ELECTRIC POWER RESEARCH INSTITUTE

Nuclear Mission in an Integrated Energy Future

Nuclear Power in a Clean Energy System

Sherry Bernhoft
EPRI Senior Program Manager

2019 IEA Workshop on Nuclear Power
25 February 2019

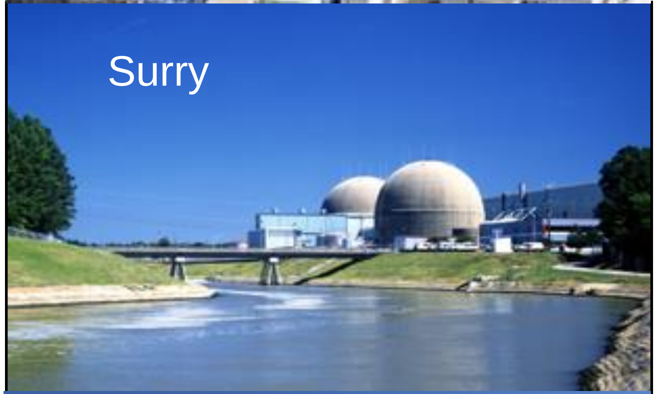
Date: Add submission date and/or revision date & #

Sustained Nuclear Power in a Clean Energy System

- Long Term Operations/Extended Operations
- Investment in Plant Modernization to Improve Efficiencies & Reduce Costs
- State the Nuclear Role in a Clean Energy System:
  - Carbon-free
  - Large synchronous generator
  - Fuel diversity
  - ***Provides system flexibility***

U.S. Second License Renewal (SLR)

- Experience from 99 U.S. operating reactors:
  - Greater than 80% have an approved LR for 40 to 60 years
  - Greater than 50% have over 40 years of operations
- Regulatory basis for SLR, 60 to 80 years is established:
  - Generic Aging Lessons Learned Report (GALL) for SLR
- Technical basis for SLR is established:
  - Aging Management Programs are in use
  - Living programs supported by research and operating experience
- Three (3) SLR Applications submitted to the U.S. Nuclear Regulatory Commission
  - Based on a recent survey ~ 50% of the utilities in the U.S. are considering SLR



Building on a Success Story for Global Life Extension

PLANT MODERNIZATION

Industry

Vision
Preserve nuclear power as a carbon-free, safe, and reliable energy resource.

Mission
Achieve nuclear power plant economic viability through collaboration, transformative technology and innovation to optimize operations and maintenance while ensuring safety and reliability.

Collaborators
- Utilities
- EPRI
- U.S. Department of Energy (DOE)
- Owners Groups, other R&D organizations, vendors
- Nuclear Energy Institute (NEI)
- Institute of Nuclear Power Operations (INPO)

2018 Early R&D

2019 Feasibility

2020 Methods

2021 Deployment

Strategic Goals

Feasibility
Show that modernization effort can be successful

Methods
Build confidence to make decisions to modernize

Deployment
Demonstrate modernization can be implemented

PHASE I
Feasibility

- End-state vision
- Basic economic return-on-investment
- Existing enabling technologies
- Research of new technologies
- Regulatory planning
- Demonstrate cost savings
- **Product: Plant modernization feasibility report**

PHASE II
Methods

- Deployment methods
- Technology research continues
- Regulatory solution
- Candidate plants
- **Product: Plant modernization handbook**

PHASE III
Deployment

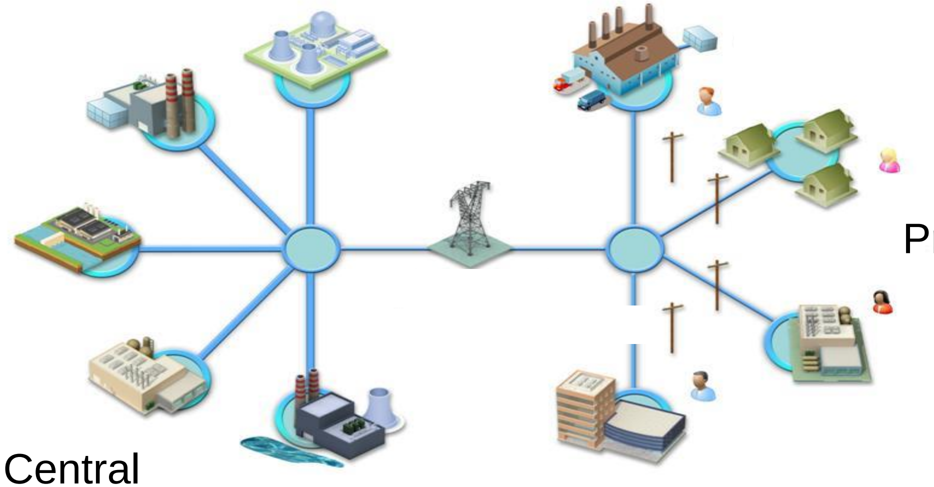
- Technology business case
- Full modernization conceptual design
- Implementation business case
- **Final Product: Plant modernization handbook with case studies**

Technology Enablers

- Automated Work Planning
- Condition Based Maintenance Monitoring
- Risk-Informed Engineering
- Digital Upgrades
- Wireless Connectivity
- Automated Chemistry Monitoring
- Automated Radiation Monitoring
- Physical Security
- Emergency Planning
- Structural Health Monitoring
- CIM Common Information Model
- Big Data Analytics

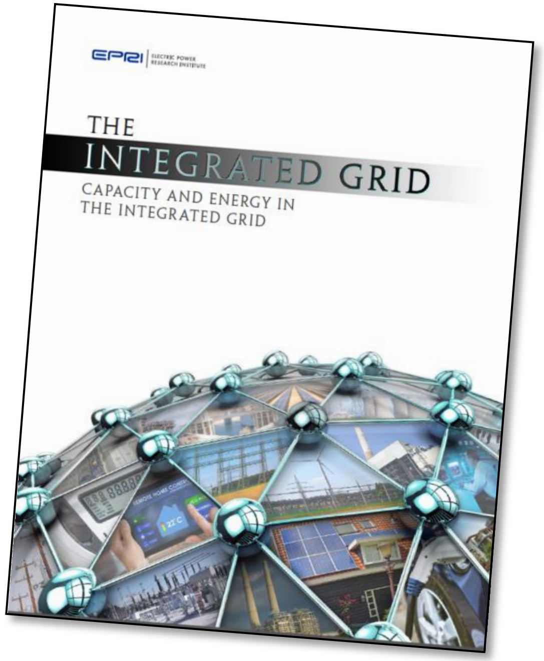
The Power Grid is *Changing*….

