Flexibility and Resilience

Overview of Recent Issues

Aidan Tuohy, PhD, Senior Program Manager
APEx Annual Conference
Oct 21, 2022
Dubrovnik, Croatia

Integrated Grid & Energy Systems Planning/Analysis Scope

Strategic Energy & Env. Planning → **Long-Term System Planning** → **Real-Time Operations**

- Energy/Decarb. Strategies
- Climate Risk and Resiliency
- Integrated Resource Planning
- Renewables/DER Integration
- Real-Time Trans. & Dist. Operations
- Resource Adequacy
- Trans. & Dist. Planning
- Market Operations & Design
- System Protection

EPRI Technology performance and assessment research underpins system modeling and analysis functions

Staff Expertise

145
Modeling & Grid Systems SMEs

R&D Collaboration

90
Utility/ISO R&D Partners

Applied Support

120
Utility Specific Applications (2021)

Requirements for a Reliable, Resilient Decarbonized Grid

New Grid Operation Capabilities

New protection, control, and other technologies to reliably and resiliently operate the grid

Revised Market Designs

Markets must incent investment and properly compensate resources for grid services provided

Grid Investment and Development

Adequate investment, supply chain, and workforce to develop extensive new supply, demand, and T&D resources

Efficient Regulation and Collaboration

Faster timelines for siting, permitting, and building new infrastructure and developing and deploying new technology

Integrated Planning for Reliability and Resiliency

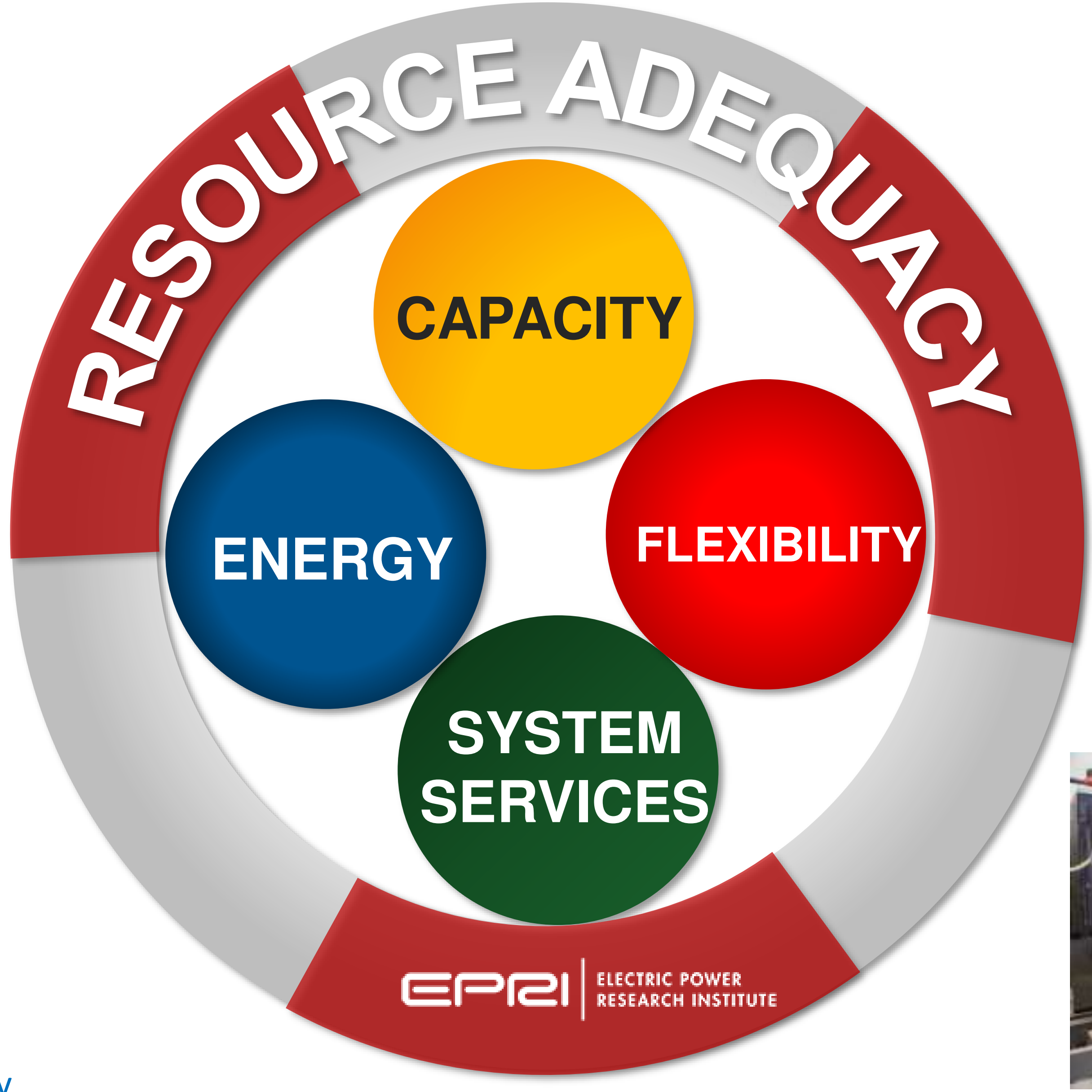
Tools and processes for regional investment plans across electric and other energy systems in context of changing climate and other hazards

See EPRI, *Enhancing Energy System Reliability and Resiliency in a Net-Zero Economy*, 2022 (link) for more details

What does it mean to have adequate resources?

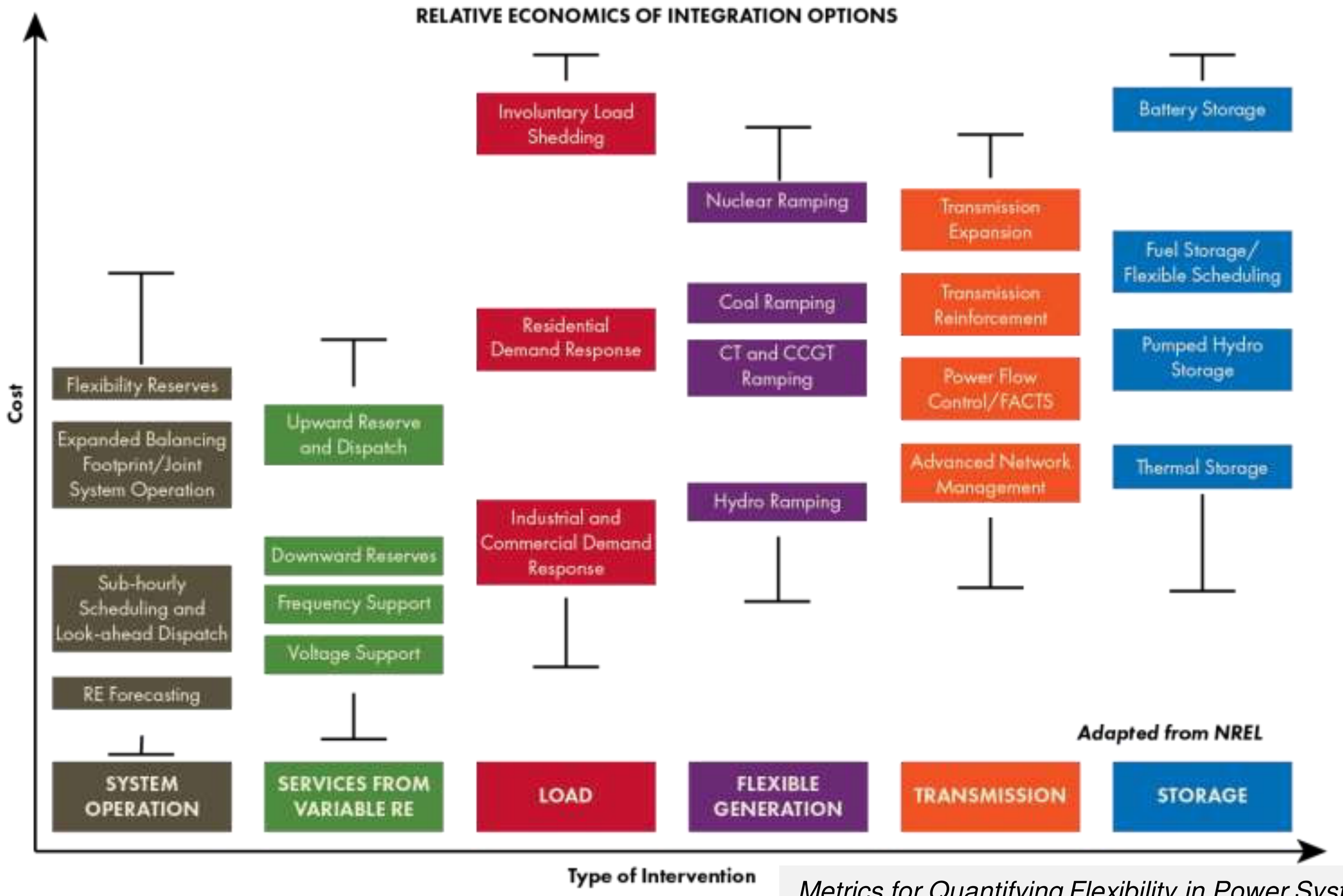
An adequate supply fleet is not just the installed MW in the ground. The capacity must have energy to sustain during critical time periods, flexibility to accommodate condition changes, and sufficient reliability services to provide when necessary

www.epri.com/resource-adequacy



Flexibility Will Become More Valuable

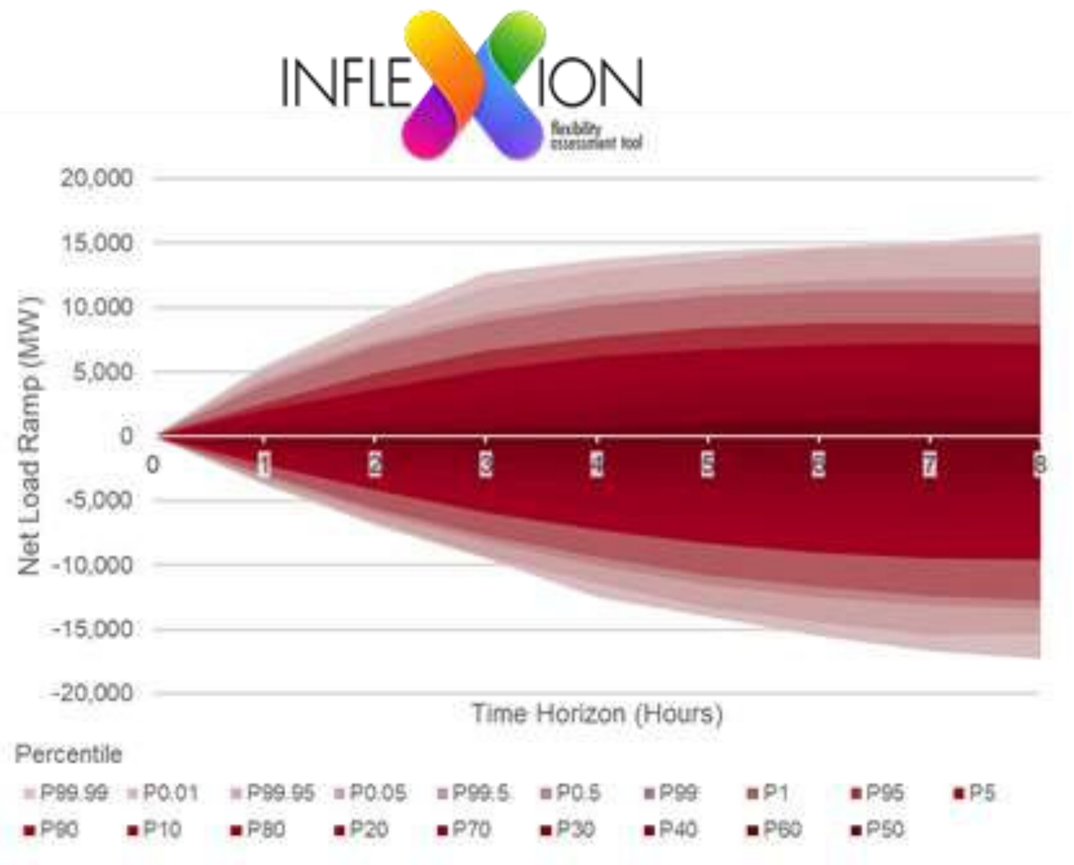
- Increasing variability and uncertainty will require flexibility on all time scales and at different spatial scales
- Different resources may contribute
  - DER, storage and inverter-based resources may provide some of the needed flexibility services
  - Retrofits and altered operational practices
- Wind/PV flexibility (with or without storage) increasingly important

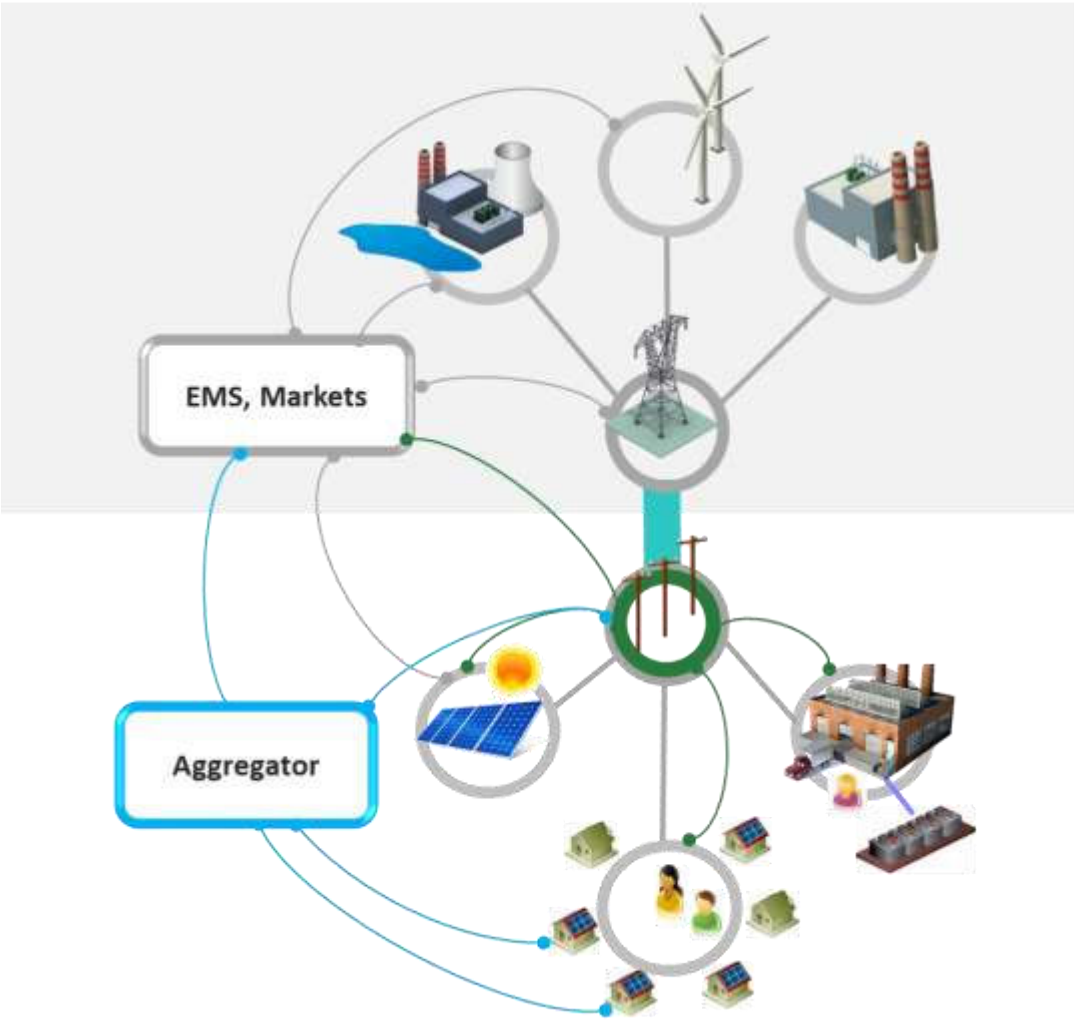


Metrics for Quantifying Flexibility in Power System Planning, 3002004243, 2014 (EPRI)

