EPRI ELECTRIC POWER RESEARCH INSTITUTE

Moving Beyond an Integrated Grid to an Integrated Energy Network

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The Energy System Today is Fragmented

Companies, products, business models, regulation

Integration can Improve Reliability, Increase Efficiency, Create New Opportunities, and Expand Customer Choice

Selected “Global Points of View”

Using Cleaner Energy

- Efficiency emerges across the energy sector
- Efficient electrification is an opportunity toward a cleaner future
- Transportation becomes more efficient and cleaner

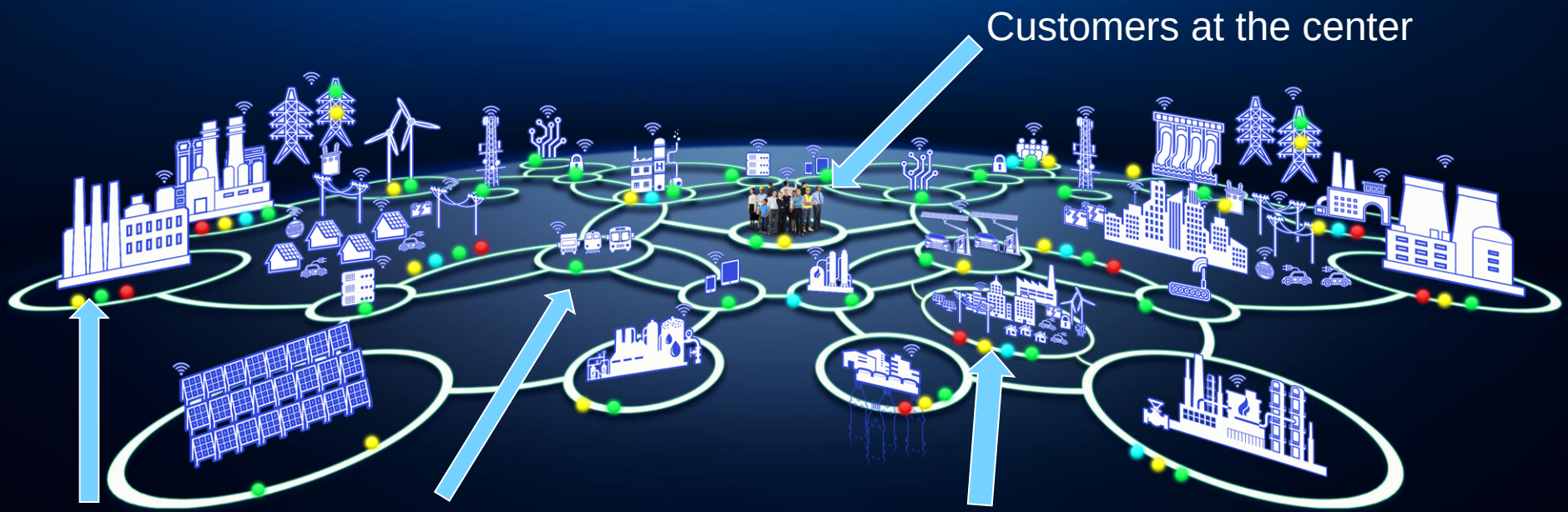
Producing Cleaner Energy

- Energy reduces its environmental footprint
- Central-station generation serves an anchor role
- Renewable energy deploys rapidly

Integrating Energy Resources

- Connections across energy sources important
- Integrated electric grid is key enabler
- Higher expectations for power quality/reliability
- Security/resiliency challenges and opportunities

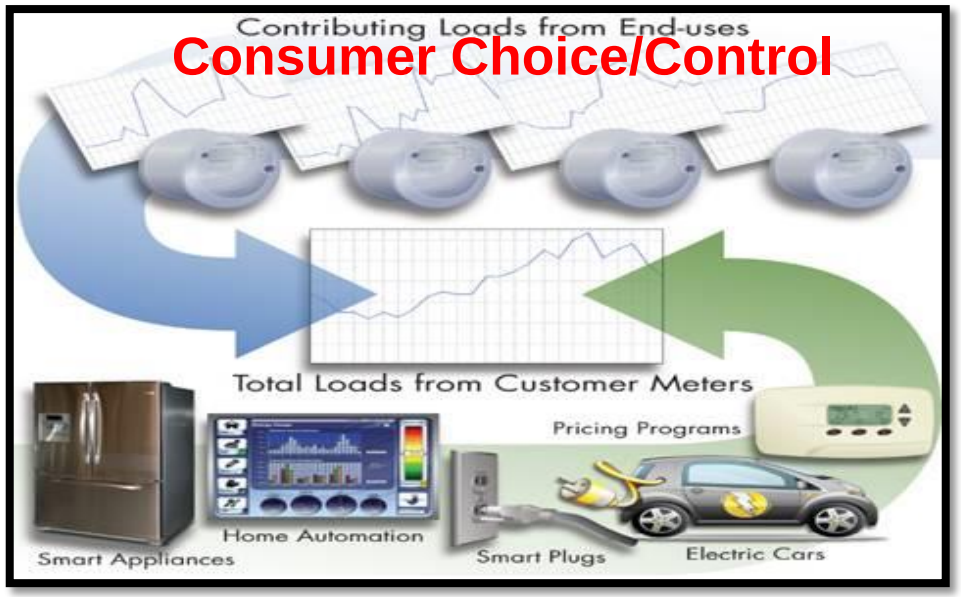
Integrated Energy Network

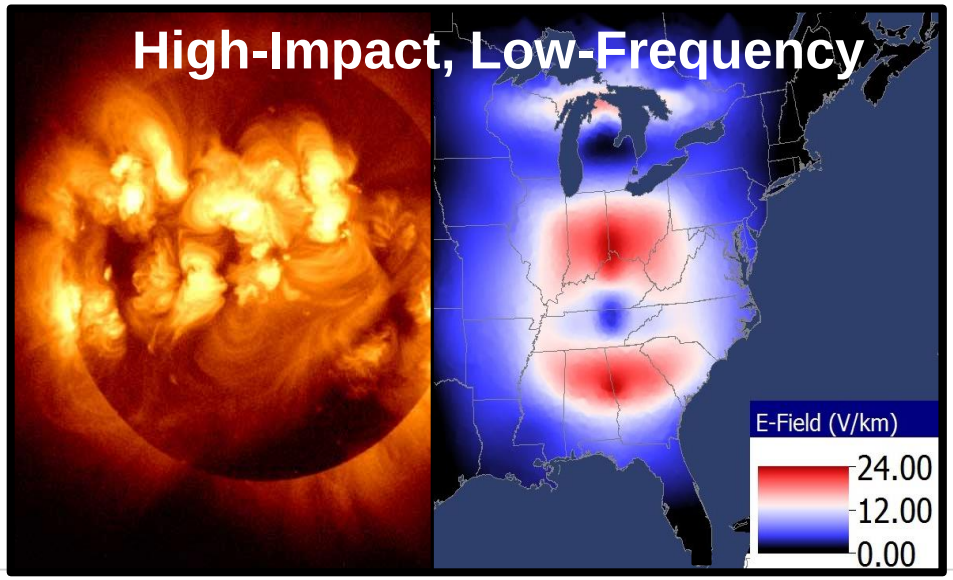


Energy and Natural Resource Systems are Integrated to Provide Reliable, Safe, Affordable, Cleaner Energy and Expanded Customer Choice

Transforming Electricity Sector – An Integrated Electricity Grid

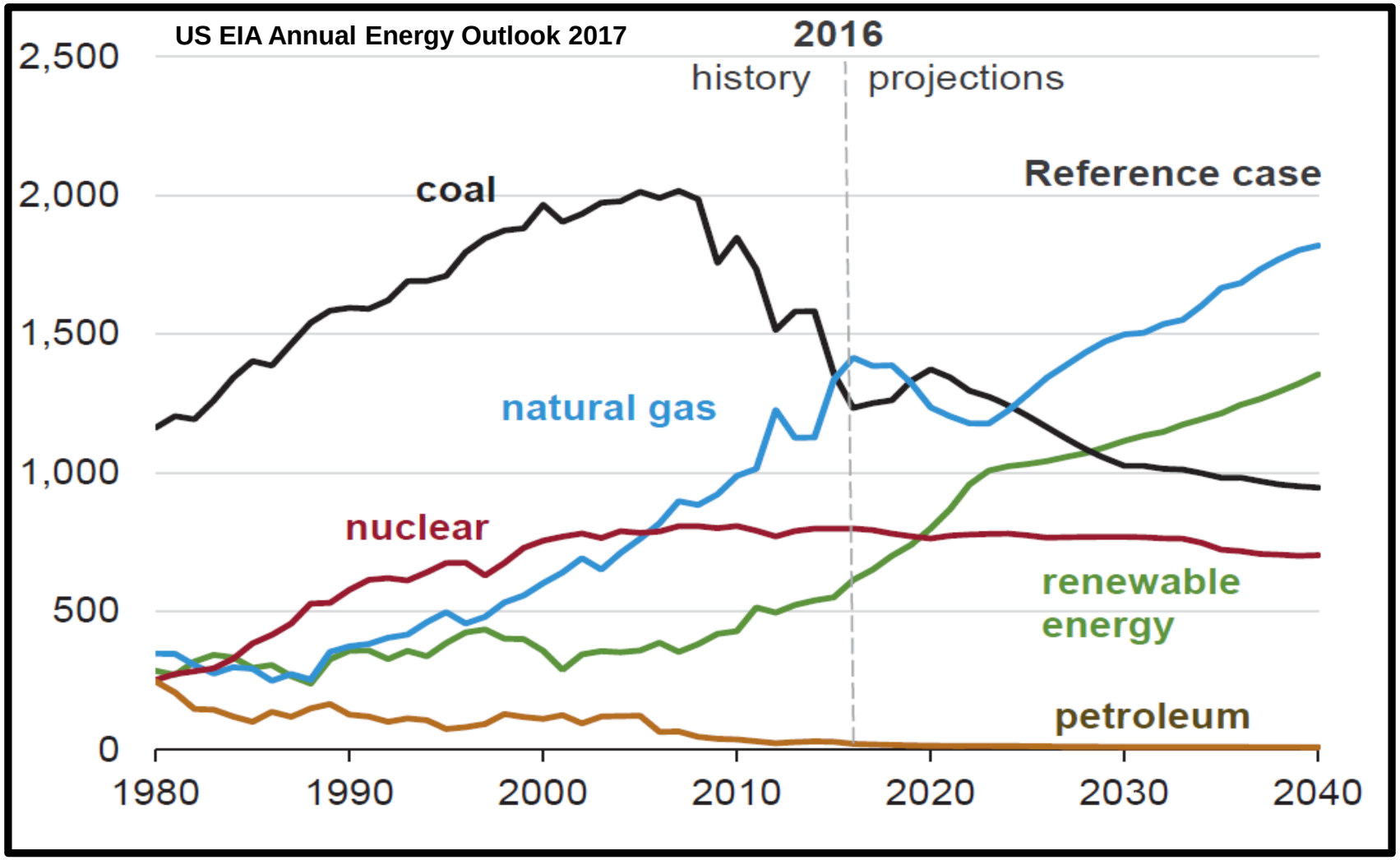
Present Trends Impacting Planning Process



