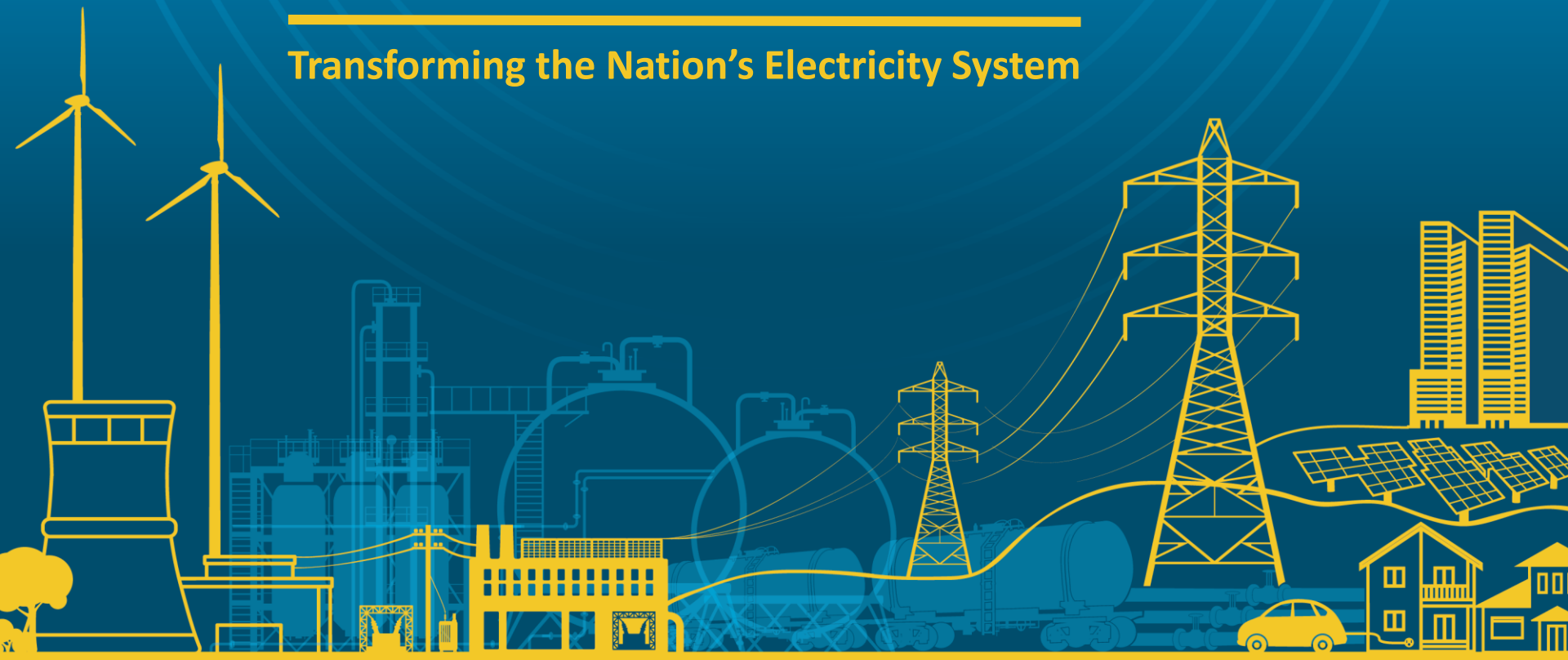
Quadrennial Energy Review

Second Installment

Transforming the Nation's Electricity System



January 2017 | Washington, D.C.

Overview of the QER

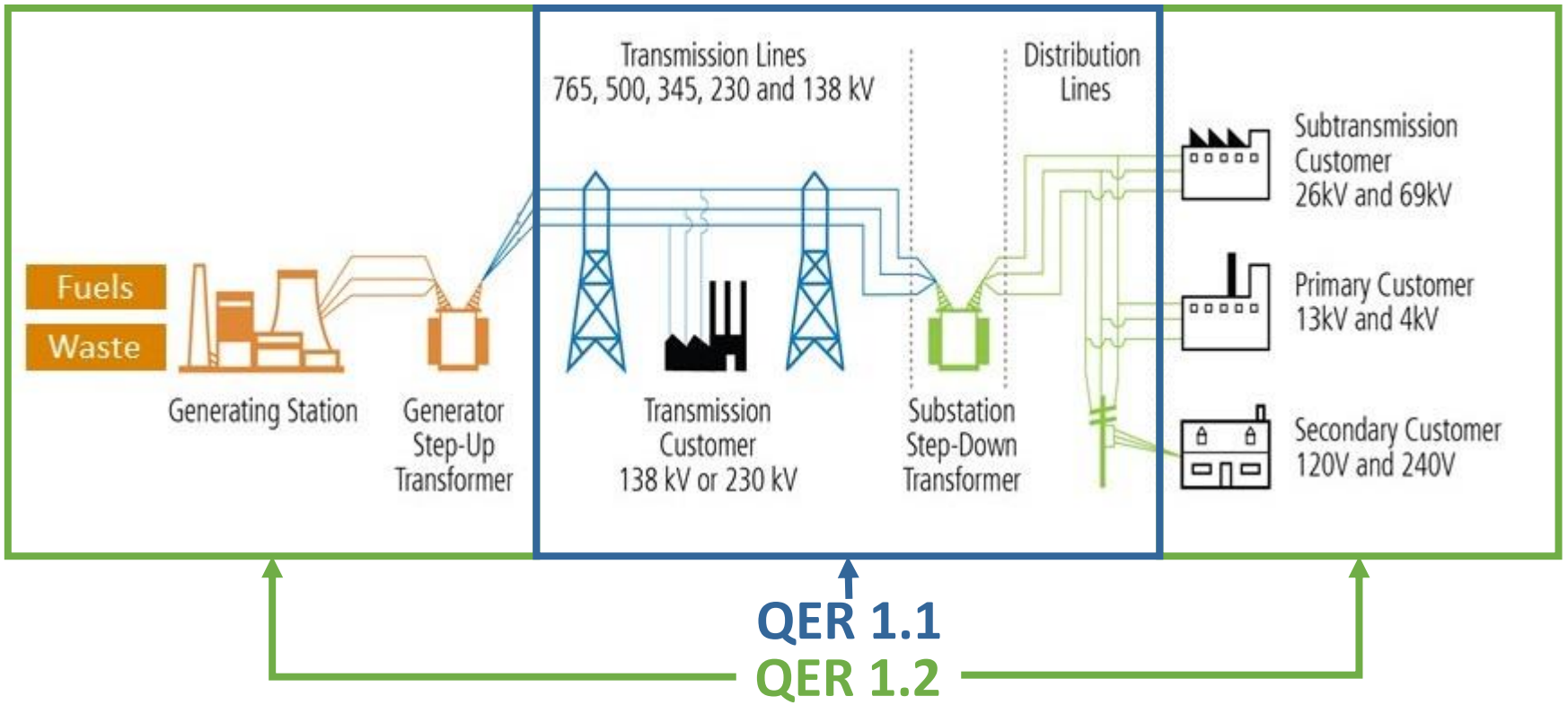
Objectives

- **Integrated view** of short-, intermediate-, and long-term objectives for Federal energy policy.
- **Strong analytical basis** for decision-making.
- **Outline of legislative** proposals to Congress.
- **Executive actions** (programmatic, regulatory, fiscal, etc.) across multiple agencies.
- **Resource requirements** for RD&D and incentive programs.

Building on Previous Work

- **First installment (QER 1.1) proposed 63 recommendations** regarding transmission, storage, and distribution infrastructure.
- **21 recommendations fully or partially implemented into law** through bipartisan support in Congress.
- **16 state and national energy organizations** issued public statements of support.
- **More than 30 countries** received overview briefings.
- **Implementation Report Card** published in November 2016.

