Transforming Energy through Innovation

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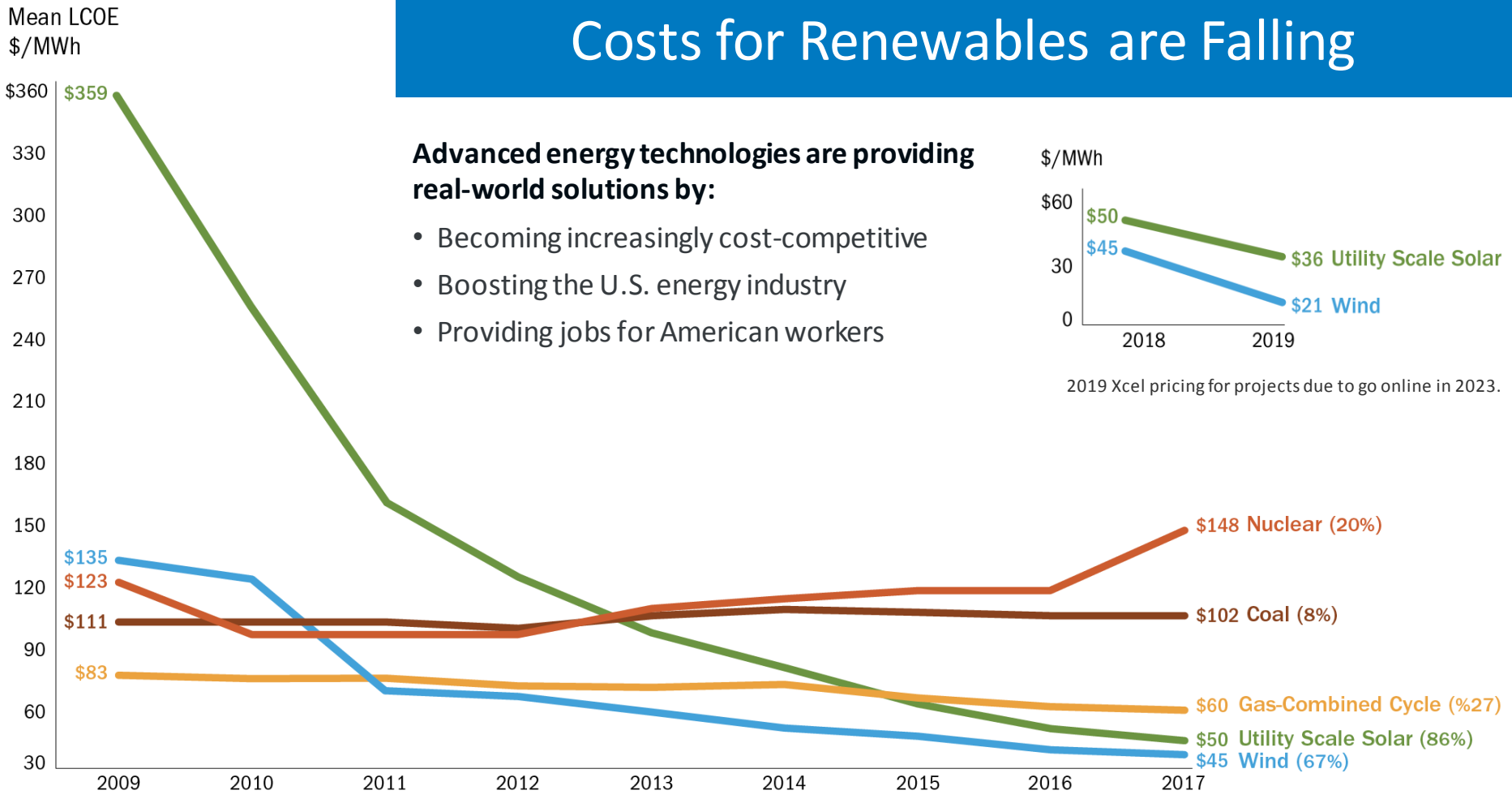
Costs for Renewables are Falling



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.

