NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Modernizing the Grid for Increased Renewables and Electric Vehicles

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Energy Systems Integration

NREL at-a-Glance

2,926

Workforce, including

219 postdoctoral researchers

60 graduate students

81 undergraduate students

World-class

facilities, renowned technology experts

More than 900

Partnerships

with industry, academia, and government

Campus

operates as a living laboratory

NREL 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

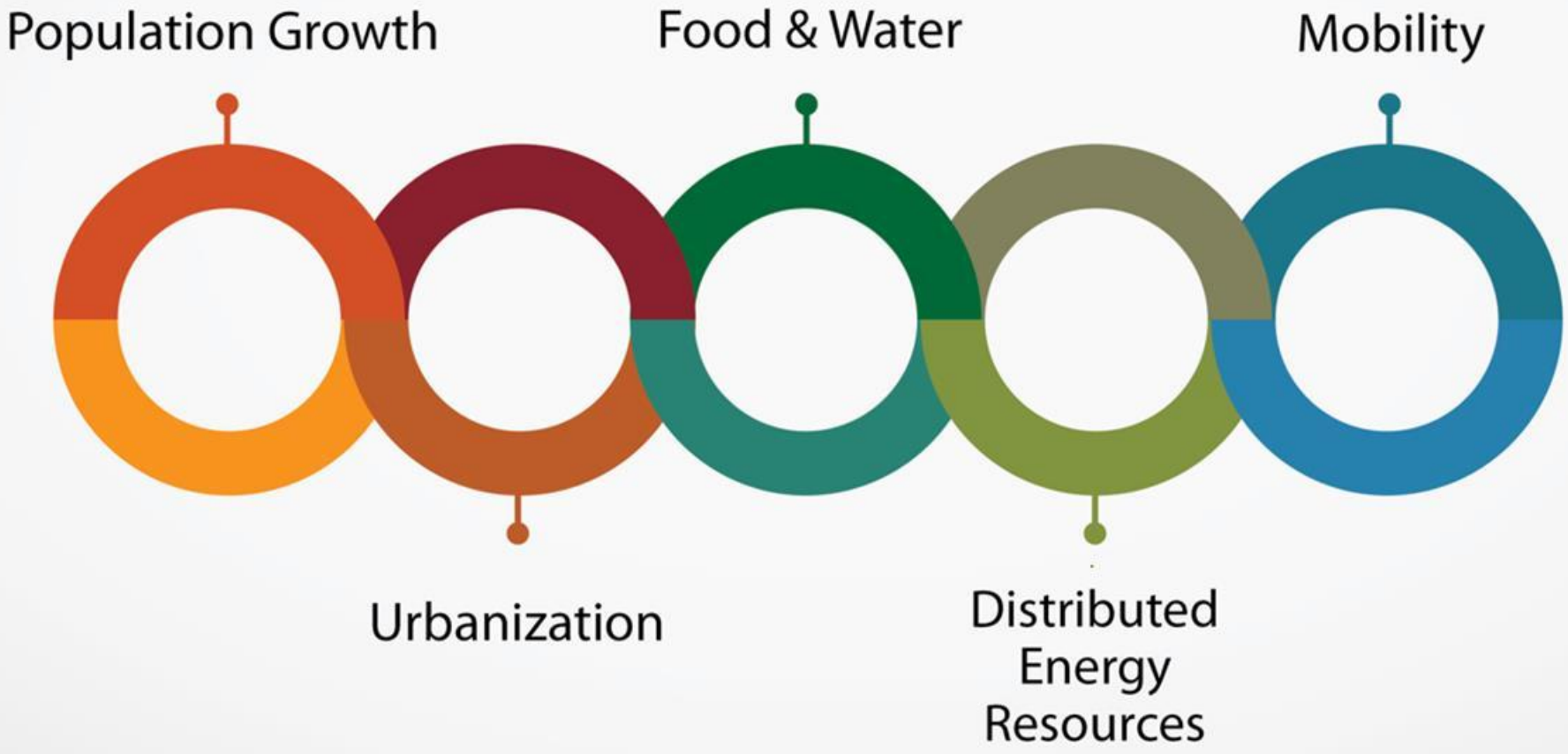
Grid Integration

Hybrid Systems

Energy Security and Resilience

Mega Trends

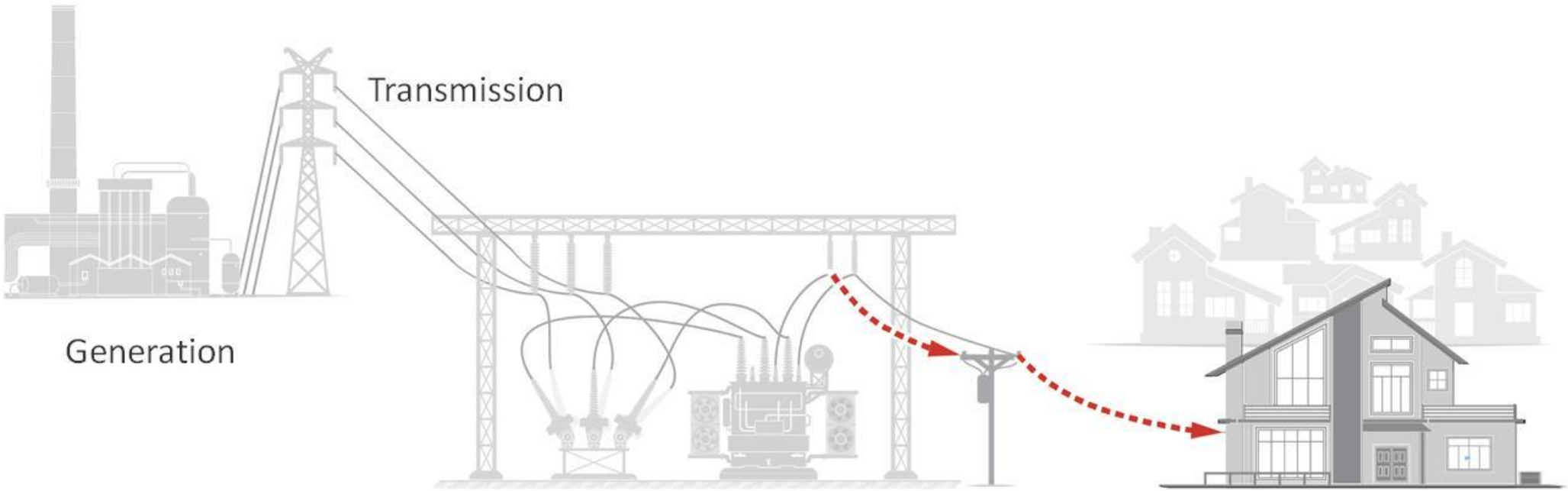
Impacting our Use of Energy

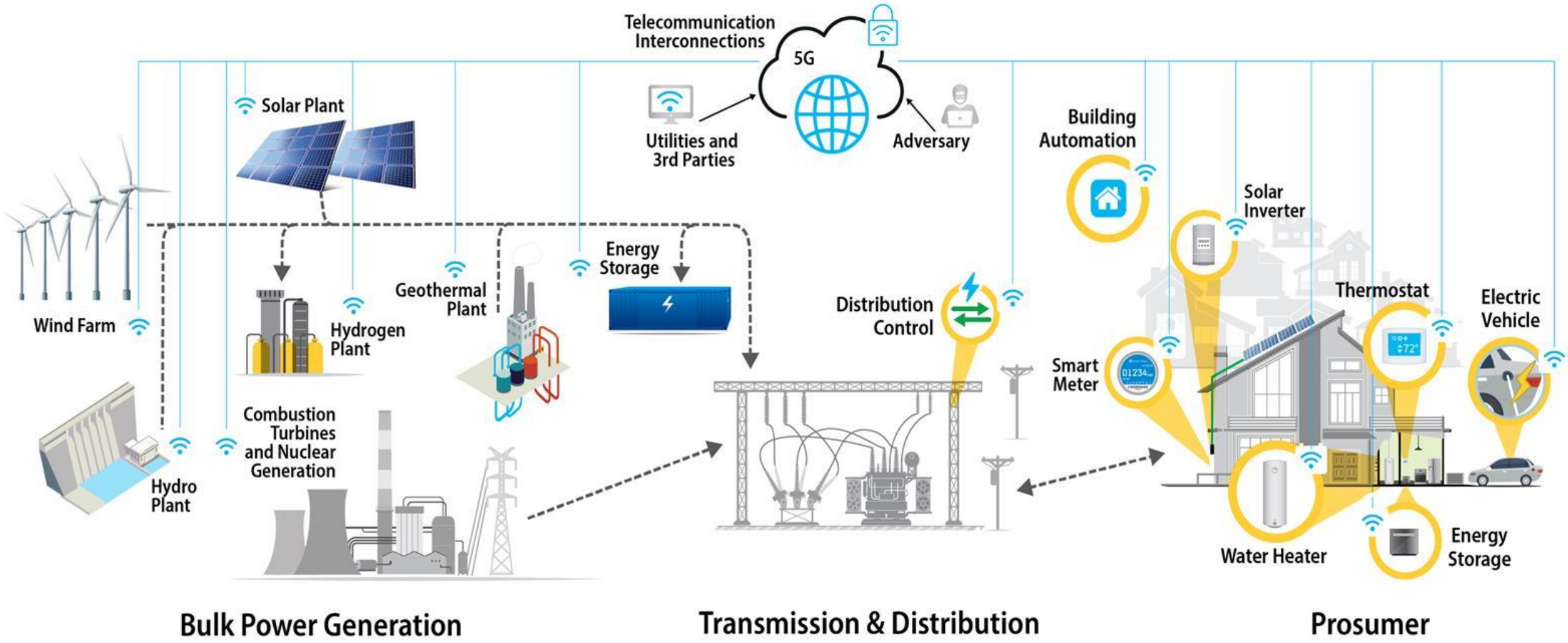


Trends Impacting the Grid

- Increasing Interdependencies
- Energy Diversification
- Vehicle Electrification
- Grid-Connected Smart Buildings
- Big Data, Artificial Intelligence, and Machine Learning
- Cybersecurity
- Resilience
- Millions of Devices at the Grid Edge