Traditional Grid:



Predictable Load

Central Generation

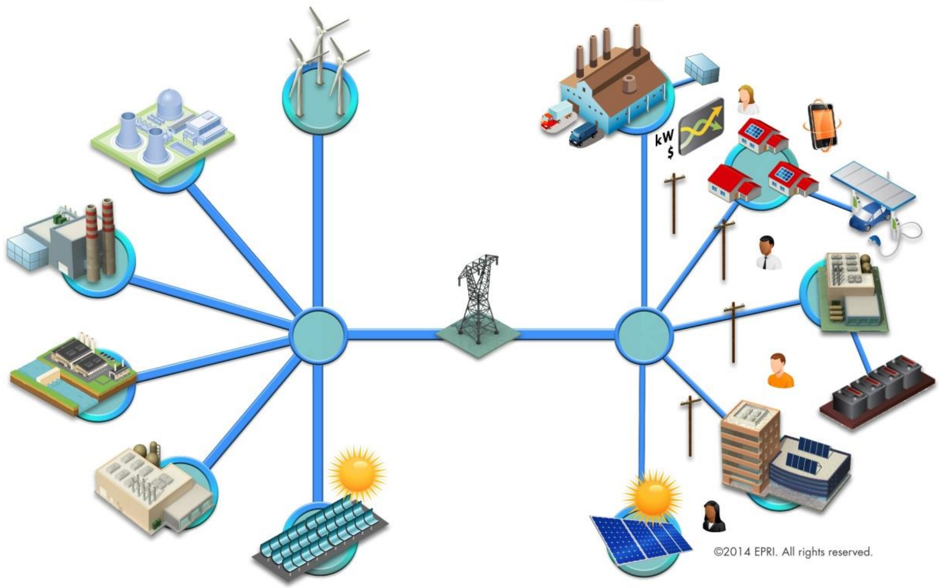


Looking Forward:

Renewables – wind & solar farms

Distributed generation – roof top solar

Changing consumer – electric cars



A More Dynamic End-to-End Power System

Impact of Variable Energy Resources on Electricity Markets

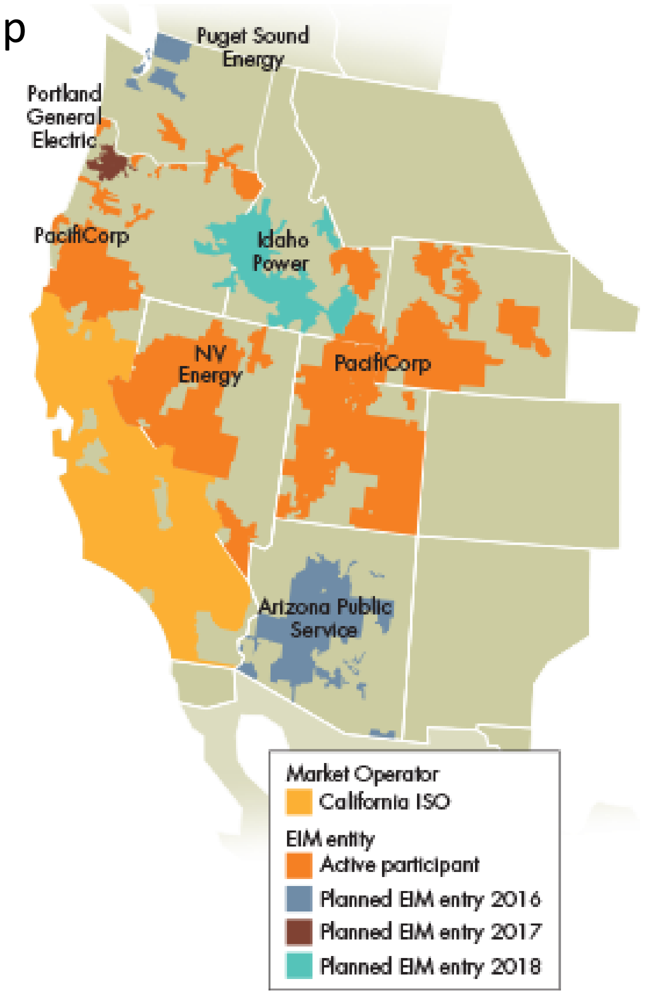
- Energy Markets
  - ***Low variable cost can reduce the average prices, and increase occurrences of zero or negative prices***
  - Increased variability in energy prices - price spikes due to insufficient capacity or ramp
  - Greater disparity between prices of forward markets (Day Ahead) and real-time markets

- Ancillary Services
  - Increase the amount of operating reserve required and potential new reserves (flexible ramping)
  - Requirements change day to day, hour to hour, and forward to real-time
  - ***Valuation of essential reliability services will become increasingly important***

- Uncertain power flows affecting financial transmission rights markets

- Increased coordination and cooperation needed → ISOs and TSOs

- ***Capacity markets may see increased value, particularly incentivizing flexibility***

