Grid Modernization

Juan Torres
Associate Laboratory Director
Energy Systems Integration

NREL at a Glance

1,800

Employees,
plus more than
400
early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

nearly 750

Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

$872M annually

National economic impact

NREL's Science Drives Innovation

Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

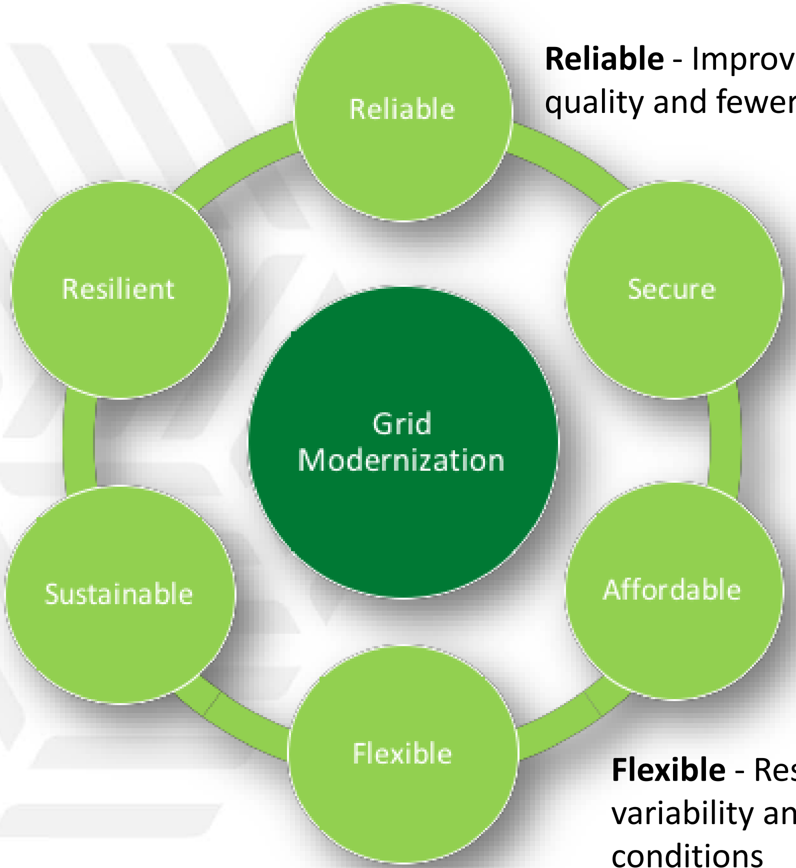
High-Performance Computing

Data and Visualization

Security and Resilience

Power Grid

Key Future Grid Attributes



Reliable - Improves power quality and fewer power outages

Resilient - Quick recovery from any situation or power outage

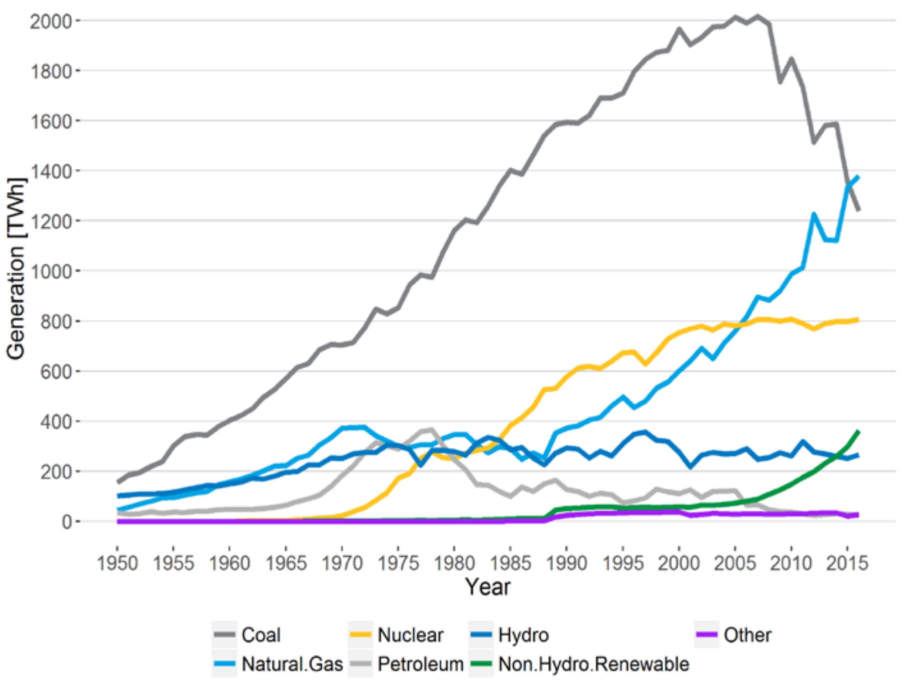
Secure - Increases protection to our critical infrastructure

Sustainable - Facilitates broader deployment of clean generation and efficient end use technologies

Affordable - Maintains reasonable costs to consumers.

Flexible - Responds to the variability and uncertainty of conditions

The Nation's Electricity Generation Mix is Changing



Source: EIA

Changes to the electricity mix: **Natural gas and renewable energy** generated nearly **50% of U.S. electricity** in 2016, up from 30% in 2007

