

# Emerging eT&D Grids

## Energy Storage, Electrification, and Modernization of Electricity Infrastructure

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# U.S. Electric Grid Today

Big interconnected system with ~850GW baseload, 1250 GW summer peak, 7,000 operational power plants

- 3,200 utilities, 60k substations, 642k miles of HV transmission lines, 6.2 million miles of distribution circuit, 159 million customers.
- Revenues reaching \$400 B, ~10.42 c/kWh avg
- Increasing NG and renewable generation

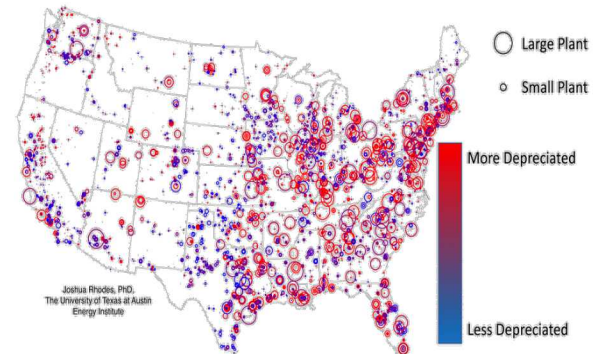
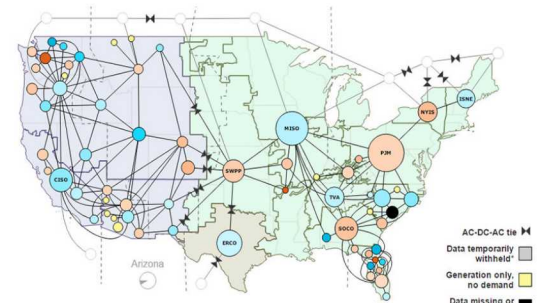
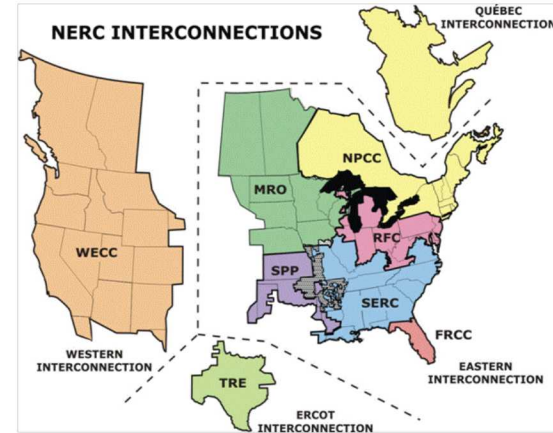
Four interconnect regions and a number of balancing authorities:

- Eastern Interconnection (31 US, 5 Canada)
- Western Interconnection (34 US, 2 Canada, 1 Mexico)
- ERCOT, Hydro-Quebec

Major grid infrastructure is aging

Accelerating retirements of coal fired power plants

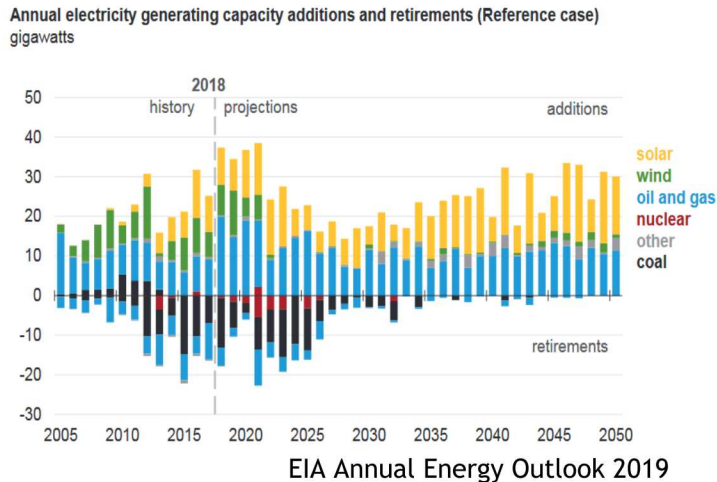
T&D congestion starting to impact deployment of renewables