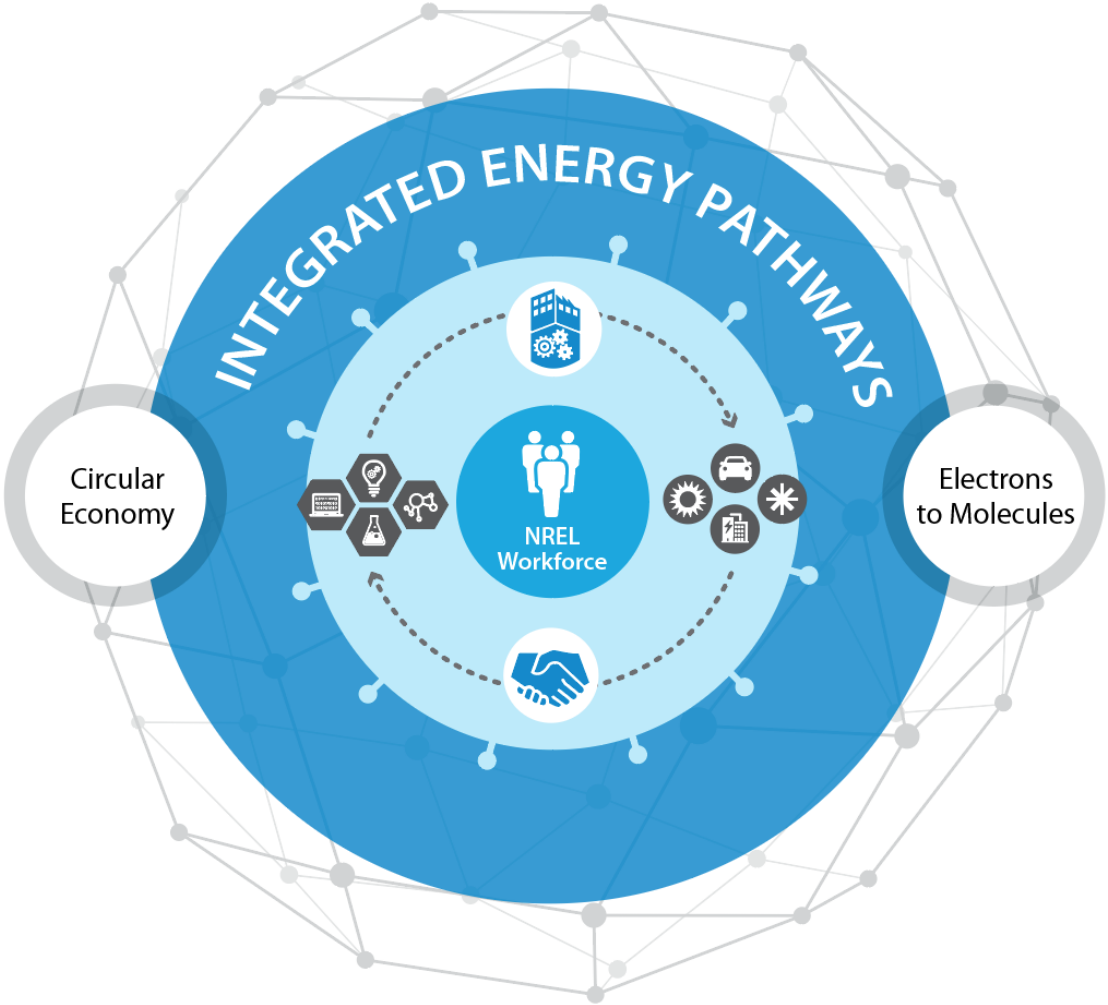
Source: *Lazard's 2017 Levelized Cost of Energy Analysis*, Version 11, 2 November 2017

