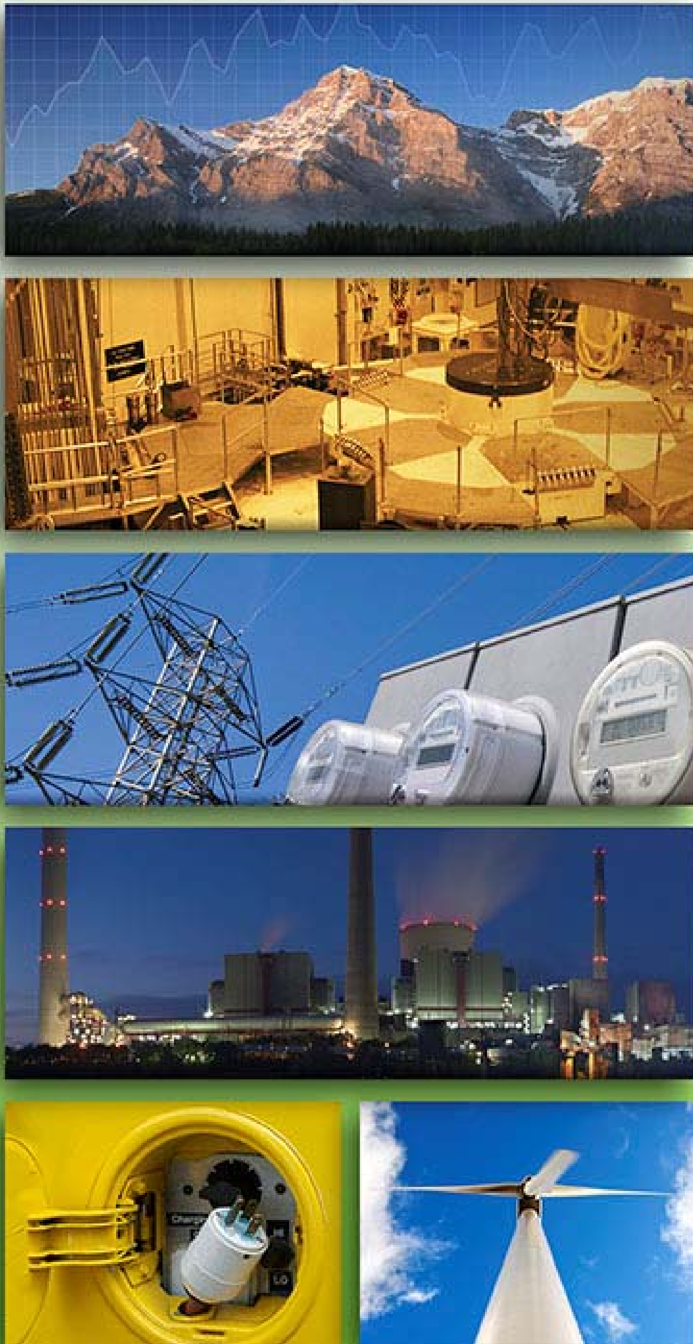

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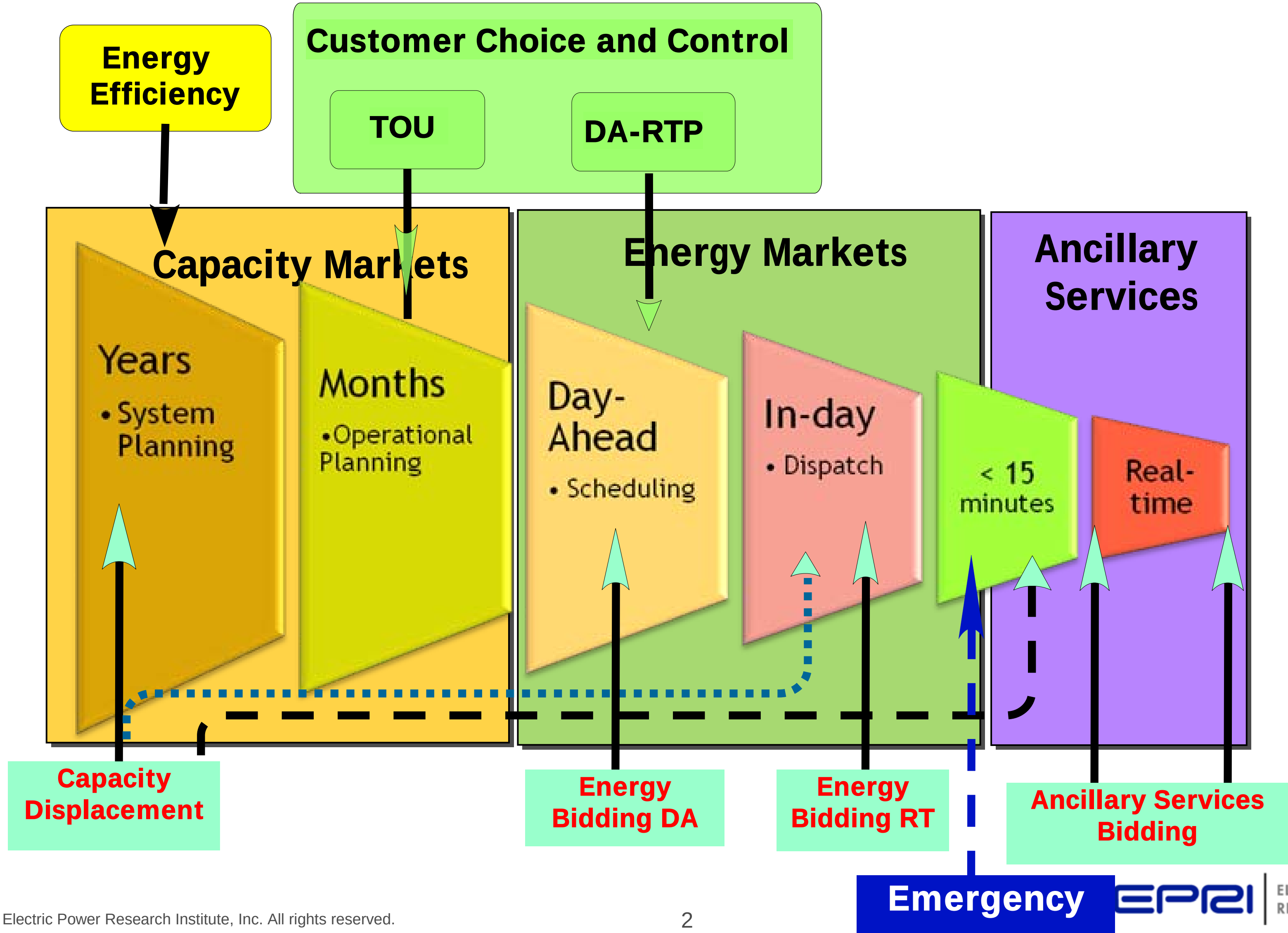
Overcoming Dispatch and Grid Modeling Challenges for Storage

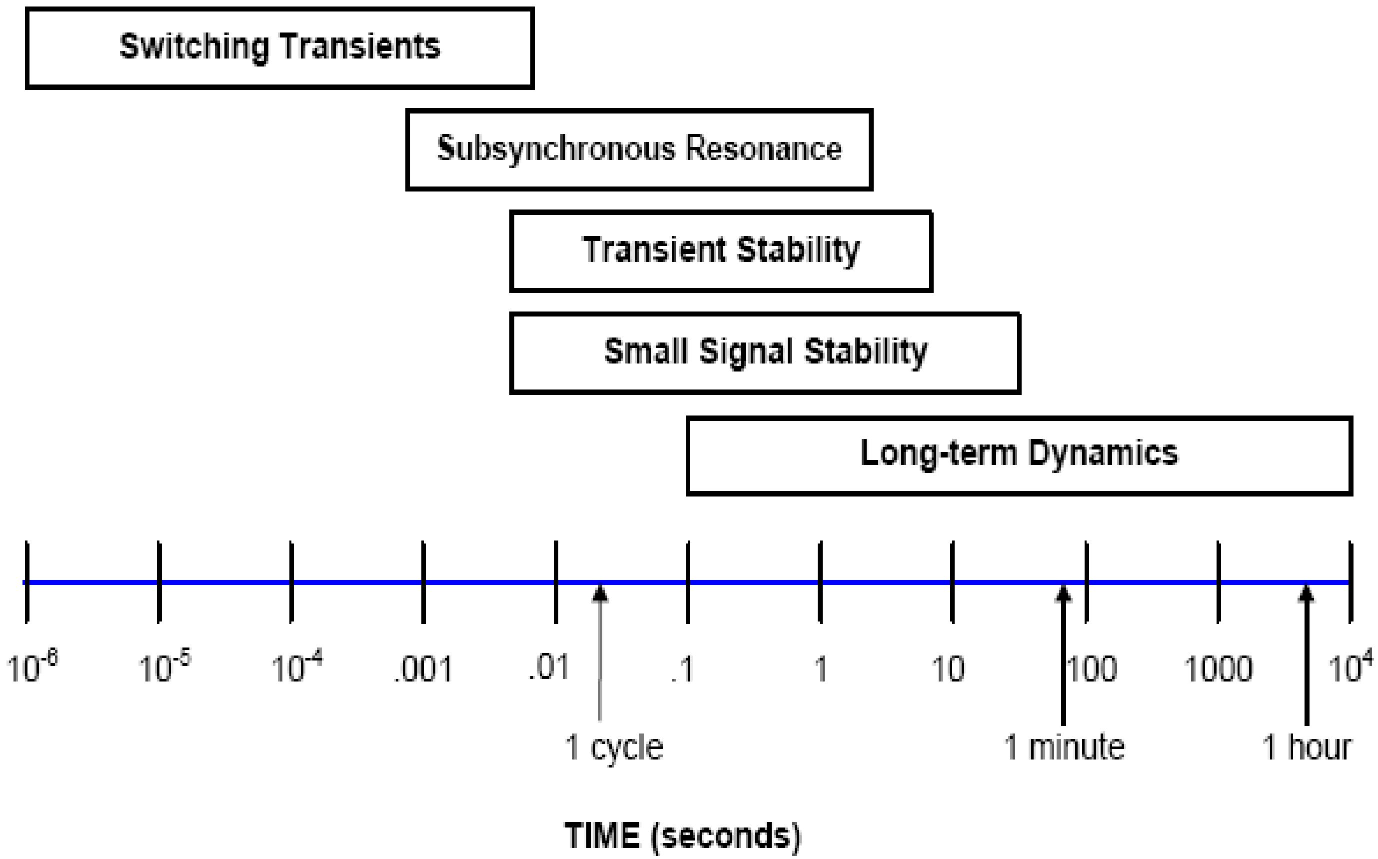
Electricity Storage :
Business and Policy Drivers
Houston Texas
January 25, 2011