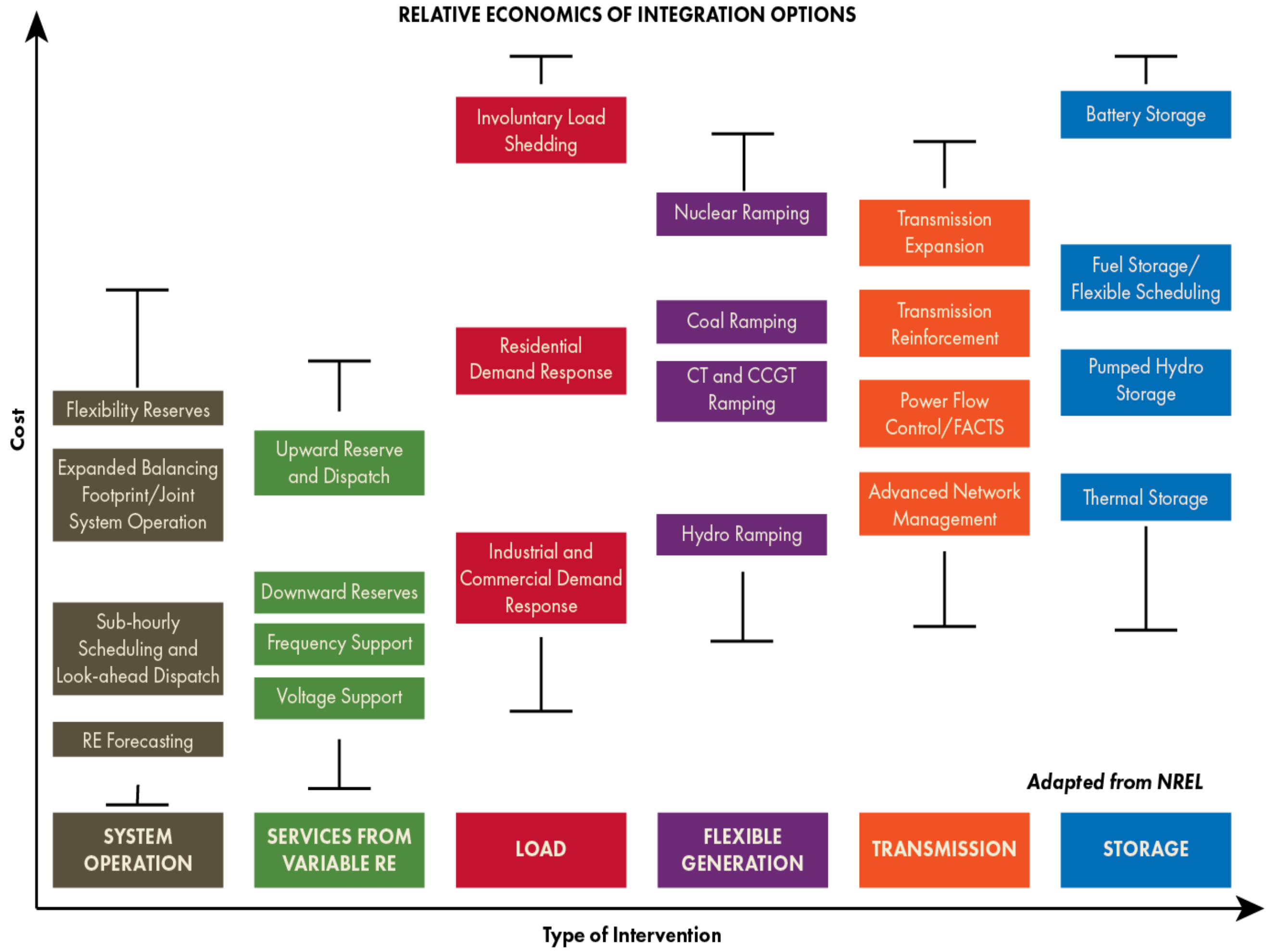


Challenges, but opportunities for existing resources

Flexibility Will Become More Valuable

- Increasing variability and uncertainty will require flexibility on all time scales and at different spatial scales

- Different resources may contribute:
  - Distributed energy resources (DER), storage and inverter based resources may provide some of the needed flexibility services
  - Retrofits and altered operational practices



Nuclear flexibility, in whatever form it takes, can provide significant value

EPRI NPP Flexible Plant Operations (FPO)

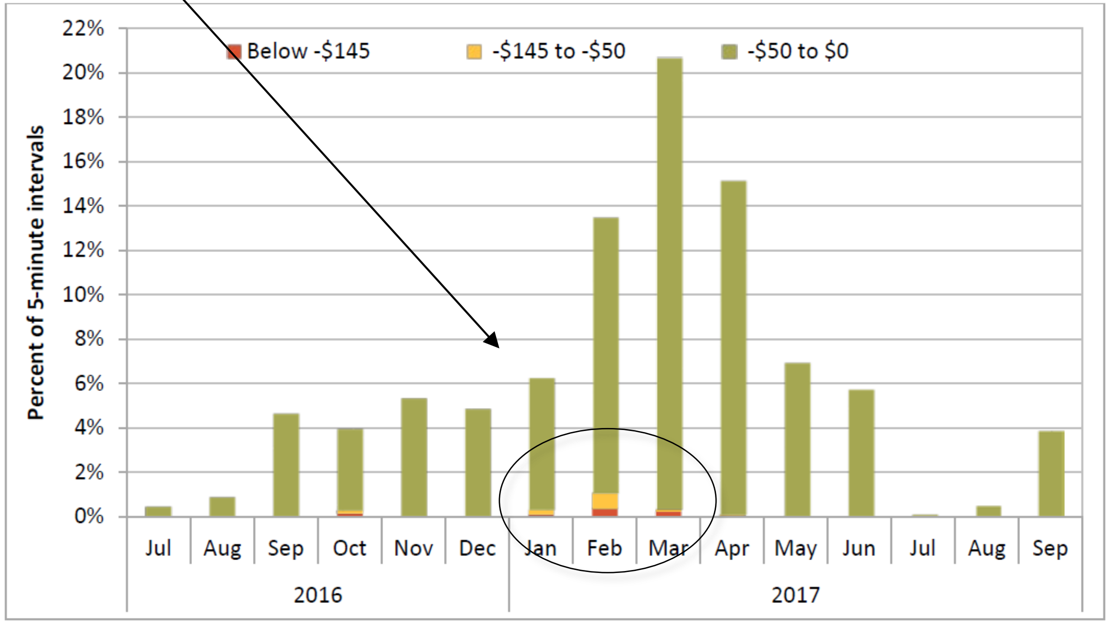
Started in 2012 to transition baseload NPPs to flexible operations due to increasing grid variability, grid congestion and negative electricity prices.

Purpose:

1. Proactive research to understand impacts on the plant and fuel,
2. Develop management strategies,
3. Stakeholder engagement, and
4. Share operating experience.

Southwest US data from CAISO

Figure 1.16 Frequency of negative 5-minute prices by month



http://www.caiso.com/Documents/2018ThirdQuarterReportonMarketIssuesandPerformance.pdf

Existing NPPs Are Flexible – and *Help* with Grid Variability

- Three pre-planned 'bounding' cases for Flexible Operation studies:

High renewable integration

Most frequent mode of FPO in the US

Extended low power operation

Seasonal for some plant operators

Response to grid transient

Will need modification to plant/design basis

Pre-Planned
100 - 80 to 70 -100% Power

- >12 hour duration - daily basis
- Ramp rate 0.5-1% per minute

Pre-Planned
50% Power

- 2-8 week duration
- Seasonal

Extreme
100-30-100%

- Ramp rate 2-5% per minute
- Response to Grid - short notice, no defined duration

