

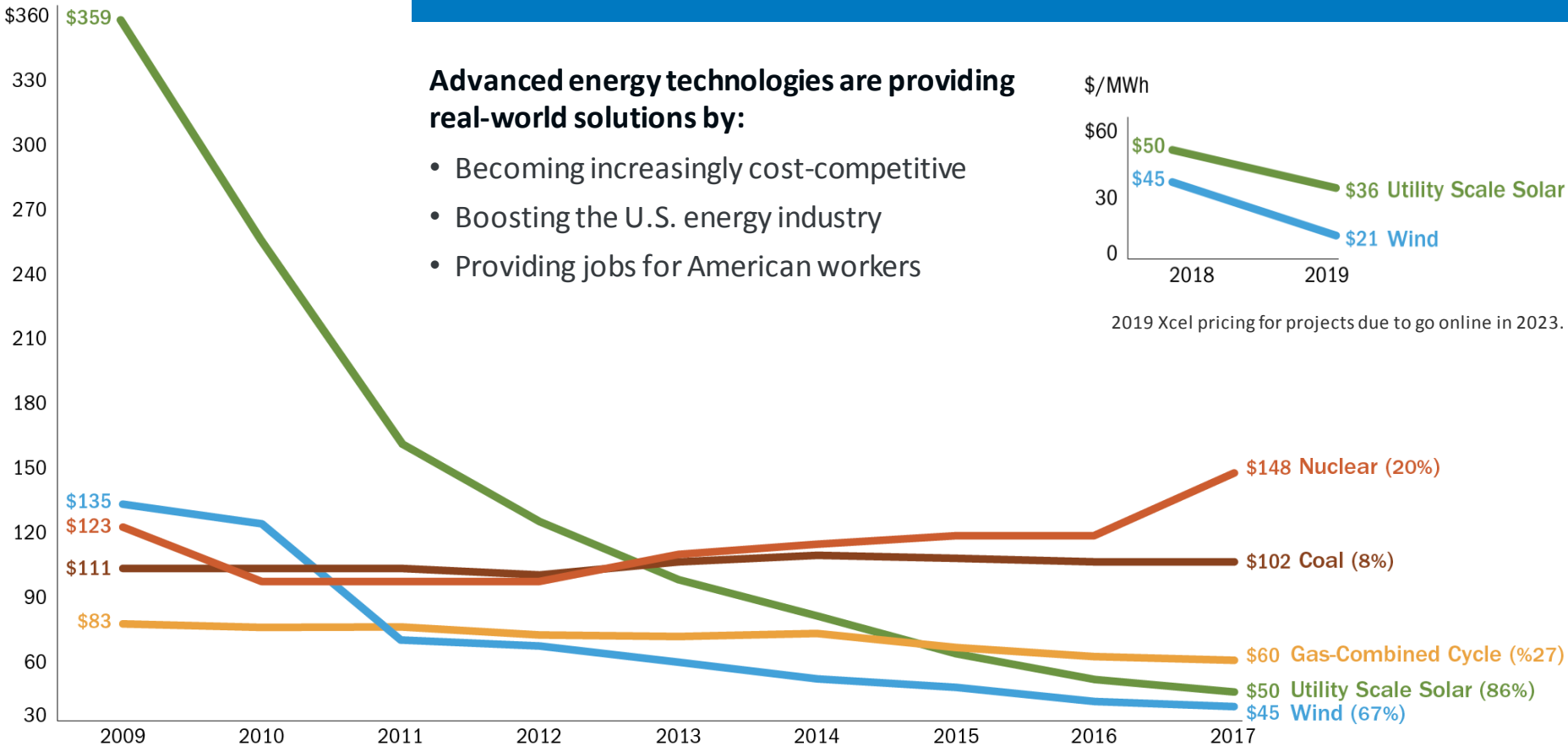


Transforming Energy through Innovation

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Director
October 30, 2019