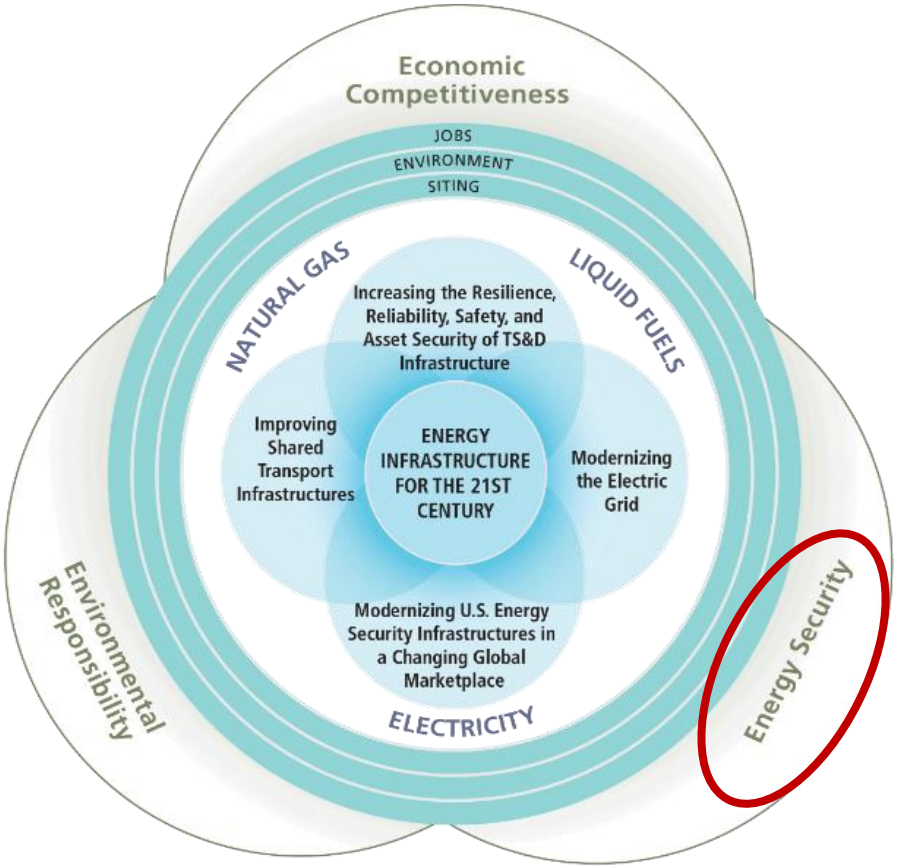
QER Scope and Context



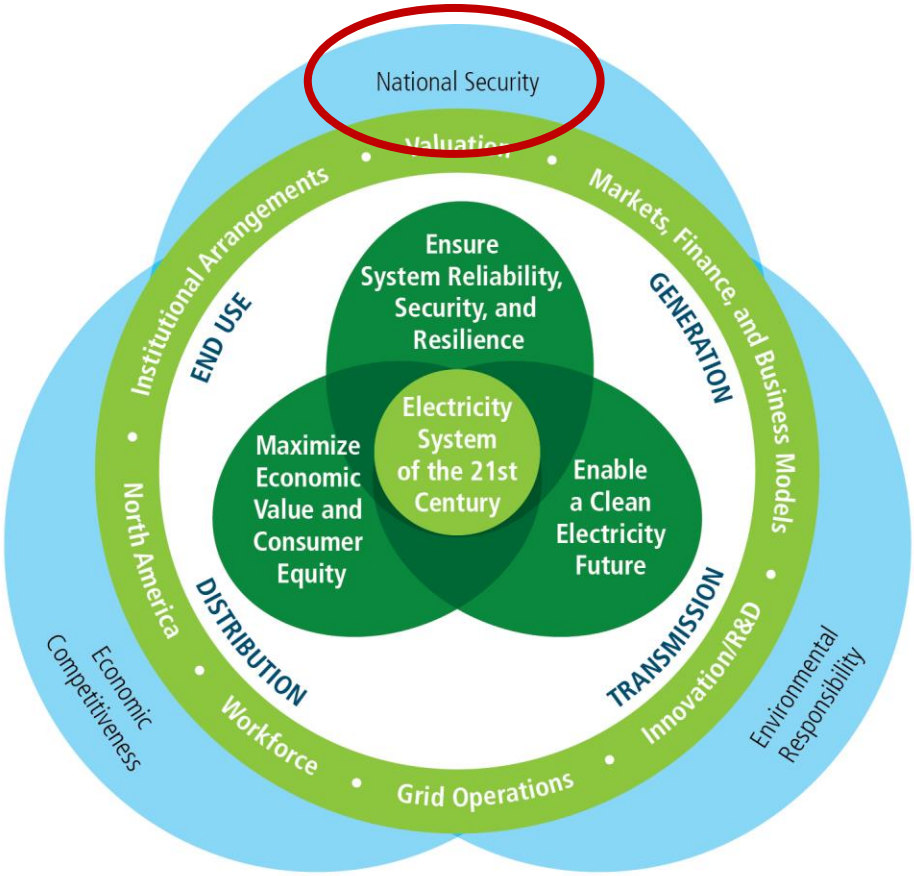
Central Finding of QER 1.2

The electricity system is the enabler for accomplishing three key national goals: ***(1) improving the economy****,* ***(2) protecting the environment****, and* ***(3) increasing national security****. As a critical and essential national asset, it is a strategic imperative to protect and enhance the value of the electricity system through modernization and transformation.*