Environmental Scan: Observations Toward 2040

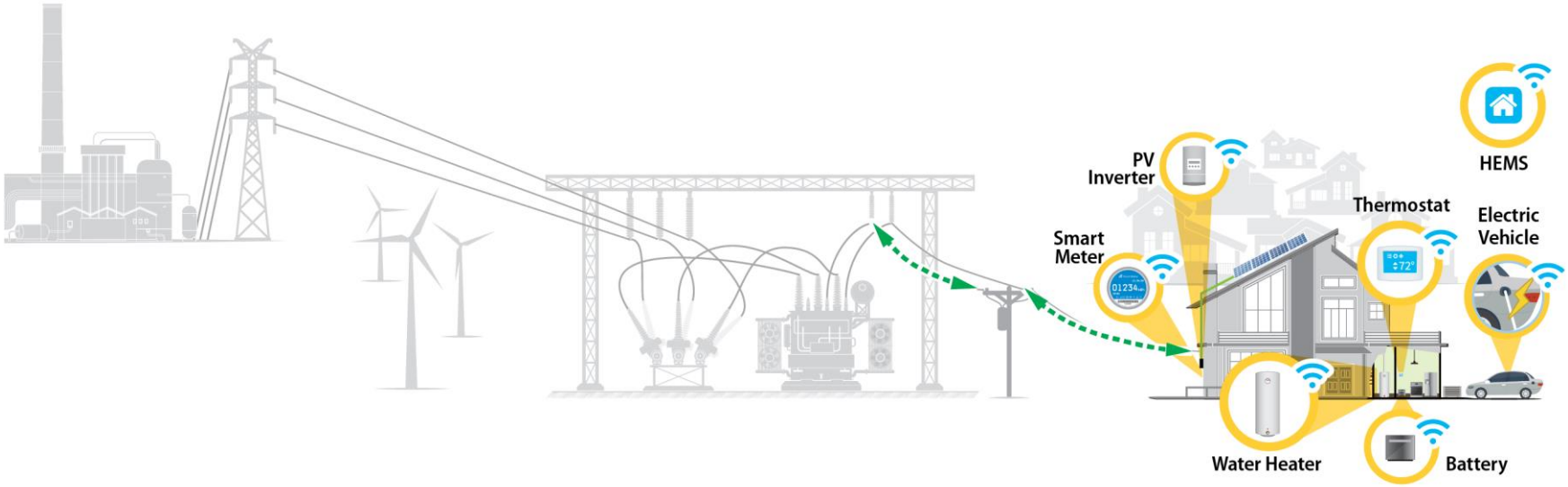
Assumptions that Guided NREL's Strategy Formulation:

- 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.

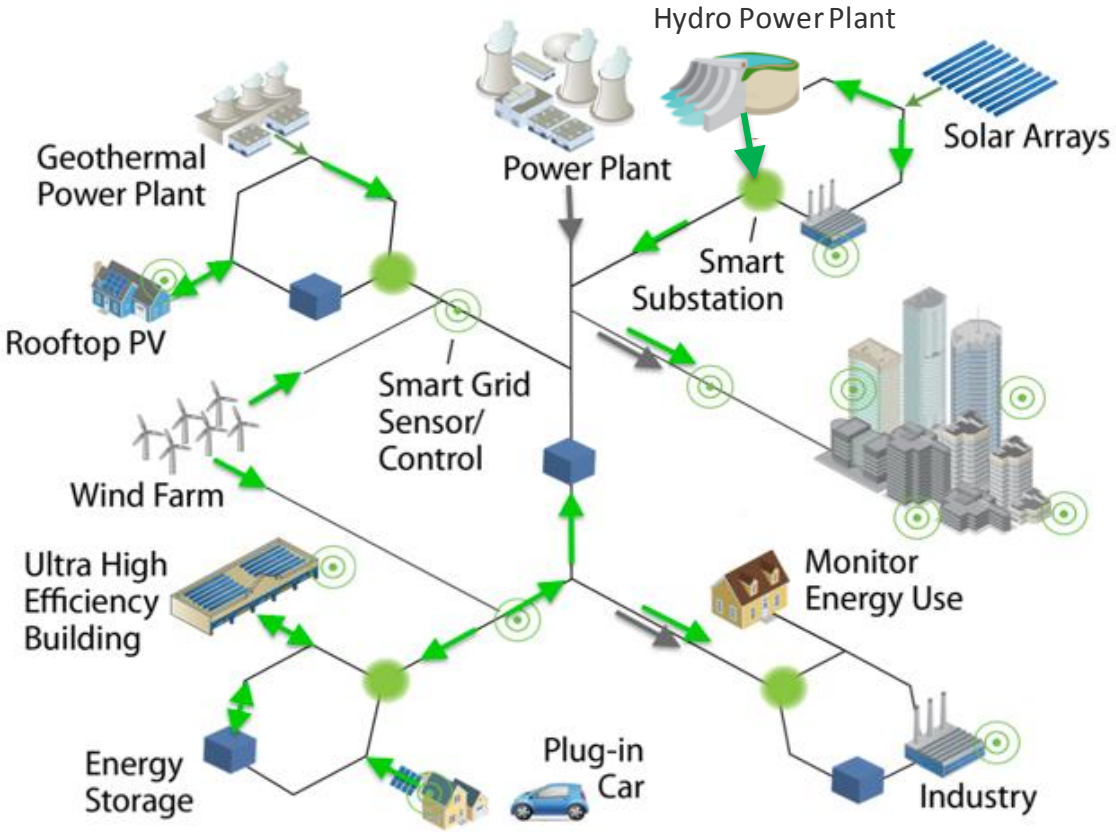
NREL Strategy



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.