EPRI working on flexibility tools and metrics to assess long term resource adequacy impacts

Flexibility – measuring needs and obtaining services





Need to be able to assess what is needed, and then get it from emerging resources

Mechanisms to Incentivize Flexibility

- Reduce costs and improve reliability with intelligence

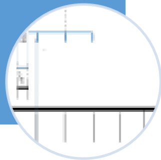
Forecasted Reserve Requirements

- Value reserve above minimum requirements

Operating Reserve Demand Curve

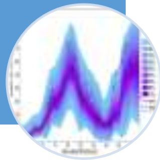
- Price opportunity costs of ramp

Multi-interval settlement



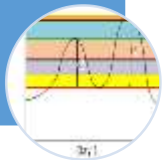
- Represent uncertainty explicitly

Stochastic models, smart reserve



- Make sure flexibility is built in the first place

Forward Flexible Capacity Attribute Procurement

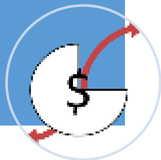


- Let demand provide flexibility

Real-time pricing, retail alignment and automation

- Transparency leads to innovation

Price Formation



- Reduce uncertainty directly

Enhanced Forecasting

EPRI comments, Modernizing Electricity Market Design Docket No. AD21-10-000, March 2022

Distributed Resources for Grid Flexibility

2030:
200
GW

Flexible Load

2020:
60
GW

Smart and Fast Charging of EV

Enabling Higher Penetration of EV/Solar/DER

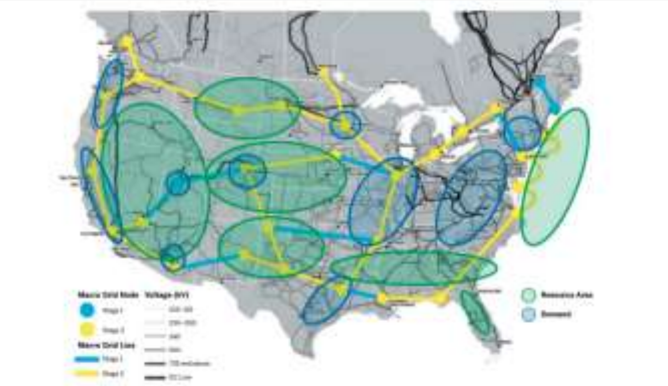
Grid-Integrated Energy Storage

Vehicle-to-Grid System Resource

Connected, Smart Demand-Responsive Load

2020 Brattle study estimates potential U.S 2030 load flexibility at 200 GW – 20% of peak load.

Role of Interconnections

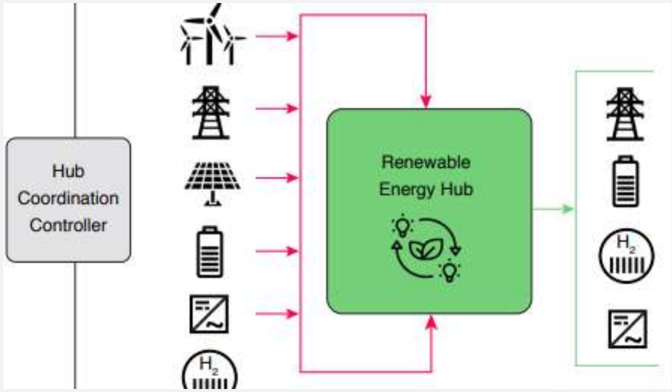


Macrogrid ideas

- Allow for broad sharing of clean energy sources
- Diversity of demand and production
- Resilience to extremes

Build out of HVDC

- Need to determine which lines provide most benefit for reliability/resilience
- Links to local and regional networks



Energy hubs

- Very different electrical requirements
- Interoperability and standards can support

Potential for significant benefits to linking different regional grids

Source: Energy Systems Integration Group (link)

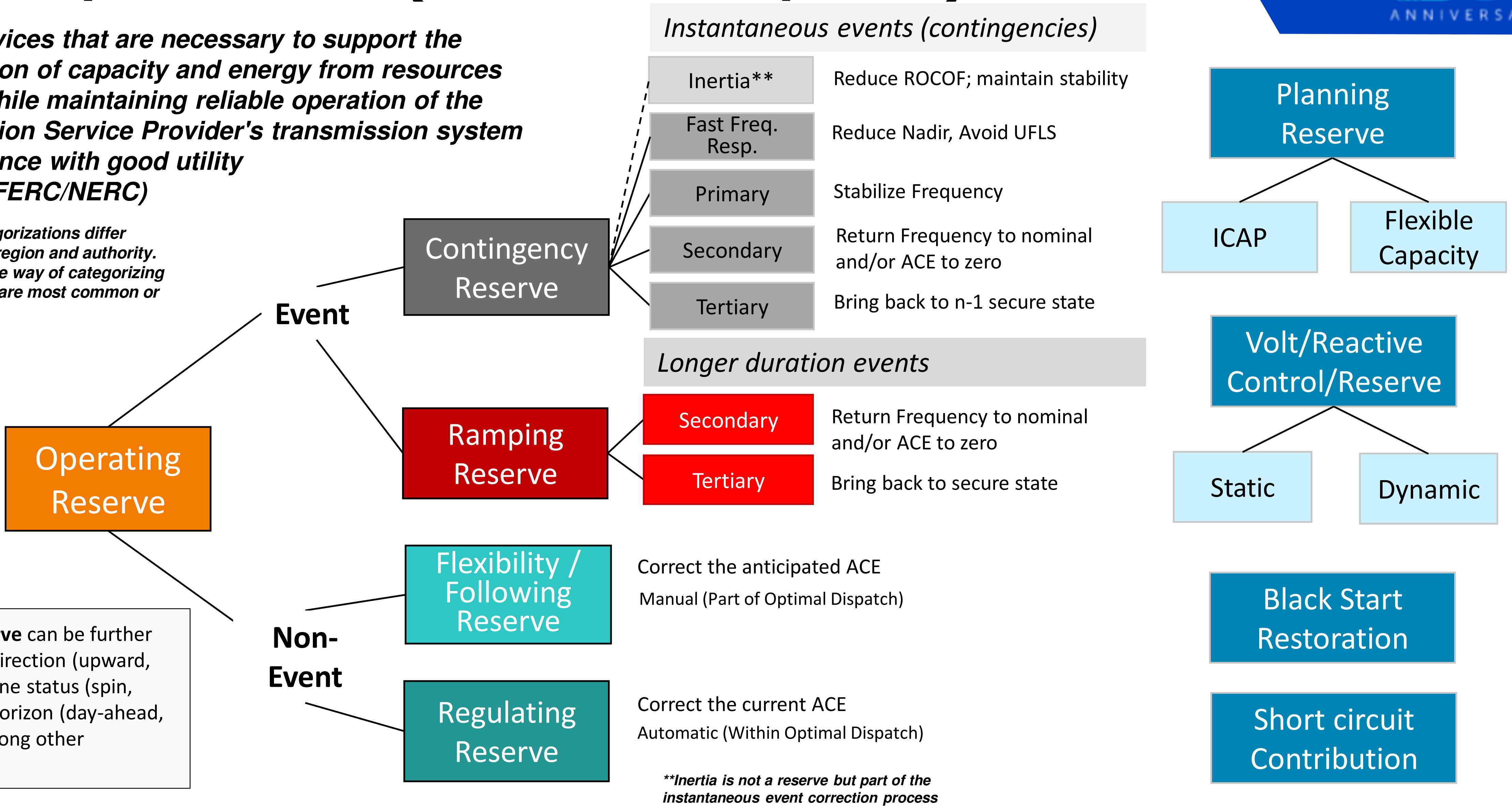
Source: EPRI Energy Hubs Paper (link)


EPRI 50th
ANNIVERSARY
Together…Shaping the Future of Energy®

Ancillary Services* (Bulk Power System)

Those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice. (FERC/NERC)

****Terms and categorizations differ substantially by region and authority. This is simply one way of categorizing using terms that are most common or most descriptive.***



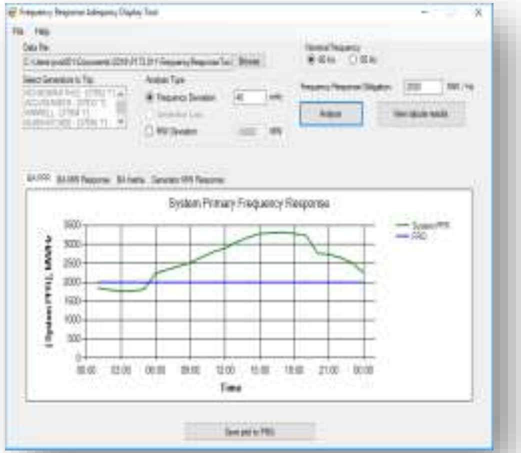
Operating Reserve can be further categorized by direction (upward, downward), online status (spin, non-spin), and horizon (day-ahead, hour-ahead) among other characteristics.

Adapted from Ela et al., An Enhanced Dynamic Reserve Method for Balancing Areas, EPRI, Palo Alto, CA: 2017. 3002010941.

Renewable Integration Reliability Assessment

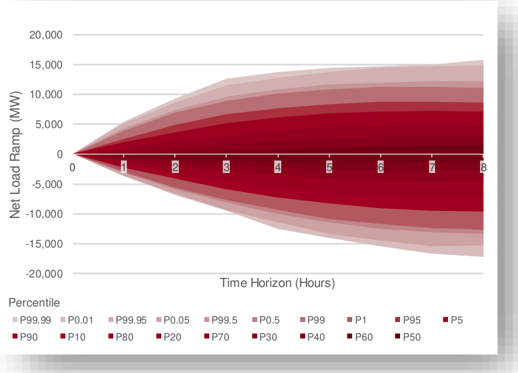
How much ___ is needed?

Frequency Response



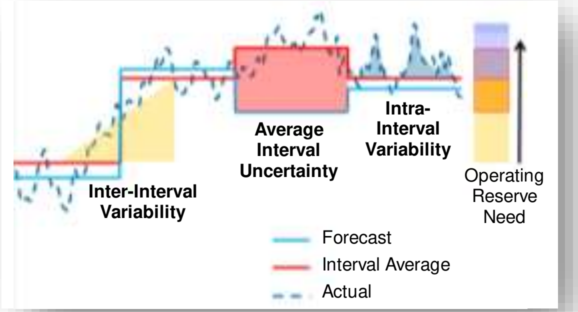
FRADT

System Flexibility



INFLEXION flexibility assessment tool

Operating Reserve



DynADOR

System Strength

Simple SCR

Thevenin Impedance Magnitude (pu)	SCC MVA	SCR
0.653507	155.6983	6.227933
1.129373	90.31558	11.28945
0.649164	157.1251	6.285003
0.326675	306.1143	2.448914
0.348464	286.9736	2.452766
0.22936	435.9957	2.62648

GSAT

These tools can support both planning and operations applications

- Study future scenarios and reliability and economic impacts with utilities
- Input or output of operational simulation tools
- How much is needed? How much will I have?

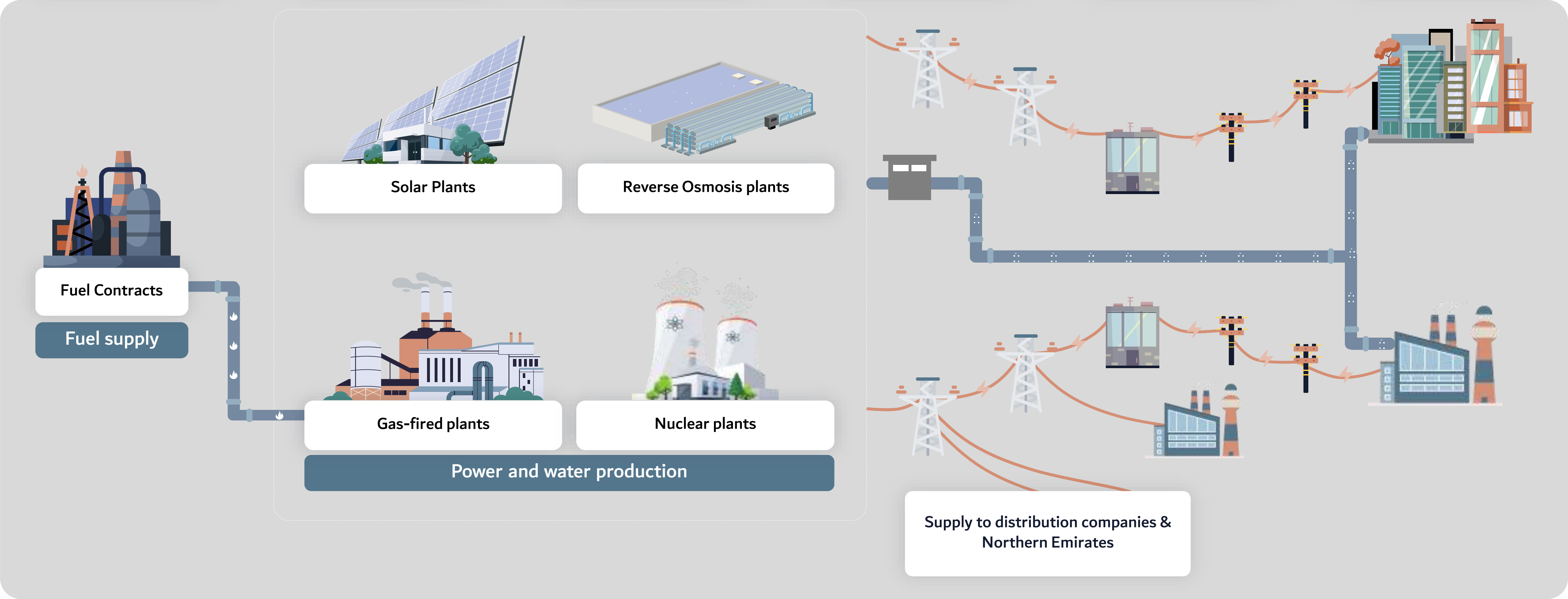
EWEC: Managing the Energy Transition In Abu Dhabi and the Northern Emirates

Dubrovnik

21 October 2022

EWEC’s role has evolved to be an Independent System Operator (ISO+) since January 2022

- Demand forecasting
- System and operational planning
- Capacity Procurement
- Fuel Procurement
- Contract management, payment & settlement
- Scheduling, dispatch & transmission system operation



EWEC partners with 15 plants for the supply of water and electricity across the UAE

