U.S. DEPARTMENT OF
ENERGY
Office of
Electricity Delivery
& Energy Reliability

U.S. Department of Energy
Electricity Grid Research and Development

Michael Pesin
Deputy Assistant Secretary
Advanced Grid R&D

February 9, 2017

America Depends on Secure, Reliable Energy

Every Minute in America

$203,596
In Amazon Sales

19,159
Pounds of Aluminum Produced

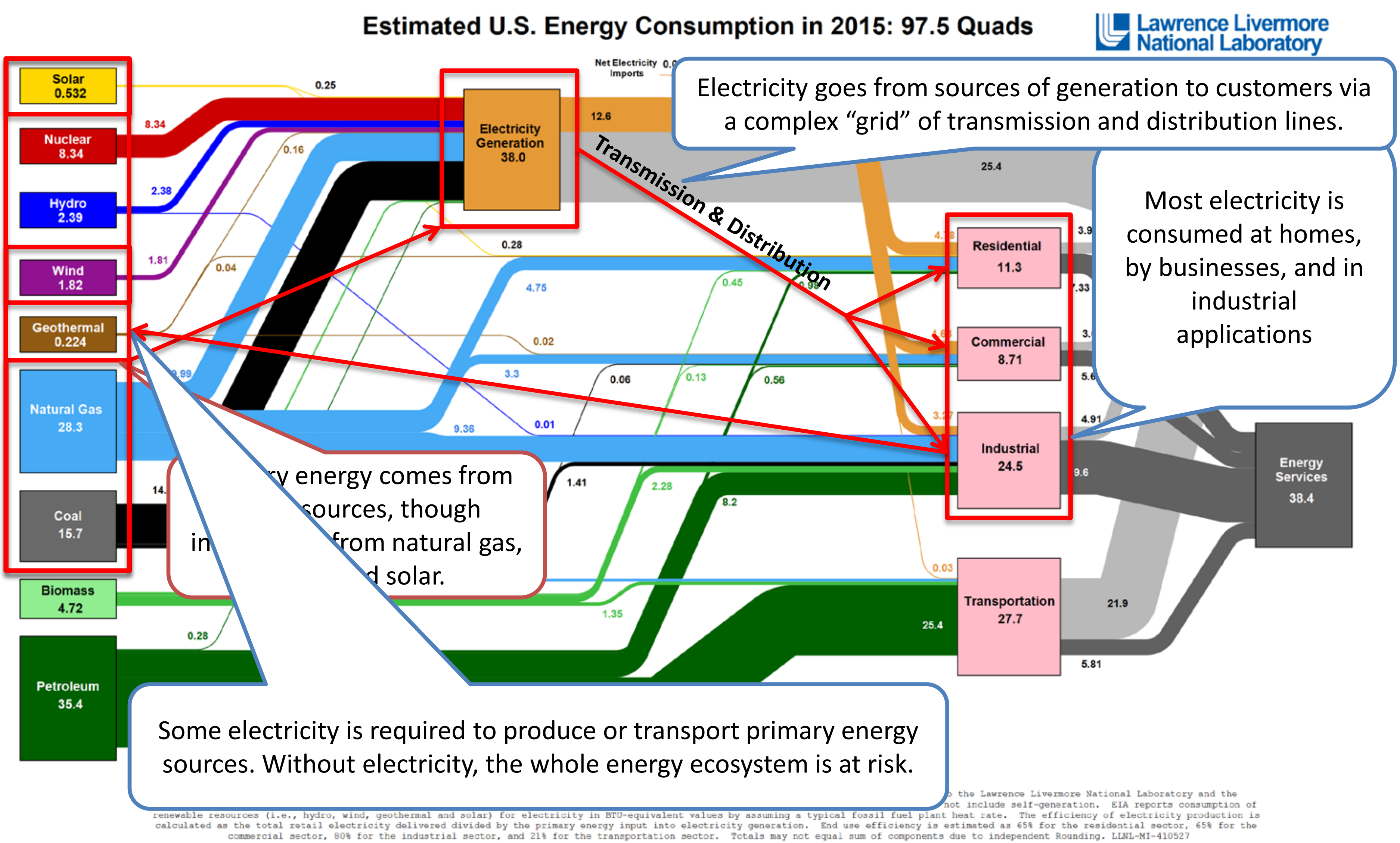
650
DC Metro Boardings

456
Calls to 9-1-1

131,000
kWh consumed by data centers

Electricity Powers Nearly Every Facet of American Life

The Energy/Electricity Ecosystem



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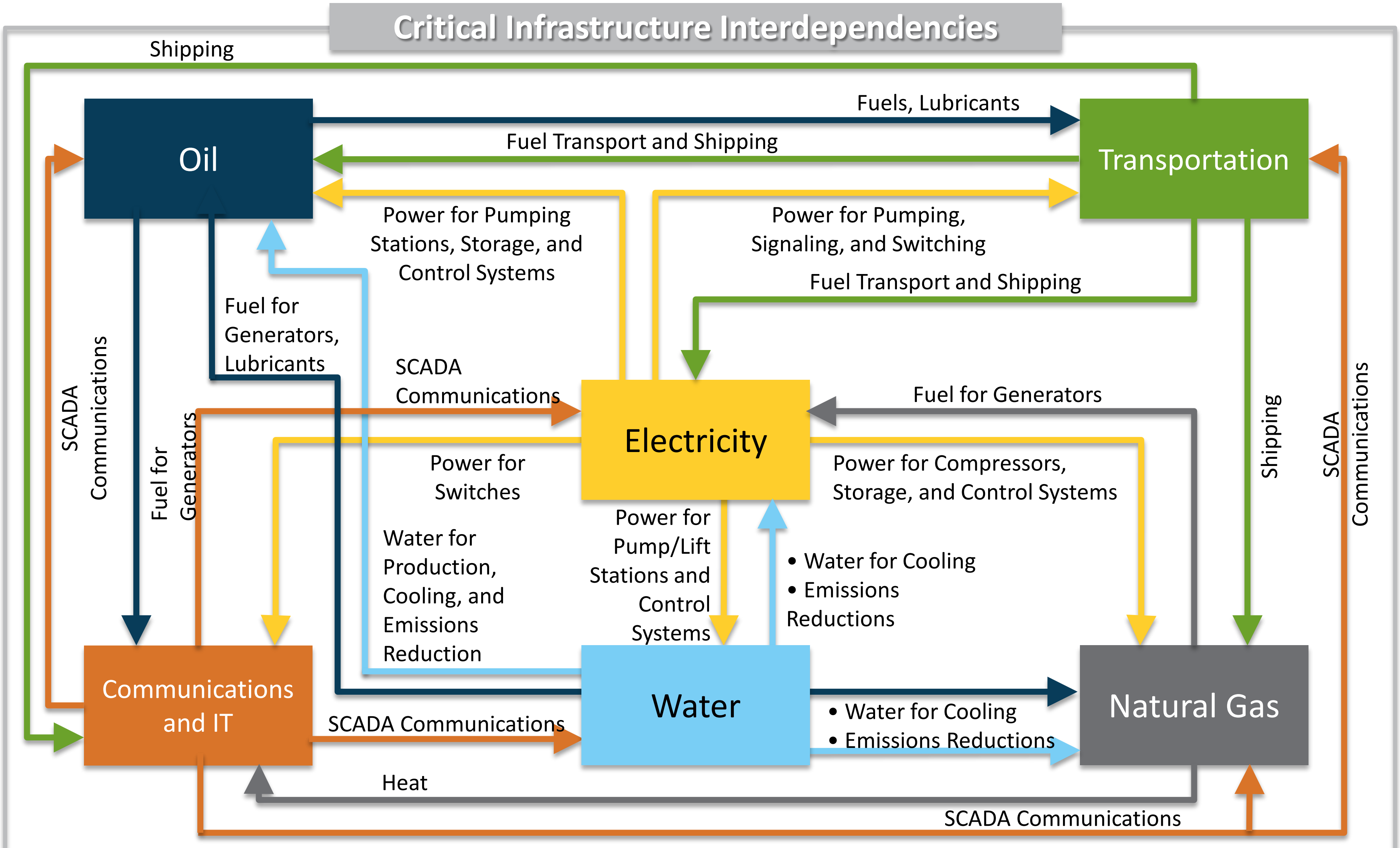
U.S. Critical Infrastructures Depend on Electricity



