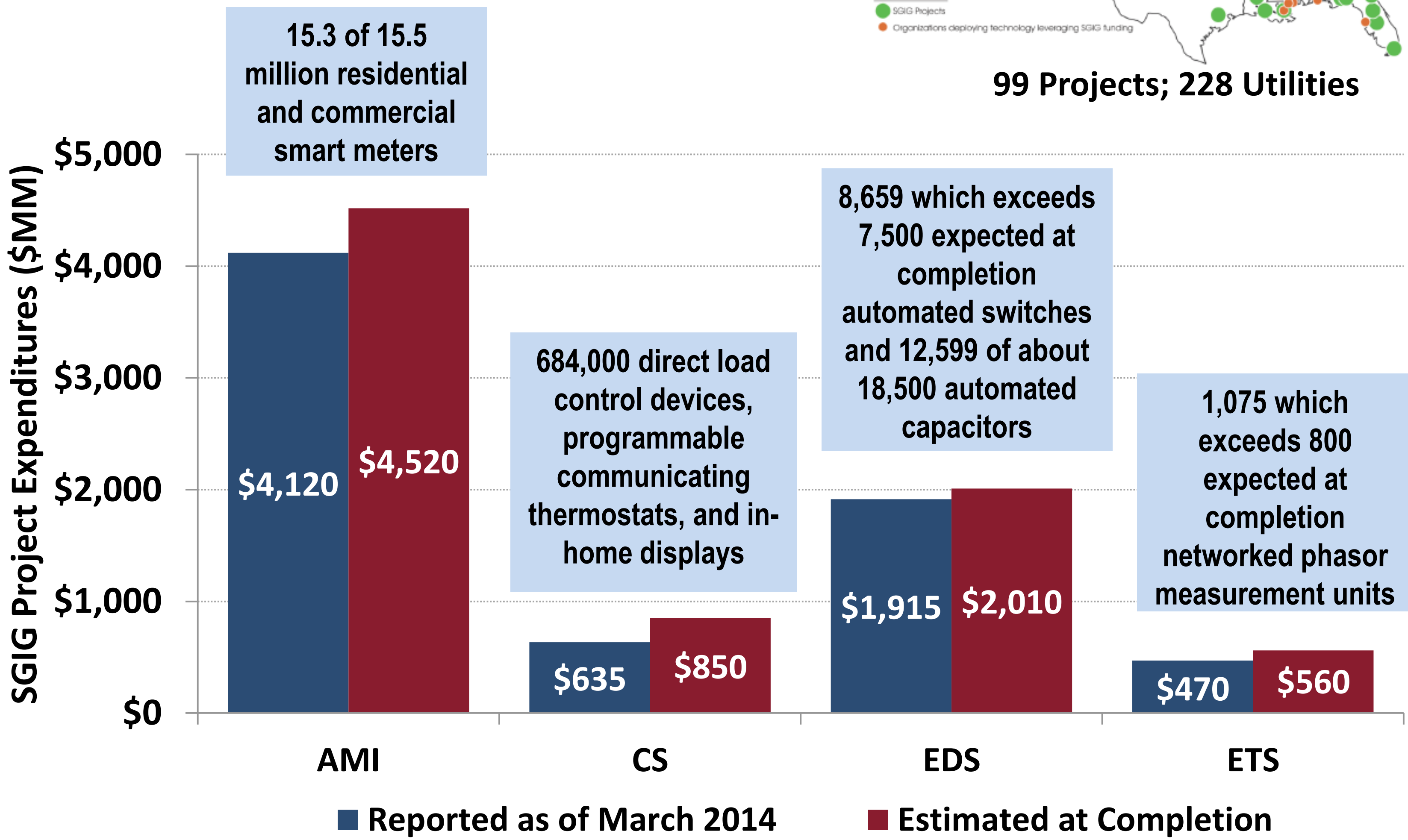


Image used courtesy of Florida Power and Light

SGIG Deployment Status



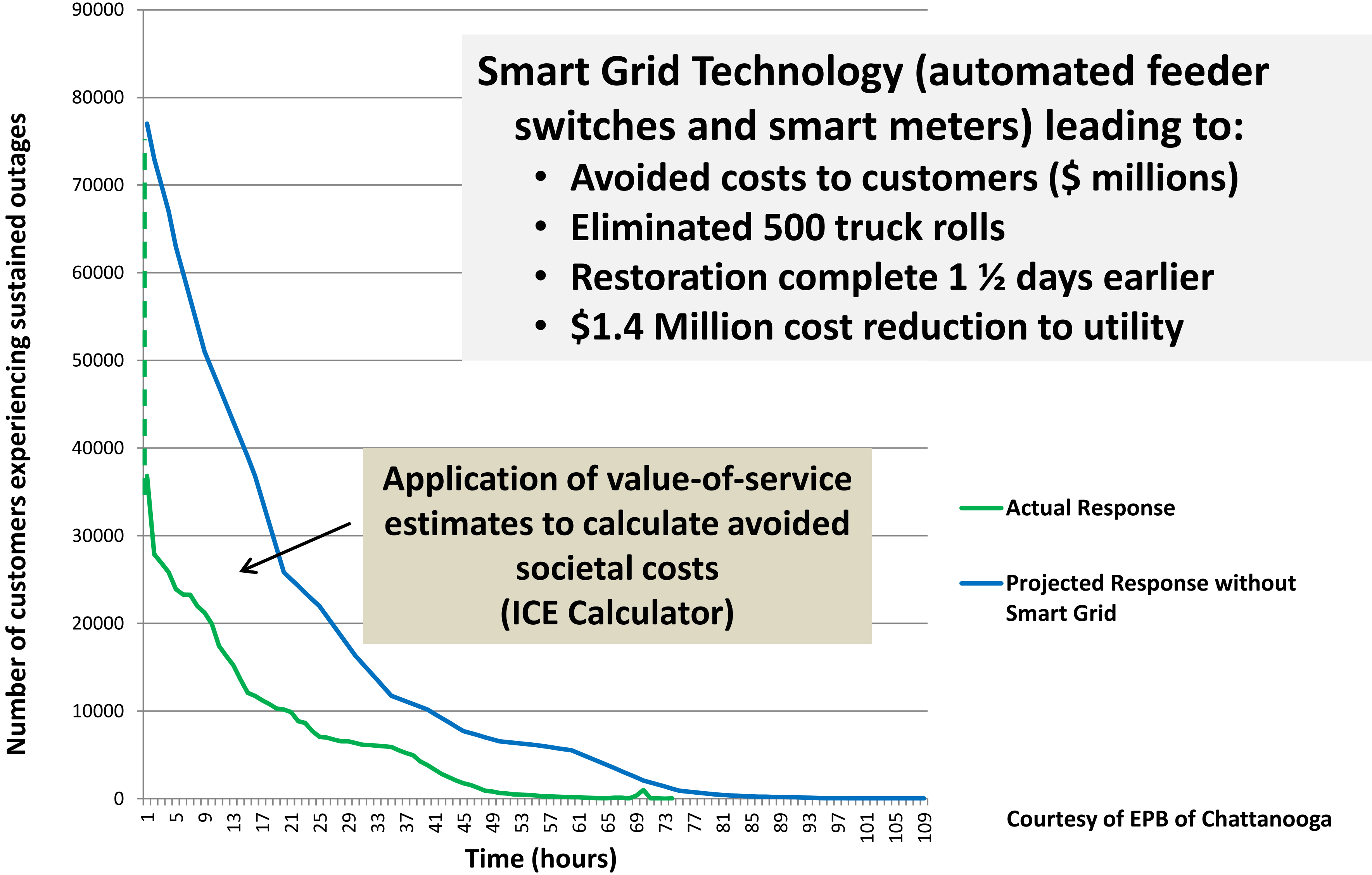
99 Projects; 228 Utilities



Applications and Benefits Matrix

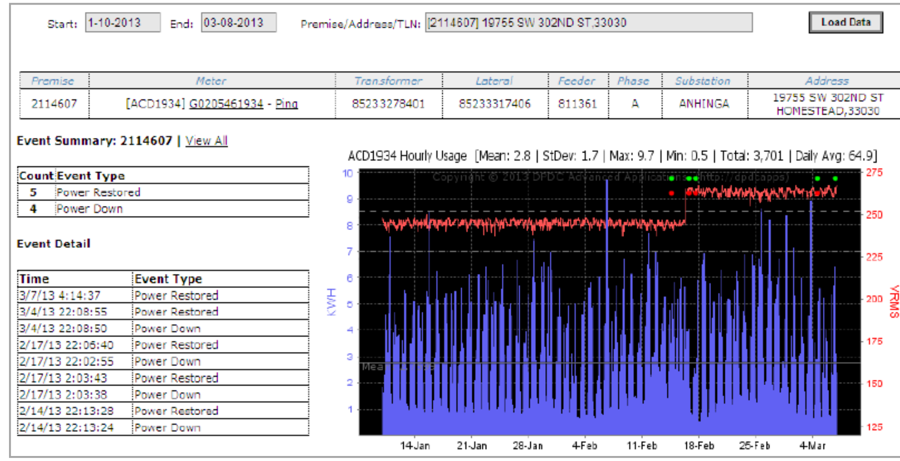
Benefits	Smart Grid Technology Applications					
	Consumer-Based Demand Management Programs (AMI-Enabled)	Advanced Metering Infrastructure (AMI) Applied to Operations	Fault Location, Isolation and Service Restoration	Equipment Health Monitoring	Improved Volt/VAR Management	Synchrophasor Technology Applications
	• Time-based pricing • Customer devices (information and control systems) • Direct load control (does not require AMI)	• Meter services • Outage management • Volt-VAR management • Tamper detection • Back-Office systems support (e.g., billing and customer service)	• Automated feeder switching • Fault location • AMI and outage management	• Condition-based maintenance • Stress reduction on equipment	• Peak demand reduction • Conservation Voltage Reduction • Reactive power compensation	• Real-time and off-line applications
Capital expenditure reduction – enhanced utilization of G,T & D assets	✓			✓	✓	✓
Energy use reduction	✓	✓	✓		✓	✓
Reliability improvements		✓	✓	✓		✓
O&M cost savings		✓	✓	✓		
Reduced electricity costs to consumers	✓				✓	
Lower pollutant emissions	✓	✓	✓		✓	✓
Enhanced system flexibility – to meet resiliency needs and accommodate all generation and demand resources	✓	✓	✓	✓	✓	✓

July 5, 2012 Storm Response in Chattanooga

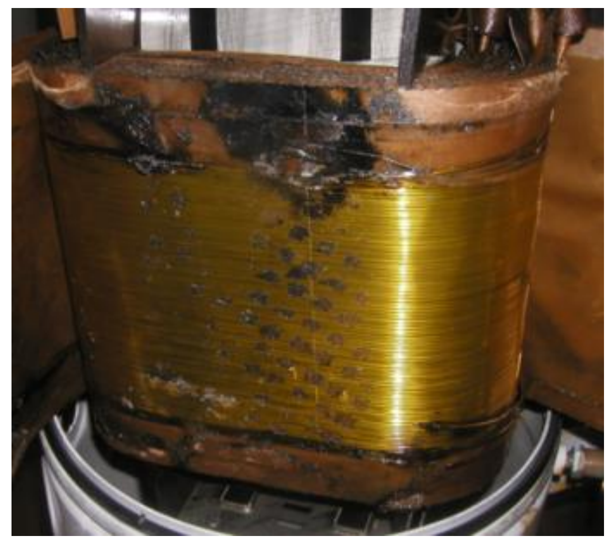


Equipment Health Monitoring With AMI - FPL Transformer Project

- FPL used smart meter data to identify transformer voltage shifts, indicating deteriorations in transformer performance and potential equipment failure.
- This approach allows for pro-active transformers replacement (shifting from schedule-based maintenance to condition-based maintenance).
- Through Q3 2014, FPL had replaced more than 1,000 distribution transformers, preventing potential unplanned outages for an estimated 10,000 customers.



Voltage shift indicating possible equipment degradation



Damage to primary winding of high-voltage transformer identified through smart meters

Benefits of Proactive
High-voltage Transformer Replacement

- Average outage time is 93 minutes shorter than an unplanned transformer replacement
- Costs are 25% lower than unplanned replacements