Research Focus Areas

Fuel integrity

Chemistry

Radiological Safety

Waste effluents

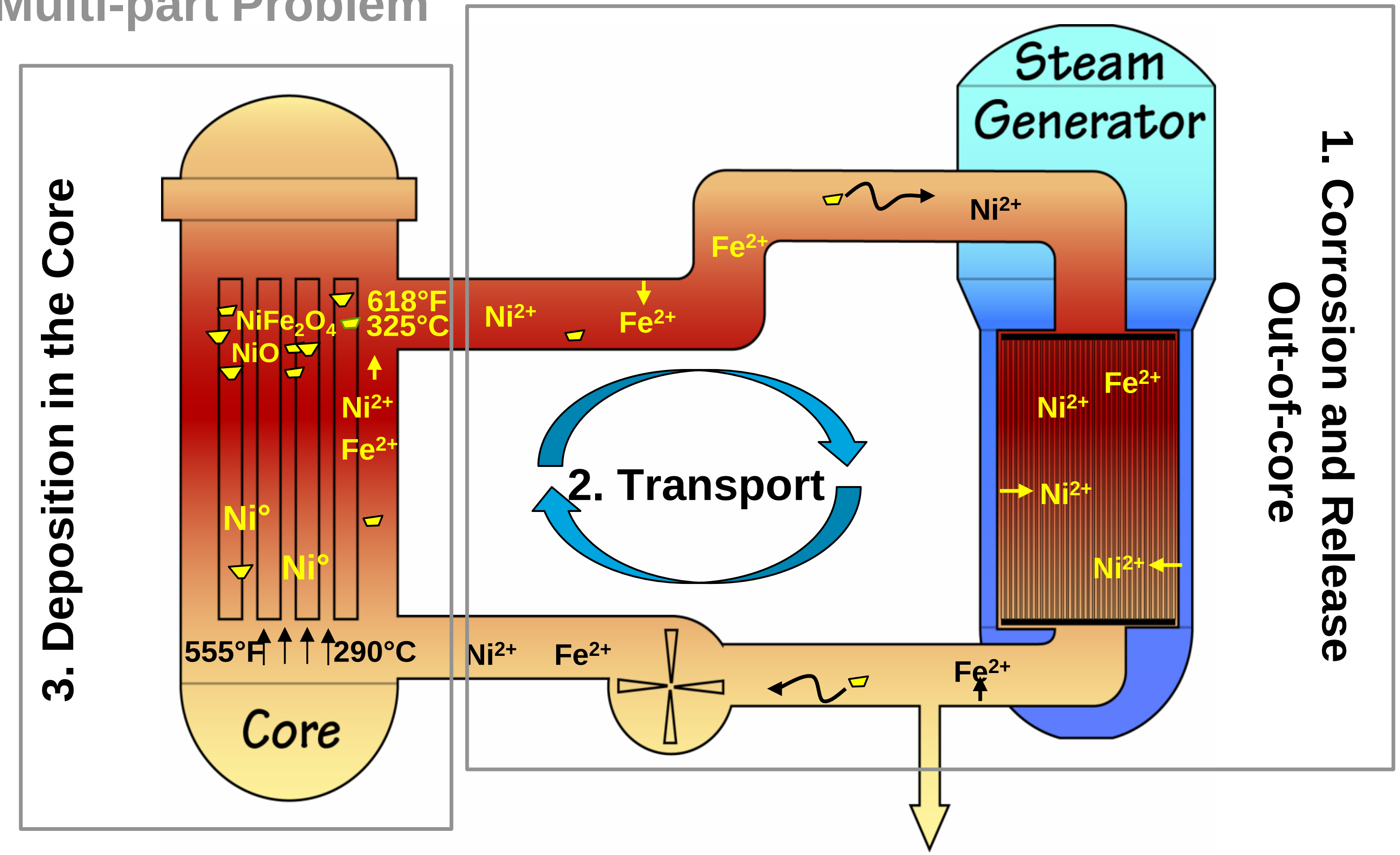
Flow Accelerated Corrosion

Balance of plant impacts

Steam Generators impacts

Primary side impacts

Multi-part Problem

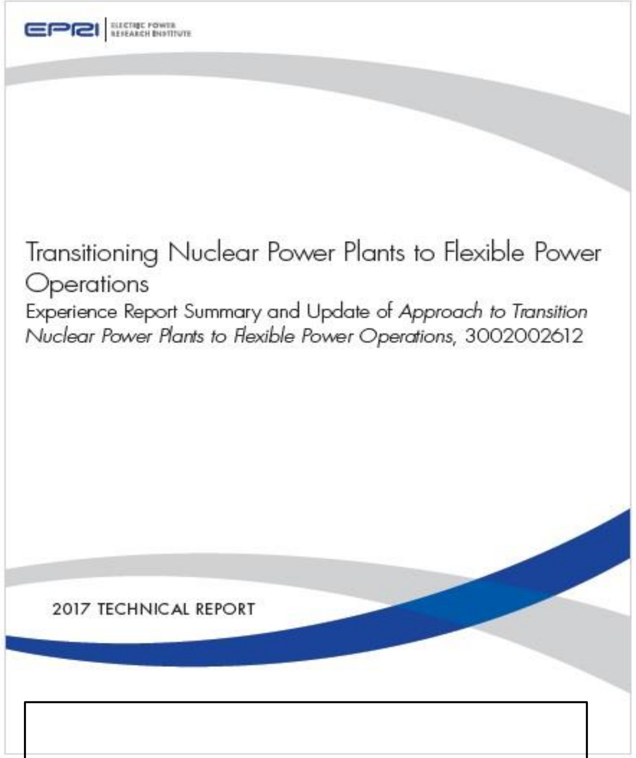


In the primary loop, materials are constantly corroding and releasing ions and particulates into the coolant. These are transported throughout the loop and deposit under certain conditions.

What We Have Learned …

- Best Practices:
  - Establish integrated team to transition and monitor for impacts
  - Define a 'safe operating envelope'* and train the operators and plant staff
  - Establish a protocol with ISO/TSO – in the U.S. and other countries only a licensed operator can maneuver the plant

- Observations:
  - Chemistry is challenged – needs more frequent monitoring
  - Core internals inspection frequency may need to be increased
  - Flow accelerated corrosion wear rates change
  - Maintenance schedules and practices need to be reviewed and adjusted
  - *Most plant impacts are latent – need to be checking for precursors such as vibrations or unexpected noises*



*Safe operating envelope:

Define the rate, depth, duration, frequency and time in core life

Flexible Operations is being successfully implemented with manageable impacts

Example – Wind Energy Impacts on Nuclear in the US

Wind energy is intermittent and seasonal

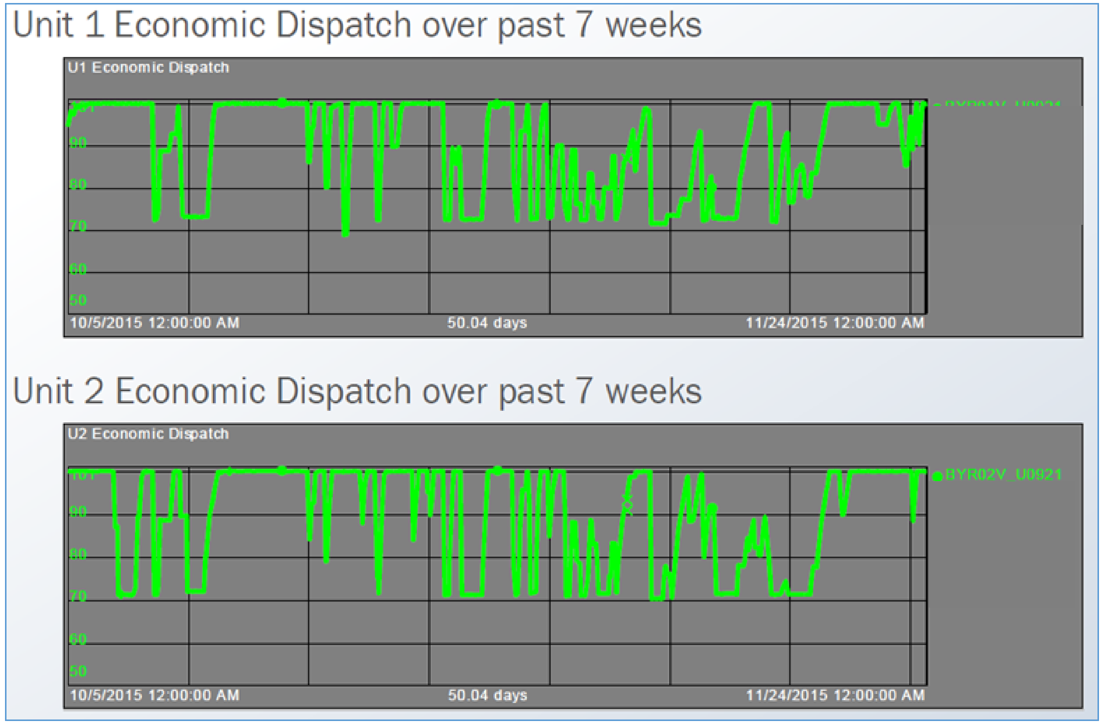
Requires short term response to system variability, minute-to-minute.