Source: Finster, 2016

Key Trends Driving Electricity System Changes

A changing mix of types and characteristics of electric generation

Growing demands for a more resilient and reliable grid

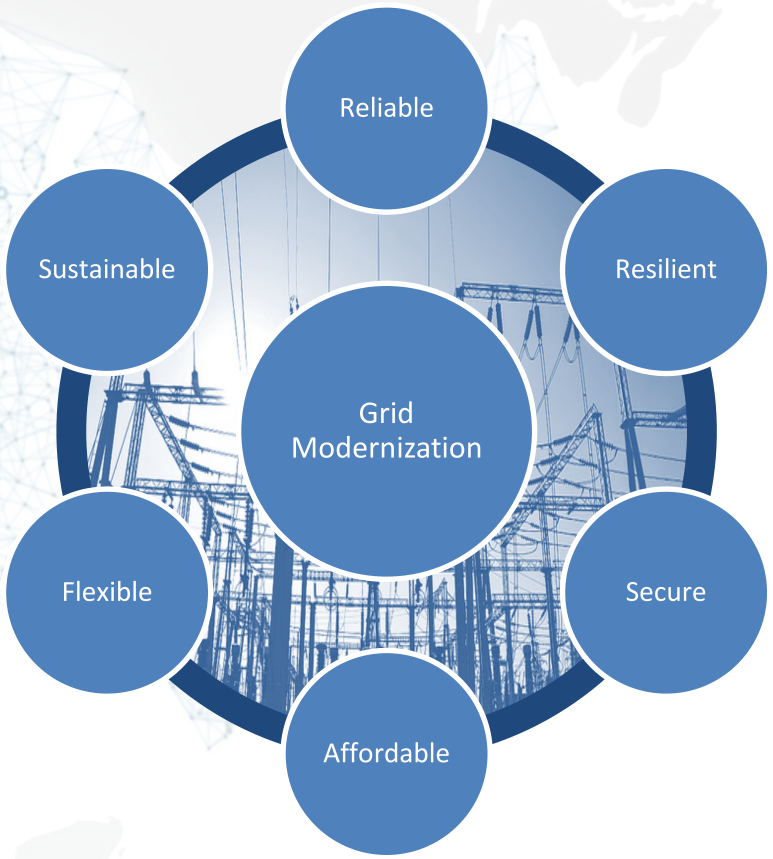
Aging Infrastructure

The emergence of interconnected electricity, information and control systems

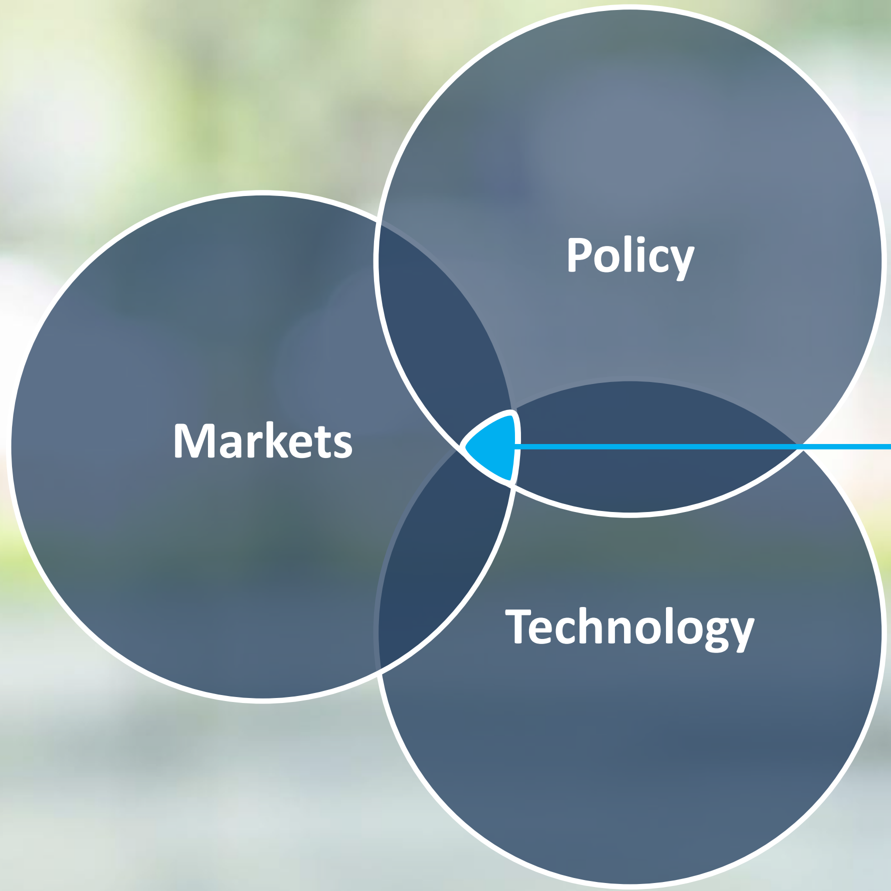
Growing supply- and demand-side opportunities for customers to participate in electricity systems

Key Characteristics of a Modernized Grid

- **Reliable**
  Not prone to outage or disruption
- **Resilient**
  Smaller scale and shorter duration of disruptions if/when they occur
- **Secure**
  Able to survive physical or cyber attack
- **Affordable**
  Delivered at an economically-competitive price
- **Flexible**
  Actively respond to the variability and uncertainty of conditions at various timescales
- **Sustainable**
  Enabling cost-effective utilization of all generation resources.



Grid Technology Commercialization



Interaction between Policy, Markets, and Technology.

Fragmented Market Authority Creates Challenges

Investor-Owned Utilities -- 192

- Account for a significant portion of net generation (38%), transmission (80%), and distribution (50%)

Publicly-Owned Utilities and Cooperatives -- ~2,900

- Account for 15% of net generation, 12% of transmission, and nearly 50% of the nation's electric distribution lines

Independent Power Producers -- ~2,800

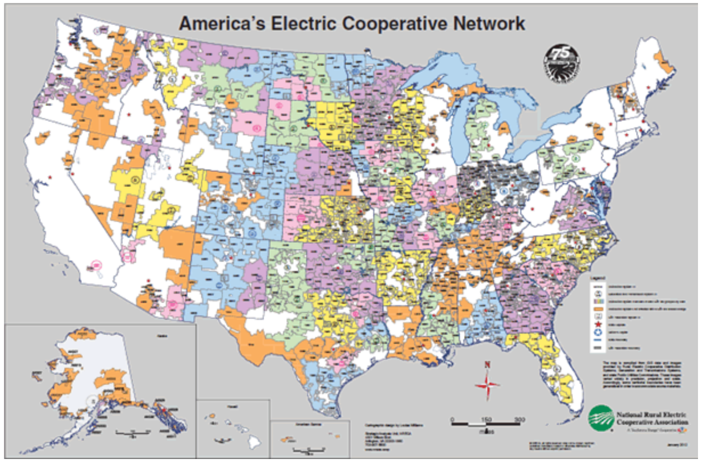
- Account for 40% of net generation

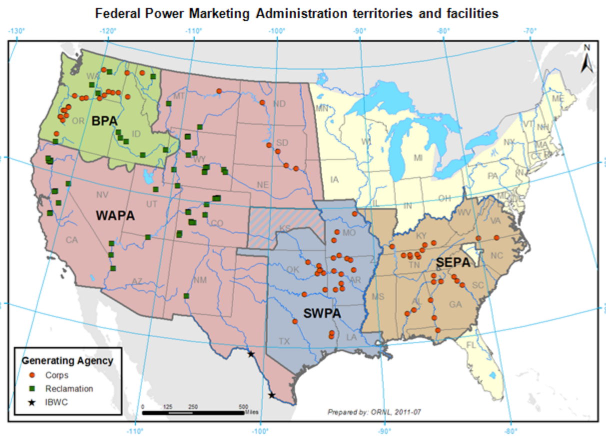
Federal Government

- Owns 9 power agencies (including 4 Power Marketing Administrations and TVA) with 7% of net generation and 8% of transmission