- Can improve customer perceptions
- Reduces potential for customer claims

Sources: http://www.ieee-pes.org/presentations/gm2014/FPL-IEEE-Presentation-Big-Data-July-2014.pdf
https://www.smartgrid.gov/sites/default/files/doc/files/B2-Master-File-with-edits_120114.pdf

Findings (So Far)

- **ARRA ($9 billion w/cost-share) significantly catalyzed deployment of smart grid technology**
  - Accounting for nearly one-half of smart-grid investments; demonstrated significant benefits
  - Advanced the adoption of cyber-security practices; advanced systems integration and interoperability
- **Much variation across utilities and regulatory jurisdictions**
- **It will take time to validate full costs and benefits of smart grid technology**
  - IT and communication infrastucture is new to the industry
  - New benefit streams (operational efficiency gains, societal benefits); some unforeseen, perhaps many
- **Emerging drivers require a more sophisticated grid**
  - State policies (climate change/ efficiency) driving DER integration (AZ, CA and NJ issues)
  - Resiliency concerns (agility, flexibility, microgrids)
  - New entrants (customers and merchant managing and generate electricity)
  - Utility becoming a "relationships manager"
- **Emerging markets**
  - Residential and buildings systems
  - Smart cities
  - Utility analytics
- **Disruptive challenges**
  - Traditional business model is threatened due to new market entrants with distributed resources that both manage and generate power (→ transactive framework)
  - Regulators will need to consider new rate structures (applying a combination of fixed and volumetric rates) with fair allocation of cost and responsibility
  - Advanced architecture and control will be needed to effectively integrate
  - State planning processes (NY, MA) emerging that are trying to optimize infrastructure investments to meet reliability, resiliency, efficiency and carbon reduction goals
  - Performance based metrics

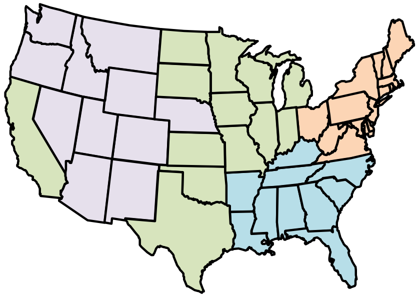
The Future of the Grid
Evolving to Meet America's Needs

Partnered with GridWise Alliance to hold a series of multi-stakeholder regional workshops to determine the changing operational, business and policy requirements needed in the electricity industry over the next 20 years to sustain the Nation's economic prosperity and facilitate the industry's transformation.