Tom Reddoch
Executive Director Energy Utilization

Different types of markets operate in different time frames



Times of Interest for Power System Models



Standard Models for Variable Generation -- NERC

Traditional Major Grid Applications of Storage

Application	Description	System Benefits when Provided by Storage	Timescale of Operation
Load Leveling/ Arbitrage	Purchasing low-cost off-peak energy and selling it during periods of high prices.	Increases utilization of baseload power plants and decrease use of peaking plants. Can lower system fuel costs, and potentially reduce emissions if peaking units have low efficiency.	Response in minutes to hours. Discharge time of hours.
Firm Capacity	Provide reliable capacity to meet peak system demand.	Replace (or function as) peaking generators.	Must be able to discharge continuously for several hours or more.
Operating Reserves			
Regulation	Fast responding increase or decrease in generation (or load) to respond to random, unpredictable variations in demand.	Reduces use of partially loaded thermal generators, potentially reducing both fuel use and emissions.	Unit must be able to respond in seconds to minutes. Discharge time is typically minutes. Service is theoretically "net zero" energy over extended time periods.
Contingency Spinning Reserve[24]	Fast response increase in generation (or decrease load) to respond to a contingency such as a generator failure.	Same as regulation.	Unit must begin responding immediately and be fully responsive within 10 minutes. Must be able to hold output for 30 minutes to 2 hours depending on the market. Service is infrequently called.[25]
Replacement/ Supplemental	Units brought on-line to replace spinning units.	Limited. Replacement reserve is typically a low-value service.	Typical response time requirement of 30-60 minutes depending on market minutes. Discharge time may be several hours.

NREL

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Traditional Major Grid Applications of Storage (Continuation)

Ramping/Load Following	Follow longer term (hourly) changes in electricity demand.	Reduces use of partially loaded thermal generators, potentially reducing both fuel use and emissions. Price is "embedded" in existing energy markets, but not explicitly valued, so somewhat difficult to capture.	Response time in minutes to hours. Discharge time may be minutes to hours.
T&D Replacement and Deferral	Reduce loading on T&D system during peak times.	Provides an alternative to expensive and potentially difficult to site transmission and distribution lines and substations. Distribution deferral is not captured in existing markets.	Response in minutes to hours. Discharge time of hours.
Black-Start	Units brought online to start system after a system-wide failure (blackout).	Limited. May replace conventional generators such as combustion turbines or diesel generators.	Response time requirement is several minutes to over an hour. Discharge time requirement may be several to many hours.[26]
End-Use Applications			
TOU Rates	Functionally the same as arbitrage, just at the customer site.	Same as arbitrage.	Same as arbitrage.
Demand Charge Reduction	Functionally the same as firm capacity, just at the customer site.	Same as firm capacity.	Same as firm capacity.
Backup Power/ UPS/Power Quality	Functionally the same as contingency reserve, just at the customer site.	Benefits are primarily to the customer.	Instantaneous response. Discharge time depends on level of reliability needed by customer.

NREL

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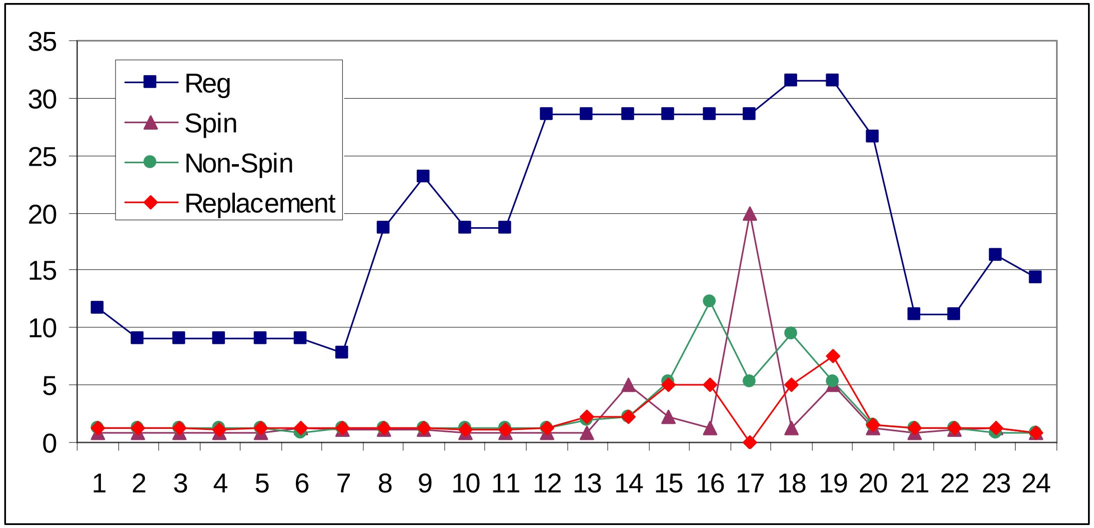
Ancillary Services

- Regulation is the most attractive AS market opportunity; regulation prices are generally higher than those for spinning and non-spinning reserves
- Regulation market is very small though – about 1% of peak load in each ISO

CAISO Ancillary Service Prices July 18, 2007



$/mwh

Market	*Regulation Market Size*
CAISO	350 MW-600 MW in each direction
PJM	1,446 MW
NYISO	150 MW - 275 MW
ISO-NE	130 MW

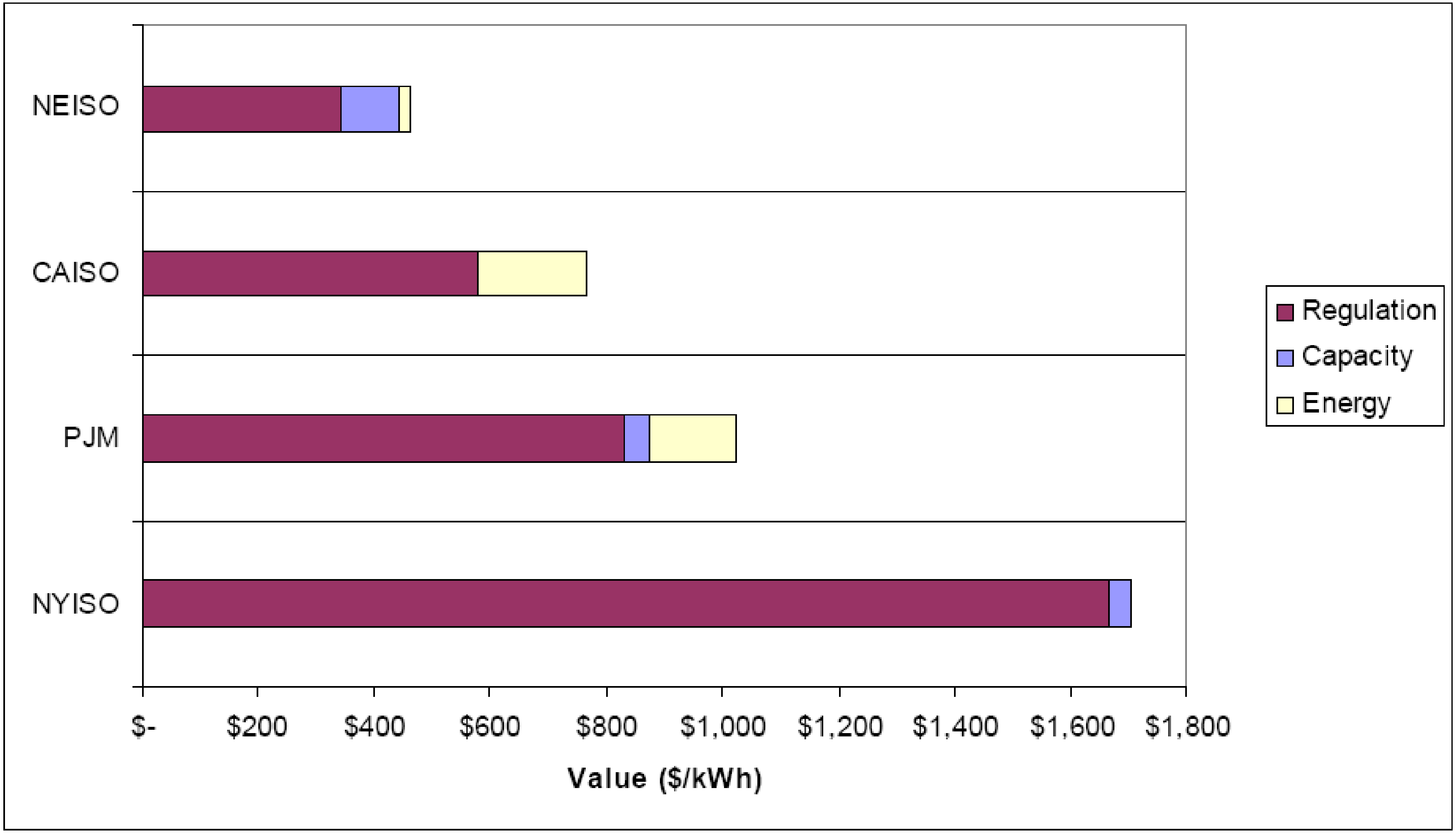
Regulation Market Rules

Regulation Market Rules					
Market	***Minimum time energy must be provided***	***Minimum resource size***	***Is there asymmetrical bidding?***	***Response time***	***Can regulation be imported?***
NYISO	1 hour	1 MW	No, not changing	6 secs	No, must be under NYISO control
PJM	1 hour	1 MW	No, but change possible	4 secs	No, must be connected within PJM footprint
ISO-NE	Typically an hour, but it can be lower - rules changing so that individual areas within ISO-NE can set their own minimum requirement	Minimum range of 10 MW	No, not changing	4 secs	Only from NY and New Brunswick through dynamic scheduling
CAISO	1 hour in day ahead, 15 min in real time	1 MW	Yes	4 secs	Yes, under dynamic scheduling