Natural gas increased from **22% to 34%**

Renewable energy climbed from **8% to 16%**

Trends in U.S. Installed Renewable Energy Capacity

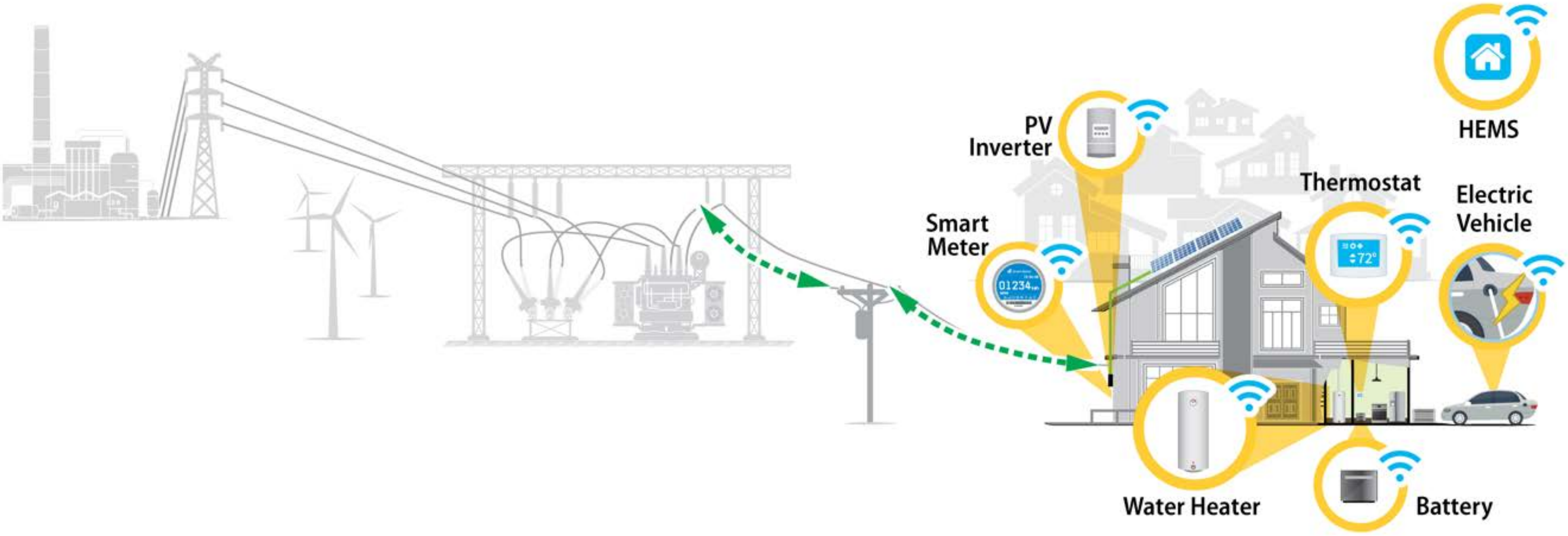
Solar

- **56 GW** = current installed capacity
- Expected to more than double over the next 5 years

Wind

- **90 GW** = current installed capacity
- By 2020, expected to increase by 10% (113 GW)
- By 2050, expected to increase by 35% (404 GW)

Consumers are Impacting Evolution of the Modern Grid



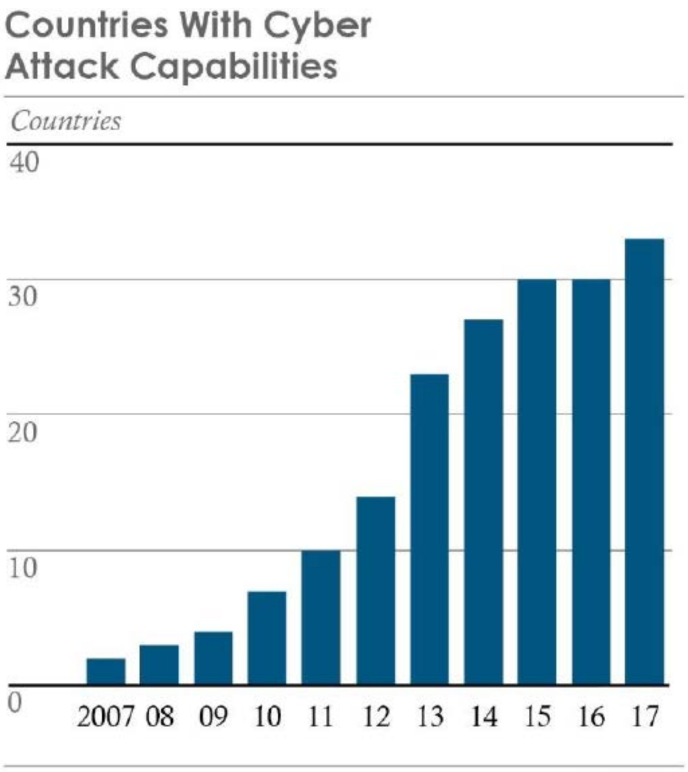
Risks to the Power Grid

Table 1: Risk Landscape

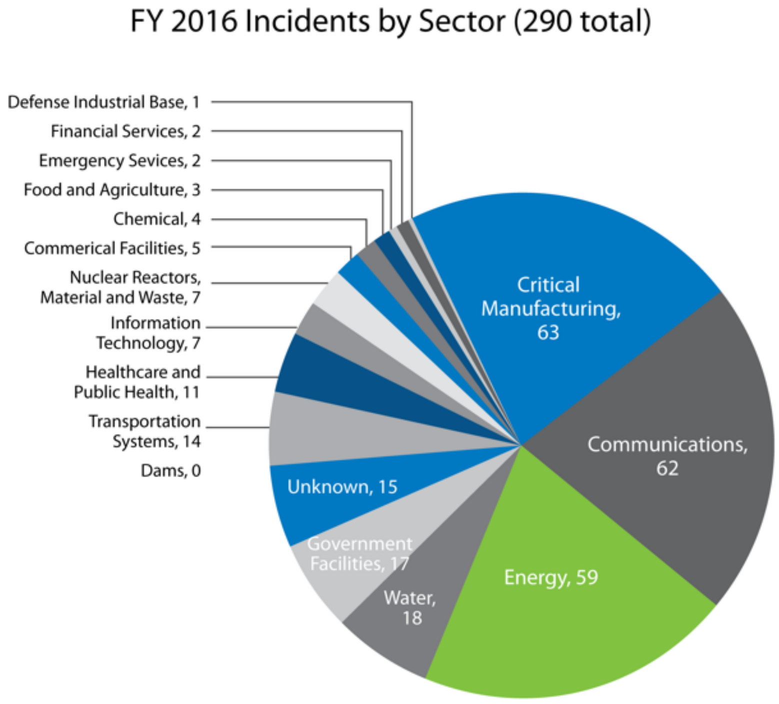
Risk Area	Opportunities for Improvement
Naturally Occurring Hazards	
• Geological (e.g. earthquake)	Plans typically in place
• Meteorological	
○ Severe storm	Plans typically in place
○ Extreme water flows (drought, flood)	Plans typically in place
○ Extreme temperature	Plans typically in place
○ Geomagnetic disturbance (GMD), solar magnetic disturbance (SMD)	Requires additional action
• Biological disease (e.g. pandemic)	Plans typically in place
Human-Caused (Unintentional) Hazards	
• Hazardous material spill or release	Plans typically in place
• Explosion, fire	Plans typically in place
• Interdependency (e.g. fuel shortage, telecommunications service disruption)	Plans typically in place
• Human operational error	Plans typically in place
Human-caused (Intentional) Hazards:	
• Local criminal activity or sabotage	Plans typically in place
• Civil disturbance, riot	Plans typically in place
• Strike or labor dispute	Plans typically in place
• Terrorism	Requires additional action
• Physical attack	Requires additional action
• Electro-magnetic pulse (EMP)	Beyond the scope of the industry
• Cyber security breach, coordinated cyber attack	Requires additional action
Technological Hazards:	
• Equipment failure	Plans typically in place
• Local information/control system failure	Plans typically in place
• Local telecommunications system failure	Plans typically in place