The Grid of the Past





Energy systems are changing

They are becoming more:

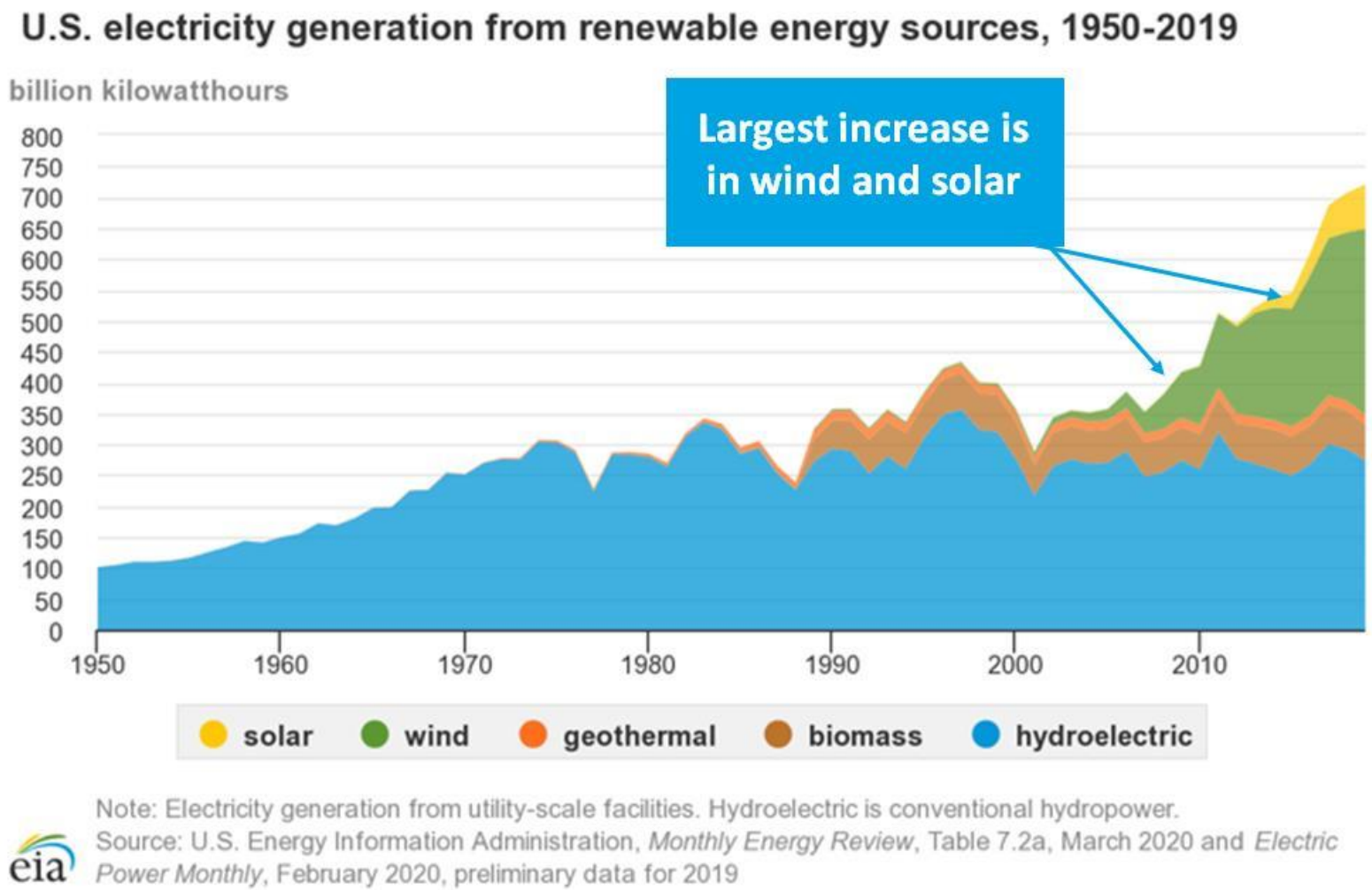
- complex
- distributed
- interdependent

The US Energy Supply is Shifting

Renewable Energy

In 2019, 17% of annual electricity was from renewable sources.