System Application

- Storage technology simultaneously participates in energy, capacity, and regulation markets

Building System Application Value from Regulation, Capacity and Energy-Arbitrage



Impact of Market Rules on Energy Storage Economics—Cutter, et.al

Why Energy Storage Now

- **Advances in Energy Storage**
- **Increase in Fossil Fuel Prices**
- **The development of deregulated energy markets including markets for high-value ancillary services**
- **Challenges for siting new transmission and distribution facilities**
- **Perceived need and opportunities for storage with variable renewable generators**

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Compilation of Energy Storage Costs for Long Duration Application (MW's & 4-10 hrs)

Technology	Round-Trip Efficiency (AC)	Life	Capital Costs	Capital Costs per hour	Capacity Capability (hours)
Pumped Hydro	75-83%	Very High	$2100-2700 (10 hr)	$200-300/kWh	20+
CAES – fuel	75-85%	Very High	$700-900 (10 hr)	$20-30/kWh	20+
CAES – no fuel	65-75%	Very High	$1000-1400 (8 hr)	$100-140/kWh	<20
Lead Acid	70-75%	Low	$1900-2400 (4 hr)	$500-600/kWh	1-6
Lithium Ion	80-90%	Medium	$3000-4000 (4 hr)	$750-1000/kWh	1-4
Sodium Sulfur	70-80%	Medium	$2700-3700 (4 hr)	$600-800/kWh	1-6
Hydrogen Fuel	30-45%	Low (?)	$5000-8000 (4 hr)	>$1000/kWh	1-4

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Overview of Energy Storage Solutions

Bulk to Distributed Storage Solutions in the Smart Grid

MWs to kWs: seconds, min, hours of energy duration

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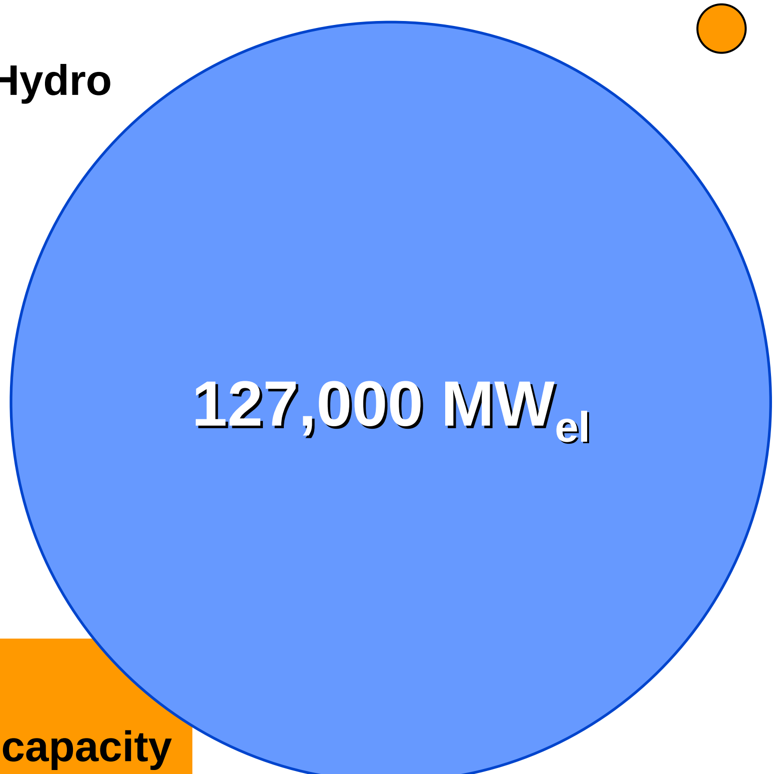
Today, Energy Storage Penetration is Very Small

Worldwide installed storage capacity for electrical energy

Pumped Hydro



Compressed Air Energy Storage
440 MWs

Sodium-Sulphur Battery
316 MWs

Lead-Acid Battery
~35 MWs

Nickel-Cadmium Battery
27 MWs

Fly Wheels
< 25 MWs

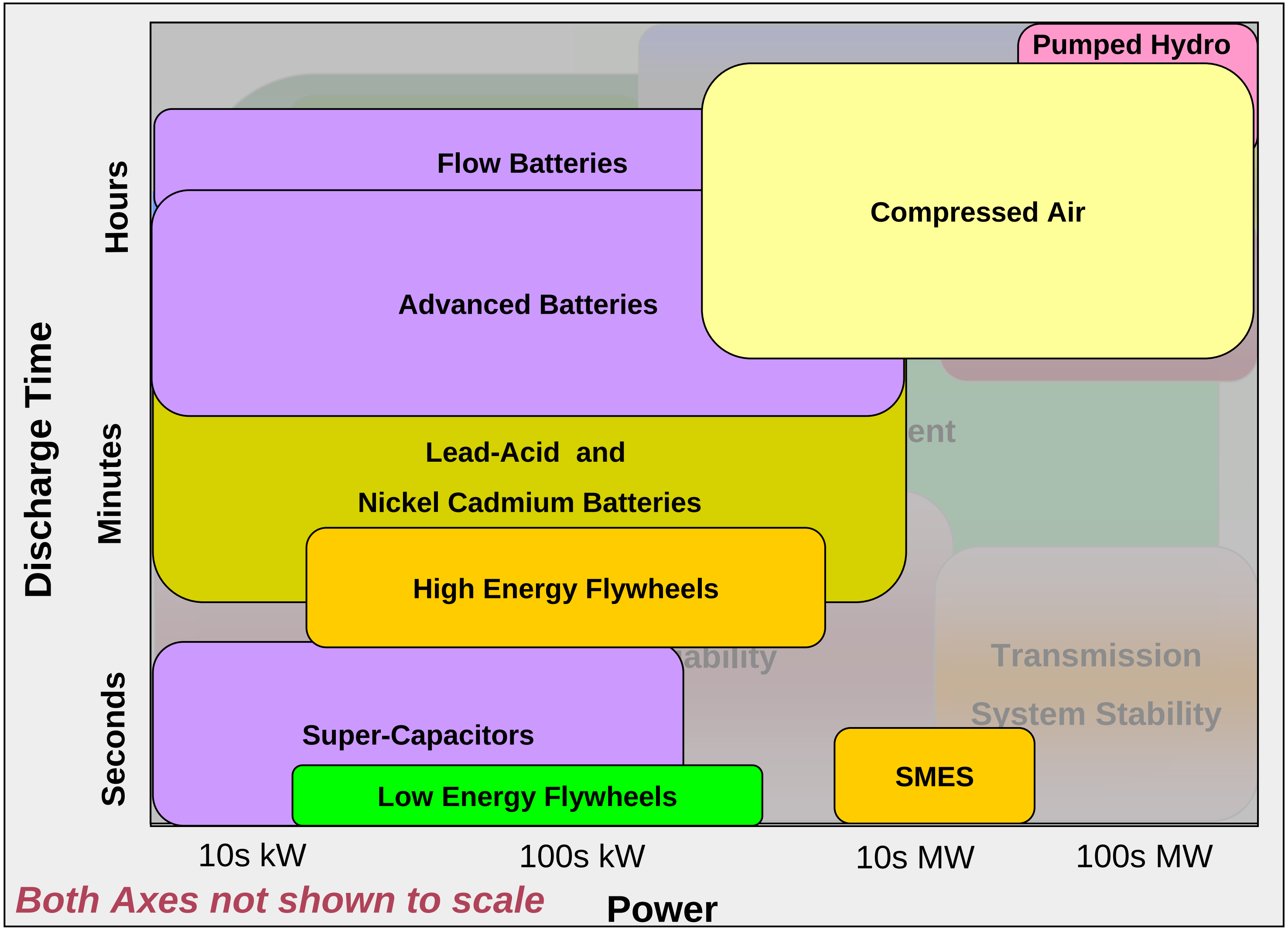
Lithium Ion Battery
~16 MWs

Redox-Flow Battery
< 3 MWs

Over 99% of total storage capacity

Source: Fraunhofer Institute, EPRI

Energy Storage Technologies



Flexibility in Grid Operations

A requirement with Variable Generation

- **Flexible Generation**
- **Demand Flexibility**

Energy Flexibility

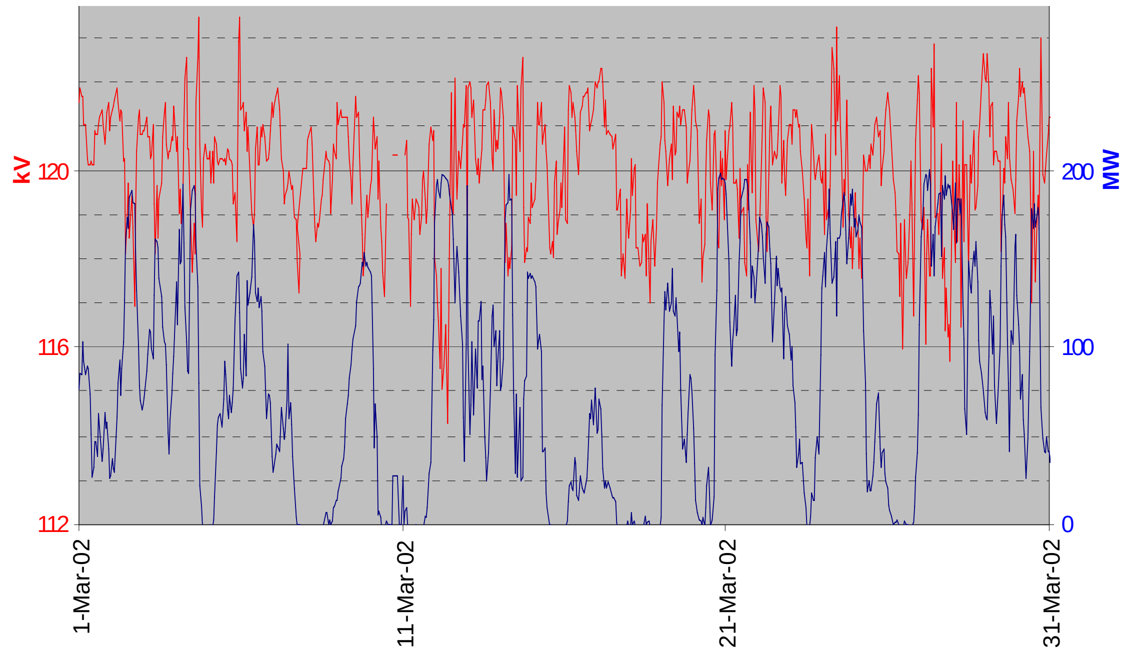
Ramping Flexibility

Strategic Objectives for Wind Power

- Reduce impact of large wind penetration
  - Cycling of baseload
  - Grid integration
  - Bulk energy storage
- Minimize effects of ‘erratic’ wind
  - O&M improvements
  - Hardware/control changes
- Optimize wind plant performance

Why do large blocks of wind generation affect electricity grid operations?