Costs for Renewables are Falling

Mean LCOE
\$/MWh



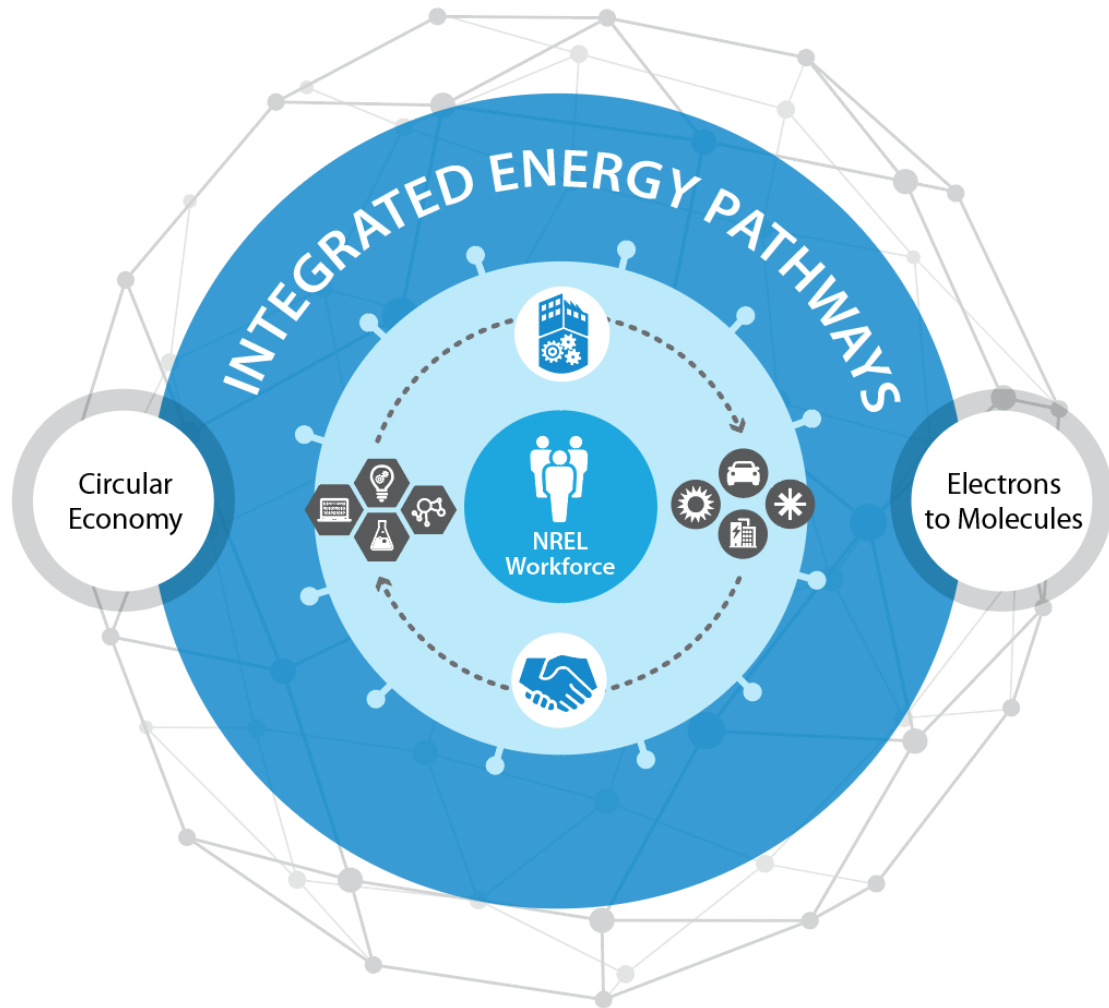
Environmental Scan: Observations Toward 2040

Assumptions that Guided NREL's Strategy Formulation:

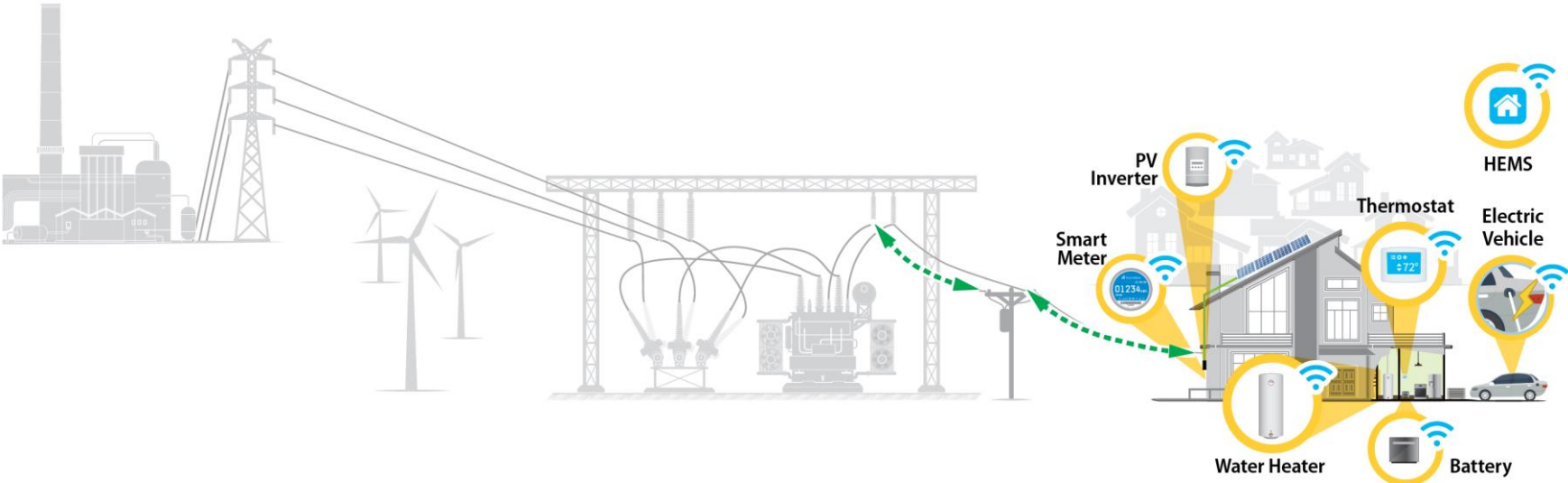
- Growth of energy use in the developing world will far outpace growth elsewhere.
- Global renewable power demand will grow.
- Urbanization trends will dominate new infrastructure growth.
- Electrification and electric vehicle adoption will grow strongly.
- Demand for high-density liquid fuels will grow.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



