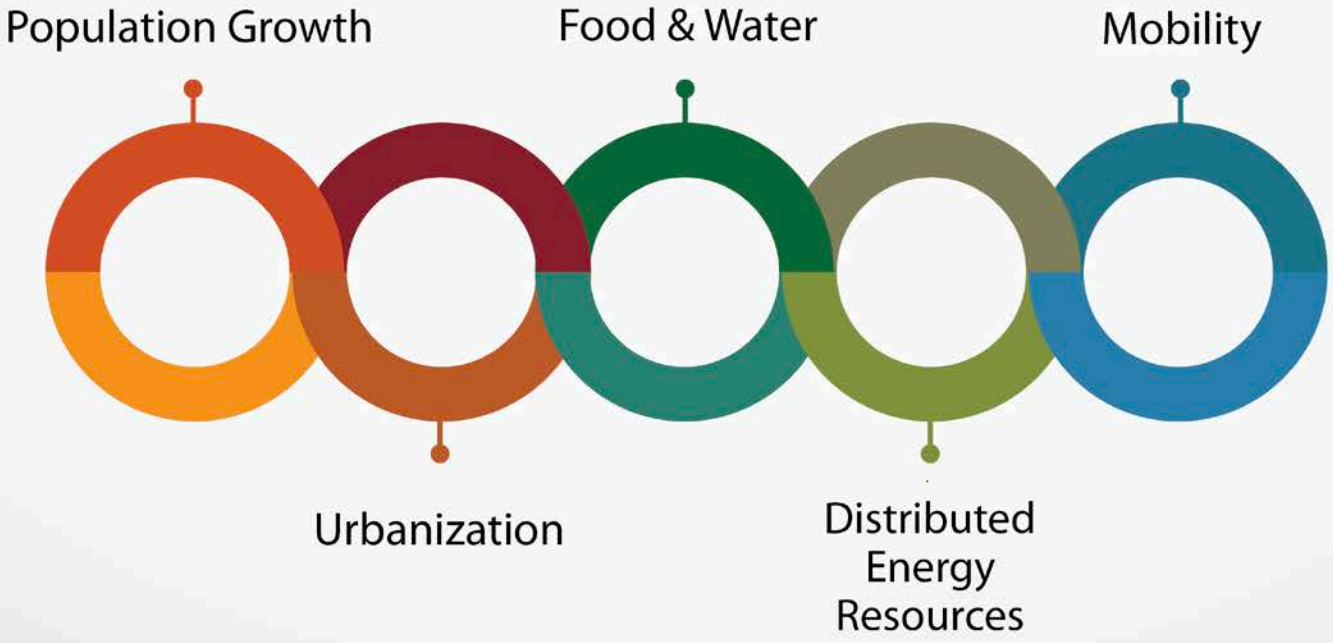
NREL: *Transforming Energy through Innovation*

Dr. Martin Keller, Director
November 12, 2019

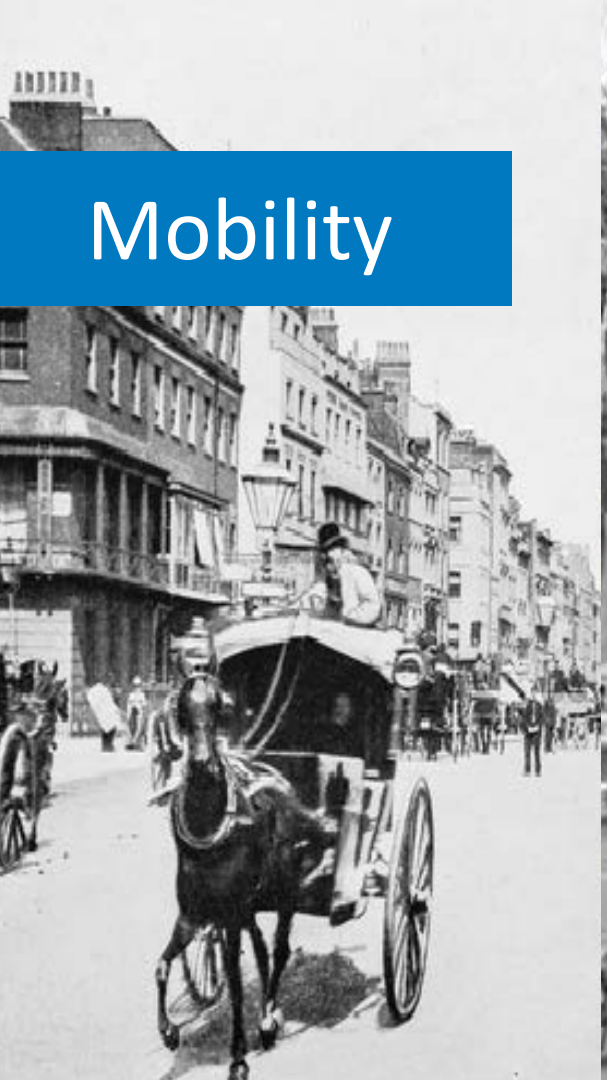
Mega Trends


Population Growth
Food & Water
Mobility
Urbanization
Distributed Energy Resources