- 7% Wind
- 7% Hydro
- 2% Solar
- 1% Biomass
- 0.5% Geothermal



Note: Electricity generation from utility-scale facilities. Hydroelectric is conventional hydropower.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, March 2020 and *Electric Power Monthly*, February 2020, preliminary data for 2019

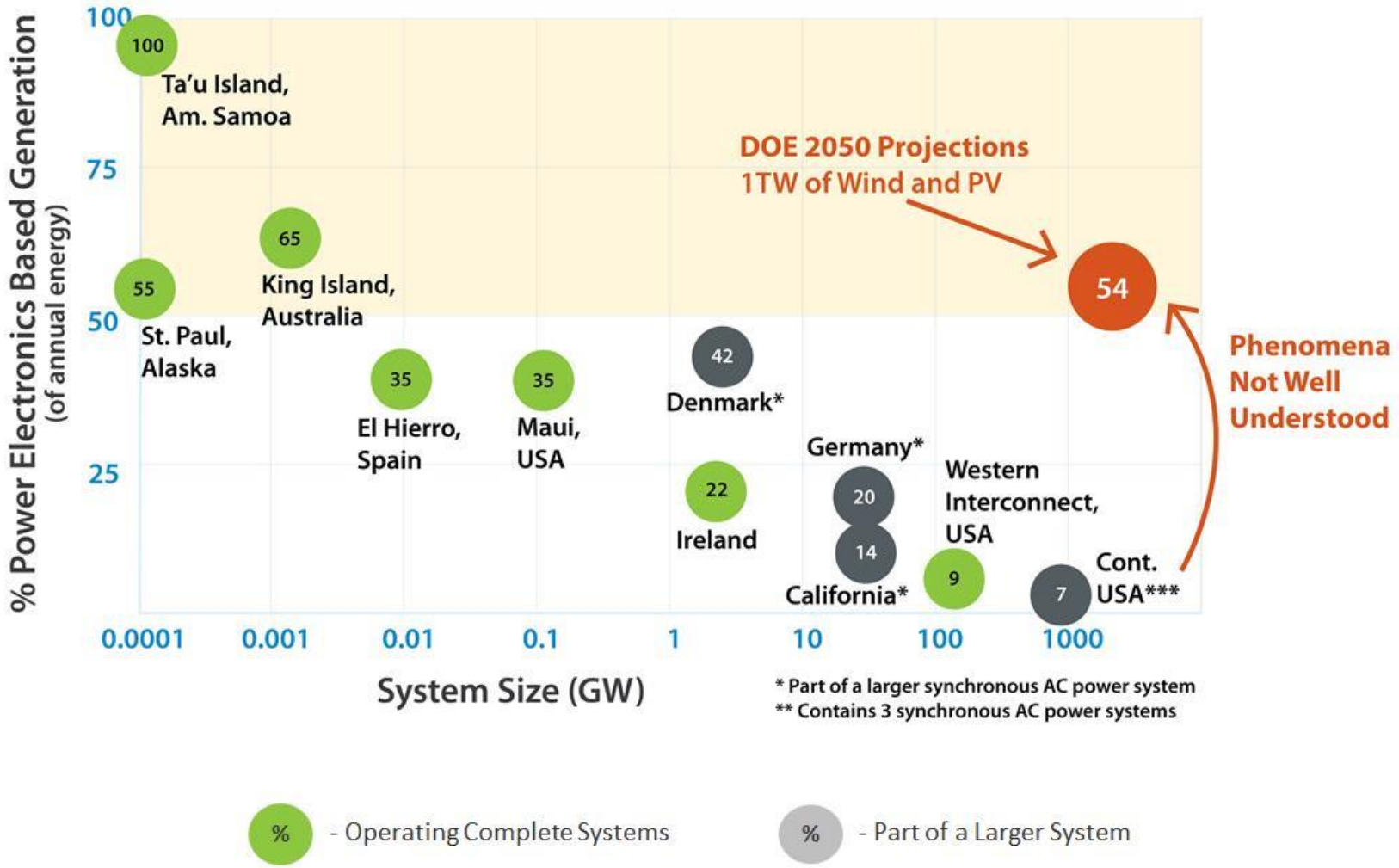
Power Electronics-Based Energy System
Operating with Less Inertia

Generation
- Solar PV, wind, microturbines, fuel cells use power electronics (PE) interfaces to connect to the grid
- Over 50% PE generation by 2050
- Other bulk source work synergistically

Storage
- Batteries use PE interfaces to connect to the grid
- Pumped hydro can add PE to increase controllability and provide grid services

Building Loads
- Over 60% of major home appliances expected to be PE-based by 2021
- Lighting switching to LEDs
- Variable speed drives for motors