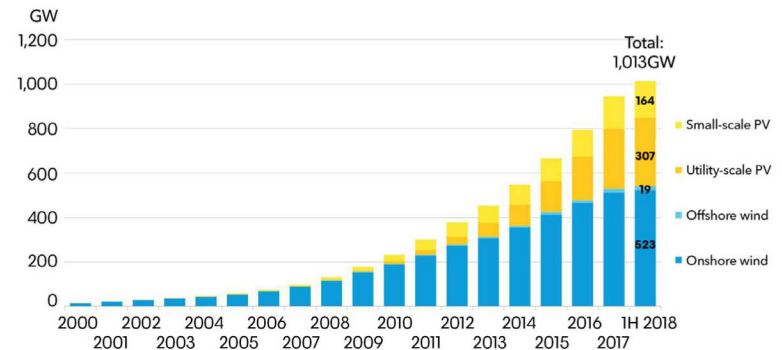


# Industry Trends – Growth of NG, Renewables, Cost Reductions

## Capacity Additions and Retirements

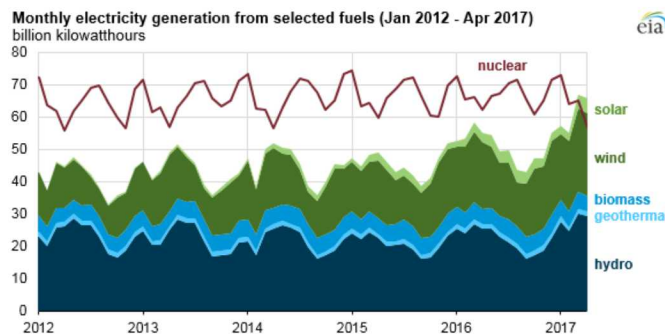


## Cumulative global solar and wind capacity (June 2018)

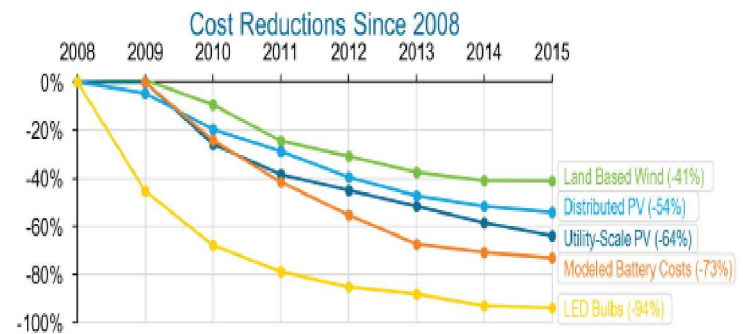


Source: Bloomberg NEF. Note: 1H 2018 figures for onshore wind are based on a conservative estimate; the true figure will be higher. BNEF typically does not publish mid-year installation numbers.

## Utility-scale Renewables Generation surpassed Nuclear Generation (April 2017)



## Cost reductions primarily due to high volume manufacturing and large scale deployments

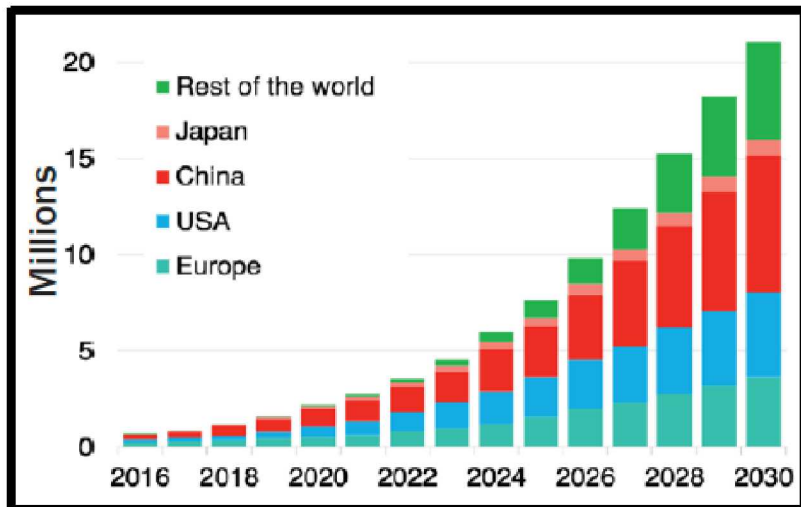


<http://energy.gov/eere/downloads/revolutionnow-2016-update>

Coal-fired unit retirements driven by low NG prices (EIA, 2017)