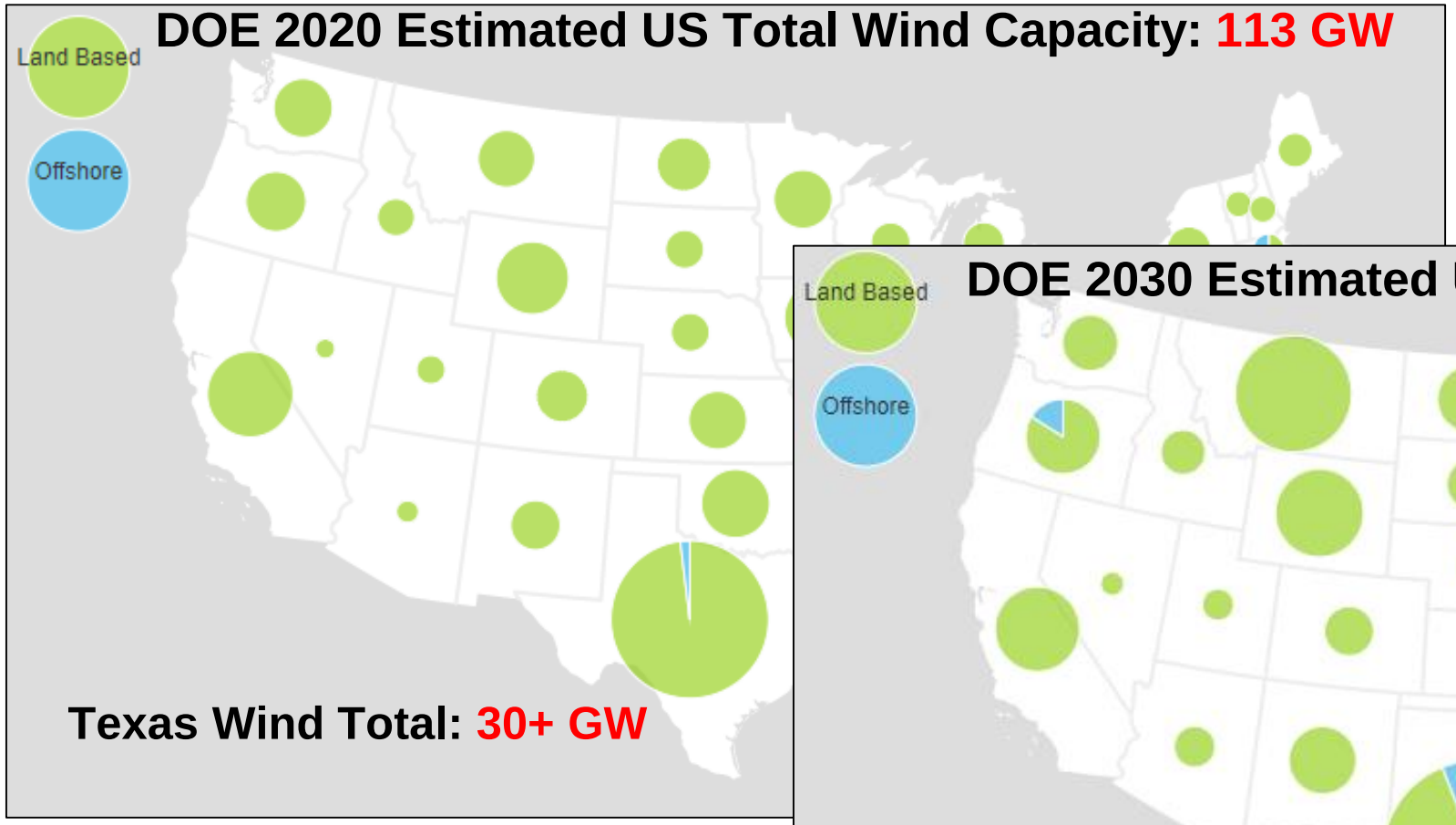


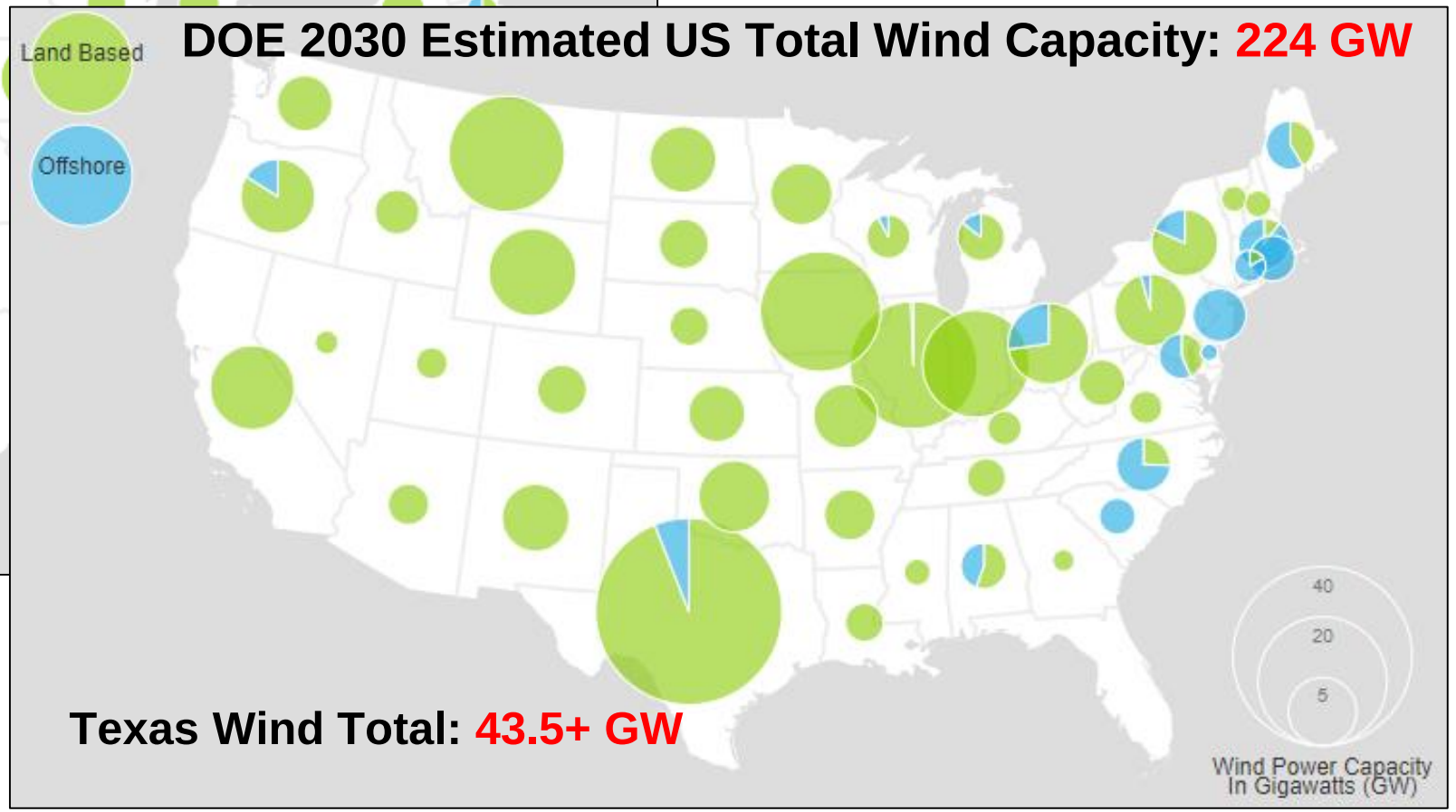
Changing Generation Mix

Gas and central-station renewables continue to replacing coal



Transmission Interconnected Wind Continues to Grow!



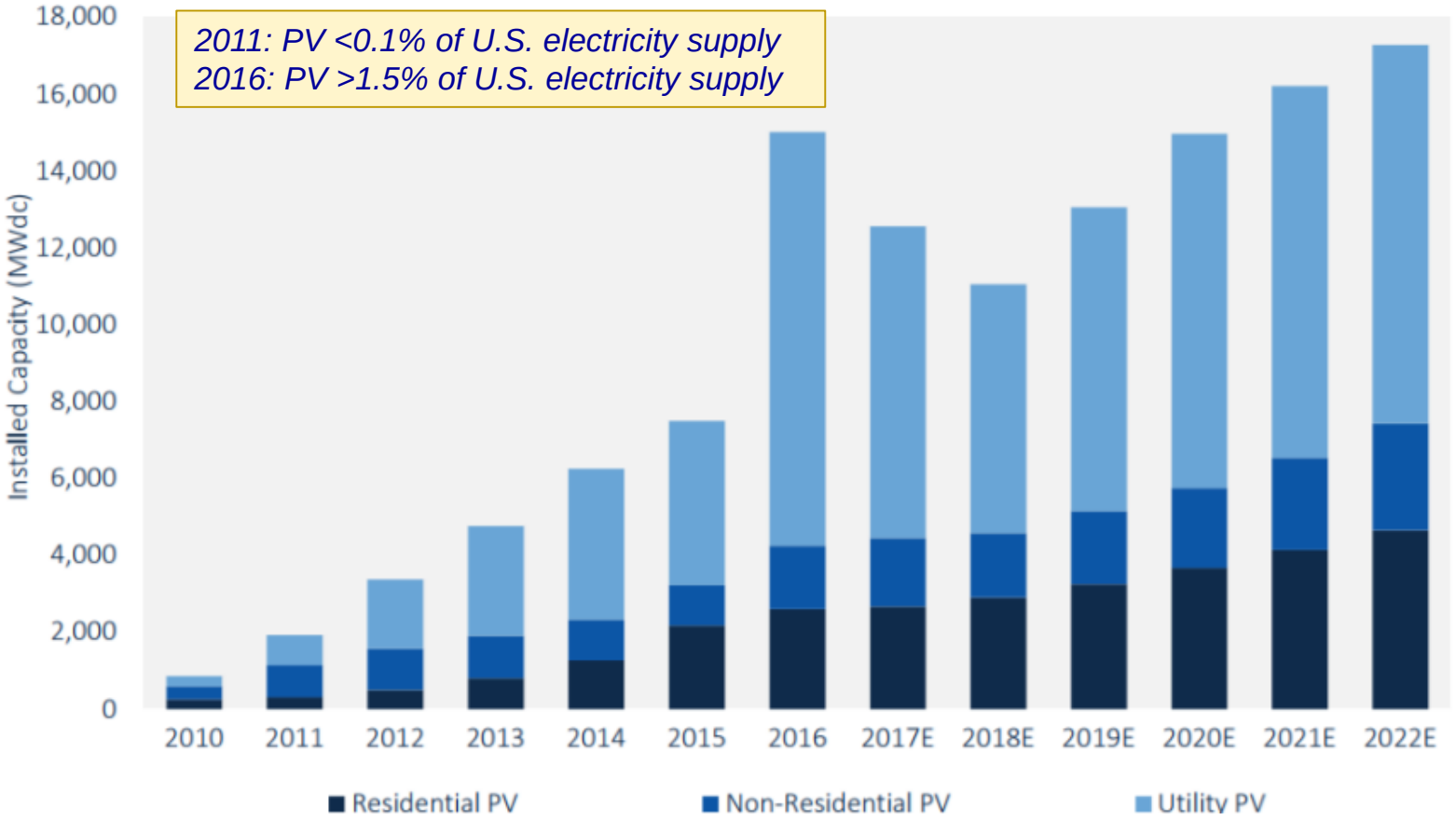


Source: U.S. DOE, *Wind Vision: A New Era for Wind Power in the United States, 2015.*