Understanding Industry Challenges

Overview and Approach

- *Multistakeholder*: Utilities (ISOs, Munis, Co-ops, PUDs, PPA) , Regulators, State Energy Offices, Consumer Advocates, Business Leaders, Technology providers, Academics and Researchers (>400 participated)
- *Four one-day regional workshops* focused on the Challenge of :
  - Balancing Supply and Demand as Grid Complexity Grows
  - Involving Customers and Their Electrical Loads in Grid Operations and Planning for Empowered Customers
  - Higher Local Reliability through Multi-customer Microgrids
  - Transitioning Central Generation to Clean Energy Sources - Large-Scale Wind, Solar, and Gas
- *National Summit* held June 2014 in Washington, DC
- *Final Report* released December 2014 with recommendations and next steps



Future of the Grid (cont.)

Findings

- Grid complexity is increasing (internally sophisticated, outwardly simple interface)
- Transmission and distribution will become further integrated requiring cross functional visibility and communications from central generation to end device
- High bandwidth, low latency, cost effective communication system will overlay the grid
- Seamless integration of wholesale and retail markets will take place
- Coordination of regulated and unregulated players is needed

Recommendations

- Need collaborative approach that engages the ecosystem of stakeholders
- Establish guiding principles and a unifying architecture
- Develop transition framework to assist with regional/state planning which includes:
  - Standardized industry metrics
  - Foundational investments
- Leverage opportunities to advance the transition (best practices, lessons learned)
- Greater industry involvement in establishing R&D priorities

Voices of Experience Initiative

Objective

Compile industry insights and lessons learned in the utility's own words

Topics

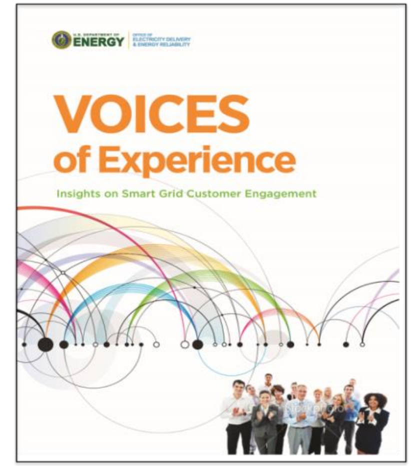
- Smart Grid Customer Engagement
- Advanced Distribution Management Systems

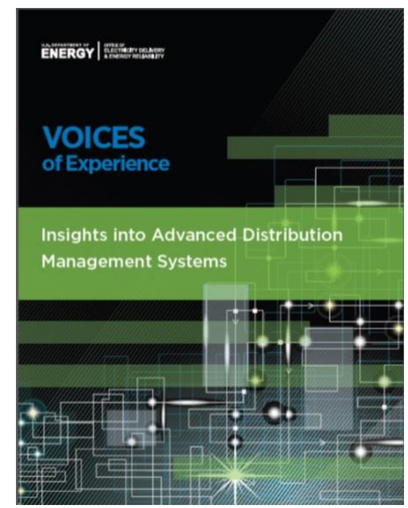
Approach and Expected Outcomes

- Directed by leadership team of industry experts
- Work group members participated in topic focused discussion groups
- Developed a *"Voices of Experience"* report
- Not a roadmap

Benefits

- Leverage experience from leading utilities to facilitate grid modernization across the U.S.
- Provide an understanding of current technology, its benefits, limitations, and future needs
- Capture specifics on current deployments





Download at: www.smartgrid.gov

Voluntary Code of Conduct (VCC) For Smart Grid Data Privacy

A multi-stakeholder process to develop a Voluntary Code of Conduct (VCC) for utilities and third parties providing consumer energy use services. The code establishes common practices that protect the access, use, and sharing of customers' electricity usage and related data.

Key Elements

- Industry-led initiative
- Participants: Utilities, consumer advocates, vendors, third parties, state and federal governments
- Meetings open to the public and all documents posted at www.smartgrid.gov/privacy
- VCC will be applicable to, and voluntarily adopted by, both utilities and third parties
- VCC will be adopted in its entirety, but limited exceptions allowed (due to laws, regulatory guidance, governing documents) if clearly noted.
- Final VCC released on January 12

VCC Initiative Timeline

February 26, 2013

- **Multistakeholder Initiative Launched**
- Work Groups (WGs) Established
  - Mission Statement
  - Notice/Awareness
  - Choice/Consent
  - Access/Participation
  - Integrity/Security
  - Management/Redress
- WGs Structured Around Fair Information Practice Principles (FIPPs)

June 4, 2013

- **Second stakeholder meeting**
- Mission statement presented
- Discussion of initial principle development

November 22, 2013

- **Third stakeholder meeting**
- Draft principles presented
- Implementation and Integration WGs established

September 12, 2014

- VCC Concepts and Principles Draft **released for public comment**

January 2015

- **President Obama** announced release of final principles
- Posted at www.smartgrid.gov/privacy

GridLAB-D: A Tool for Designing and Studying Smart Grids

Unifies models of the key elements of a smart grid:

Power Systems

Loads

Markets

- ✓ Smart grid analyses
  - field projects
  - technologies
  - control strategies
  - cost/benefits
- ✓ Time scale: sec. to yrs
- ✓ Open source
- ✓ Contributions from
  - government
  - industry
  - academia
- ✓ Vendors can add or extract own modules

GridLAB-D is a DOE-funded, open–source, time-series simulation of all aspects of operating a smart grid from the substation level down to loads in unprecedented detail

- Simultaneously solves:
  - Unbalanced, 3-phase power flow (radial or network), w/explicit control strategies
  - End use load physics, voltage-dependency, behavior & control in 1000s of buildings
  - Double-auction retail supply/demand markets

Value of Service

One utility has installed 230 automated feeder switches on 75 circuits in an urban area. From Apr 1 – Sep 30 2011:

SAIDI improved 24%; average outage duration decreased from 72.3 minutes to 54.6 minutes (or by 17.7 minutes).

Estimated Avg. Customer Interruption Costs US 2008$ by Customer Type and Duration						
Customer Type	**Interruption Cost Summer Weekday**	**Interruption Duration**				
		Momentary	**30 mins**	**1 hr**	**4 hr**	**8 hr**
Large C&I	Cost Per Average kWh	$173	$38	$25	$18	$14
Small C&I	Cost Per Average kWh	$2,401	$556	$373	$307	$2,173
Residential	Cost Per Average kWh	$21.6	$4.4	$2.6	$1.3	$0.9