In California, solar, storage and wind capacity additions expected to exceed NG by '21(GTM)

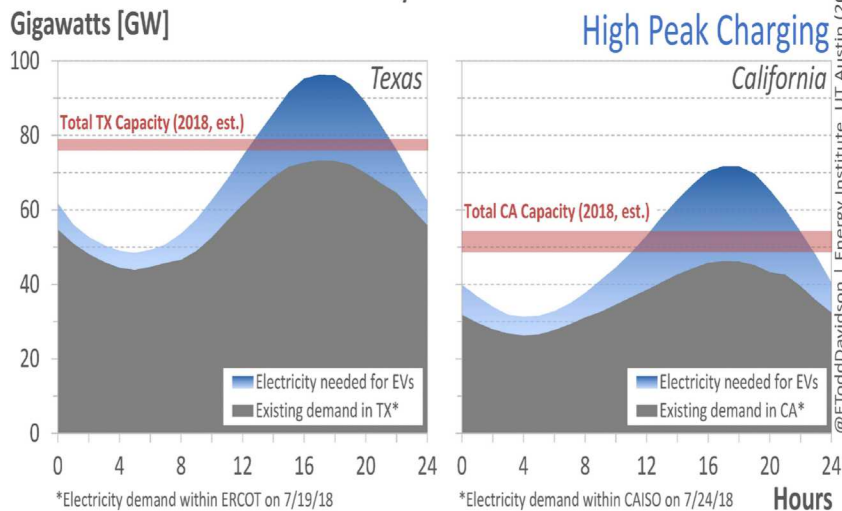
# Another Trend – Electrification of Transportation Fleet



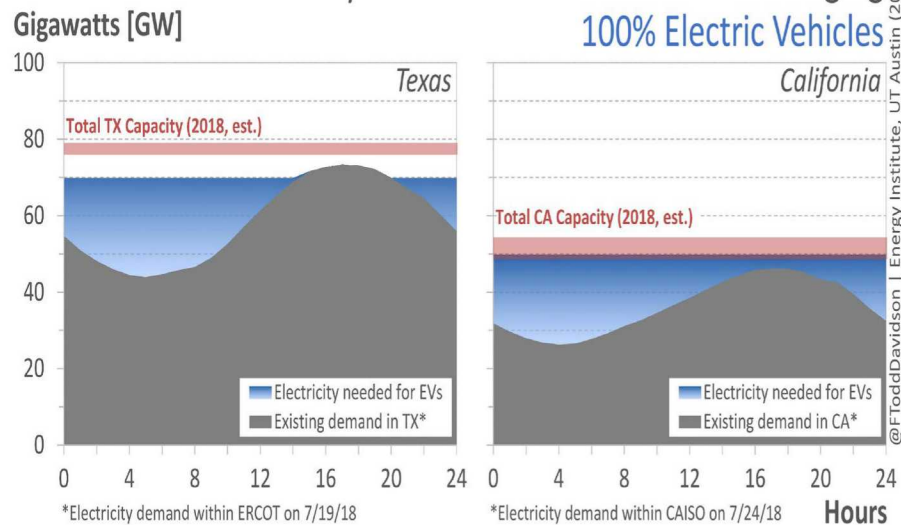
Source: Bloomberg New Energy Finance

- Projections for annual production of electric vehicles reaching 20 Million by 2030 and a fleet of 130M (mostly passenger vehicles) on road as base case; 230M vehicles optimistic case (BNEF, IEA, 2018)
- Electrification will drive demand growth, overloading distribution systems and causing transmission congestion. Total load may double.
- Needs major T&D upgrades if EVs are mainly charged from the grid.