Framing National Goals



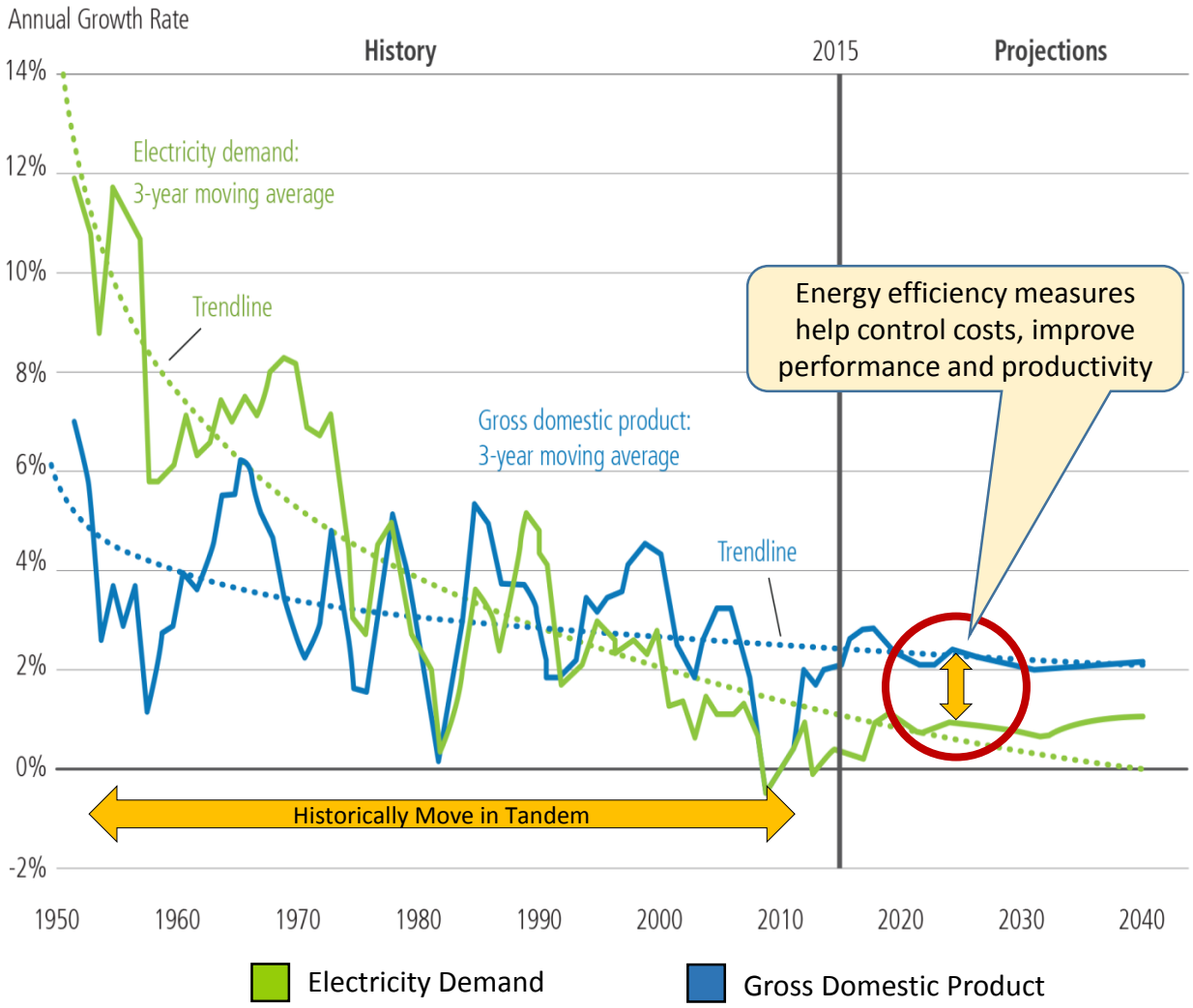
QER 1.1



QER 1.2

National Goal: Economic Competitiveness

U.S. GDP and Electricity Demand Growth Rates, 1950–2040



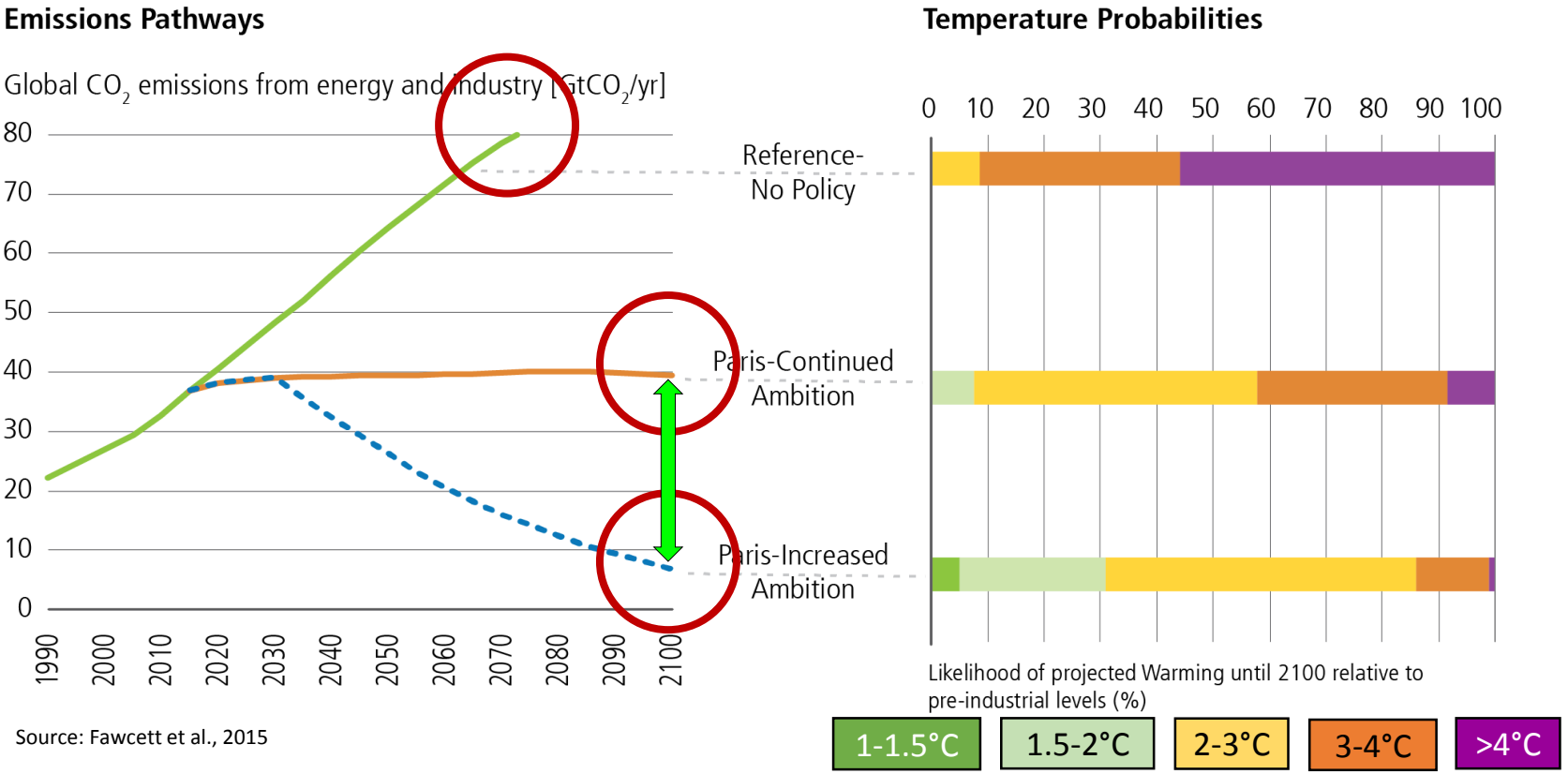
Source: Energy Information Administration, 2016

- With some of the lowest electricity prices in the developed world, the U.S. electricity sector supports the economic competitiveness of U.S. goods and services in both domestic and global markets.
- Almost all economic sectors now rely, in varying degrees, on highly interconnected, data-driven, and electricity-dependent systems to manage operations and provide services.
- Three electricity-reliant areas of the economy—online talent platforms, big-data analytics, and the Internet of Things—could increase GDP by as much as $2.2 trillion in 2025.

National Goal: Environmental Responsibility

- The electricity system is the largest source of air emissions impacting public health; it is also one of the largest users of fresh water and the principal source of radioactive waste.
- The electricity system will likely play a significant role in the decarbonization of other sectors of the U.S. economy as electrification of transportation, heating, cooling, and industrial applications continues.

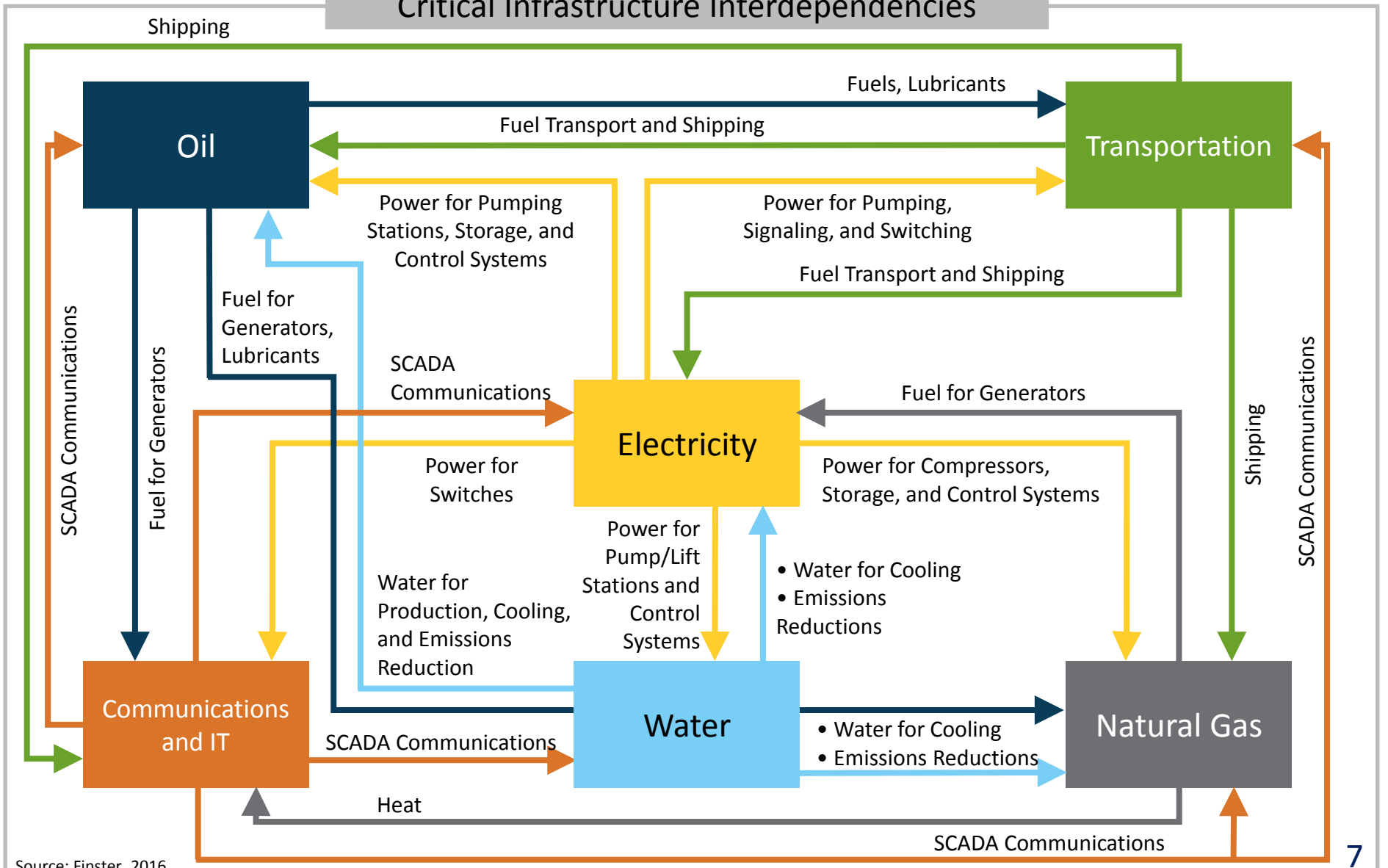
Global CO_2 Emissions and Probabilistic Temperature Outcomes