Population Growth

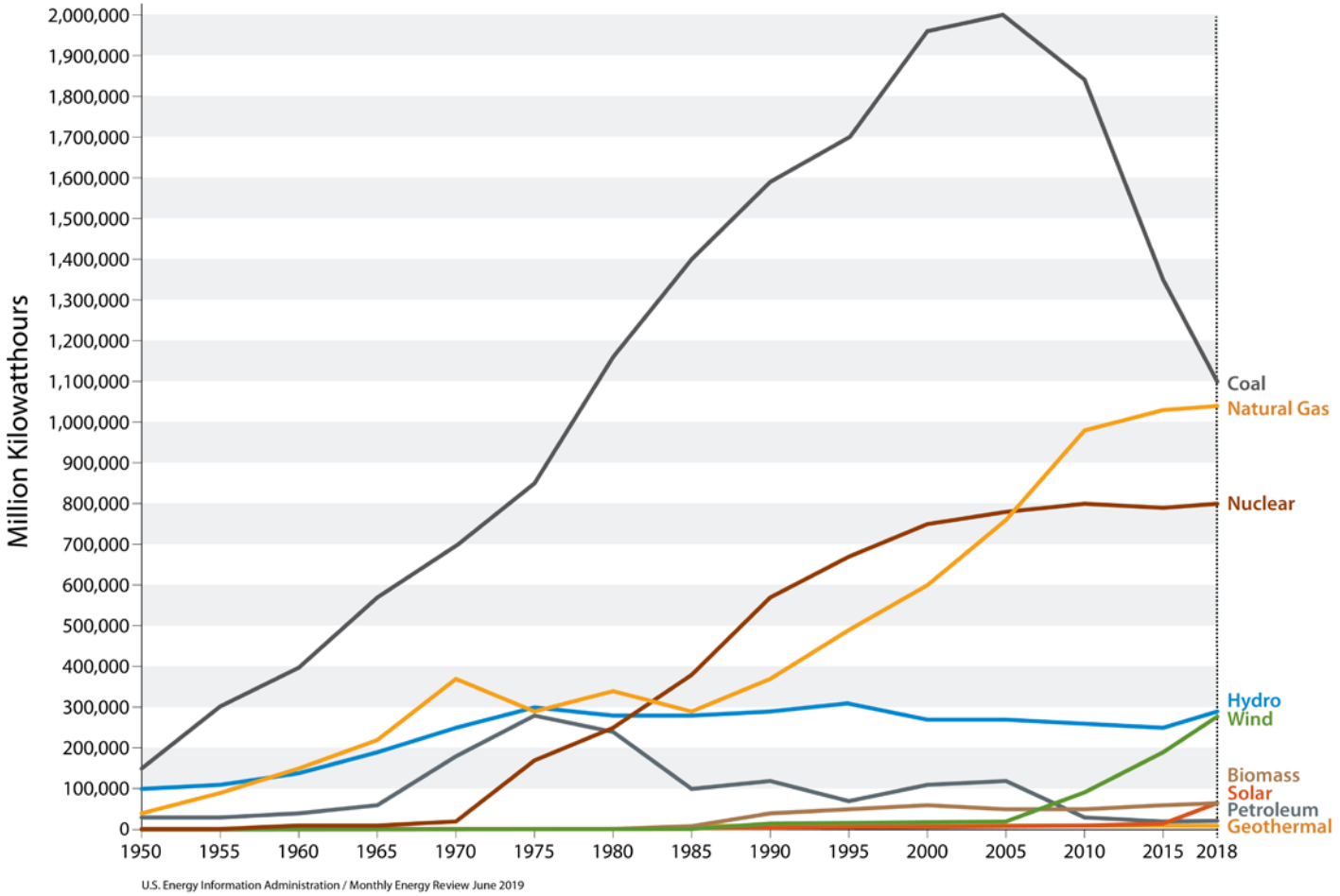
Urbanization

Mobility



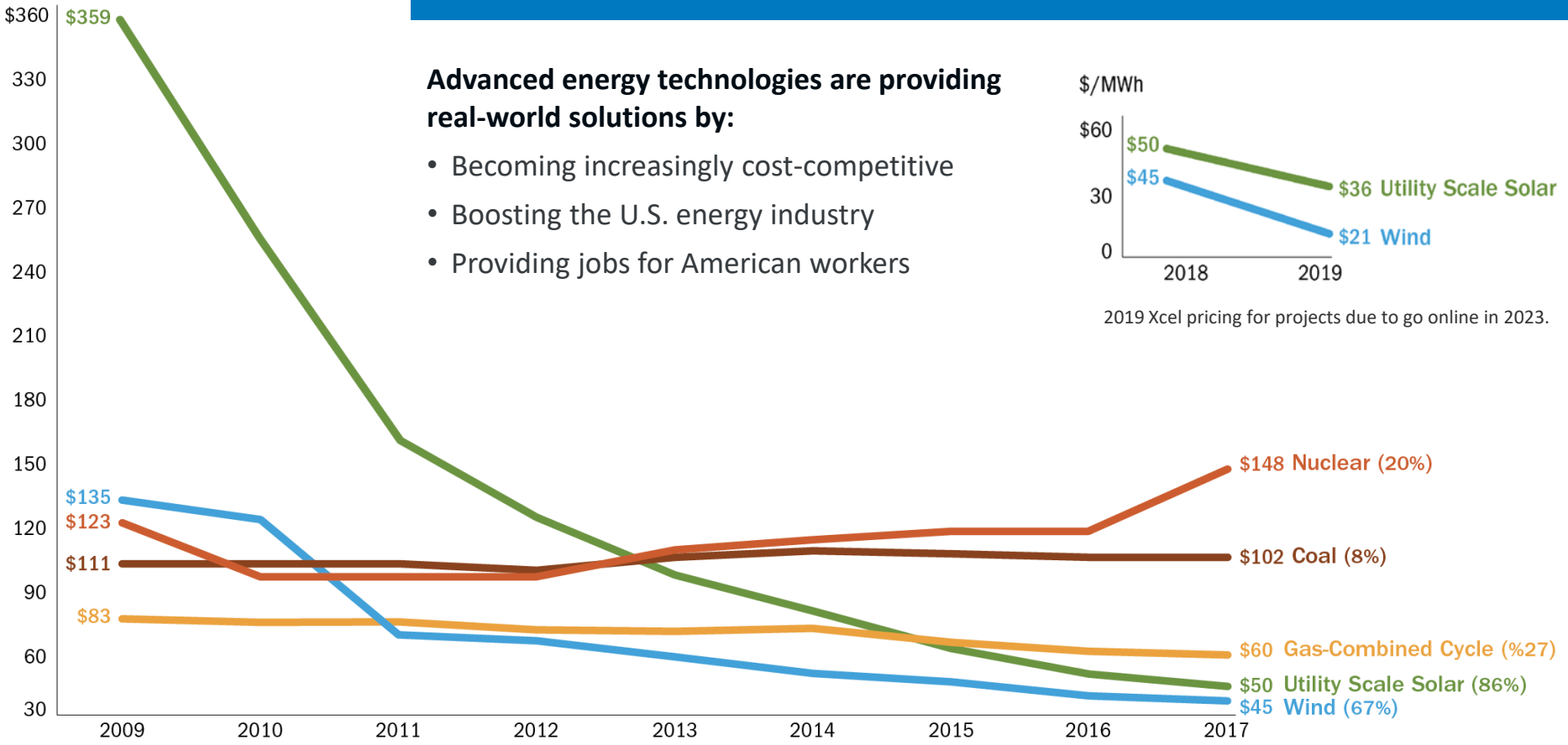
Ongoing Transformation of the Energy Supply in the United States