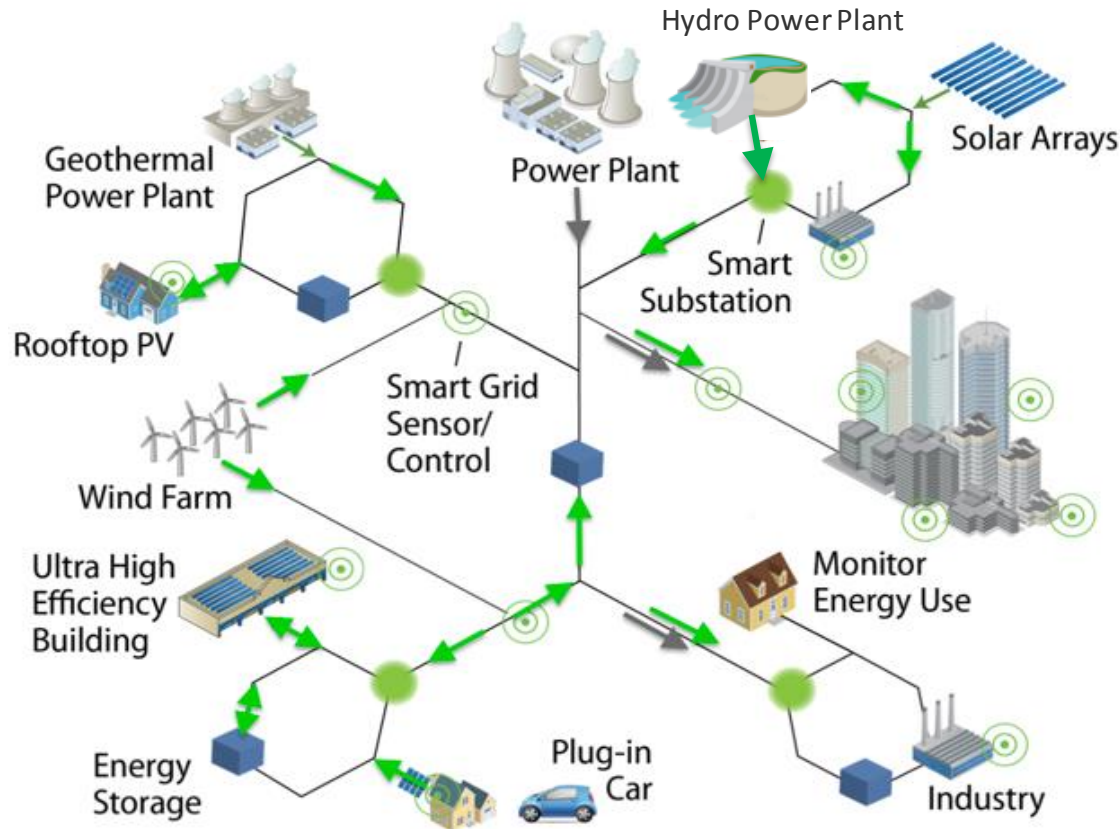
NREL Strategy



How We Use Electricity is Changing



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

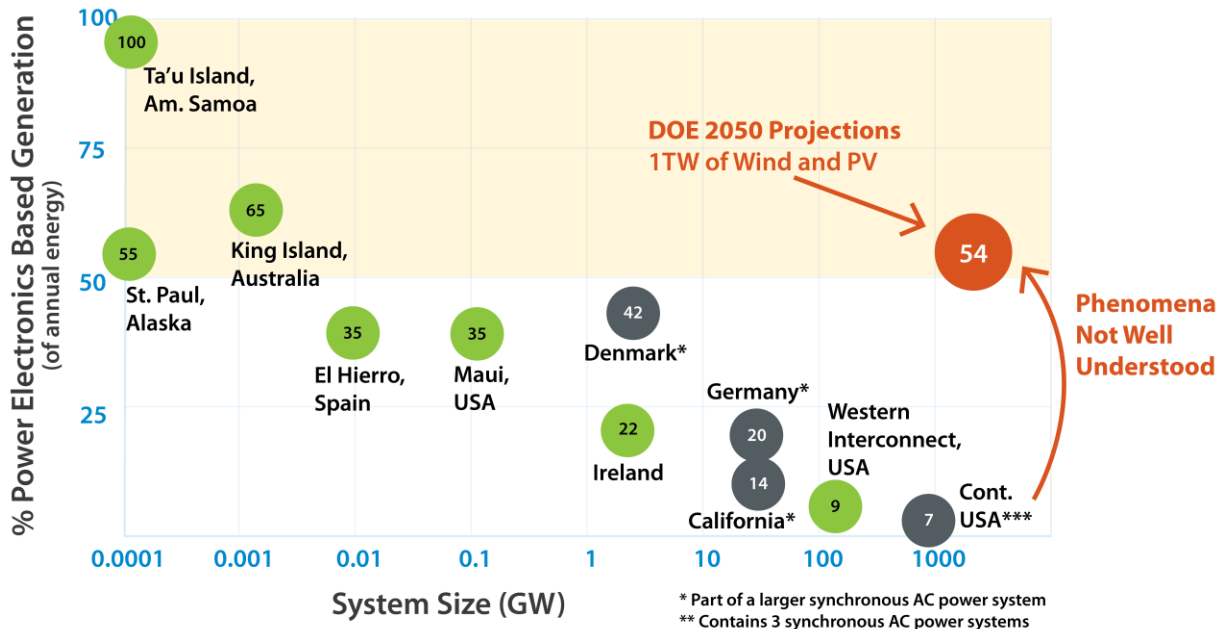
- Batteries use PE interfaces to connect to the grid
- Pumped hydro can add PE to increase controllability and provide grid services

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



● - Operating Complete Systems

● - Part of a Larger System

Too Complex to Control?