PV Market Assessment: The Genie's Out of the Bottle

Total installed US solar PV capacity (Q3 2017): 44.7 GW

Texas installed solar PV: 1.6 GW (670 MW in 2016)



Source: GTM Research / Wood Mackenzie

Time to new installation:

- 2016 – 1-2 minutes
- 2015 – < 2 minutes
- 2014 – 2.5 minutes
- 2013 – 4 minutes
- 2004 – 2 hours

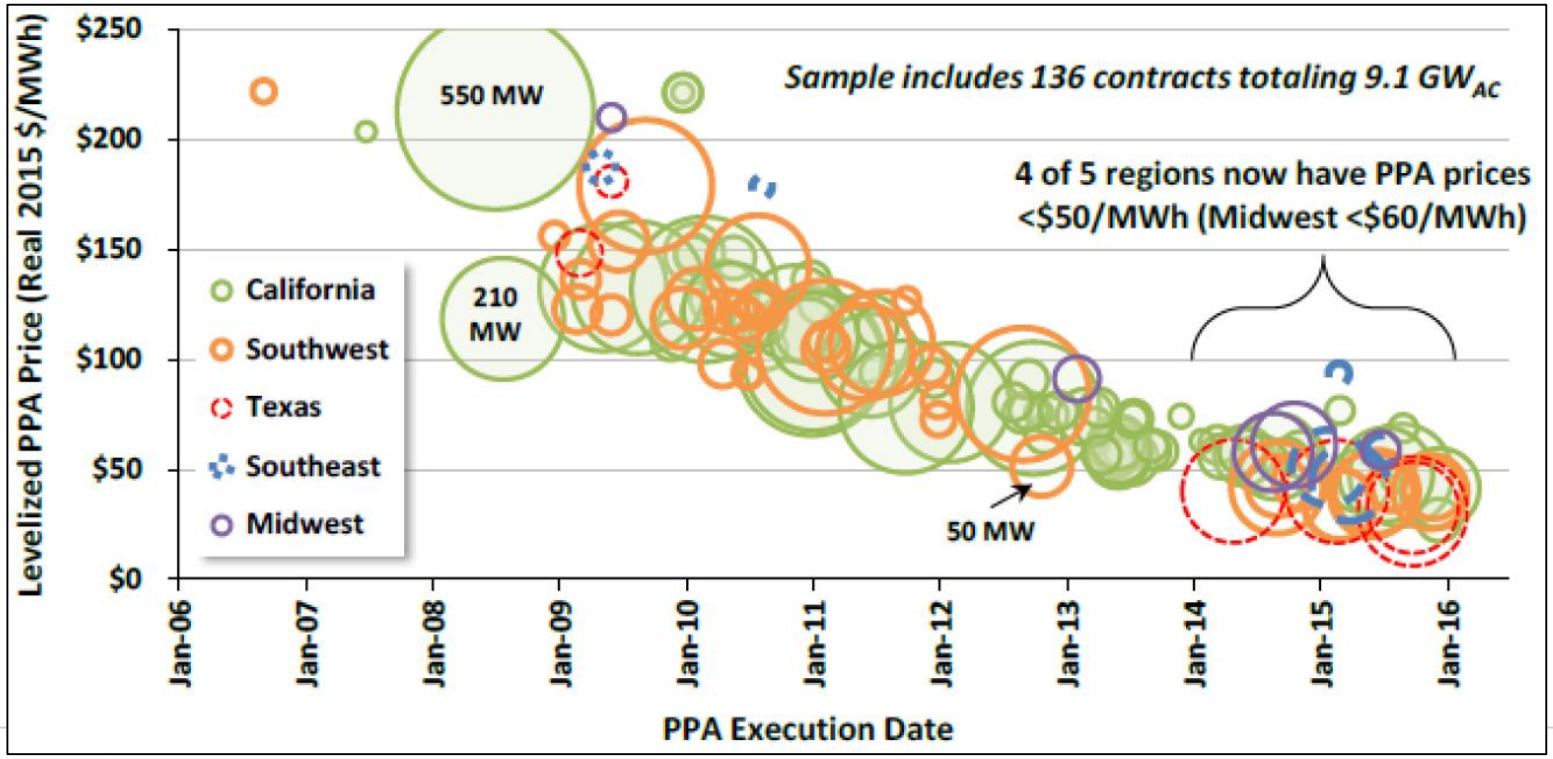
Cumulative Systems Installs	
Q4 2016	1,300,000+
2013	475,000
2011	225,580
2009	96,500
2007	48,800
2005	21,150

Source: SEIA / SEPA

PV Costs Declining: It's All Economics!

PV Price	Residential	Commercial	Utility-Scale
2007	$8.20/$W_{dc}$	$7.50/$W_{dc}$	$6.20/$W_{dc}$
2017 (Q1)	$2.92/$W_{dc}$	$1.53/$W_{dc}$	Fix: $1.10/$W_{dc;}$ SAT: $1.14/$W_{dc}$
2022E	$1.99/$W_{dc}$	$1.03/$W_{dc}$	$0.79/$W_{dc}$

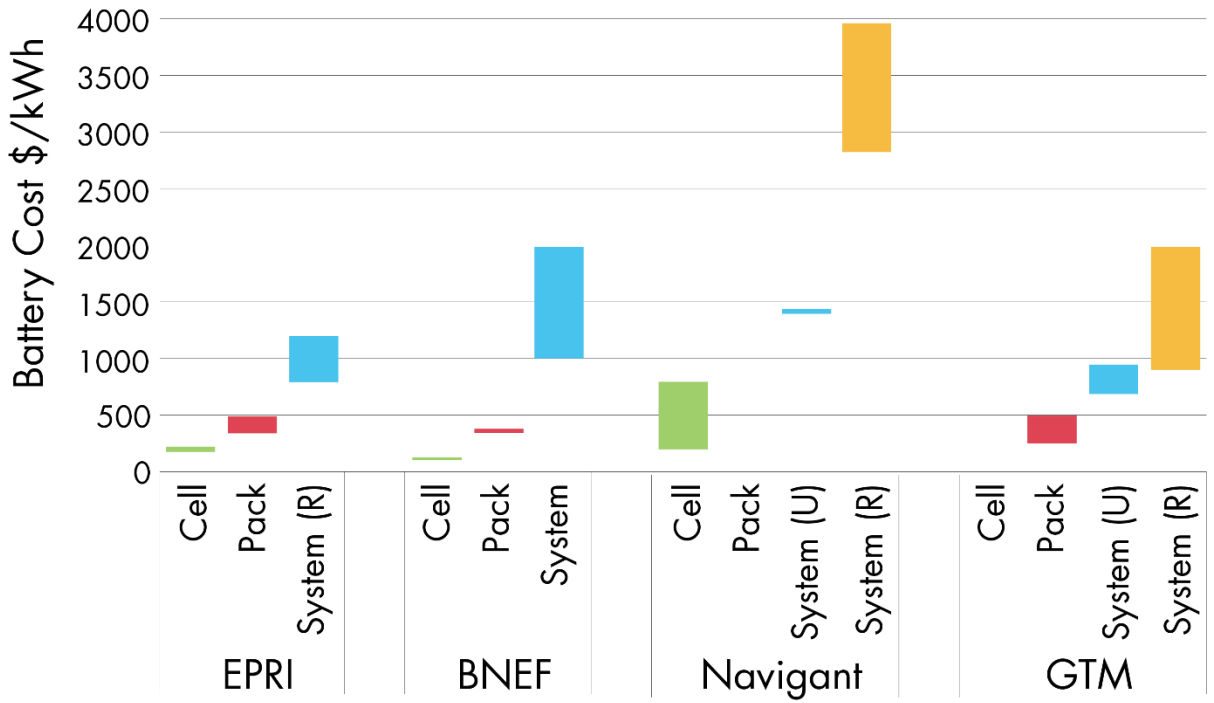
Source: GTM Research, *PV System Pricing H1 2017: Breakdowns and Forecasts; Note: National Average Turnkey PV Installation / EPC Price ($/Wdc)*



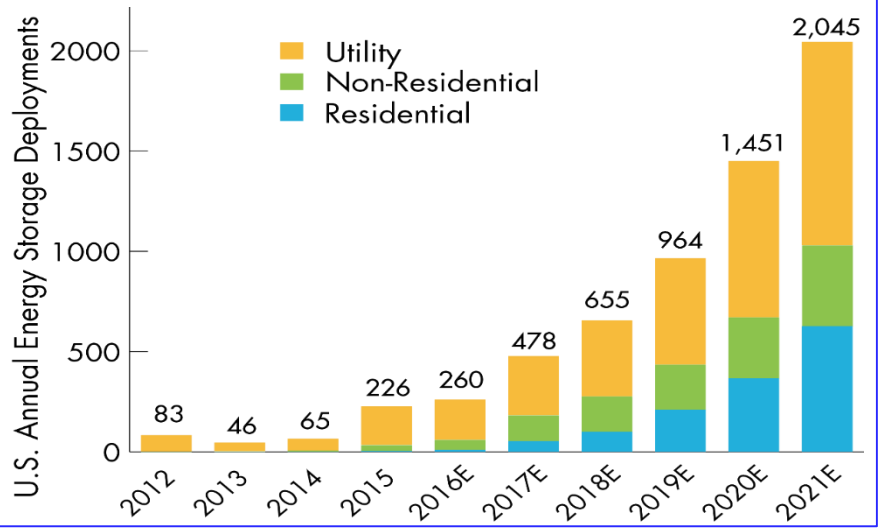
Energy Storage Market Outlook

Battery Energy Storage Systems gain momentum primarily as distribution system and microgrid asset.