- Wind power is a variable generation resource.
- Wind energy flow to grid rises and falls with wind speed.
- Possible transmission bottlenecks during high wind.



Buffalo Ridge, MN 115-kV Bus kV and Transformer MW (NREL, March 2002)

- Impacts on system reliability, power quality, cost of ancillary services, such as voltage support and spinning reserve.

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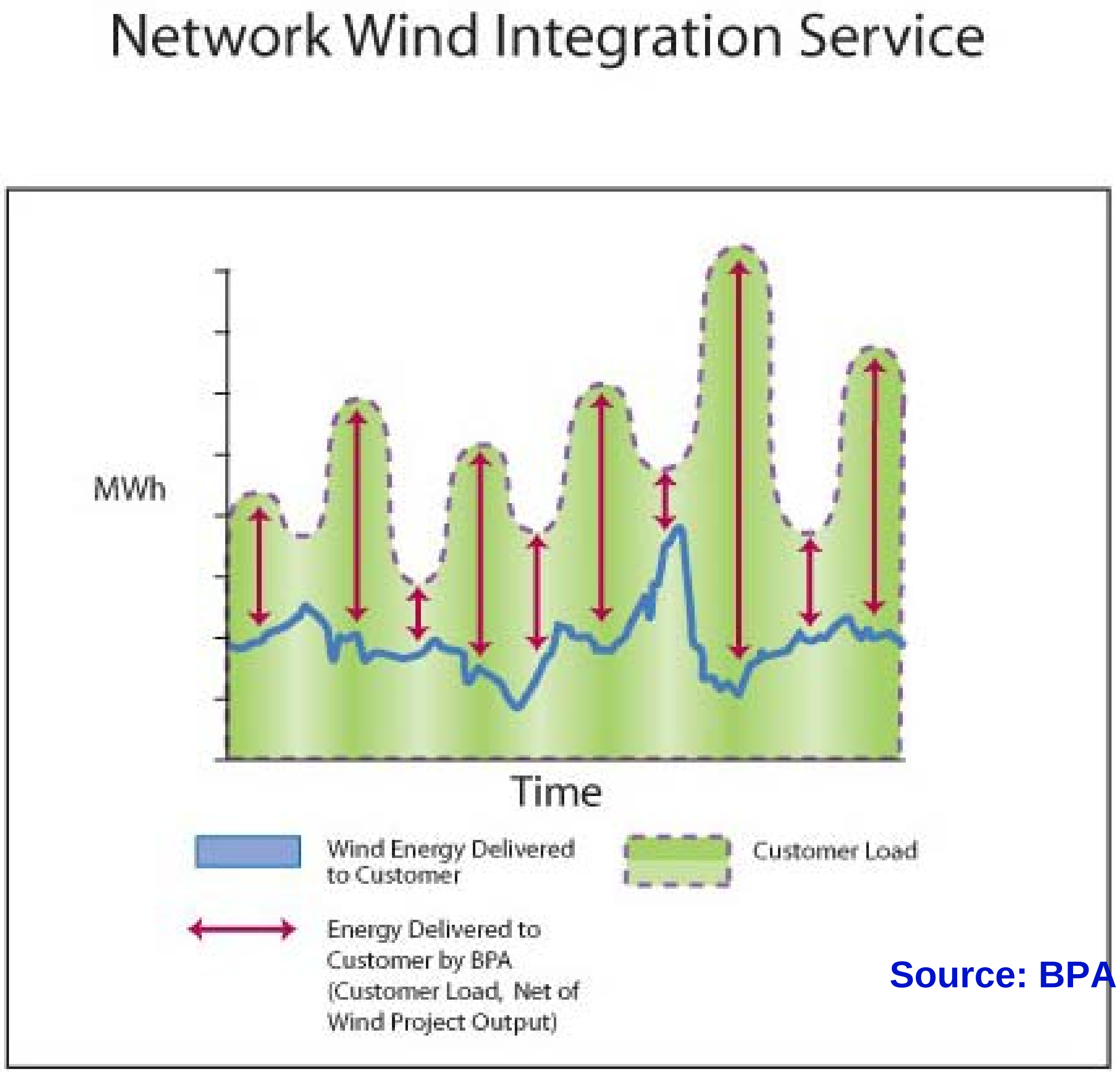
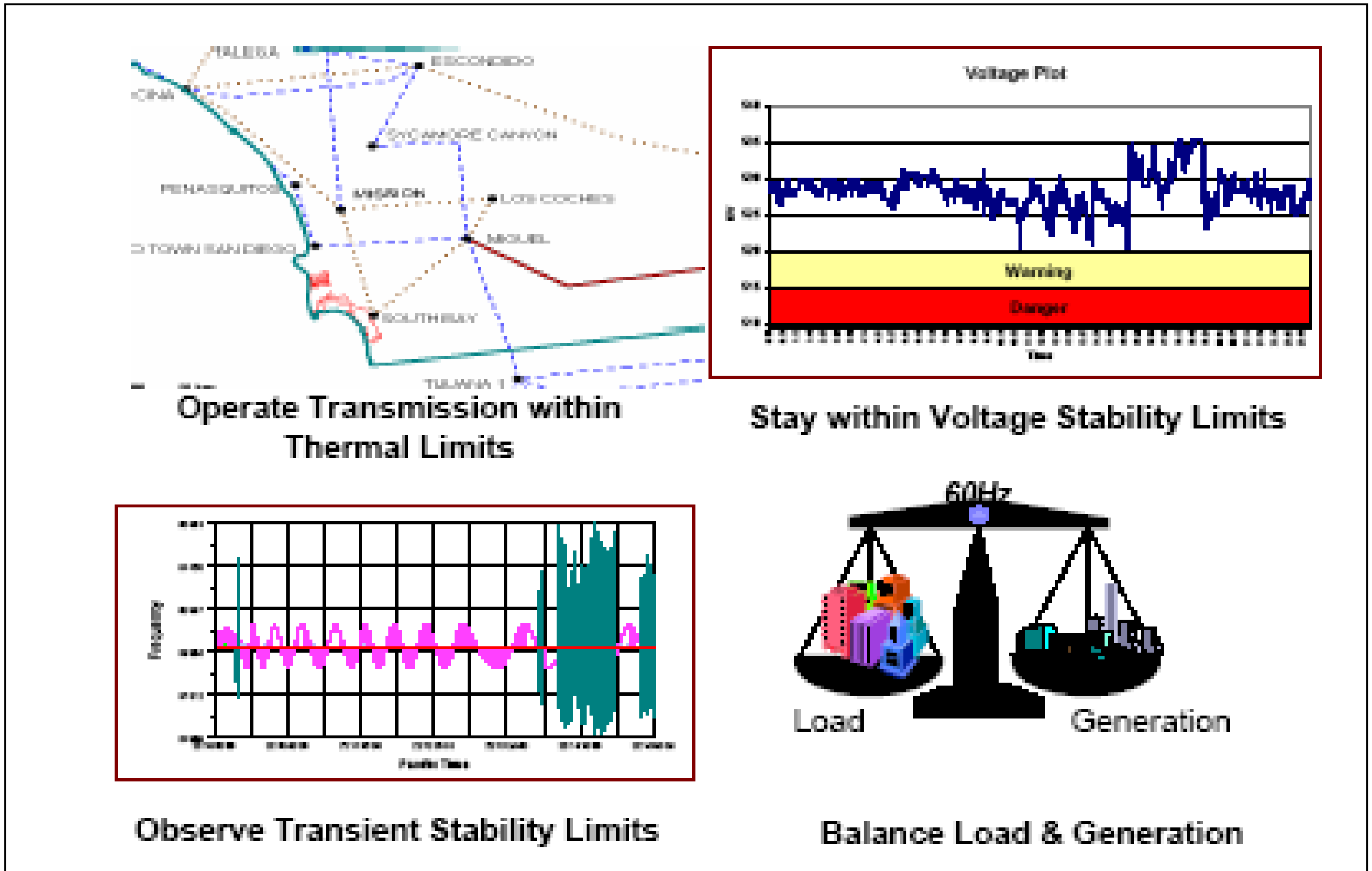
Wind Variability Challenges Grid Operators