Source: Fawcett et al., 2015

National Goal: National Security

Critical Infrastructure Interdependencies

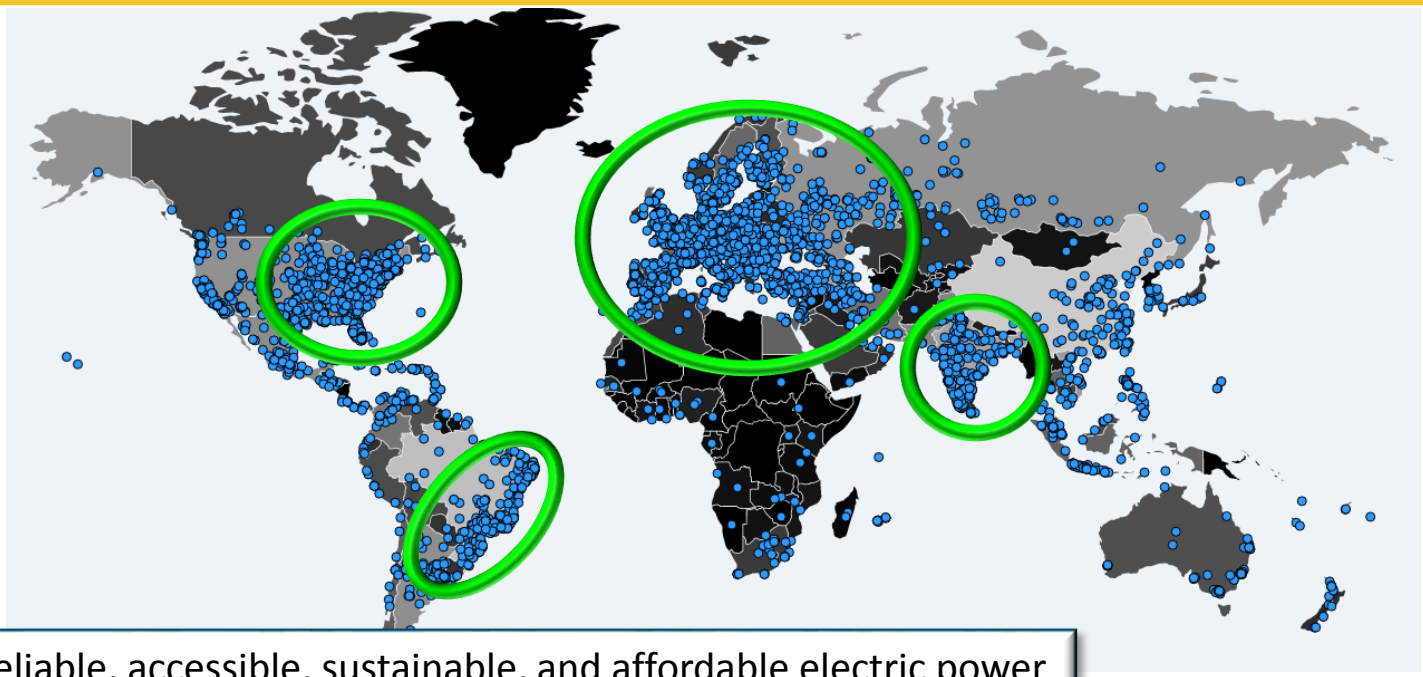


Source: Finster, 2016

Electricity Is a Critical and Essential Asset

Mirai Botnet Attack

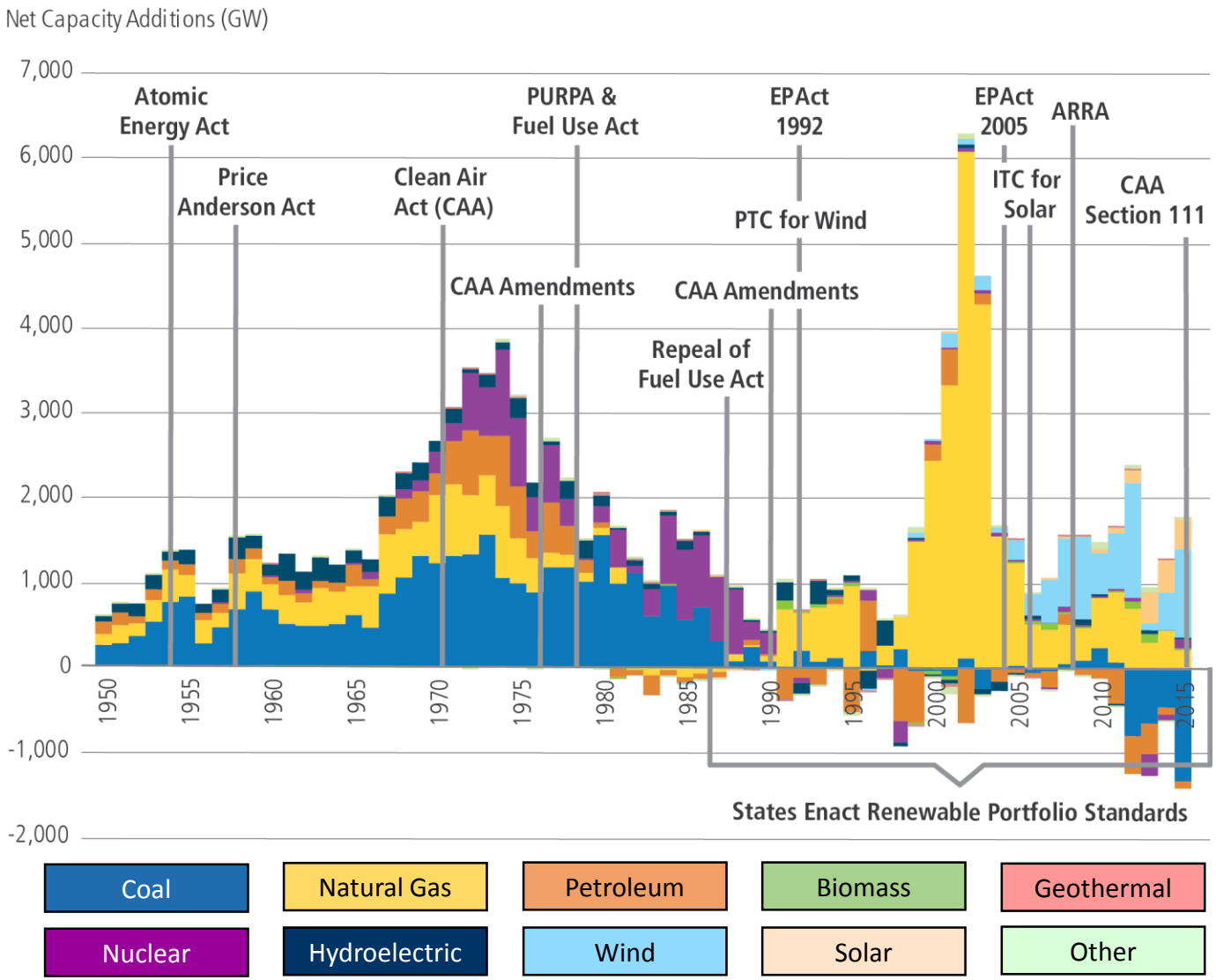
October 21, 2016



"Assuring that we have reliable, accessible, sustainable, and affordable electric power is a national security imperative. Our increased reliance on electric power in every sector of our lives, including communications, commerce, transportation, health and emergency services, in addition to homeland and national defense, means that large-scale disruptions of electrical power will have immediate costs to our economy and can place our security at risk. Whether it is the ability of first responders to answer the call to emergencies here in the United States, or the readiness and capability of our military service members to operate effectively in the U.S. or deployed in theater, these missions are directly linked to assured domestic electric power."

– Center for Naval Analysis, 2015

Federal Policy Shapes Electricity Generation



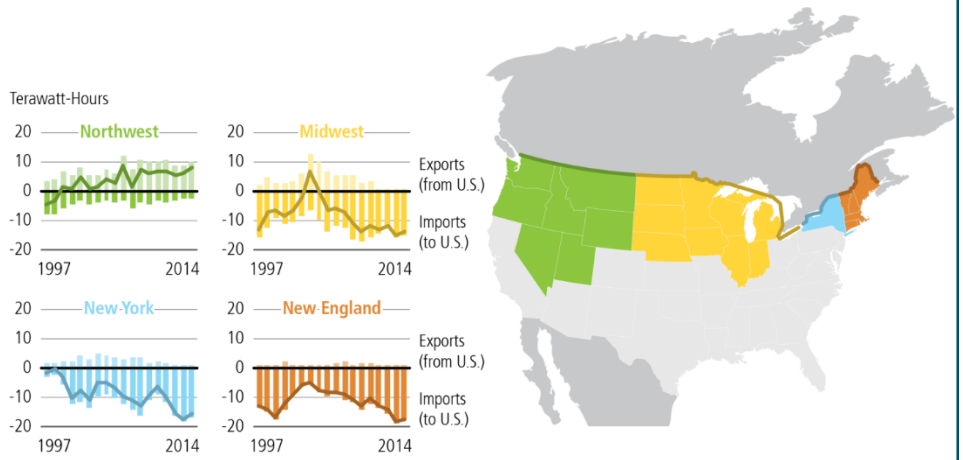
Source: Energy Information Administration, 2015

Findings

- Federal policies can shape investment decisions as much or more than fuel costs and technology development.
- This is currently evident with variable energy resources (VERs) increasing in both capacity additions and generation due to new technologies, cost reductions, and a range of state and Federal policies.
- Regional generation mixes vary significantly from the national generation profile.

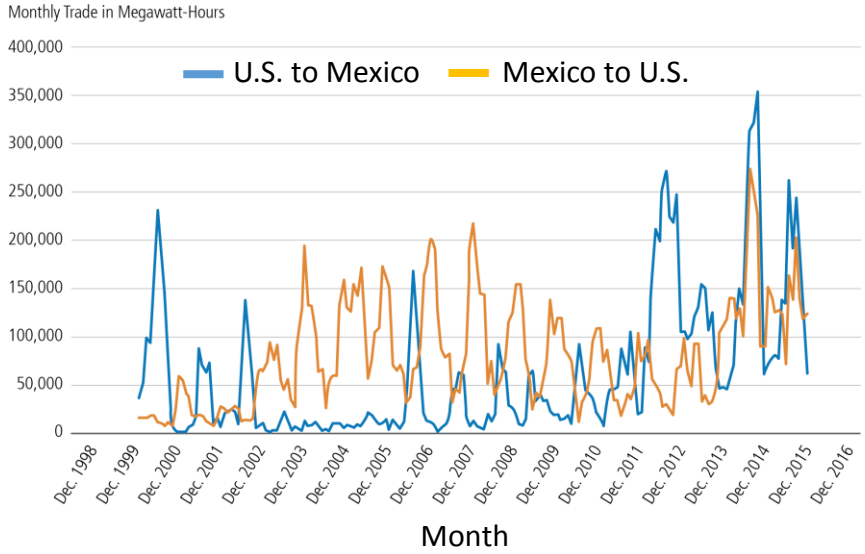
North American Electricity Integration

U.S. Electricity Trade with Canada in Four Regions



Source: Energy Information Administration, 2015

Electricity Flows between the U.S. and Mexico



Source: Department of Energy, 2016

Findings

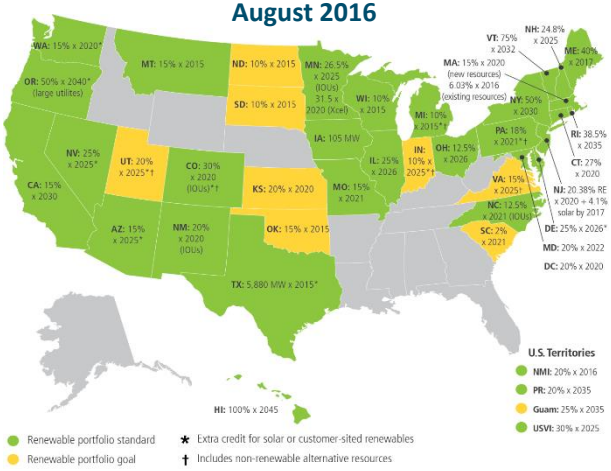
- Trade has been increasing across the North American bulk power system, but cross-border flows, especially between Canada and the United States, are now using the full capacity of existing transmission infrastructure.
- U.S.-Canada cross-border electricity trade and coordination of operations, policy, and regulatory planning are extensive, mature, and efficient, as evidenced by the December 2016 *Joint U.S.-Canada Electric Grid Security and Resilience Strategy*.
- One model for power-sector collaboration across national borders is demonstrated by the reliability planning under NERC, but this engagement has been limited to Canada, the U.S., and the Baja California region of Mexico. Notably, Mexico's ongoing electricity reform could have significant impacts on the future of cross-border integration.