Electric Power Marketers – 211

- Accounts for approximately 19% of sales to consumers





Sources: *EIA, Electric Power Annual 2013, March 2015*
EIA, Annual Energy Review 2011, Chapter 8 (Electricity)
2014-15 Annual Directory & Statistical Report, American Public Power Association
NRECA Co-op Facts & Figures, www.nreca.coop

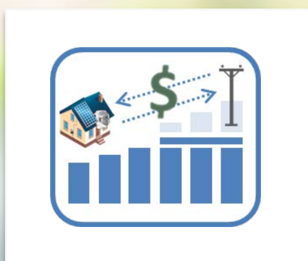
Advanced Grid R&D Programs At-A-Glance

Energy Storage Systems

Advanced Power Grid Components

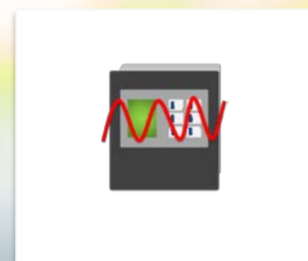
Advanced Distribution Capabilities

Microgrids

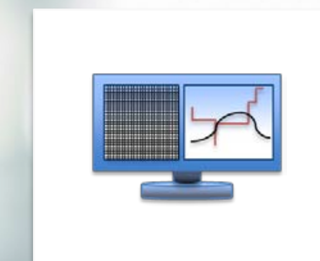


Transactive Energy

Advanced/Low-Cost Sensors



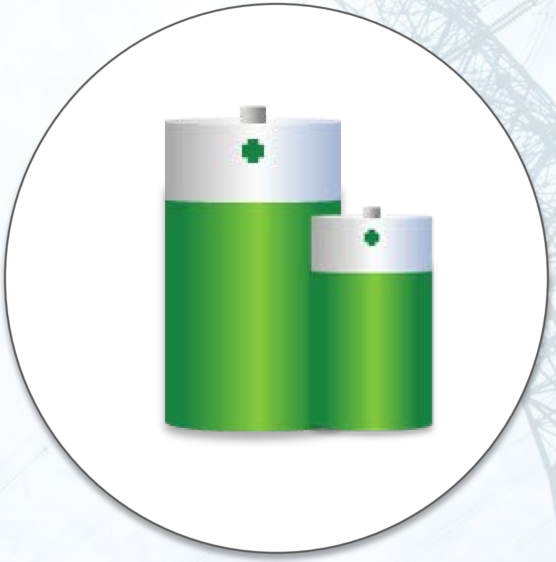
Synchrophasors



Advanced Grid Modeling

Energy Storage Systems

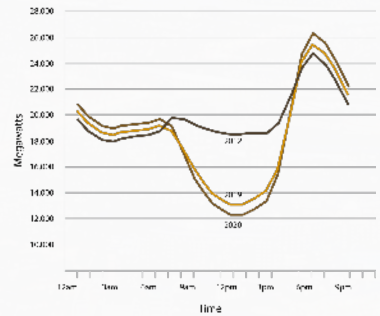
Increase the asset efficiency, reliability, and flexibility of the transmission and distribution infrastructure



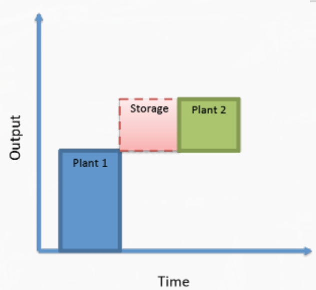
The Need for Energy Storage

Breakthroughs in grid-scale energy storage can enable significant cost savings to industry while improving infrastructure reliability and efficiency.

The installation of variable generation sources places a strain on grid reliability.



Significant ramping events could cause energy disruptions.



Market driven uptake in demand response services is seeking low cost solutions.

The grid could be more flexible to allow it to improve resilience and maintain efficiency, while remaining generation neutral.

Where We Are – Where We Are Going

Grants and Cost Shared Projects

Energy Independence and Security Act (2007)

The Recovery Act (2009)

PAST

Research and Development

Demonstration

Market Enablement

PRESENT

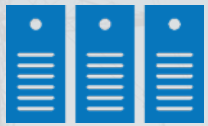
Robust Market

Load Smoothing

Robust Policies

FUTURE

Energy Storage Vision



Added storage at generation to ease issues of supply intermittency or load ramping

Strategically located storage across the transmission and distribution lines to improve reliability, efficiency, ramping, and resilience

Storage at Load to support distributed grid services and add redundancy to improve resilience

Energy Storage Program Areas

Program Areas	Objective	Goals
Cost Competitive Technology	• Materials and chemistry • Systems and manufacturing • Cost reduction • Expanded applications	Capability and cost to meet industry requirements.
Reliability & Safety	• Lab testing • Codes and standards • Guidebooks • Certifications	User confidence and low liability
Regulatory Environment	• Policy analysis • Valuation methods • Resolution of benefits	Barriers and requirements equal or comparable to other grid resources
Industry Acceptance through Demonstrations	• Stakeholder engagement • Proving success • Seamless integration • Consumer benefits	Sustainable progress

Energy Storage System Economics

The Cost of a Storage System depends on the Storage Device, Power Electronics, and Balance of Plant

The Value of a Storage System depends on Multiple Benefit Streams, both monetized and unmonetized

Energy Storage Device
25-50%

Power Electronics
20-25%

Balance of Plant
20-25%

Industry Acceptance through Demonstration

2009 American Recovery and Reinvestment Act Energy Storage Demonstration Projects

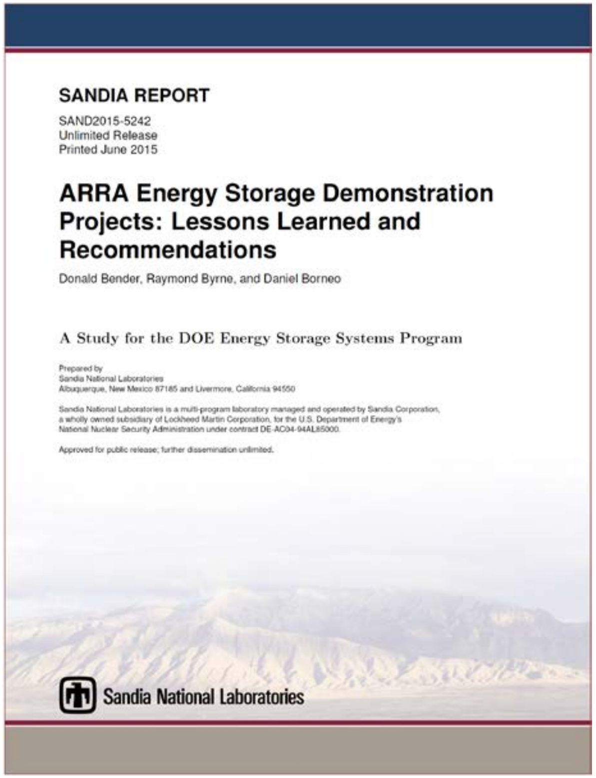
- **16 demonstration projects (12 grid connected)**
- **$623M total investment, $188M Federal cost share**

20 MW, 5 MWh Flywheel plant

East Penn Advanced Lead Carbon

SCE Tehachapi 8MW, 32 MWh Li-ion plant

Aquion Sodium Technology



SANDIA REPORT

SAND2015-5242
Unlimited Release
Printed June 2015

ARRA Energy Storage Demonstration Projects: Lessons Learned and Recommendations

Donald Bender, Raymond Byrne, and Daniel Borneo

A Study for the DOE Energy Storage Systems Program

Prepared by
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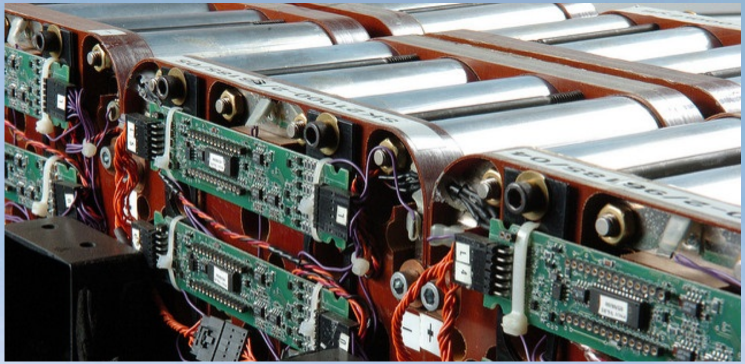
Program Accomplishments