U.S. Power System Massive Transition



Costs for Renewables are Falling

Mean LCOE
$/MWh



Advanced energy technologies are providing real-world solutions by:

- Becoming increasingly cost-competitive
- Boosting the U.S. energy industry
- Providing jobs for American workers

2019 Xcel pricing for projects due to go online in 2023.

Source: *Lazard's 2017 Levelized Cost of Energy Analysis,* Version 11, 2 November 2017

NREL at a Glance

2,250

Employees,
plus more than
500
early-career researchers
and visiting scientists

World-class
facilities, renowned
technology experts

about
872

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

Solar Research

Understanding how to achieve affordable and dispatchable solar generation systems that operate as a typical power plant is the ultimate pinnacle for solar to achieve extremely high penetration levels in our grid system.

Research Challenges

- Develop solar interface and control technologies to enable greater grid reliability, resilience, and overall system efficiency
- Reduce solar hardware costs through innovative materials, manufacturing, and design, and de-risk technology to reduce balance of system costs
- Develop CSP-integrated or stand-alone thermal energy storage to provide flexible, long-duration storage needed to enable high penetrations of renewables on the grid
- Increase solar system lifetimes and performance through improved efficiency and lower degradation rates
- Understand how to integrate and optimize solar at scale within systems such as buildings, microgrids, distribution systems, and hybrid systems.

Wind Research

Enabling low-cost and accessible wind energy by joining forces with DOE, industry, and interagency and state partners to advance scientific knowledge and technological innovation.

Research Challenge

- Validate multiple wind technologies at scale to achieve an integrated energy system that can meet the complex energy challenges of the future.
- Develop taller wind turbines with larger rotors to capture greater wind resources at higher elevations and lower the levelized cost of wind energy.
- Develop innovations for offshore wind such as floating platforms, scaling solutions for larger offshore designs, advanced turbine controls, and lightweight drivetrains.
- Optimize power output across the entirety of a wind plant instead of at the individual-turbine level.

Energy Systems Integration Facility

Research Focus Areas

- Renewable electricity to grid integration
- Vehicle-to-grid integration
- Renewable fuels-to-grid integration
- Battery and thermal energy storage
- Microgrids
- Large-scale numerical simulation
- Cybersecurity and resilience
- Smart home and building systems
- Energy-water nexus
- High-performance computing, analytics, and visualization