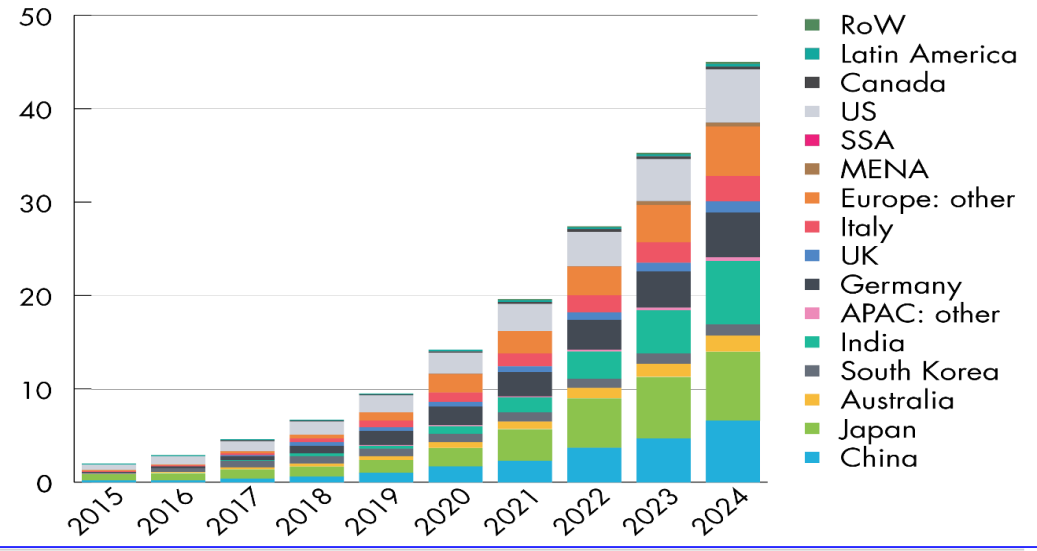
Li-ion Cost Estimates at the Cell, Pack, and System Level ($/kWh)



GTM Research: U.S. Annual Energy Storage Deployment Forecast, 2012-21 (MW)



BNEF: Global Installed Capacity Forecast, 2015-24 (GW)



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Trends in Demand Response

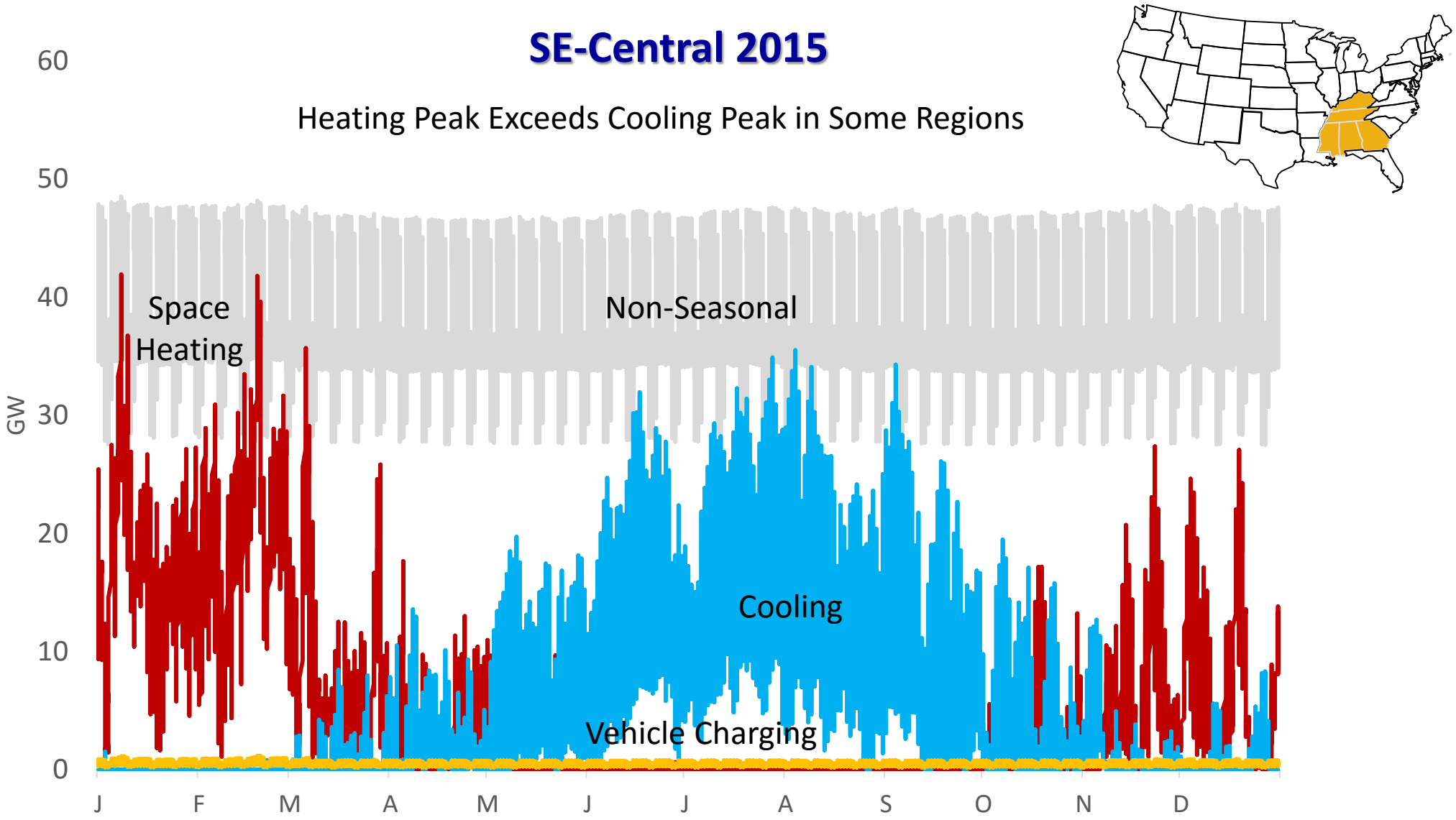
- FERC Order 745 upheld…
- But, transition in capacity markets impacting amount of DR clearing
  - E.g., PJM capacity performance
- Transition to flexible load management
- More variety in needs, timescales and applications
  - Greater focus on distribution systems
- Integration of ISO – DSO

DR Unforced Capacity Cleared in PJM Forward Capacity Markets

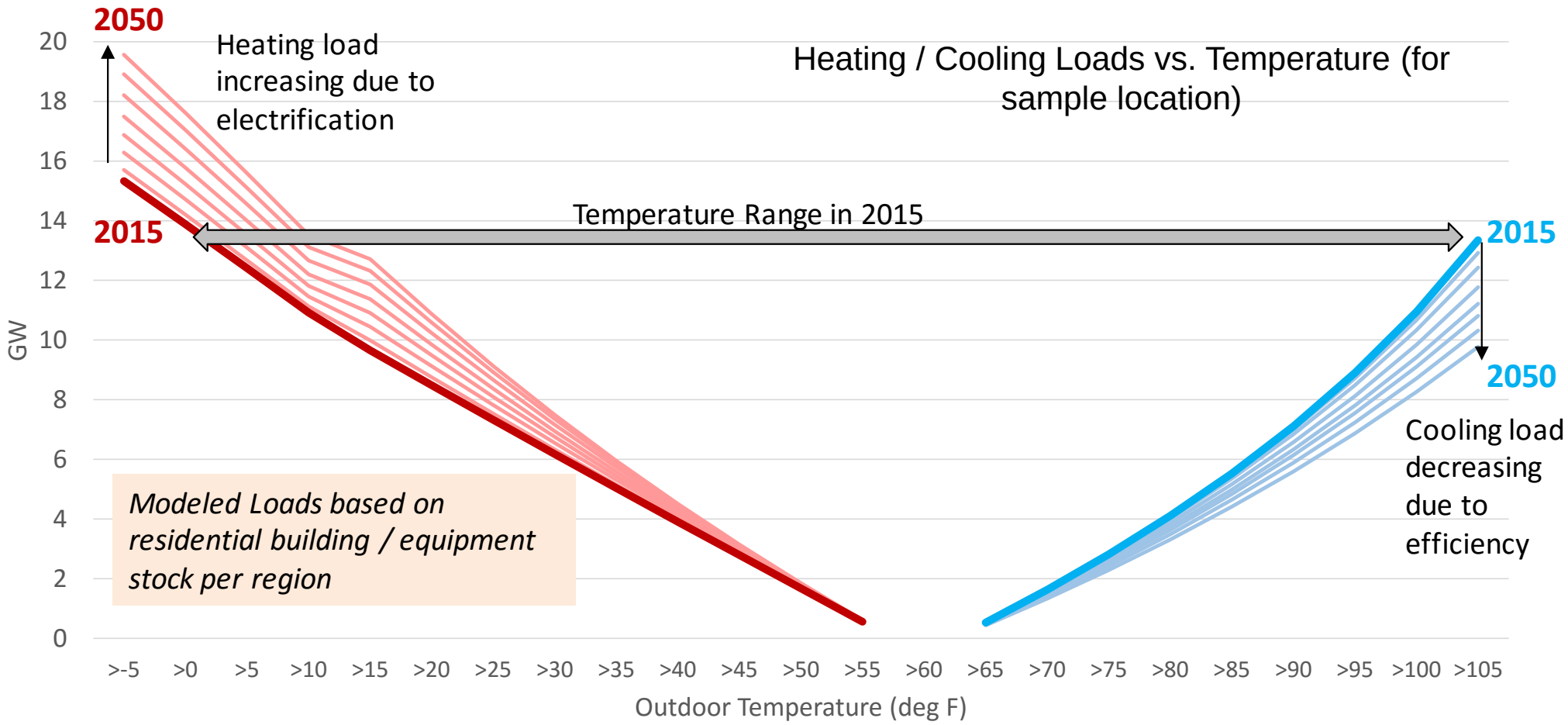
Delivery Year	Cleared DR (MW)
2020/2021	7820.4
2019/2020	10,348.0
2018/2019	11,084.4
2017/2018	10,974.8
2016/2017	12,408.1
2015/2016	14,832.8
2014/2015	14,118.4