Impacts of State Electricity Policies

Findings

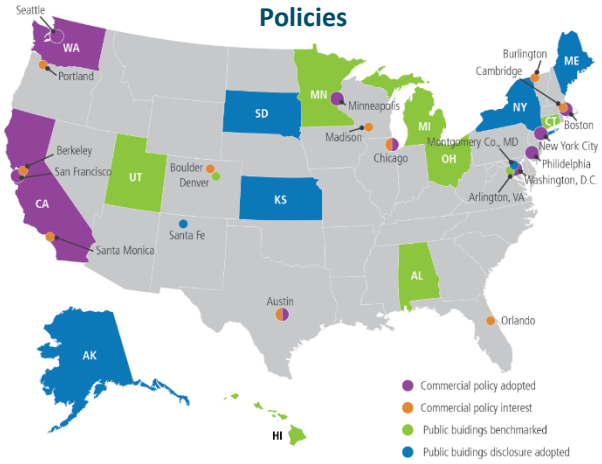
- Over half of the 230 TWh of total non-hydro renewable electricity generation growth since 2000 was to meet RPS mandates.
- Building energy benchmarking and transparency policies have been implemented by 8 states and 14 cities.
- More than 20 state and Federal policies exist to incentivize the installation of PEV charging infrastructure.
- Net metering has contributed to the deployment of 12,300 MW of installed distributed PV in the U.S. as of Sept. 2016.

State Renewable Portfolio Standard Policies, August 2016



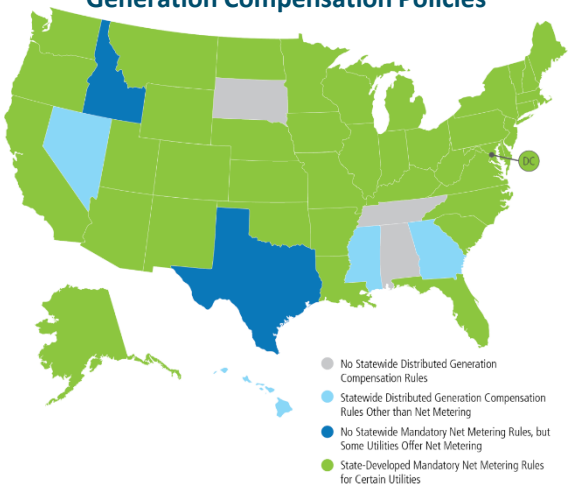
Source: NC Clean Energy Technology Center, 2016

U.S. Building Benchmarking and Disclosure Policies



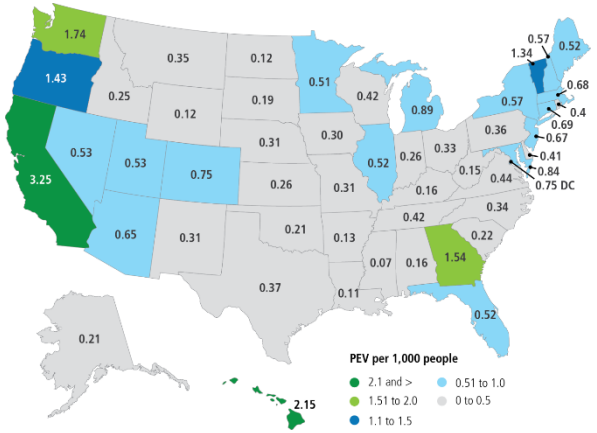
Source: Keicher, 2016

Current Net Metering and Distributed Generation Compensation Policies



Source: NC Clean Energy Technology Center, 2016

PEV Registrations Per 1,000 People by State in 2015



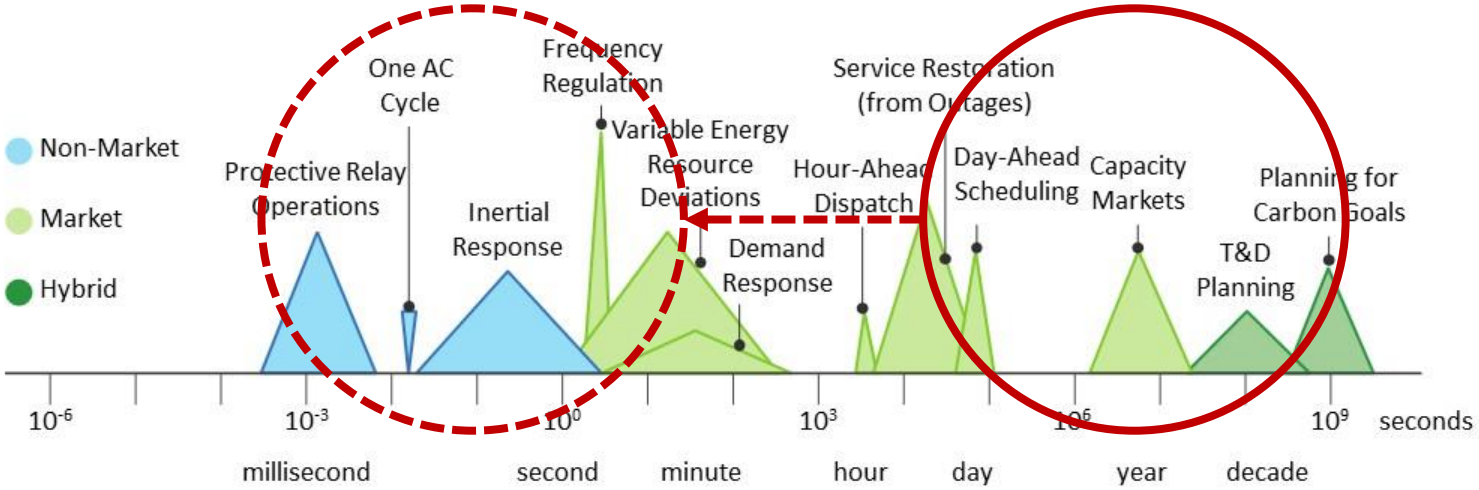
Source: Department of Energy, 2015

Evolving Requirements for System Operations

Findings

- The widespread integration of VERs at both utility scale and distributed across all consumer segments requires much faster response time by grid operators to maintain resilience and an efficient grid.
- Dispatch effectiveness will require the integration of automated grid management with continuing human oversight as well as an increase in the granularity, speed, and sophistication of operator analytics.