Shuweihat S1
101 MGD
1,615 MW

Shuweihat S2
101 MGD
1,627 MW

Shuweihat S3
1,627 MW

Barakah 1 and 2
2 x 1,390 MW

Future:
Barakah 3 and 4
2 x 1,390 MW

Mirfa
53 MGD
1,702 MW

Um Al Nar
95 MGD
2,290 MW

Taweelah A1
84 MGD
1,671 MW

Taweelah RO (early)
100 MGD

Taweelah B
162 MGD
2,220 MW

Future:
Taweelah RO (Full)
200 MGD

Fujairah F1
131 MGD
861 MW

Fujairah F2
132 MGD
2,114 MW

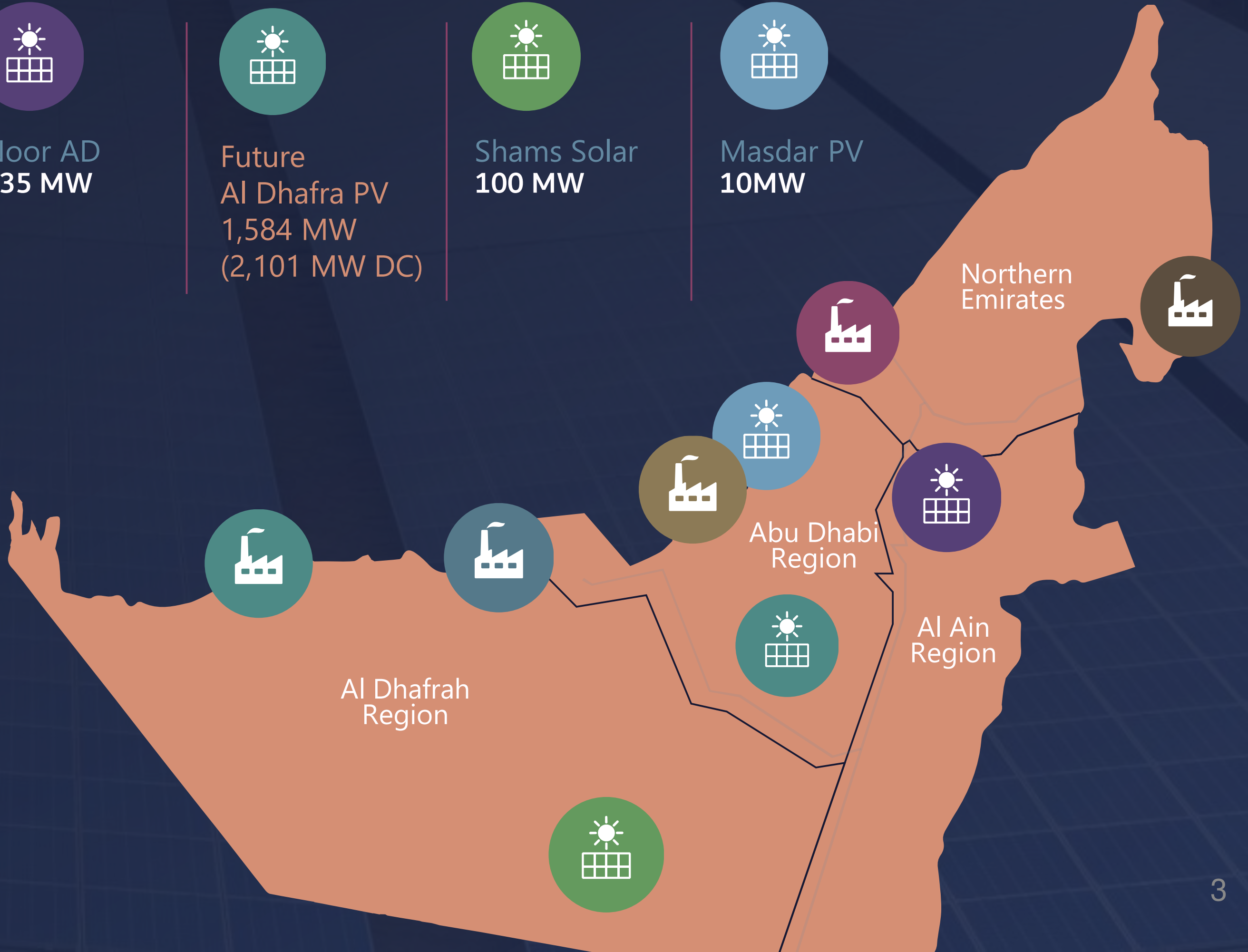
Future:
Fujairah F3
2,457 MW

Noor AD
935 MW

Future
Al Dhafra PV
1,584 MW
(2,101 MW DC)

Shams Solar
100 MW

Masdar PV
10MW



Current market structure results in low risk for project developers and world record low-cost tariffs are offered to EWEC

Competition for the Market but not in it

- Capacity auctions for 20 – 30-year supply contracts
- Payment made for availability and energy supplied (with fuel supplied as a pass-through)
- Technology, size and location of new plants specified
- EWEC's payment default risk underwritten by Abu Dhabi government

Combination of these factors results in low risk for project developers and world record low-cost tariffs offered to EWEC

EWEC Sells to its Bulk Customers

- EWEC is a "not for profit"
- Objective to minimize the cost of supply
- Net Zero by 2050; 60% "Clean" energy by 2035
- Principle customers are the distribution companies
- They pay a "bulk supply" tariff that recovers full cost of supply
- Overseen by an independent Regulator
- EWEC can supply other customers if this results in a reduction in the Bulk supply tariff

With UAE's commitment to Net-Zero, the market structure is evolving

EWEC
Emirates Water & Electricity Co.

Net-Zero commitment requires:

Greater Interconnection

Solar or Nuclear

- If Solar: A lot of land + a lot of storage
- If nuclear: A lot more $$

Both solar or nuclear will require additional grid stability services

Enhancement of Operability Planning capability and integration into Techno-economic planning

Potential UAE Market Evolution

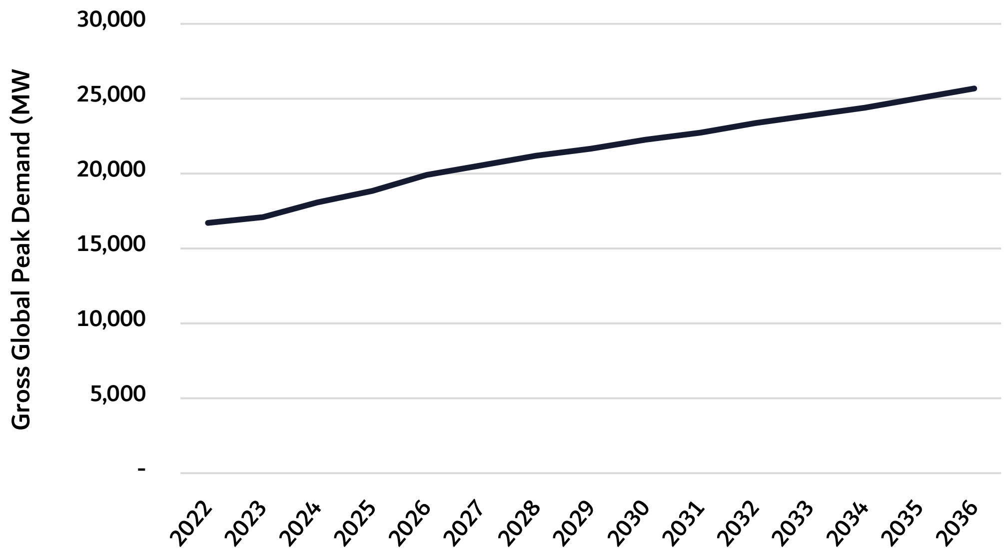
Day ahead market + Capacity Market + Ancillary Services market

Peak power demand is expected to increase by 30% between 2022 and 2029 requiring additional generation capacity

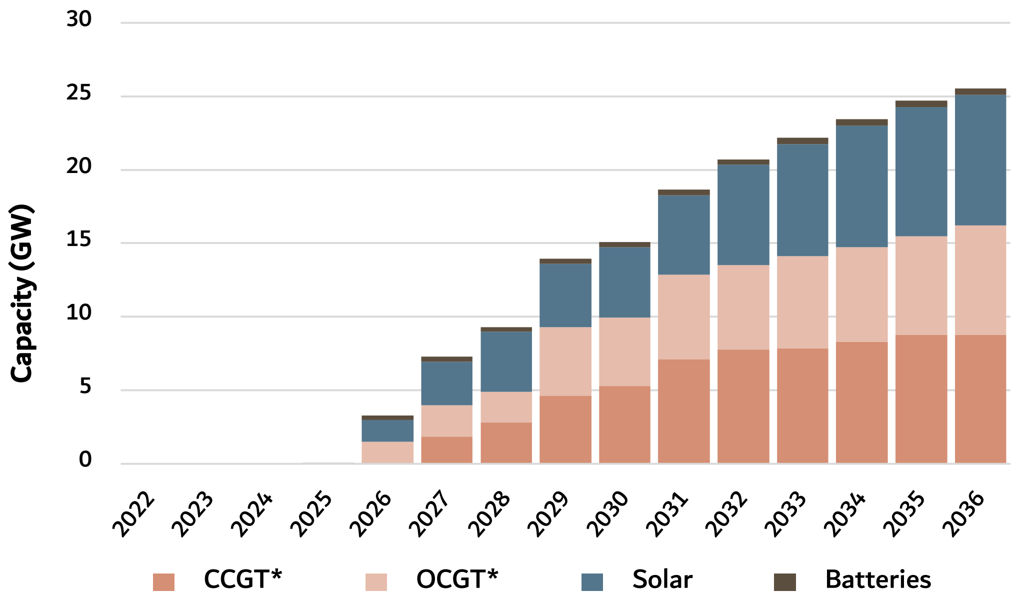
Higher peak demand requires additional thermal and solar generation capacity along with batteries to enhance system reliability

- Thermal: Significant gas capacity (3.9GW) needed in 2026 and 2027 to replace expired PPAs
- Solar: An additional ~5GW of solar PV is recommended by 2030 (Total 7.3GW installed)
- Batteries: 300MW of batteries configured for reserve provision needed by 2026 to enhance system reliability

Peak demand forecast 2022 - 2036

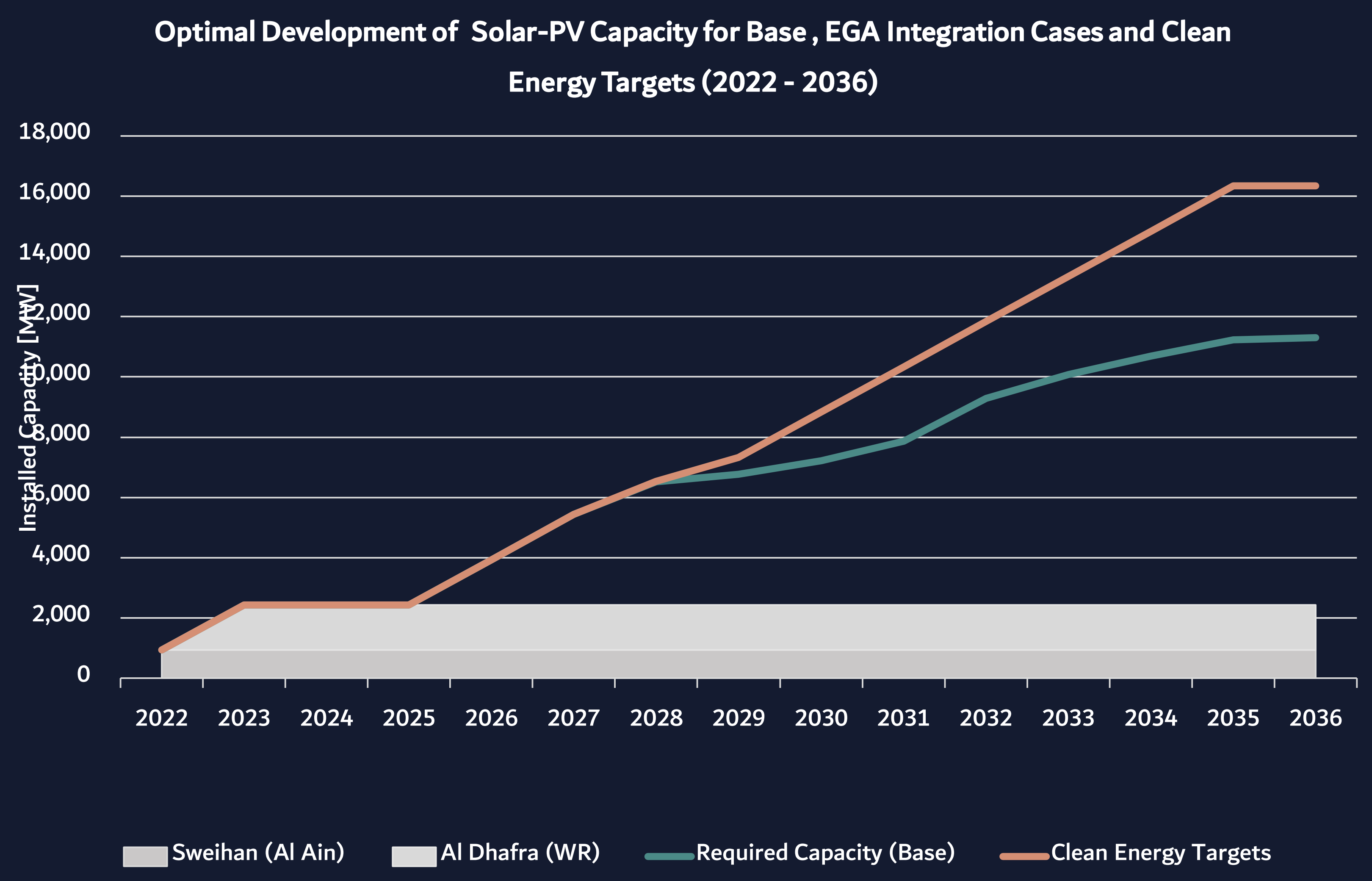


Base Case[1] Capacity Projection, EWEC + EWE (GW – Gross Capacity)