Source: PJM Interconnection

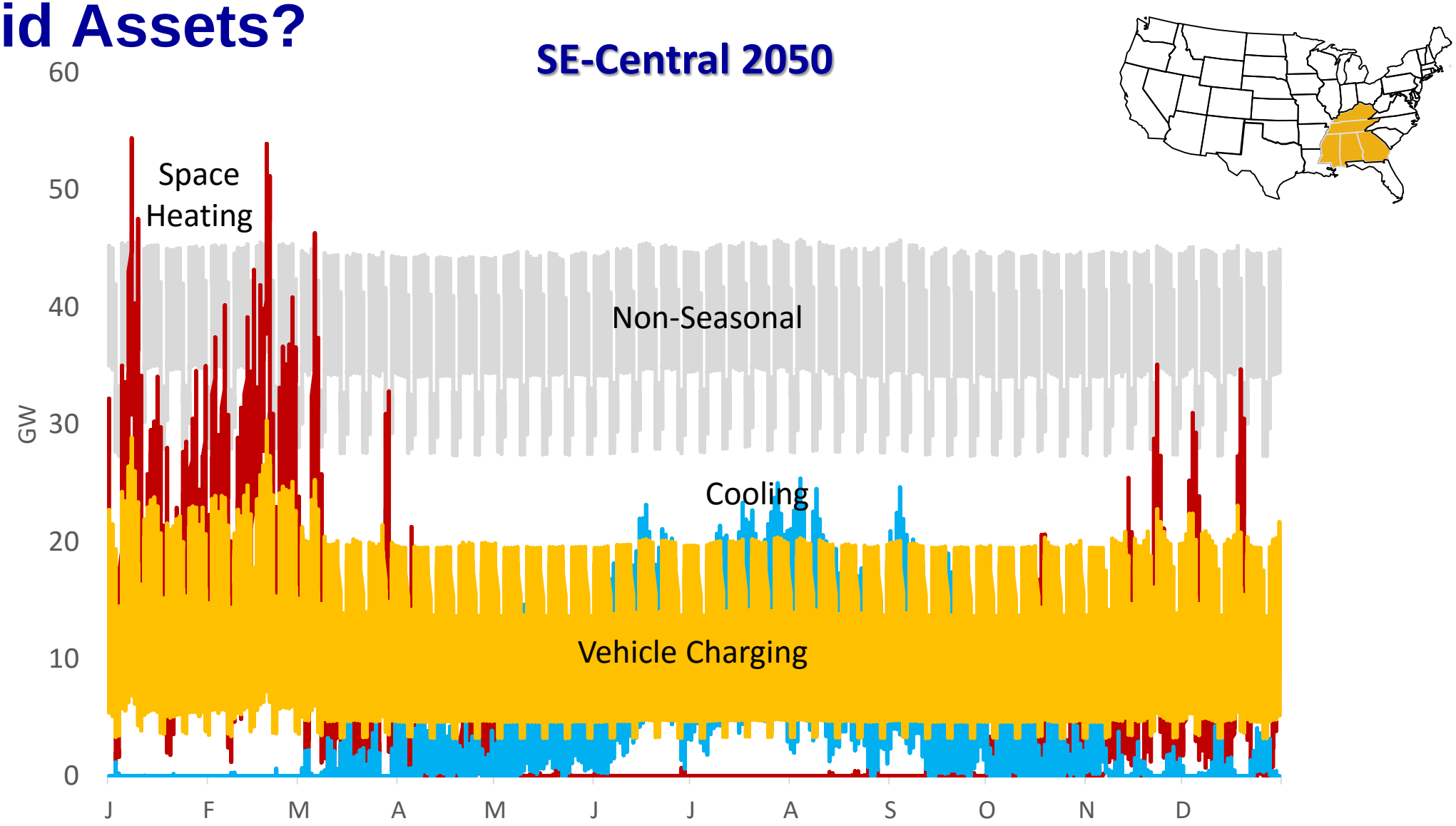
Load Shape Changes…Electrification and Efficiency Impact



Potential Load Shape Changes… Electrification and Efficiency

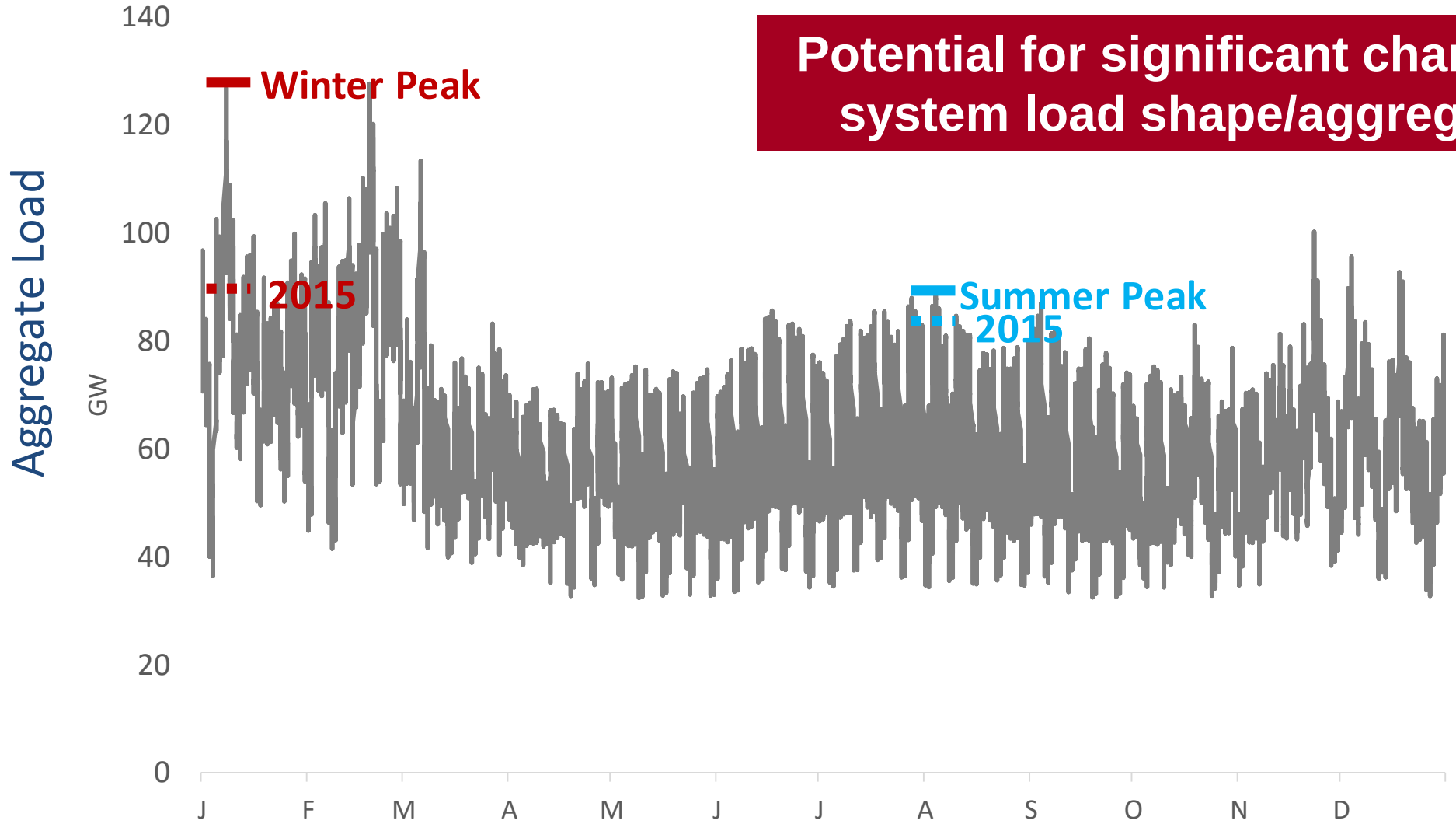


Load Shape Changes…How Will This Impact Supply Mix/Grid Assets?



Potential Load Shape Changes…
Electrification and Efficiency

Potential for significant change in 2050 system load shape/aggregate peak.



Resiliency and Restoration in Context of HILF Events

- HILF events can cause wide-scale effects.
- Voltage collapse and damage to long-lead time components can occur over wide areas.
- Black start paths can be disrupted and/or damaged.
- Interdependencies between sectors (electricity, gas, etc.) can be critical.
- **New questions to answer:**
  - How will the system respond to a given HILF event?
  - How can the impacts be mitigated?
  - How can recovery efforts be expedited?
  - What are the relative benefits of improving resiliency?

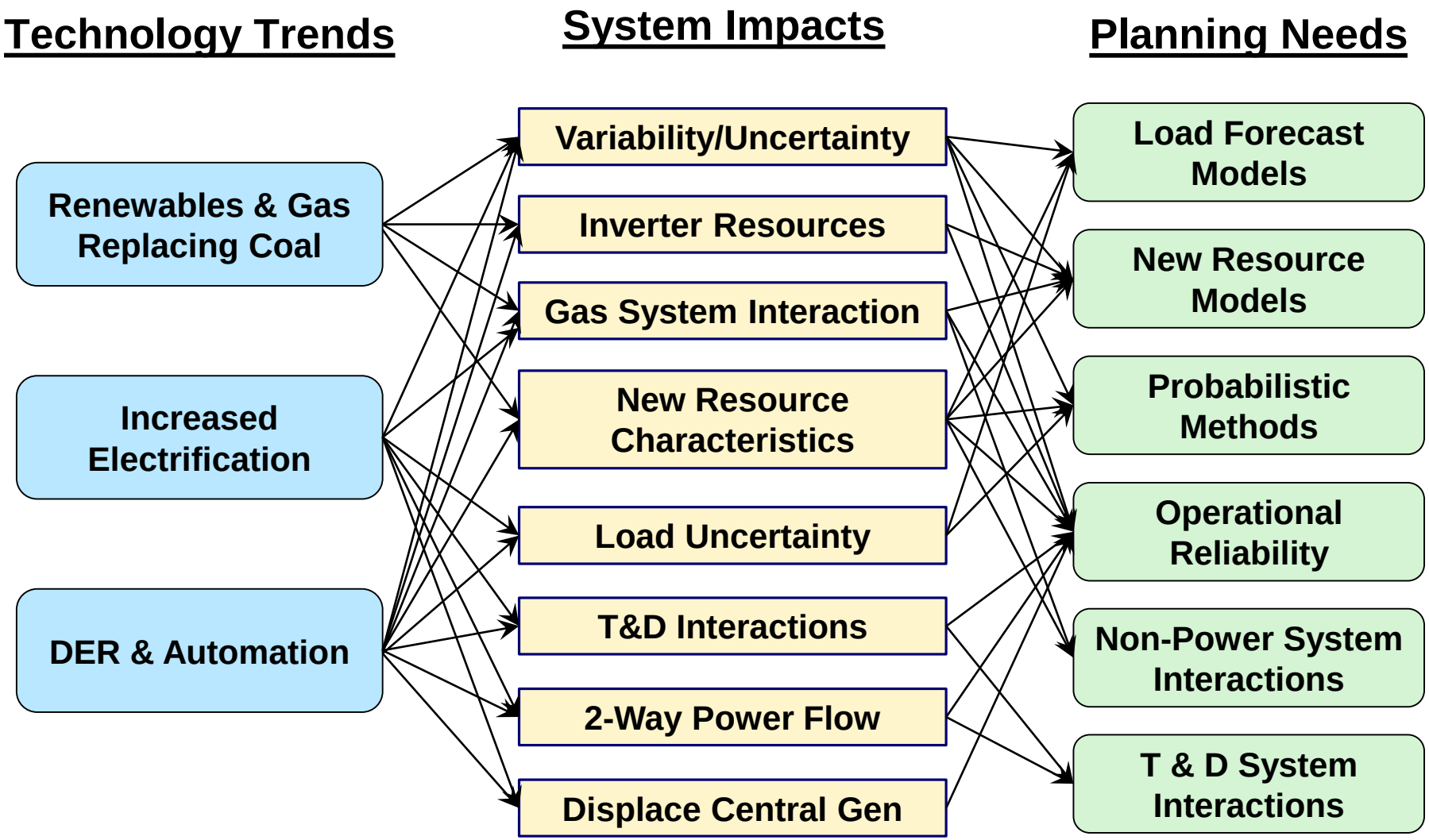
Evolving wholesale markets

- More resources for fewer periods?
- Incentives for flexibility?
- Incentives for “essential reliability services”?
- What is the right price?
- Interfacing transmission/wholesale with distribution/retail?
- Changing resource mixes: Technology agnostic vs. realism?
- Simplicity vs. complexity?

