NREL Transforming ENERGY

G-PST Workshop: Establishing an ISO Planning & Operations

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NREL
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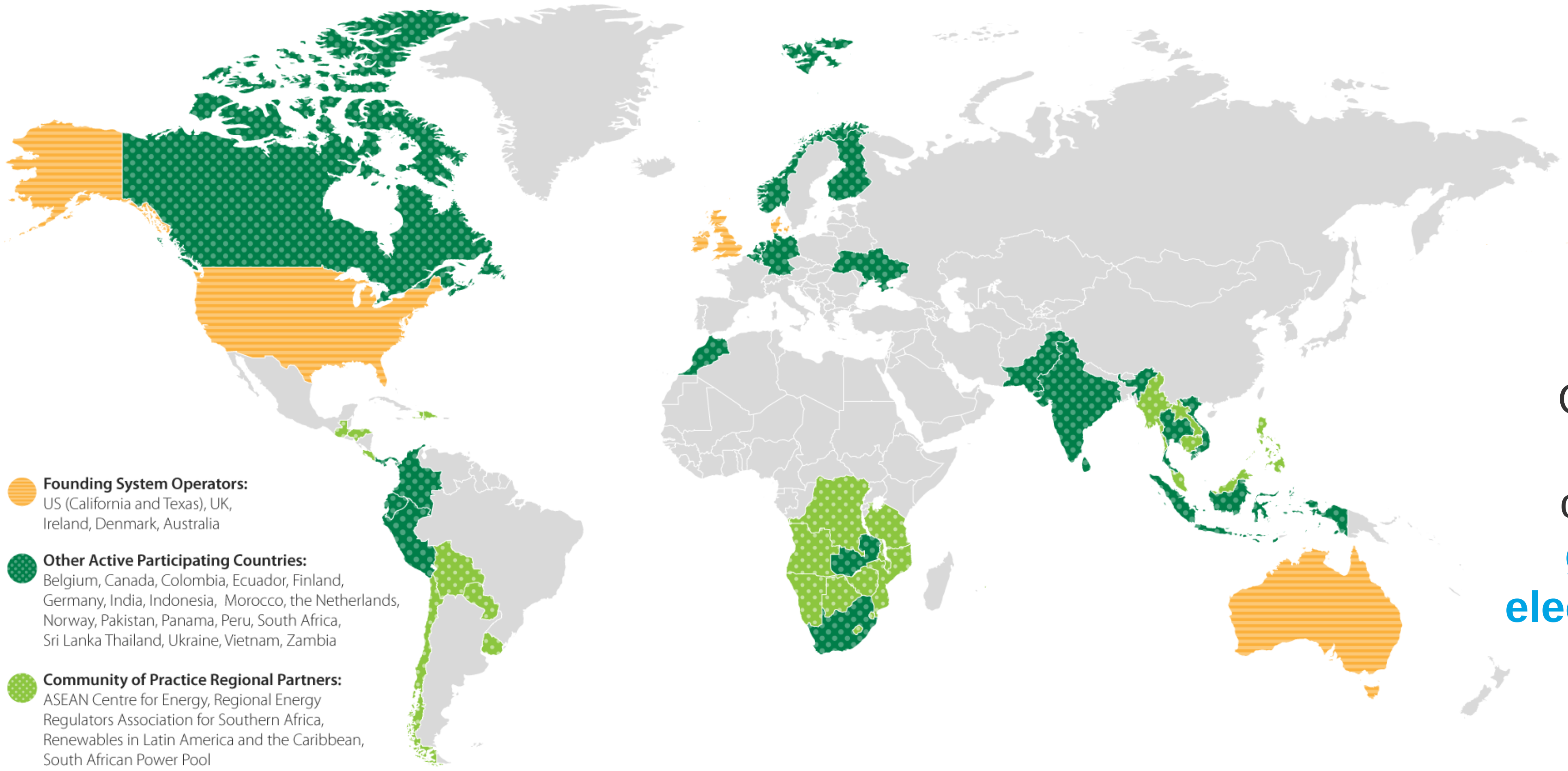
G-PST was established to address system operator technical challenges

The Global Power System Transformation Consortium (G-PST) was founded by the CEOs of the world's most advanced system operators and power system research institutions to develop, deliver, and scale the technical solutions that will accelerate the energy transition.



G-PST countries represent **1/3** of **global power generation** and **electricity emissions**

G-PST has grown to include system operators all around the world

Content

1. Overview Independent System Operators in North America
2. Planning process: long term, medium term, short term
3. Operating reserves
4. Control room of the future

Overview Independent System Operators in North America

The Independent System Operator manages the power system like the director manages the orchestra.

Source: NYSO

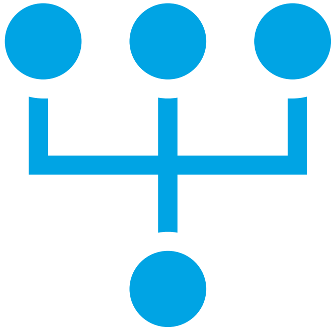
Source: https://www.britannica.com/art/symphony-music

Overview Independent System Operators in North America

1882	Early 1900s	1977	1970s–1990s	1996	1999
• **First complete electric power system** in New York City	• **Local networks spring up across US,** run by vertically-integrated private or municipal utilities	• **Federal Energy Regulatory Commission (FERC)** is created to regulate interstate aspects of electric power	• The vertically-integrated utility model leads to a **lack of competition** within the industry	• **Deregulation (“market restructuring”) begins** when FERC Orders 888 and 889 open transmission systems to fair and nondiscriminatory access and remove obstacles to competition in wholesale trade of electricity	• FERC Order No. 2000 encourages voluntary formation of **Regional Transmission Organizations (RTOs)** to administer transmission grid regionally throughout North America

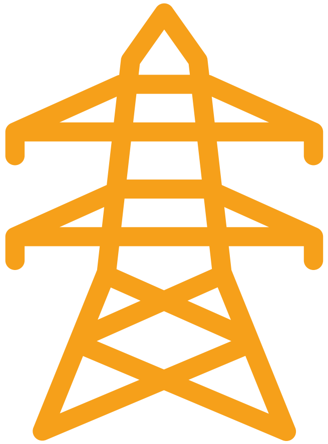
Source: https://www.iso-ne.com/about/what-we-do/history

Independent System Operators
Regional Transmission Organizations



Independent System Operators (ISOs) emerged from FERC Order Nos. 888/889, where the Commission proposed the concept of an Independent System Operator as a way for existing power pools to comply with the requirement to provide nondiscriminatory access to transmission.

In Order FERC No. 2000, the Commission encouraged the voluntary formation of Regional Transmission Organizations (RTOs) to manage the transmission grid on a regional basis across North America (including Canada).



Source: FERC

Advantages of implementing an ISO

Enhanced Reliability

- For large geographic areas, regional markets promote efficiency through resource sharing.
- Organized markets are designed so that an area with surplus electricity can benefit by sharing MW with another region via the open market.

Efficient Grid Dispatch

- Using advanced technologies and market-driven incentives, the performance of power plants within regional markets tends to be better than in areas under monopoly control.
- There are lower power plant outage rates within competitive market regions because generation owners are motivated to keep plants online, especially during peak periods, to maximize their revenues.

Source: CAISO

Advantages of implementing an ISO

Better Price Transparency

- ISOs/RTOs are better equipped to identify transmission bottlenecks, analyze reliability and evaluate the economic benefits of investing in additional transmission in an unbiased manner.
- In monopoly-controlled markets, consumers and investors are faced with a "black box" regarding information about prices and locational value of transmission, which inhibits investment in the power grid.

Ease of Entry and Private Investment

- ISOs/RTOs develop standardized non-discriminatory rules for grid interconnection and provide important price signals for new investment.
- As grid planners, they identify the best economic solutions to transmission issues across a large footprint.

Source: CAISO

Advantages of implementing an ISO

Renewable Power Added to Grid

- ISOs and RTOs level the playing field for diverse types of power plants to compete to bring the lowest cost electricity to consumers.
- ISOs and RTOs are seeing robust investment in environmentally friendly power generation in their regions.

Market Monitoring Benefits

- Market monitors identify ineffective market rules and tariff provisions, identify potential anticompetitive behavior by market participants and provide the comprehensive market analysis critical for informed policy decision making.

Source: CAISO

Advantages of implementing an ISO

Market Flexibility

- Organized markets offer diverse power products and services that can be used to hedge against price risks.
- Increased and improved price transparency means better contract pricing.

Liquidity in the Marketplace

- ISO and RTO markets have more buyers and sellers than non-competitive markets.
- Prior to restructuring, only a handful of companies were competing to bring the lowest cost power to consumers.

Source: CAISO

Advantages of implementing an ISO

Market Diversity

- Regions with organized wholesale markets have numerous buyers and sellers, but generator ownership is more concentrated in non-competitive regions.
- Formalized markets can monitor for the exercise of market power abuse and address market power through mitigation rules, recommending new operating procedures or proposing market structure changes.

Demand Response Development

- ISOs and RTOs provide more information and market data is available publicly. As a result, more companies are encouraged to participate in energy markets—even companies that are paid to reduce demand on the grid.
- Demand response bids are very important during peak periods of electricity use and it is cleaner and more economical.

Source: CAISO

North America has nine independent system operators

Two-thirds of the United States is served by these independent system operators.

Source: https://www.caiso.com/about/Pages/OurBusiness/Opening-access.aspx

The California Independent System Operator (CAISO)

- CAISO was founded in 1998 and became a fully functioning ISO in 2008.
- CAISO operates a competitive wholesale electricity market and manages the reliability of its transmission grid.
- CAISO provides open access to the transmission and performs long-term planning.
- CAISO centrally dispatches generation and coordinates the movement of wholesale electricity in California and a portion of Nevada.
- CAISOs markets include energy (day-ahead and real-time), ancillary services, and congestion revenue rights.

Source: FERC

Source: FERC

The California Independent System Operator (CAISO)

52 GW peak demand

(Sep 6, 2022)

239 million MW-h of electricity delivered in 2022

76.2 GW power plant capacity (August 2023)

1119 power plants

26000 circuit miles of transmission lines

Source: CAISO

Source: CAISO

The California Independent System Operator (CAISO)

Within its balancing authority area, the California ISO:

- Maintains reliability on the grid
- Manages the flow of energy
- Oversees the transmission planning process
- Operates the wholesale electric market

For much of the western U.S., the ISO:

- Operates the Western Energy Imbalance Market (WEIM)
- Serves as Reliability Coordinator (RC West)

Midcontinent Independent System Operator (MISO)

- MISO became the nation's first FERC-approved Regional Transmission Organization (RTO) on December 20, 2001
- MISO began market operations in April 2005
- In 2009, MISO started operating an ancillary services market and combined its 24 separate balancing areas into a single balancing area.
- In 2013, the RTO began operations in the MISO South region.