Source: BPA

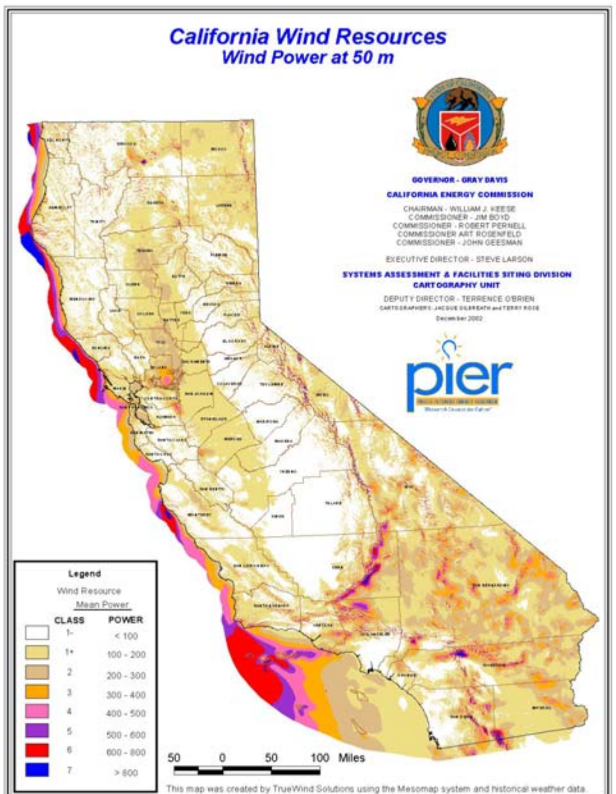
Wind Integration Requirements



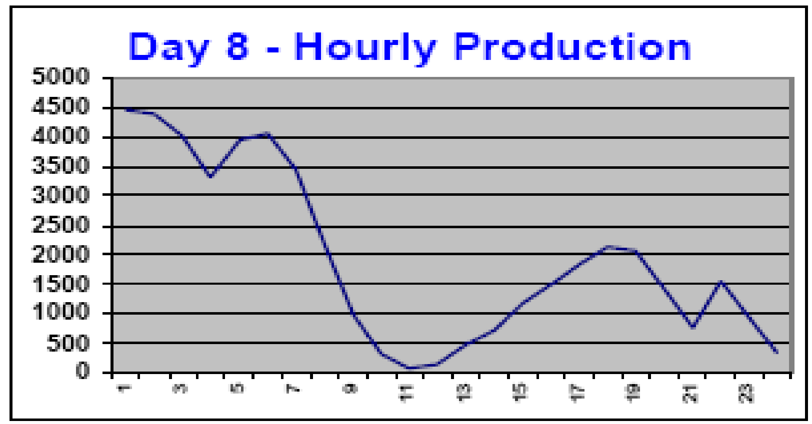
Source: Cal ISO

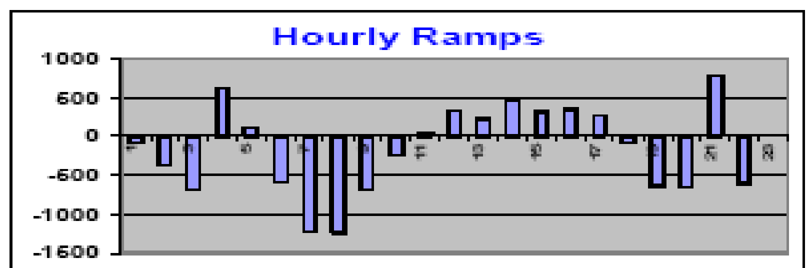
High Wind Penetration Scenario

High wind penetration leads to high ramp rates on system



Tehachapi Region
4500 MW Rated Capacity

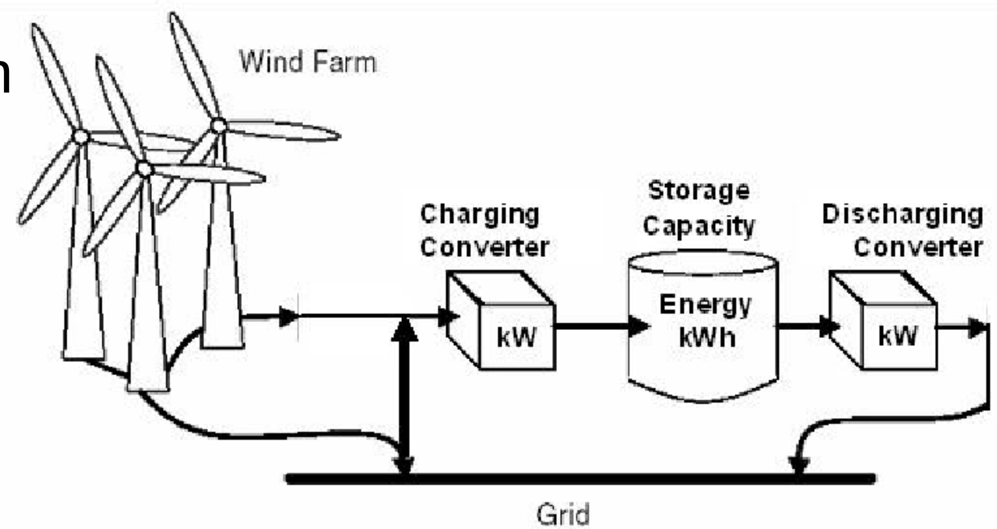




Source: Cal ISO

Wind and Energy Storage Project

- Electric energy storage can provide system reliability functions required for high penetrations of wind generation
  - Provide regulation capacity
  - Management of system minimum and peak load
  - Ramping capacity
- Electric energy storage can support delivery of wind energy from specific plants
  - Manage transmission congestion
  - Firm and shape to increase capacity credit

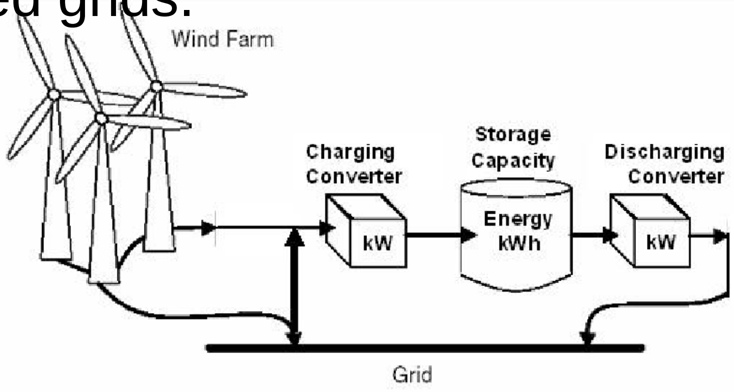


Project Objectives

Purpose: To investigate the value, and operational system benefits, of directly integrated energy storage and wind generation for scenarios of heavy transmission congestion and ISO based wind curtailment.

To investigate the use of energy storage to:

- Store otherwise curtailed wind energy to improve wind generation capacity factors and production tax credit revenues.
- Reduce cycling of fossil plants.
- Provide dispatchable capability for wind generation.
- Increase operational flexibility of isolated grids.
- Facilitate higher wind penetration.
- Identify the most promising energy storage options for this application.

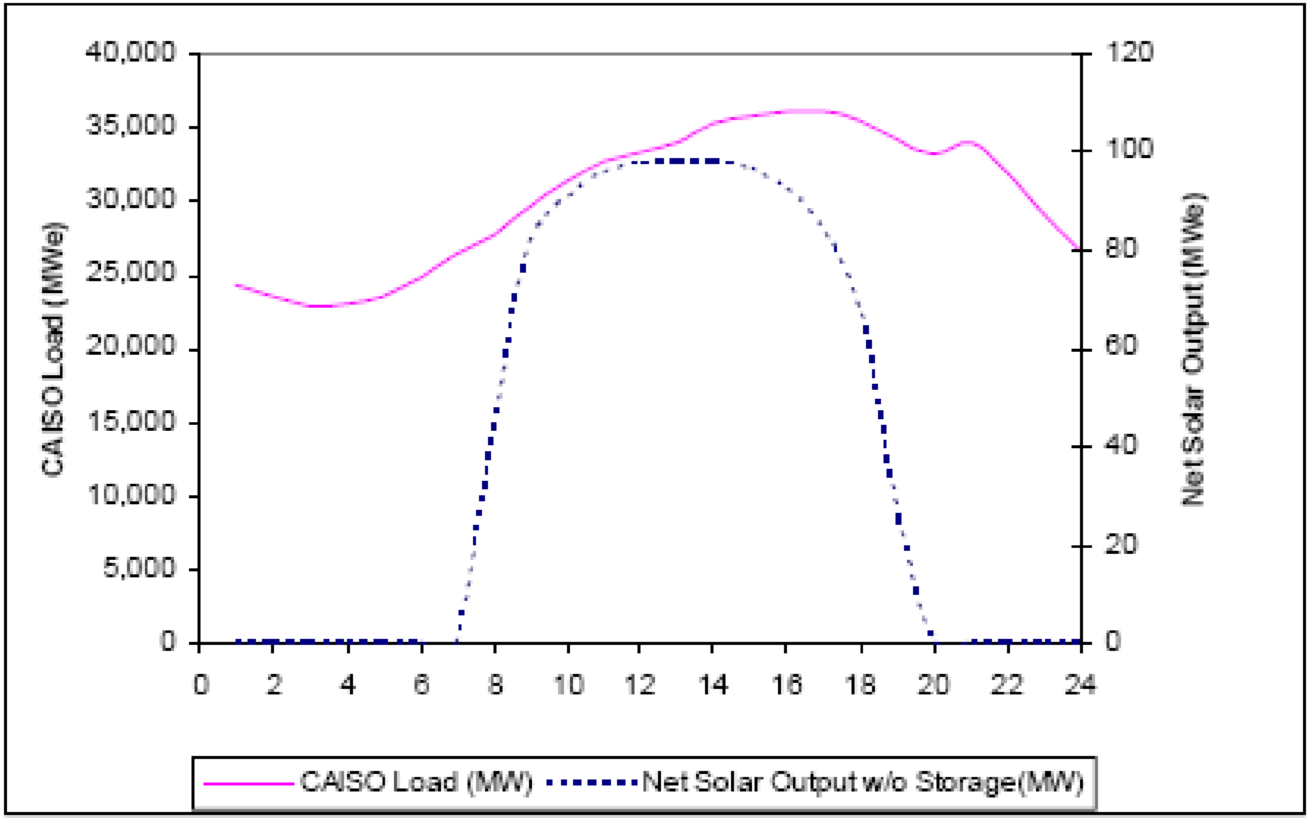


Engineering and Economic Evaluation of Integrated Wind-Onsite Energy Storage

Candidate Technologies:

- Sodium-Sulphur (NaS) Batteries,
- Lithium-Ion Batteries,
- Zinc-Air Batteries,
- Flywheel Energy Storage,
- Sodium-Nickel-Chloride Battery Energy Storage,
- Zinc-Bromine Battery Energy Storage,
- Vanadium-Redox Battery Energy Storage,
- Pumped hydro (PH),
- Compressed air energy storage (CAES),
- Above and below-ground compressed air energy storage, and
- Production of ammonia for end use.