System Reliability Depends on Managing Multiple Event Speeds



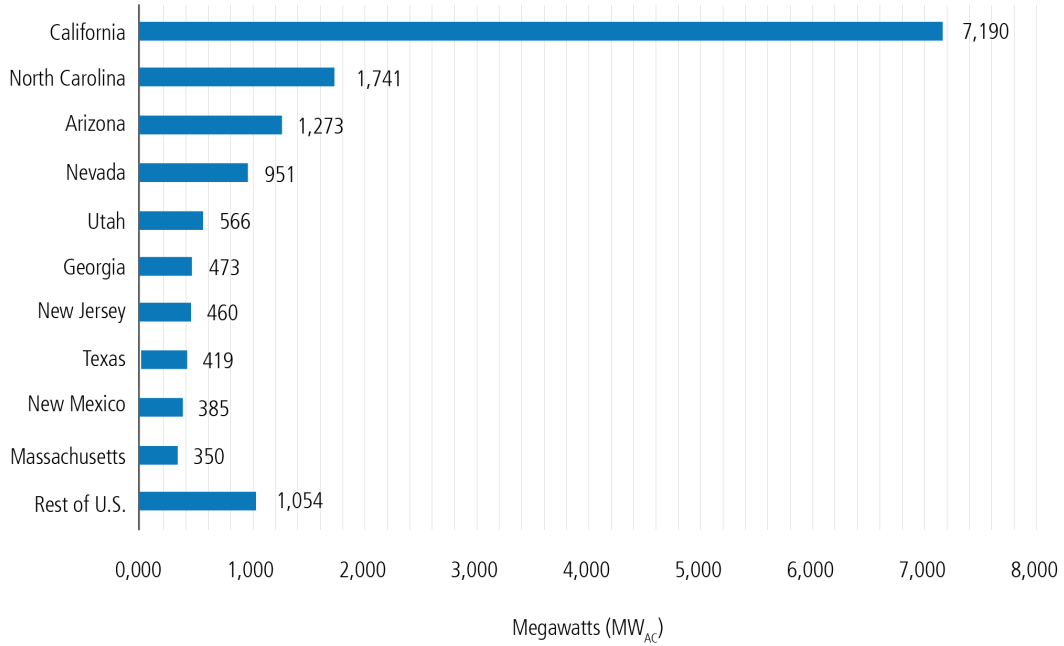
Source: von Meier, 2014

Role of Utility Scale Renewables

Findings

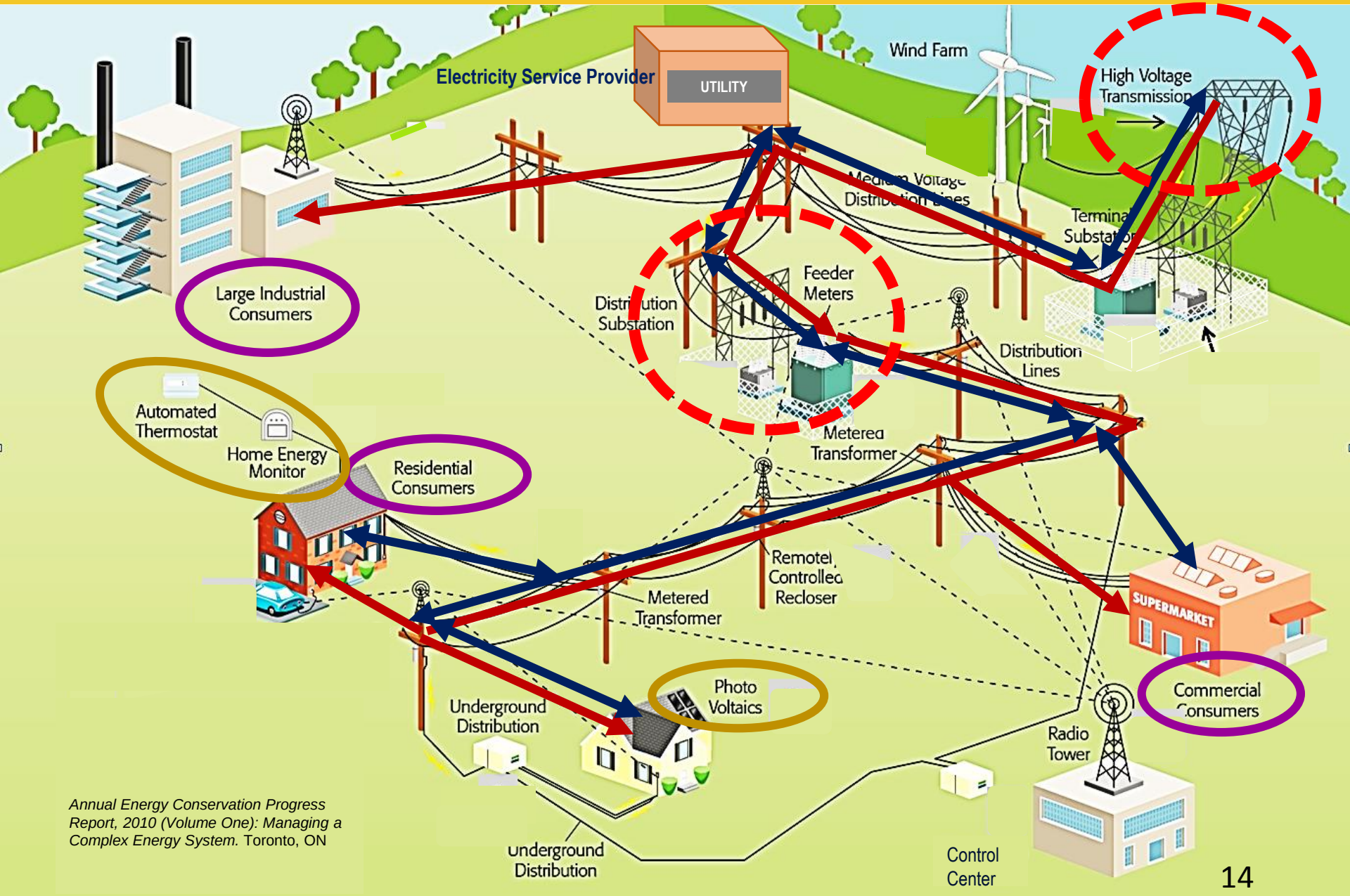
- The integration of variable renewables increases the need for system flexibility as the grid transitions from controllable generation and variable load to more variable generation and the need and potential for controllable load. There are a number of flexibility options such as demand response (DR), fast ramping natural gas generation, and storage.
- At high penetration levels, distribution system changes to enhance DER value to grid reliability will require development of advanced distribution circuits and substations that allow for two-way power flows, new protection schemes, and new control paradigms.

Utility-Scale PV Installed Capacity, Top 10 States, as of August 2016



Source: Energy Information Administration, 2016

Increasingly Complex Electricity Systems

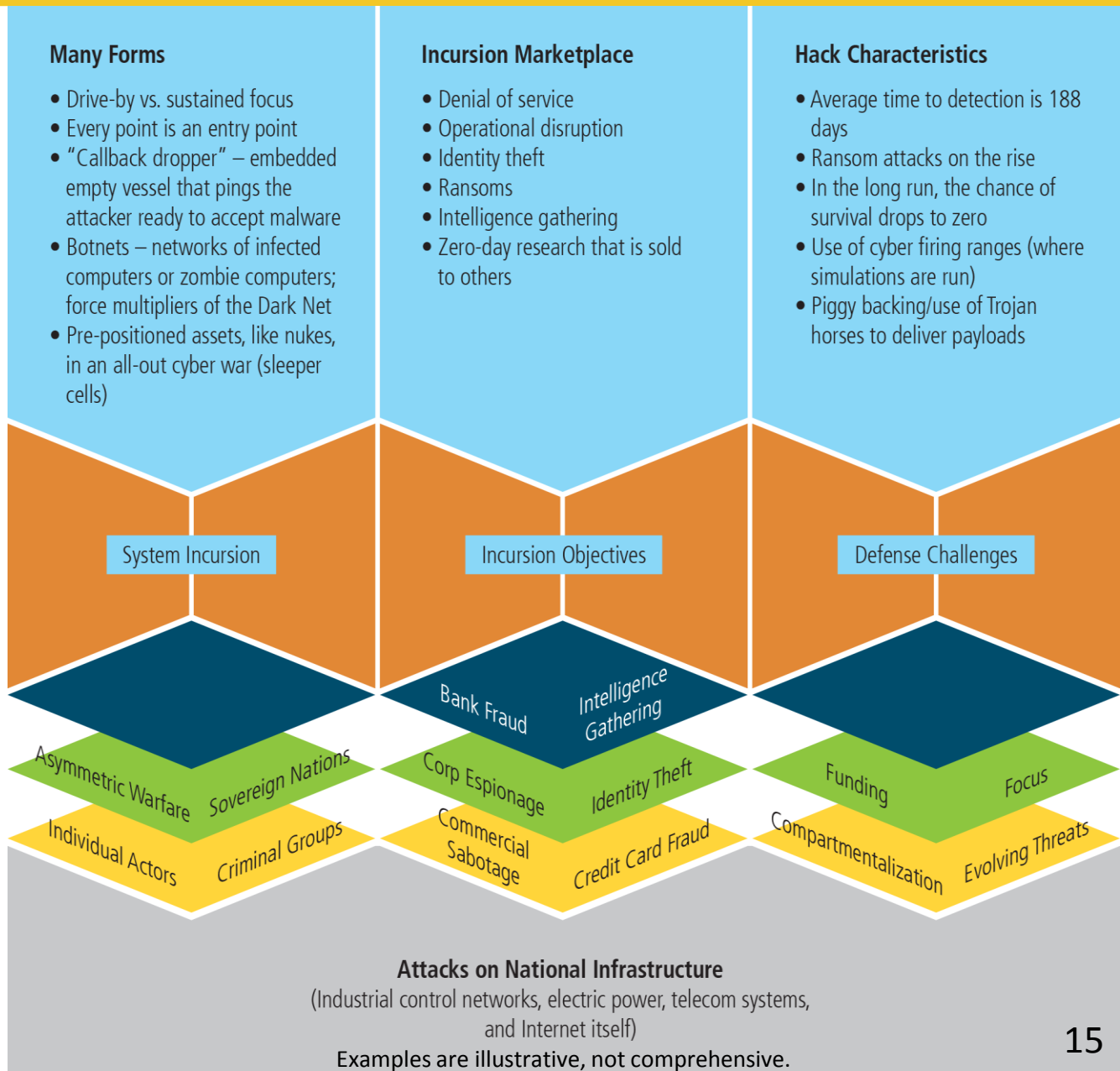


Annual Energy Conservation Progress Report, 2010 (Volume One): Managing a Complex Energy System. Toronto, ON

