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Assessing the Challenge

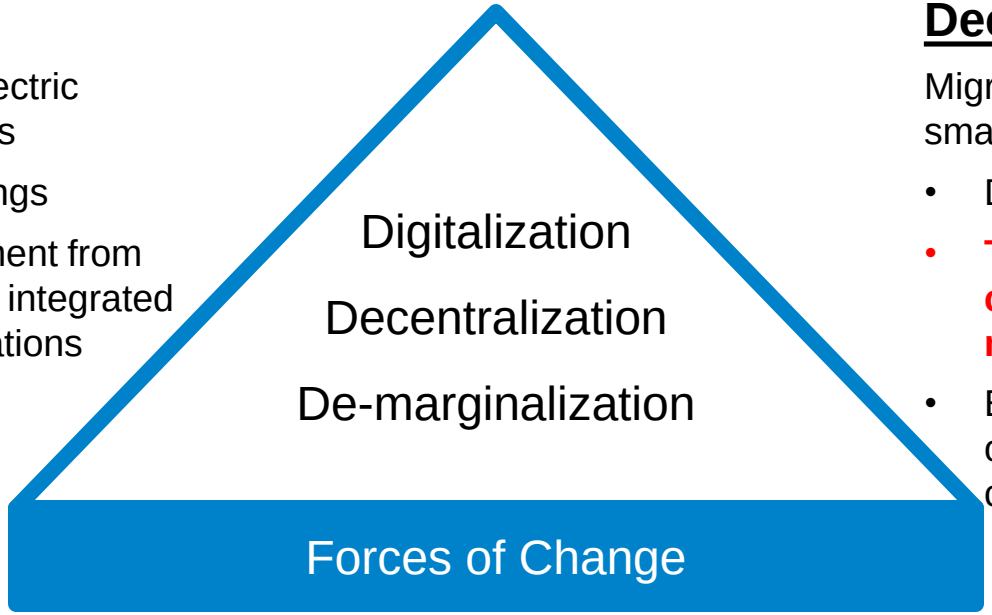
- MISO region is undergoing rapid and substantial changes from portfolio evolution on both the supply and demand side
  - Transition away from legacy coal to renewables and other new technologies
  - Majority of energy from zero marginal cost resources (Nuclear, Hydro, Wind, Solar, Storage & DR)
  - Many more smaller, less centralized resources
  - Emergence of new and different forms of load from “digital” classes of resources (Cars, Thermostats, other Internet of Things devices)
- Market design, technology platform, planning and operating tools/processes developed for legacy resource mix and Distribution interface will be inadequate in this new environment
- MISO will assess the probability and impacts suggested by these changes and develop a strategy to address each
- Report on initial (Tranche 1) recommendations by Q1 2019

Driven by the probability and impact of emerging industry changes and the need for a strategy to address them

Digitalization

New classes of electric consuming devices

- Internet of Things
- Grid management from digital controls integrated into bulk operations



Decentralization

Migration from large stations to smaller distributed resources

- DER (storage, solar, EVs, DR)
- **Tighter operational coordination with distribution networks**
- Evolved value prop based on optimization new fleet of non-central resources

De-marginalization (low / no marginal costs)

Substantial growth of renewables, non-price sensitive DERs, and continued availability of nuclear and hydro

- Reduced flexibility and potential shortages of currently free ancillaries (e.g., voltage, frequency)
- Market design must incentivize availability of all needed essential reliability services.

De-Marginalization

What are the future foundations of price formation?

- Major growth of central station renewables (wind/solar)
- Maintenance of zero marginal cost legacy resources (Nuclear & Hydro)
- Growth of non-price sensitive demand side including energy efficiency and digital devices

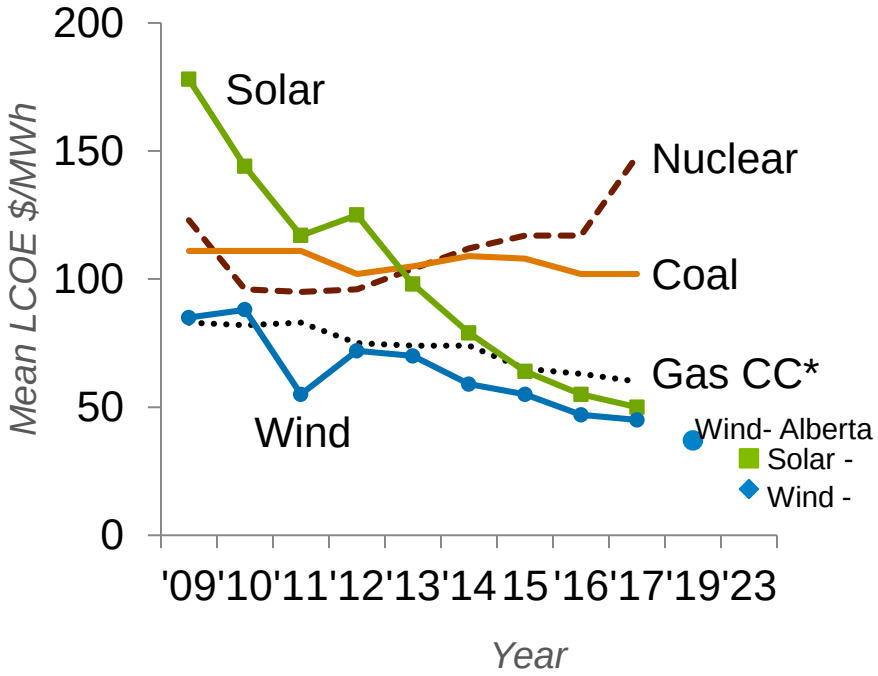
- Need to improve valuation and pricing of the services beyond energy delivery.
  - Review Products