Source: FERC

Source: FERC

Midcontinent Independent System Operator (MISO)

127 GW peak demand

(July 7, 2022)

651 million MW-h of electricity delivered in 2022

190 GW power plant capacity (Dec 2022)

6800 power plants

75000 circuit miles of transmission lines

Source: MISO

Source: MISO

Midcontinent Independent System Operator (MISO)

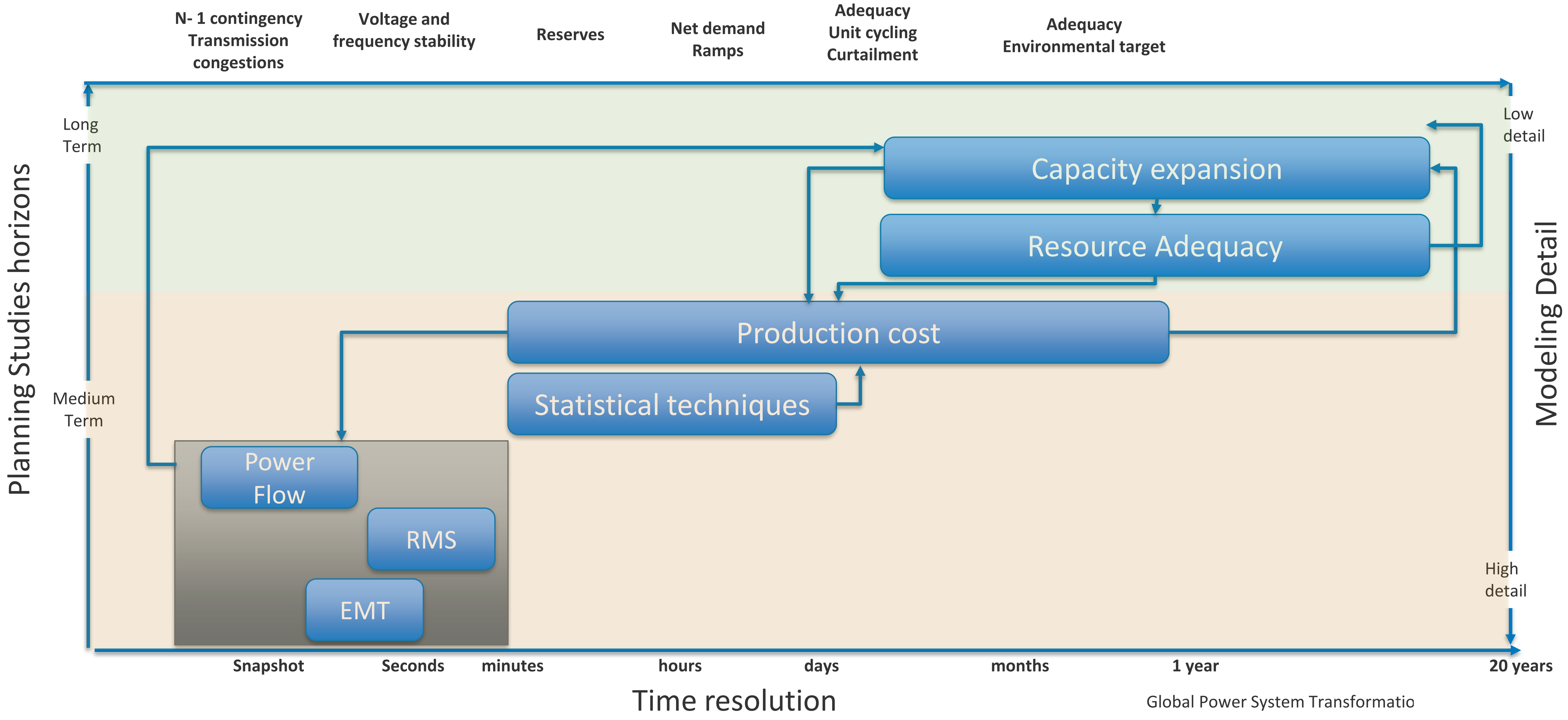
MISO is an independent, not-for-profit, member-based organization responsible for keeping the power flowing across its region reliably and cost effectively.

MISO focuses on three critical tasks:

1. Managing the flow of high-voltage electricity across 15 U.S. states and the Canadian province of Manitoba
2. Facilitating one of the world's largest energy markets with more than $40 billion in annual transactions
3. Planning the grid of the future

Planning process: long term, medium term, short term

Planning process for adequacy and reliability



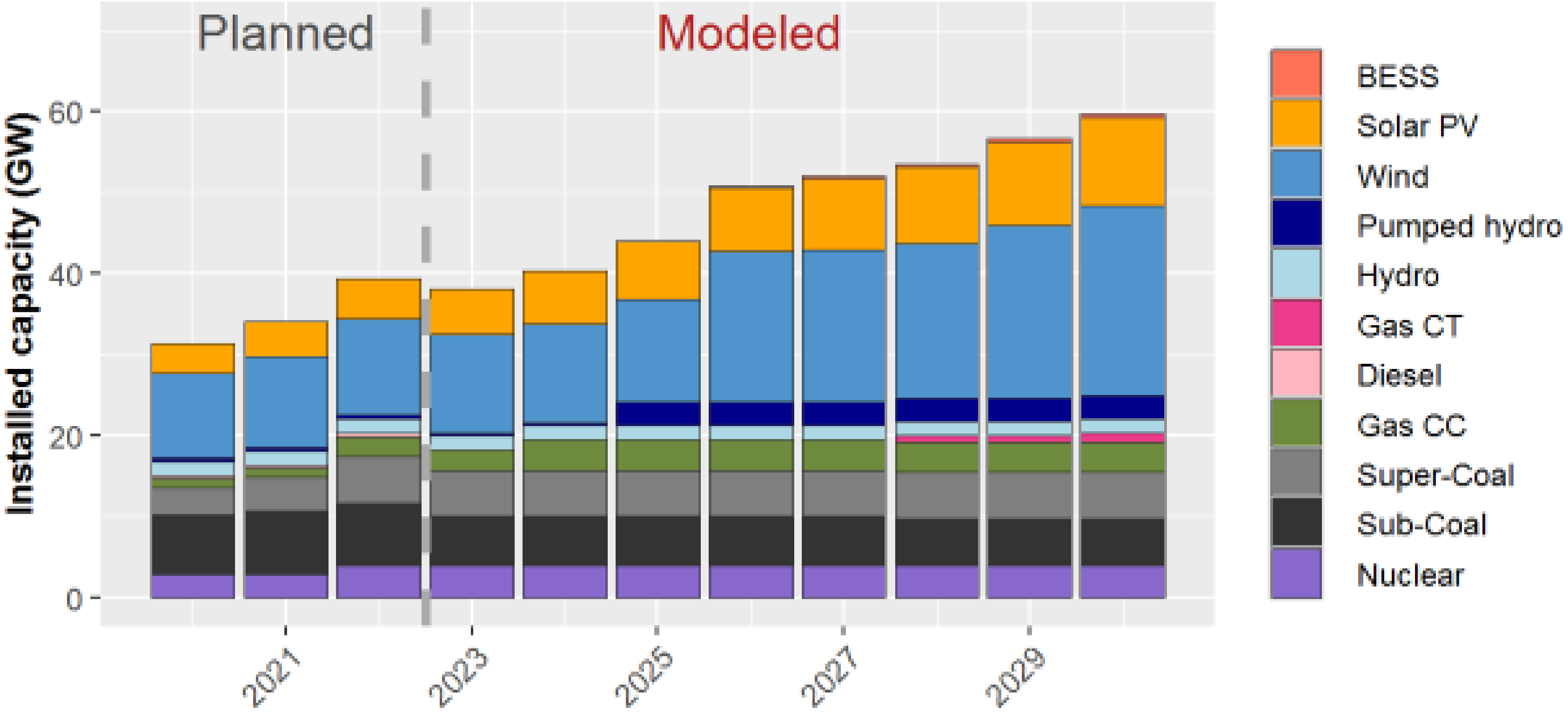
Capacity Expansion

Capacity expansion models (CEMs) are used to identify the least-cost mix of power system resources, taking into consideration factors such as new policies, technological advancement, changing fuel prices, and electricity demand projections, among other factors.

In many power systems globally, CEM analysis serves as a key tool for the development of power sector master plans or integrated resource plans

Source: https://www.nrel.gov/docs/fy21osti/80192.pdf

Results Capacity Expansion
Tamil Nadu's Electric Power Sector



Source: https://www.nrel.gov/docs/fy21osti/78266.pdf

NERC's definition of resource adequacy

The ability of supply-side and demand-side resources to meet the aggregate electrical demand (including losses).

Standard BAL-502-RFC-02: one day in ten years loss of Load expectation (LOLE)

Source: https://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-502-RFC-02.pdf

IRENA’s definition of resource adequacy

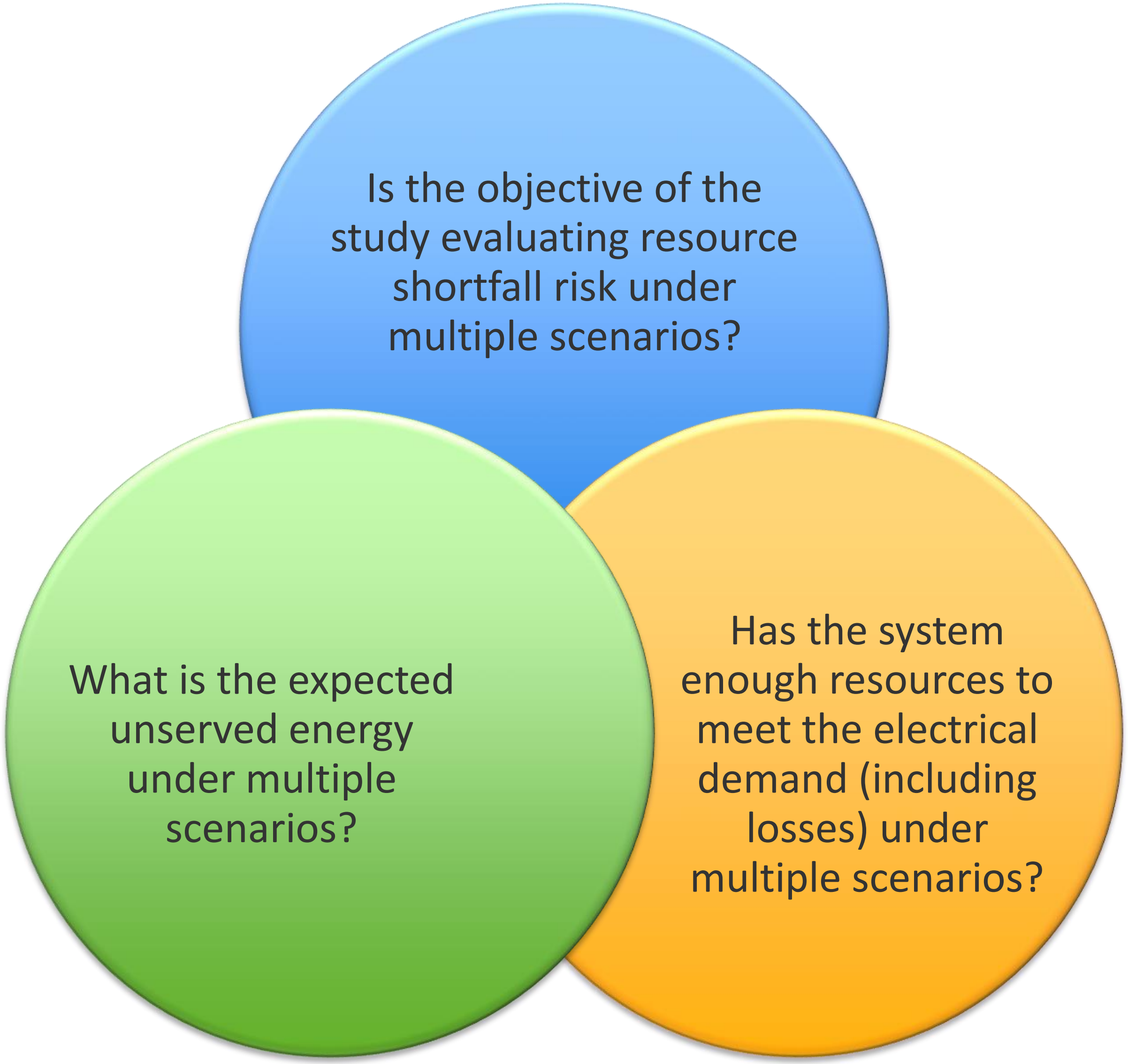
Generation adequacy refers to the availability of sufficient generation to meet demand (i.e.,firm capacity)