Source:
Critical Infrastructure Strategic Roadmap,
NERC
Electricity Sub-Sector Coordinating Council
November 2010

Trends in Cybersecurity for Critical Infrastructure Systems



Source: Worldwide Threat Assessment of the U.S. Intelligence Community, 2018



Source: National Cybersecurity and Communications Integration Center, 2016

Cyber and Physical Attacks on the Grid

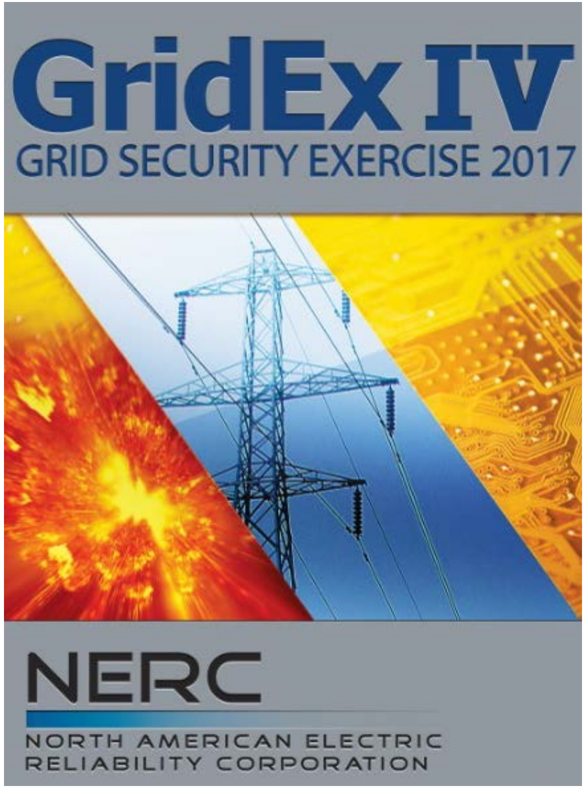
- April 16, 2013 - Metcalf substation near San Jose, CA sustained a combined physical and cyber attack
- December 23, 2015 - Cyber attack on Ukraine power system is first cyber attack resulting in power grid disruption

National Exercises Focus on Combined Cyber-Physical Attacks

GridEx is a biennial exercise designed to exercise national level response to a cyber/physical attack on the North American power grid and other critical infrastructures.

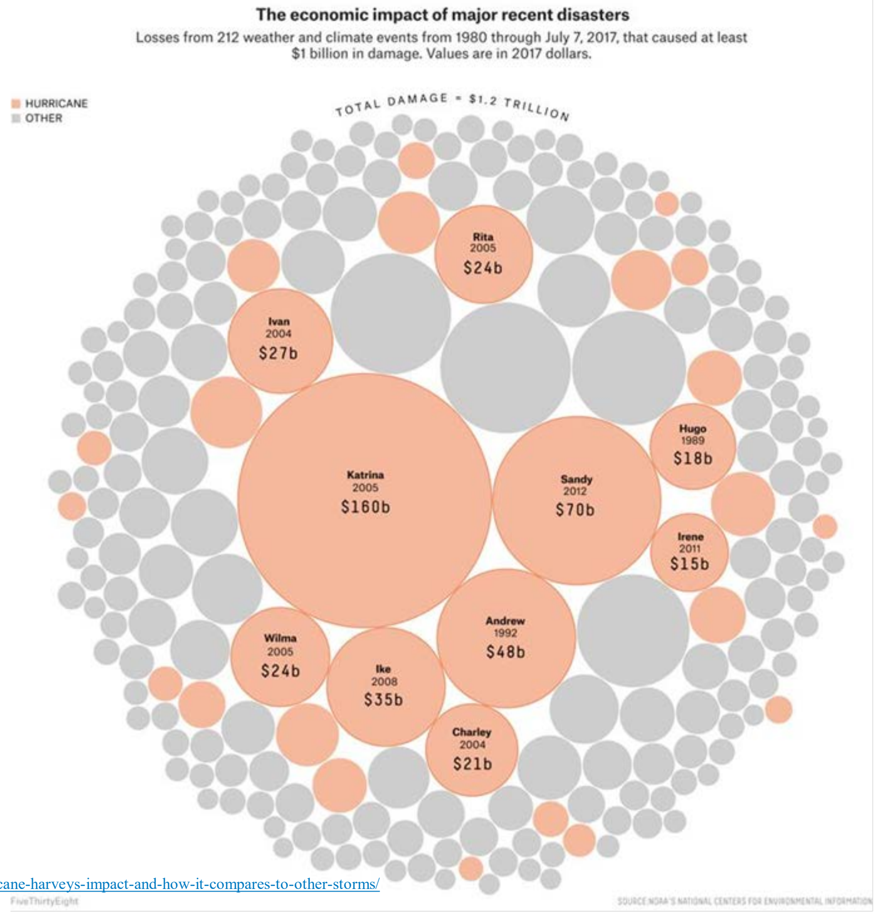
GridEx involves:

- Electric utilities
- Regional (local, state, provincial) and Federal government agencies in law enforcement, first response, and intelligence community functions
- Critical infrastructure cross-sector partners (ISACs and other utilities)
- Supply chain stakeholder organizations



Weather matters

Storms Are Costly…and Somewhat Predictable.