Current Grid

Distributed, Hierarchical Control

10^8 Generators, Storage, Active Loads
1 sec optimizations at each level

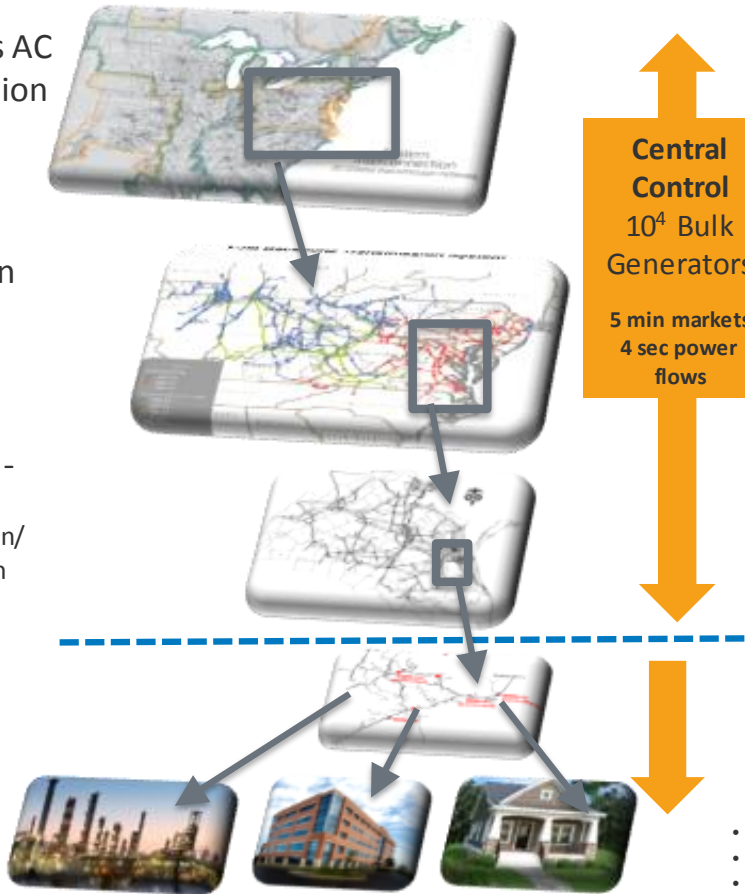
Synchronous AC
Interconnection

Regional
Transmission
Operator -
Market/
Reliability
Coordinator

Local Utility -
Transmission/
Subtransmission/
Bulk Generation

Local Utility
Distribution

Industry/
Commercial/
Residential



Central Control
 10^4 Bulk
Generators
5 min markets
4 sec power
flows

Central Control
 10^4 Bulk
Generators
and
Storage
+
 10^8 DER



Millions

1000s

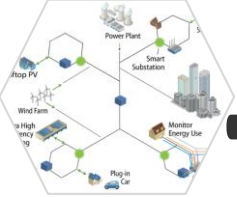
1-100

- 128M Households in US
- 6M Commercial buildings
- + Industry and Transportation

Creating Autonomous Energy Systems

Applications

Power Grids



The diagram illustrates a power grid with various components: Power Plant, Smart Substation, Monitor Energy Use, Plug-in Car, High Efficiency, Wind Farm, and Risp PV. These are interconnected by a network of lines.

Transportation



The image shows a road with several cars. The lanes are highlighted with green and yellow, suggesting intelligent traffic management or autonomous driving paths.

Buildings



The illustration shows a modern city skyline with various skyscrapers and buildings, representing smart buildings and urban energy systems.

Wind Plants



The image shows a wind farm with several wind turbines in a field under a blue sky.

Common Problems:

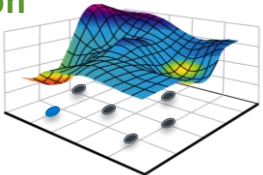
- Real-time controls and optimization
- Hundreds to millions of control points
- Asynchronous data and communications
- Multi-domain systems (complex) and stochastic systems (variable renewables, consumer/occupant behavior)

Nonlinear Control



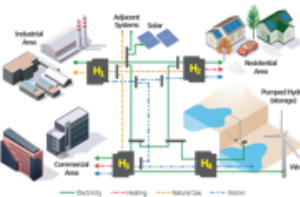
The diagram shows a spiral path with arrows, representing a nonlinear control system or a complex trajectory in a control space.

Optimization



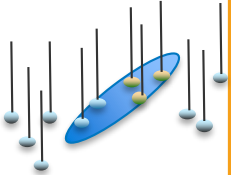
The 3D surface plot shows a landscape with a peak and a valley, representing an optimization problem where the goal is to find the minimum or maximum of a function.

Complex Systems



The diagram shows a complex energy system with various components: Industrial Area, Residential Area, Commercial Area, and Power Plant. It includes flows for Electricity, Heating, Natural Gas, and Water, and mentions Adjacent Networks, Solar, and Purified Hydrogen Storage.

Big Data Analytics



The diagram shows several vertical lines representing data points, with a blue oval highlighting a specific area, representing big data analytics.



Thank you

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