Electricity Demand for 100% EV Scenario



Electricity Demand with Ideal Vehicle Charging





### Electrification of the Transportation Sector

- EV charging infrastructure and fast charging
  - Ensure stability of the power grid
  - Accommodate large loads
  - Provide grid services and infrastructure for transactive energy

### Behind-the-meter solar and energy storage

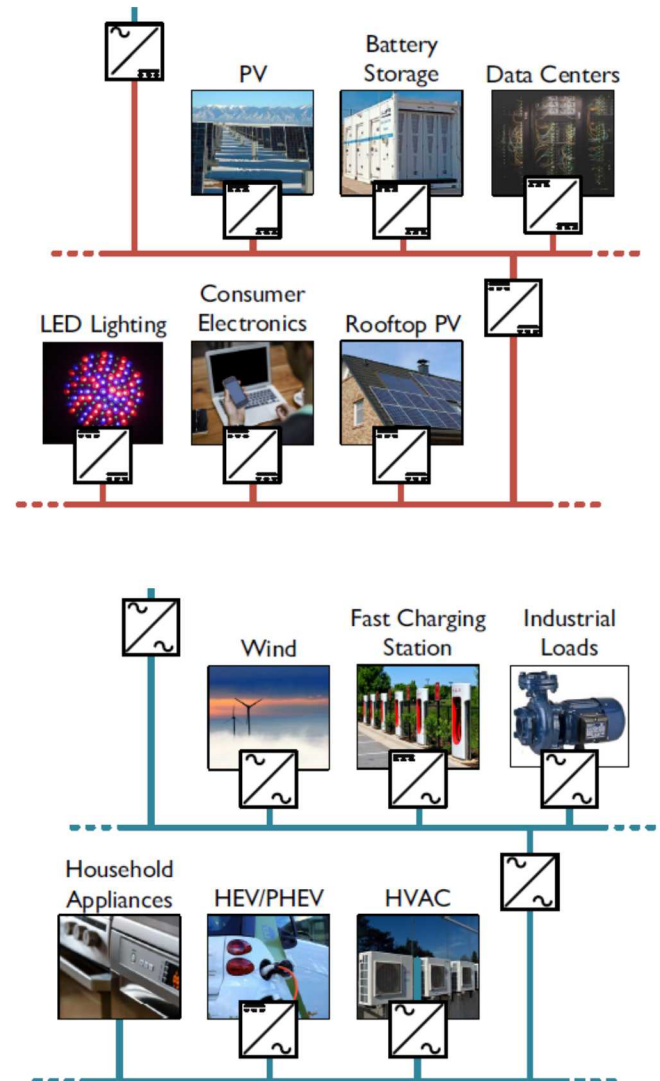
### Rapid evolution of off-grid and micro-grids

- Potential to disrupt existing electricity market structures

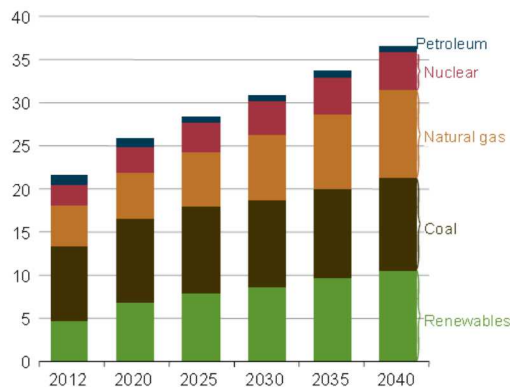
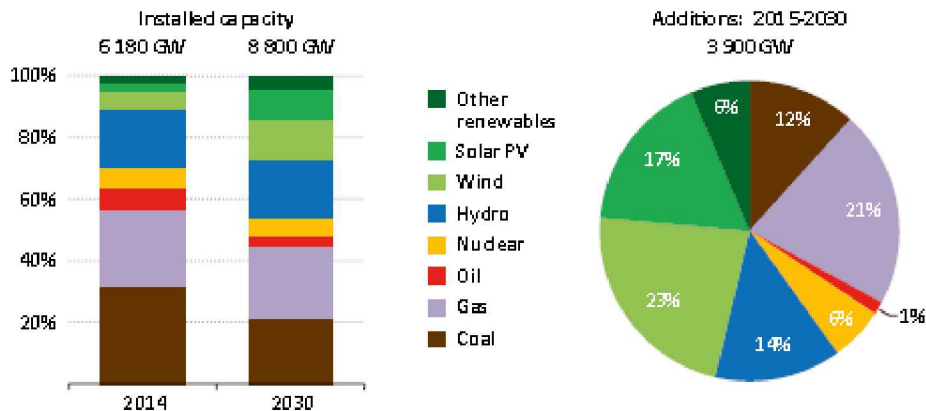
### Behind-the-meter technologies with bi-directional communication