    Do current products incent resources to participate at the time and locations where they are the most valuable?

  - Augment LMP

    Identify and value attributes needed to reliably operate the grid and price those attributes efficiently and equitably

Unsubsidized average Levelized Cost of Energy 2009-2017



*Combined Cycle

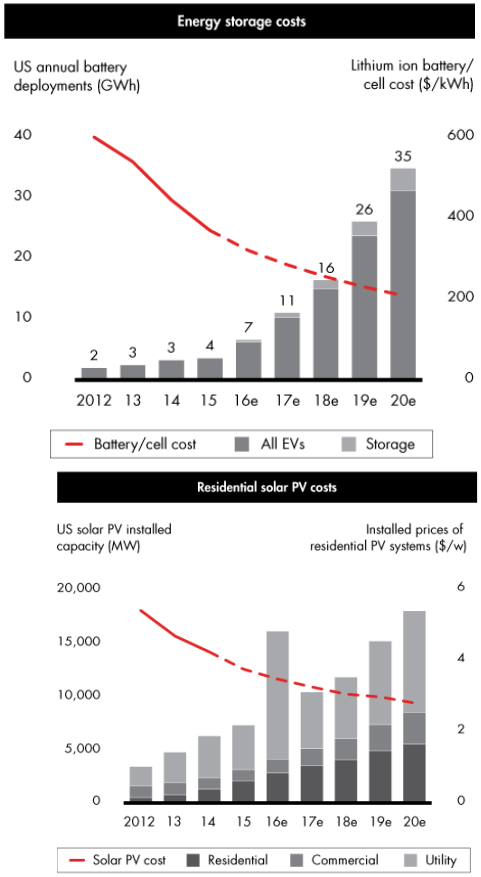
De-Centralization

How to manage an evolving transmission/distribution interface?

- Major growth of small-scale distributed supply and storage, including solar, combined heat and power, micro-turbines, combinations of assets
- Wide-spread emergence of internet connected digital devices with controls enabling grid flexibility management from load at scale
  - Smart Thermostats
  - Internet connected appliances
  - Growth of Electric Vehicles

- Review compensation
  - Do current compensation approaches reflect the value of services delivered?

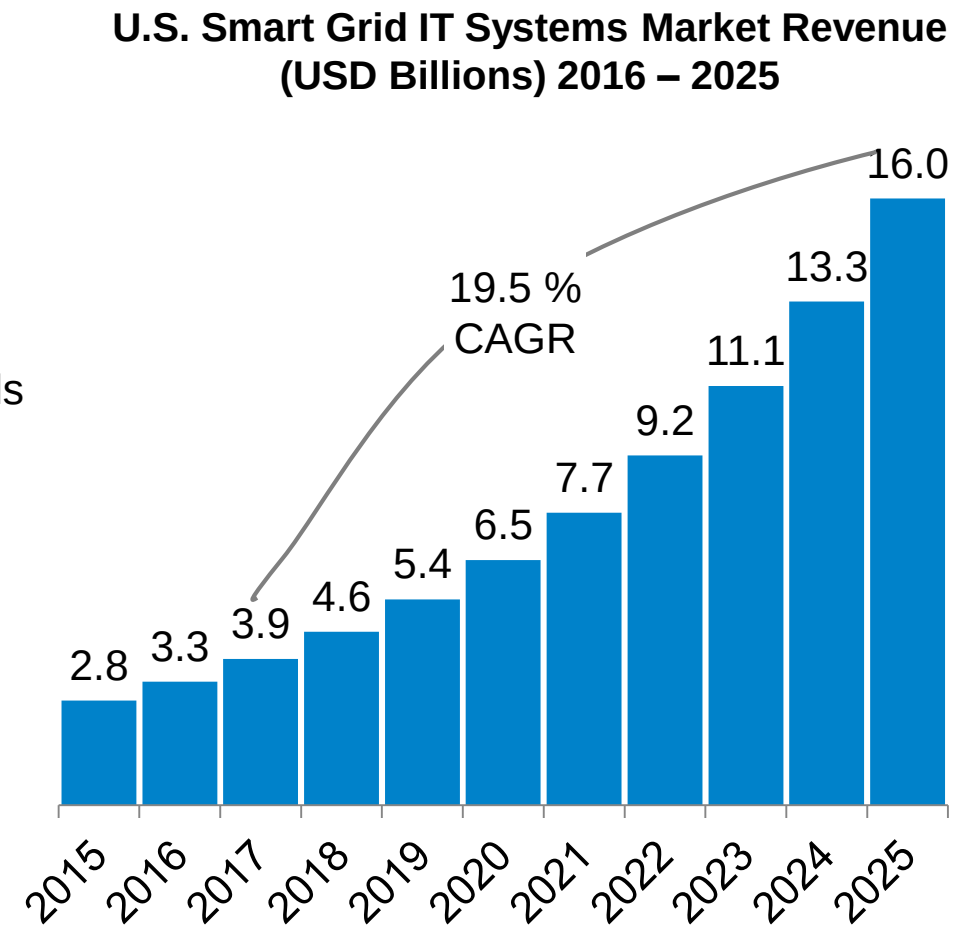
- Define the Transmission & Distribution interface
  - Manage increase in volatility of the demand at the interface & uncertainty in the timing of demand
  - Enhance value for region through integration