- Nine R&D 100 Awards, 169 peer reviewed publications, and 70 patents
- Licensed V/V redox flow battery technology and successful scale-up and commercialization
- Supported energy storage technology development and demonstrations, including in WA, OR, VT, HI, AK, MA, CA, TN, NC
- Established industry-wide Energy Storage Safety Working Group
- Established DOE Electric Power Research Institute Handbook and Energy Storage Technology Advancement Project Webinar Series
- Established Global Energy Storage Database

Energy Storage On the Horizon



R&D prototyping new aqueous soluble organic flow battery chemistries for 2X reduction in cost

Expand Safety Forum to include national and international community for adoption of codes and standards

Expand regional workshops to engage utility regulatory commissions

Expand technical assistance to states on demonstrations with 8MW+ of energy storage assets

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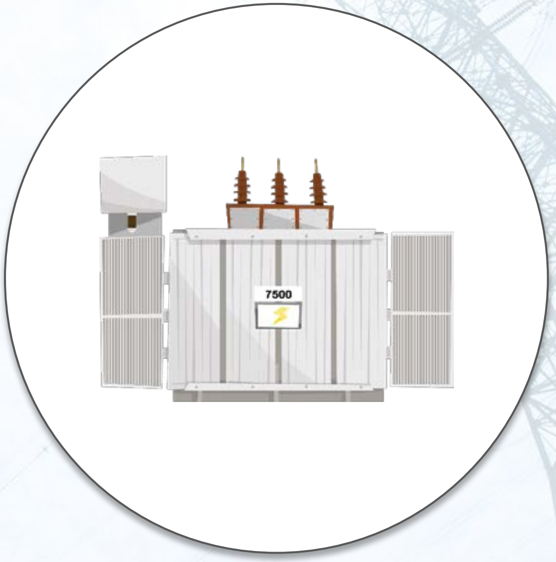
Advanced Power Grid Components

Develop technologies and approaches that will maximize the value and lifetimes of existing grid hardware components and facilitate the upgrade and transition to the grid of the future



The Need for Advanced Power Grid Components

Power grid components are costly to replace, aging rapidly, and potential targets for malicious actors.

Grid components are reaching a critical point of increasing asset retirement.

Consumer demand for reduced disruptions after major weather events is on the rise.

Policy makers are seeking opportunities for added resilience and physical, cyber, and natural threats.

Electricity disruptions are getting more expensive with the increased interdependence of major infrastructure.

Where We Are – Where We Are Going

PAST	PRESENT	FUTURE
Domestic Capacity	Complex Supply & Production	Energy Security
Minimal Threat Environment	Dynamic Threat Environment	Security Built In
Traditional Materials/Manufacturing	Manufacturing Advances	Leap-ahead Materials/ Manufacturing/Flexibility

Advanced Components Vision

Enable more efficient & optimal power flows across transmission lines to increase reliability

Unlock higher grid asset performance and build greater resilience against major weather events, supply interruption, and physical and/or cyber attack

Dynamic two-way flows of electricity and information to build out grid flexibility, reliability, and efficiency

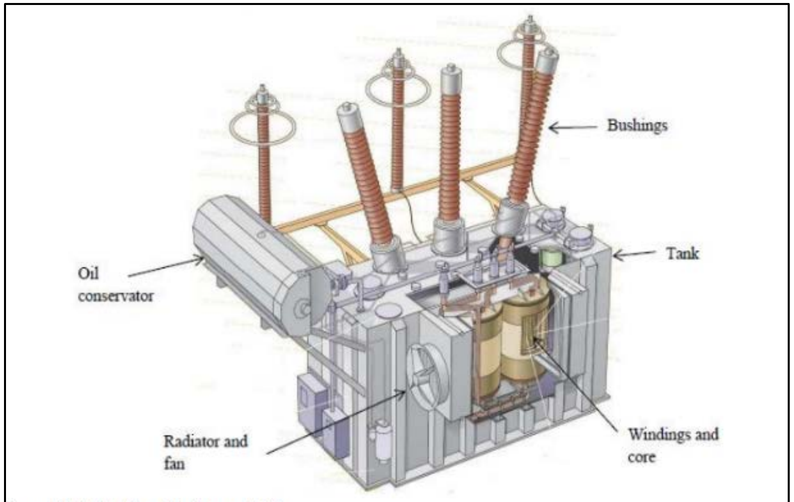
Advanced Components Program Areas

Program Areas	Objective	Benefit
Market & System Impact Analysis	• Understand the system impact of new technologies • Techno-economic analysis of costs/benefits of advances	Reduces the uncertainty and costs of technology adoption
Component Design & Development	• Design and prototype components with enhanced functionality • Develop manufacturing ecosystem for cost, performance, adoption	Reduce the risk and cost of breakthrough componentry
Monitoring & Testing	• Develop embedded equipment sensors to improve design and operation • Testing and demonstration to show performance and value	Improve knowledge of component behavior and demonstrate viability
Applied Materials R&D	• Evaluate and develop new materials and devices that underpin advanced components	Foundational to improved performance and costs

System Engineering & Development

New Designs

Spur innovation in design of transformers and transformer components

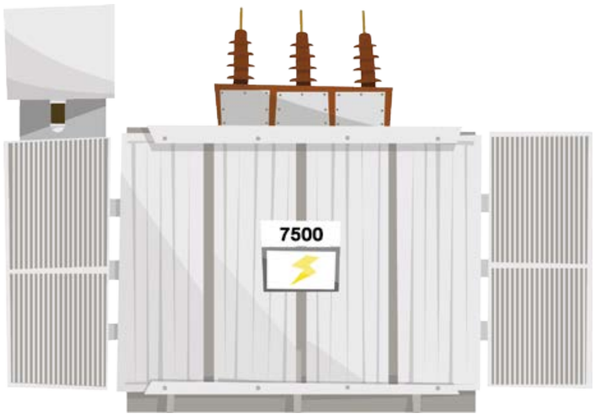


Source:"Liquid-Filled Power Transformers," ABB

DE-FOA-0001579
Next-Generation Transformers – Flexible Designs
Department of Energy
National Energy Technology Laboratory

New Applications

Spur the application of new materials and techniques in the design and manufacture of transformers and components



Modular solid state transformers could rapidly scale up or down to meet demand or resilience needs.

On the Horizon

Solid State Substation

Two-way Power Advances

Transformer – Flexible Designs

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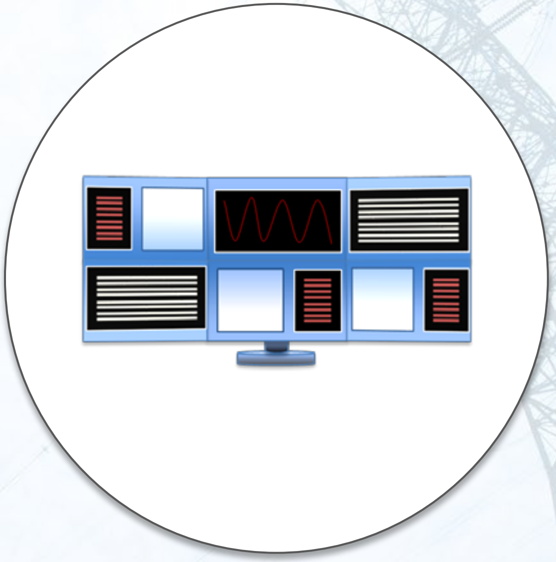
Advanced Distribution Capabilities

Advanced Distribution Management Systems (ADMS)

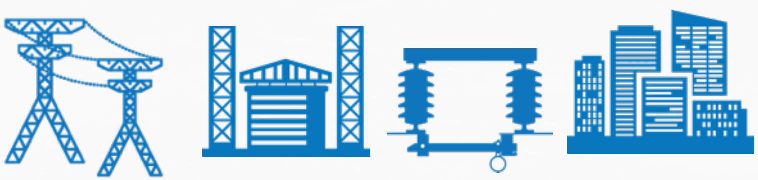
Develop a software platform capable of integrating current and emerging distribution utility data, and support the development of vendor-independent measurement and control applications to manage and optimize distribution utility operations



The Need for ADC

The current grid does not know enough about the new technology that is being attached to it.