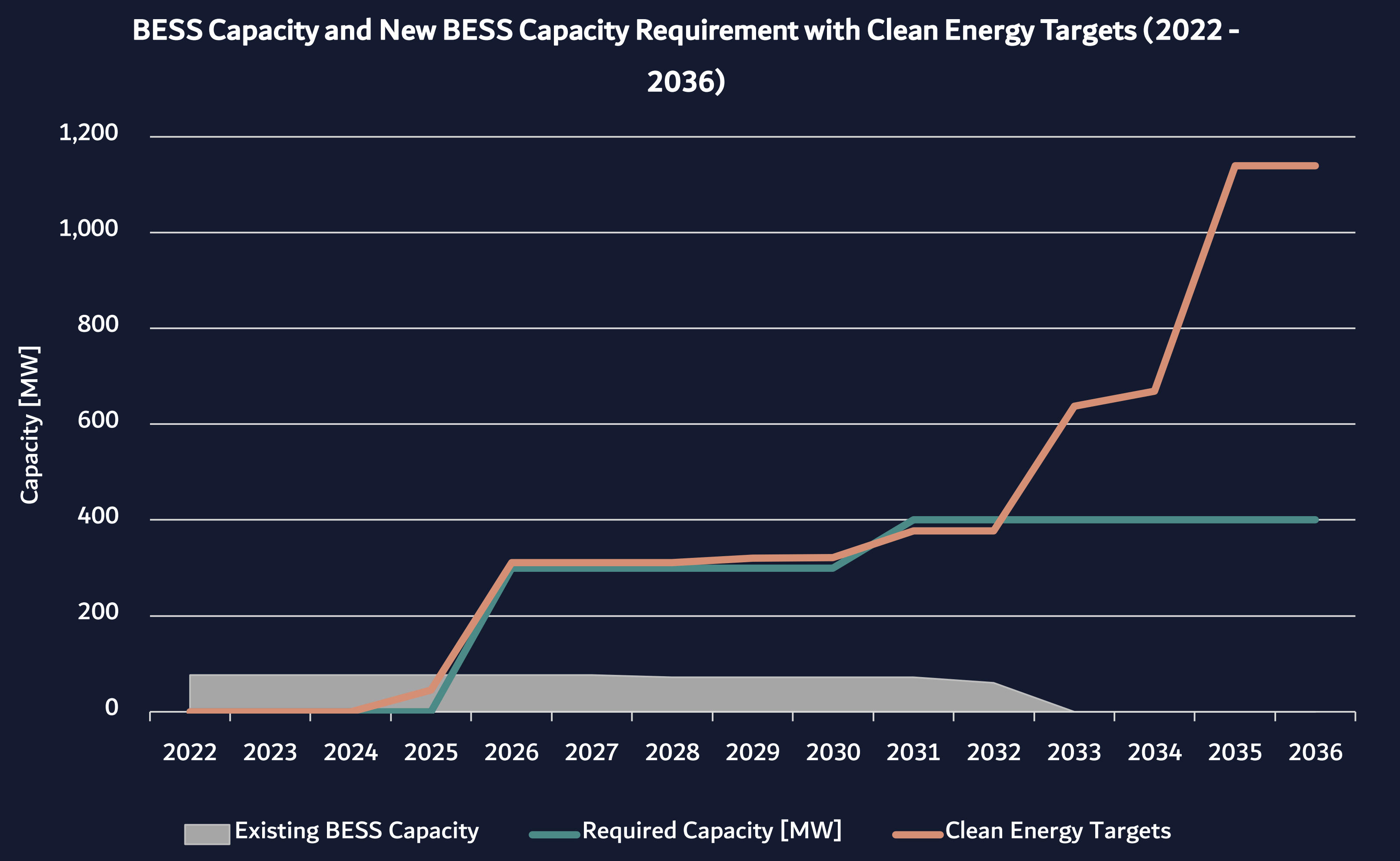
[1]The base case excludes committed capacity (Al Dhafra at 1,500MW and F3 at 2,457MW).
* CCGT and OCGT could be new build or contract extension

A significant amount of solar PV capacity is recommended from 2025 onwards



- By 2030, **the recommended optimal new solar-PV capacity is between c.4.5 - 6GW**. Including the two committed projects at Sweihan PV and PV2 (Al Dhafra) the total solar-PV capacity will reach 7.2 - 8.5GW
- By 2036, following **recent commitment to new Clean Energy Targets** significantly more Solar-PV capacity is recommended bringing the total to between 16-20 GW
- **New Solar-PV capacity is recommended a soon as possible** (assumed by 2026), with further additional Solar-PV capacity entering service in subsequent years

Over 300 MW of batteries are required from 2026 to enhance system reliability



- Battery Energy Storage Systems (BESS) are recommended to provide **primary and secondary reserves**. They provide system cost savings by enabling a higher penetration of low-cost solar PV
- Batteries become **essential for system security** following the commissioning of all 4 nuclear reactors at Barakah and the resulting decline in dispatch of gas generation
- Analysis of a proposal to reconfigure the existing NGK sodium-sulphur battery capacity for reserve provision has indicated that this option is significantly more costly than replacing it with new Li-ion based batteries
- **4 new BESS projects** of a total size 575 MW is recommended between 2026 – 2033
- **Lead to build** new BESS – 3 Years

Combination of evolving market, growing demand and increasing renewables in the energy mix, can lead to system flexibility challenges

Increased Operability Requirements

Curtailment of 17% of total solar energy expected with 16 GW of solar in a 25 GW system

Active dispatch of solar capacity including the provision of grid flexibility services will be essential

Specification, delivery and management of grid flexibility services needed

Increased interconnection – larger systems. Dubai, Oman, Saudi / GCCIA

Getting from low carbon to no carbon will require the integration of lower cost storage + control solutions with solar that are not currently available:

- People
- Systems
- Technology / cost

EWEC's ISO+ market model provides a flexible framework for managing changes in portfolio composition and identifying operability challenges

Flexible market model	EWEC's ISO+ market model provides a flexible framework for: • Managing a rapid change in portfolio composition • Identification of Operability Challenges and specification, delivery and management of grid flexibility services needed
Clean energy targets	60% clean energy by 2035 will require the system to produce ~60% of energy from solar during daylight hours in addition to the nuclear baseload contribution
Increased interconnection	Increased interconnection will be needed– larger systems (Dubai, Oman, Saudi / GCCIA)
Transition to "no" carbon	Transition from 'low carbon' to 'no carbon' will require a major transformation in the portfolio composition, human capabilities, systems and processes
Technological challenges	The integration of lower cost storage + control solutions with solar that are not yet available

EWEC

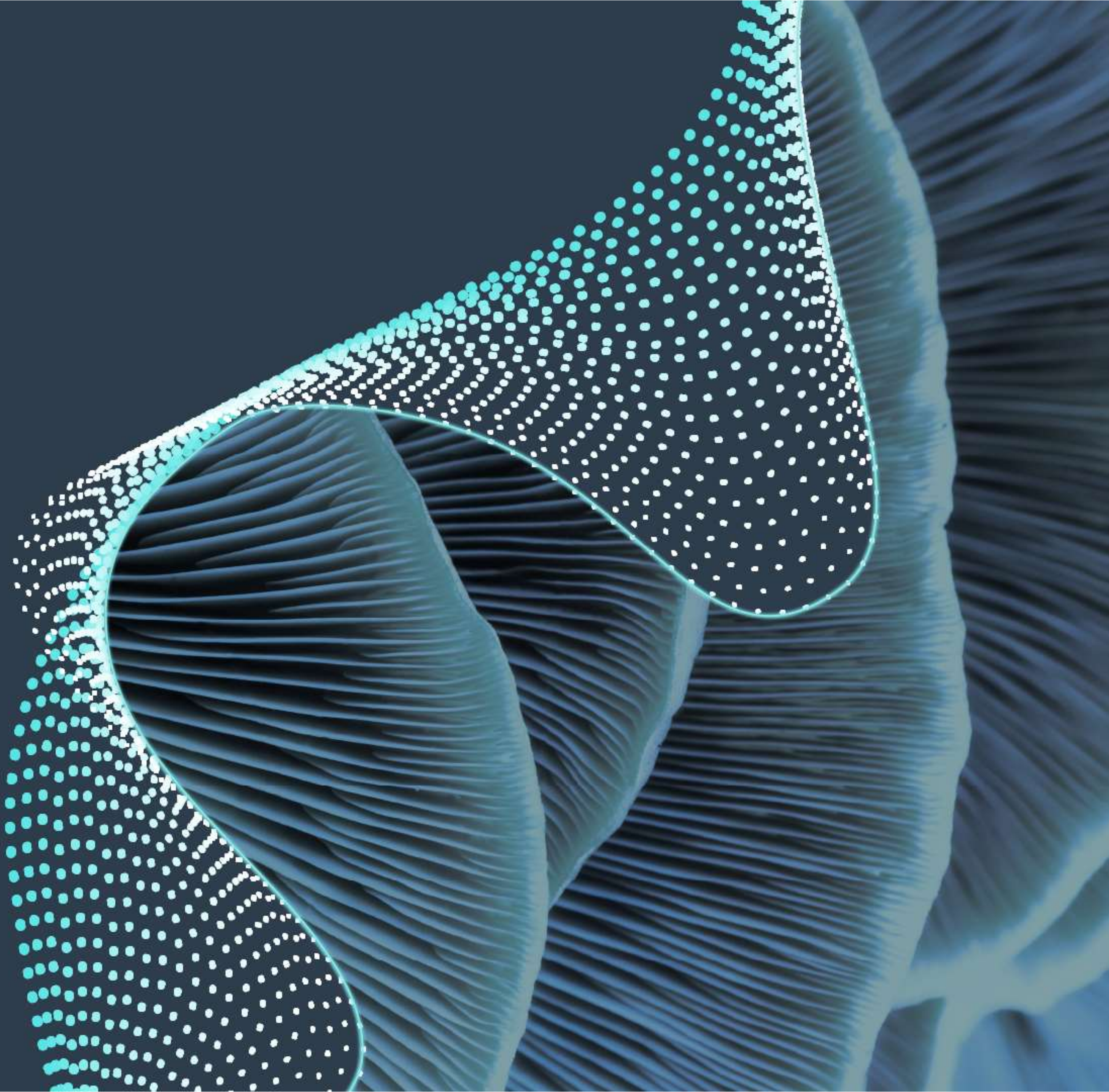
Emirates Water & Electricity Co.

www.ewec.ae

NEOM ENERGY AND WATER

INTRODUCTION TO ENERGY FLEXIBILITY

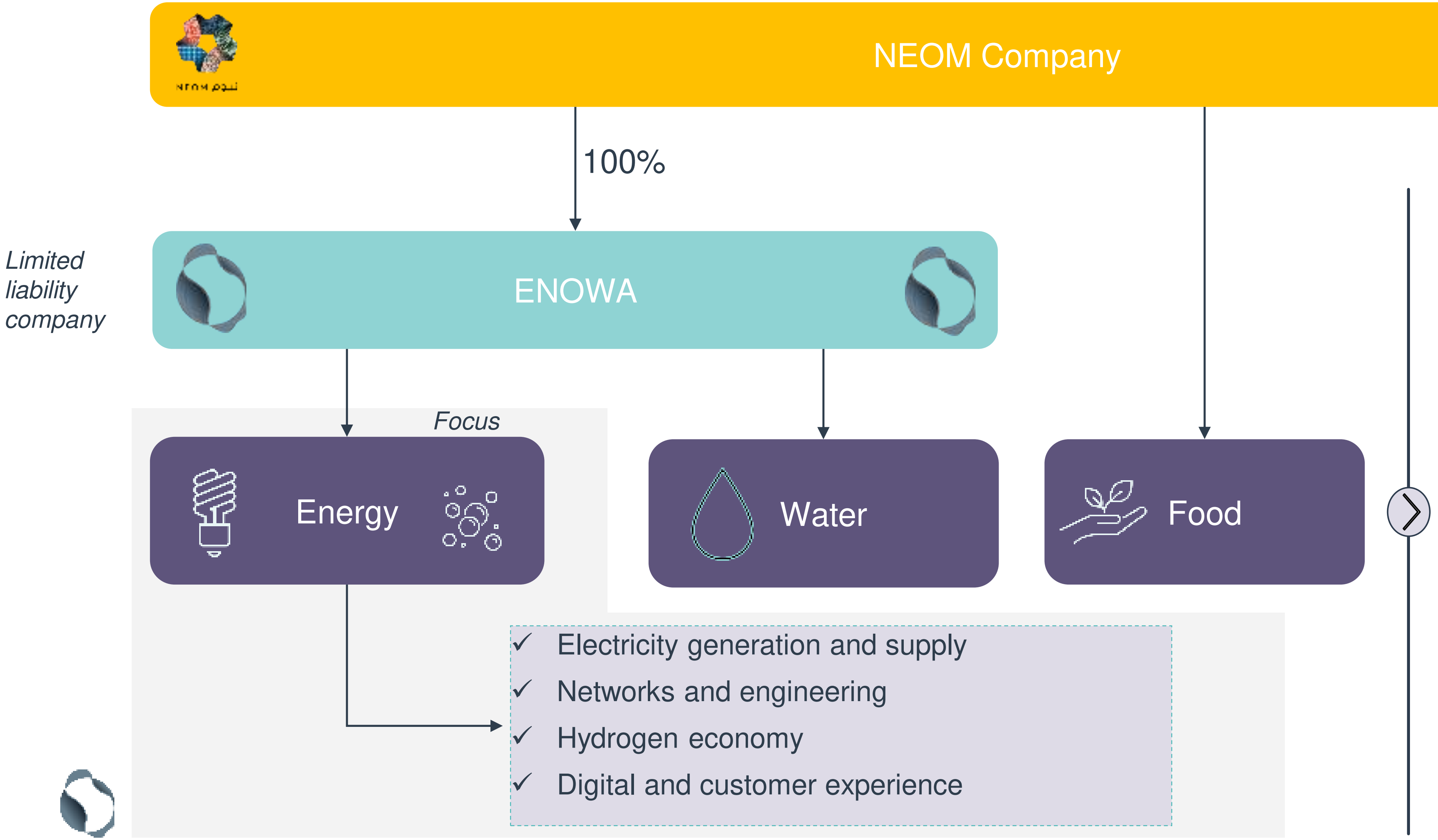
OCTOBER 2022



- Who is ENOWA Energy Flexibility?
- What challenge are we trying to solve?
- What is flexibility and how does it help?
- What are the sources of flexibility?
- What is the value of flexibility?
- How is NEOM planning to enable?