A typical generation adequacy study, for example, would consider the firm capacity of all power generation capacity on a system in any future year, and whether it is sufficient to cover peak demand.

Given the importance of having sufficient firm capacity to system reliability, understanding the relevant range of capacity credit values for VRE and matching the timing of VRE supply patterns with that of load patterns are key elements in long-term generation expansion planning.

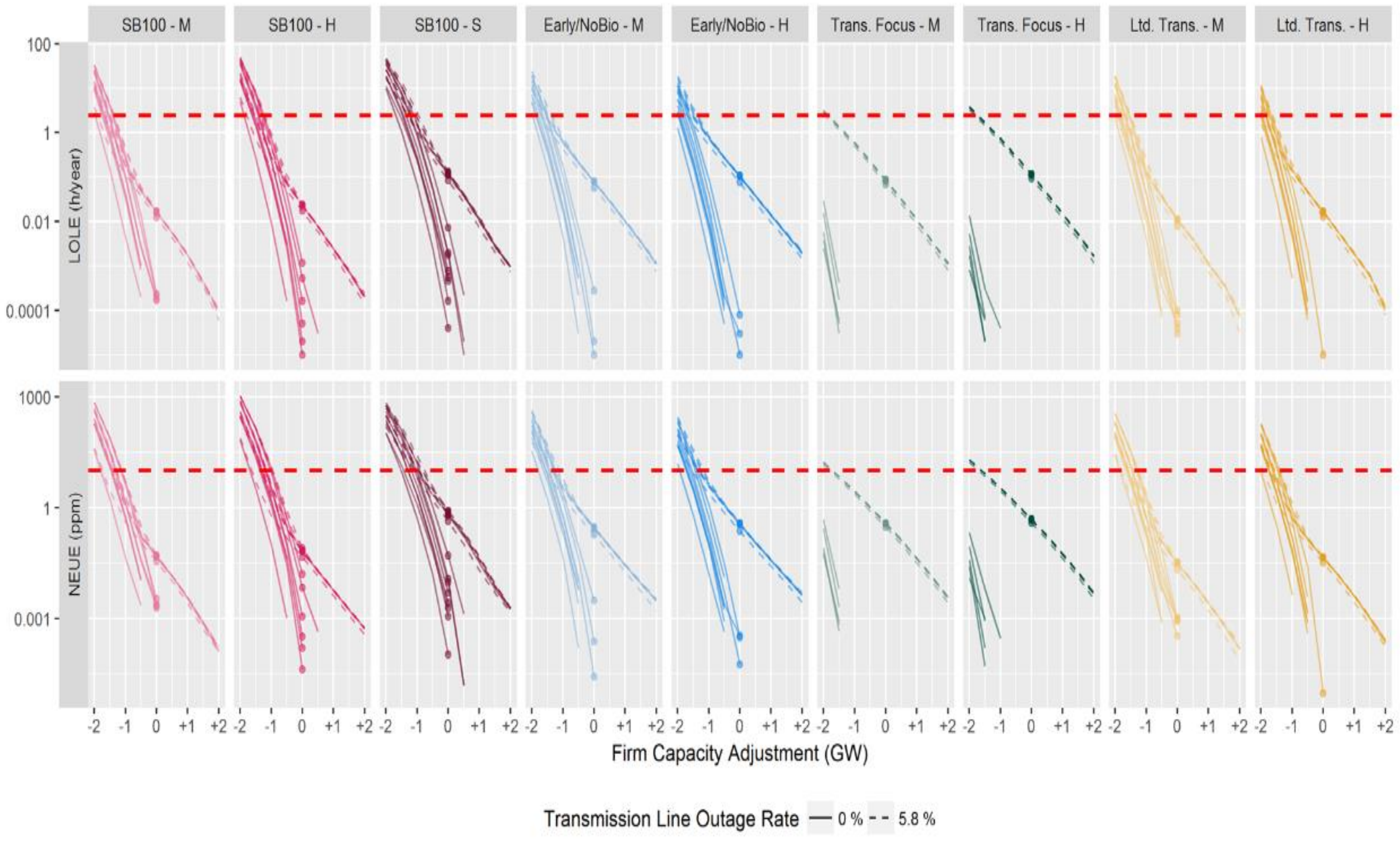
Source: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Planning_for_the_Renewable_Future_2017.pdf?rev=8bf1e29230e74ce39e19b6f3bfd5914d

What questions can be solved with resource adequacy studies?



Generation Resource Adequacy Analysis
The Los Angeles 100% Renewable Energy Study

Resource adequacy results across multiple scenarios



Multiple scenarios analyzed:

- 1300 sensitivity runs.
- 100,000 random hourly draws of generator and transmission outages for each of 7 weather years.

Source: https://www.nrel.gov/docs/fy21osti/79444-6.pdf

Production Cost

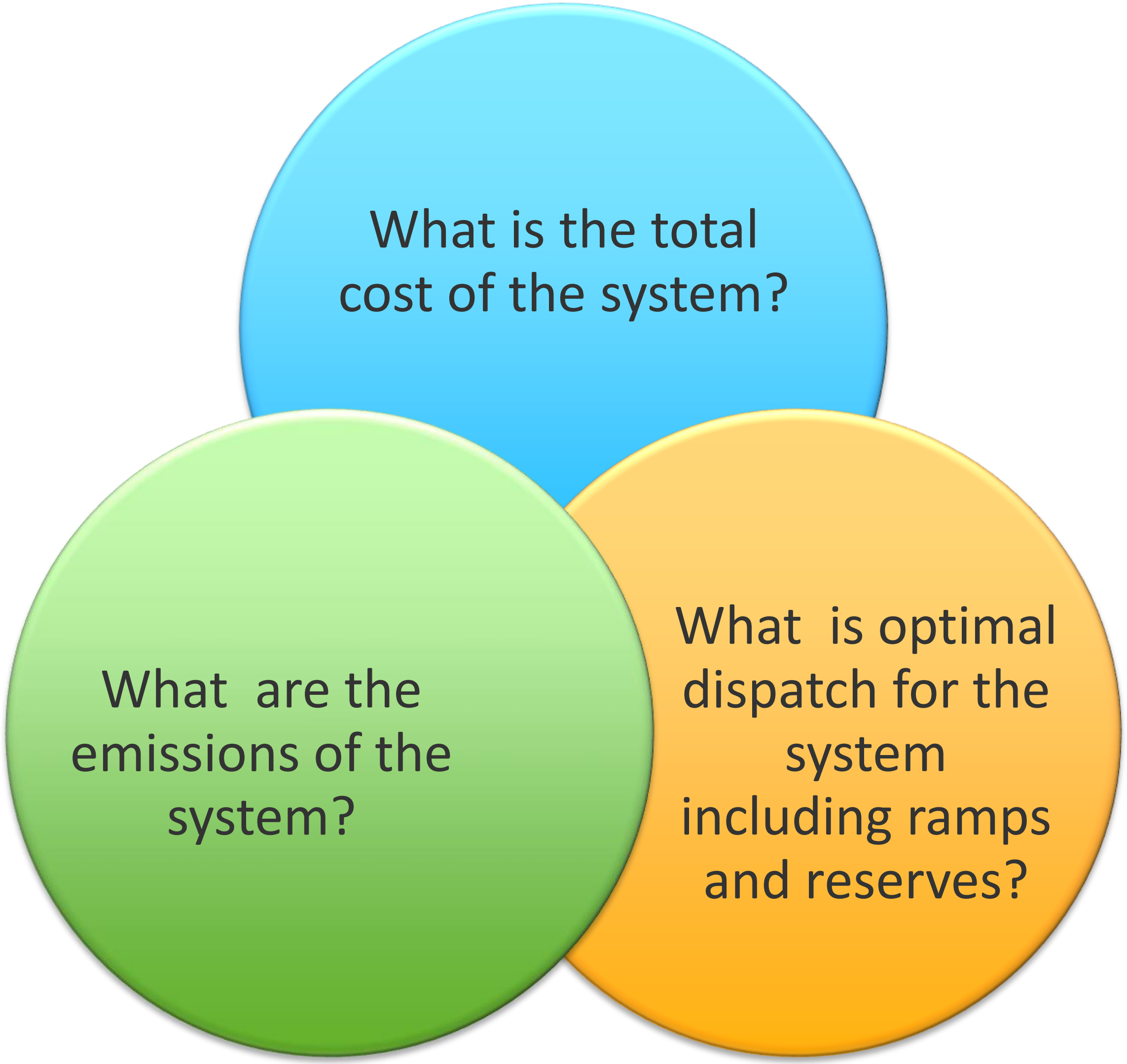
Captures the costs of operating a fleet of generators.

Simulate unit commitment and dispatch at a sub-hourly resolution for a single year using a static fleet.

Regarding renewables is used to analyze:

- Curtailment
- Reserves
- Ramps
- Production costs reductions
- Greenhouse gas emissions reductions

What questions can be solved with production cost studies?