Significant additions of distributed energy resources could threaten grid reliability.



Uncoordinated connection among systems on the grid hurts efficiency.

Increased customer participation and consumer energy management opens new low-cost opportunities.

Interaction of new systems and new technologies adds complexity.

Where We Are – Where We Are Going

PAST	PRESENT	FUTURE
Manual Systems	Mix of Old/New Systems	Holistic Interoperable System
DERs-as-Exclusions	DERs-as-Exceptions	DERs-as-Standard
Post-event Analysis	Limited, Real-Time Analysis	End-to-end, Predictive View

ADC Vision

Develop an open platform to support grid operators and promote technology innovation

Standardize grid information to support third-party vendor opportunities and ensure interoperability across the system

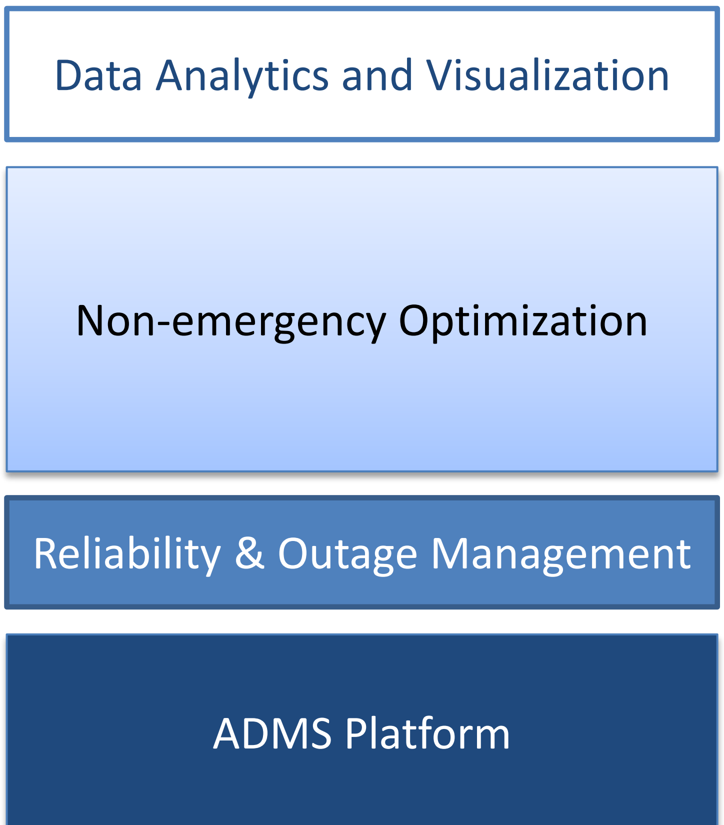
Allow private markets to compete and provide advanced applications and services to grid operators

ADC Program Areas

Program Areas	Objective	Benefit
Platform	• Develop open-source platform • Connect to operational systems • Framework for benefits evaluation	An open, interoperable platform for diverse users, developers, and stakeholders.
Testbed	• Span multiple vendors and management/data systems • Integrate legacy and new	Speed integration and enable identification/validation of value.
Applications	• Develop initial application suite • Baseline safety, resilience and reliability, and integration	Seed platform with valuable, market-ready applications to speed adoption.
Advanced Control	• Control theory and system architecture • Scale to 10,000 DERs • Validate performance	Ensures the complete integration of DERs as a core function
EMS/BMS/DMS Integration	• Open framework for EMS/DMS/BMS integration • Incorporate edge sensors • Span spatial/temporal scales	Enable full, accurate, and useful view to "The Edge"

ADC Applications

Develop an integrated suite of ADMS applications that includes non-emergency optimization, reliability and outage management, as well as data analytics and visualization.

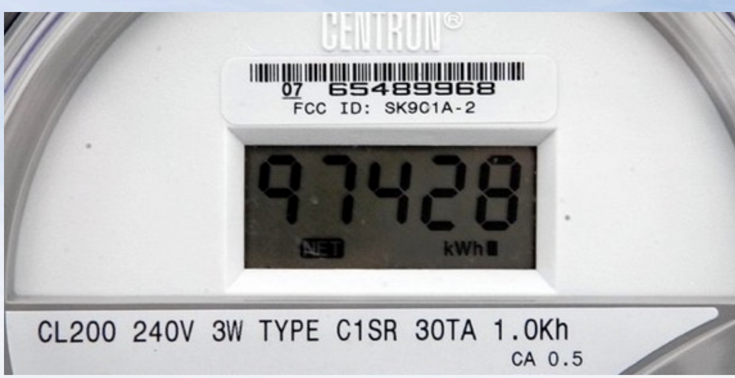


- **Non-emergency optimization:** Voltage and VAR Optimization, Distributed Energy Resource Management, Demand Response, and transactive energy
- **Reliability and Outage Management:** Fault Location, Isolation, and Service Restoration, Workforce management, risk-based tools, predictive maintenance, reliability-as-a-service
- **Data Analytics and Visualization:** State estimation, load/distributed generation forecasting, switch plan management, and analysis tools based on sensors

On the Horizon

Broader integration of DER and DER-enabling technologies

New control/operational theories for distribution



Real-time, spatial data of all connected devices

Integration of distribution sensors into DMS/ End-to-end visibility

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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.

A remote microgrid is a variation of a microgrid that operates in islanded conditions.

Microgrids

Develop an integrated network of
multiple microgrids as a building block
for the resilient, secure grid of the future

The Need for Microgrids

The current grid needs more redundancy to protect critical infrastructure and open new value streams.

Critical infrastructure is vulnerable to major disruptions.

Grid infrastructure should be neutral to generation sources while maintaining system reliability.

Intentional physical attacks could cause major damage.

Customers are seeking new opportunities to provide grid services to operators and tenants.

Where We Are – Where We Are Going

PAST

- Campuses and Military Bases
- Single Owners
- Microgrid Design Tools

PRESENT

- Commercial Applications
- Grid-connected and Off-grid Applications
- Local, State, Multi-state and Regional Partnerships

FUTURE

- Networked Microgrids
- Multiple Value Streams
- New Ownership Models

Microgrid Vision

Enhance resiliency, particularly for critical infrastructure, during major weather events

Speed the recovery process after a major disruption, maintain electricity supply of critical loads, and deter malicious actors seeking to cause harm

Work seamlessly in parallel with grid to provide a variety of microgrid services

Microgrid Program Areas

Program Areas	Objective	Goals
Cost Competitive Technology	• Microgrid controller • Tools development • Testing and validation • Standards	Meet end user needs for critical loads, power flexibility, reliability, and sustainability
Institutional Frameworks	• Peak shaving and provision of other grid services • Quantify cost and benefits	Support the macro-grid with handling and support of sensitive loads; provide ancillary services
Industry Acceptance through Demonstrations	• Intentional islanding • Grid integration • Enhance local reliability and power quality	Promote industry and customer participation and optimal use of generation assets
Resiliency Tools	• Response • Recovery	Optimize operations to achieve maximum resilience and reliability and provide uninterruptable services to the critical loads