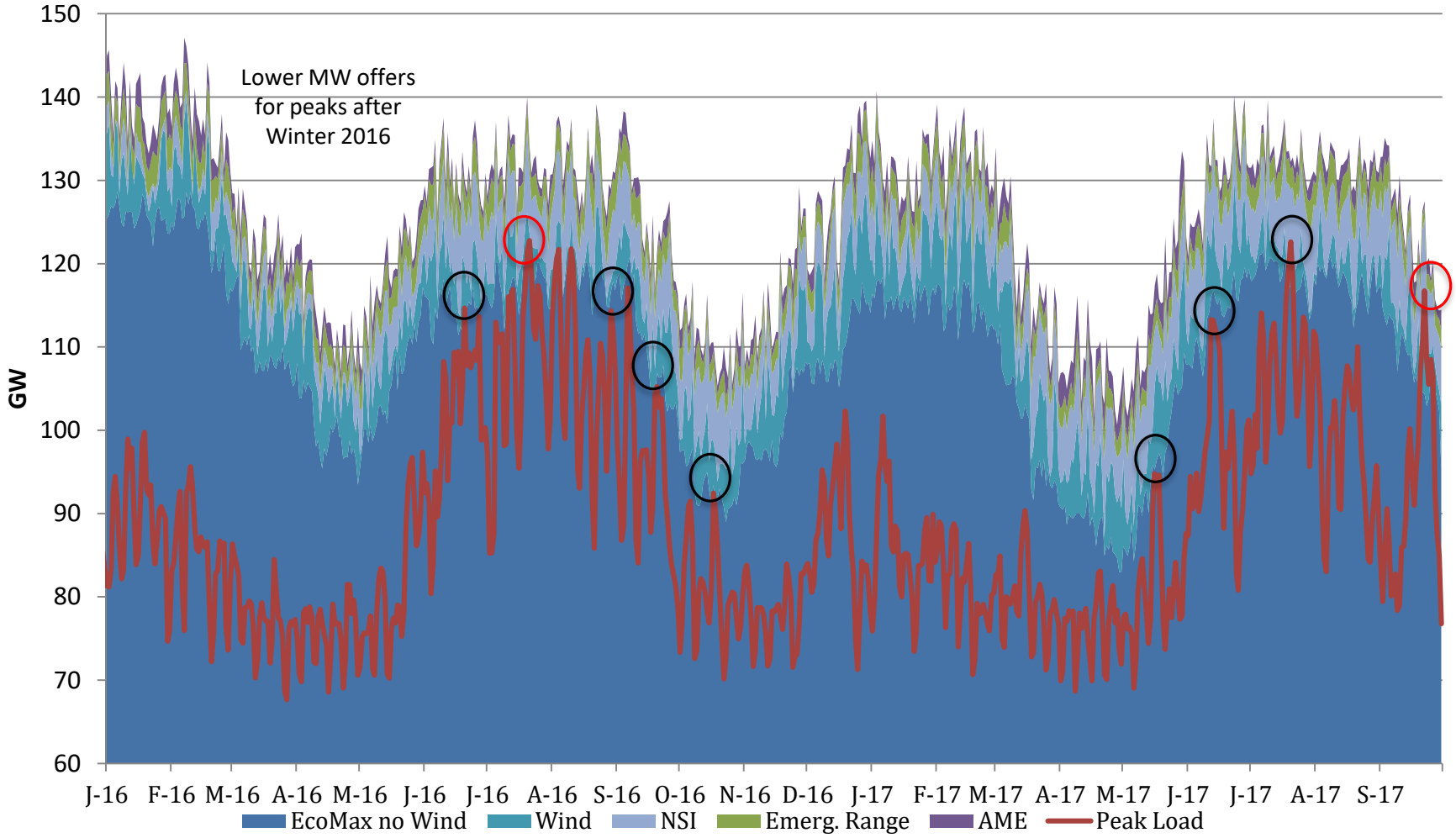
Digitalization

How can we leverage new levels of flexibility?