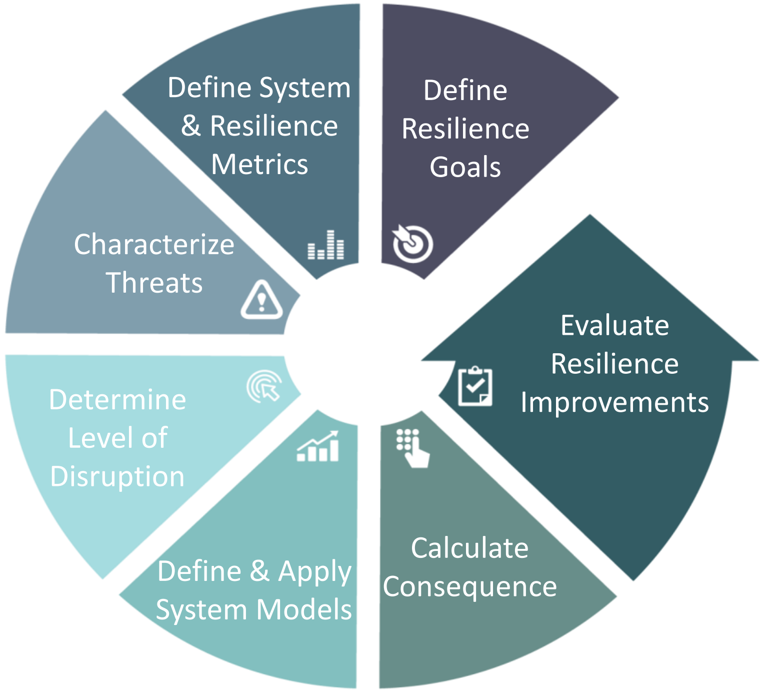
Sullivan J, Michael, 2009 *Estimated Value of Service Reliability for Electric Utility Customers in the US*, xxi

VOS Improvement Δ = Δ SAIDI x Customers Served x Avg Load x VOS Coefficient

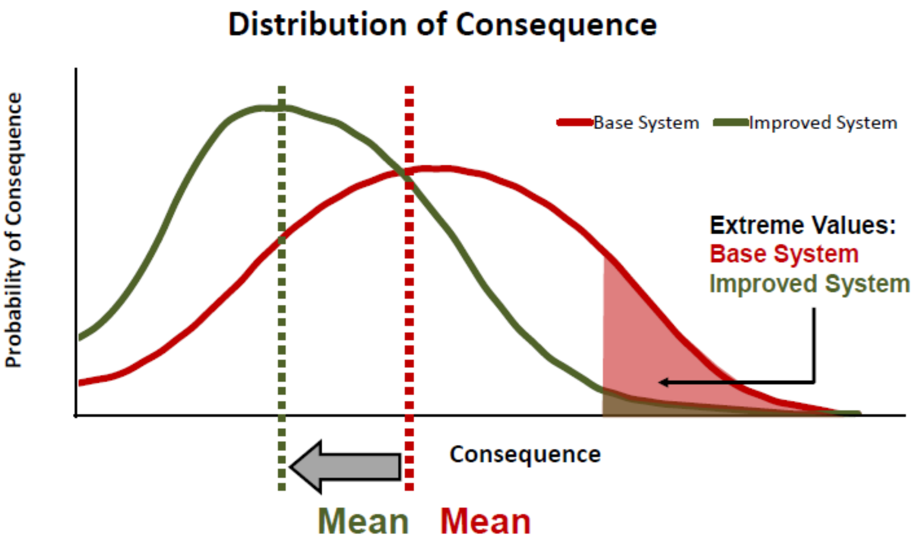
VOS Estimate for SAIDI Improvement on 75 feeders from Apr 1 to Sep 30 2011					
Customer Class	**Δ SAIDI**	**Customers Served within a Class**	**Average Load (kW) Not Served**	**VOS Coefficient ($/kWh)**	**Δ VOS**
Residential	17.7 mins (0.295 hrs)	107,390	2	$ 2.60	$ 164,736
Commercial		8,261	20	$ 373.00	$ 18,179,477
Industrial		2,360	200	$ 25.00	$ 3,481,325
Total		**118,011**			**$ 21,825,537**

Framework for Developing Resilience Metrics

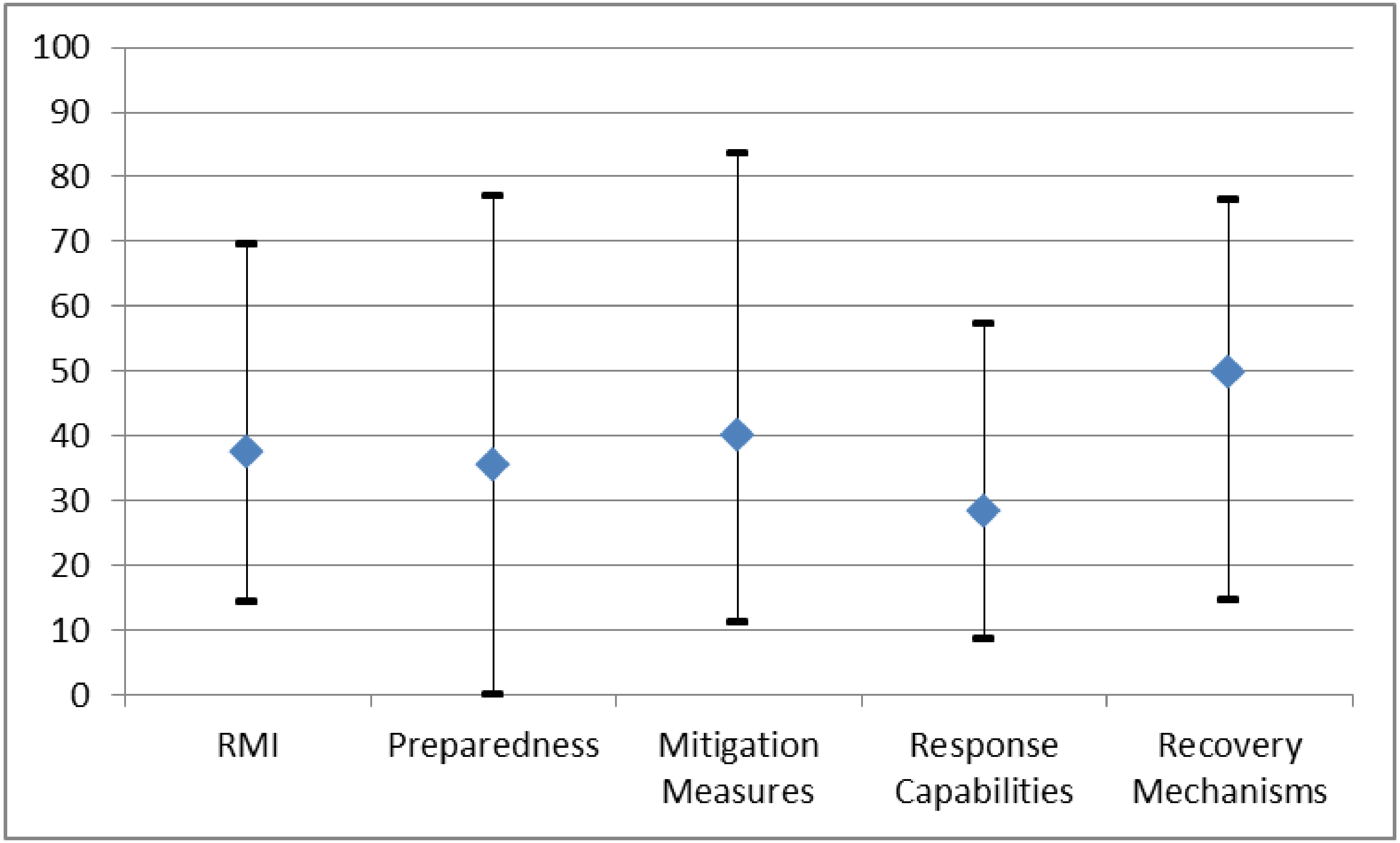
Resilience Analysis Process: How metrics should be defined and used