Microgrid Value Proposition

Microgrid Applications

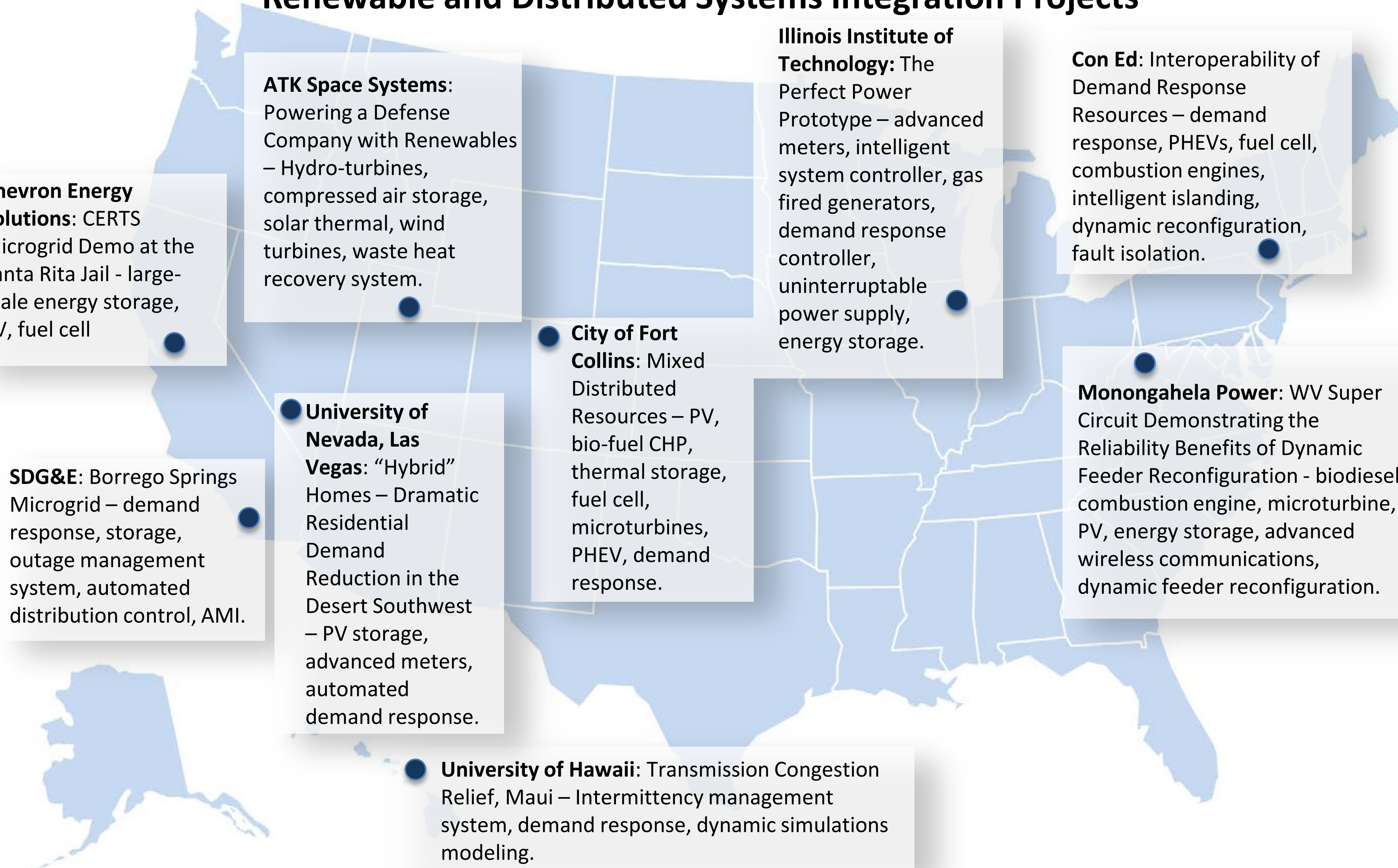
- Intentional islanding for safety and reliability
- Energy surety during outages and emergency conditions
- Peak-shaving and provision of other grid services (i.e. ancillary services, demand response)
- Enabling integration of distributed energy resources
- Enhance local reliability and power quality
- Smoothing of intermittent and variable resources
- Arbitrage of energy price differentials

Multiple Objectives

Flexibility	Maximizes electricity produced and consumed from all types of resources including renewables
Economic	Responds to real-time changes in electricity prices to minimize total energy and operational costs
Reliability	Serves as a grid resource in grid-connected mode and switches to island mode upon detecting a contingency
Resilience & Security	Ensures that critical loads can be served for sustained periods of time during and after catastrophic events

DOE Demonstration Projects

Renewable and Distributed Systems Integration Projects



Chevron Energy Solutions: CERTS Microgrid Demo at the Santa Rita Jail - large-scale energy storage, PV, fuel cell

ATK Space Systems: Powering a Defense Company with Renewables – Hydro-turbines, compressed air storage, solar thermal, wind turbines, waste heat recovery system.

Illinois Institute of Technology: The Perfect Power Prototype – advanced meters, intelligent system controller, gas fired generators, demand response controller, uninterruptable power supply, energy storage.

Con Ed: Interoperability of Demand Response Resources – demand response, PHEVs, fuel cell, combustion engines, intelligent islanding, dynamic reconfiguration, fault isolation.

City of Fort Collins: Mixed Distributed Resources – PV, bio-fuel CHP, thermal storage, fuel cell, microturbines, PHEV, demand response.

University of Nevada, Las Vegas: “Hybrid” Homes – Dramatic Residential Demand Reduction in the Desert Southwest – PV storage, advanced meters, automated demand response.

SDG&E: Borrego Springs Microgrid – demand response, storage, outage management system, automated distribution control, AMI.

Monongahela Power: WV Super Circuit Demonstrating the Reliability Benefits of Dynamic Feeder Reconfiguration - biodiesel combustion engine, microturbine, PV, energy storage, advanced wireless communications, dynamic feeder reconfiguration.

University of Hawaii: Transmission Congestion Relief, Maui – Intermittency management system, demand response, dynamic simulations modeling.

Program Accomplishments

- Seven industry partnerships – commercially viable microgrids for more resilient communities
- Microgrid design decision analysis tools for remote off-grid applications
- Tech transfer and tech assistance to cities and utilities for resiliency
- FY 2016 state partnership on demonstrating microgrid-enabling technologies – Alaska Energy Authority and Alaska Center for Energy and Power

On the Horizon

Local electricity delivery infrastructure funding opportunity announcement (FOA)

FOA 997 down selection and ROMDST down selection

Networked microgrid lab call

Resilience tools development

Transactive Energy

Develop techniques for managing the generation, consumption or flow of electric power through the use of economic or market based constructs while considering grid reliability constraints

The Need for Transactive Energy

Information and communication technology is not leveraging the potential of economic incentives to reduce grid operation costs.

The flexibility of distributed energy resources are not accessible enough in traditional control systems.

Current operational models are not capturing the efficiency potential of new technology.

Energy management systems and building operations are missing out on additional revenue streams.

Traditional utility models are not fully capturing potential new sources of cost recovery.

Where We Are – Where We Are Going

Lack of Interaction

Human-in-the-loop Control

The Recovery Act (2009)

PAST

Research and Development

Tools

Market Enablement

PRESENT

Automated Control with Human Supervision

Renewable Energy Enablement

Robust Policies

FUTURE

Transactive Energy Vision

Address the needs of the early adopter stakeholder community, but design and educate for nationwide adoption

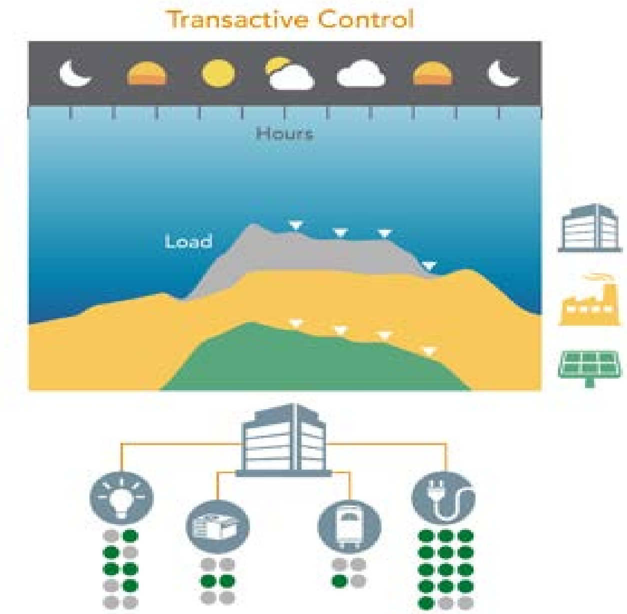
Understand the value of financial incentives to support system reliability and a well-functioning market environment

Reduce the cost of managing the grid through outsourcing services to external market actors

Transactive Energy Program Areas

Program Areas	Objective	Benefit
Policy and Market Design	• Continued reliability • Understand volatility of generation and demand • Varying timescales and cost effectiveness	Fair and transparent energy market to support grid reliability
Business Models and Value Realization	• Understanding of customer value streams • Understand DER transactions	Greater proliferation of DERs and volume services
Conceptual Architecture Guidelines	• Clear structure • Establish traditional and distributed interfaces	Navigate a seismic shift in regulatory, business and technology domains
Strong Interfaces and Partners	• Enhance intra-grid information and value flows • Ensure “docking” with critical partners at the grid edge.	Interoperability that minimizes integration cost and maximizes asset utilization

Transactive Campus Demonstration



Research Focus

Design, implement and test transactive control technologies to coordinate building loads and distributed energy resources (DERs) to demonstrate methods that enable significant energy savings, increased distributed renewable generation, and coordination of loads and DERs at scale.