- Wide-spread emergence of internet connected digital devices with controls
- Enables grid flexibility management from load at scale
  - Smart Thermostats
  - Internet connected appliances
  - Behind the meter storage
- Enables advanced monitoring & controls of distribution & transmission infrastructure
  - Smart, interconnected flow control devices
  - DER management systems
- Faster pace of change due to software upgrade cycles driving change rather than hardware replacement cycle
- Efficiency & reliability improvements

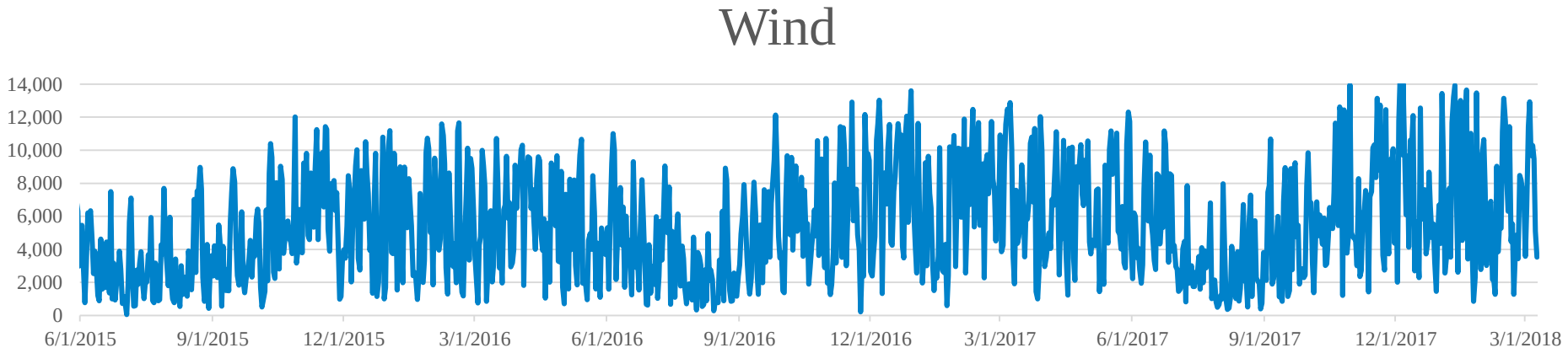


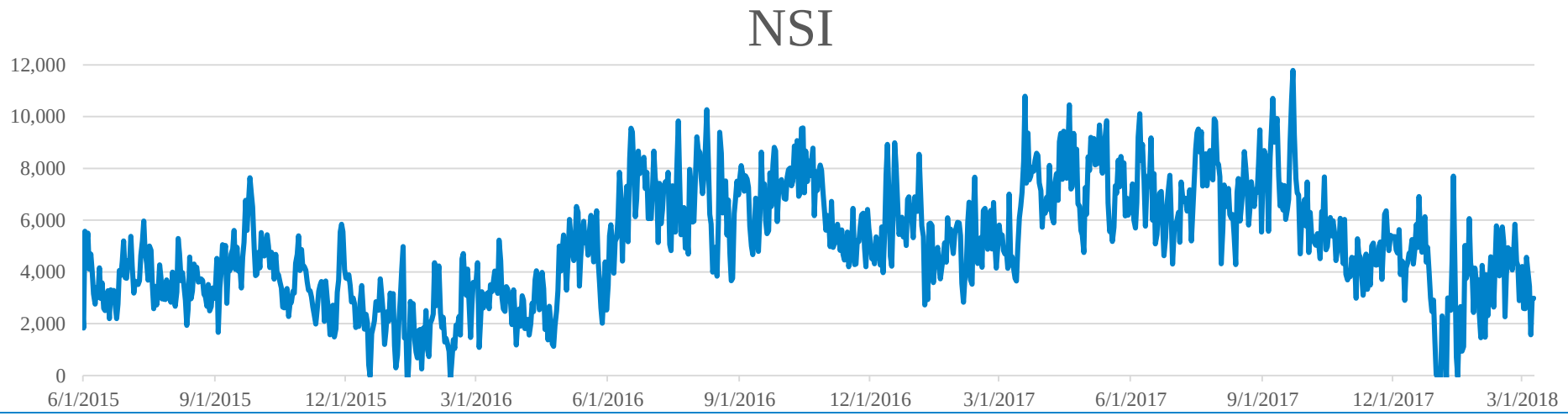
Less energy available each succeeding year combined with increased supply and demand volatility have led to increasing reliance on non-firm and emergency energy resources