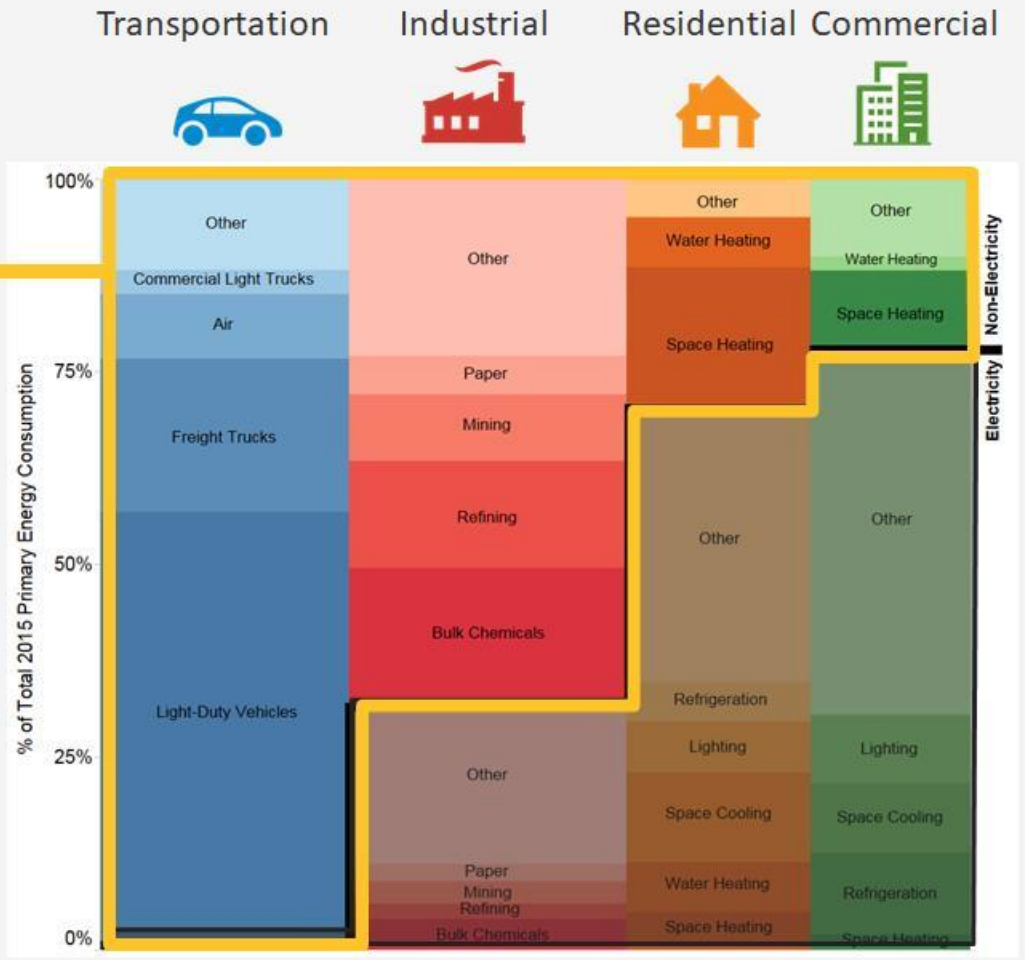
Mobility
- EVs – 7 million by 2025
- MD/HD – Electrifying