Resilience Metric: Used to compare performance of improved system vs. baseline



Tool for Distribution Utilities to Assess Resilience to Extreme Weather Events



An example display of overall Resilience Measurement Index (RMI) and component Indices

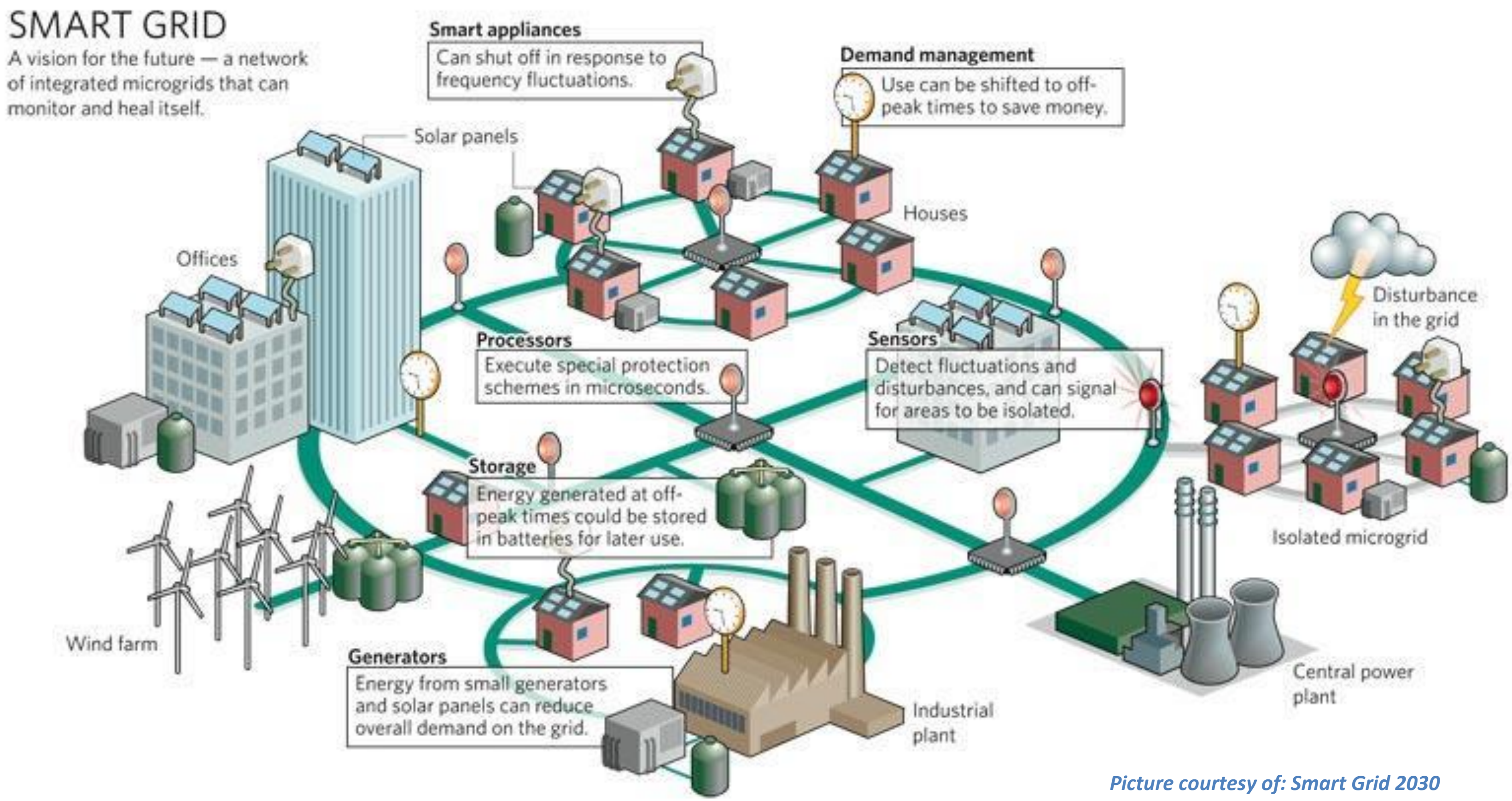
Emissions Impacts Estimator
(in progress)

- **Goal** – construct a web-based tool that:
  - Uses a (new) *standardized methodology* for estimating the environmental impacts of a range of types of smart grid projects
  - Uses *quantitative inputs describing the scope* of a project
  - Computes *impacts on carbon, particulates, & transportation fuel* use
  - *Reflects regional differences* regarding effects of displacing generation

- **Objectives**:
  - Help utilities & policymakers (e.g., public utility commissions) *evaluate smart grid projects*
  - Provide a *transparent, objective process* for estimating impacts that helps acceptance
  - *Document all input assumptions*

- This is a new Office of Electricity funded project just getting underway

Developing a Smarter, More Resilient Grid by Employing ADMS and Transactive Controls and Integrating Networks of Microgrids



Picture courtesy of: Smart Grid 2030

Final Idea

All Other Industries Test Market New Products and Services. Why Not Our Industry?

Only test something you would seriously consider doing post-study
(e.g., don't give away technology for free unless you plan to do so in the future)

Use studies to address viability and reasonableness of *specific* utility objectives
(e.g., reduce peak demand by X% per customer on average)

Studies must be designed to be rigorous enough to provide credible and accurate estimates of benefits (e.g., remove accuracy of impact estimates as grounds for concern)

Test recruitment approaches (e.g., opt-in, opt-out) **in a way that would help inform decision making about a broad-based roll out after the study is over** (e.g., perform adequate market research, test market messages, gain sufficient knowledge of customers' ability to qualify)

Studies provide an opportunity to understand the impact of technology and work out systems integration issues before being rolled out at scale

For More Information

Contact: russell.conklin@hq.doe.gov, +1 202 586 8339

Website: www.smartgrid.gov

Example Reports:

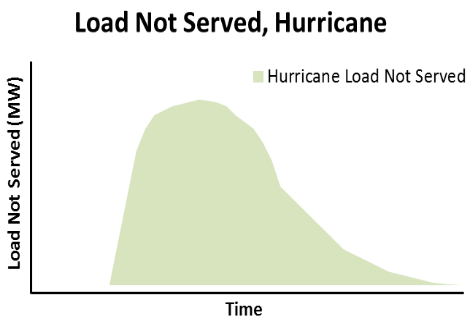
SGIG Progress Report (July 2012)
Peak Demand Reductions – Initial Results (December 2012)
AMI O&M Savings – Initial Results (December 2012)
Reliability Improvements – Initial Results (December 2012)
Voltage Optimization – Initial Results (December 2012)
Economic Impact (April 2013)
Customer Enrollment Patterns in Time-Based Rate Programs (June 2013)
Synchrophasor Technologies and Their Deployment in Recovery Act Smart Grid Programs (August 2013)
Voices of Experience – Insights on Smart Grid Customer Engagement
Experience from the Consumer Behavior Studies on Engaging Customers (Sept. 2014)
Factors Affecting PMU Installation Costs (October 2014)
Voices of Experience – Insights into Advanced Distribution Mgmt Systems (Feb. 2015)