Less energy available each succeeding year means increased reliance on intermittent or unscheduled resources

- These resources regularly vary from 2 to 12 GWs

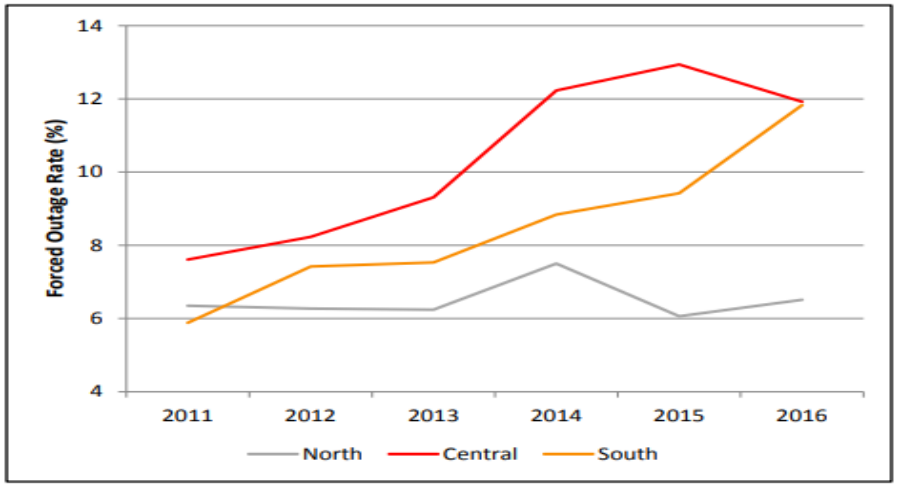




Less energy available each succeeding year resulting from aging fleet and retirements

- Higher outages

Year	Combined Rate	Eq. Planned Outage Factor	Eq. Maintenance Outage Factor
2011	5.34%	4.31%	1.03%
2012	5.58%	4.21%	1.37%
2013	5.56%	4.39%	1.17%
2014	6.09%	4.83%	1.26%
2015	6.33%	5.16%	1.17%
2016	6.16%	5.06%	1.10%