ENOWA –NEOM ENERGY AND WATER COMPANY

INCORPORATED IN DECEMBER-21 AS A 100% SUBSIDIARY OF NEOM COMPANY WITH ITS OWN BOARD AND STRATEGY



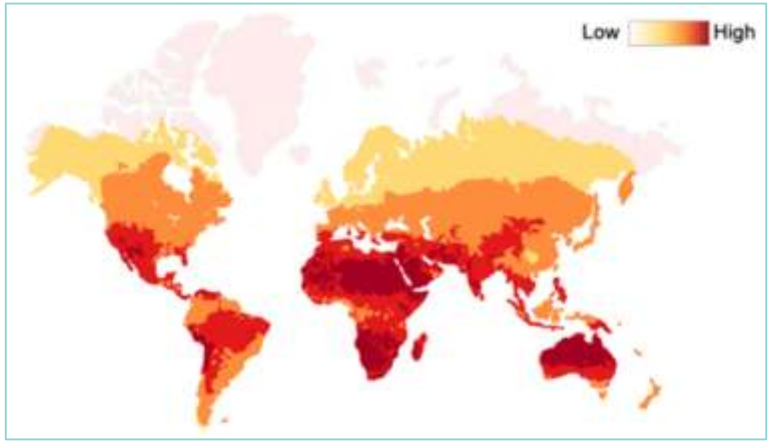
<u>Mission</u>

PARTNERING WITH NATURE TO CREATE SUSTAINABLE ABUNDANCE OF LIFE’S BASIC ELEMENTS

NEOM HOSTS AN UNRIVALED COMPLEMENTARY WIND & SOLAR PROFILE

Highest wind speed regions, m/s

Highest solar radiation regions, kWh/m²



Regions with high joint wind speed and solar radiation[1]

★ Exemplary regions with favourable wind and solar PV conditions

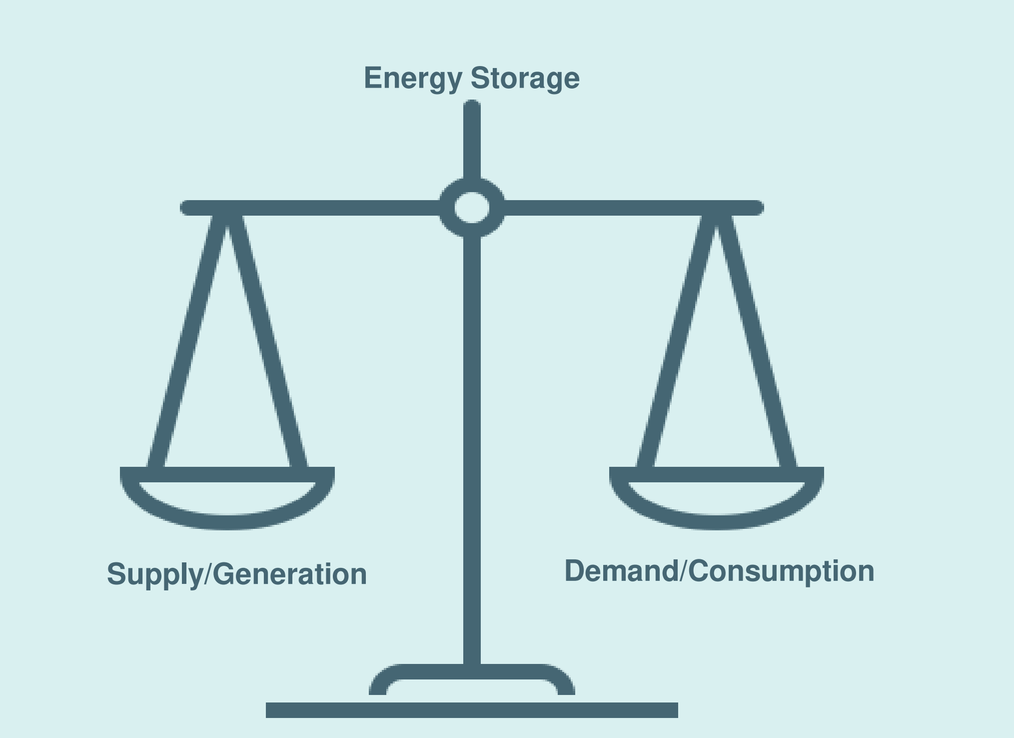
NEOM's complimentary solar and wind profile enables a value proposition of low cost 100% renewable power

[1] Map is a graphical combination of the two maps on the left

SOURCE: NEOM Energy and Water Team, IRENA, Meteonorm

THE FUNDAMENTALS OF POWER SYSTEM ECONOMICS AND AVAILABLE CLEAN TECHNOLOGIES MAKES ACHIEVING LOW TOTAL SYSTEM COST IN A 100% RENEWABLE SYSTEM A CHALLENGE

The Power Balancing Law



Electricity generation must equal demand for every second to maintain system stability

Supply/Generation

- **Intermittency:** Wind and solar are variable and weather dependent
- **Profile:** Times of available generation does not match times of peak consumption

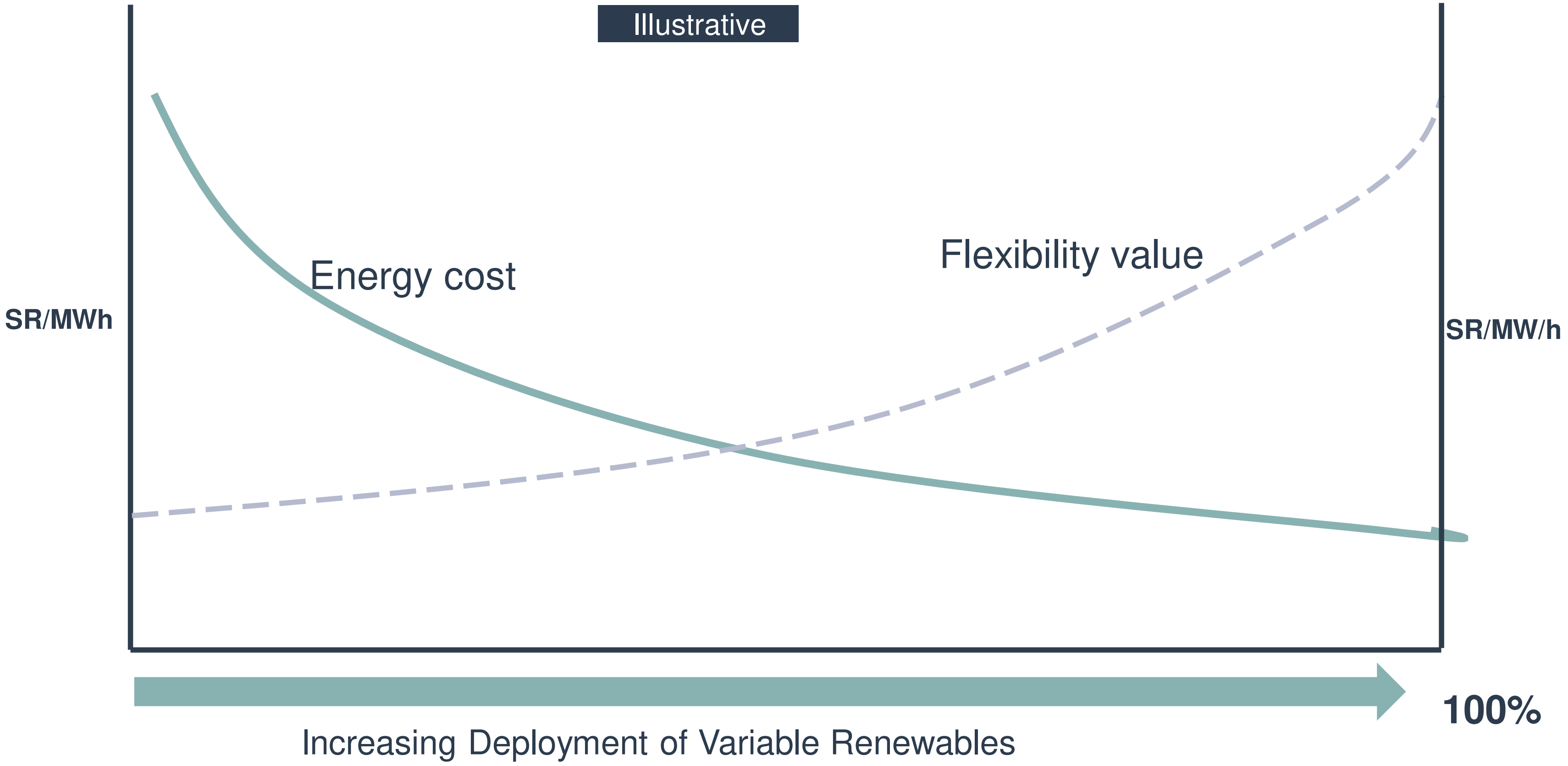
Demand/Consumption

- **Behaviour/Comfort:** Use energy when and how they want.
- **Opportunity cost:** Need for business to plan for core value propositions

Energy Storage

- **Cost:** Storing energy for long periods is difficult and still expensive
- **Resource:** Geographic, and resource constraints make some proven technologies challenging

THE MAIN IMPLICATION OF THE POWER BALANCING LAW GIVEN THE OPPORTUNITIES AND CHALLENGES OF A 100% RENEWABLE GRID IS THE HIGH COST OF "FLEXIBILITY"



Energy relates to generation costs and excludes additional cost for transport, distribution and losses.

Flexibility is inclusive of short-term balancing, ancillary services and energy profiling/shifting costs.

WHAT IS POWER SYSTEM FLEXIBILITY?
International Energy Agency

‘Power system flexibility is one aspect of power system transformation (PST). It is the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of supply and demand across all relevant timescales.’

Different timescales of flexibility for power system operations and planning

Ultra-short term (sub-seconds to seconds)	Very short-term (seconds to minutes)	Short-term (minutes to hours)	Medium-term (hours to days)	Long-term (days to months)	Very long-term (months to years)
Dynamic stability (inertia, grid strength)	**Primary/ Secondary Frequency Response**	**Balancing real time market / regulation**	**Hour-ahead to day-ahead operations**	**Scheduling adequacy for specific weather**	**Power system planning / seasonal adequacy**

0.1s **secs** **mins** **hours** **days** **months** **years**

Source: International Energy Agency. Status of power system transformation 2018: Advanced power plant flexibility [Internet] Paris: IEA. 2018

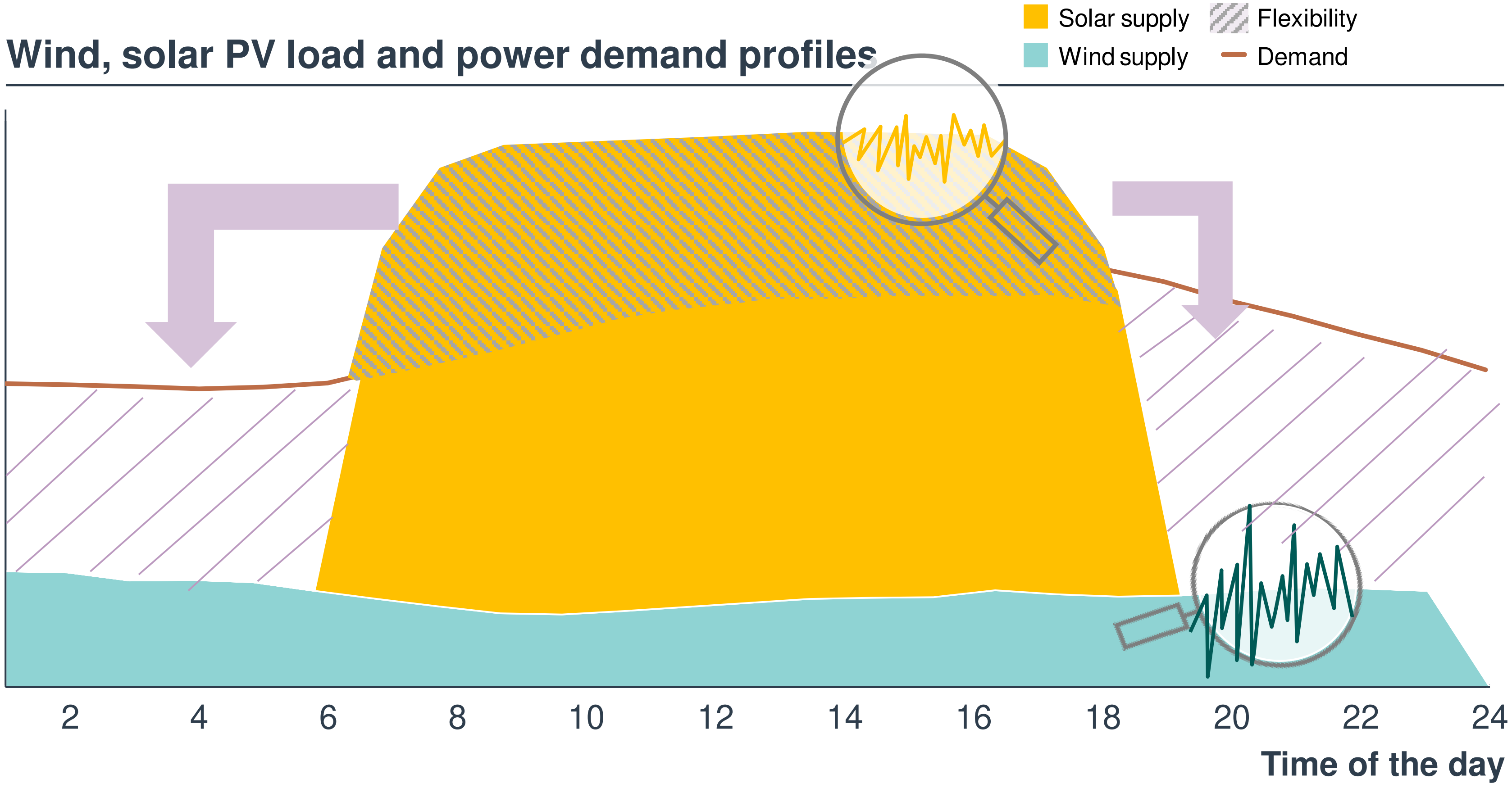
FLEXIBILITY IS INTRINSIC TO THE MANAGEMENT OF ENERGY SYSTEMS AND HAS A VARIETY OF APPLICATIONS

APPLICATION	PURPOSE
Frequency and Voltage Regulation	Maintaining system frequency (50/60Hz) and voltage in safe operating conditions
Energy Shifting	Deferring consumption and/or generation to optimal period for energy balancing , price arbitrage and/or avoiding curtailment
Congestion and Constraints	Deferring significant investments in grid infrastructure and/or offering short term relief to overloaded grid systems
Stability and Other Ancillary services	Ensuring resilience and stability of the grid system by maintaining inertia and planning for the underlying physics of the grid

SUPPLY / DEMAND BALANCING

RENEWABLE BASED SUPPLY FLUCTUATE ACROSS TIMESCALES AND CHANGES IN WEATHER MAKING IT DIFFICULT TO MATCH DEMAND WHEN IT IS NEEDED AND REQUIRES STORAGE AND SYSTEM FLEXIBILITY

Wind, solar PV load and power demand profiles



Even though load profiles and power demand are generally presented as average, actual load and demand includes continuous fluctuation

Solar PV capacity **only available during the day, while wind capacity is** more stable and is **available continuously throughout the 24h**

During the day, power consumption peaks are driven in part by

- **Temperature differential** increasing **cooling load** and,
- Increased **economic and social activity**

Additionally, **seasonal temperature changes drive different consumption profiles**

Solar-Charged Li/PHS can provide Off-peak supply at >2-3X cost of wind

Customers carry the responsibility of optimizing the trade-off of cost & time-of-use objective with min intrusion from utility

Source: NEOM wind, solar and demand profiles

NEOM EXPECTS TO INVEST IN FLEXIBILITY FROM MULTIPLE SOURCES TO DIVERSIFY RISK AND KEEP COST DOWN FOR THE CONSUMER

SUPPLY FLEXIBILITY

Dedicated Flexibility Assets

- Battery energy storage
- LDES*
- Clean gas turbines and reciprocal engines

Regional Interconnection

- HVDC

DEMAND FLEXIBILITY

Infrastructure Co-optimisation

- Power and water co-optimisation
- District Cooling Demand
- Electric mobility

Demand Response

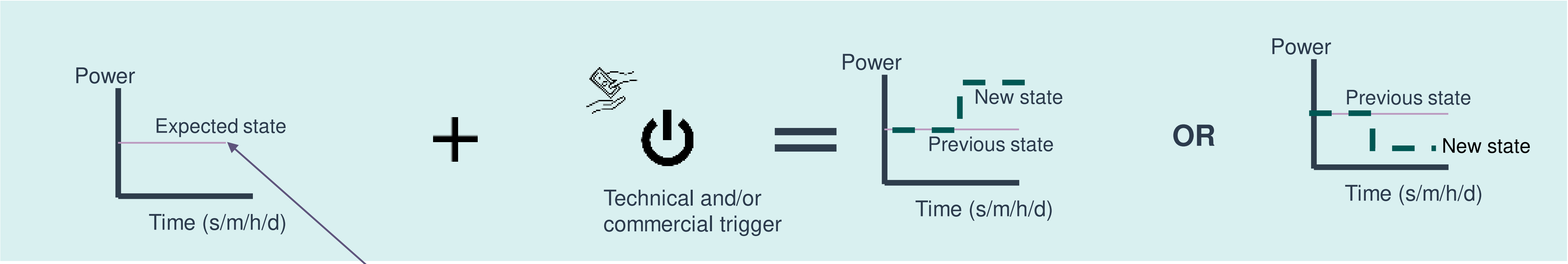
- Residential Demand
- Commercial Demand
- Industrial Demand