Result examples of Production Cost Model

Optimal dispatch

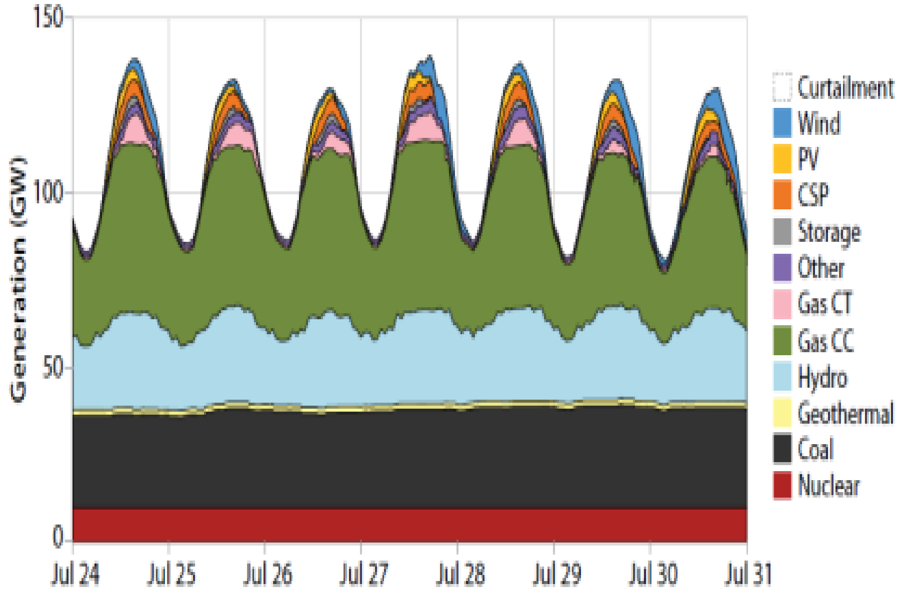


Image from NREL

Total production cost

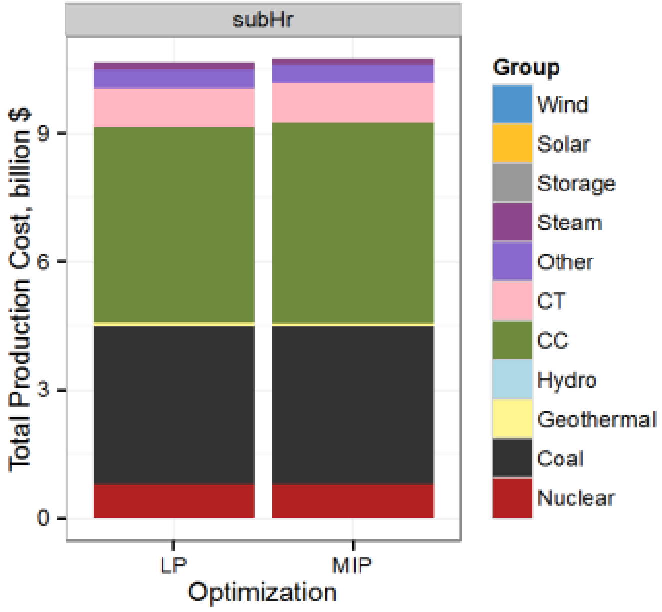


Image from NREL

Total emissions

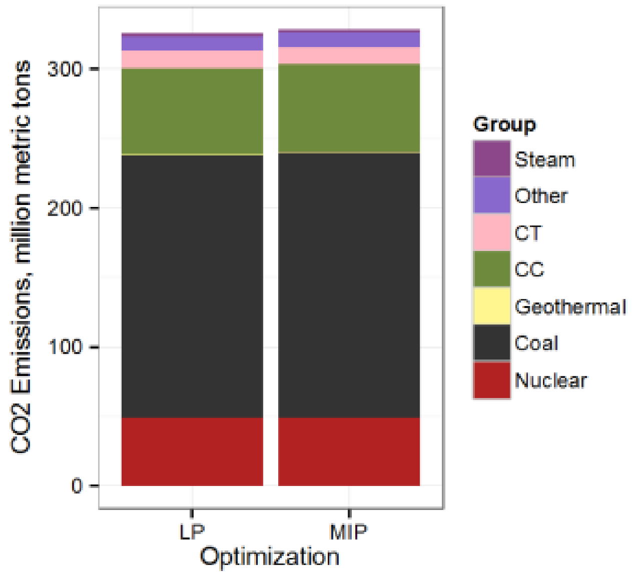
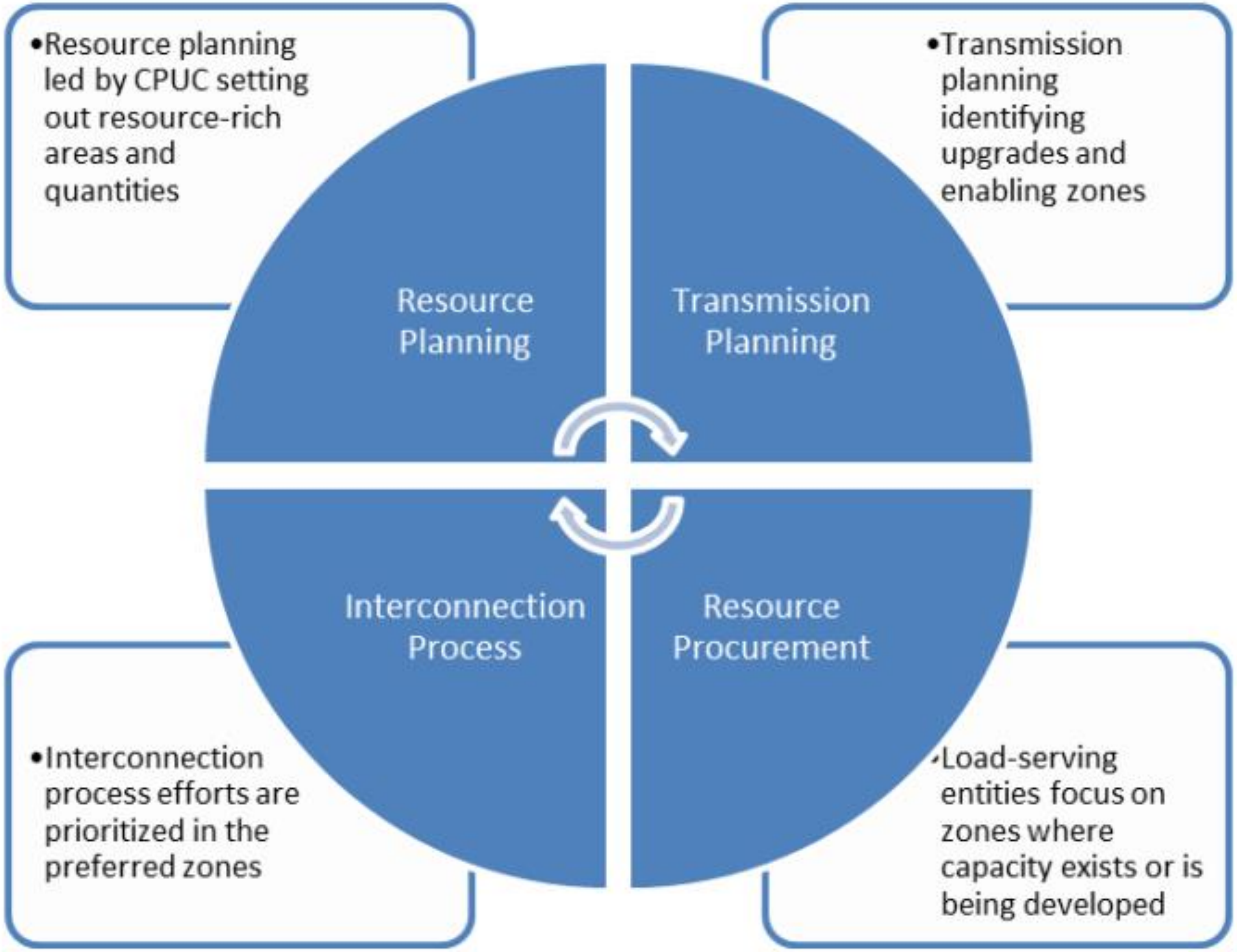


Image from NREL

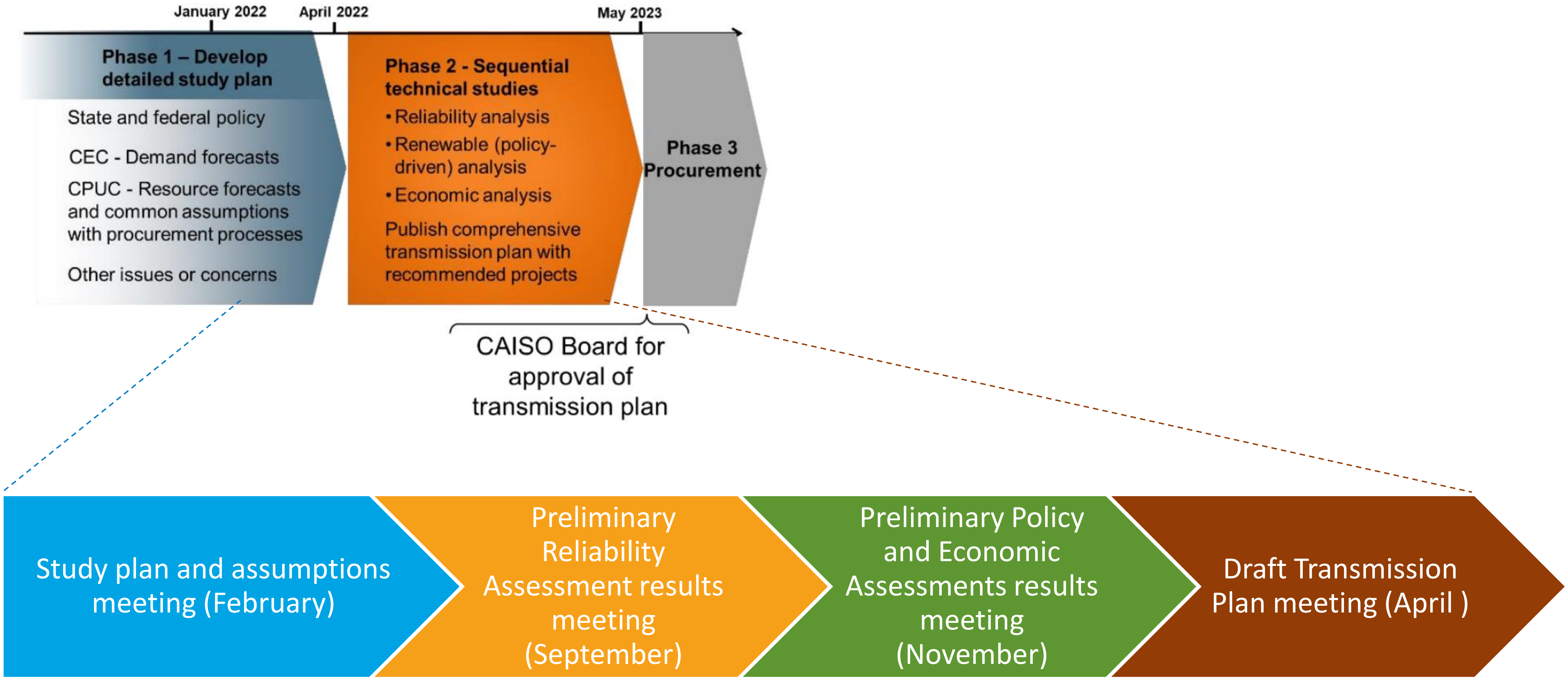
Sources: https://www.nrel.gov/docs/fy16osti/64905.pdf
https://www.nrel.gov/docs/fy16osti/65383.pdf