More flexibility is required in the spring and the fall.

Case Study

One utility in the U.S. upper mid-west operates 8 units flexibly:

- > 250,000 MWh is 2016 and > 140,000 MWh in 2017
- Team monitors and evaluates impacts
- PWRs are limited to 6 directional changes per day
- BWRs are limited to 12 directional changes per day
- PWR can respond to system dispatch in 15 minutes and takes up to 30 minutes
- BWR can respond to system dispatch in 5 minutes and takes up to 15 minutes to initiate ramp
- Chemistry is notified at the beginning and end of each maneuver



Data provided by Exelon for a PWR

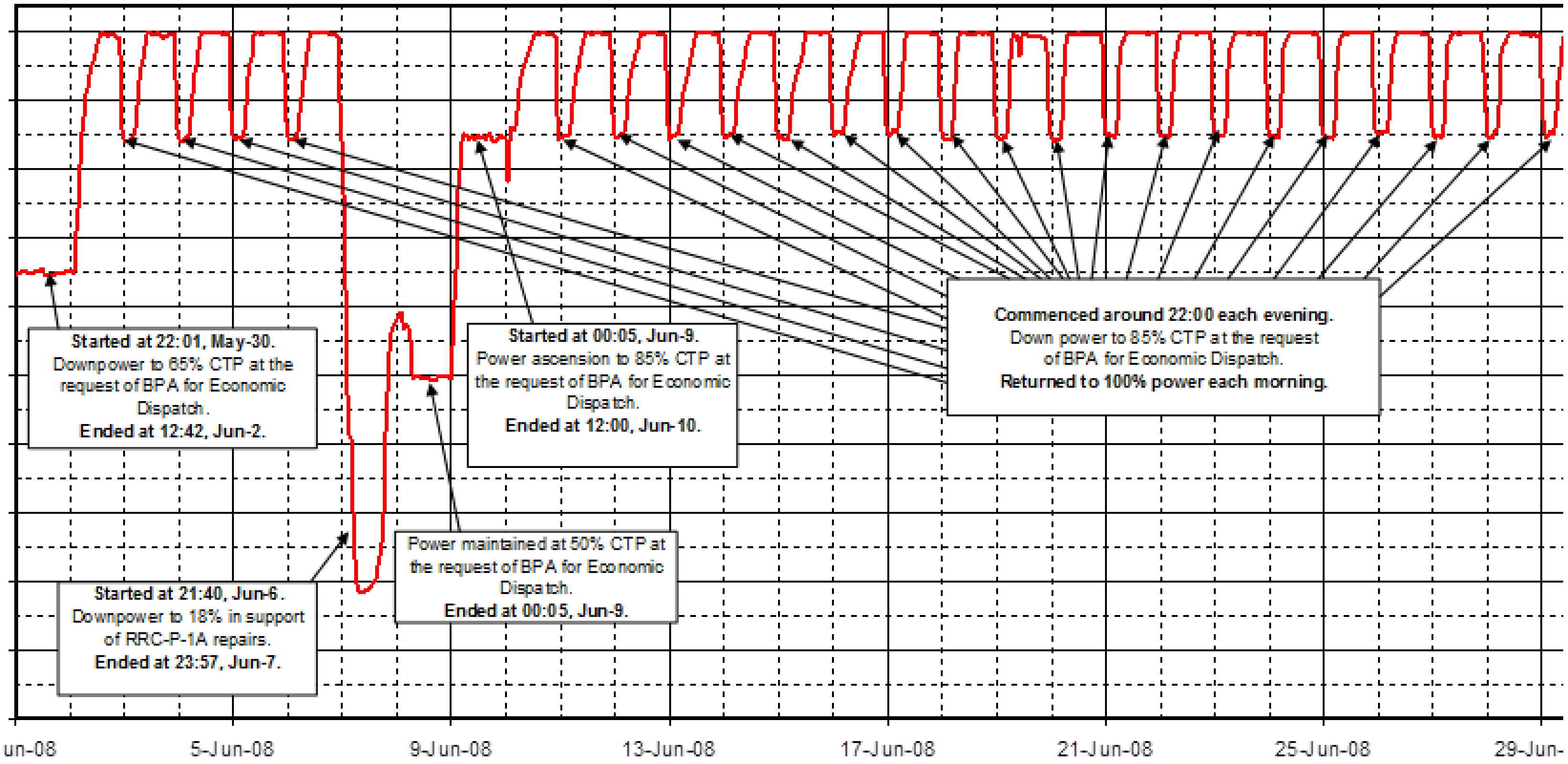
Example – Hydro Impacts on a Nuclear Plant in the US

Hydro Power

Typical can use day ahead planning due to predicted river flow and weather conditions.

More flexibility is required in the spring and fall, and in the spring periods of extended low power operations (ELPO) are common.

Thermal Power (BWR)



Example – Solar Impacts on Nuclear in the US

Solar Energy

Day ahead planning, but can require hour-by-hour variations throughout the day.

More flexibility is required in the spring and the fall.

Challenges:

- Depth of negative prices
- Reserve margins during the middle of the day
- Ramp rate in the afternoon