Solar Incidence and Load



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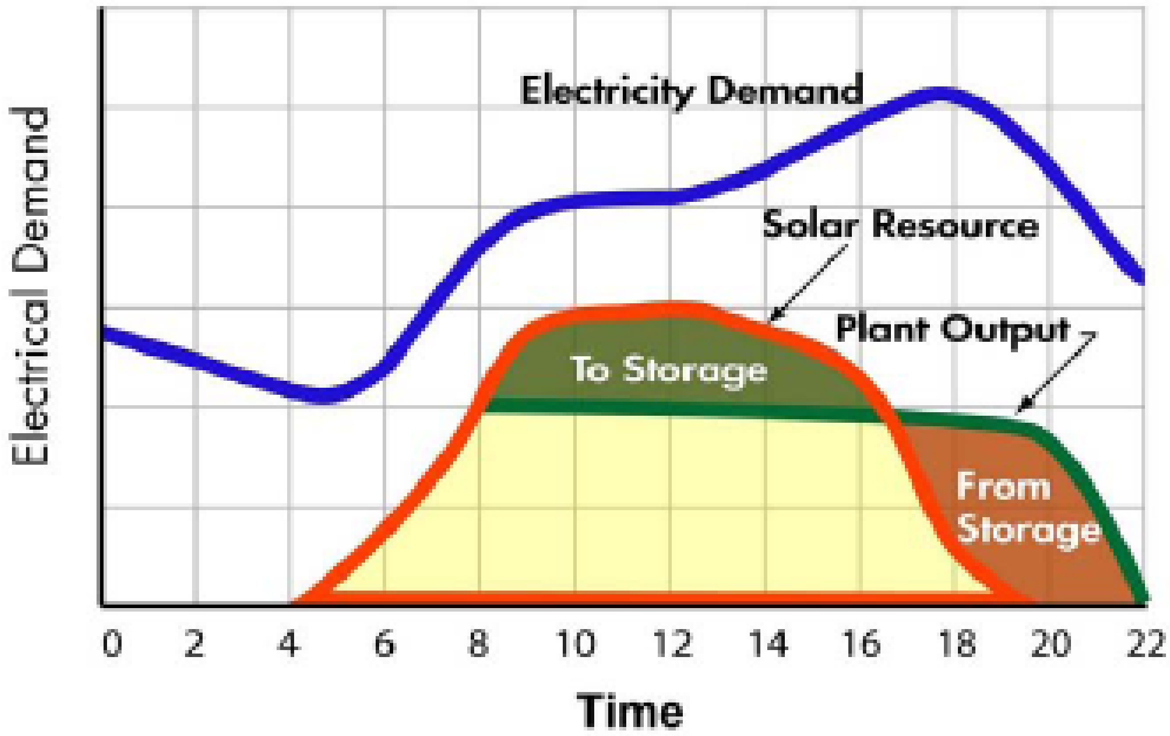
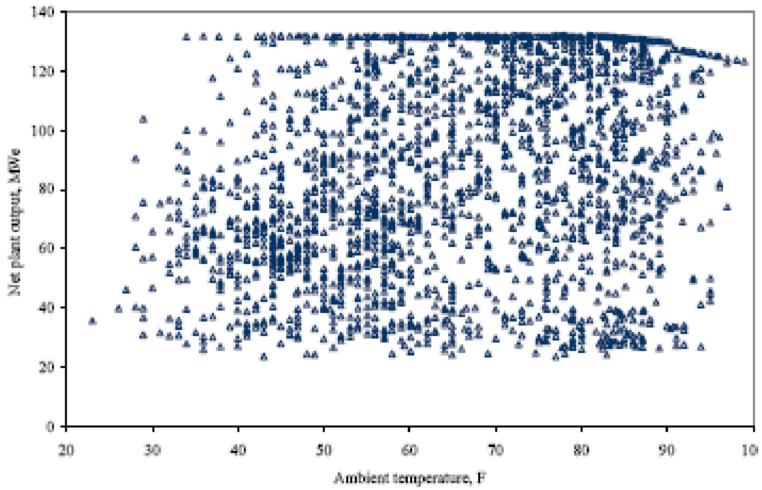
Concentrating Solar Thermal

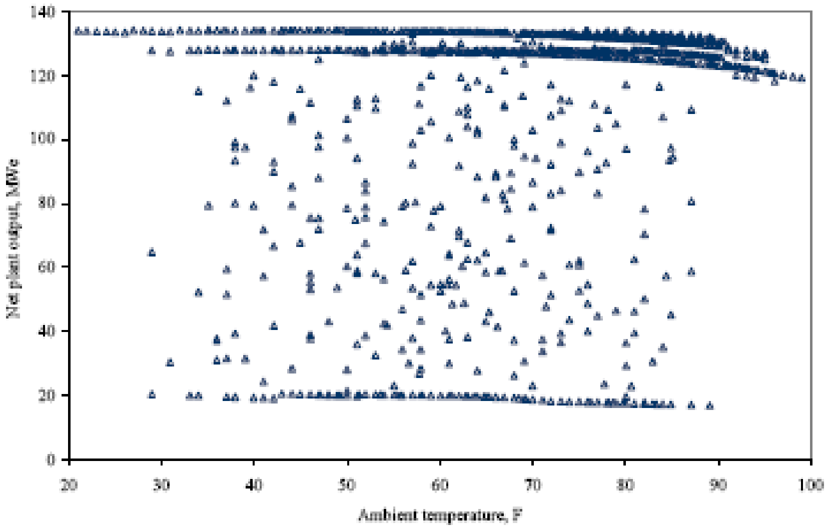


Smoothing Solar Power Production with Storage

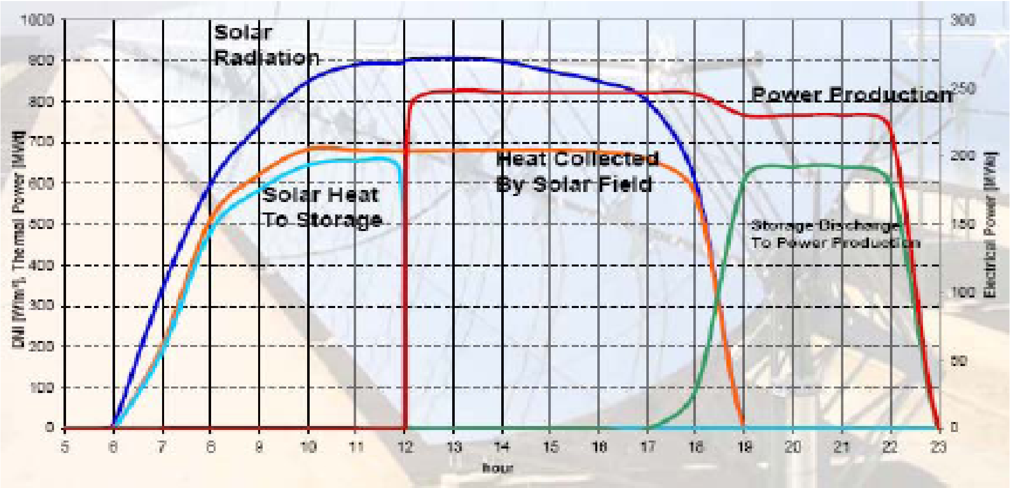


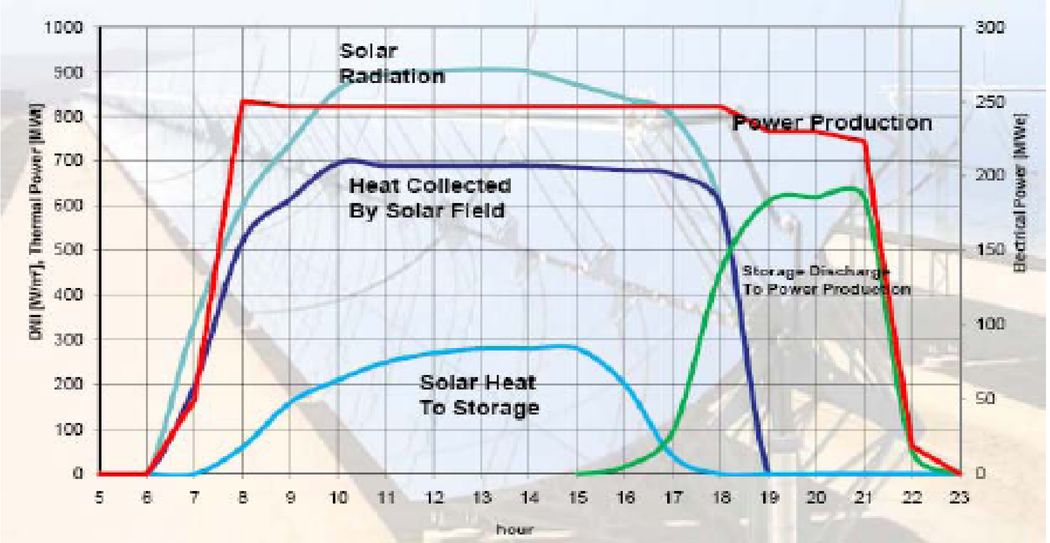
Solar Production –no Storage

Solar Production – with Storage



Displacement and Extension of Power Production Using CST





EPRI has identified the following key research questions

- How much additional renewable integration is economically feasible on the US electric system using energy storage?
- What is the scale and type of energy storage that is economic for balancing; reliability, improved T&D utilization and optimizing T&D investments?
- What are the relative economics of energy storage vs. other fossil generation (e.g. combined cycle generators)?
- Can storage improve the economics of wind without a contractual relationship, based on existing price signals in markets? If not, what market rules may be beneficial?
- How does this vary by ISO region and function of wind penetration? What are the critical variables that influence the role of storage? Market rules, Generation mix, T&D robustness, types and sizes of loads, location of wind relative to load.
- What are the optimal storage portfolio storage mix and what are the cost / benefits including GHG implications. What storage mix provides the least cost and greatest system benefits such as production cost savings?
- What is the role of storage in T&D investment planning; operation, use, asset management and congestion management given future wind penetration assumptions.
- What role can storage play in minimizing the thermal cycling of fossil generation assets and improving the value of other base load generation assets like nuclear.
- Using real world market simulations of energy storage portfolios, what are the technical, performance and functional characteristics of storage systems to improve renewable integration and to system benefits to the electric enterprise ?