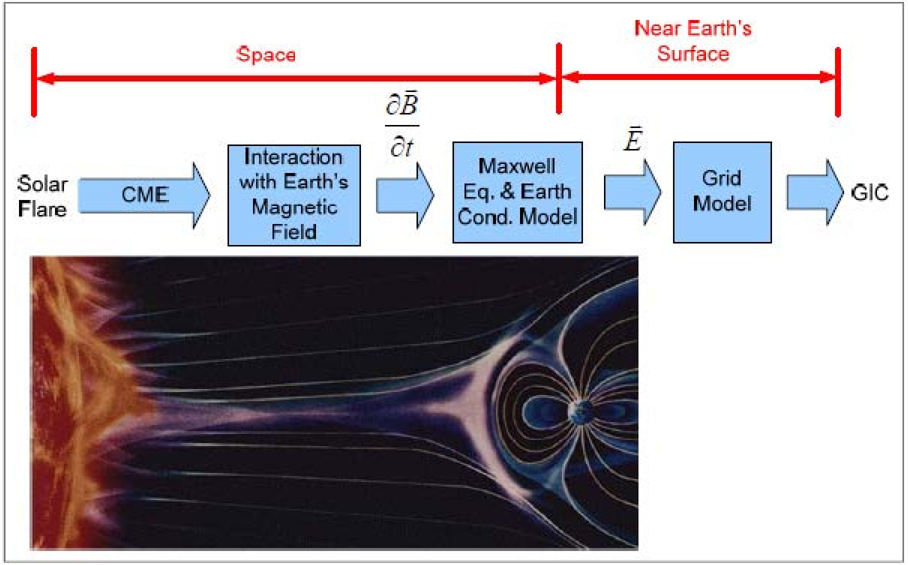
https://fivethirtyeight.com/features/hurricane-harveys-impact-and-how-it-compares-to-other-storms/

Harvey
2017
$125B

Maria
2017
$90B

Space Weather
Risks from Geomagnetic Disturbance

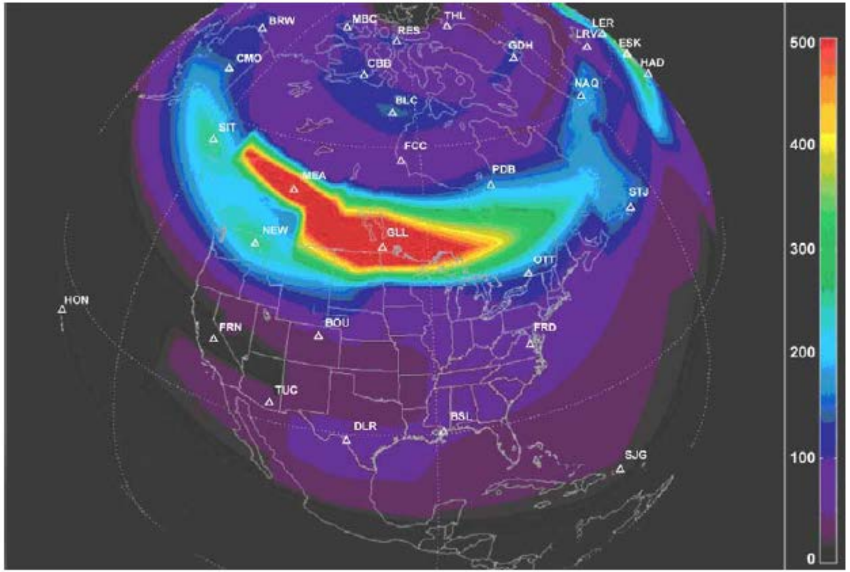
- Damage to bulk power system assets, typically associated with transformers
- Loss of reactive power support, which could lead to voltage instability and power system collapse.



Source: NERC 2012 Special Reliability Assessment Interim Report: Effects of Geomagnetic Disturbances on the Bulk Power System

Solar Storm Example

- 1989 Hydro-Quebec outage due to solar storm
- 6M people affected
- 9 hour outage