California ISO 'Duck Belly Curve' for Over-Generation

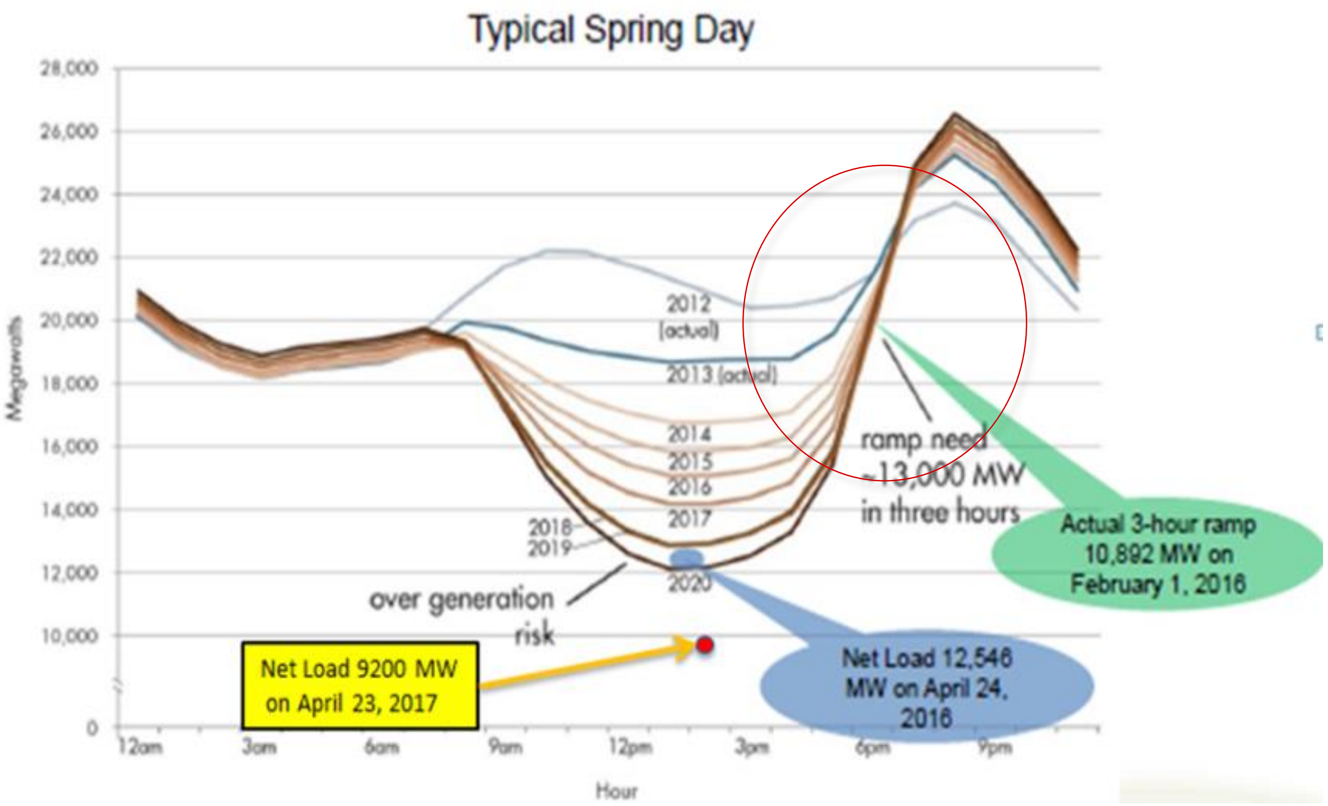
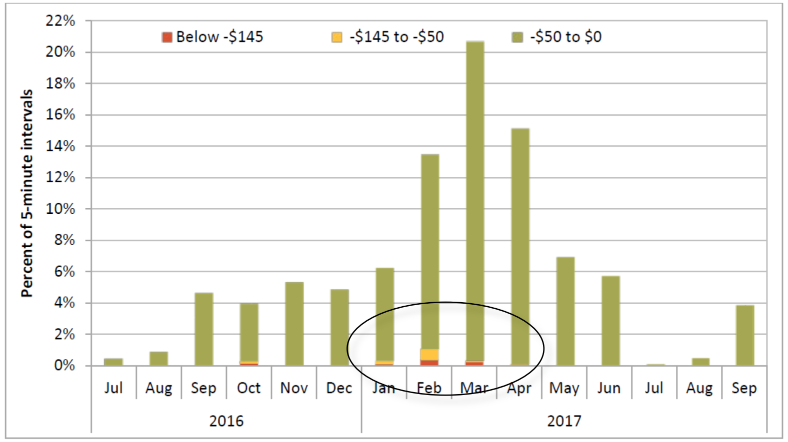


Figure 1.16 **Frequency of negative 5-minute prices by month**



What Role Can Energy Storage Play?

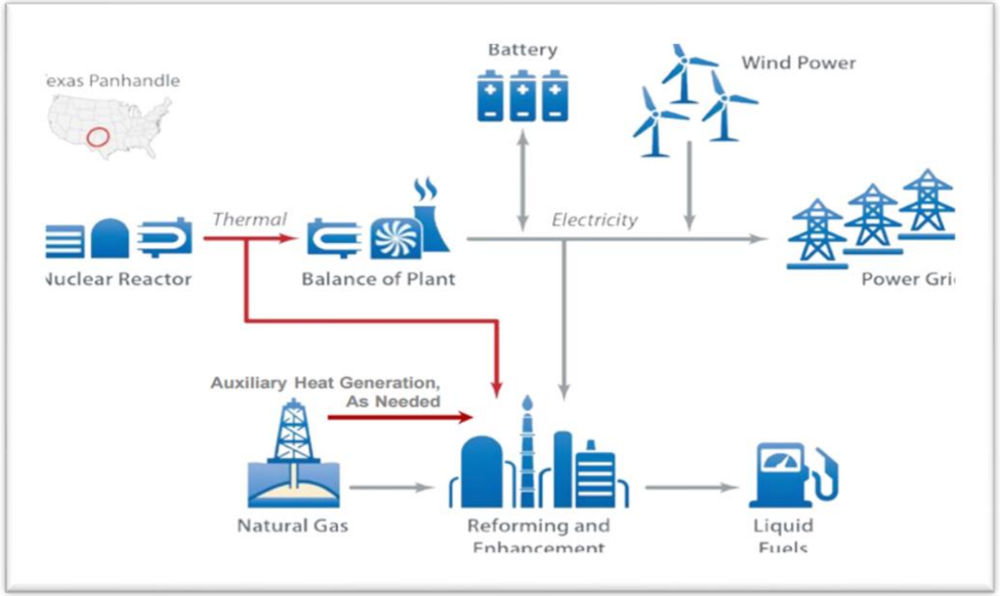
Value Proposition for Energy Storage (ES):

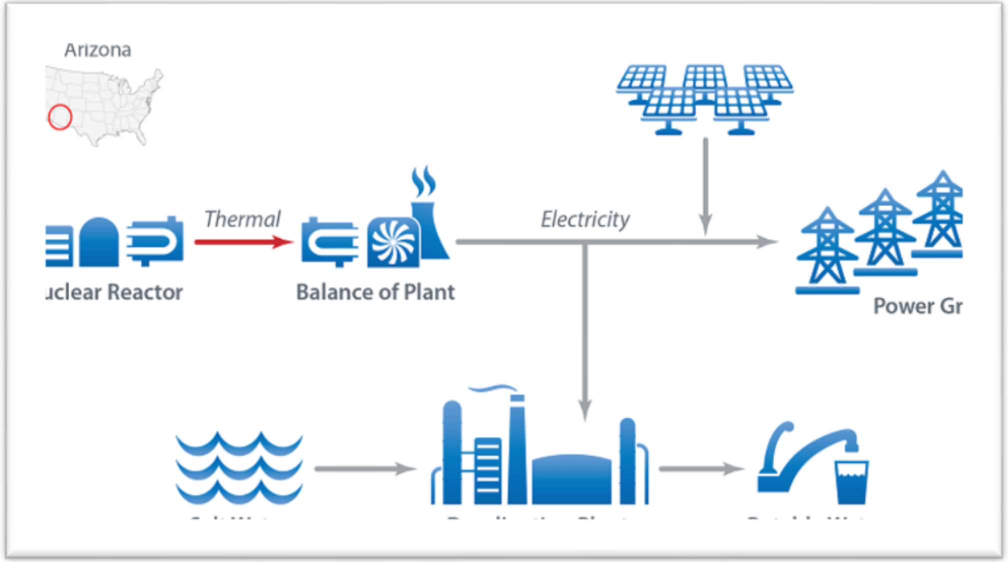
- Optimize operation of the nuclear asset with respect to energy to storage vs. selling electricity to the grid while continuing to provide grid reliability, resiliency and fuel diversity.