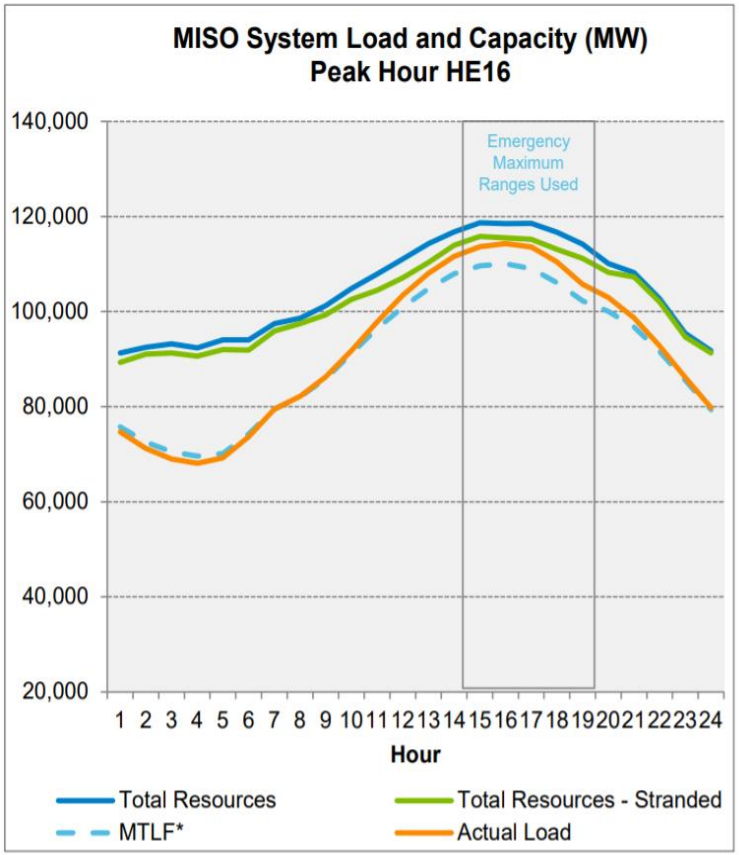


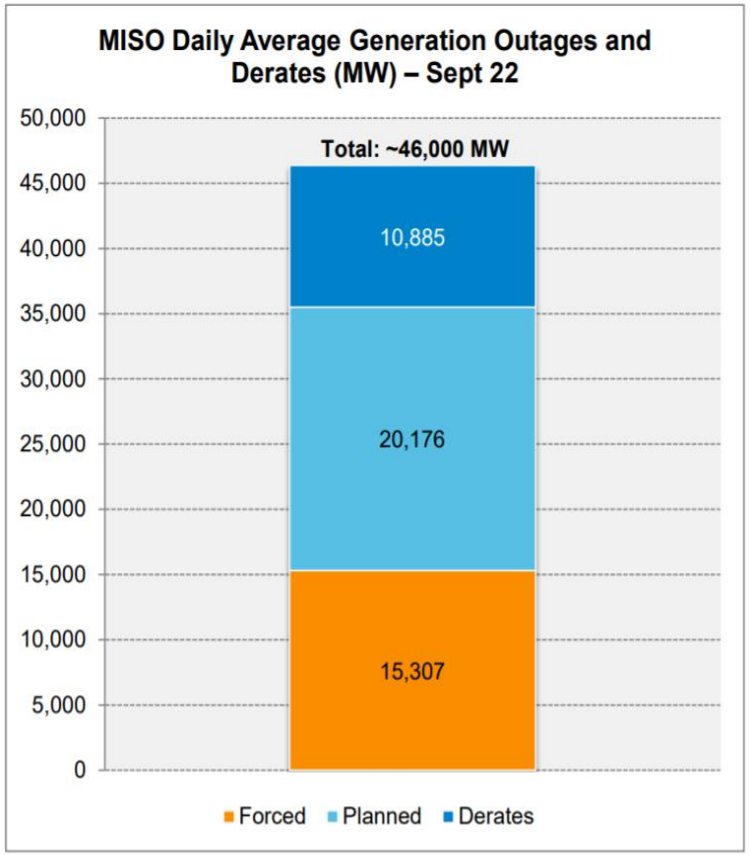
- Lower average energy offers

Planning Year	Average Energy Offers (MWs)	Avg. Outages (MWs)
2014/15	126,400	16,800
2015/16	125,100	18,400
2016/17	117,100	22,600

Less energy available each succeeding year from increasing impact of outage correlation

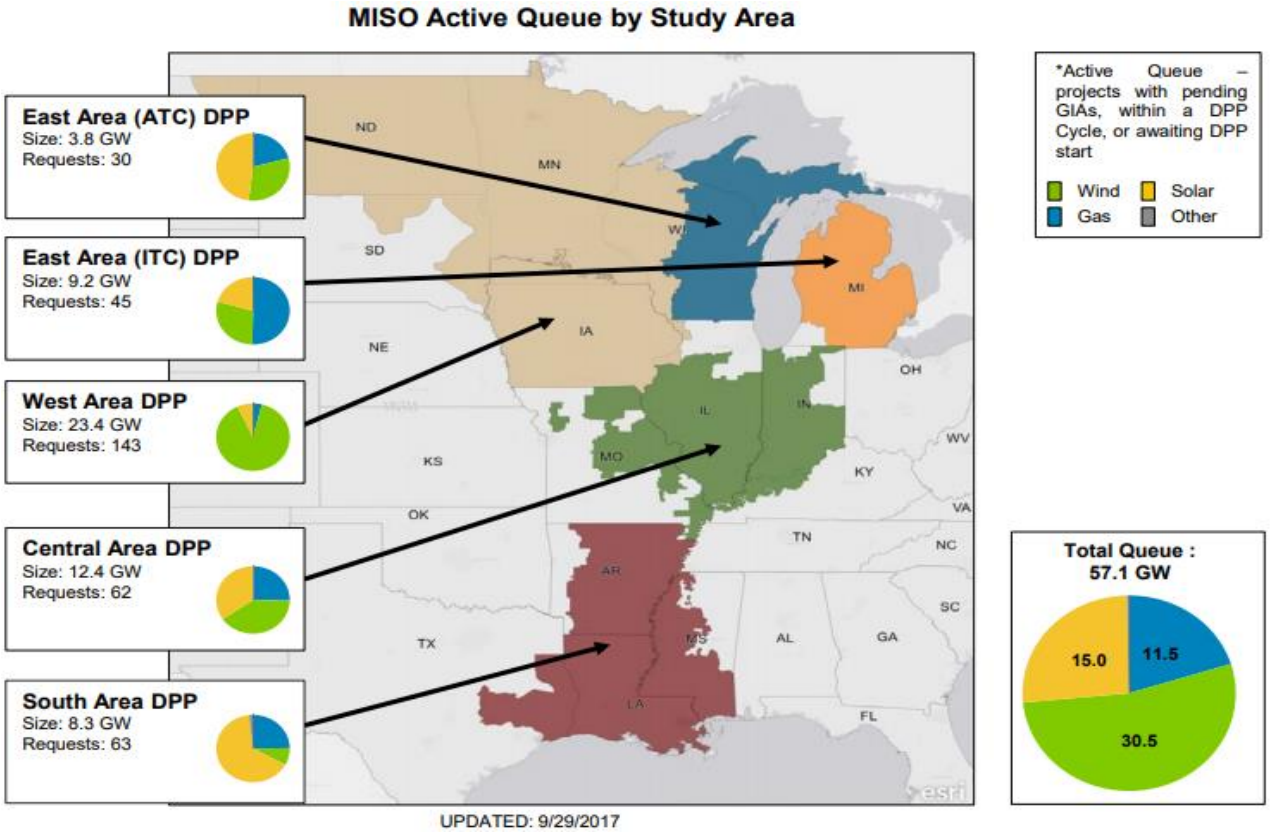
- Outages have been a significant factor in the 12 Maximum Generation Emergencies since June 1, 2016