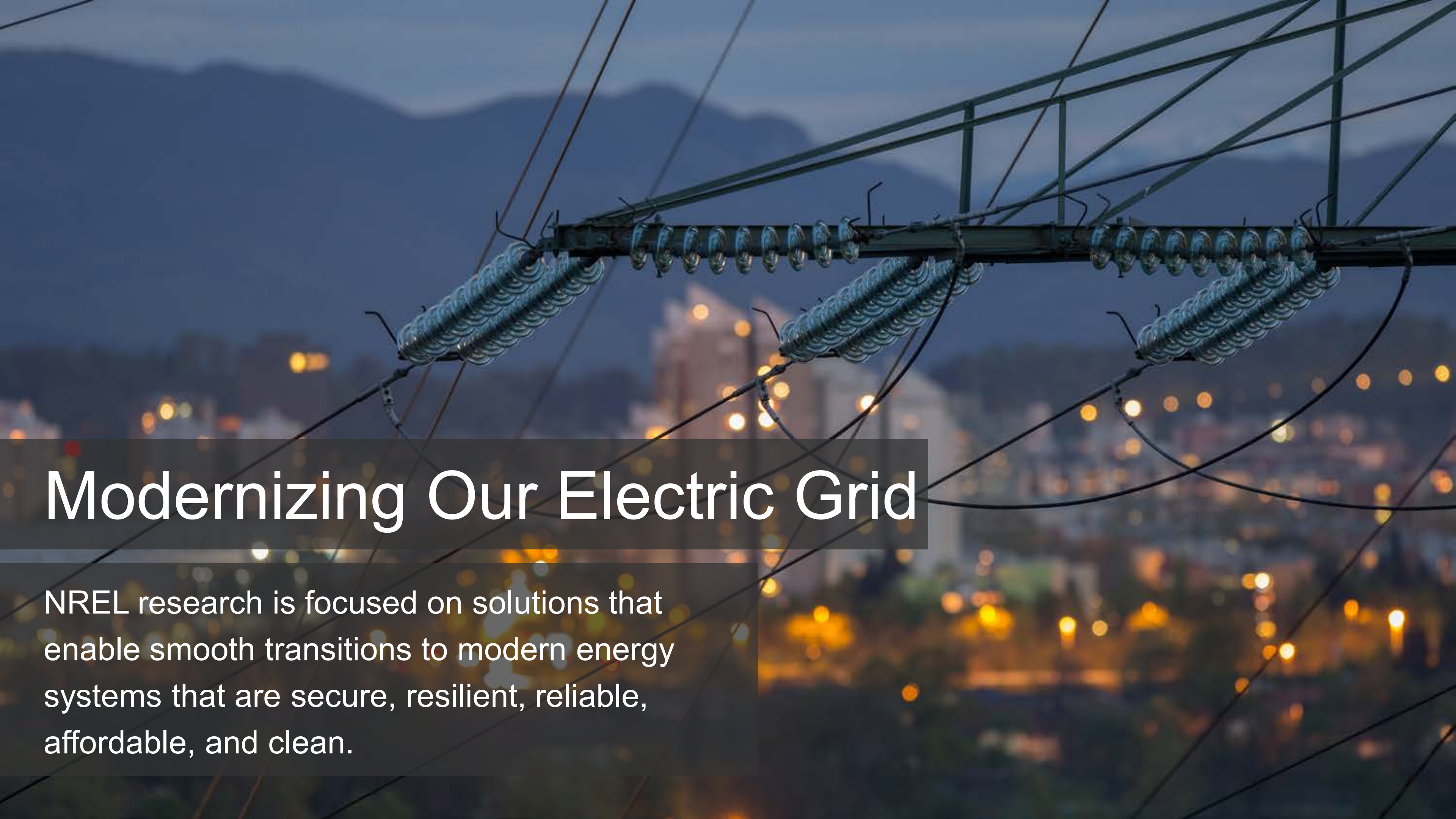


Geomagnetic intensity–March 1989 storm

Source:
NERC 2012 Special Reliability Assessment Interim Report:
Effects of Geomagnetic Disturbances on the Bulk Power System

An Integrated All-hazards Approach is Needed

- Storms and natural disasters
- Cybersecurity attacks
- Physical attacks



Modernizing Our Electric Grid

NREL research is focused on solutions that enable smooth transitions to modern energy systems that are secure, resilient, reliable, affordable, and clean.

Grid Modernization Laboratory Consortium

GMLC Co-Leads

- Pacific Northwest National Laboratory
- NREL – National Renewable Energy Laboratory

Sandia National Laboratories

Brookhaven National Laboratory

Los Alamos National Laboratory EST. 1943

Argonne National Laboratory

SRNL Savannah River National Laboratory

SLAC National Accelerator Laboratory

Oak Ridge National Laboratory

Berkeley Lab

INL Idaho National Laboratory

NETL

Lawrence Livermore National Laboratory

- Institutional Support
- Devices and Integrated Systems
- Sensing and Measurement
- System Operations and Control
- Planning and Design Tools
- Security and Resilience

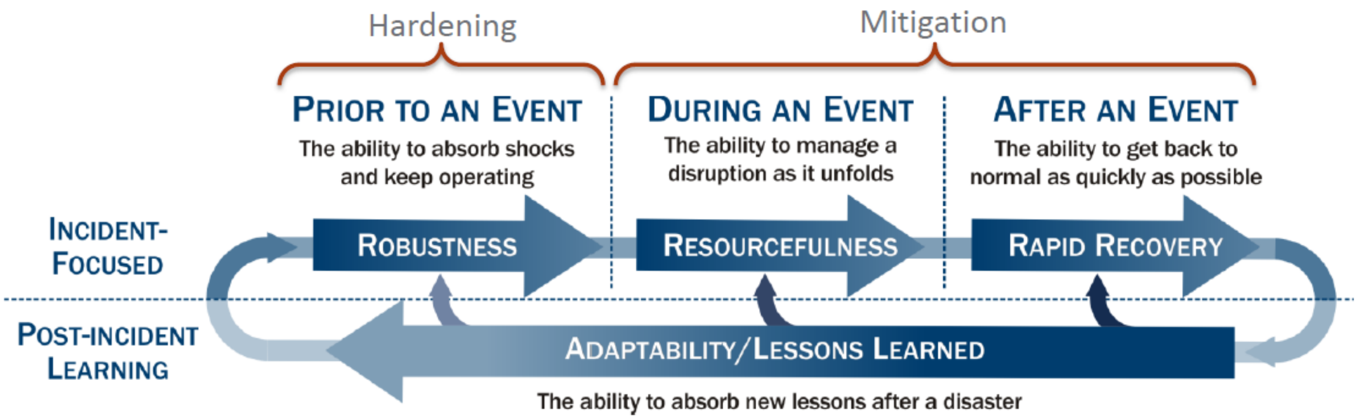
87 projects, $220M over 3 years

GRID Modernization Initiative U.S. Department of Energy

A Definition of Resilience

The ability to **anticipate**, **prepare for**, and **adapt** to changing conditions and **withstand**, **respond** to, and **recover** rapidly from disruptions through adaptable and holistic planning and technical solutions.

Sequence of the NIAC Resilience Construct



"A Framework for Establishing Critical Infrastructure Resilience Goals," National Infrastructure Advisory Council, October 19, 2010

GMLC Framework for Security and Resilience
Based on NIST Cybersecurity Framework

Identify:

Develop understanding of threats, vulnerabilities, and consequences to all hazards

Outcome: Improved risk management and streamlined information sharing

Protect:

Inherent system-of-systems grid resilience

Outcome: Increase the grid's ability to withstand malicious or natural events

Detect:

Real-time system characterization of events and system failures

Outcome: Accelerated state awareness and enhanced event detection

Respond:

Maintain critical functionality during events and hazards

Outcome: Advanced system adaptability and graceful degradation

Recover:

Real-time device management and transformer mobilization

Outcome: Timely post-event recovery of grid and community operations

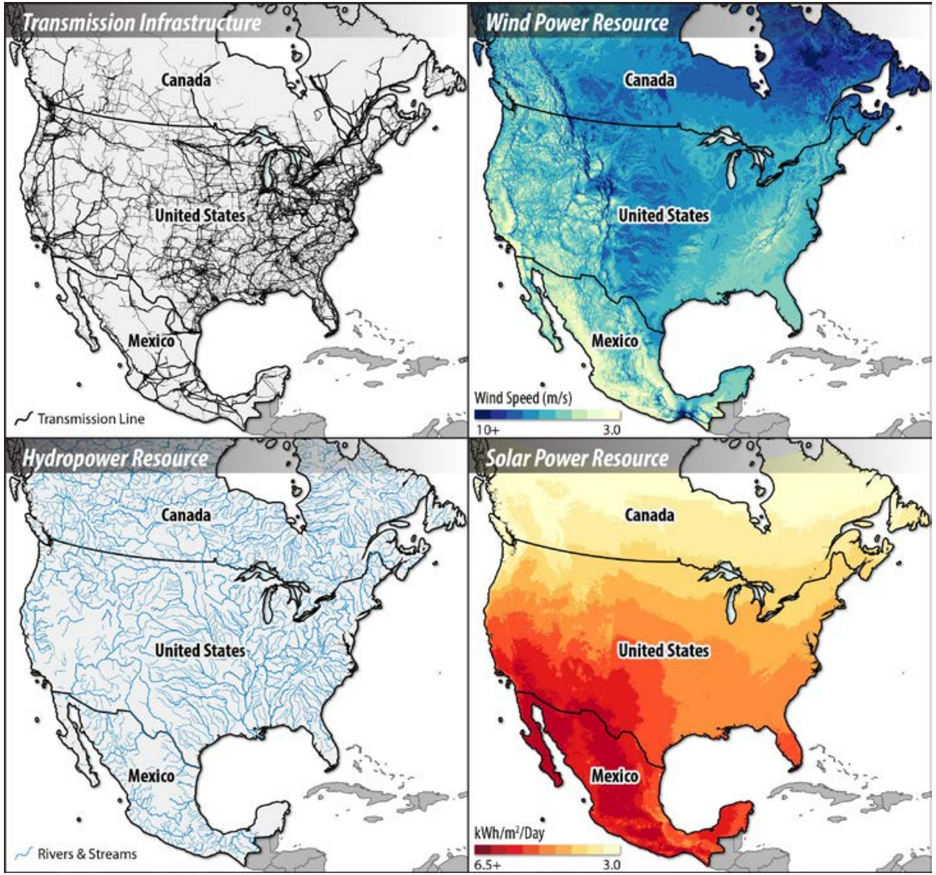
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

North America Is Very Diverse in Energy Resources and Load

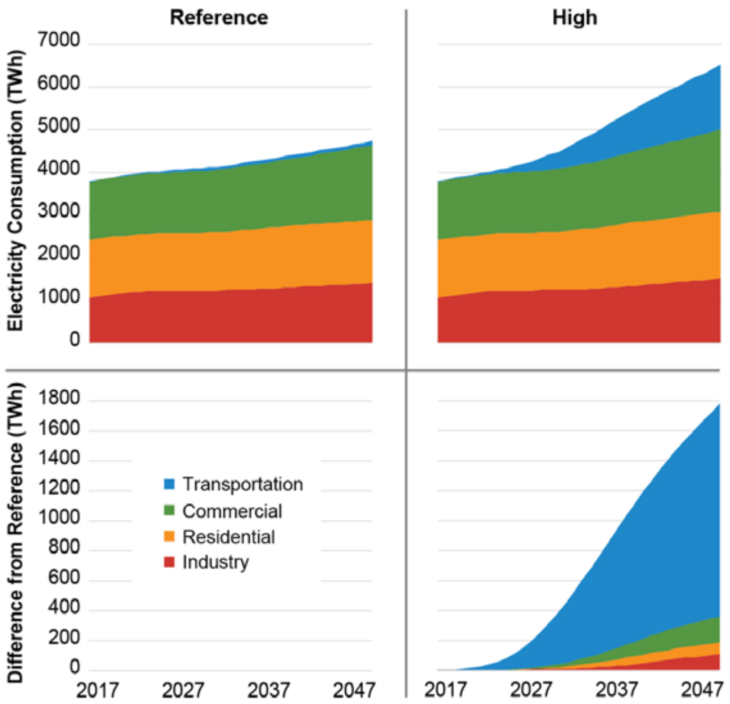
The availability of natural resources varies widely across regions.

So does how and when energy is used on the grid.

A modern power system can take advantage of this diversity to provide reliable, affordable, sustainable power.