- Smart meters, smart loads, rooftop solar, electric vehicles, battery storage

### Computation challenges associated with distributed sensing, control, and big data



# Are We at the Cusp of a Major Transformation?



Source: International Energy Outlook, EIA

Of the 6 TW of worldwide generation capacity, renewables are reaching the 20% range in many markets

- Installed solar and wind capacity reached 1 TW in 2018, penetration levels approaching 30-40% in some markets.

Handling intermittency is becoming a challenge in many markets

- High level integration of energy storage and hybrids, on a grand scale
- Electric vehicles are coming
- Electrification of aviation is next

We are beginning to see existing business models not keeping pace with changes

Conservative regulated utility industry

- Not open or reluctant to change business models
- IOUs and PUCs struggling to adapt to rapid change

Flat to declining electricity sales in OECD markets

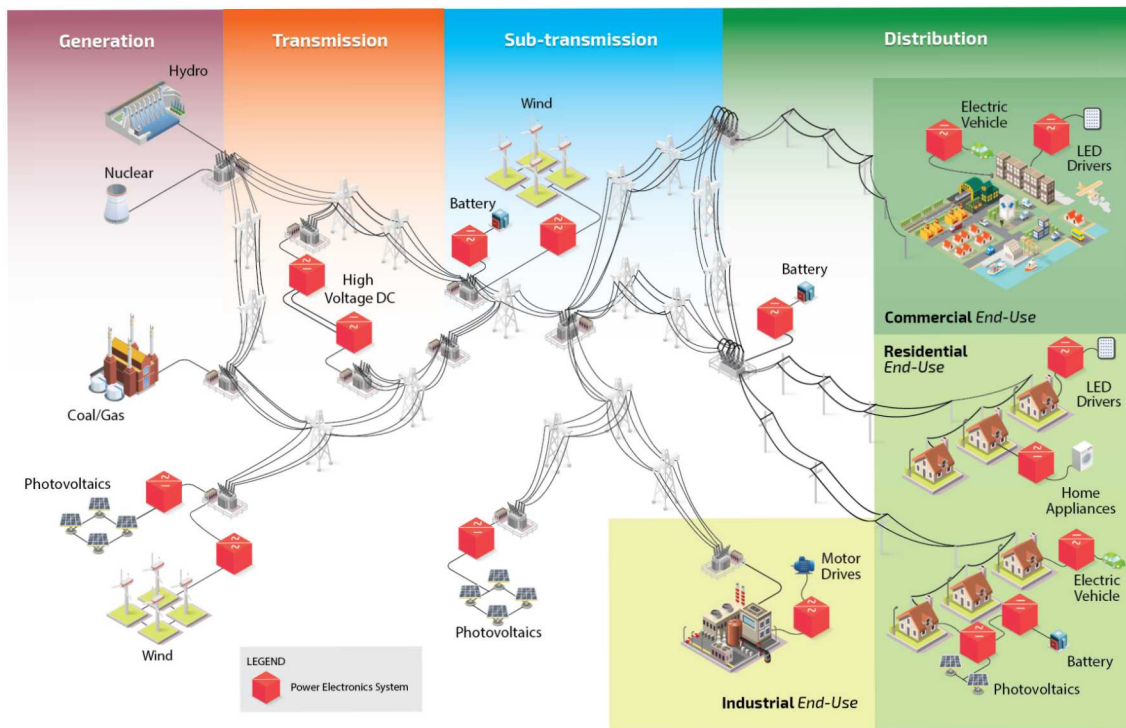
- Investors struggling with poor returns due to long adoption cycles. \$2 Trn Asset Base in the US alone