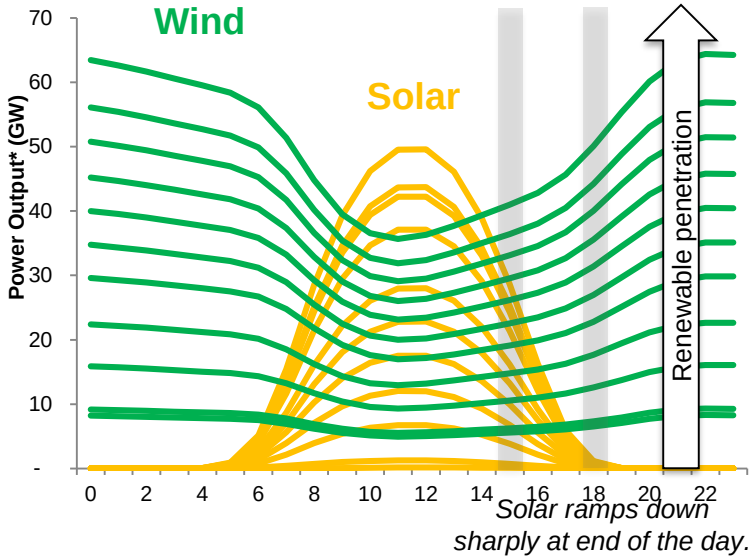


Less scheduled energy available each succeeding year through growth of variable energy resources

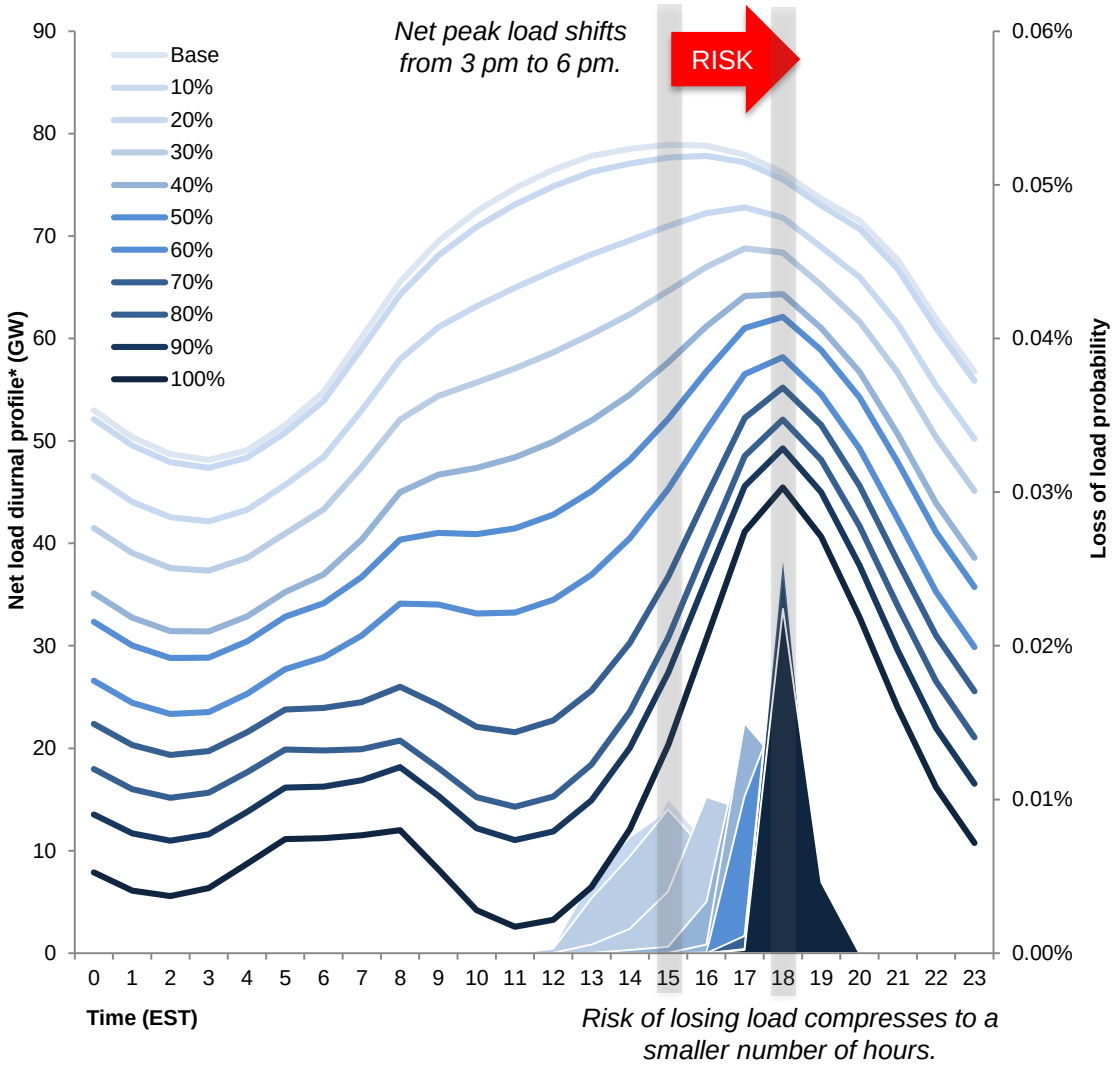
- Significant growth is expected for solar and wind as illustrated by MISO's generator interconnection queue