The California ISO's Transmission Planning Process

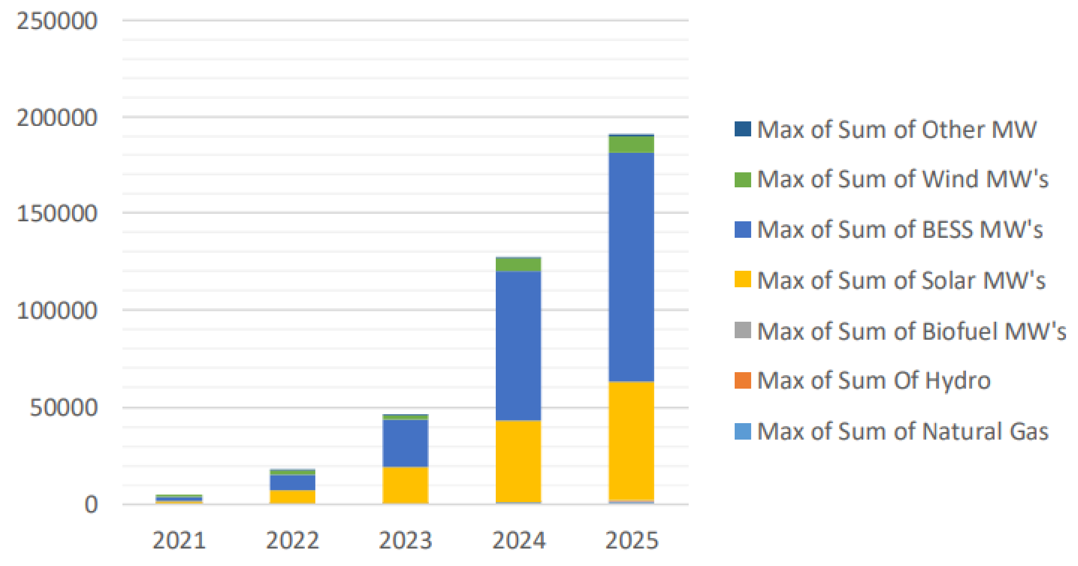


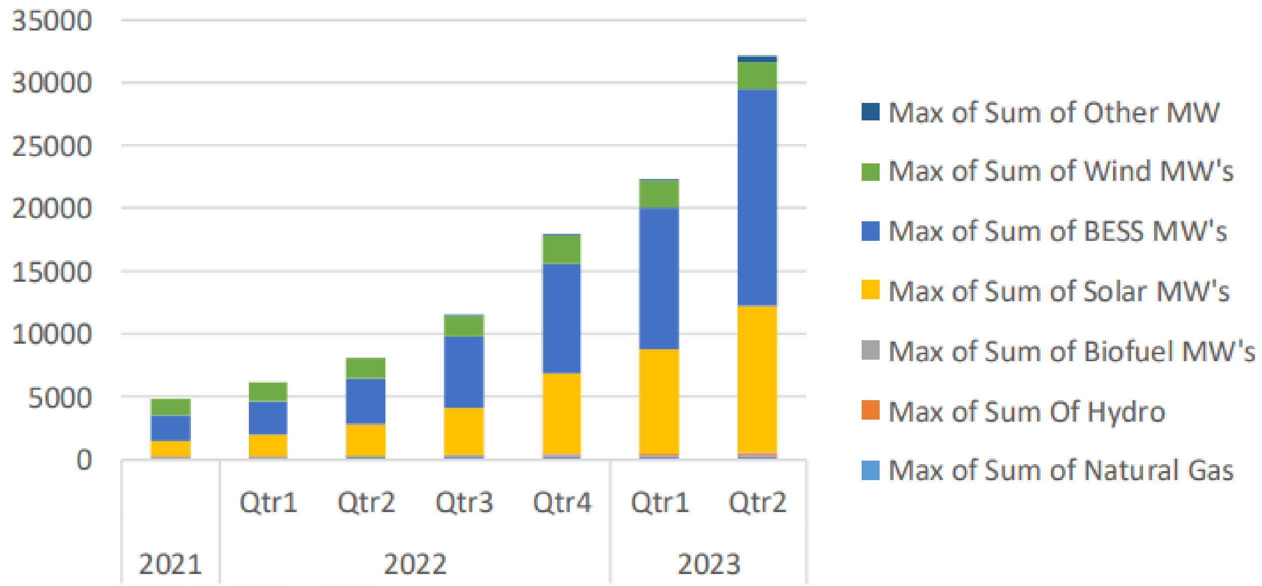
Source: https://www.caiso.com/Documents/Transmission-Planning-Process-Overview.pdf

CAISO manages a transparent and open transmission planning process



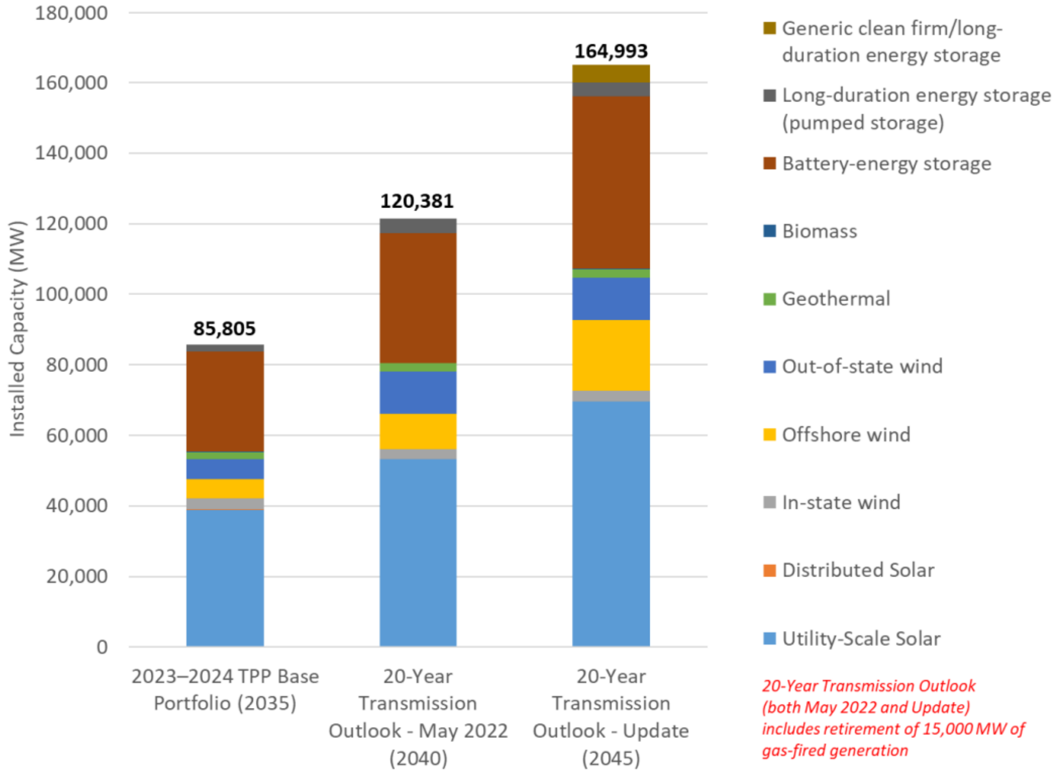
CAISO- Generator Interconnection





Source: https://www.caiso.com/planning/Pages/GeneratorInterconnection/Default.aspx
https://www.caiso.com/Documents/Briefing-ResourcesAvailable-NearTermInterconnection.pdf

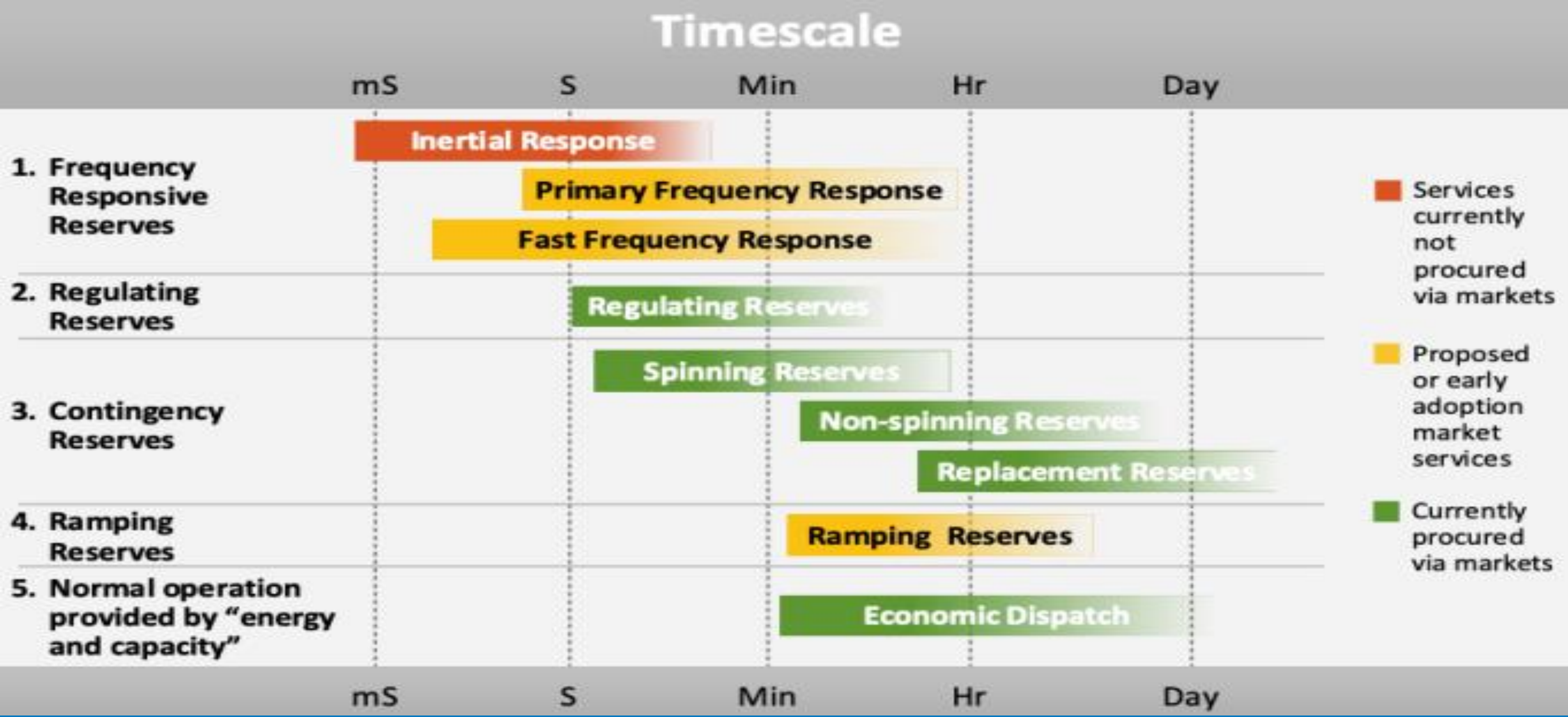
The California ISO's 20-Year Transmission Outlook