- Reduce or eliminate curtailment of renewables during periods of electricity over generation.

- Produce a valuable product for end users:
  - H2 to feedstock or fuel
  - Thermal energy to electrical energy
  - Thermal or electrical energy to de-salinization

- Possibility to bid into other markets:
  - Ancillary services
  - Capacity market
  - Ramping services

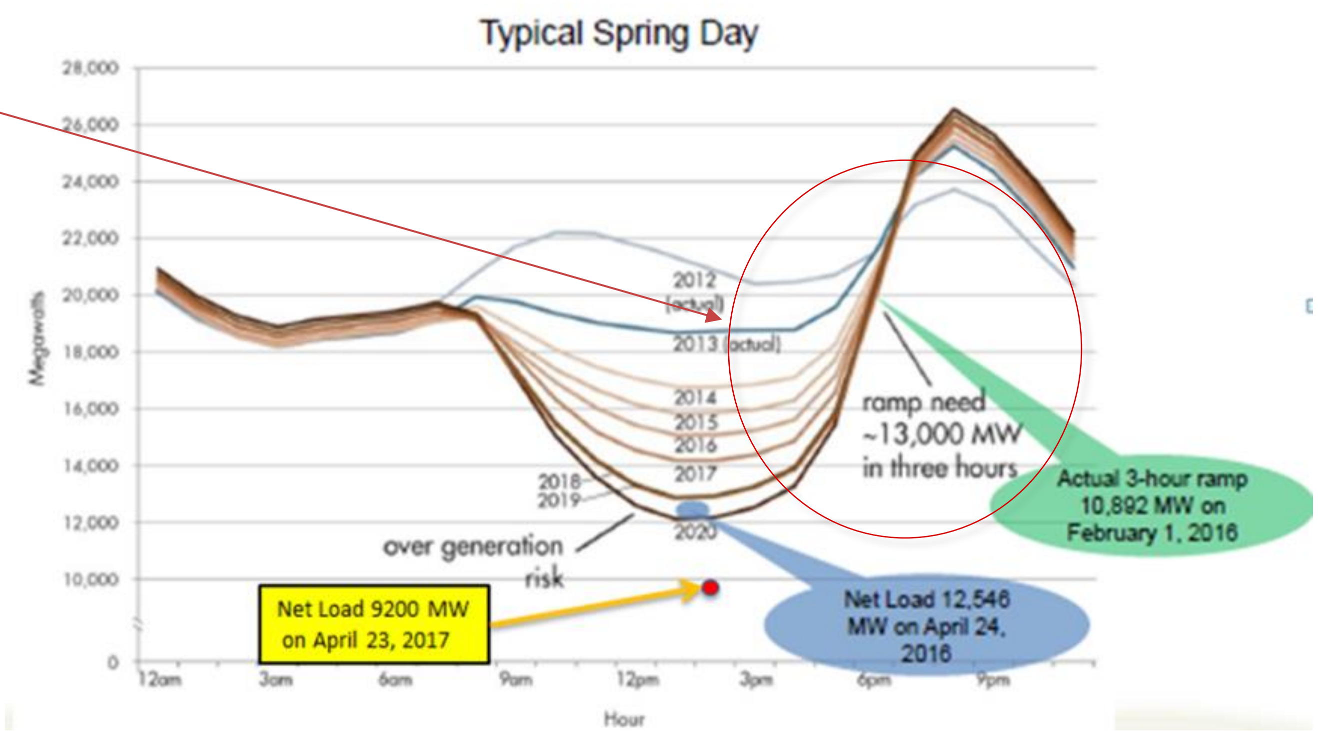




Use the Solar Market as an Example

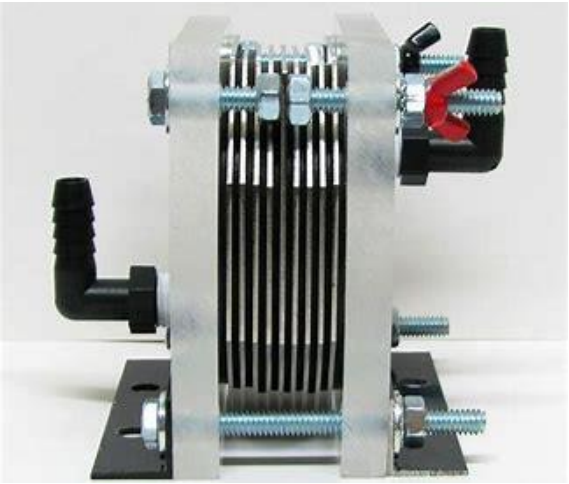
- Can a system be designed to store energy during the day and 'shift-the load'?
- Considerations:
  - Thermal or electrical storage
  - Storage capacity for 6 to 8 hours needs to be on the MW scale
  - Discharge capabilities needs to meet the ramp rate
  - Siting and licensing requirements
  - Economics – what is the benchmark to compare against

California ISO 'Duck Belly Curve' for Over-Generation



Potential Demonstration Project in US

- Project Team:
  - EPRI, National Laboratories, utilities with nuclear assets, designer, AE, H2 system provider, H2 storage
- 2 MW Demonstration:
  - Use electrical power from the nuclear asset to produce and store H2 during periods of over production due to wind
  - Demonstrate the safety (licensing case) that can be generically applicable
  - Collect data to assess the system performance to respond to variability (from wind) and support grid reliability and resiliency
  - Collect data to assess the 'all in' economics of the system
  - Collect and share lessons learned
  - Target a scale up demonstration in a solar market for load-shifting and ramping



Project Phases:

Phase 1. System Design, Siting, Storage and Installation for **Hydrogen Water Chemistry**