*Long duration energy storage (including pumped hydro storage)

HOW DOES FLEXIBILITY APPLY IN ENERGY SYSTEMS

‘The ability of an energy asset to effect a change in active/reactive power at a unique measurable point in the grid and sustain this for a predefined period based on a trigger’

EXISTING STATE **TRIGGER** **END STATE**

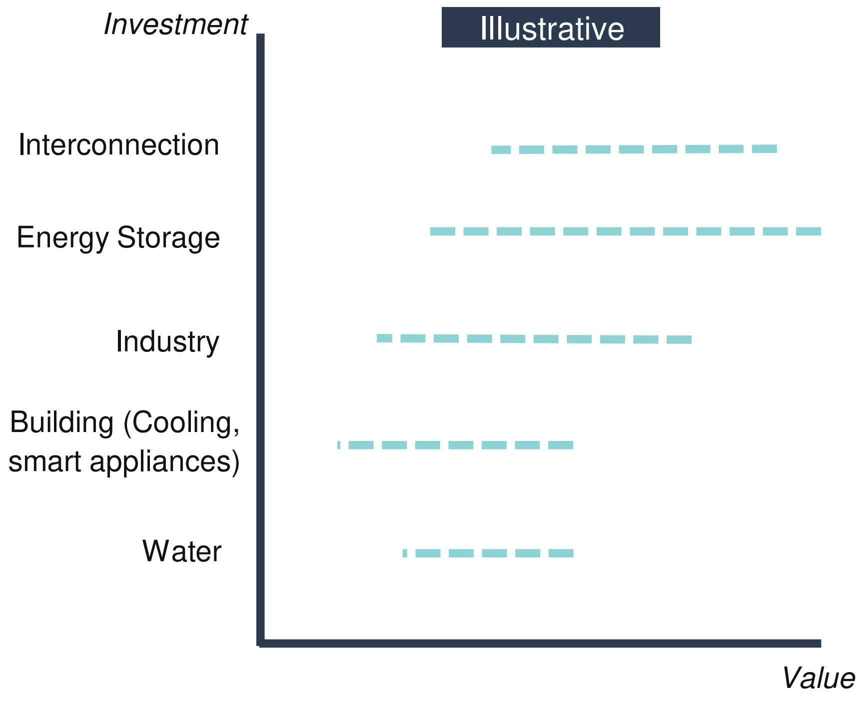


Baseline assumptions for existing/expected states are used to measure flexibility response. Baselining can be challenging with possible market gaming

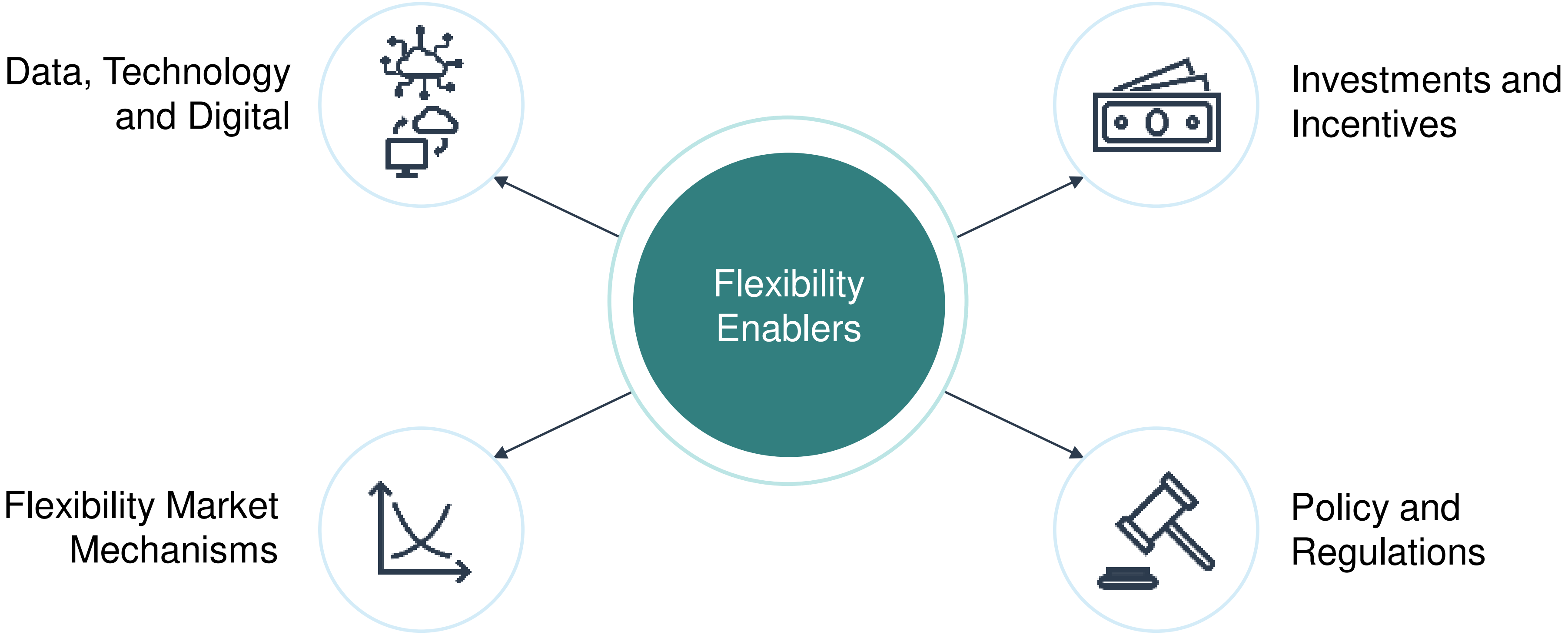
FLEXIBILITY IS CHARACTERIZED BY KEY DRIVERS THAT HELP DETERMINE VALUE TO THE POWER SYSTEM WHICH WILL ENABLE NEOM TO ASSESS THE OPTIMAL MERIT ORDER OF INVESTMENTS

Flexibility Characteristic	Value Driver
Speed of Response	The faster the better
Depth of Response	The bigger the better
Duration of Response	The longer the better
Location of Response	The nearer the better
Opportunity Cost	The lower the better

Flexibility Investment vs Value Merit Order



NEOM INTENDS TO UTILIZE A VARIETY OF LEVERS TO ENABLE FLEXIBILITY IN ITS GRID FOR THE LONG TERM

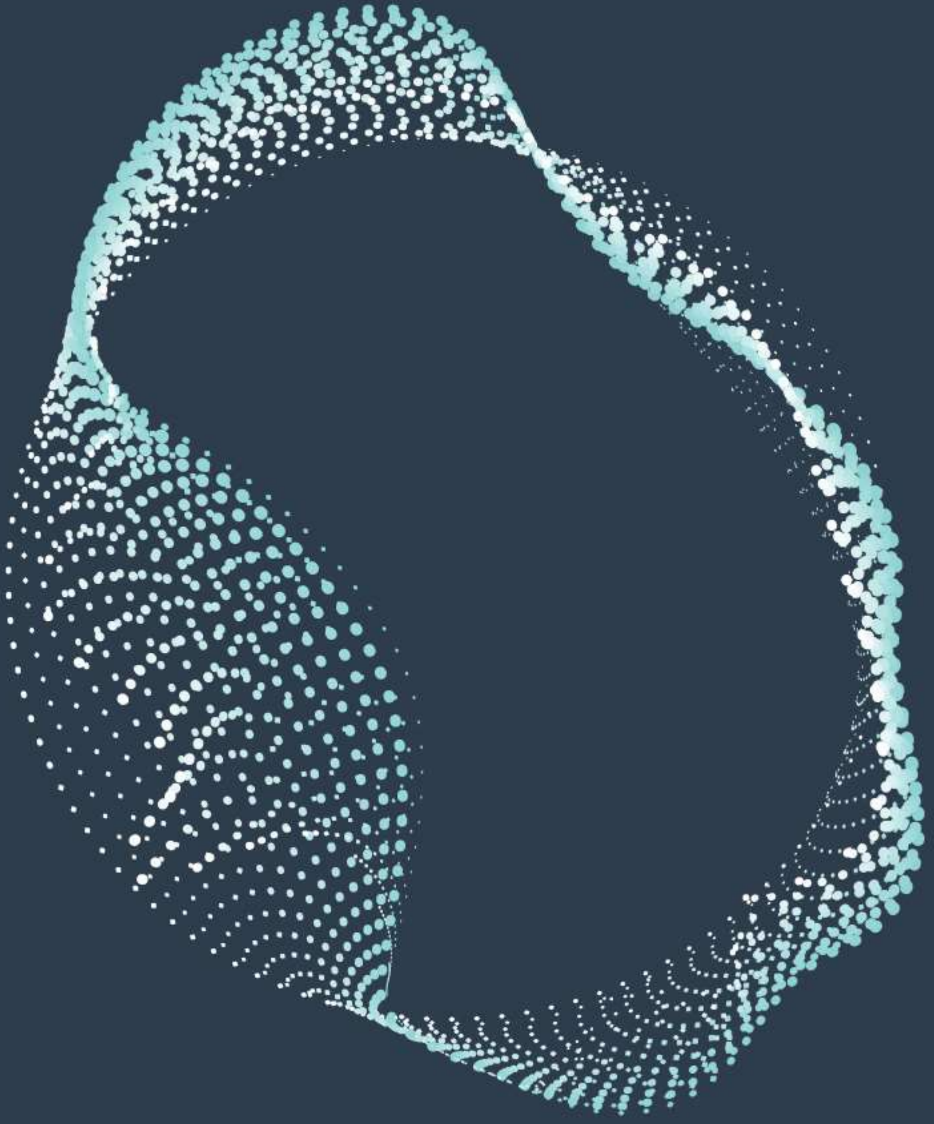


THANK YOU

FRANCK BERNARD

DIRECTOR FLEXIBILITY
CERTIFICATES – NEOM

franck.bernard@neom.com



Importance of Flexibility in a Changing Resource Environment

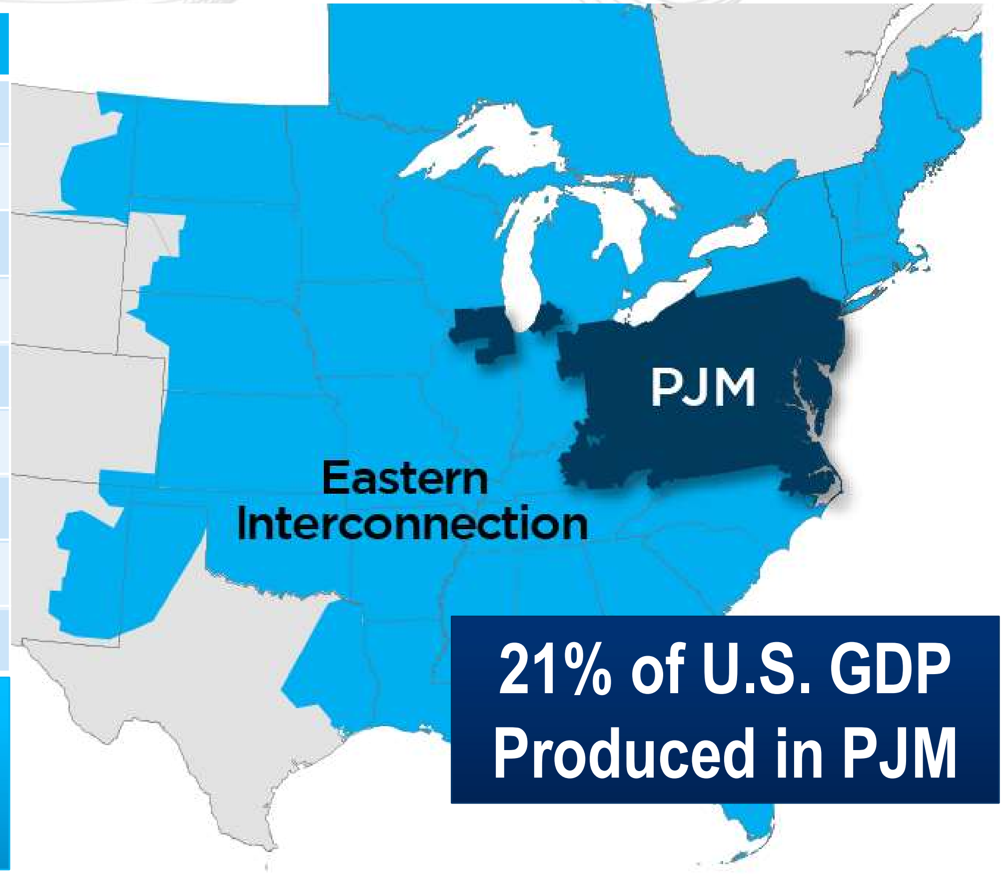
APEx October 2022

Tim Horger
PJM Interconnection L.L.C.
Senior Director, Forward Market Operations & Performance Compliance

PJM as Part of the Eastern Interconnection

Key Statistics	
Member companies	1,060+
Millions of people served	65
Peak load in megawatts	165,563
Megawatts of generating capacity	185,442
Miles of transmission lines	85,103
2020 gigawatt hours of annual energy	782,683
Generation sources	1,436
Square miles of territory	368,906
States served	13 + DC

- 26% of generation in Eastern Interconnection
- 25% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