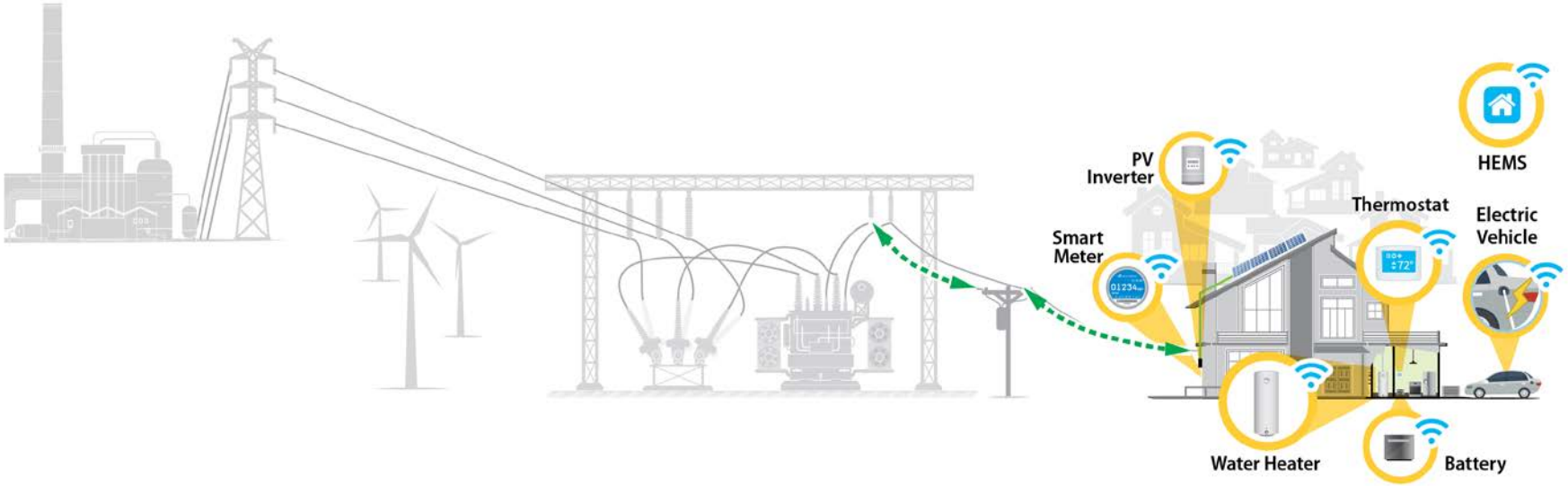

Looking to the Future

Environmental Scan: Observations Toward 2040

Assumptions that Guided NREL's Strategy Formulation:

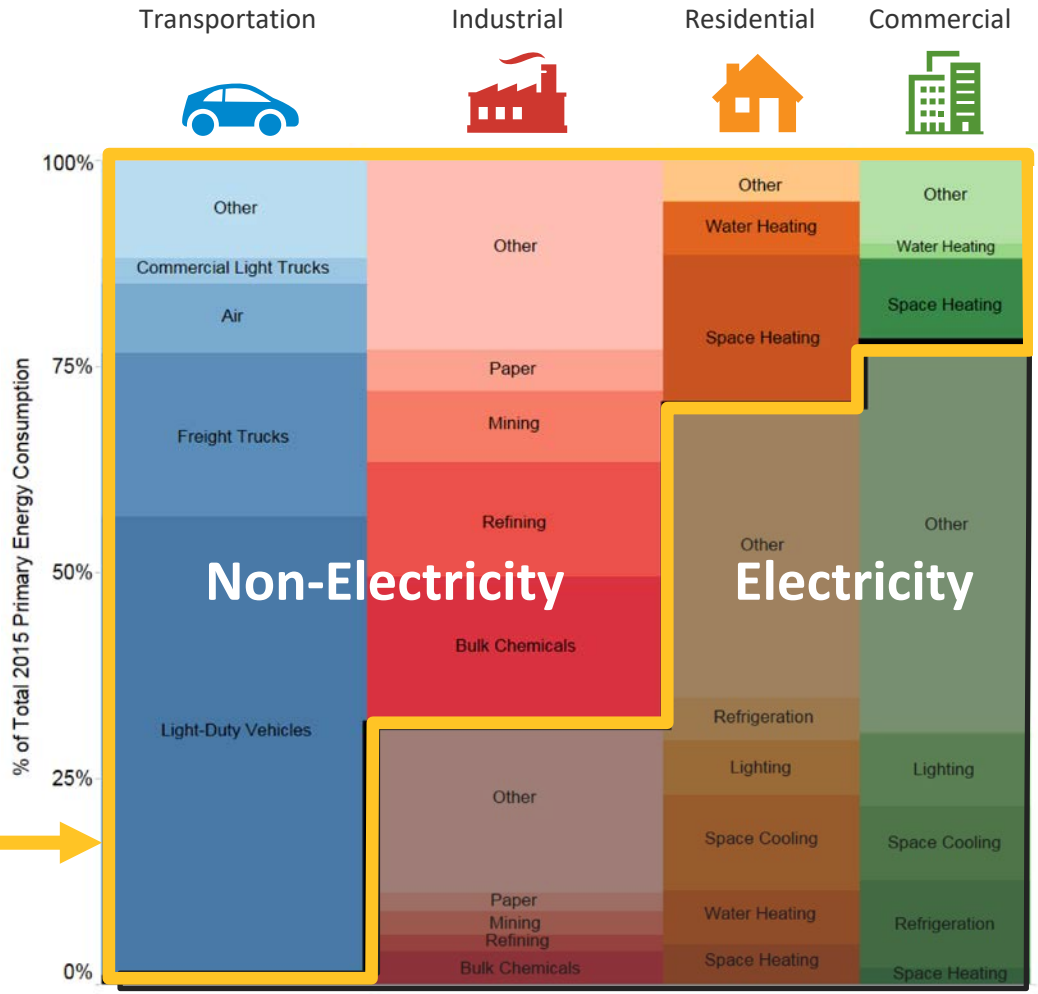
- Growth of energy use in the developing world will far outpace growth elsewhere.
- Global renewable power demand will grow.
- Urbanization trends will dominate new infrastructure growth.
- Electrification and electric vehicle adoption will grow strongly.
- Demand for high-density liquid fuels will grow.
- Digitization, data, decentralization will be strong drivers of energy transition.