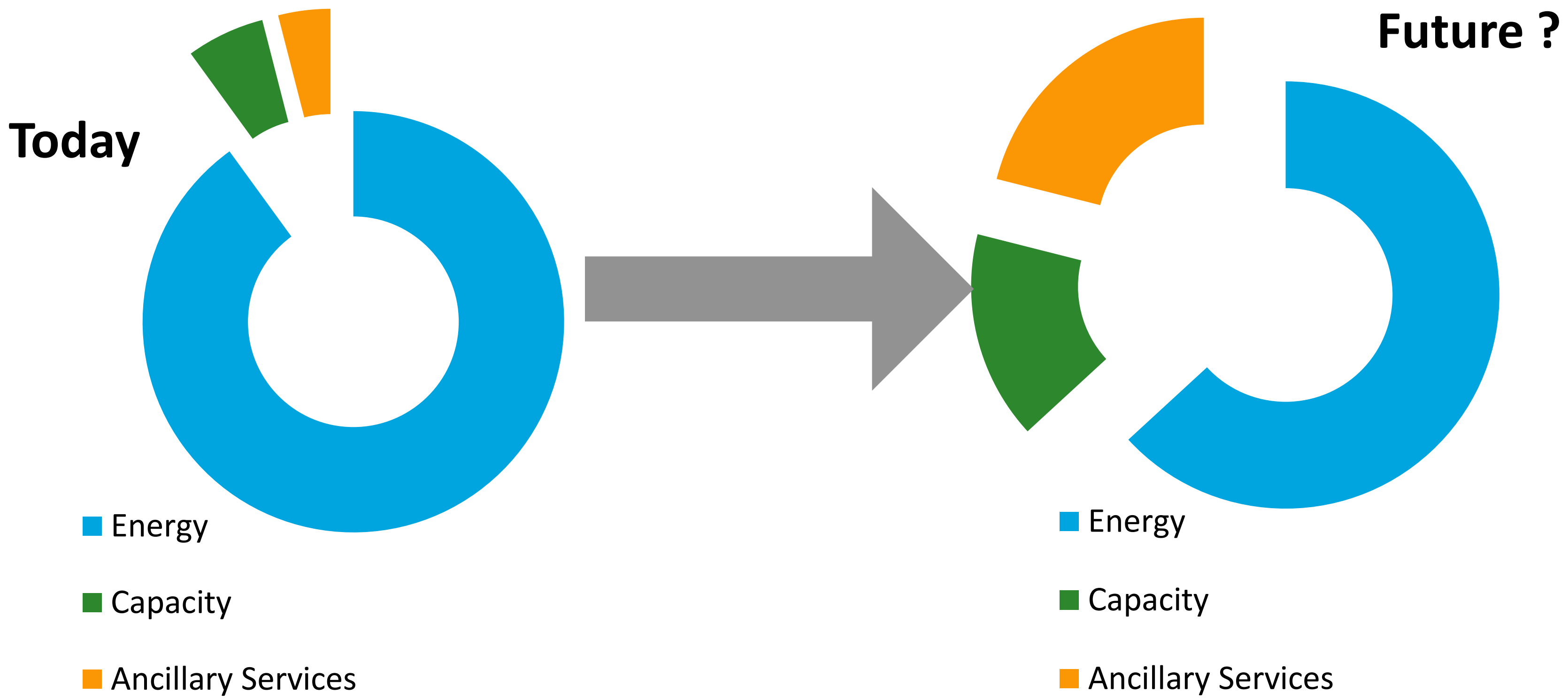
Phase 2. Hydrogen for **On-site Process Heating** Application --Nuclear (Application 2)

Phase 3. Hydrogen **Injection into a Gas Line**—Gas Turbine (Application 3)

Phase 4. Hydrogen to **Electricity Production** (Application 4)

Electricity Markets –Some Closing Thoughts

Market Evolution



Electric Power Research Institute, *Capacity and Energy in the Integrated Grid*, EPRI, Palo Alto, CA: 2015 Product 3002006692, Available: https://www.epri.com/#/pages/product/000000003002006692/

What does Mr. Webster or Mrs. Oxford say?

- Reliability:
  - Consistently good in quality of performance, able to be trusted
  - Suitable or fit to be relied on
- Resilience
  - The capacity to recover quickly from difficulties; toughness
  - An ability to recover from or adjust easily to misfortune or change

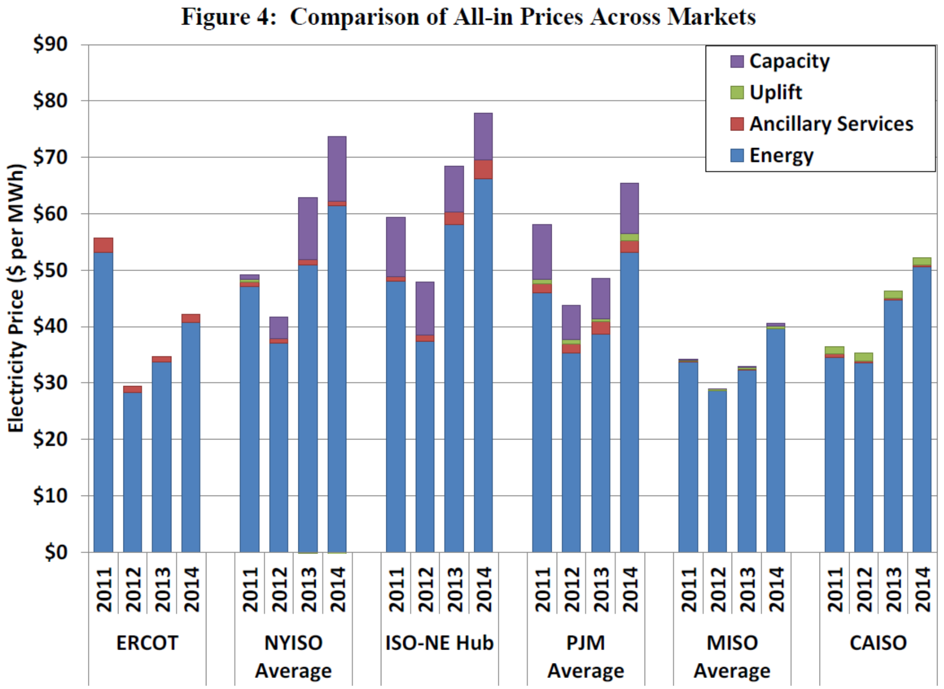
*Contribution of Supply and Demand Resources to Required Power System Reliability Services**

Identified key grid reliability functions:

1. Reactive Power/Voltage Control
2. Short Circuit Contribution
3. Frequency Support
   A. Inertial response
   B. Primary frequency control
   C. Regulation
   D. Load following/ramping
   E. Spinning reserve
4. Resource Availability
   A. Fuel availability
   B. Equipment availability
5. Black Start

* EPRI Report ID 3002006400, available on EPRI.com

How much money flows through these markets?



EPRI report # 3002009273

2014 data

	ISO-NE	NYISO	PJM	MISO	SPP	ERCOT	CAISO
Total Market Volume ($B)	10.6	14.7	50.0	32.5	10.6	15.0	12.1
All-in Price ($/MWh)	78	75	65	40	34	41	52
Energy ($B)	9.0	11.2	41.4	31.9	7.4	13.8	11.7
Ancillary Services Markets ($M)	236	150	1,881	180	116	513.4	69
Uplift ($M)	174	147	965	351	77	N/A	95
FTR ($M)	34	183	733	1,155	373	375	104
Capacity Market ($M)	1,060	3,220	7,030	145	N/A	N/A	N/A

Defining Different Types of Power System Resilience

Electric Power System Resilience

	Supply Resilience	Transmission, Substation, and Distribution Resilience	Communications Resilience
Events	• Extreme weather • Hurricanes, flooding	• EMP, GMD events • Natural disasters	• Cyber attacks • Natural disasters
Strategy	• Generator hardening • Fuel supply assurance	• Line hardening • Network redundancy	• Enhanced cyber security • Network redundancy
Incentives	• Opportunities for market incentives • Cost based recovery	• Side payments from operators • Cost based recovery through LSE	• Cost based recovery • New technology and devices (IoT, microgrids)

Together…Shaping the Future of Electricity