Benefits

- Provides a roadmap for industries interested in microgrids
- Identifies institutional and regulatory challenges associated with development of an industrial microgrid
- Clarifies interaction between industrial customer and utility
- Delivers reference documents to assist industrial companies in overcoming institutional barriers and assessing their capabilities to implement a microgrid at their facilities.

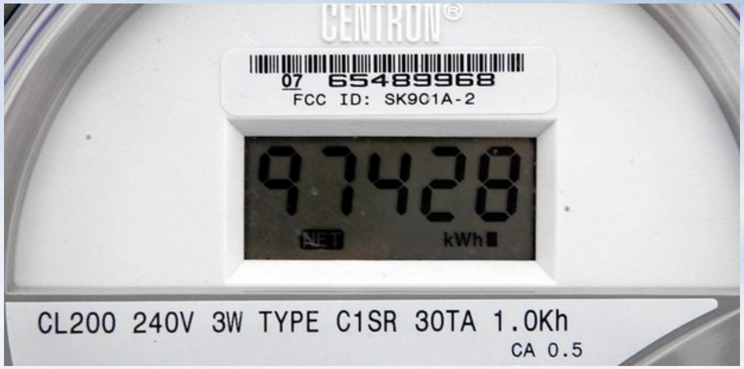
Partners

- Pacific Northwest National Laboratory
- Washington State University
- University of Washington

On the Horizon

Distributor operating models

Distribution/Transmission Interchange



Customer behavior models

Mechanisms to provide market signals and to share signals

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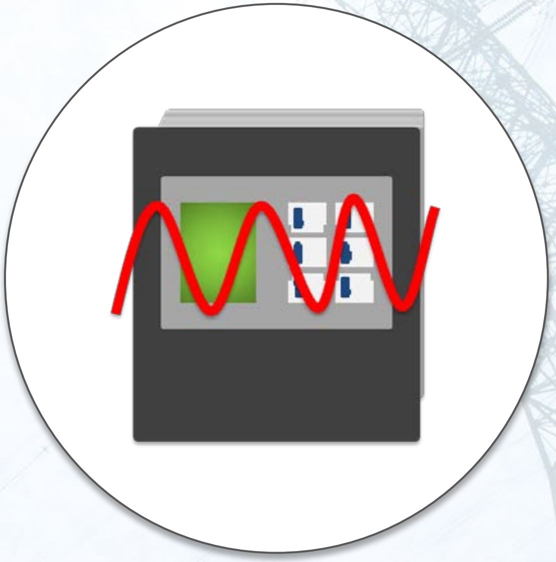
Synchrophasors

Integrate synchrophasor data into planning and operational decision-making, supporting reliability through wide-area situational awareness and control



The Need for Synchrophasors

We must capitalize on the full potential of the rapid deployment of synchrophasors to continue improvement in wide-area reliability.

The grid is vulnerable to major disruptions, like the 2003 NE blackout.

Grid operation decision models cannot be evaluated to increase reliability.

The value of new grid services are not being captured during this time of increased complexity and market uncertainty.

A rigid grid system is insecure, and flexibility is needed to limit potential grid damage.

Where We Are – Where We Are Going

Post-Event Analysis

Blackouts of 1996, 2003

The Recovery Act

North American Synchrophasor Initiative

Standards

Data Analytics and Applications Discovery

Community of Practice

Control Room Integration

Automatic Control and Decision Support

PAST → **PRESENT** → **FUTURE**

Advanced Synchrophasor Vision

Research and evaluate the benefits of new capabilities of Wide Area Visibility and Situational Awareness

Model, interpret, and react to stream of new data to build and operate an efficient, reliable, and flexible grid system.

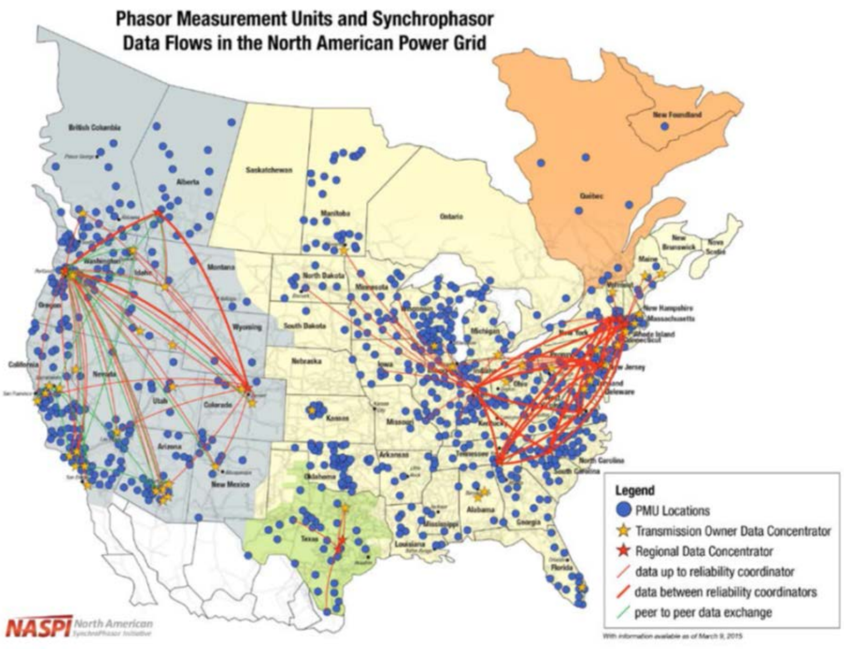
Incorporate new data to assist and inform grid operators and develop an automatic switchable grid responding to the real-time environment