Simulation Model

Project Objectives

The goal of this project is to investigate regional system benefits of energy storage under high wind penetration scenarios. Specific objectives are to:

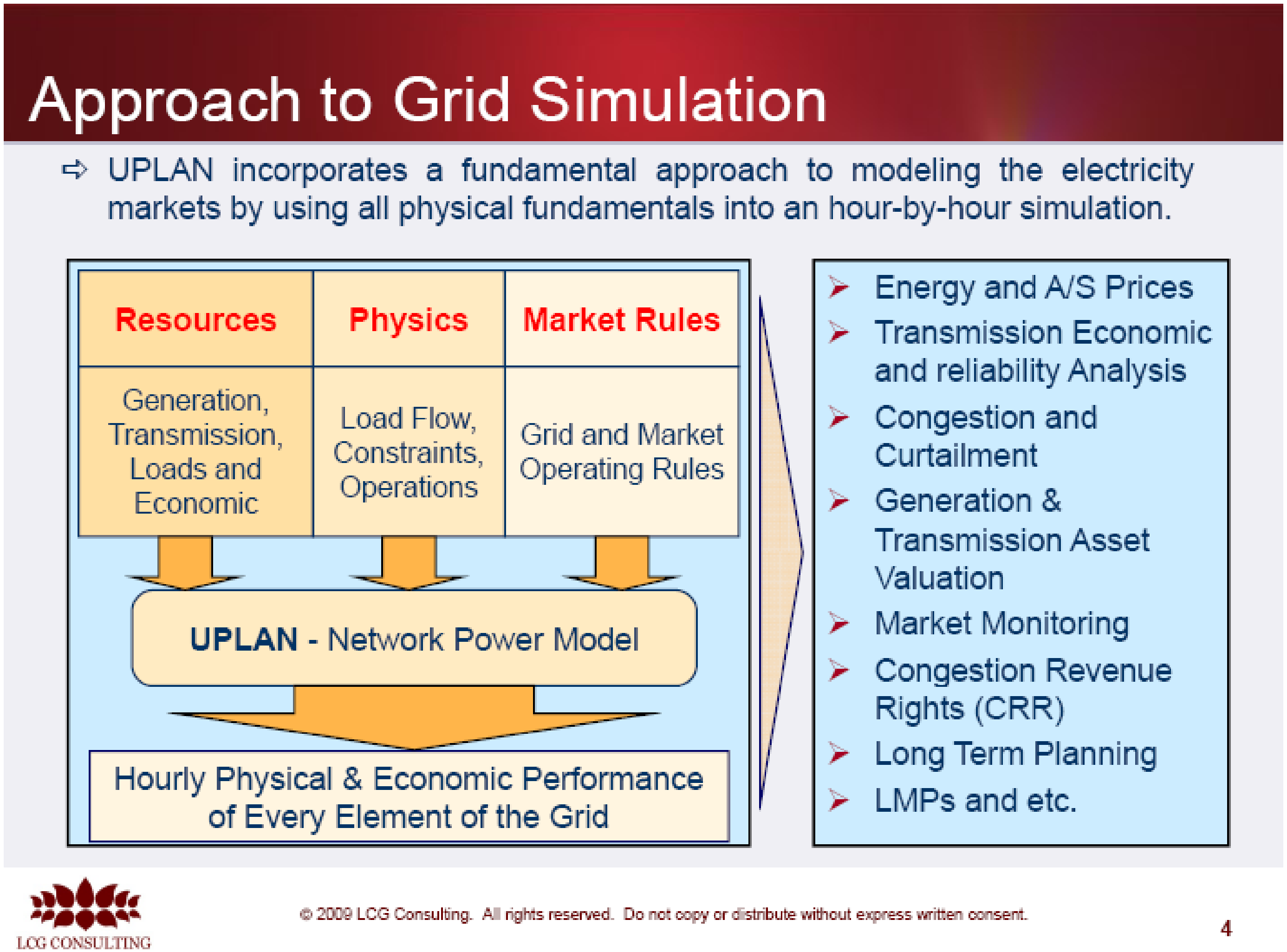
- Assess how first and second generation Compressed Air Energy Storage Systems (CAES) could increase wind utilization and penetration in ERCOT,
- Estimate green house gas emissions impacts of deployment of CAES systems,
- Estimate the impacts and interplay of CAES investments on wind curtailment, Transmission congestion and the societal / system benefits,
- Assess similar impacts and the costs and benefits of deploying bulk battery energy storage system and distributed battery systems in ERCOT.

Approach

The UPLAN model enables a fundamental, granular simulation of ERCOT market dynamics based on very detailed characterization of generators and the transmission network along with realistic representation of market protocols. The assessment of the energy storage systems was carried out in three phases:

- Phase I: Base case simulation (without any storage systems) in the post- CREZ Scenario 2
- Phase II: Compressed Air Energy Storage Analysis
  - CAES I – First generation CAES unit of 268 MW was located at a wind farm site in West Texas. This system is typical of the unit in Alabama operated by the Alabama Electric Cooperative (Figure ES-2). The capital costs have been updated.
  - CAES II – Two Second generation CAES units of 200 MW each were located at a wind farm site in West Texas. This is an improved design which features the use of a conventional gas turbine system. This system is being planned for demonstration within the next two years (Figure ES-3)
- Phase III: Battery Storage Analysis
  - Bulk Battery – This scenario utilizes the CAES II scenario with 100 MW of CAES storage capacity replaced by a 100 MW bulk battery.
  - Distributed Battery Storage – This scenario employs 240 MWs of distributed energy storage systems. 120 batteries of 2MW each were placed at different demand buses across all the four zones in Texas.

Approach – UPLAN Simulation Model



Approach – UPLAN Simulation Model

Market Features in UPLAN

⇨ UPLAN is capable of simulating all types of generators, optimizes unit commitment and dispatch. It incorporates a full transmission model that performs an optimal power flow and SCUC/SCED for each hour.

Market Features

- Supply
  - Integrated SCUC / SCED and RUC
  - Day Ahead Energy and A/S Markets
  - Regulation Up / Down
  - Spinning / Non-Spinning Reserve
  - Hourly Generation Profile (Wind & Solar)
- Demand
  - Bus Level Loads
  - Zone Level A/S
  - Hubs: Laps, EZGen, Trading Hubs
- Transmission and Revenue Rights
  - Optimal Power Flow
  - Congestion Management
  - CRR

Output

- Locational Prices (LMP) at Bus Level
- Generation Dispatch
- Generator Costs and Revenues
- Zonal Energy and A/S Prices
- Optimal Power Flow
- Congestion, Curtailment and Costs
- Binding Contingencies
- CRRs, TCRs, and FTRs
- Hourly Wind Dispatch
- Renewable Energy
- Emissions Rates and Costs

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Approach – UPLAN Simulation Model

Transmission

⇨ UPLAN incorporates the full nodal transmission system to perform an hourly Security Constrained Unit Commitment (SCUC) & Security Constrained Economic Dispatch (SCED).

Network Representation

- Thermal Limits
- N-x, G-x Contingency Constraints
- Remedial Action Schemes (RAS)
- Flow gates, Nomogram Constraints
- Marginal & Average Losses
- Phase Angle Regulators (PARs)
- Bus level demand for Energy and A/S
- Phase Shifter
- AC/DC Optimal Power Flow

Output

- Real and Reactive Power Flow
- Binding Lines
- Marginal & Average Losses
- Generation Shift Factors
- Shadow prices and CRRs
- Line Outage Distribution Factor (LODF)
- Power Transfer Distribution Factor (PTDF)
- Outage Transfer Distribution Factor (OTDF)

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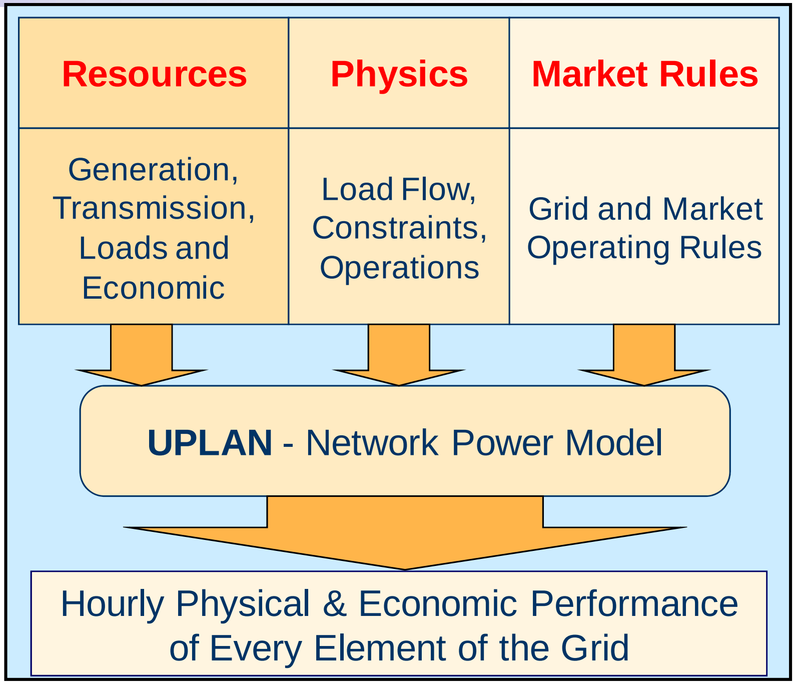
Executive Summary – Market Simulation Approach
UPLAN Simulation Model[1]

- The UPLAN model was used with inputs from PJM, NYISO and ERCOT. UPLAN uses marginal cost based generator offers and opportunity cost based offers for A/S, storages and other secondary resources to determine nodal Locational Marginal Prices.
- One year of hourly nodal prices at the bus where storage is located are generated; Hourly storage operation is optimized using linear programming;
- Monthly net income is maximized which equals revenue minus charging cost, fuel cost, and emission cost;
- The scheduled hourly charging MW is treated as load and added to the storage bus
- The scheduled hourly discharging MW is treated as the storage maximum available capacity in the unit commitment and dispatch.
- Impacts of Storage Portfolio is the difference from a Base Case (no storage) and the UPLAN Storage Portfolio Case.