CAISO produced its first ever 20-Year Transmission Outlook focused on providing a longer-term view of transmission needed to reliably meet state clean energy goals: http://www.caiso.com/InitiativeDocuments/ 20-YearTransmissionOutlook-May2022.pdf

Source: https://www.caiso.com/InitiativeDocuments/20-YearTransmissionOutlook-May2022.pdf

Operating Reserves



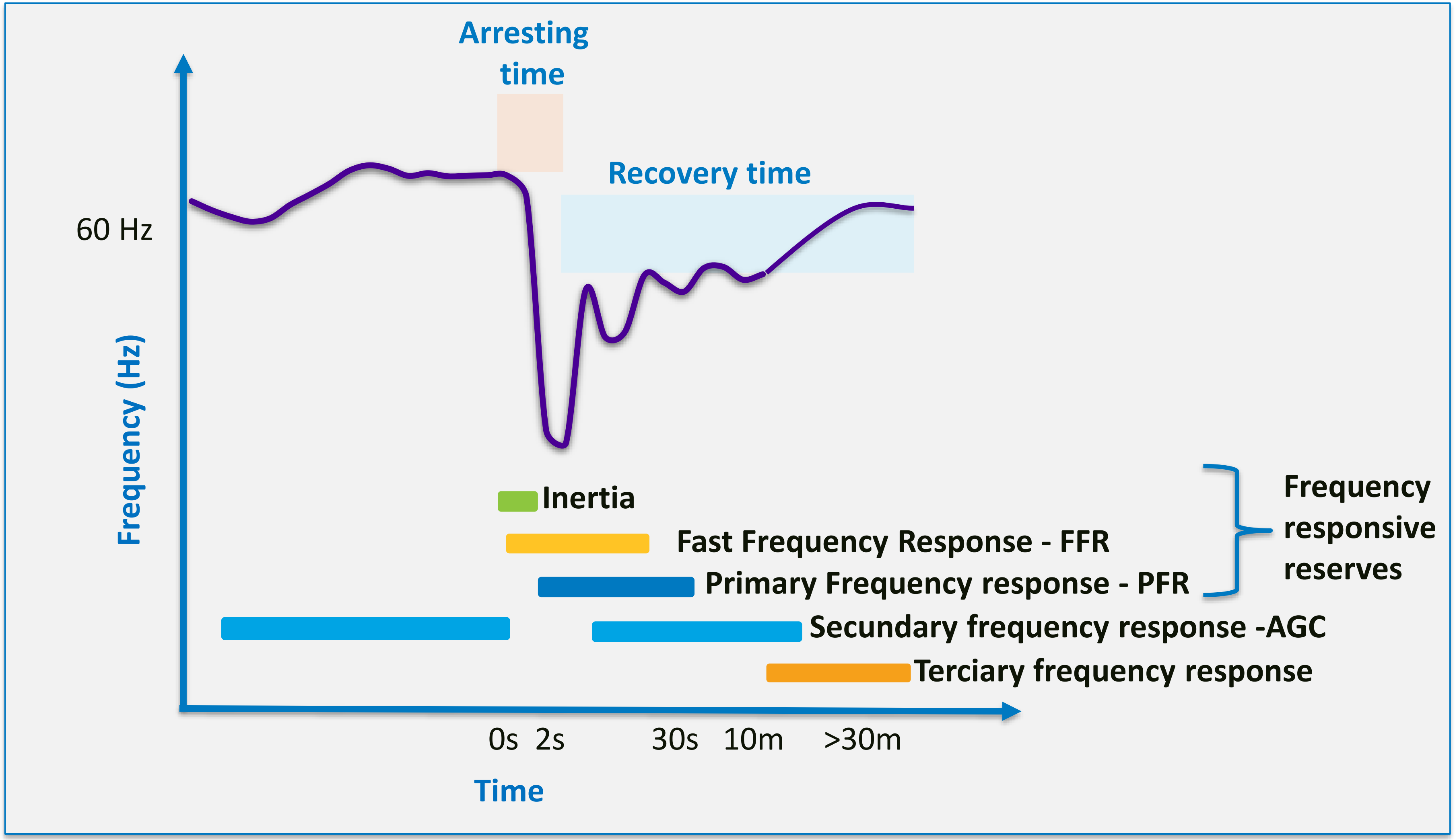
Operating Reserves

Source: Denholm, Paul L., et al. An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind. National Renewable Energy Laboratory, Golden, CO, 2019, https://www.osti.gov/biblio/1493402.

What is frequency control?

Refers to the dynamic response of generation, load, and storage devices to control the grid frequency during normal operation and after unplanned outages.

Frequency control



Inertia

Inertia is the kinetic energy stored in rotating masses of synchronous machines (synchronous generators, condensers and motors loads) that gives them the tendency to keep rotating.

This stored energy is important to power systems when a large generator fails because it can compensate for the power imbalance for a few seconds.

This temporary response allows other mechanisms to compensate for the imbalance, as primary and secondary response.

The importance of inertia to a power system depends primarily on the size of the grid, the interconnections, and how quickly generators in the grid can detect and respond to imbalances.

Fast Frequency Response

AEMO:

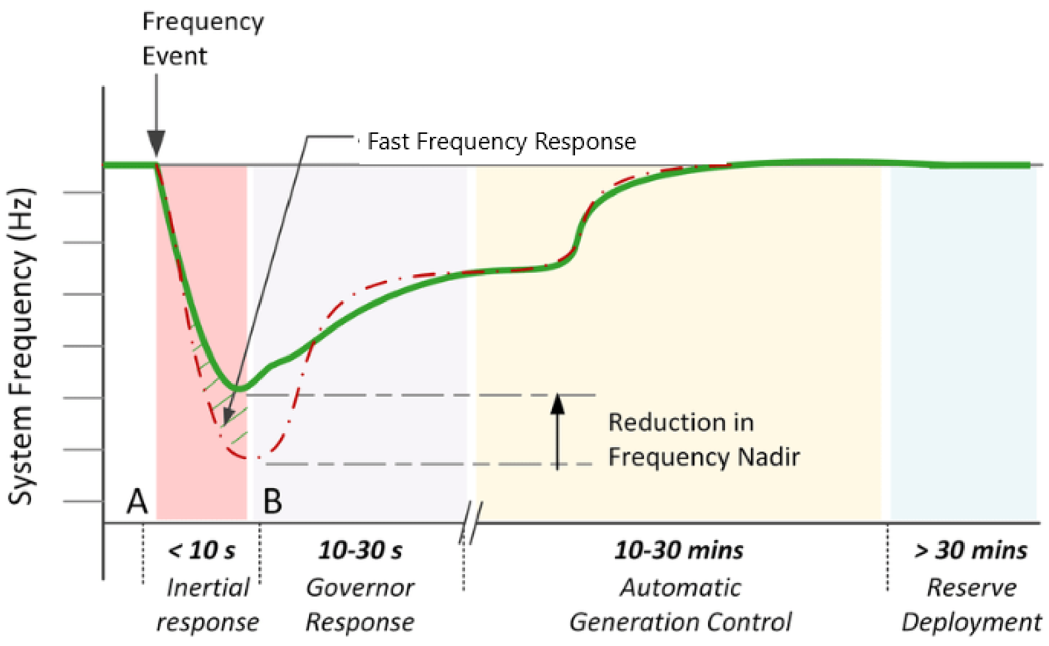
- FFR refers to delivering a rapid increase or decrease of generation or load in a two second or less time frame.

ERCOT:

- A response from a resource that is automatically self-deployed and provides a full response within 30 cycles after frequency meets o drops below a preset threshold. FFR1: trigger frequency at 59.8 Hz FFR2: trigger frequency at 59.7 Hz

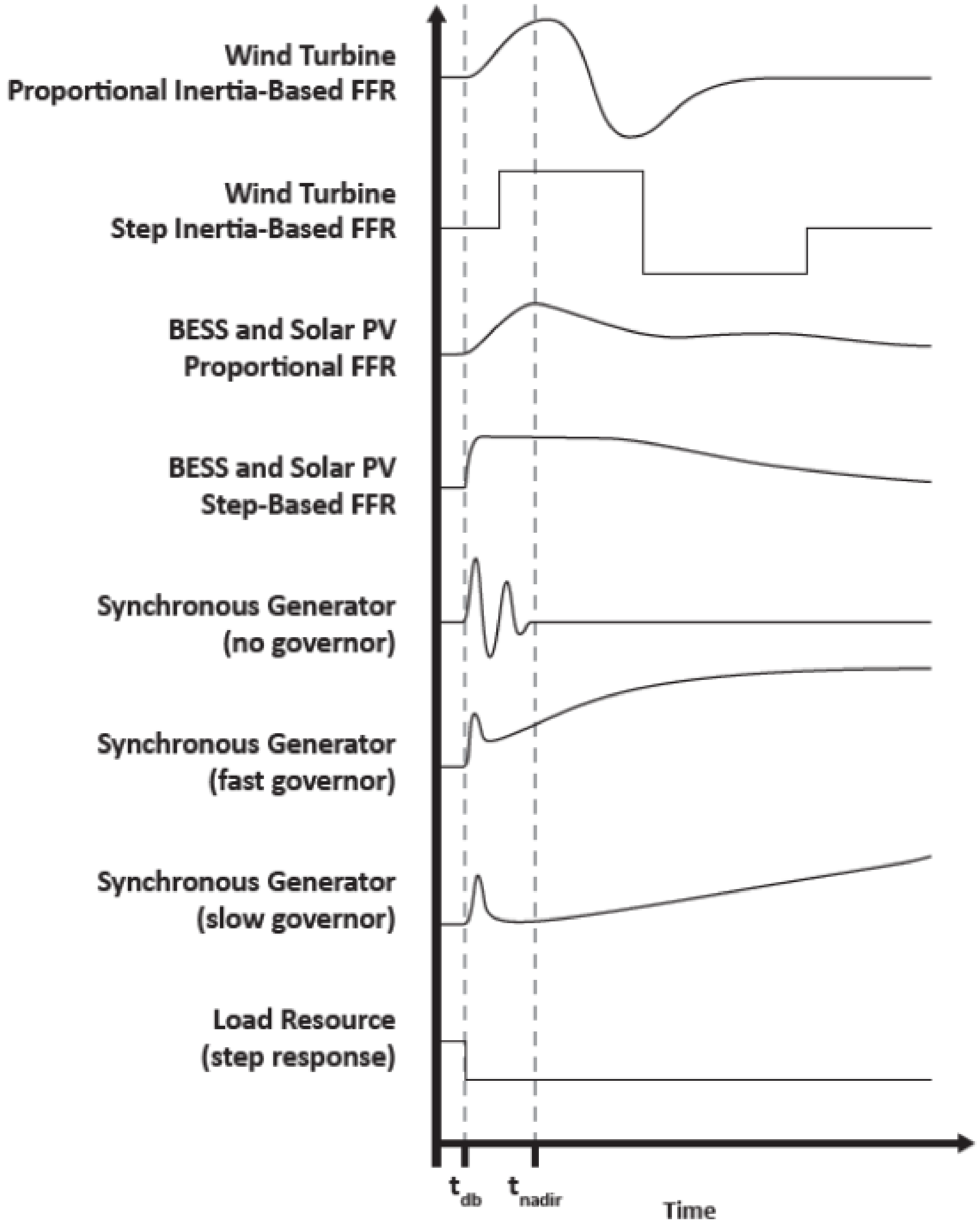
EIRGRID

- FFR is defined as the additional increase in MW output from a unit or a reduction in demand following a frequency event that is available within two seconds of the start of the event and sustainable for at least eight seconds afterwards.