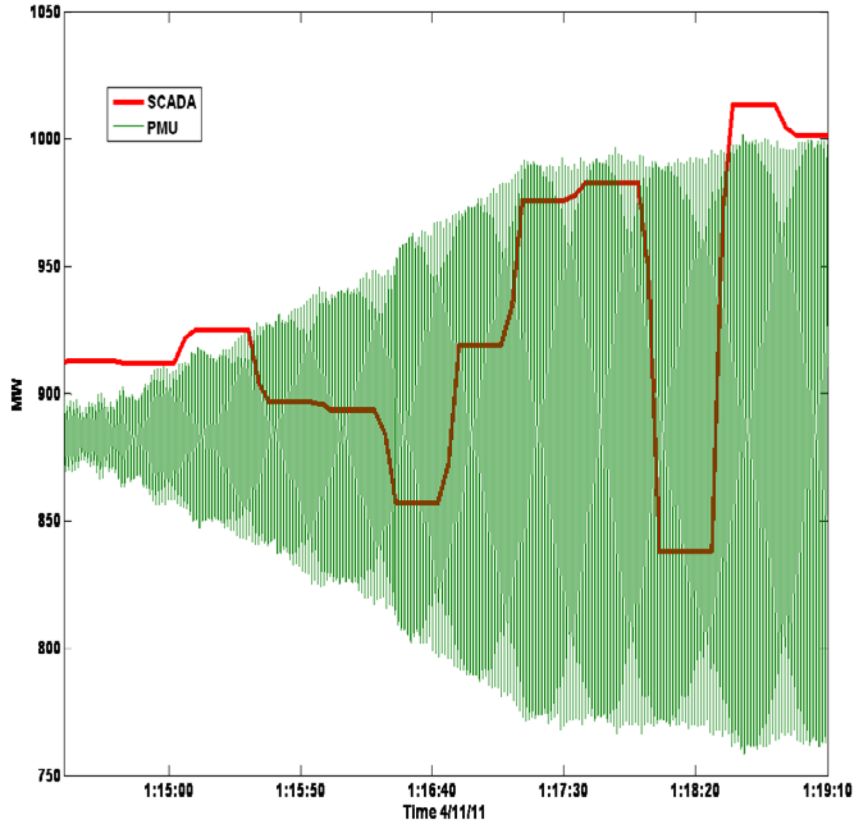
Advanced Synchrophasor Program Areas

Program Areas	Objective	Goal
North American Synchrophasor Initiative	• Realize promise of synchrophasor technology • Facilitate intelligent deployment of synchrophasors	Improve the electric power grid, improving reliability and efficiency of electricity delivery system
Advanced Application Development	• Automatic switchable network for reliable early warning for informed remedial reaction • Reliability monitoring and NERC compliance tools • Oscillation behavior	Enable wide-area measurement, monitoring management and control of electricity delivery system
Reliability and Markets	• Research, develop, and implement electricity infrastructure and market simulations	Ensure electric reliability and improve efficiency and economics of markets
Measurement Devices	• Data quality • Device calibration (NIST) • Micro PMUs at distribution level	Sustainable progress

North American Synchrophaser Initiative

The mission of the North American SynchroPhasor Initiative (NASPI) is to improve power system reliability and visibility through wide area measurement and control, by fostering the use and capabilities of synchrophasor technology.





http://fnetpublic.utk.edu/gradientmap.html

Synchrophasor Technology Accomplishments

Operators have near 100% visibility of the behavior of the entire U.S. high-voltage transmission network using over 2,000 PMUs

Better Tools, Better Reliability, Better Decisions

openECA significantly accelerates the production use and ongoing development of real-time decision support tools, automated control systems and off-line planning systems that use synchrophasor data and enhance system reliability while enabling the reliability coordinator, transmission operator, and balancing authority to work more effectively.

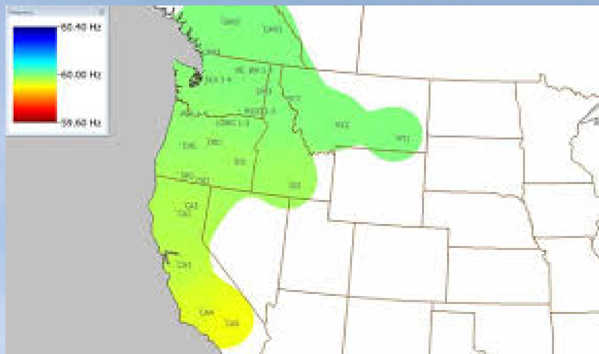
The Right Data to the Right People at the Right Time

Hawaiian Electric Company is accessing and reviewing synchrophasor data from devices on Maui and Hawaii. The project informs and encourages use of new, diverse visualization techniques and high-fidelity grid data, including synchrophasor data within familiar, production-ready environments to aid decision making and transformational change.

Improved Situational Awareness

Burns & McDonnell is developing a suite of tools to address key stability issues in a power grid: small signal stability, voltage stability, and transient stability. Benefits include integrated power grid stability monitoring and analysis, improved capability of real-time visualization of system operation status, and enhanced situational awareness for operators in real-time operation environment.

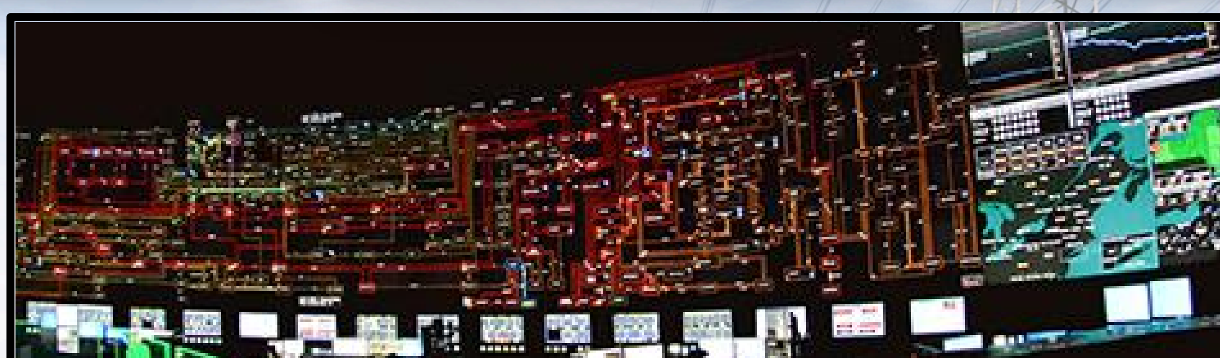
On The Horizon



- Distributed PMUs
- Timing functions: Better atomic clock in PMUs; GPS and Loran for positioning

- Integrate renewables, solar, wind and model validations
- Data sharing at utility level

- Data quality
- Micro PMUs for operational purposes at distribution level

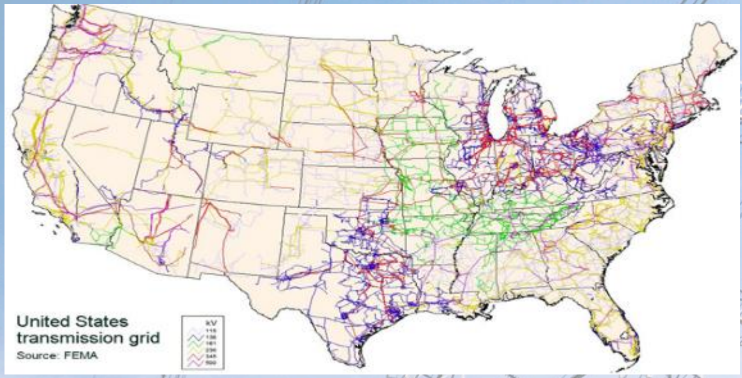


Program Accomplishments

- Developing High-Performance Computing (HPC) **State Estimation** to estimate the missing information and keeping pace with data speeds
- Developing new approached to understanding and delivering **Contingency Analysis** to address the what if scenario
- Integrating **planning dynamics and system protection simulations models** in computer aided protection engineering tool (CAPE ™), enabling more accurate analysis of the behavior of protection
- **Modeling Governor Deadband** and adjusting active governor ratio and load composition to match up measured Eastern Interconnection frequency responses to obtain an accurate operational model
- Developing **GridPACK** for utilities, research community and policy makers **-** Open source HPC library

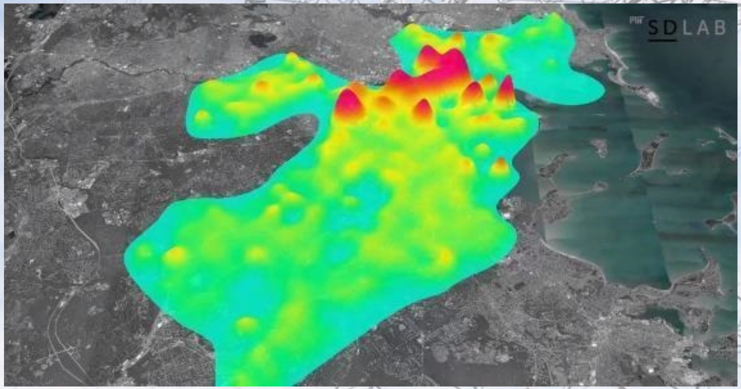
On the Horizon

Define future uncertainties, how they interact, and define priorities



Use research to address the dynamic and uncertain behavior of the system

Manage risk for better grid operations and planning



Address the proper data set and modeling

U.S. DEPARTMENT OF ENERGY | Office of Electricity Delivery & Energy Reliability

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