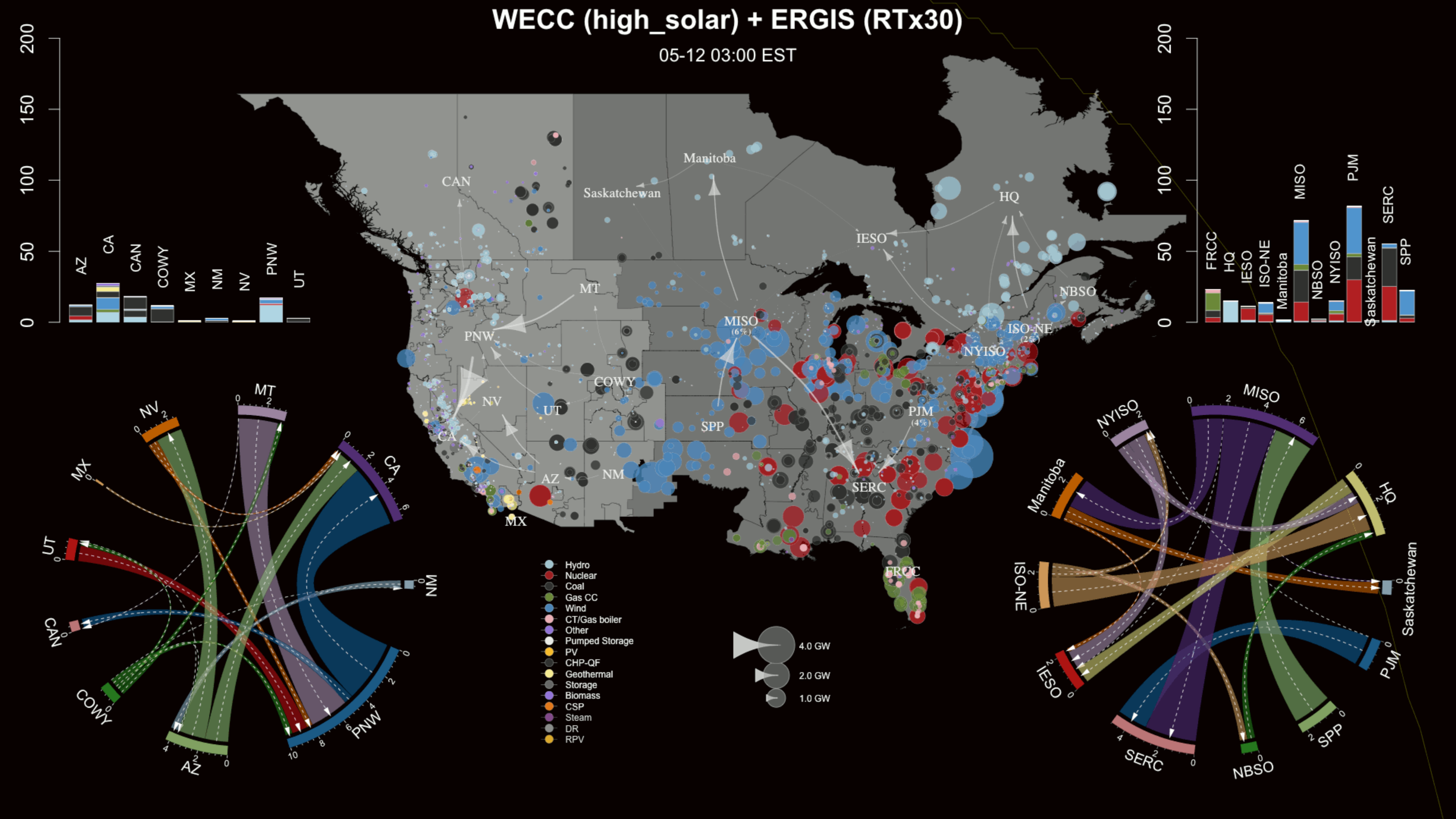
Electrification Futures Study



Through the **Electrification Futures Study**, NREL is exploring scenarios with and impacts of widespread electrification in the United States.

Several energy system transformation scenarios assume a great degree of future electrification, especially for transportation.

Work is ongoing and planned, including developing future load scenario snapshots, to help us understand pathways to effective electricity.


WECC (high_solar) + ERGIS (RTx30)
05-12 03:00 EST
AZ
CA
CAN
COWY
MX
NM
NV
PNW
UT
FRCC
HQ
IESO
ISO-NE
Manitoba
MISO
NBSO
NYISO
PJM
Saskatchewan
SERC
SPP
Hydro
Nuclear
Coal
Gas CC
Wind
CT/Gas boiler
Other
Pumped Storage
PV
CHP-QF
Geothermal
Storage
Biomass
CSP
Steam
DR
RPV
4.0 GW
2.0 GW
1.0 GW
MISO (6%)
ISO-NE (2%)
PJM (4%)

The North American Renewable Integration Study

State-of-the-art analysis of the U.S., Canada, and Mexico power systems, from planning through operations

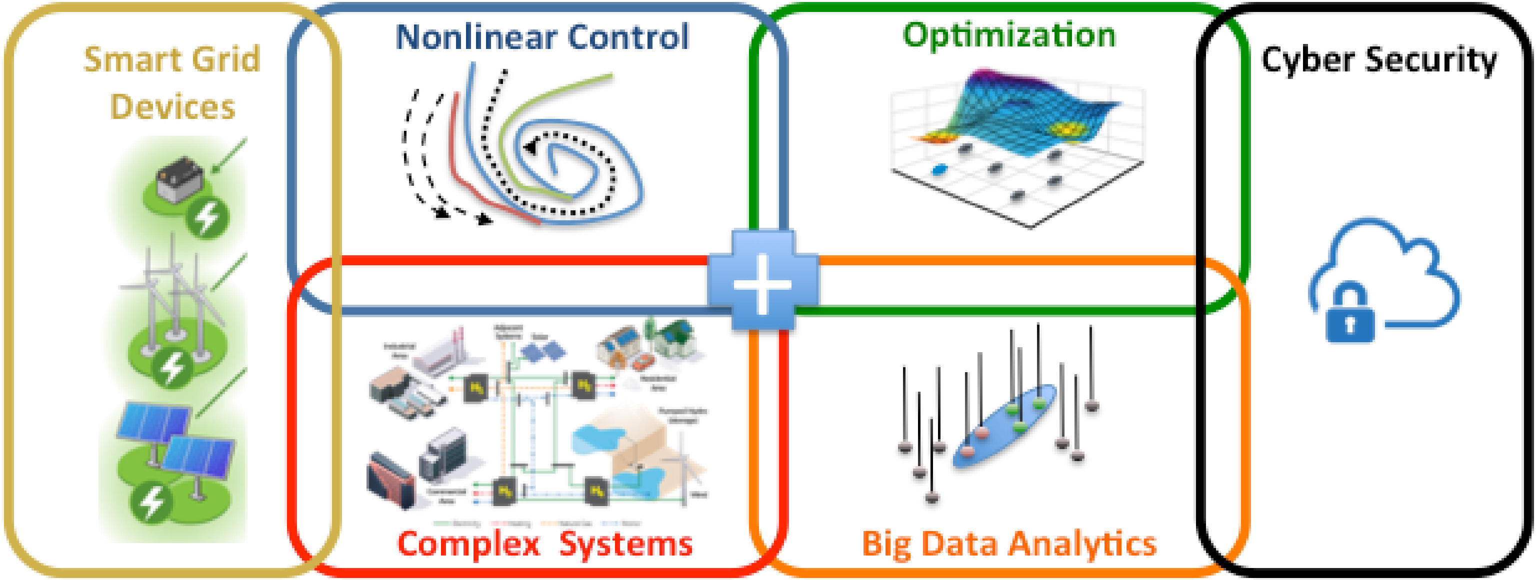
Natural Resources Canada Ressources naturelles Canada

Canada

SENER SECRETARÍA DE ENERGÍA

WHAT WE'RE STUDYING

- Long-term pathways to a modern power system in North America
- Operational feasibility of very high-penetration scenarios
- Weather variability and uncertainty
- Value of enabling technologies: flexible hydro, thermal generation, demand response, storage, transmission
- Value of operating practices: interchange, enhanced scheduling, local generation, reserve provisions



Autonomous Energy Grids

- The number of controllable devices connecting to the grid is increasing. This presents a new challenge: how do you control a grid with this much complexity?
- AEGs would rely on scalable cellular blocks that are able to act similarly to microgrids, self-optimizing when islanded, and participating in optimal operation when interconnected to a larger grid.