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

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

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

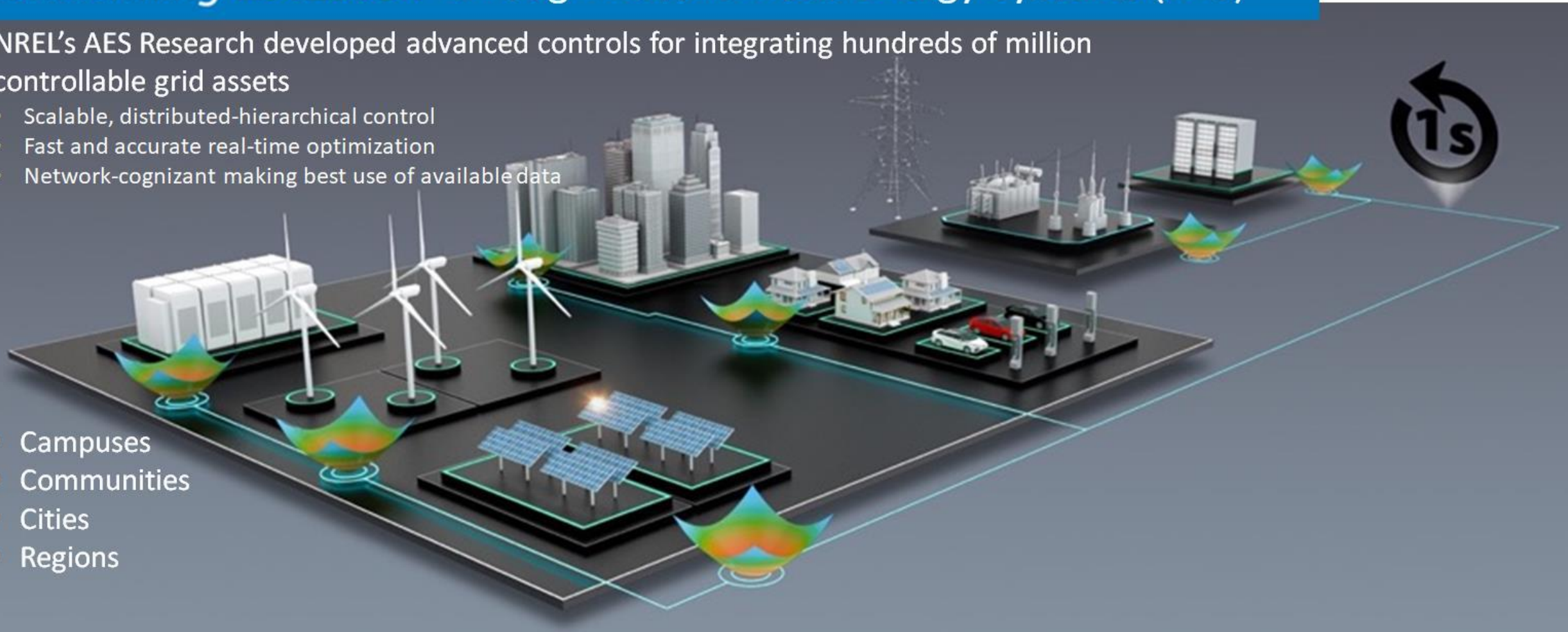


Further *exploration* is needed to enable widespread electrification.

Transforming ENERGY through Autonomous Energy Systems (AES)

NREL's AES Research developed advanced controls for integrating hundreds of million controllable grid assets

- Scalable, distributed-hierarchical control
- Fast and accurate real-time optimization
- Network-cognizant making best use of available data



- Campuses
- Communities
- Cities
- Regions

Enabling large-scale deployment of distributed energy resources (EVs, Buildings, Generation) through advancements in optimization, control, data analytics, and complex system simulation

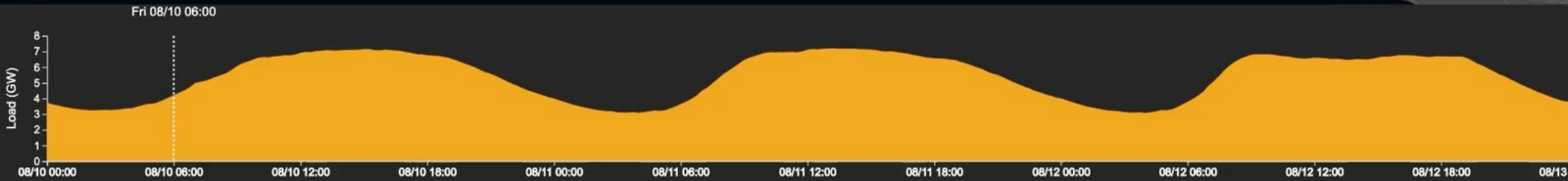
LA100

The Los Angeles 100% Renewable Energy Study

Detailed, ultrahigh resolution analysis evaluating a range of future scenarios to equip LA decisionmakers to understand:

- What are the **pathways and costs to achieve a 100% renewable electricity supply** while electrifying key end uses and maintaining the current high degree of reliability?
- What is the **impact on the environment**?
- How might the **economy** and **rates** respond to such a change?


High 2045
Net Loads
25 kWh
0 kWh
Bakersfield
Lancaster
Palmdale
Santa Clarita
Santa Paula
Simi Valley
Oxnard
Thousand Oaks
NTD
Santa Monica
Los Angeles
LAX
El Monte
West Covina
Chino
ONT
CNO
Fontana
Corona
Anaheim
Santa Ana
Irvine
Rolling Hills Estates
Long Beach
LGB
Victorville
Phelan
Barstow
mapbox
©Mapbox, ©OpenStreetMap