Energy Storage, Electric Vehicles, Power Electronics, and Communications at the center of grid modernization

**In 2000**, the IEA forecast that by 2030, renewable energy would be 4.4% of the total mix  
**In 2018**, installed wind and solar capacity reached 1 TW; new generation is more renewable

## 7 Increasing Role of Power Electronics in Electricity Infrastructure

The power conversion system is at the center of DER, Energy Storage, and EV infrastructure



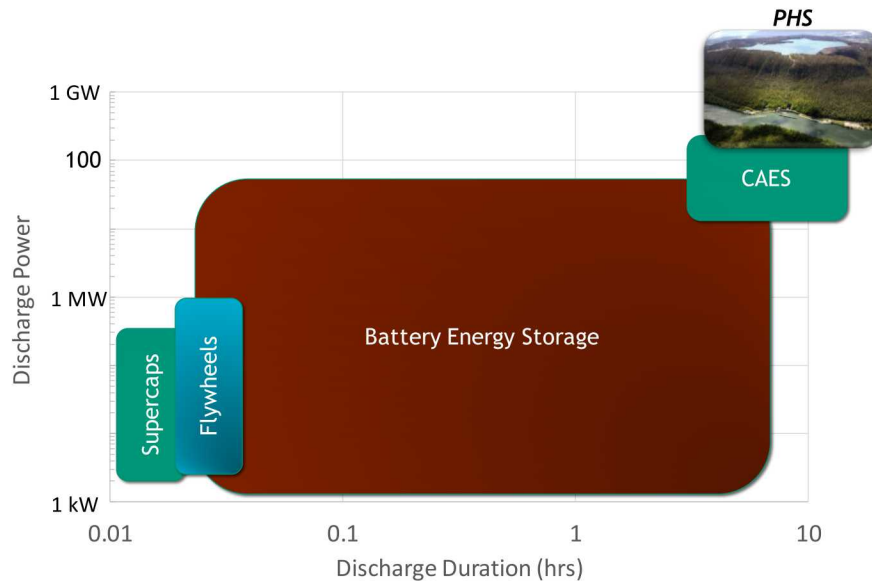
Source: K. Cheung, US DOE

Approximately 30% of all electric power currently generated uses PE somewhere between the point of generation and distribution.

By some estimates, 80% of energy will flow through power electronics.

Cost reductions in power electronics and power conversion systems has been slow to come.

- Bringing in WBG devices can make format factor smaller, reducing thermal management issues
- New magnetics and high temperature capacitors can make the systems more compact and robust



Range of applications and storage system needs [Adapted from: DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, 2013]

Range of battery technologies for short duration energy storage, seconds to days

- Li-ion, advanced lead acid, Sodium and Zinc-based battery for power and some energy applications
- Flow batteries – energy applications

Pumped hydro and CAES for hours to day long energy storage

No ready solutions for real long duration and seasonal storage needs

- Range of options including liquid fuels, hydrogen, thermal storage technologies

## Energy Applications

Arbitrage  
 Renewable energy time shift  
 Demand charge reduction  
 Time-of-use charge reduction  
 T&D upgrade deferral  
 Grid resiliency

## Power Applications

Frequency regulation  
 Voltage support  
 Small signal stability  
 Frequency droop  
 Synthetic inertia  
 Renewable capacity firming

## Energy storage application time scale

- “Energy” applications – slower times scale, large amounts of energy
- “Power” applications – faster time scale, real-time control of the electric grid

## The grid needs energy storage – right now there are several barriers

- Expensive, especially in energy markets
- Electricity markets/utilities do not properly allocate payments/costs for services provided