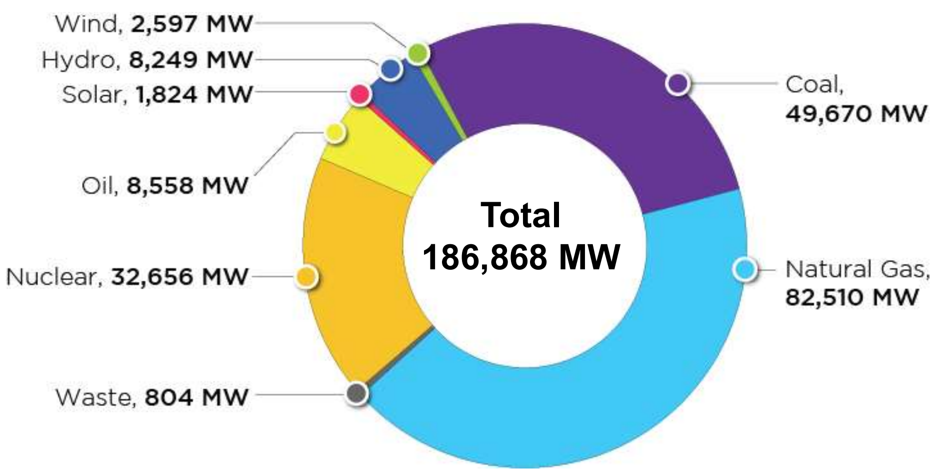


21% of U.S. GDP Produced in PJM

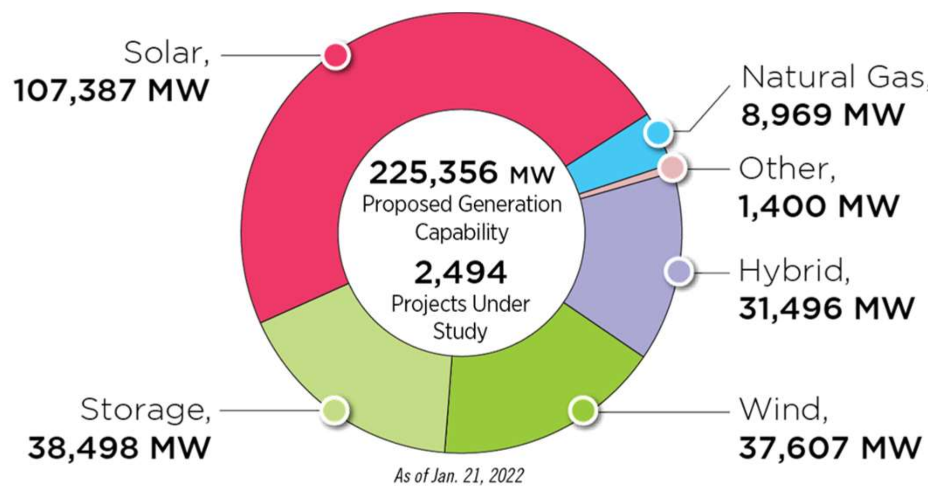
As of 2/2022

PJM Today and Tomorrow - Changing Fuel Mix

PJM Existing Installed Capacity Mix



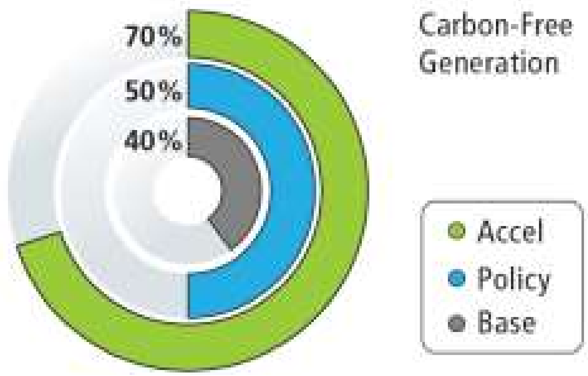
Current Interconnection Queue

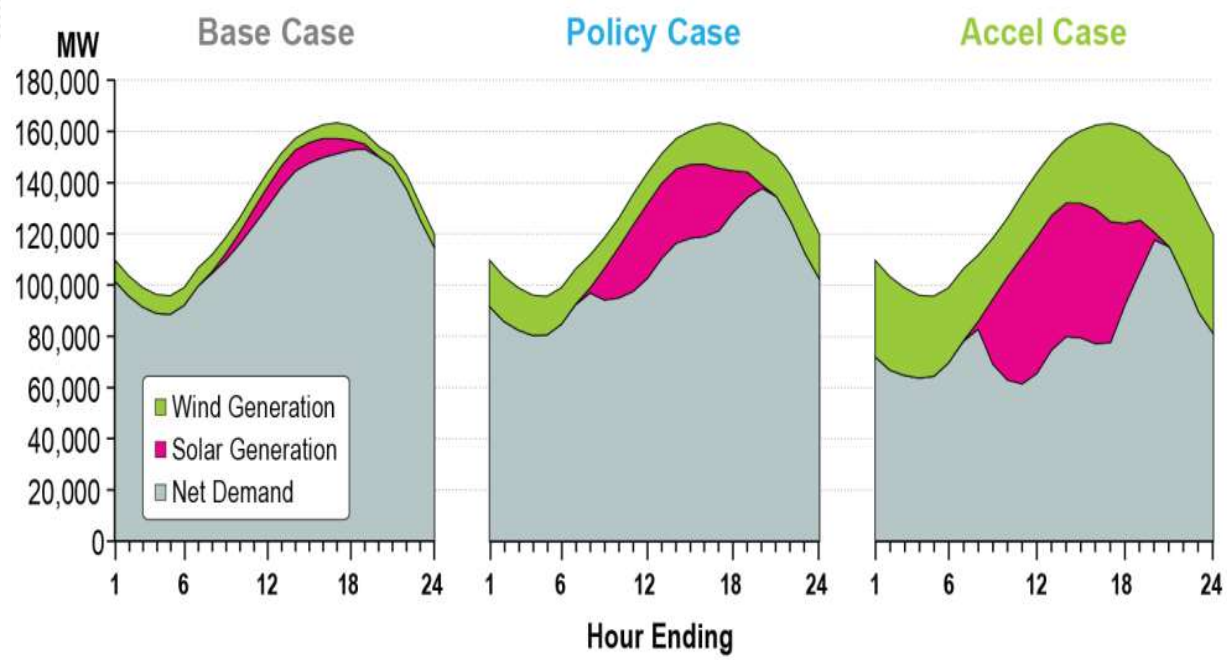


Key Point: Significant shift to cleaner resources is expected in PJM Region.

PJM Study - Importance of Flexibility

Annual Assumption of PJM Energy from Carbon-Free Resources





Key Point: The peak load level and ramping needs shifts with an increase in renewables.

Flexibility is the ability for a resource to quickly, accurately and predictably:

- **change output/consumption in response to a signal, and/or**
- **come online/offline in response to a signal.**

Flexible Resources	Inflexible Resources
• Thermal • Pumped Hydro • Demand Response • Storage/Hybrid	• Solar • Wind

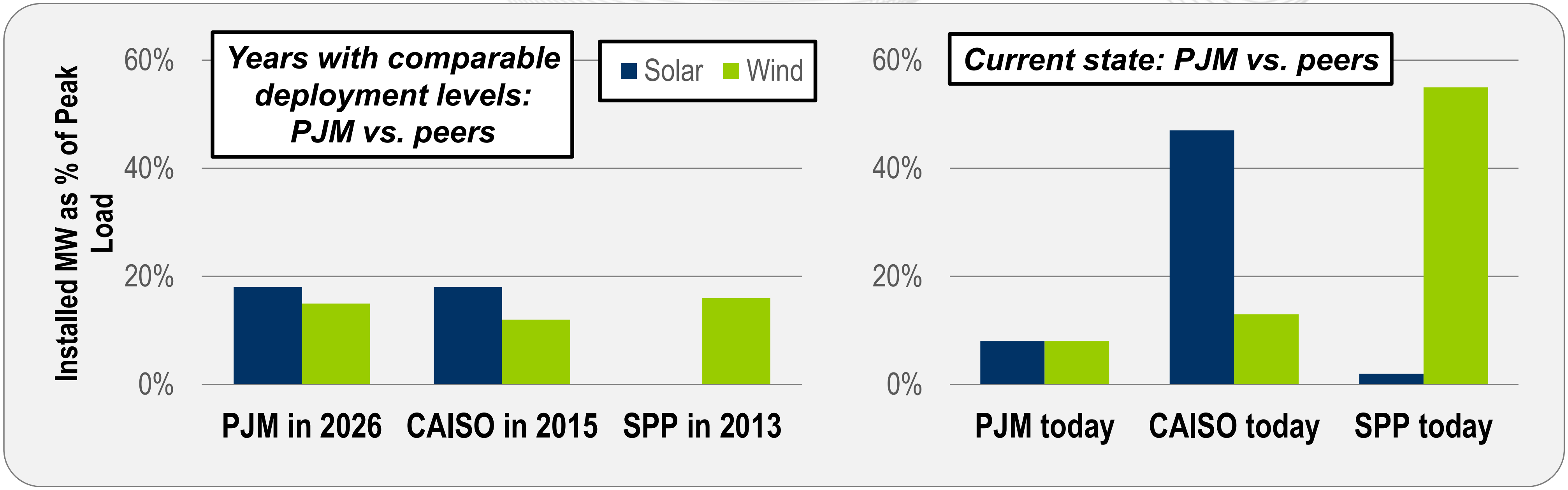
Important for Reliability → Flexible Resources

Important for Environment → Inflexible Resources

Lower Costs

Key Point: Maintaining Incentives for Flexibility is critical as resource mix shifts

Where is PJM compared to peers?



Key Point: PJM has time for preparing for the resource shift and can learn from others

Solutions?

Optimization of storage schedules

Up and Down Regulation signals (minimizes min gen impacts)

Resource flexibility requirements

Demand Response

Enhance interaction of wind and solar forecast/bids/curtailment with constraint management

Sloped Reserve Demand Curves

Regulation for wind/solar

Intraday unit commitment: more frequent updates, more granular

Other Ideas?

New Technologies

Research

Enhance forecasting

Derate renewables with higher deployment

Flexibility & Resilience

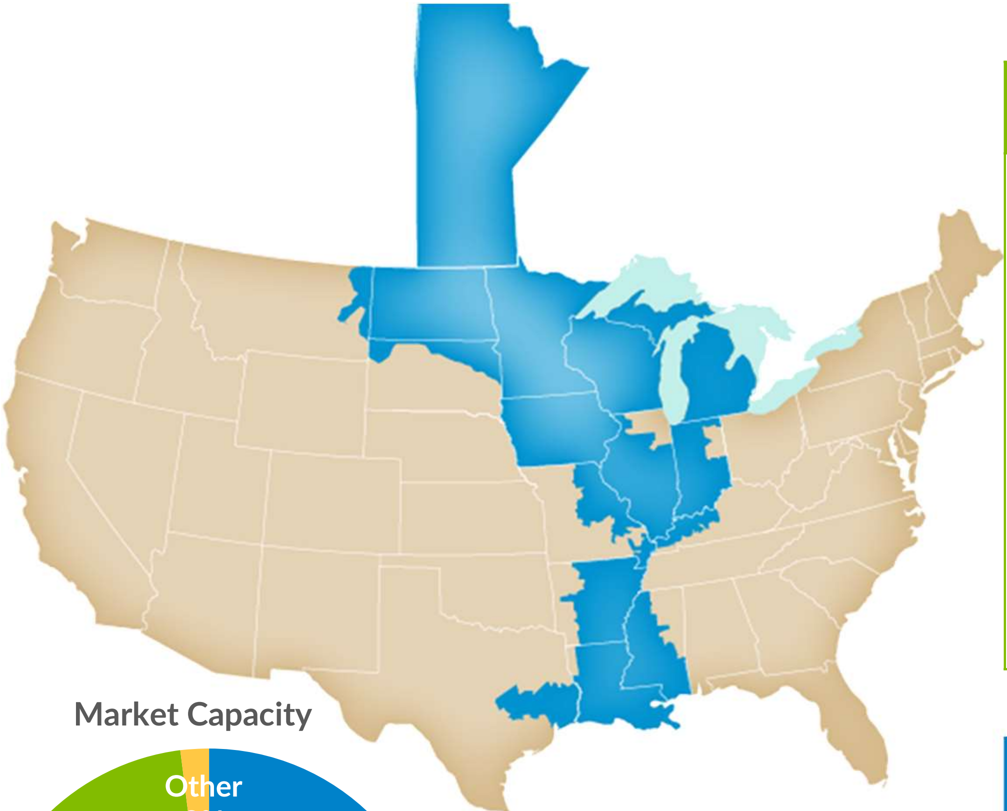
APEX

Wayne Schug

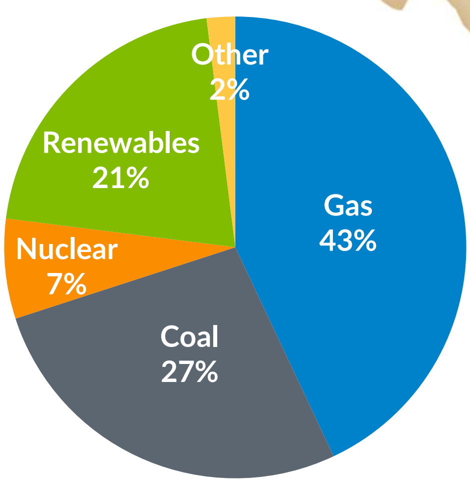
MISO

October 21, 2022

MISO is an independent, not-for-profit Regional Transmission Organization serving 15 U.S. states and one Canadian province



Market Capacity



What we do

- Provide independent transmission system access
- Deliver improved reliability coordination through efficient market operations
- Coordinate regional planning
- Provide a platform for wholesale energy markets

MISO by the numbers*

High Voltage Transmission	65,800 miles**
Generation Capacity	205,177 MW
Peak Summer System Demand	130,917 MW
Customers Served	42 Million

*As of June 2022
**72,000 including Manitoba

Executive Summary

- Aggressive decarbonization strategies and accelerated policies are driving rapid change in our region
- As the evolution of the resource fleet accelerates, variability is increasing, and attributes required to reliably operate the system are diminishing
- Traditional methods (e.g., static reserve margins) used to ensure resource adequacy do not capture the emerging dynamic fleet risks
- Policymakers and the financial community are not supporting the required investment in controllable resources to manage the transition
- We must develop a coordinated transition plan to reliably navigate from the present to the future

MISO

The MISO Region's accelerated resource transformation is creating a future that is both more complex and less predictable

Past

- Primarily controllable resources
- Ample reserve margins
- Predictable resource outages
- Relatively predictable weather
- Focus on providing energy in *the worst peak load hour* during the summer

Present

- Transitioning resource mix
- Tightening reserve margins
- Less predictable resource outages or unavailability
- Growing uncertainty in weather conditions
- Greater inter-dependence between utilities, states, and RTOs
- Focus on providing energy on *the worst day in each season*

Future

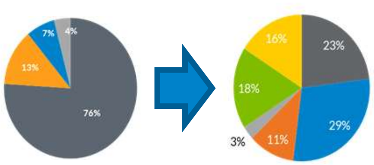
- Primarily weather-dependent resources
- Risk-adjusted reserve margin requirements
- Less predictable resource outages or unavailability
- Less predictable weather
- Increasing scarcity of essential reliability attributes
- Increasing electric load
- Increasing importance of accurate load and renewable forecasting
- Focus on providing energy for *the worst week in each season*

To maintain reliability during the energy transition, MISO must understand what changes are coming (and when), understand the implications of the changes and prioritize work to both influence and prepare for the changes

Policy Drivers

- Environmental regulations
- Federal policy (IRA, DoE)
- Wall Street criteria
- State and large customer goals

Utility Fleet Changes



MISO Models – In Order to Understand and Communicate Coming Change

Pace of Change

- Regional Resource Assessment
- MISO Futures
- OMS-MISO Survey
- Interconnection Queue
- Retirements

External Factors

- Increasing weather risks
- Technology Change

Impact of Aggregate Changes

- Renewable Integration Impact Assessment (RIIA)
- Resource Adequacy
- Other Attributes