Microgrid Research with SDG&E Expands Resilience at Scale

NREL is simulating microgrid control at a scale that matters for communities and utilities. Through multimegawatt grid simulation and analysis of a remote, at-risk grid, SDG&E and NREL will deliver technical and economic insight about microgrid deployment.

NREL and Panasonic Plan Denver-Based Smart Community

NREL has produced an immersive and interactive planning tool for Denver’s forthcoming smart city, Peña Station NEXT. The visualization captures complex interactions between systems, allowing stakeholders to explore the broader implications of their choices

NREL and HECO—Reaching 100% Renewable Grids

Hawaii has the highest levels of renewable energy, largest percentage of citizens with rooftop solar, and the nation's most ambitious electricity goal—100% renewable by 2045. The Hawaiian Electric Companies (HECO) are working with NREL to implement emerging technologies and to ensure the islands' six electric grids continue to provide reliable service to customers.

Cybersecurity

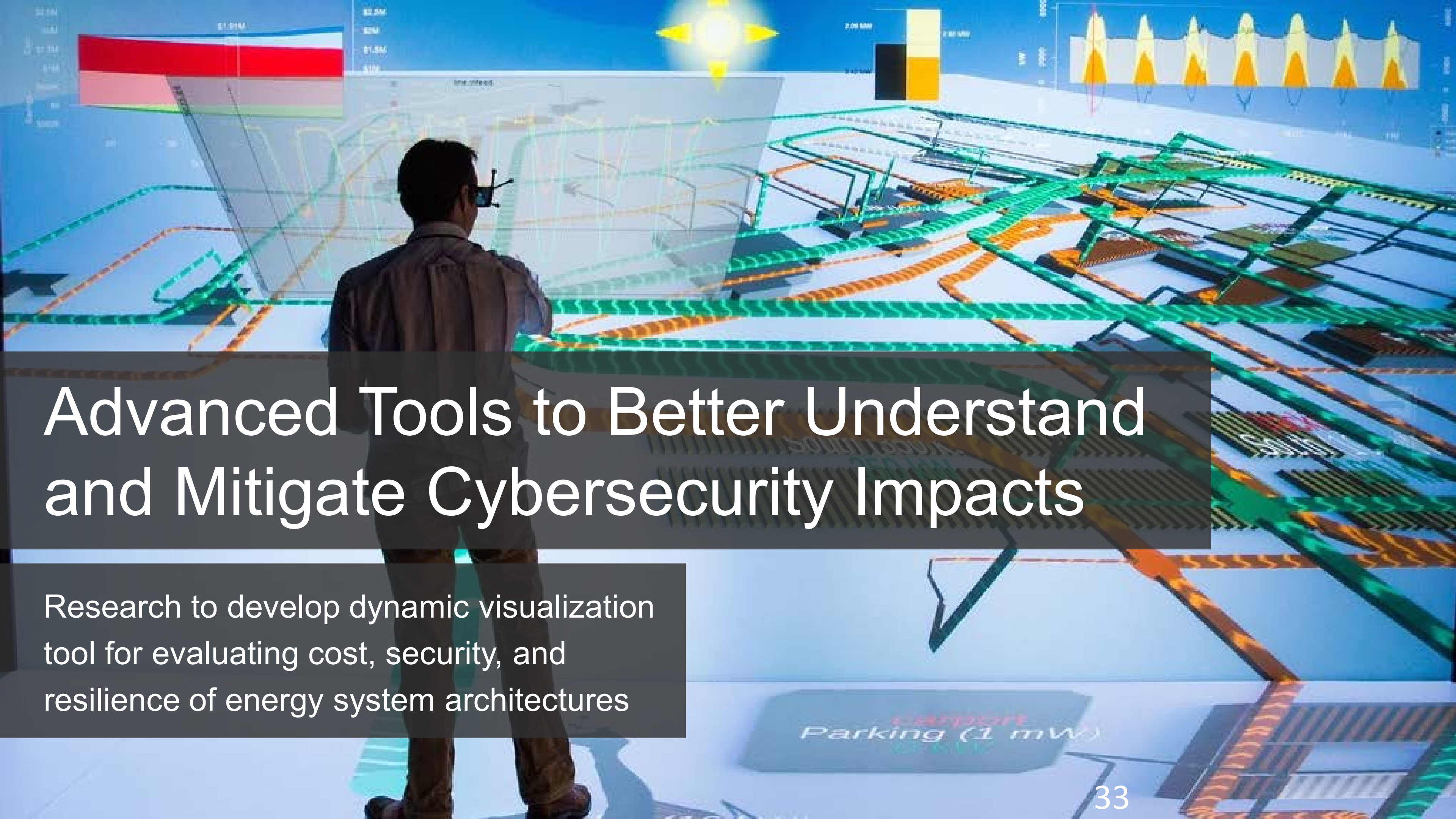
NREL is conducting research to identify, detect, protect against, and respond to today's biggest threats to an evolving energy grid.

Site Security Assessments

- In order to move toward a more inherently secure grid, we recognize the importance in understanding where security vulnerabilities exist.
- NREL offers onsite cybersecurity assessments using the DOE Cybersecurity Maturity Model and the National Institute of Standards Technology Cybersecurity Framework.
- Reports provide a detailed analysis on policies and business processes that should be strengthened to improve cybersecurity practices.

Vendor Product Cybersecurity Evaluations

Evaluating microgrid controllers, inverters,
wind controllers, security devices, electric vehicle
charging stations, and energy storage systems



Advanced Tools to Better Understand and Mitigate Cybersecurity Impacts

Research to develop dynamic visualization tool for evaluating cost, security, and resilience of energy system architectures

Cybersecurity Standards

Accelerating codes and standards for secure advanced energy networks.

A Systems Approach

Our goal for cybersecurity research at NREL is to develop and evaluate solutions that secure our electric grid and the millions of new renewable and advanced energy technologies powering it.

- Advanced whole-system and device-level cybersecurity
- All-hazards security and resilience (physical, cyber, storms and natural events)
- Reducing risk with greater resiliency

Thank you

www.nrel.gov

NREL
Transforming ENERGY