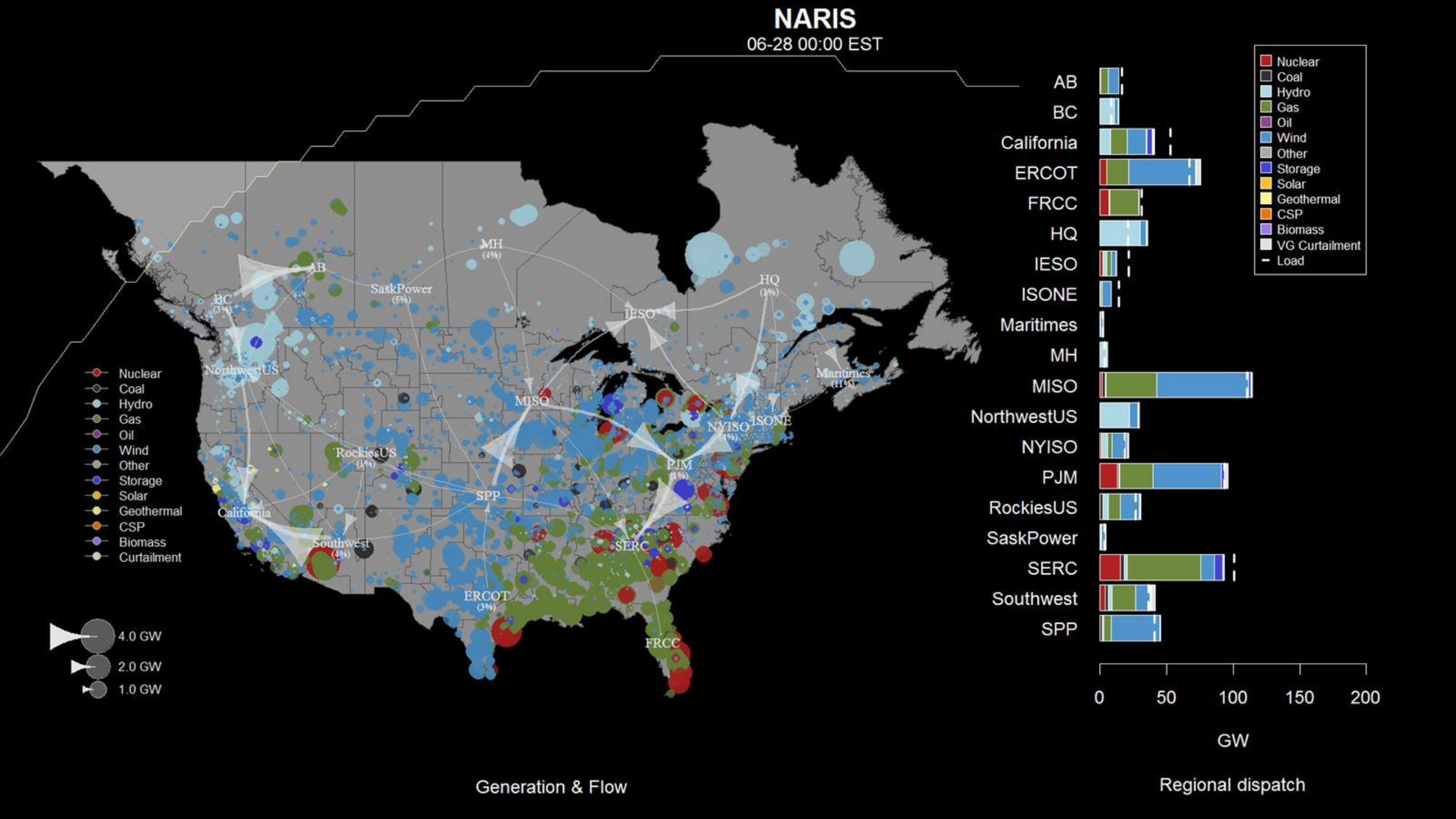

Fri 08/10 06:00
Load (GW)
0
1
2
3
4
5
6
7
8
08/10 00:00
08/10 06:00
08/10 12:00
08/10 18:00
08/11 00:00
08/11 06:00
08/11 12:00
08/11 18:00
08/12 00:00
08/12 06:00
08/12 12:00
08/12 18:00
08/13

NARIS: North American Renewable Integration Study Highlights Continental Low-Carbon Grid Opportunities

Collaboration between DOE and Natural Resources Canada

- Applied a suite of **advanced modeling tools** to model the entire continent
- Analyzed scenarios to understand the impacts of renewable technology cost trajectories, emission constraints, and demand growth on **emissions**, **resource adequacy**, and the **specific technologies** that help enable the transition to a low-carbon grid
- Results show **increasing electricity trade between countries** and **expanding interregional transmission** can support a reliable future power system

nrel.gov/analysis/naris.html


NARIS
06-28 00:00 EST
Nuclear
Coal
Hydro
Gas
Oil
Wind
Other
Storage
Solar
Geothermal
CSP
Biomass
Curtailment
4.0 GW
2.0 GW
1.0 GW
AB
BC
SaskPower
(5%)
MH
(4%)
HQ
(3%)
IESO
NorthwestUS
MISO
Maritimes
(1%)
NYISO
(1%)
ISONE
RockiesUS
(1%)
PJM
(1%)
SPP
California
Southwest
(4%)
SERC
ERCOT
(3%)
FRCC
Generation & Flow
AB
BC
California
ERCOT
FRCC
HQ
IESO
ISONE
Maritimes
MH
MISO
NorthwestUS
NYISO
PJM
RockiesUS
SaskPower
SERC
Southwest
SPP
Nuclear
Coal
Hydro
Gas
Oil
Wind
Other
Storage
Solar
Geothermal
CSP
Biomass
VG Curtailment
Load
0
50
100
150
200
GW
Regional dispatch