Source: Virtual Inertia: Current Trends and Future Directions - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Multiple-time-frame-frequency-response-in-a-power-system-following-a-frequency-event_fig3_317937853

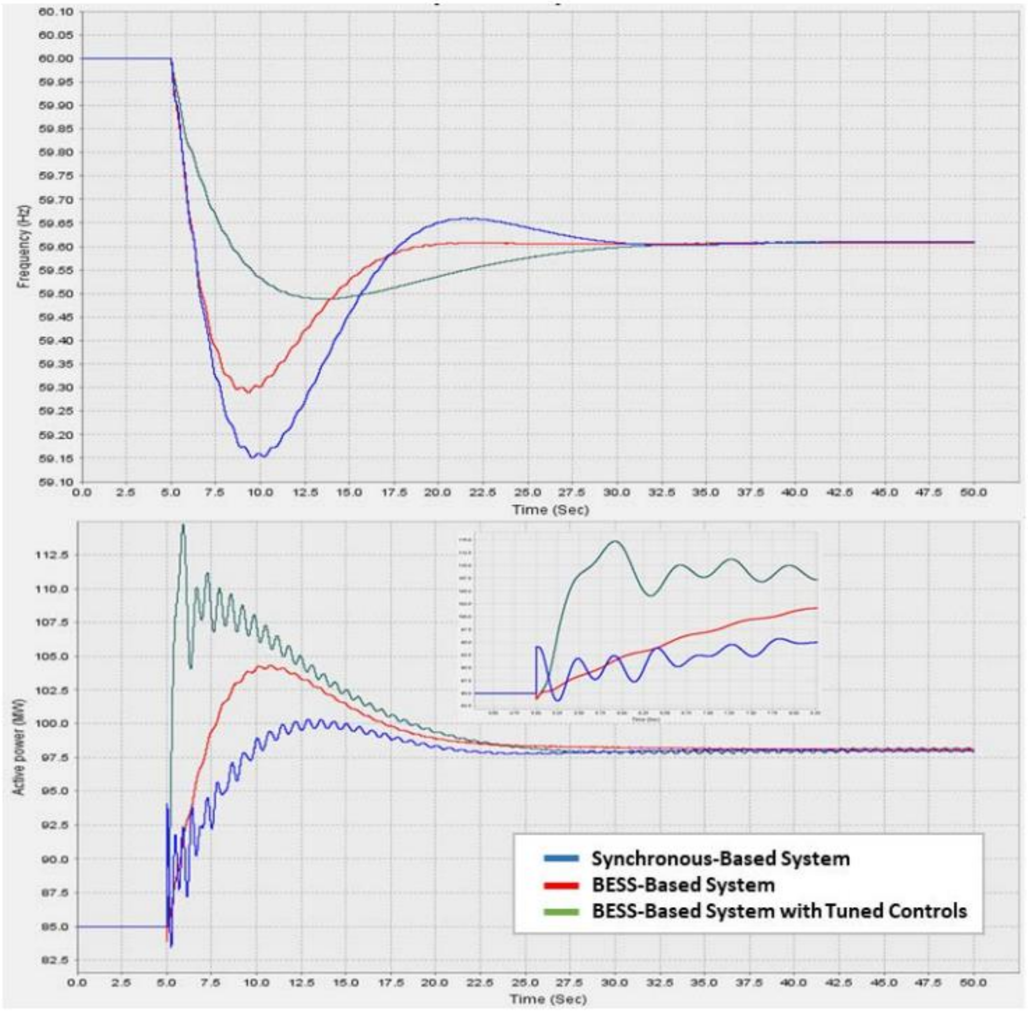
Fast frequency response offered by multiple technologies



Source: NERC

Fast Frequency Response - Storage systems

Battery-based storage systems have the ability to provide fast frequency response to counteract rapid frequency changes due to disturbances in the system. Like solar PV, there are no rotating elements and therefore the active power output is predominantly driven by the controls that are programmed into the inverter



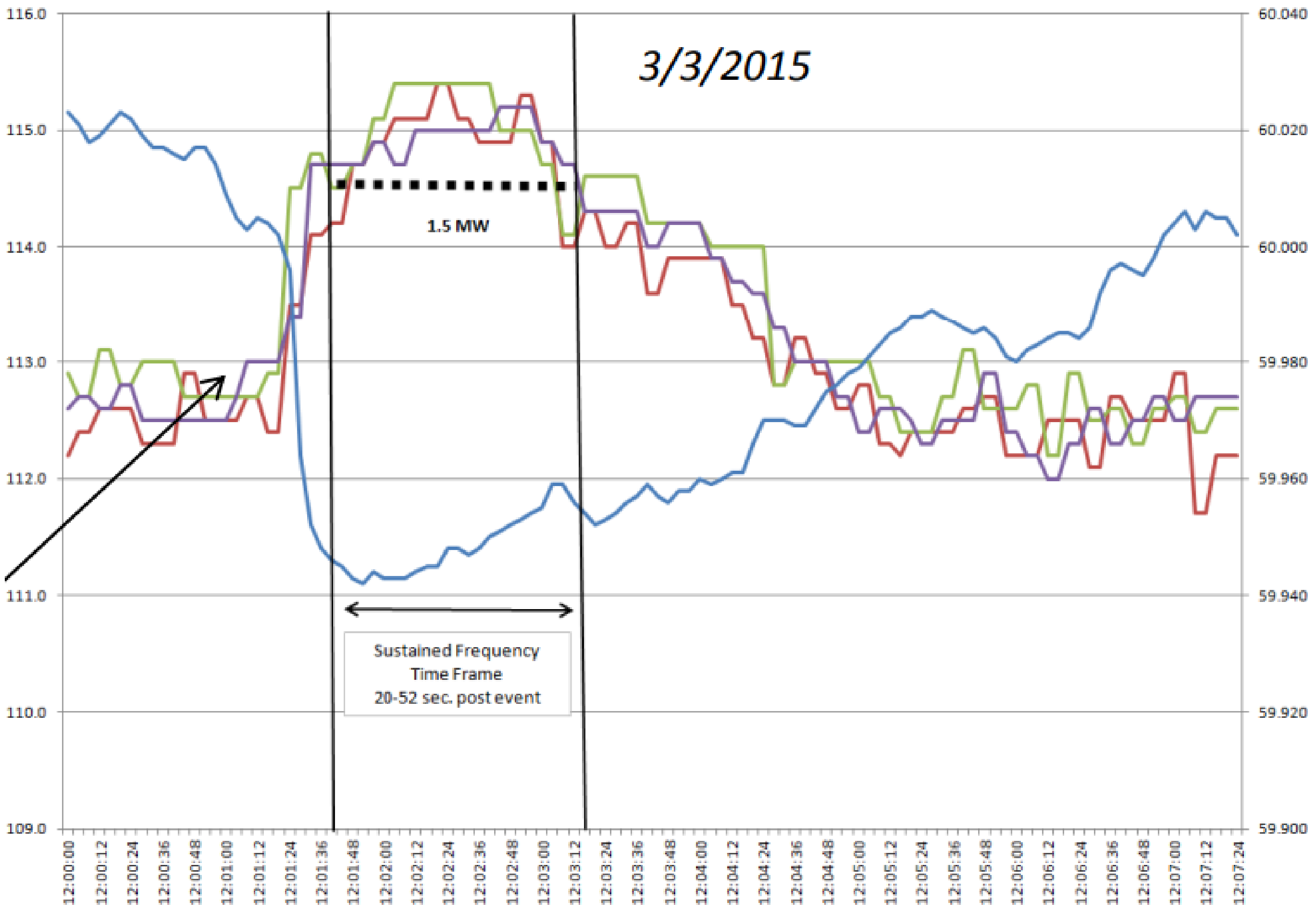
Source: EPRI

Primary Frequency Response

Primary Frequency Response are actions to arrest and stabilize frequency in response to frequency deviations.

comes from generator governor response, load response (motors) and other devices that provide immediate response based on local

Generator Governor Response within 0-10 seconds..