Evolving Cyber Threats

Findings

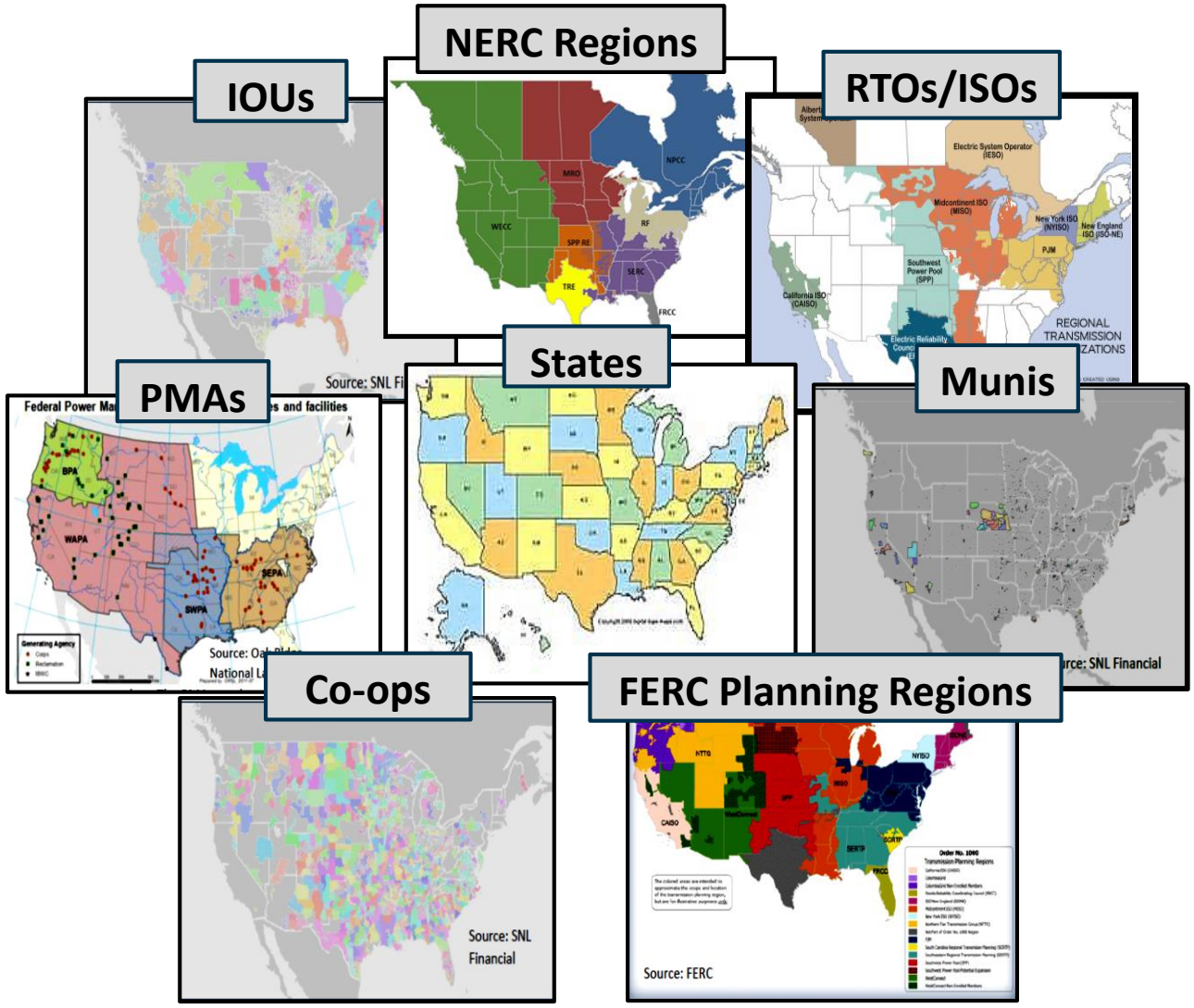
- Mitigation and response to cyber threats are hampered by fragmented information-sharing among utilities and with government, the lack of security-specific technological and workforce resources, and challenges associated with the need for multi-jurisdictional responses to threats and consequences.
- Key vulnerabilities include unpatched networks, un-vetted vendor access, access to the public Internet, and insider threats.



Electricity System Governance Issues

Findings

- Responsibility for regulating and overseeing the electric power industry spans Federal, state, local, and tribal levels.
- Division of authorities between the Federal and state levels is becoming increasingly hazy as new technologies and services create more two-way connections between the transmission and distribution systems.
- Varying markets—including regulated cost-of-model and organized structures–have differing levels of jurisdictional oversight.



Recommendation Overview

- The analysis conducted for QER 1.2 identified *integrated objectives* that address the needs and challenges to enable the electricity sector of the 21st century.

- Recommendations will provide the incremental building blocks for longer-term, planned changes and activities, undertaken in conjunction with state and local governments, policy-makers, industry and other stakeholders.

QER 1.2 Proposes 76 Recommendations in Six Focus Areas

- Key Crosscutting National Security and Reliability Priorities
- Maximize Economic Value & Consumer Equity
- Enable a Clean Electricity Future
- Ensure System Reliability, Security, and Resilience
- Electricity Workforce
- Enhancing Electricity Integration in North America

QER 1.2 Recommendations

Protect the Electricity System as a National Security Asset.

- Amend the *Federal Power Act* to:
  - Clarify and affirm DOE's authority under the FAST Act to develop preparation and response capabilities that will ensure it is able to issue a grid-security emergency order to protect critical electric infrastructure from cyber attacks, physical incidents, EMPs, or geomagnetic storms. In this regard, DOE's authority should include the ability to address two-way flows that create vulnerabilities across the entire system; and
  - Authorize FERC to propose new reliability standards and to modify NERC-proposed reliability standards if FERC finds that expeditious action is needed to protect national security in the face of fast-developing new threats to the grid.
- Collect information on security events to inform the President about emergency actions and imminent dangers.
- Adopt integrated electricity security planning and standards on a regional basis.
- Assess natural gas/electricity system infrastructure interdependencies for cybersecurity protections.

QER 1.2 Recommendations

Increase Financing Options for Grid Modernization

- Expand DOE's loan guarantee program and make it more flexible to assist in deployment of innovative grid technologies and systems.

Increase technology demonstrations and utility/investor confidence.

- Significantly expand existing programs to demonstrate the integration and optimization of distribution system technologies.

Build Capacity at the Federal, State, and Local Levels.

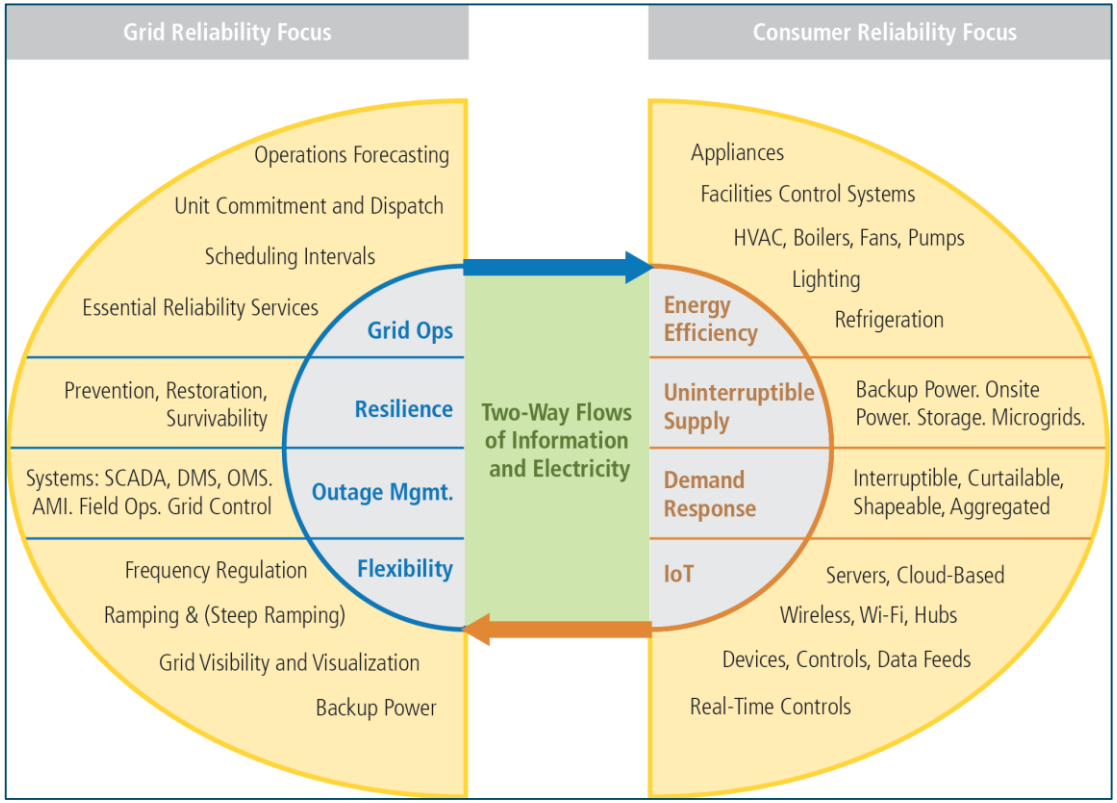
- Provide funding assistance to enhance capabilities in state public utility commissions and improve access to training and expertise for small and municipal utilities.
- Create a center for Advanced Electric Power System Economics to provide social science advice and economic analysis on an increasingly transactive and dynamic 21st century electricity system.

Inform Electricity System Governance in a Rapidly Changing Environment.

- Establish a Federal Advisory Committee on alignment of responsibilities for rates and resource adequacy.