(Source: Southwest Power Pool)

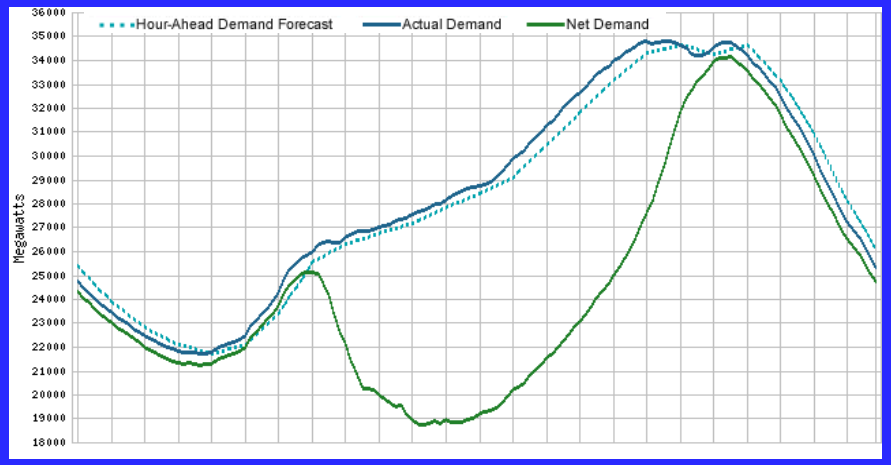
How do we plan for an Integrated Energy Network?

Emerging System Characteristics & Planning Impacts



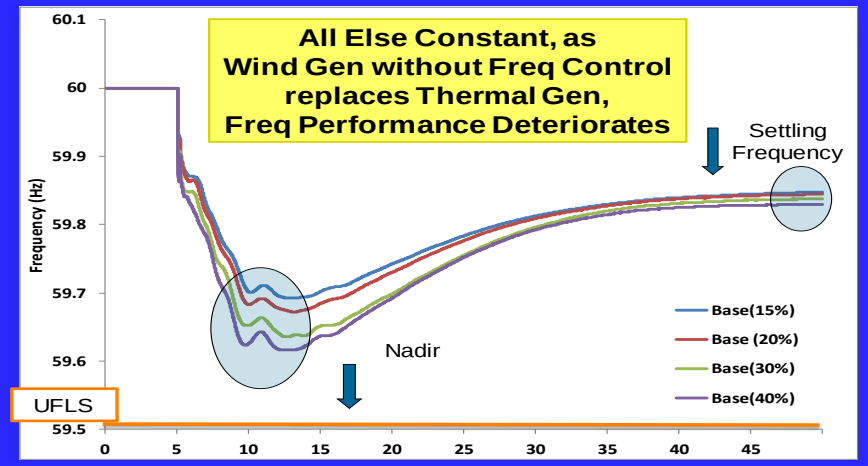
Variable and/or Distributed Energy Resources (VER/DER)

Variability and Uncertainty

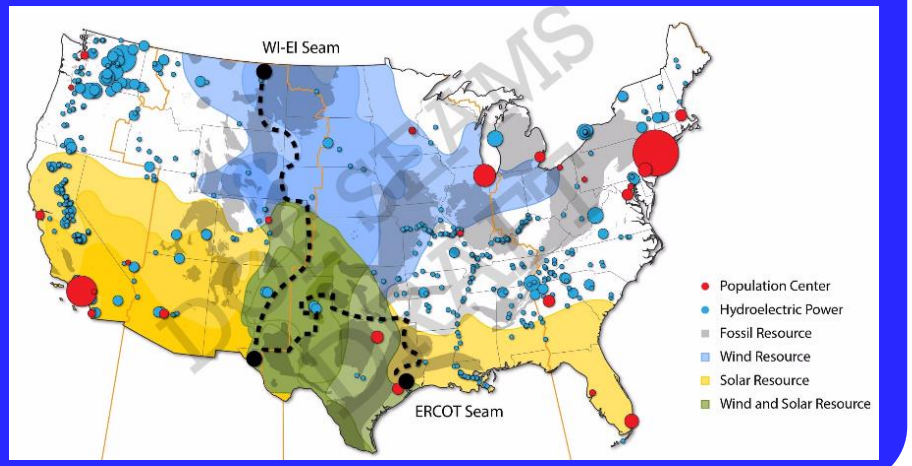


VER/DER unique characteristics that drive planning and operational challenges.

Inverter Interface



Resource Location



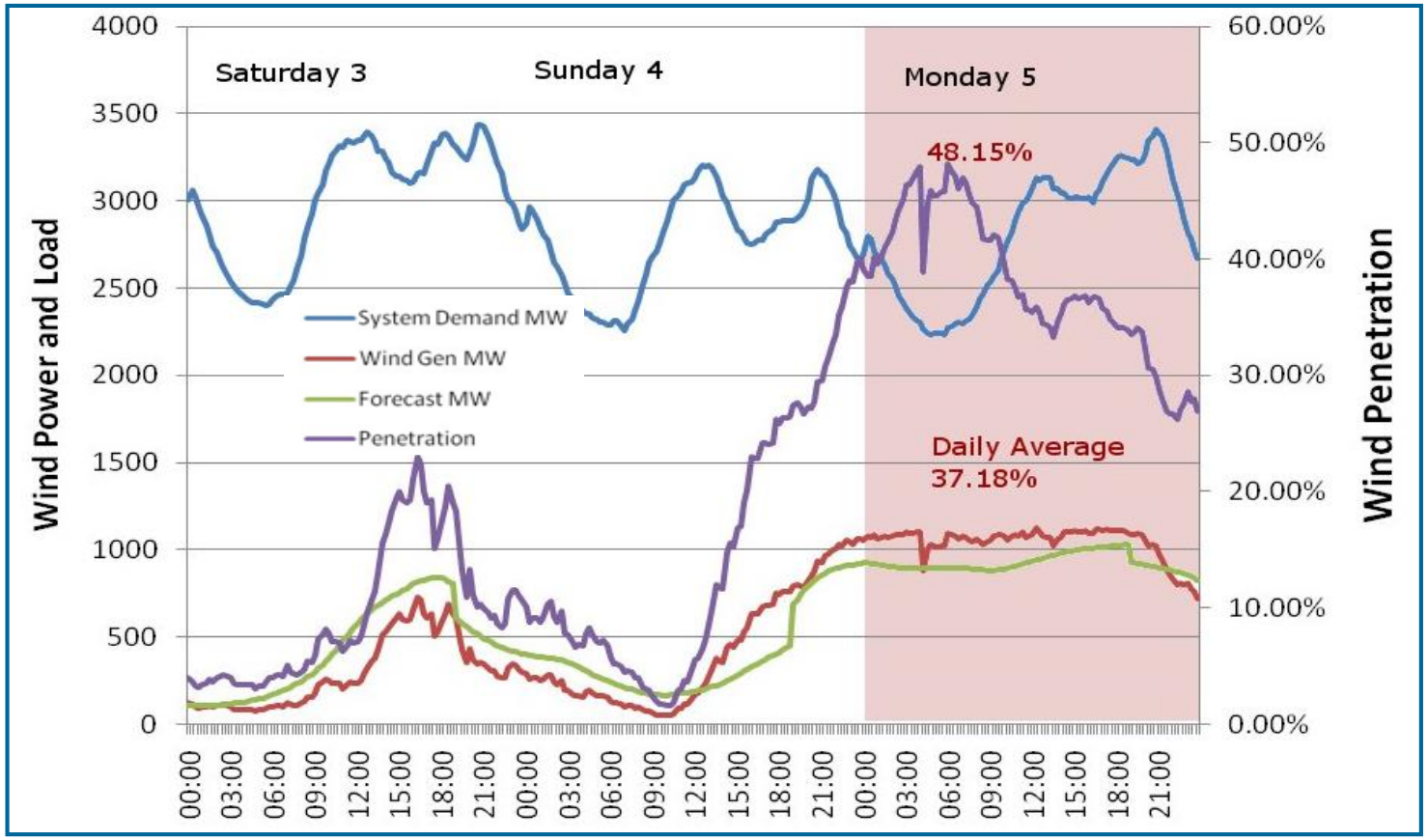
Variability and Uncertainty Considerations

Resource Adequacy
- Planning reserve margin
- Dispatchable Gen revenue
- Operational flexibility

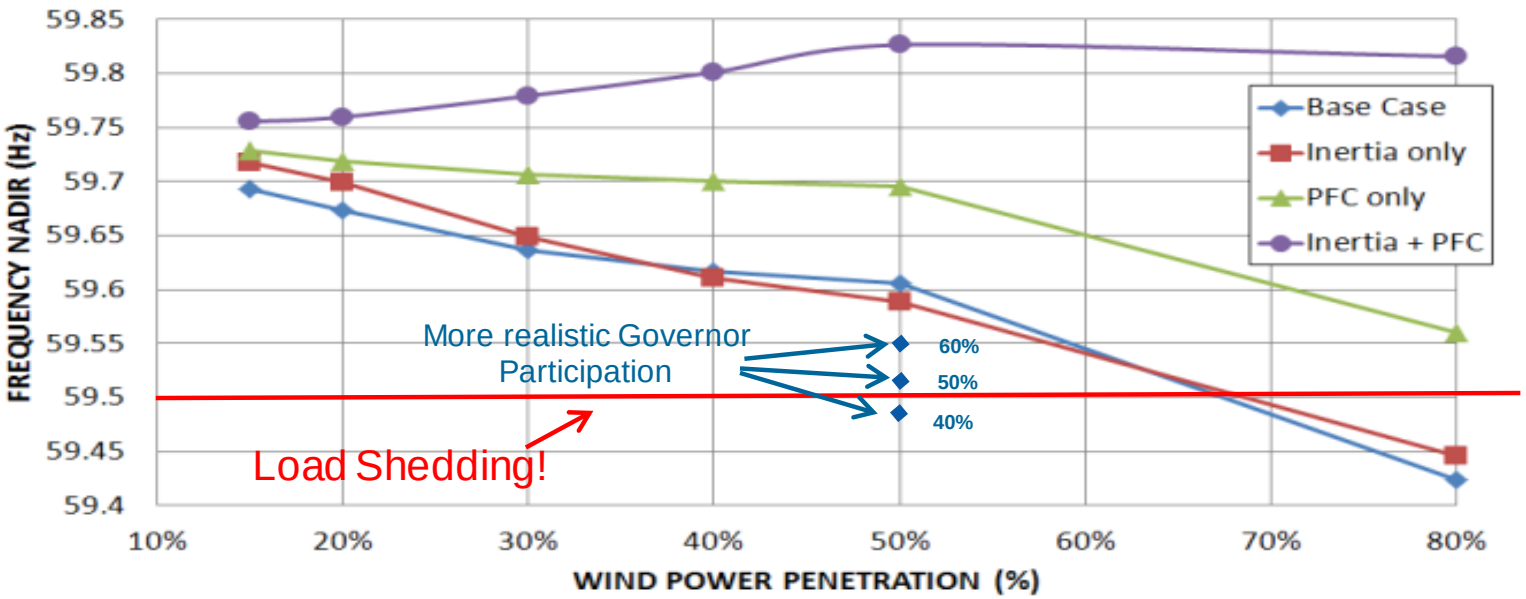
Transmission Planning
- Which power flow cases?