Sources of Energy System Disruption

Natural Disasters

Space Weather

Physical Threats

Electromagnetic Pulse

Cyber Threats

Natural Hazards

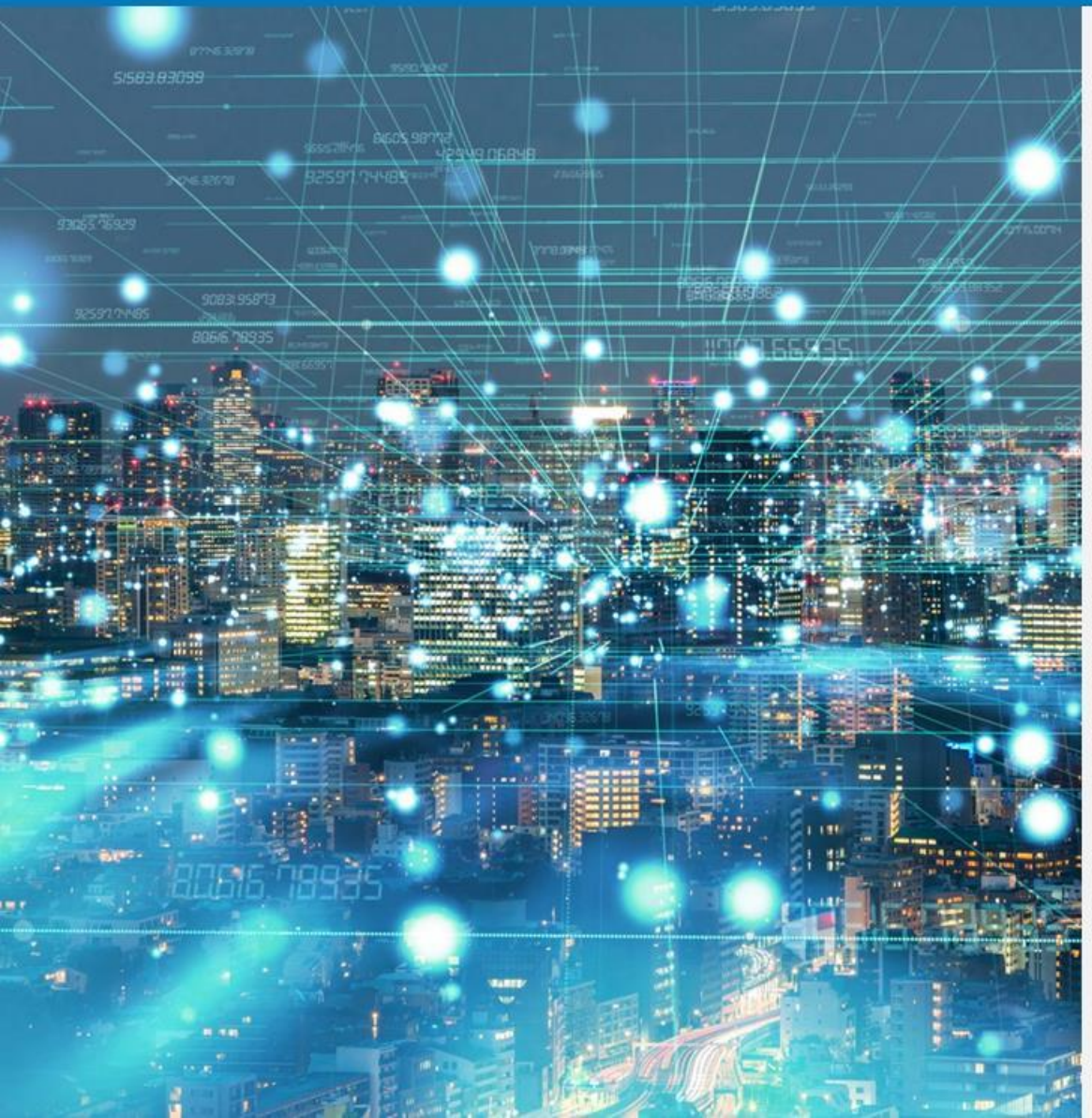
Human Threats

NREL's Cyber-Energy Emulation Platform (CEEP)

The CEEP generates emulated, multilayer grid environments that allow researchers to visualize and evaluate the interdependencies of power systems and network communication flows—and to safely explore vulnerabilities and mitigation effectiveness.

Advanced Research on Integrated Energy Systems (ARIES)

ARIES: A research platform to accelerate the transition to a modern energy system



- Identify the best path to reach local and national **decarbonization goals**
- Look at **system-wide resilience** to pinpoint weaknesses and solutions
- **Troubleshoot and de-risk new technologies** before they are connected to the electric grid
- **Embed cybersecurity** as a fundamental layer to all research
- **Accelerate deployment** by providing a research platform that can replicate the real-world

Thank You

www.nrel.gov