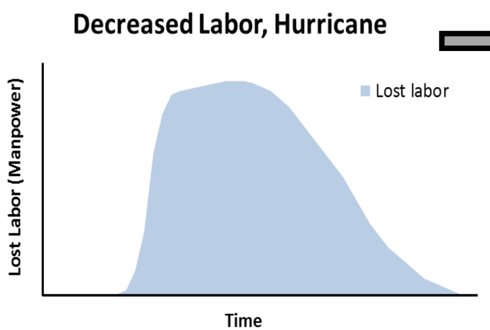
Plus… Case studies and reports by recipients (CBS evaluation studies, technology performance reports)

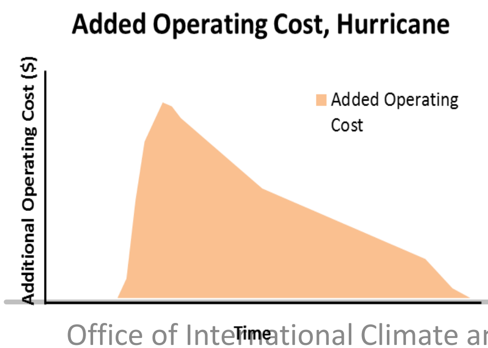
Back-Up

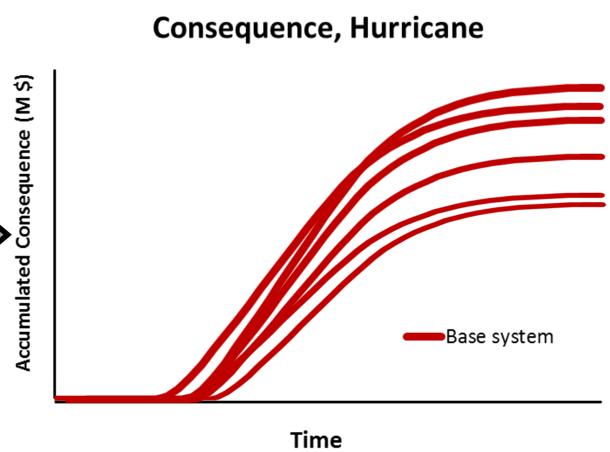
Additional: Framework for Developing Resilience Metrics

Performance Indicators









Alternative units:

Safety

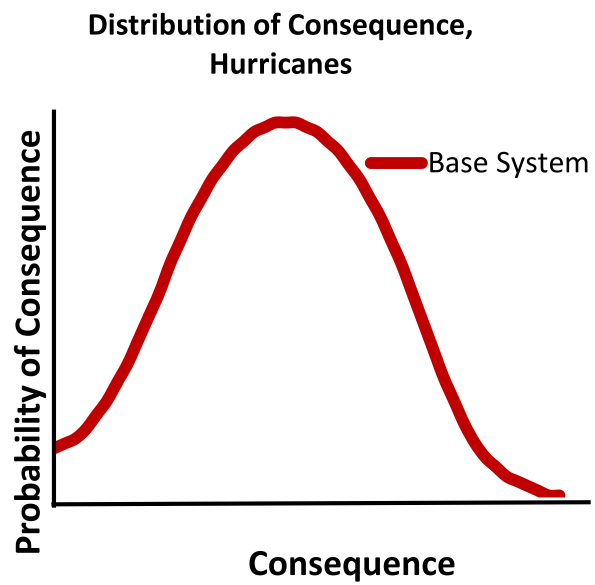
Economics

Population affected

etc…

An exemplar consequence distribution is created to account for uncertainty

(Threat intensity, Available resources, System response, Interdependencies, Disruption impacts, etc.)



This distribution is the RESILIENCE METRIC.

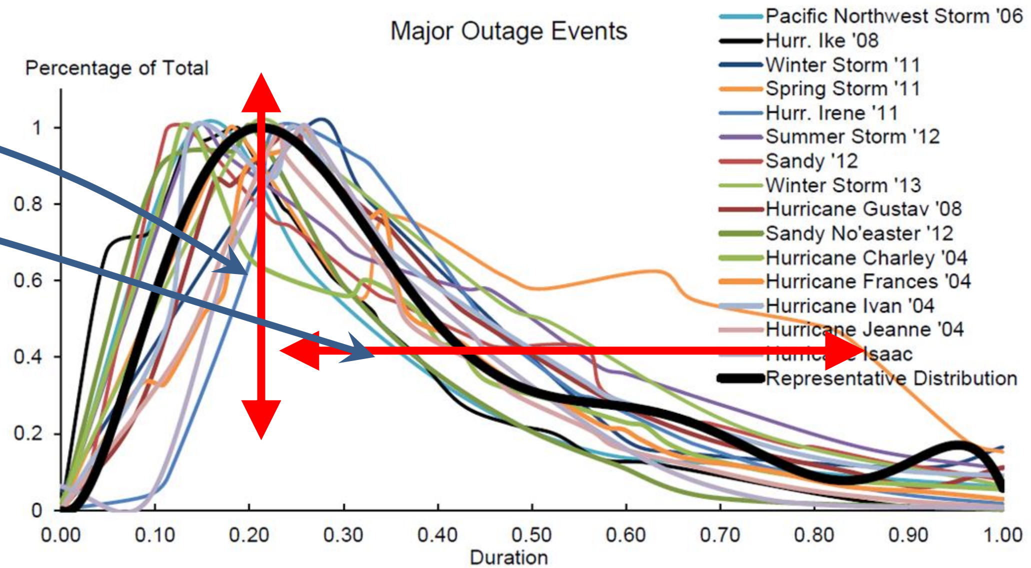
Decision Support Analysis Tool for Resilience

Enable distribution grid designers to prioritize cost-effective system upgrades and expansions to minimize future damage to their grid and outages to customers

- **Hardening/Resilience options**
  - *Asset hardening*
  - *System design*
  - *System operations*
  - *Repair scheduling*
  - *Emergency operations*

withstand

recover



Source: Department of Energy, Office of Electrcity Delivery and Energy Reliability