MISO simulations show as renewable penetration increases, the risk of losing load shifts and compresses to a smaller number of hours

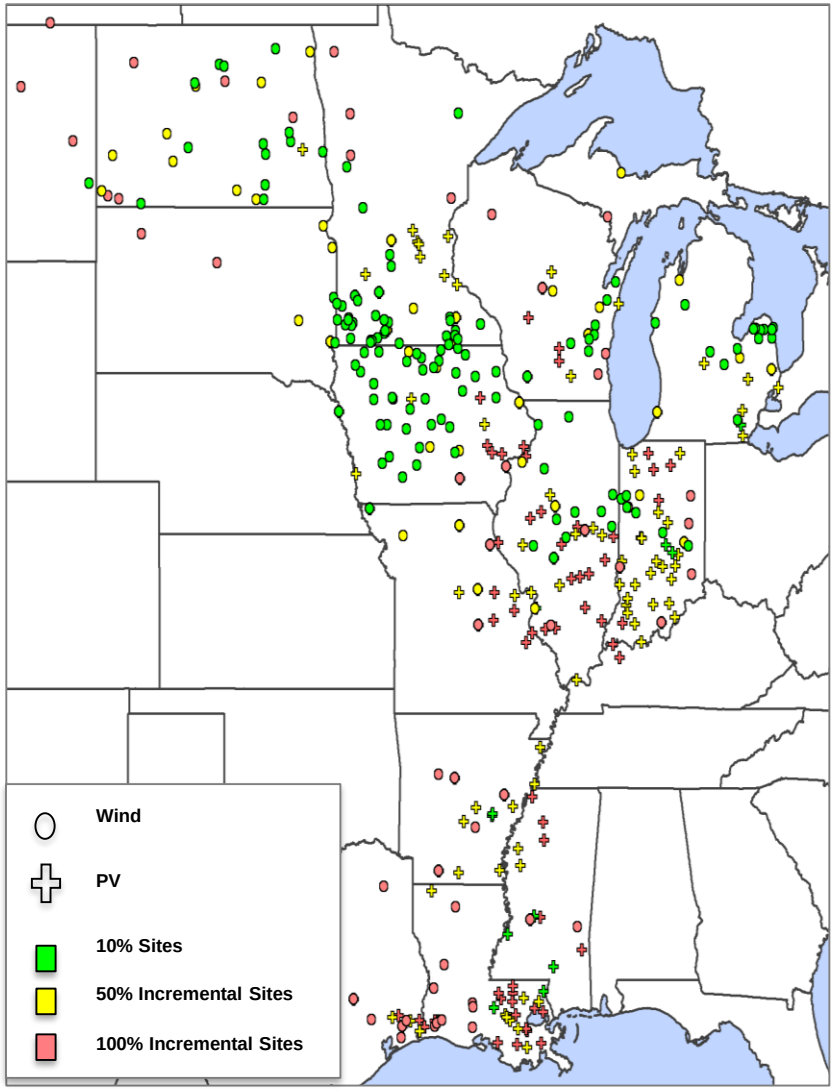


- Probability of losing load is targeted at one day in ten years over all penetration levels.
- While aggregate risk remains constant, the risk in particular hours increases.



*Profile shapes represent hourly averages across all days of the 6 study years.

Simulations also show geographic diversity improves the ability of renewable resources to mitigate the risk of losing load



Sites	ELCC
10% sites scaled to 100% level*	11.1%
50% sites scaled to 100% level*	13.4%
100% sites	14.0%

**Generation at sites selected for 10% and 50% penetration levels was scaled to match the generation needed for the 100% penetration level.*