QER 1.2 Recommendations

Electric Service Reliability Increasingly Interactive between Grid and Consumer



Source: Department of Energy, 2016

Select Recommendations

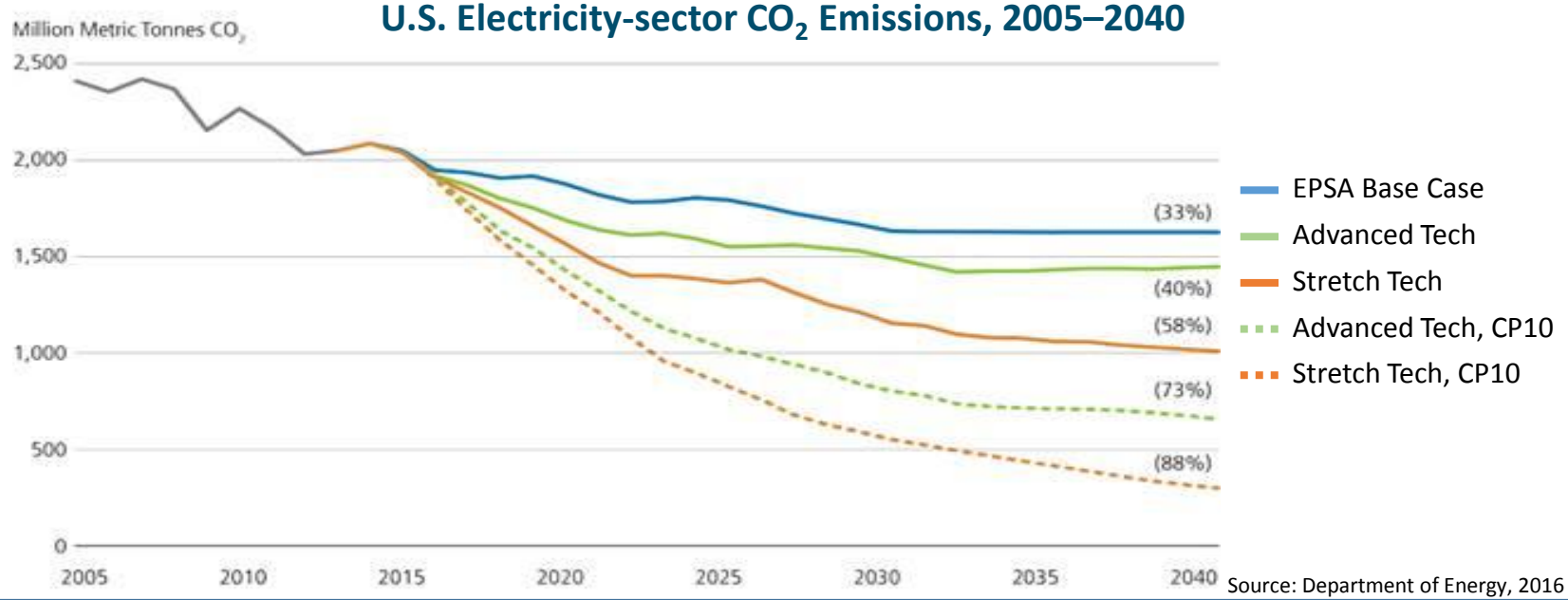
- Tailor and increase tools and resources for states and utilities to effectively address transitions underway in the electricity system.
- Expand Federal and state financial assistance to ensure electricity access for low-income and under-served Americans.
- Increase electricity access and improve electricity-related economic development for tribal lands.
- Strengthen rural electricity and broadband infrastructure.

QER 1.2 Recommendations

Select Recommendations

- Transform the electricity system through leadership in national clean electricity technology innovation by significantly increasing Federal investment in innovative energy technology RD&D.
- Address challenges to large-scale, centralized clean generation including nuclear, hydropower, and non-hydropower renewables.
- Address significant energy-water nexus issues affecting—and affected by—the electricity sector.
- Provide federal tax incentives for a range of electricity-related technologies and systems including renewable energy, electric vehicles, energy efficiency, nuclear generation, and CCUS.

U.S. Electricity-sector CO_2 Emissions, 2005–2040



Source: Department of Energy, 2016

QER 1.2 Recommendations

- Key Crosscutting Priorities
- Reliability, Security, Resilience
- Economic Value & Consumer Equity
- Electricity Workforce
- Clean Electricity Future
- North American Integration

Select Recommendations

- Support industry, state, local, and Federal efforts to enhance grid security and resilience.
- Improve data on all-hazard events and losses as well as EIA's data, modeling, and analysis capabilities.
- Encourage cost-effective use of advanced technologies that improve transmission operations.

Levels of Risk	Current Status of Risk Management Practice
○ Low	○ Nascent: Critical Vulnerabilities Exist
◔ Moderate	◑ Established, but opportunities for improvement remain
● High	● Well-established and robust
○ Unknown	

Source: Preston et al., 2016

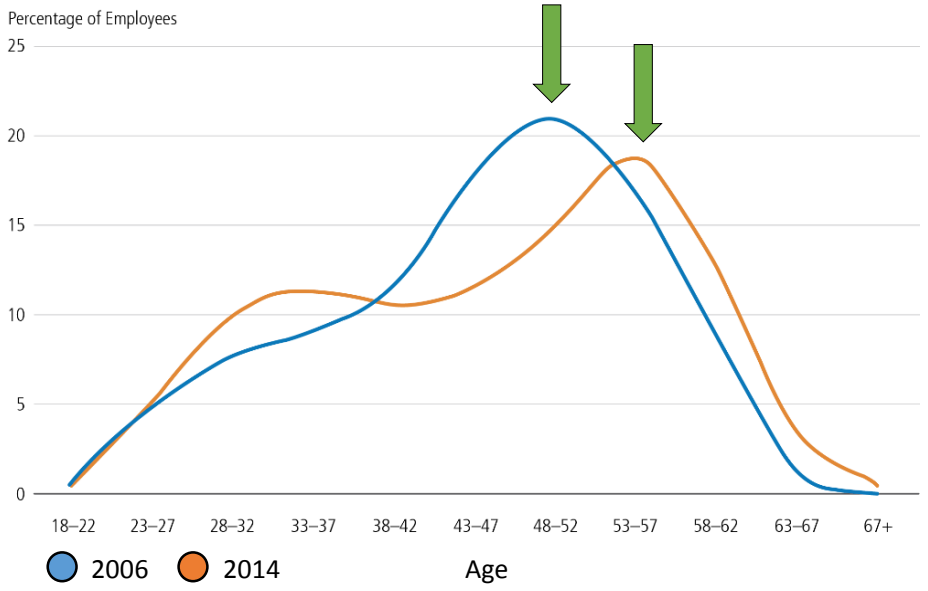
Threat	Intensity	System Components: Electricity Transmission	Electricity Generation	Electricity Substations	Electricity Distribution (above)	Electricity Distribution (below)	Storage
		Assessment of Risk & Resilience					
Natural/Environmental Threats							
Hurricane	"Low (<Category 3)"	●	●	●	●	●	◑
	"High (>Category 3)"	◑	●	●	◑	●	◑
Drought	"Low (PDSI>-3)"	●	●	●	●	●	●
	"High (PDSI<-3)"	●	◑	●	●	●	◑
Winter Storms/Ice/Snow	"High (PDSI<-3)"	●	●	●	●	●	●
	"Low (Minor icing/snow)"	●	●	●	●	●	●
Extreme Heat/Heat Wave		●	◑	●	●	●	●
Flood	"Low (<1:10 year ARI)"	●	●	●	●	●	●
	"High (>1:100 year ARI)"	●	◑	◑	◑	●	●
Wildfire	"Low (>Type III IMT)"	●	●	●	●	●	●
	High (Type I IMT)	●	●	●	●	●	●
Sea-level rise		●	●	●	●	●	●
Earthquake	Low (<5.0)	●	●	●	●	●	●
	High (>7.0)	●	●	●	●	●	●
Geomag-netic	"Low (G1-G2)"	●	●	●	●	●	●
	"High (G5)"	○	◑	○	◑	○	◑
Wildlife/Vegetation		●	●	●	●	●	●
Human Threats							
Physical	Low	●	●	●	●	●	●
	High	◑	◑	◑	●	●	◑
Cyber	Low	◑	◑	◑	○	○	
	High	○	○	○	○	○	○
Electromag-netic	"Low (Ambient EMI)"	●	●	●	●	●	●
	"High (NEMP & HEMP)"	●	○	○	●	●	○
Equipment Failure		●	●	●	●	●	●
Combined Threats		○	○	○	○	○	○

QER 1.2 Recommendations

Select Recommendations

- Support development of the electricity sector workforce through curriculum, training, and education using Federal and regional approaches.
- Meet Federal commitments to communities impacted by the rapid pace of change in electricity markets.

Age Distribution in Electric and Natural Gas Utilities, 2006 and 2014



Source: Center for Energy Workforce Development, 2016

Electric Power Generation and Fuels Extraction and Mining Employment Estimates by Technology, First Quarter 2016

Technology	Electric Power Generation (Employment Estimates)	Fuels Extraction and Mining (Employment Estimates)
Hydroelectric	65,554	-
Coal	86,035	74,084
Natural Gas	88,242	309,993
Nuclear	68,176	8,592
Solar	373,807	-
Wind	101,738	-
Geothermal	5,768	-
Bioenergy	7,980	104,663
Oil	12,840	502,678
Combined Heat and Power	18,034	-
Other	32,695	82,736
Total	860,869	1,082,746

Source: USEER, 2017

QER 1.2 Recommendations

Select Recommendations

- Increase North American cooperation on electric grid security and resilience, including U.S. and Mexican cooperation on reliability and the U.S.-Canadian Grid Security Strategy and domestic Action Plans.
- Promote permitting of cross-border transmission facilities and modernize international cross-border transmission permitting processes.
- Increase North American clean energy and technical coordination to more deeply coordinate on clean energy and climate goals.

Border Crossings of Electric Transmission Lines

Source: Energy Information Administration, 2016

Accessing the QER

Electronic Version

www.energy.gov/qer