Scheduling & Dispatch
- Increase operating reserve
- Masking of load (DER)

Ops Planning & Real-Time
- Outage scheduling
- Changing flows & SOLs



Inverter Interface Resource Considerations



E, Ela et al., *Active Power Control from Wind Power: Bridging the Gaps,* NREL Technical Report, December 2013.

Transmission Reliability

- Displaced inertia/PFR
- Inverter controls/capability
- Dynamic behavior
  - -- disturbance response
  - -- voltage/freq ride-through

System Protection

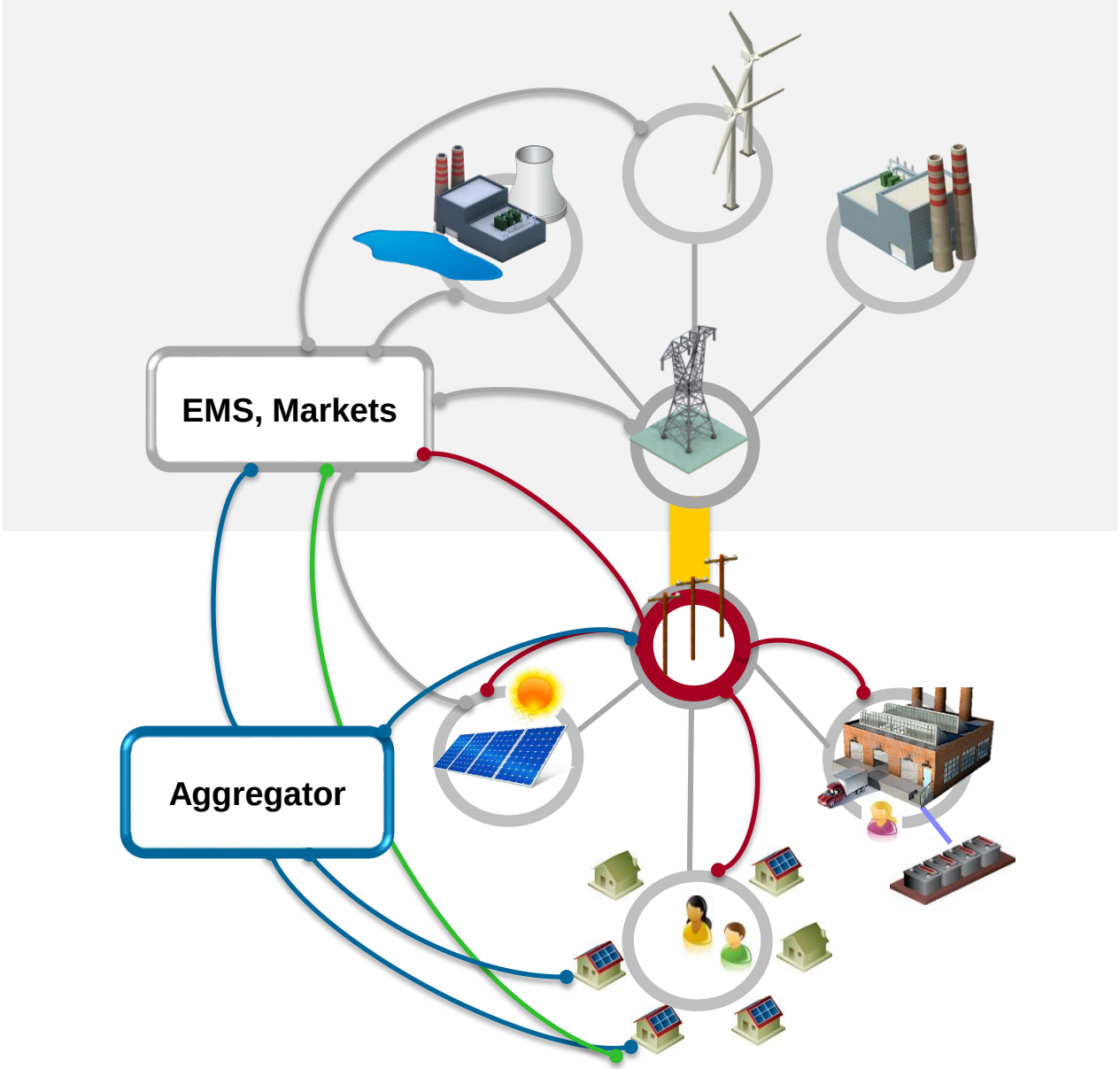
- Reduced short circuit
- Different fault contribution

Transmission Planning

- Validated dynamic models
- Modeling DER in Trans Plan

Changing Transmission and Distribution Interface

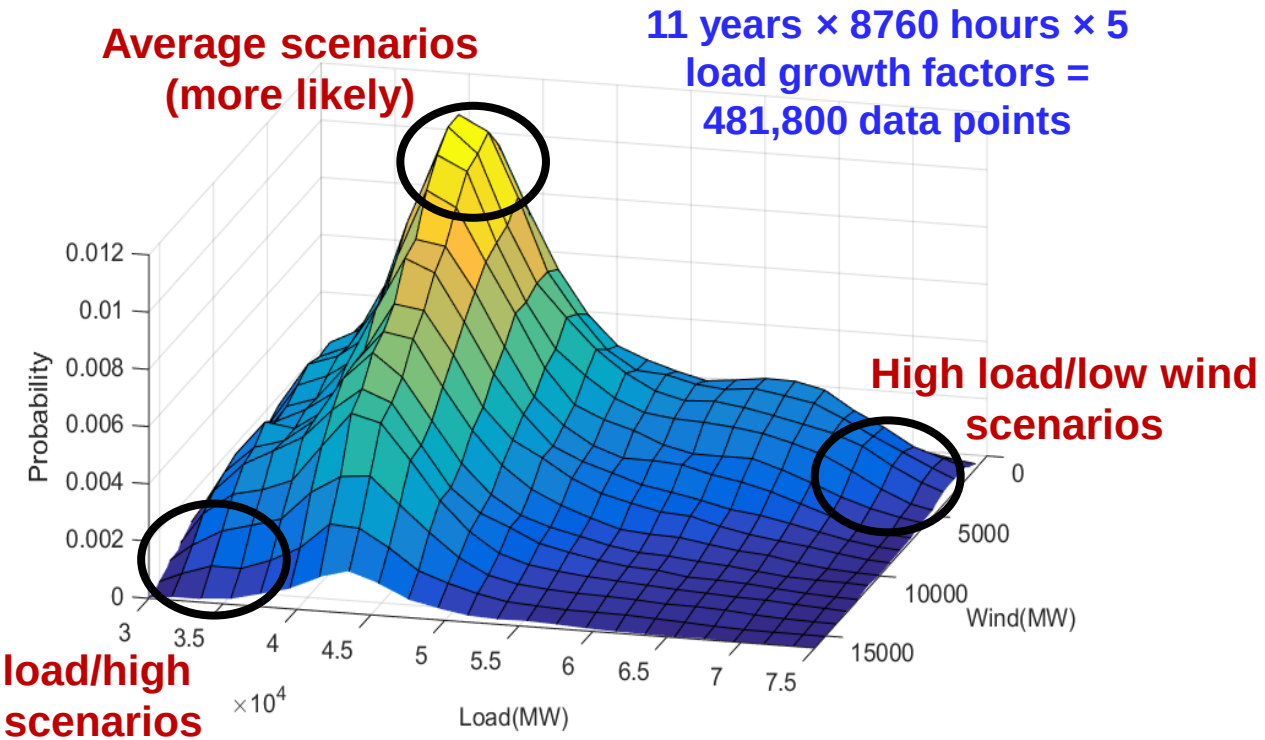
Proliferation of distributed resources providing energy and A/S to the bulk system require closer integration across the T & D interface



Implications

- Market design
- Modeling/planning coordination
- Visibility/operations coordination
- Controls paradigm/architecture

Probabilistic Tools to Determine Trans. Planning Scenarios and Cases across Uncertainties

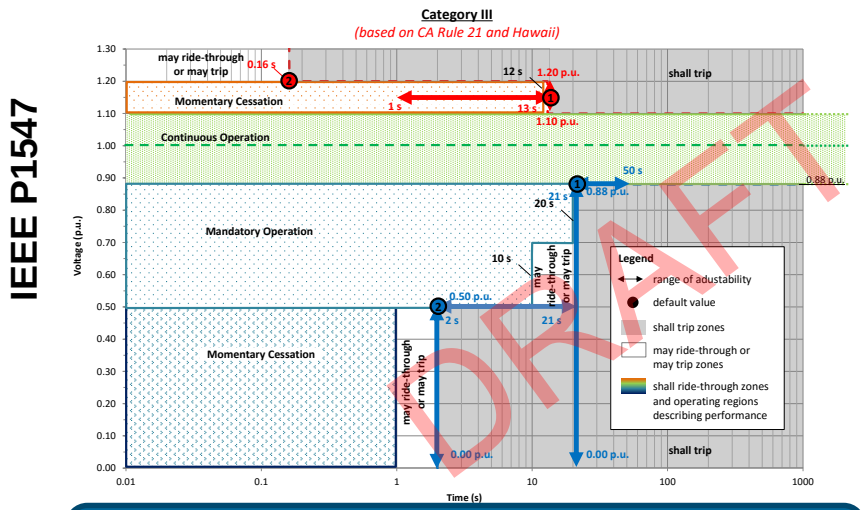


Probabilistic analysis of many years of data and co-optimized G&T expansion tools can better characterize scenarios to ensure reliability and illuminate value of investments.