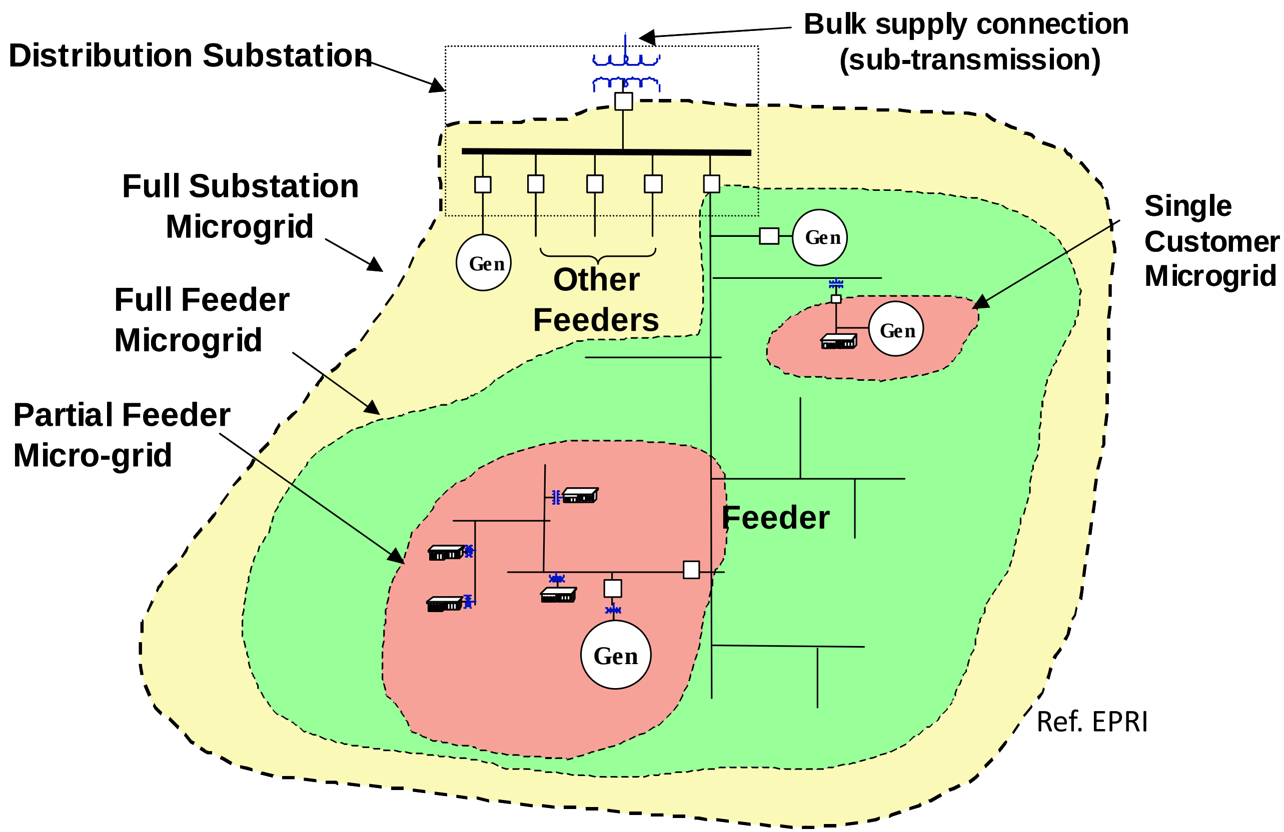
- **Flexibility for the user**
  - *User's base network model*
  - *User-defined resilience metrics*
  - *User suggested upgrades*
  - *User-defined costs*
  - *User-defined threat and scenarios*

- **Tool capabilities**
  - *Assess current resilience posture*
  - *Optimize over user-suggested upgrades to improve resilience considering budget*

Leverage many existing modules developed under the DHS National Infrastructure Simulation and Analysis Center (NISAC)

Microgrid R&D to Enhance Energy Surety, Reliability and Resiliency

- Small combustion and μ-turbines
- Fuel cells
- IC engines
- Small hydro and wind
- Solar electric and solar thermal
- Energy storage (batteries, flywheels,…)
- Plug in hybrid vehicles
- Modular energy sources



Residential	Less than 10-kW, single-phase
Small Commercial	From 10-kW to 50-kW, typically three phase
Commercial	Greater than 50-kW up to 10MW

Microgrids Help Communities as They Prepare for Climate Impacts

NJ TransitGrid Project

- Microgrid to enhance grid-rail resiliency to serve over 900,000 riders/day
- Key evacuation service for Manhattan & N. New Jersey
- MOU between DOE and State of NJ
- **Completed the feasibility study; received the FTA award in Sept 2014 to build microgrid**

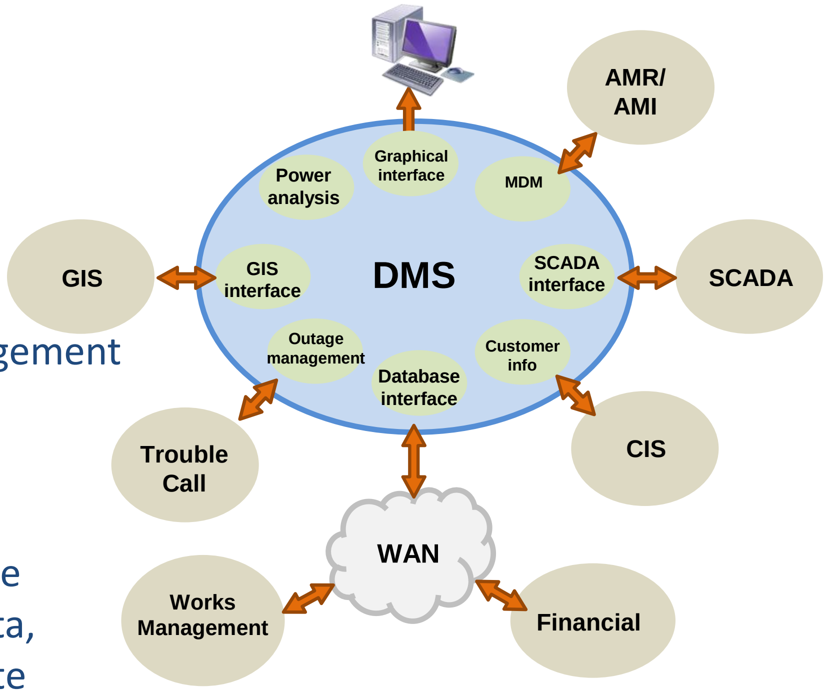
Hoboken ESDM Project

- Provide electrical power to support critical functions up to 7 days for 52,000 residents in 1.2 sq. mi.
- Key evacuation route for Manhattan
- DOE-Hoboken-BPU-Sandia-PSEG Partnership
- **Completed microgrid conceptual design for Hoboken, NJ, to enhance system resilience post-Sandy**

Adv. Distribution Management Systems

What is Advanced DMS (ADMS)?

- An integrated software platform that helps manage and optimize the distribution system, incorporating real-time and spatial data.
- Analogous to the operating system of a computer (coordinating, managing and processing)



Today's DMS

- Stand alone modules for various distribution management functions. Interface capabilities between modules requires costly and lengthy custom solutions.

Future Advanced DMS

- An open source architecture that integrates multiple utility functions, integrates real time and spatial data, from both utility and customer assets with corporate information systems, and couples these with market-based controls.