How We Use Electricity is Changing



Scenarios of Electrification of the U.S. Economy

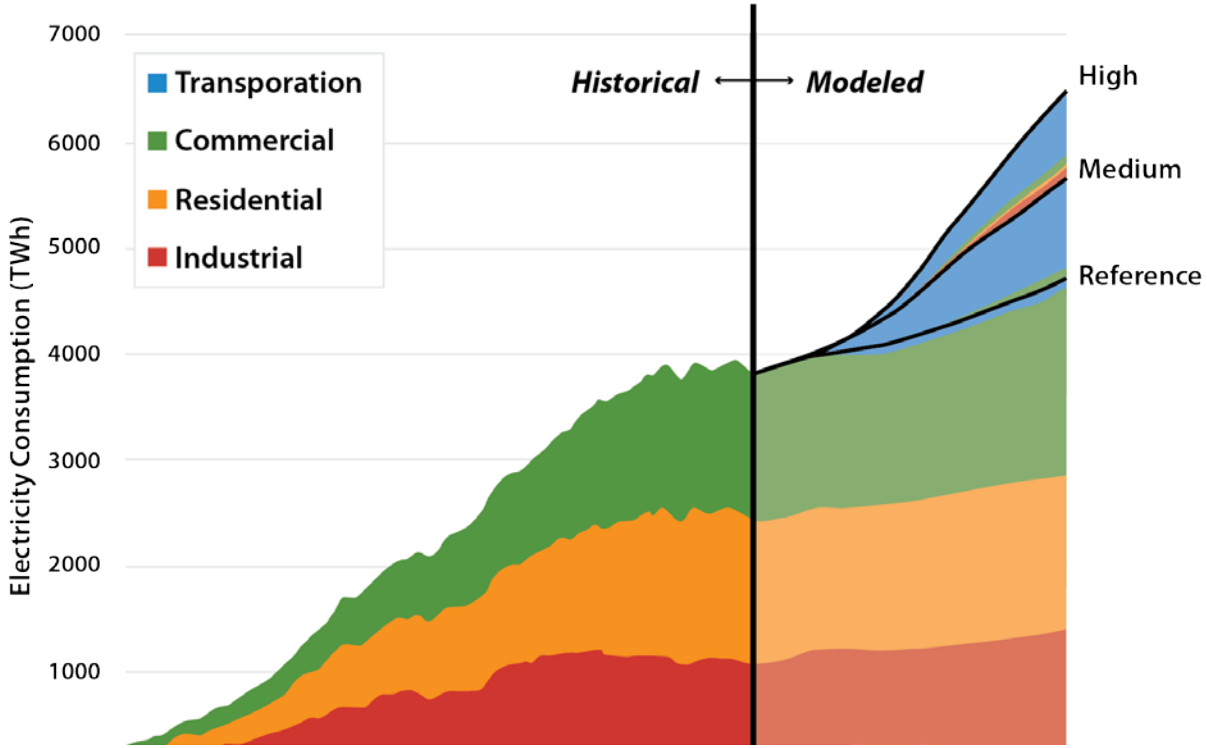
Several energy system transformation scenarios assume a great degree of future electrification, especially for transportation.



Source: https://www.nrel.gov/analysis/electrification-futures.html

Electricity Consumption 1950–2050

Historical and Projected Annual Electricity Consumption



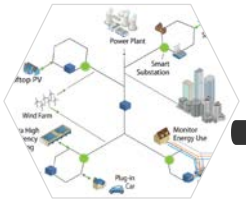
Moderate technology advancements are shown. Slight adjustments were made to the modeled industry consumption estimates for 2017 – 2020 to align them with available historical data.

Source: Electrification Futures Study, *NREL*, 2018

Creating Autonomous Energy Systems

Applications

Power Grids



Transportation

Buildings

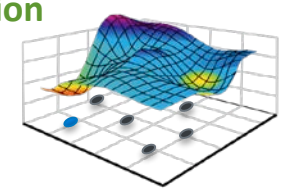
Wind Plants

Common Problems:

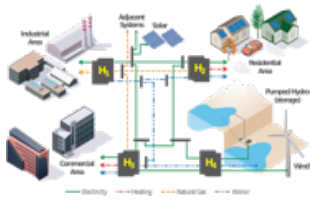
- Real-time controls and optimization
- Hundreds to millions of control points
- Asynchronous data and communications
- Multi-domain systems (complex) and stochastic systems (variable renewables, consumer/occupant behavior)