Compared to the need, the scale of energy storage deployments is insignificant. In US, we have a 1 TW grid, even 1 hr of energy storage means 1 TWh



Electronic T&D Grids are Communications Intensive - Many technologies that will fulfill requirements of the grid of the future are communication-intensive

- Pervasive communication systems with low latency and high bandwidth
- Sensors with high sampling rates in great numbers
- Response to fast grid dynamics, IP-based communication protocols
- More fiber optics and cellular network links (LTE, 5G)

Change of paradigm from centralized to decentralized

- Agents that participate actively in power grid will be more granular
- Coordinated participation of large numbers of small energy resources will require fast and reliable communications

Cybersecurity will be a challenge with distributed resources actively participating

- Increased connectivity of grid assets can improve its performance, but comes with risks
- Coordination between electric vehicles
- Communication over public networks

Physical Security

- EMP, GMD, and other large scale disturbances
- Weather related



Electric systems	Traditional Grid	Development Trends and Needs	Future Grid
Generation	<ul style="list-style-type: none"> <li>• Large centralized power plants</li> <li>• Dispatchable generation</li> <li>• Mechanically coupled</li> <li>• Minimal DER</li> </ul>	<ul style="list-style-type: none"> <li>• Growing role of DER</li> <li>• Energy storage</li> <li>• New planning tools to handle RE</li> <li>• Control coordination</li> <li>• NG replacing coal plants</li> </ul>	<ul style="list-style-type: none"> <li>• Hybrid control architectures</li> <li>• Bidirectional power flows and stochastic loads</li> <li>• Power electronic centric infrastructure across the grid</li> </ul>
Transmission	<ul style="list-style-type: none"> <li>• SCADA for status visibility</li> <li>• Operator-based controls</li> <li>• Aging infrastructure. Low peaking capacity utilization.</li> <li>• Threats/vulnerabilities not well defined</li> </ul>	<ul style="list-style-type: none"> <li>• HVDC transmission</li> <li>• Growing dc loads</li> <li>• Improving EMS</li> <li>• Integrated planning tools</li> <li>• Growing security awareness</li> <li>• Increasing role of storage</li> </ul>	<ul style="list-style-type: none"> <li>• Wide-spread PMU deployment</li> <li>• Coordinated sensing and control infrastructure</li> <li>• System-wide dynamic power flow management</li> <li>• Resilient and self healing</li> </ul>
Distribution	<ul style="list-style-type: none"> <li>• Minimal to non-existent sensing and automation</li> <li>• Radial design and one-way power flows</li> <li>• Aging distribution infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>• Deployment of ADMS</li> <li>• FACT/inverter enabled voltage regulation</li> <li>• Early adoption of storage in distribution systems</li> </ul>	<ul style="list-style-type: none"> <li>• Truly bi-directional power flows and large scale DG</li> <li>• Pervasive sensing and communications</li> <li>• Local, autonomous coordination</li> <li>• Asynchronous networks</li> </ul>
Consumption	<ul style="list-style-type: none"> <li>• Regional, location and customer specific rate structure</li> <li>• Uniformly high reliability</li> <li>• Predictable behavior based on historical needs and weather</li> <li>• Reliable, yet inflexible</li> </ul>	<ul style="list-style-type: none"> <li>• Customer-determined reliability/power quality</li> <li>• Real time pricing, time of use rates, demand charges</li> <li>• Improved utility communications</li> <li>• Behind-the-meter storage</li> </ul>	<ul style="list-style-type: none"> <li>• Autonomous microgrids</li> <li>• Advanced EMS</li> <li>• Widespread DERs and transactive energy</li> <li>• Pervasive sensor environment</li> </ul>
Operation/Market structure	<ul style="list-style-type: none"> <li>• Vertically integrated utilities, wholesale markets</li> </ul>	<ul style="list-style-type: none"> <li>• Market reform to compensate for services provided</li> </ul>	<ul style="list-style-type: none"> <li>• Diversity of energy products and services</li> </ul>



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