Research is Needed

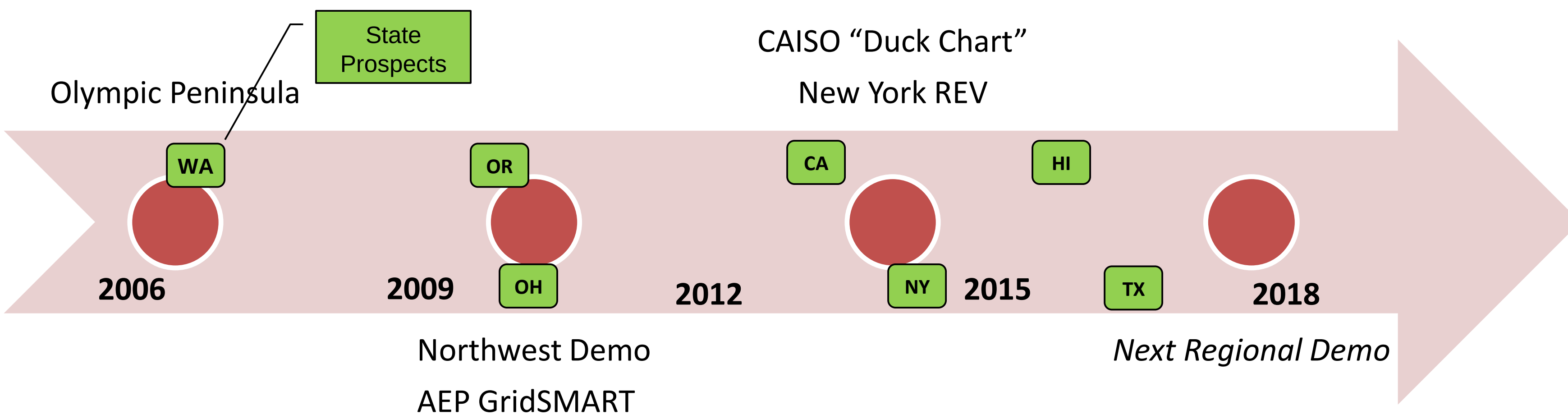
- To develop an open source platform, building on advanced mathematical models at the transmission level, that will allow utilities to integrate multiple applications and utilize input from local conditions (e.g., weather, power flow, asset conditions).
- Establish new control strategies and protection schemes to improve the ability to address intermittency, manage bidirectional power flows, improve restoration capability, accommodate market mechanisms, etc.

Transactive Energy Vision & Timeline

As generation shifts from centralized to more distributed, a grid capable of powering our society will require the development of new approaches based on distributed intelligence and capable of exchanging a range of market-driven energy services with customers.

Transactive Control could enable utilities to balance energy on the distribution grid and actively seek customer capabilities through transparent, competitive means.

There is a need to enhance modelling and simulation capability, establish a valuation and theoretical framework, and ensure necessary advances in architecture and standards.

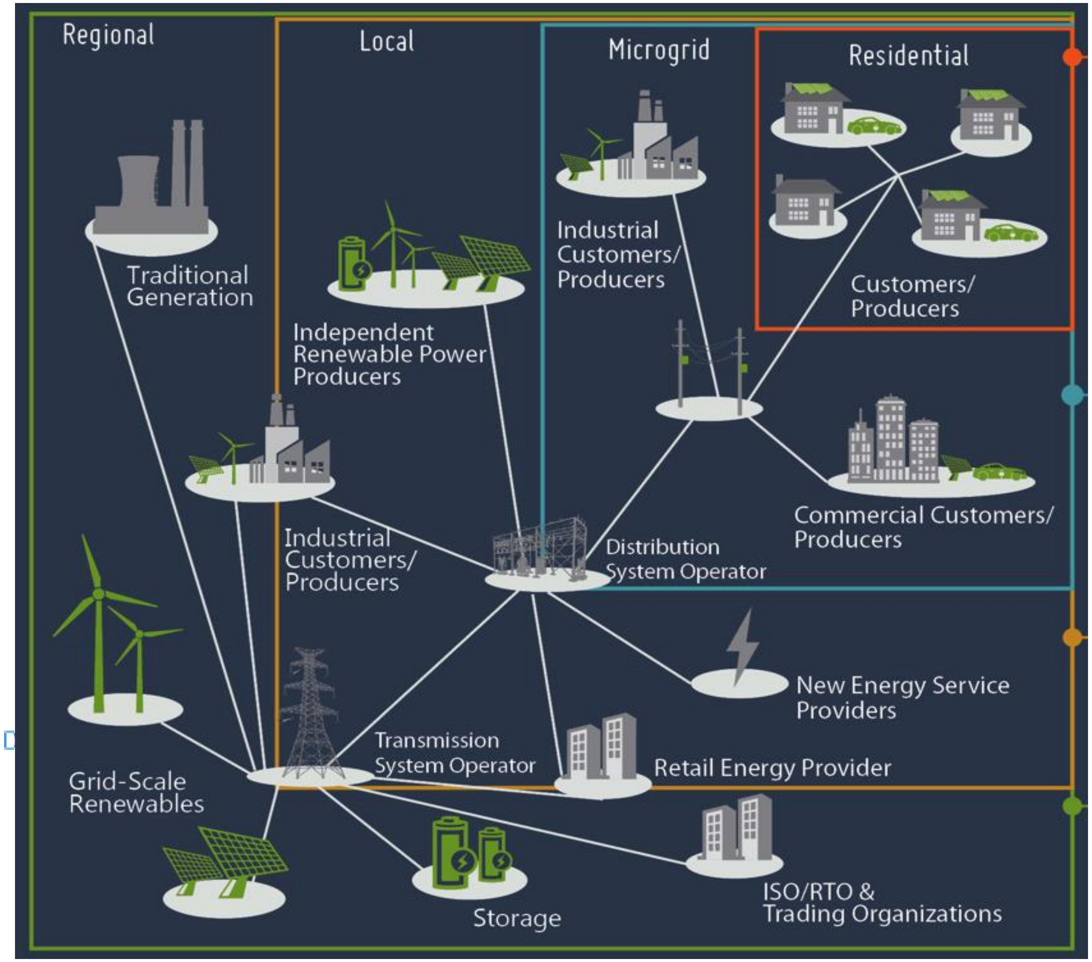


From Physics-Dominant to Network-Dominant Control
(Energy is just along for the ride in either case)

Growth of distributed resources (CHP, EVs, PV, microgrids, et al) <u>owned by others</u> requires new control system methodologies that elicit cooperation through value to ensure system reliability.

BENEFITS:

- **Market-based (Transactive) approach ensures reliability of multi-ownership system AND allows consumer choice**
- **Consumers can prioritize what matters to them - cost, reliability, profitability or sustainability with minimal active engagement**
- **Encourages adoption of clean energy resources by BOTH utilities and consumers**
- **Clean energy resources are on an equal competitive footing with large scale generation**
- **Increases ROI opportunities for microgrids and adds market-layer control options for ADMS**



Source: www.gridwiseac.org

Transactive Systems Progression

Capability	Olympic Peninsula Demo (2006-07)	AEP gridSMART® Demo (2009-14)	Pacific NW Smart Grid Demo (2009-15)	Industry Transactive Prog Pilots (2020)	Future Transactive System (2030)
Proof of real-time retail market concept	X	X		X	X
Agent-based, automated transactive load controls	X	X		X	X
Integrates controllable distributed generation and storage	X	X	X	X	X
Consumer empowerment and privacy satisfaction	X	X		X	X
Scale – Number of responsive customers/assets	~100	~200	~500	10^5	10^9
Approved tariff a function of wholesale prices		X		X	X
Smart meter measurement and validation		X	X	X	X
Mitigate energy market price volatility		X		X	X
Mitigate system & feeder capacity constraints with incentive		X		X	X
Modeling and simulation to evaluate design and analyze results		X	In progress	X	X
Transactions at distribution/retail levels		X		X	X
Transactions at bulk/wholesale level			X	X	X
Integrates variable bulk system renewable resources			X	X	X
Incorporates forecasts (weather, forward markets, etc.)			X	X	X
Interoperability & cybersecurity standards for transactive systems			X	X	X
Emergency response and adaptive-reconfiguration				X	X
Theoretical principles for control/economic stability, risk mgmt				X	X
Provide ancillary services (regulation, ramping, spinning reserves)				X	X
Supportive regulatory and business environment					X