Nonlinear Control

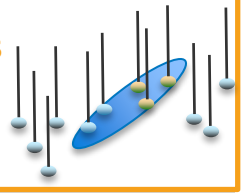
Optimization



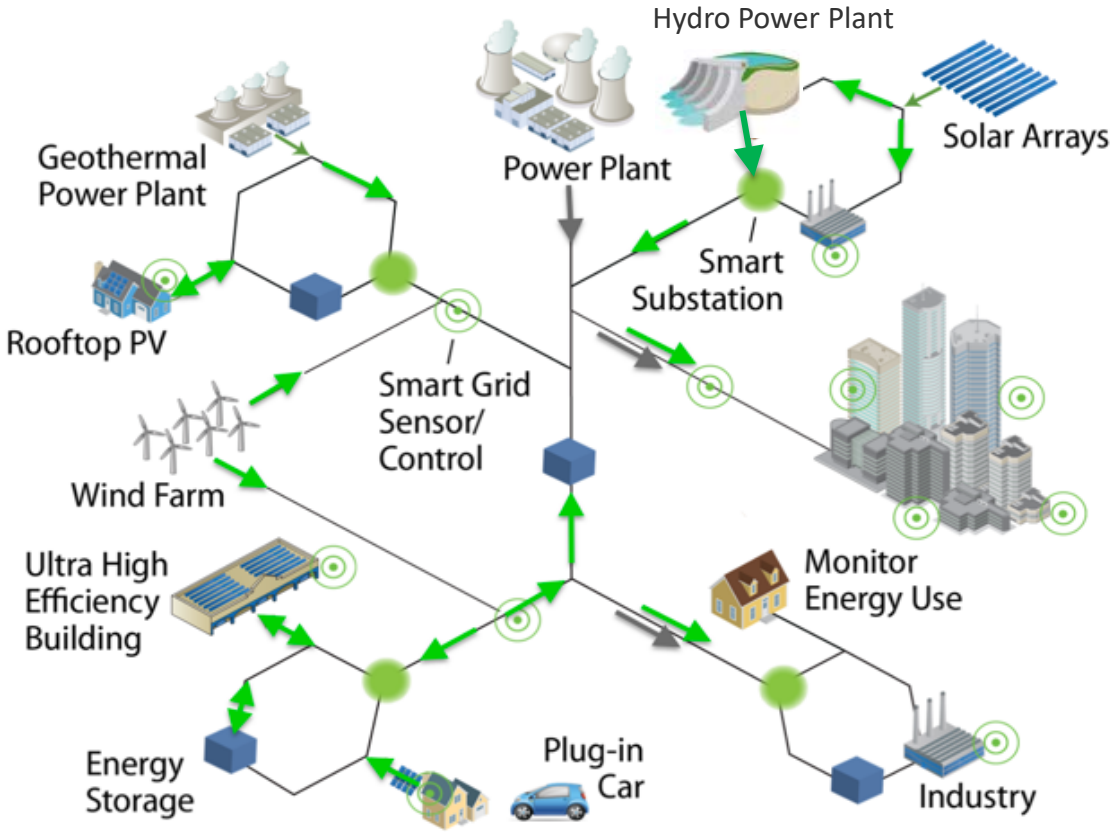
Complex Systems



Big Data Analytics



Future Energy System



- The future energy system will integrate all types of energy systems and be more complex, distributed, and interdependent.
- If designed properly, it will also be more efficient, resilient, and affordable.