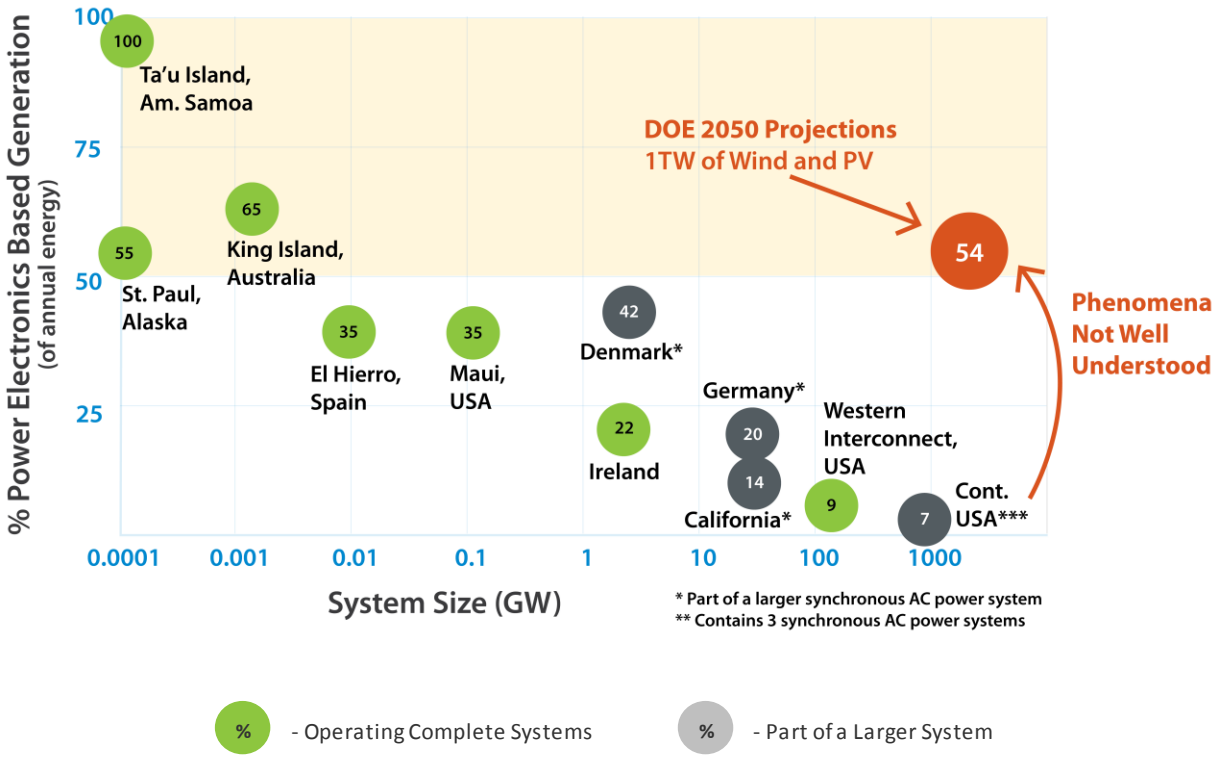
Power Electronics-Based Energy System

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

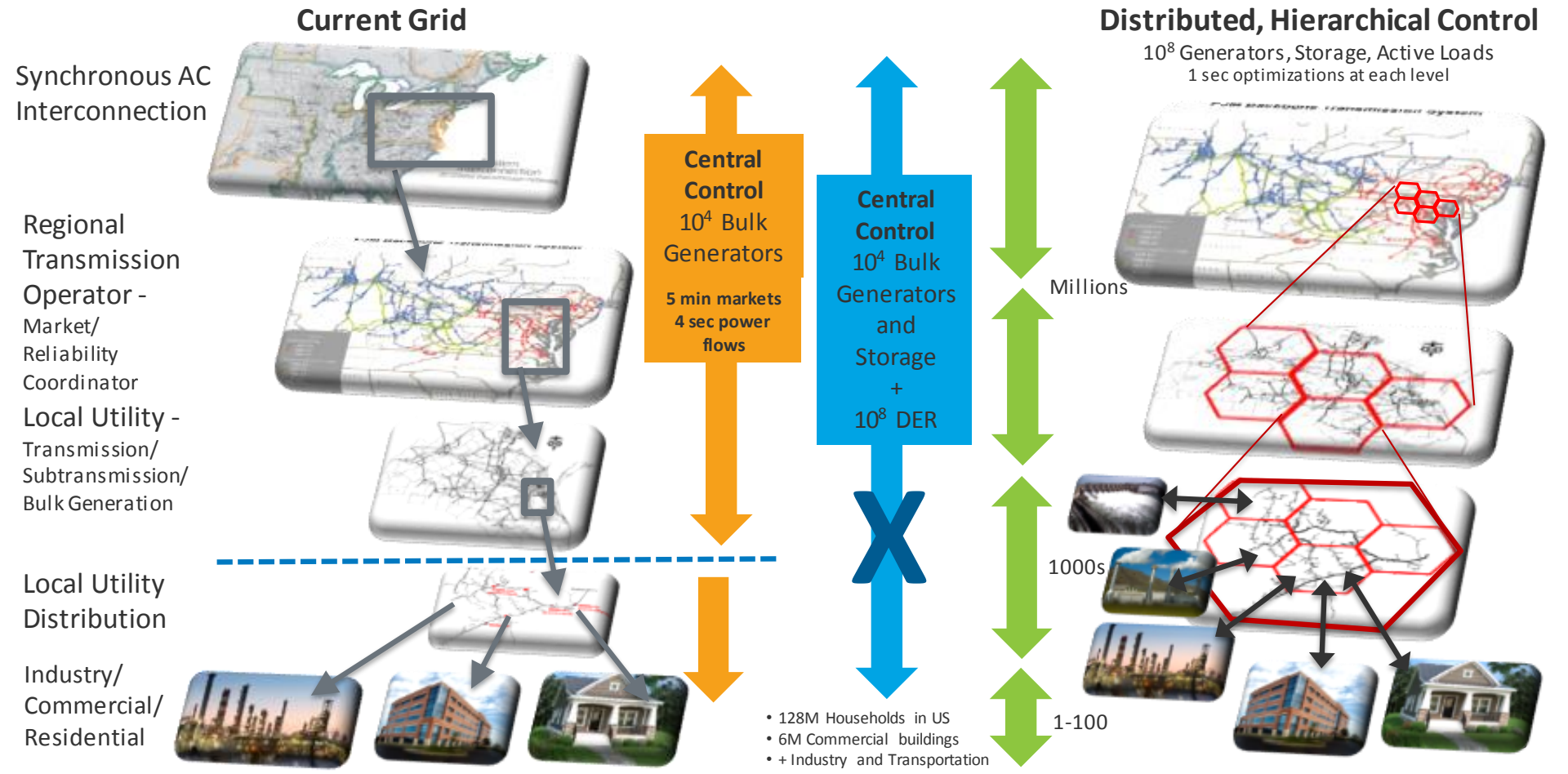
Storage
- Batteries use PE interfaces to connect to the grid
- Pumped hydro can add PE to increase controllability and provide grid services

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



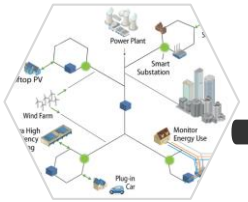
Too Complex to Control?



Creating Autonomous Energy Systems

Applications

Power Grids



Transportation

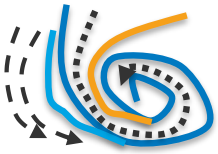
Buildings

Wind Plants

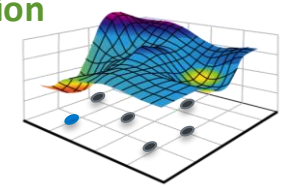
Common Problems:

- 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)

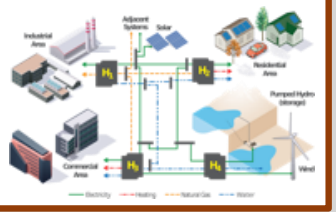
Nonlinear Control



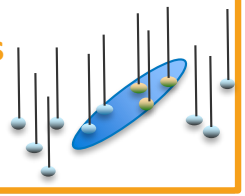
Optimization



Complex Systems



Big Data Analytics



Thank you

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