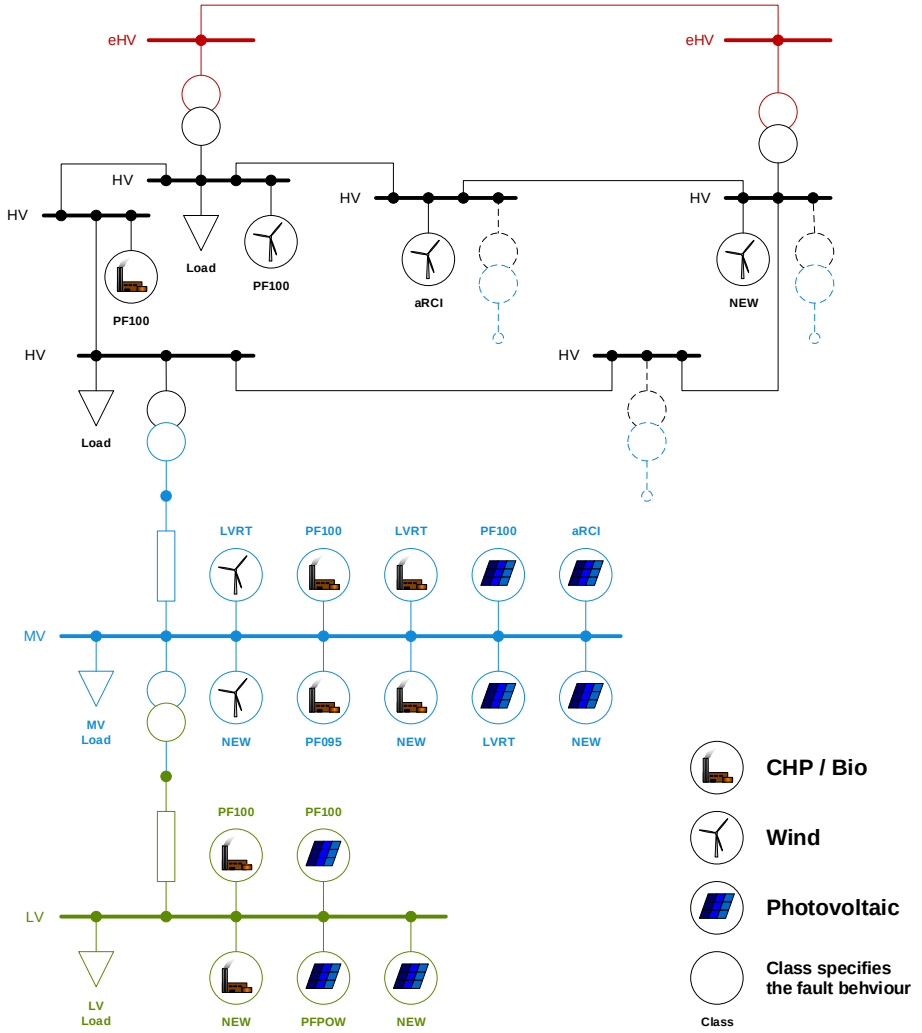
New Validated Models and Forecasting Methods

Validated emerging resource models including models of customer adoption/behavior

Voltage Ride-Through Requirements for IEEE P1547 for Category III DER



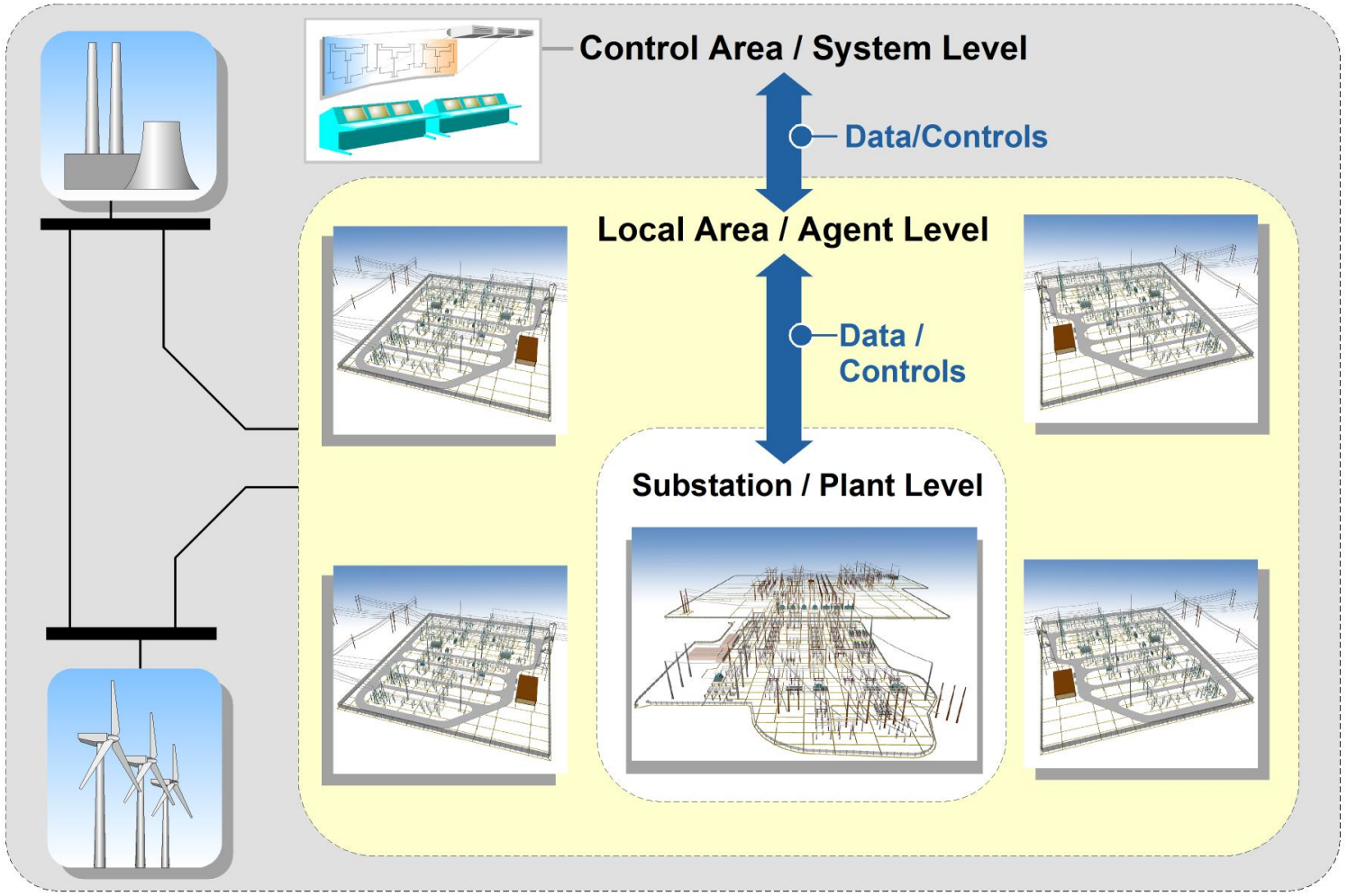
Need to be adequately modeled in bulk system studies.



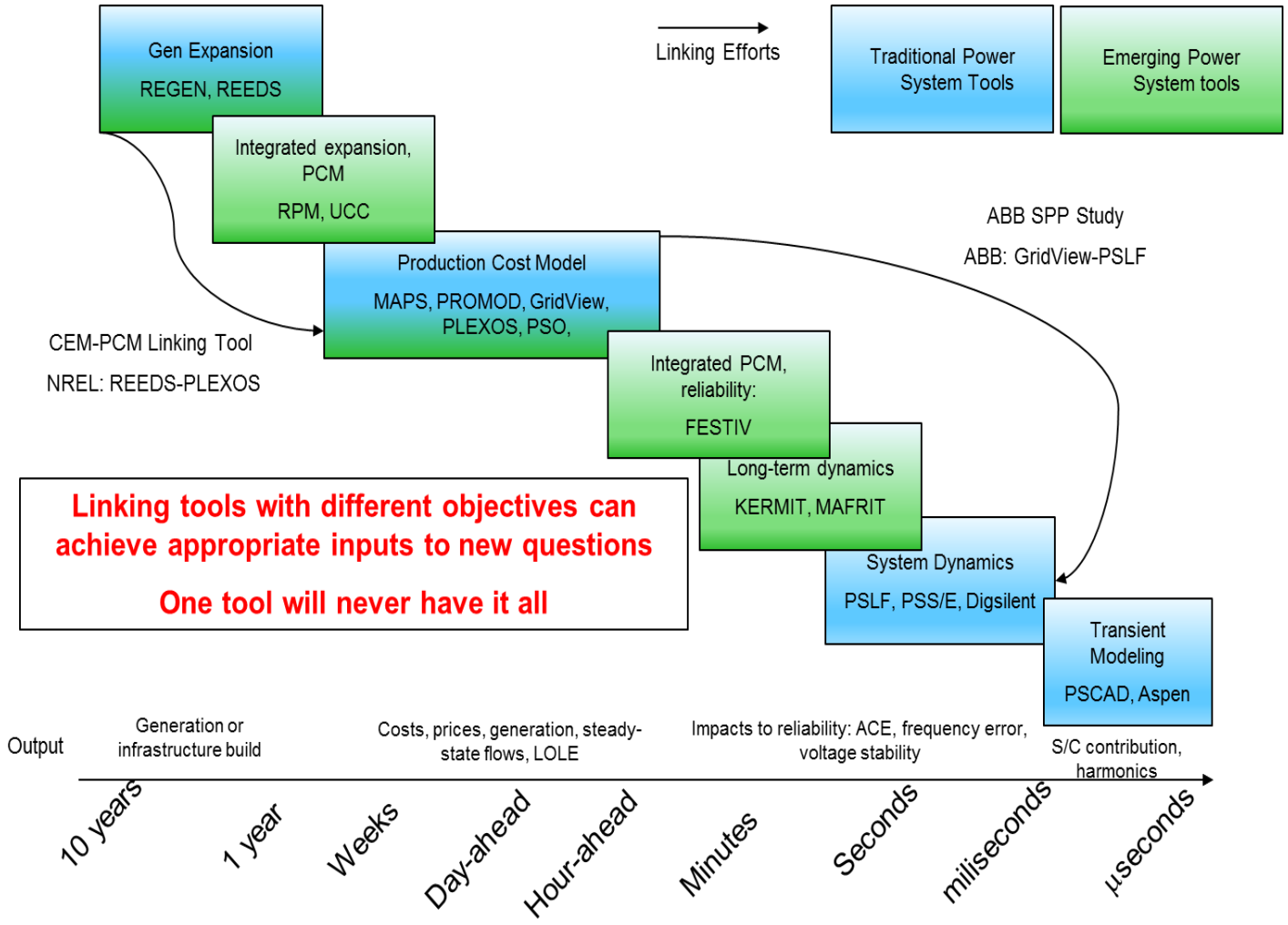
Source: Delft University of Technology (2014) / J.C. Boemer (2016)

Need for Next Generation Grid Monitoring & Control

- Increasing # controllable devices (wind/PV, power flow controllers, HVDC)
- Fully utilize new resource control capabilities
- Advanced sensing/metering and comms (e.g., PMUs, sub automation, et. al.)
- Autonomous operations with human oversight



New Planning Paradigm Needed



- Interaction between Resouce and T&D planning tools
  - Spatial/temporal granularity
  - T&D infrastructure costs?
  - Operational issues included?
- Interdependent systems
  - gas, transport, water, etc.
- EPRI TI project to link different modeling domains

Key IEN Resource Planning Challenges

Category	Key IEN Planning Challenge
Modeling the Changing Resource Mix	1. Incorporating operational detail 2. Increasing modeling granularity 3. Integrating generation, transmission, & distribution planning 4. Expanding analysis boundaries and interfaces
Ensuring Adequate System Attributes	5. Incorporating new planning objectives and constraints 6. Integrating wholesale power markets
New Inputs for Resource Planning	7. Improving forecasting 8. Addressing uncertainty and managing risk 9. Improving modeling of customer behavior and interaction 10. Supporting expanded stakeholder engagement

Integrated Energy Network

Imagine an energy future where all forms of energy can be optimally integrated to connect customers with safe, reliable, affordable, and clean energy resources

Together…Shaping the Future of Electricity