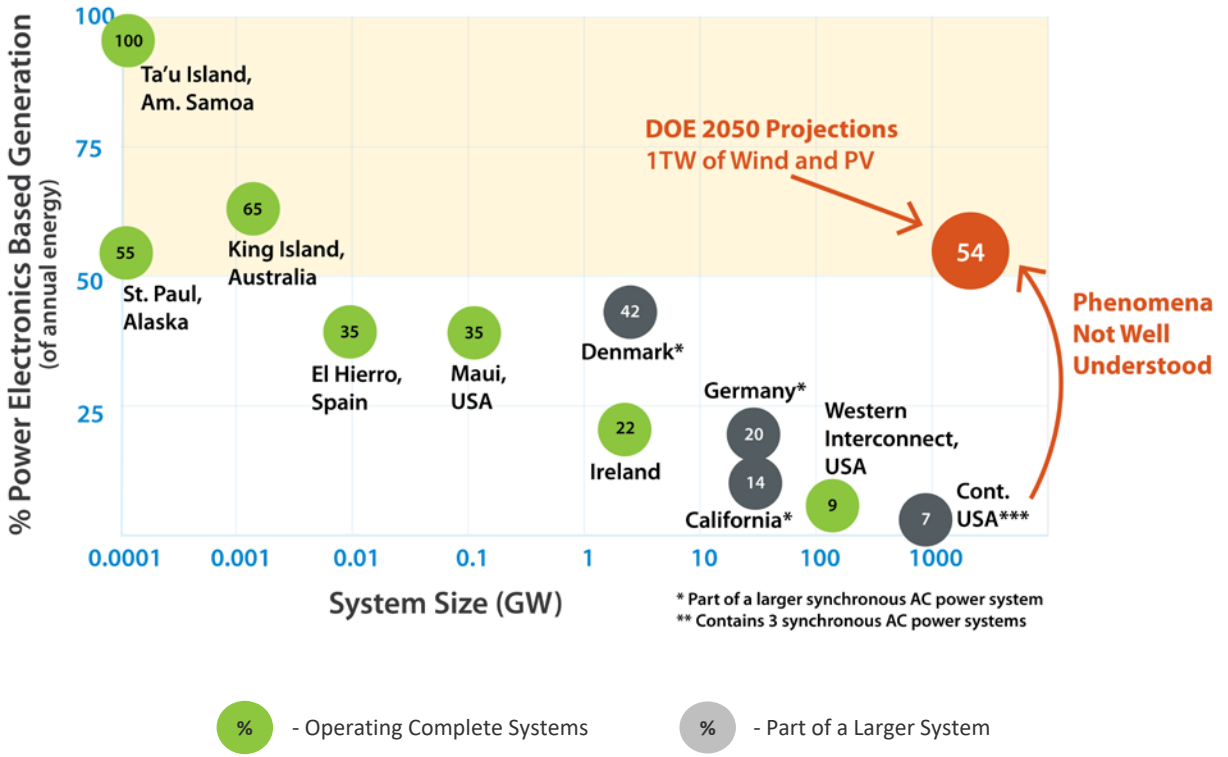
Power Electronics-Based Energy System

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

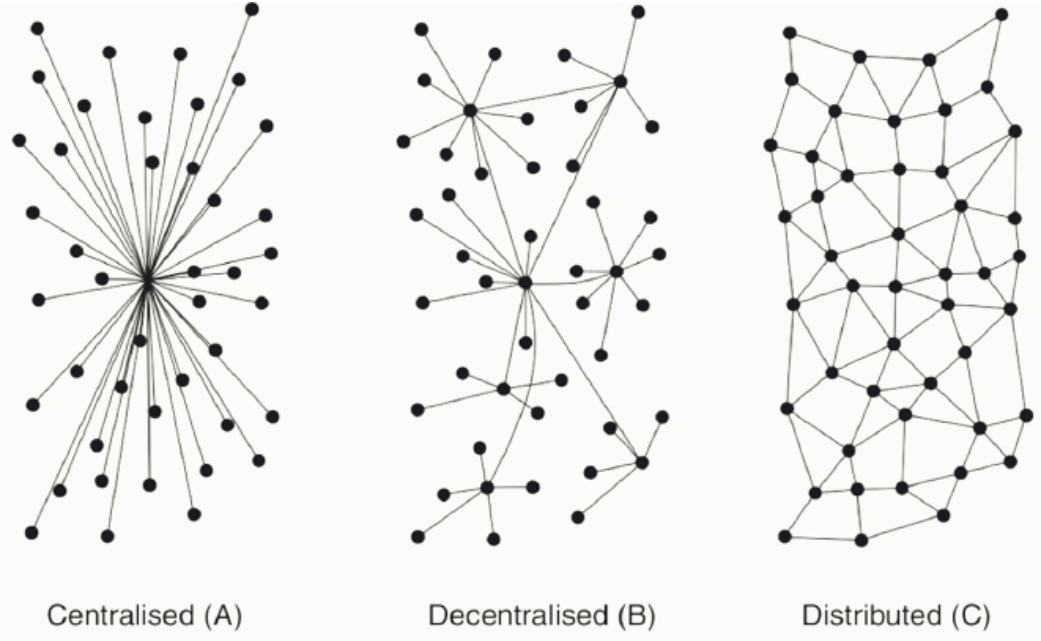
Storage
- Batteries use PE interfaces to connect to the grid
- Pumped hydro can add PE to increase controllability and provide grid services

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



New Controls that are Distributed, Scalable, and Operate in Real-Time are Needed

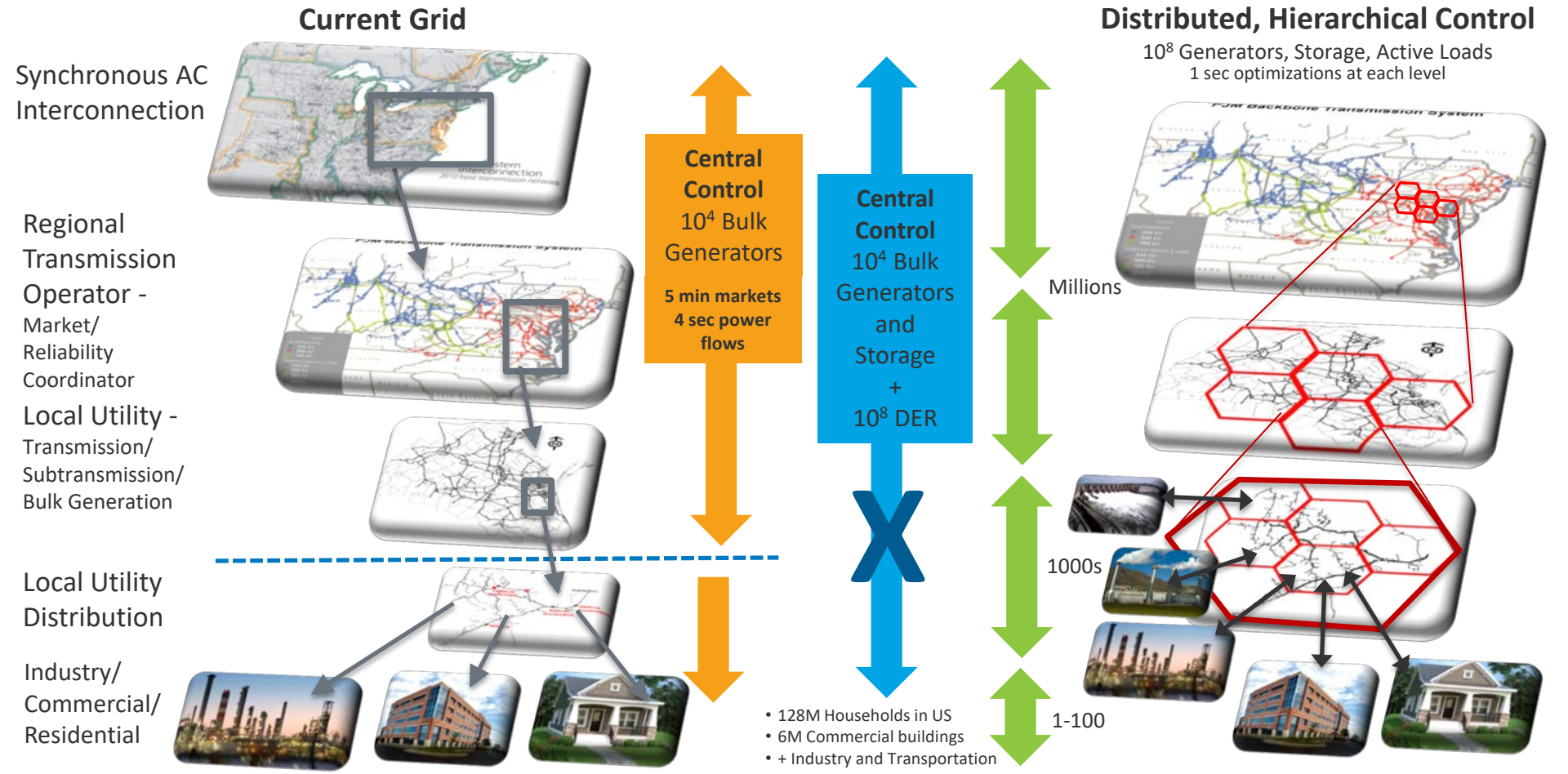


Not only are the technologies changing, but the device system controls will also need to change.