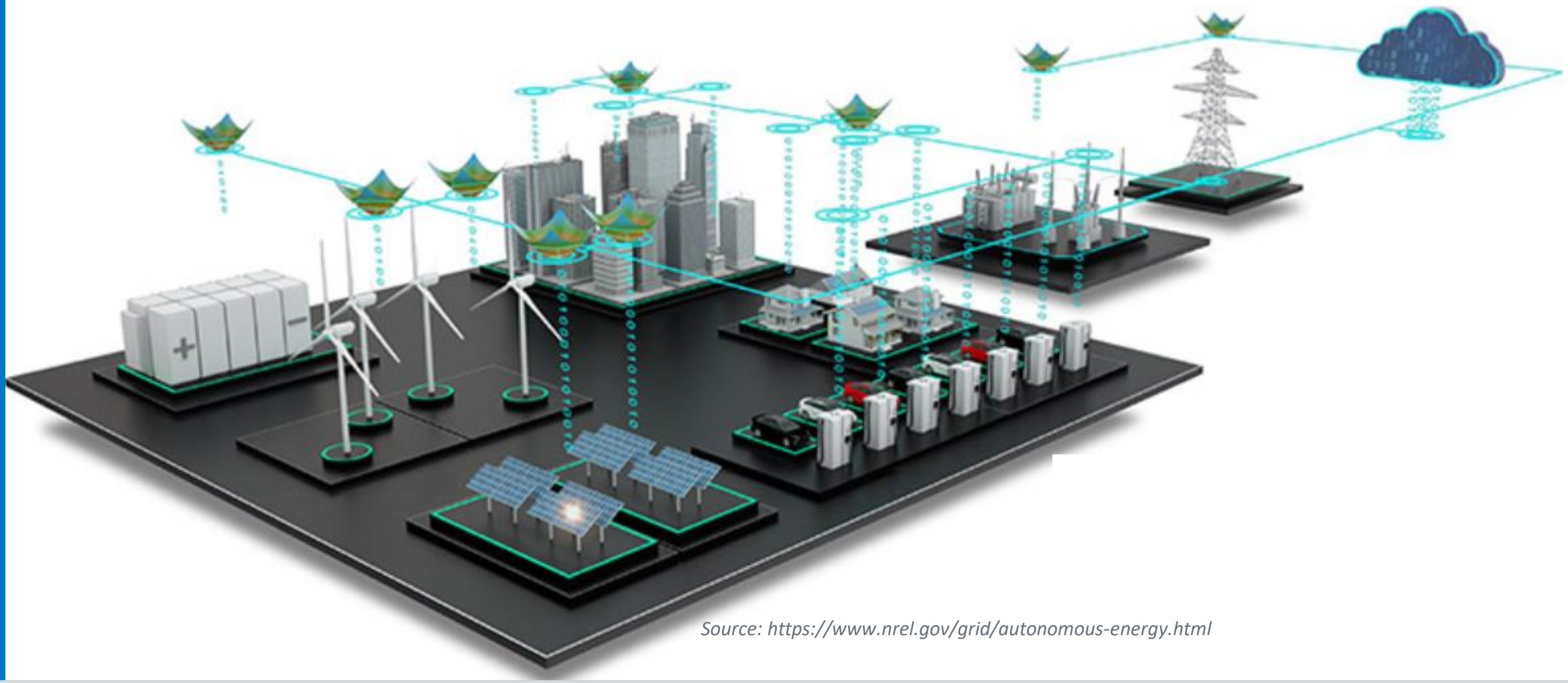
Source: https://www.nerc.com/pa/rrm/Webinars%20DL/Generator_Governor_Frequency_Response_Webinar_April_2015.pdf

Primary Frequency Response - Storage systems

Source: Benato, et.al. (2017)

Control Room of Future

An evolving network requires an evolving operational capability



Source: https://www.nrel.gov/grid/autonomous-energy.html

Evolving network

- Decentralised generation
- PV, wind, demand HVDC ramping, variability, and unscertanty
- Lower System strenght and inertia.
- Transmission constrains
- Electrification

Evolving operation

- Human Factors
- Operational data
- Operational technology
- Control
- Operational Architecture
- Facilities and equipment

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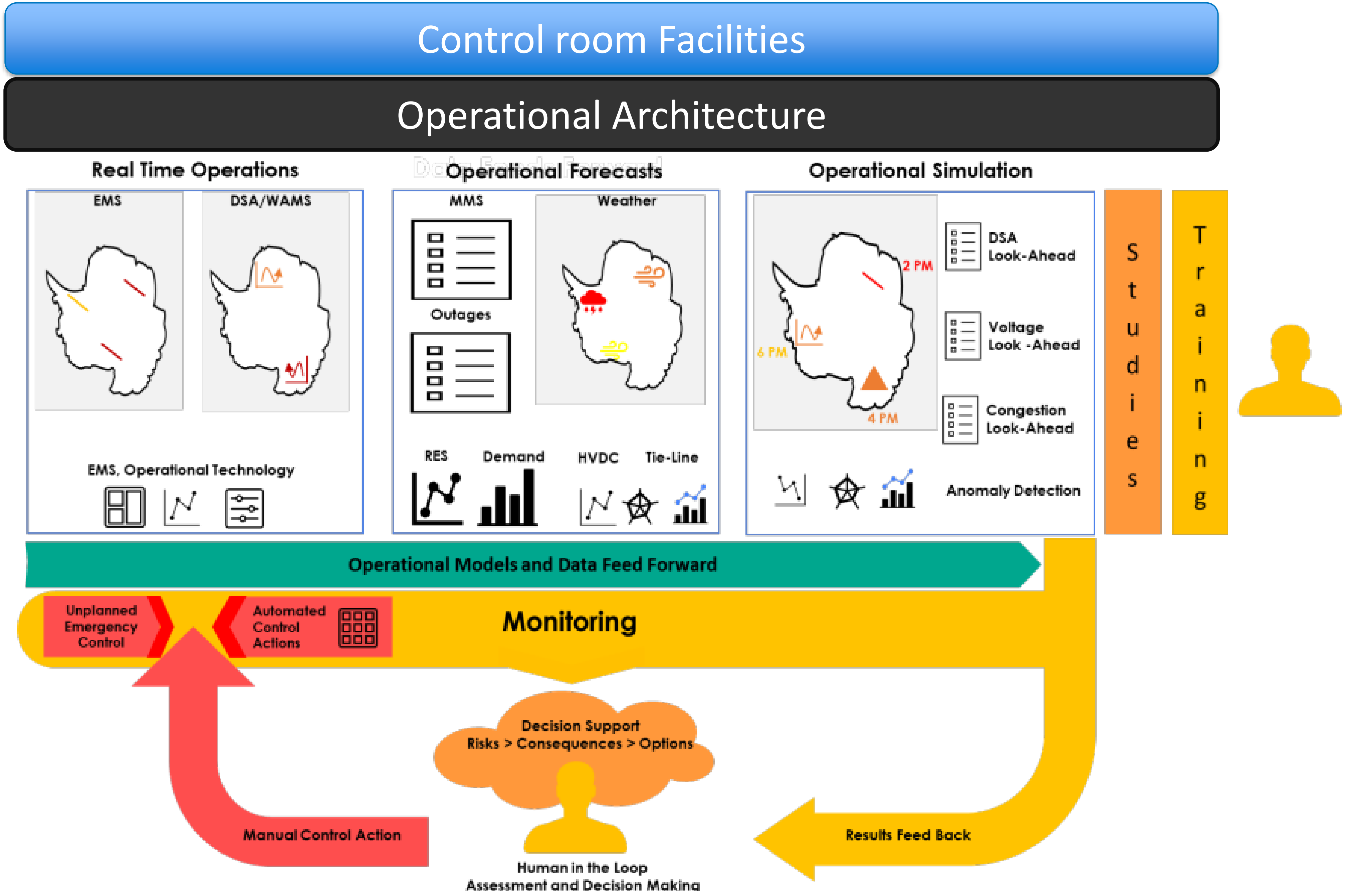

Source: EPRI https://globalpst.org/wp-content/uploads/G-PST-Vision-for-the-Control-Room-of-the-Future-V0.5-Final.pdf

Evolving operation

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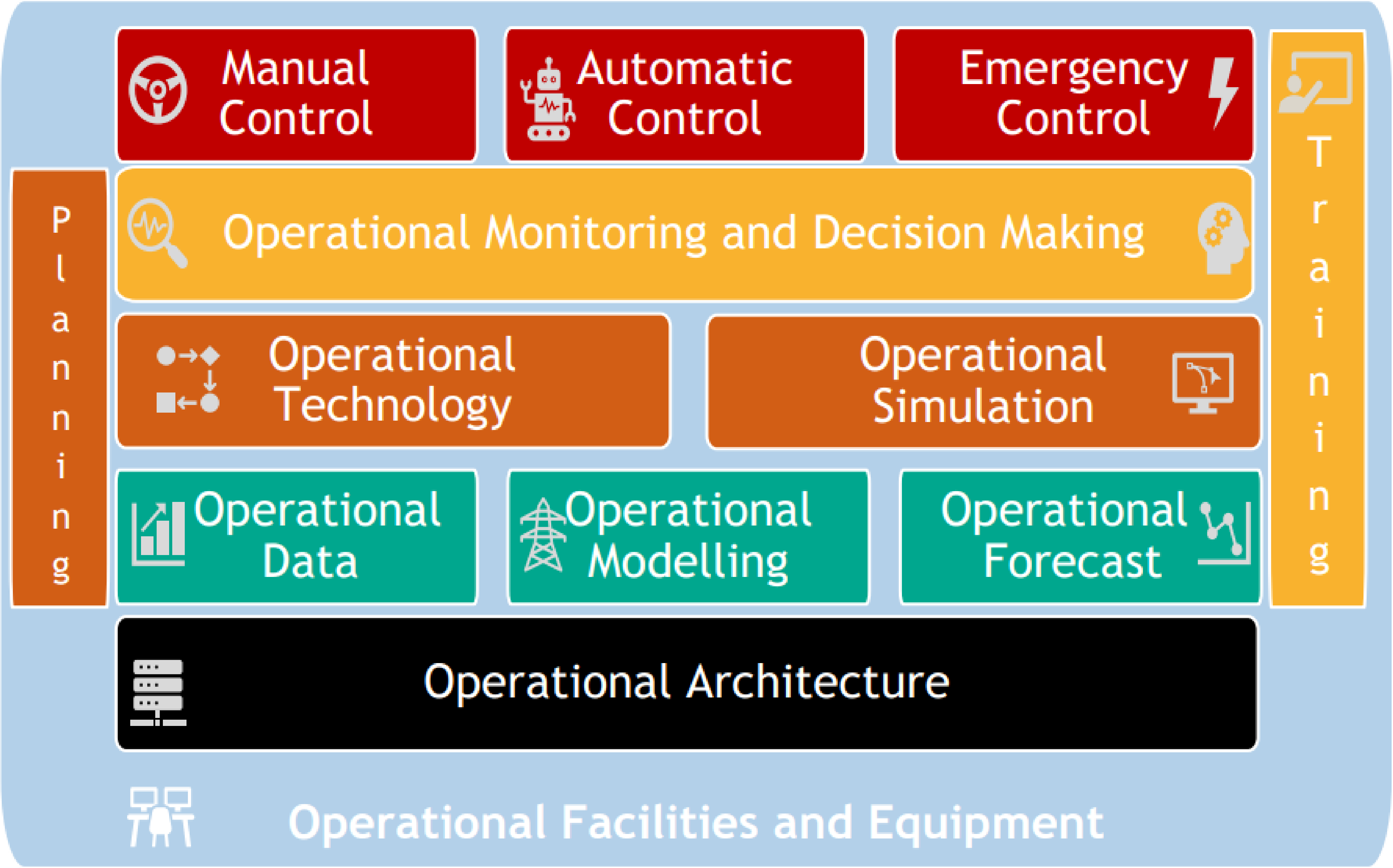

Source: EPRI https://globalpst.org/wp-content/uploads/G-PST-Vision-for-the-Control-Room-of-the-Future-V0.5-Final.pdf

Steps for Developing a Road Map Control Room of Future

Human Factors
Operational data
Operational technology
Control
Operational Architecture
Facilities and equipment

***"It is possible, that is why we are here.
Go back 20 years and people said you'll wreck the power system. It took people stepping up and providing real leadership and real vision to get us where we are today. That is what it will take to achieve more progress on the road to net-zero"***

– Mark Foley, CEO, EirGrid

Photo: GPST https://globalpst.org

Thank you

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