MISO's Response: Reliability Imperative

Long Range Transmission Planning
Enable fleet change

Market Redefinition
Enables development and operations of reliable fleet

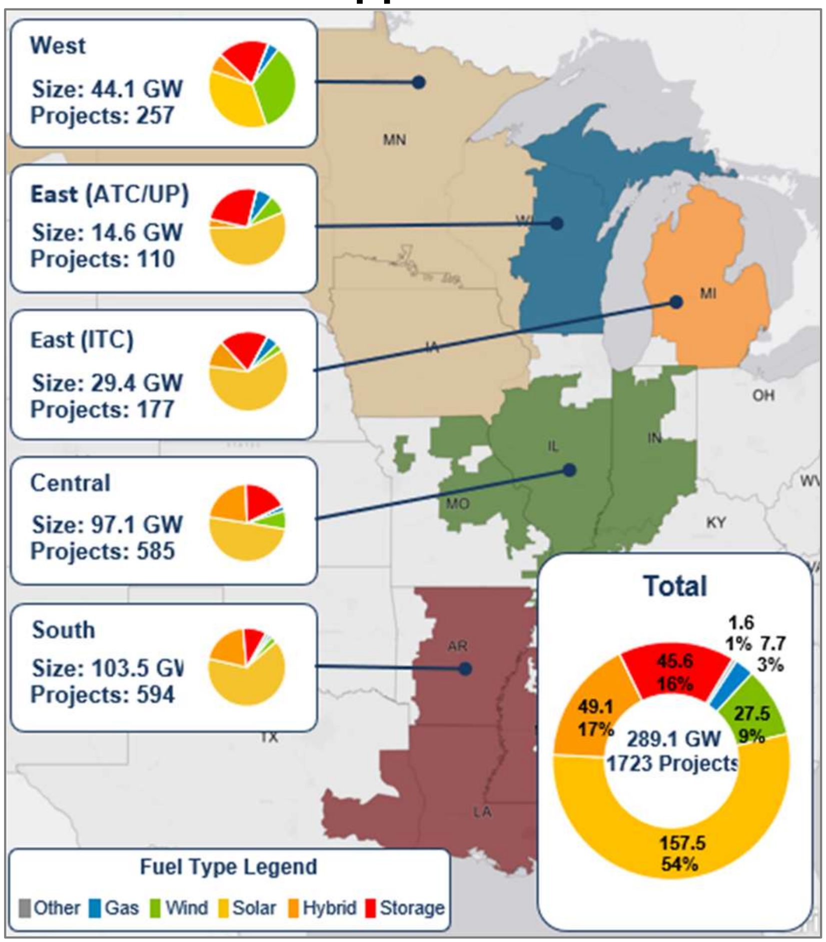
Operations of the Future
Monitors and reacts to reliability needs of the changing fleet

Market System Enhancements
Enables Market Redefinition and Operations of the Future

MISO's 2022 interconnection queue reveals continued growth in renewable resources, growth in limited duration storage resources, and relatively few resources with long duration dispatchability

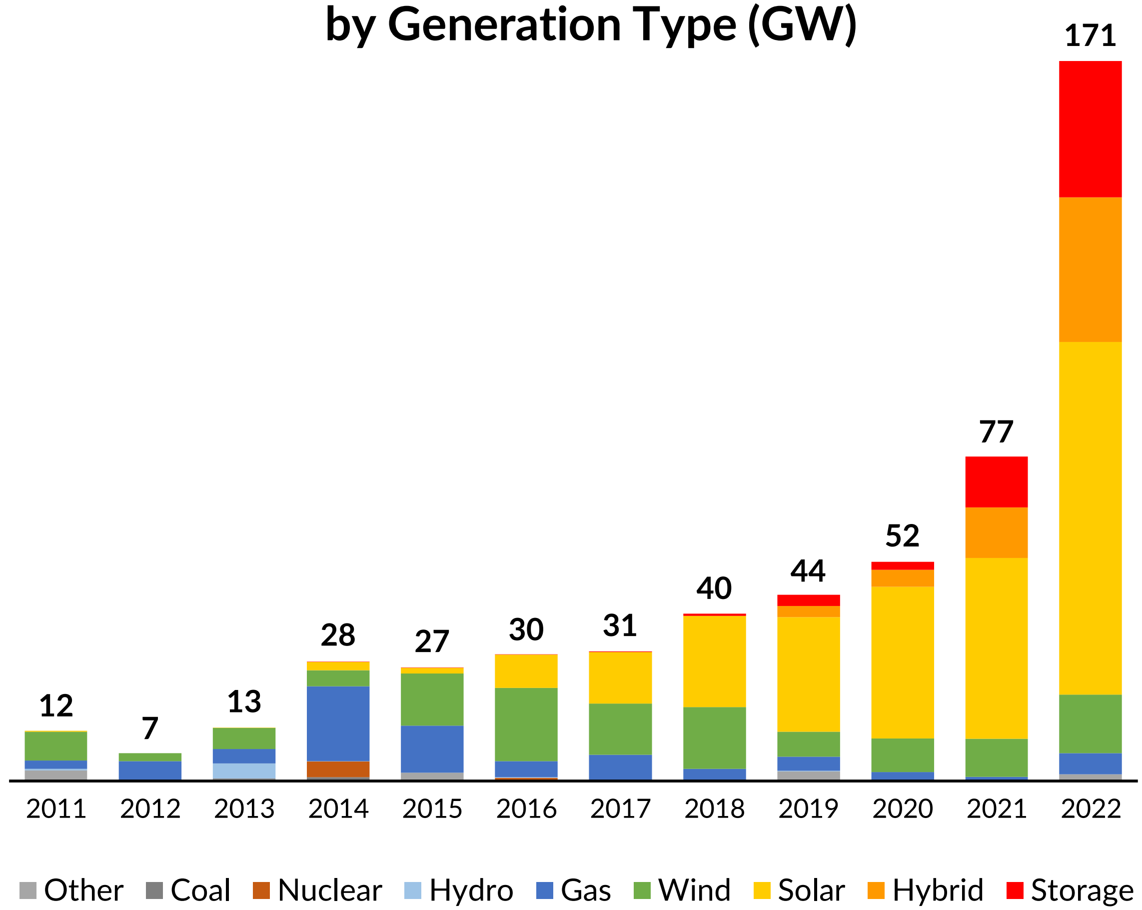
NOTE – All values shown in Nameplate Capacity

MISO Active Queue plus 2022 Applications*



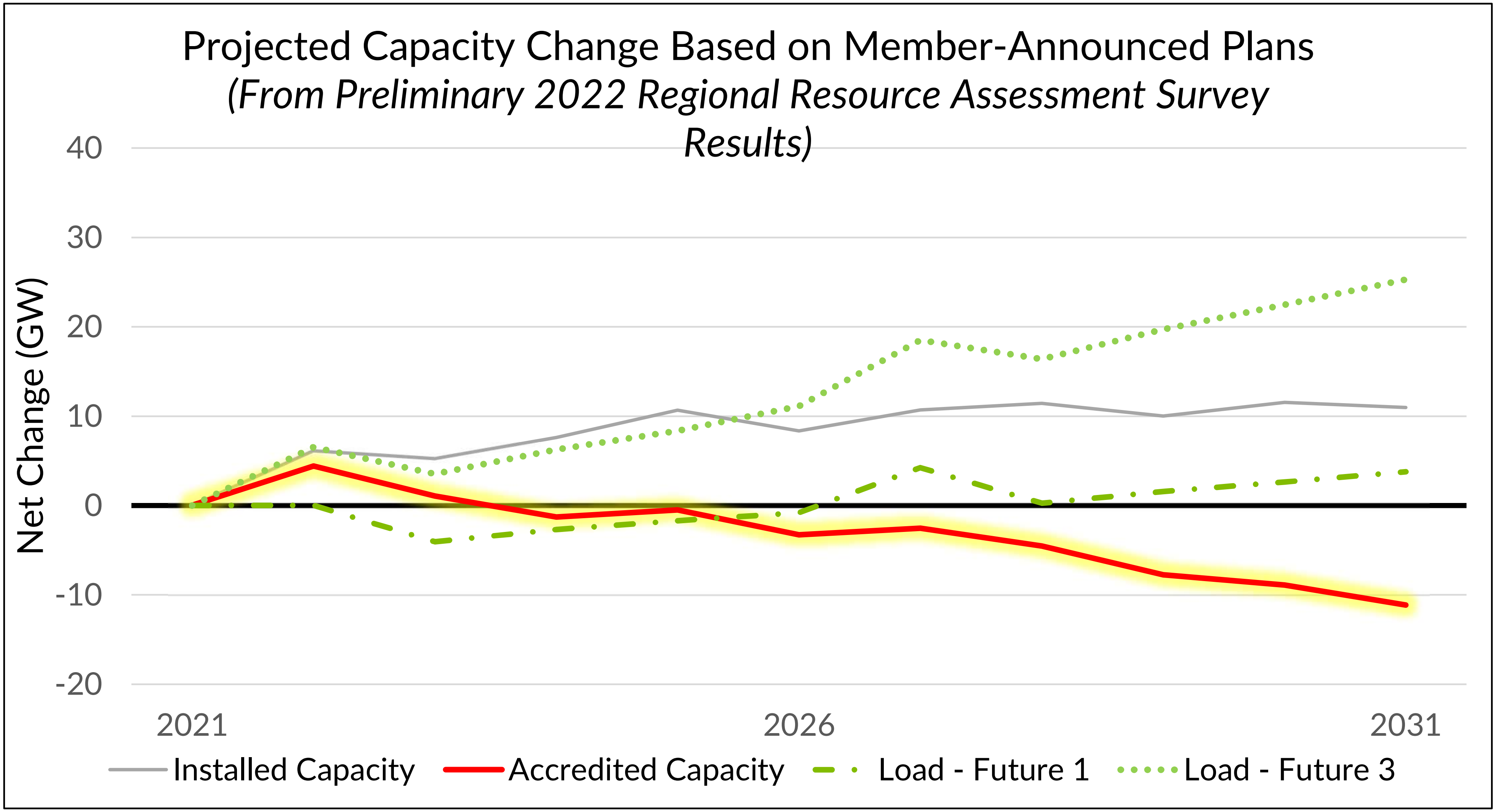
9/13/2022

MISO Queue Applications* by Generation Type (GW)



*Not all project applications will enter the active queue. Historically, 10% to 30% have been withdrawn/removed during the application review phase.

Our current member plans indicates accredited capacity will continue to decline, combined with increasing intermittent resources and demand



*Future projections calculated as change from Future 1 2022 load assumption

Estimated accredited capacity: 16.6% for wind; 35% for solar, 87.5% for battery, 90% for coal, 90% for gas, and 95% for nuclear

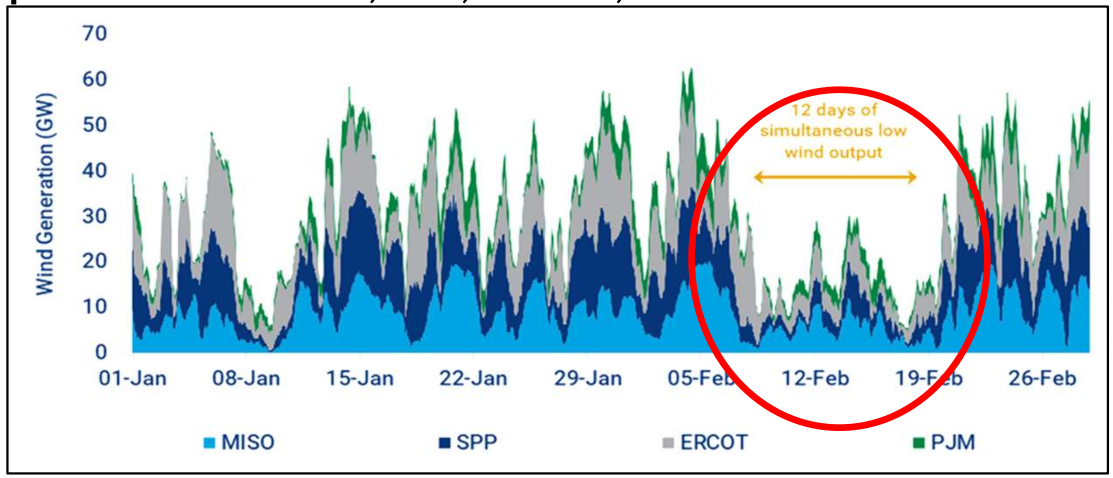
Traditional reserve margin calculations are no longer sufficient to address the growing system level risks

PROBABILISTIC FORECASTS AND RISK ASSESSMENT

RISK PORTAL INPUTS

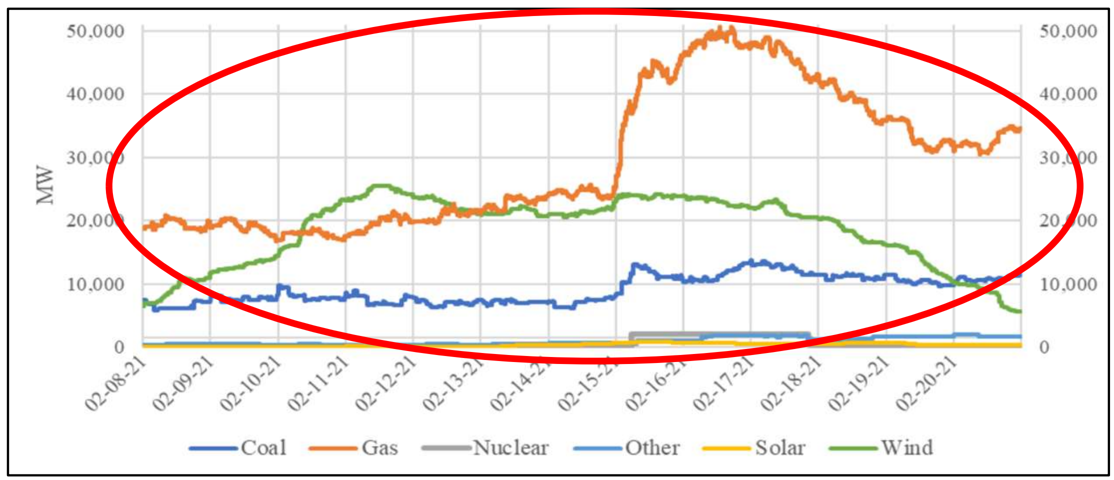
SOURCE	PROGRESS TOWARD QUANTIFYING UNCERTAINTY
Load	
Wind	
Solar	
Generation Availability	
Fuel	
Net Scheduled Interchange (NSI)	
Transmission Congestion	

During Winter Storm Uri, wind output was low for a 12-day period across MISO, SPP, ERCOT, and PJM…



Source: Wood Mackenzie

…concurrently, all resource types in MISO South, SPP, and ERCOT experienced increased outages



Source: FERC Report on The February 2021 Cold Weather Outages in Texas and the South Central United States

MISO's Reliability Imperative defines the changes necessary to reliably manage the changing resource portfolio and system risks

Market Redefinition

Aims to ensure that resources with needed capabilities and attributes will be available in the highest risk periods across the year

Long Range Transmission Planning (LRTP)

Assesses future transmission needs holistically, reflecting utility/state plans for new generation; will also consider potential cost-allocation changes

Market System Enhancements (MSE)

Transforms MISO's legacy platform into a flexible, upgradeable, and secure system that can evolve for years to come; will also integrate advanced technologies to process increasingly complex information

Operations of the Future

Focuses on the skills, processes, and technologies needed to ensure MISO Operations can effectively manage the grid into the future under increased complexity

Appendix

MISO's Market Redefinition is working on reforms to enhance alignment of fleet capability with system needs

Recently Approved by FERC	
Resource Adequacy Construct	➢ Moves from annual to seasonal model, improves accreditation, and updates planned outage thresholds
Ongoing Activities	
Improved Resource Accreditation	➢ Renewable and Load Modifying Resources are the focus in 2022
Resource Adequacy Construct	➢ Potential improvements to the Planning Resource Auction, including reevaluation of a reliability-based demand curve
Pricing	➢ Continued refinement of scarcity price reforms ➢ Improved modeling to achieve more efficient market outcomes and price signals
Resource Attributes	➢ Evaluating approaches to value resource attributes critical to reliably operating the evolving portfolio

Maintaining reliability with the changing resource portfolio and evolving risks requires a better understanding of system attributes that were "included" in the historic fleet