Power electronics devices allow more controllability.

We are moving from a system that centrally controls 10^4 devices at the largest scale to a system that will have 10^8 controllable devices.

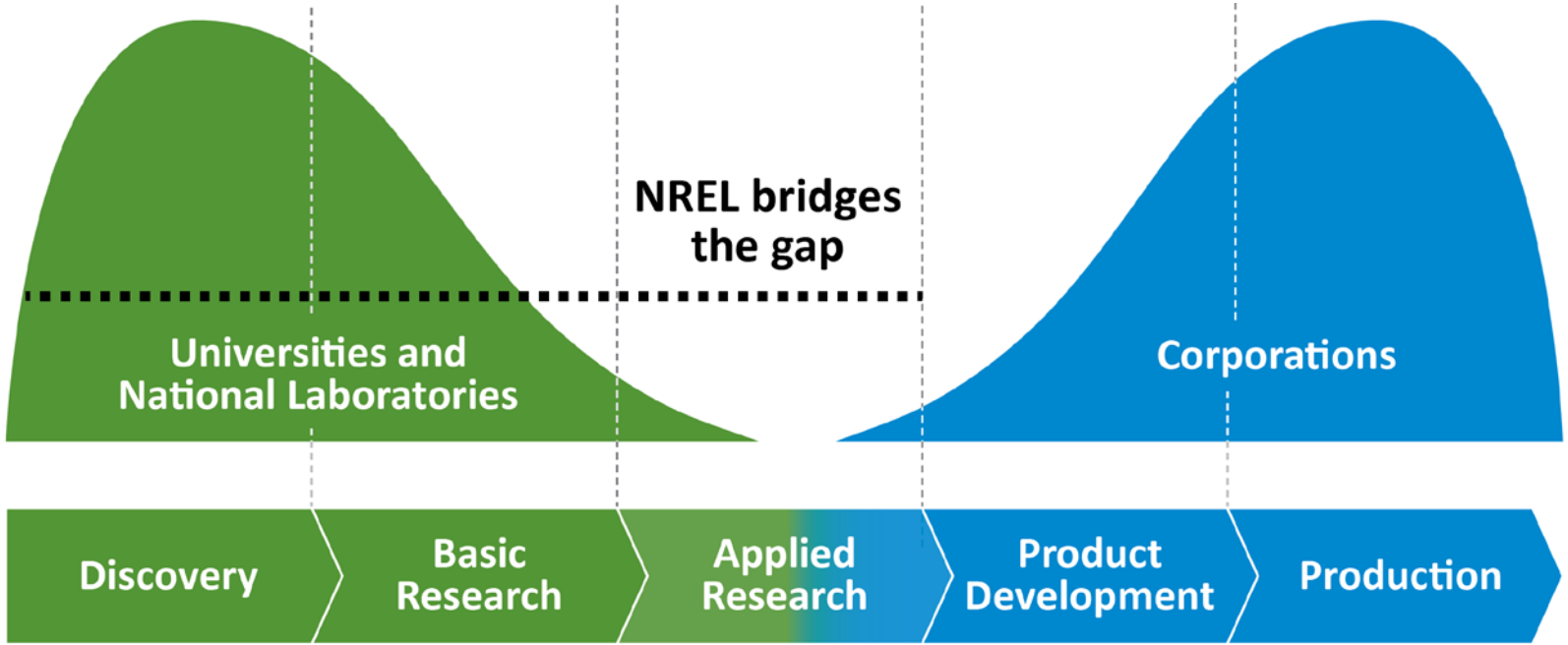
Too Complex to Control?



Partnering for Impact

NREL Reduces Risks in Bringing Innovations to Market

- Bridging the gap from basic science to commercial application.
- Forward-thinking innovation yields disruptive and impactful results to benefit the U.S. economy.
- Accelerating time to market delivers advantages to American businesses and consumers.



Partnering for Impact

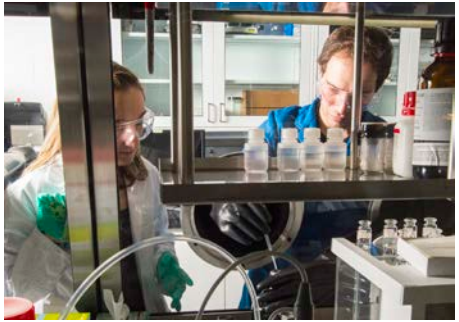
ExxonMobil

Shell

EATON
Powering Business Worldwide

WELLS FARGO

This is a 10-year $100 million partnership that is intended to fill gaps in traditional energy approaches. Our scientists and engineers are collaborating to conceive and create solutions for today's energy challenges.



Shell Gamechanger Powered by NREL is our five-year multi-million-dollar partnership program with Shell. We have branded the program GCxN, and it focuses on battery longevity and advanced smart grid controls.

NREL and Eaton are working together in the ESIF on grid intelligence, distributed energy resource management, advanced energy storage systems, virtual modeling and analysis, high-performance computing and other research.

Our Innovation Incubator (IN_2) is expanding this scalable model to other partners and technologies and growing to a multiyear, $30 million program.

Thank you

NREL
Transforming ENERGY