UPLAN enables a detailed, granular simulation of market dynamics based on characterization of generators and the transmission network along with realistic representation of market protocols.

UPLAN Network Power Model

http://www.energyonline.com/products/uplane.asp

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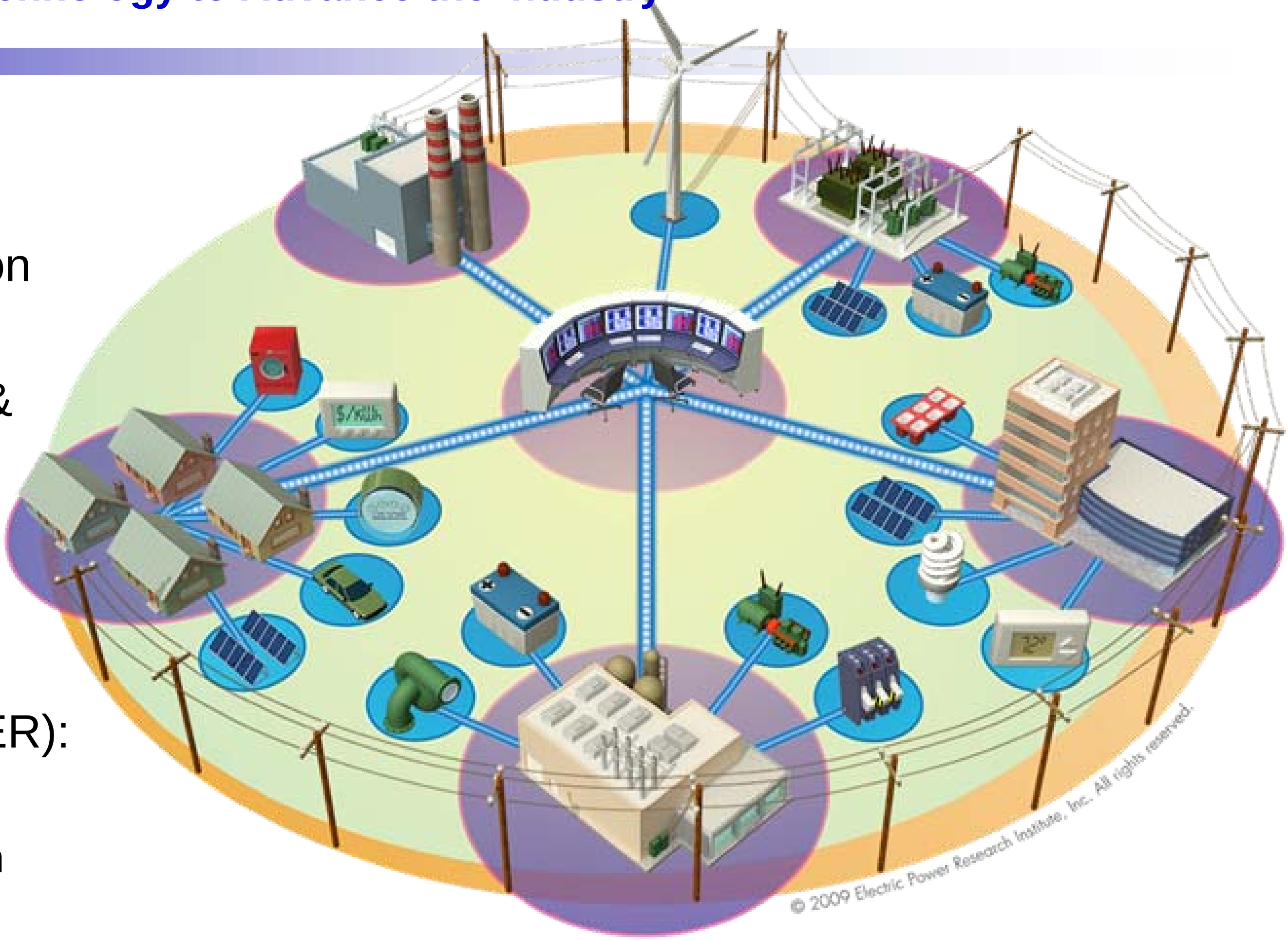
EPRI Smart Grid Demonstrations

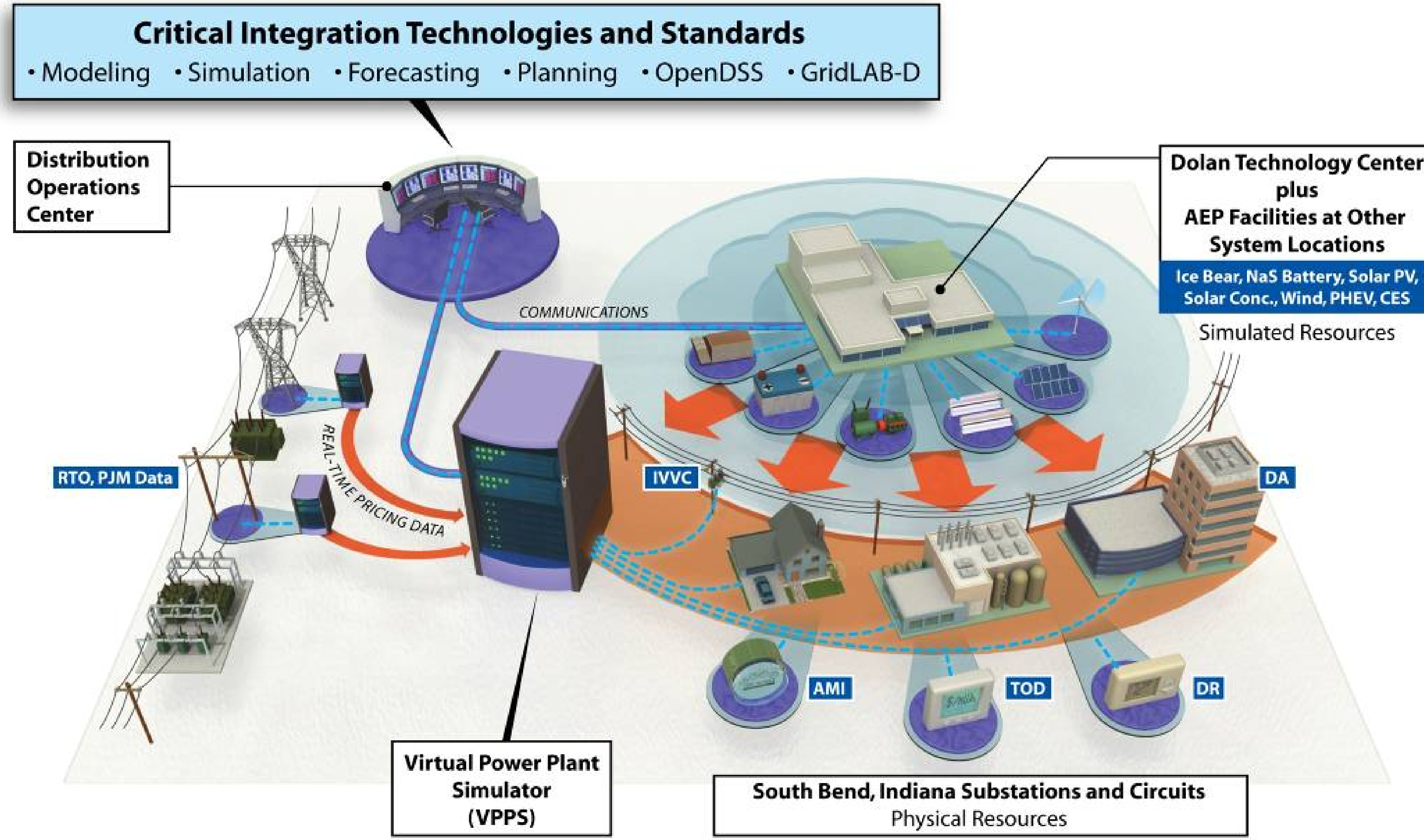
Leveraging Today's Technology to Advance the Industry

- Deploying the Virtual Power Plant
- Demonstrate Integration and Interoperability
- Leverage information & Communication Technologies
- Integration of Multiple Types of Distributed Energy Resources (DER):
  - Distributed Generation
  - Renewable Generation
  - Storage
  - Demand Response



Multiple Levels of Integration - Interoperability

American Electric Power Demonstration Project



To Optimize Storage, AEP Research Indicates

The need for energy storage with the following FOUR key features:

1. Very Close to Customers
- Backup Power,
- Buffer Customer Renewables

2. Grid-Connected
- Load Leveling,
- Volt / VAR support

3. Utility-Operated
- Load Diversity (multiple customers on one storage)
- Improved Safety
- Optimizing Grid Performance

4. Utility-Owned
- Standardization & Commodity Pricing
- Socializing the Cost

Benefits of Local Energy Storage

While Local Storage can function as a Multi-MW, Multi-hour Substation Battery, It has Inherent Advantages over Larger Batteries located in Substations:

- More **reliable** Backup Power to customers (closer)
- More **scalable**, flexible implementation (many small units)
- More **efficient** in buffering customer **renewable** sources
- More synergy with **Electric Vehicle** batteries
- Easier installation and **maintenance** (240 V)
- A **Unit outage is less critical** to the grid (smaller)

CES – A Virtual Substation Battery

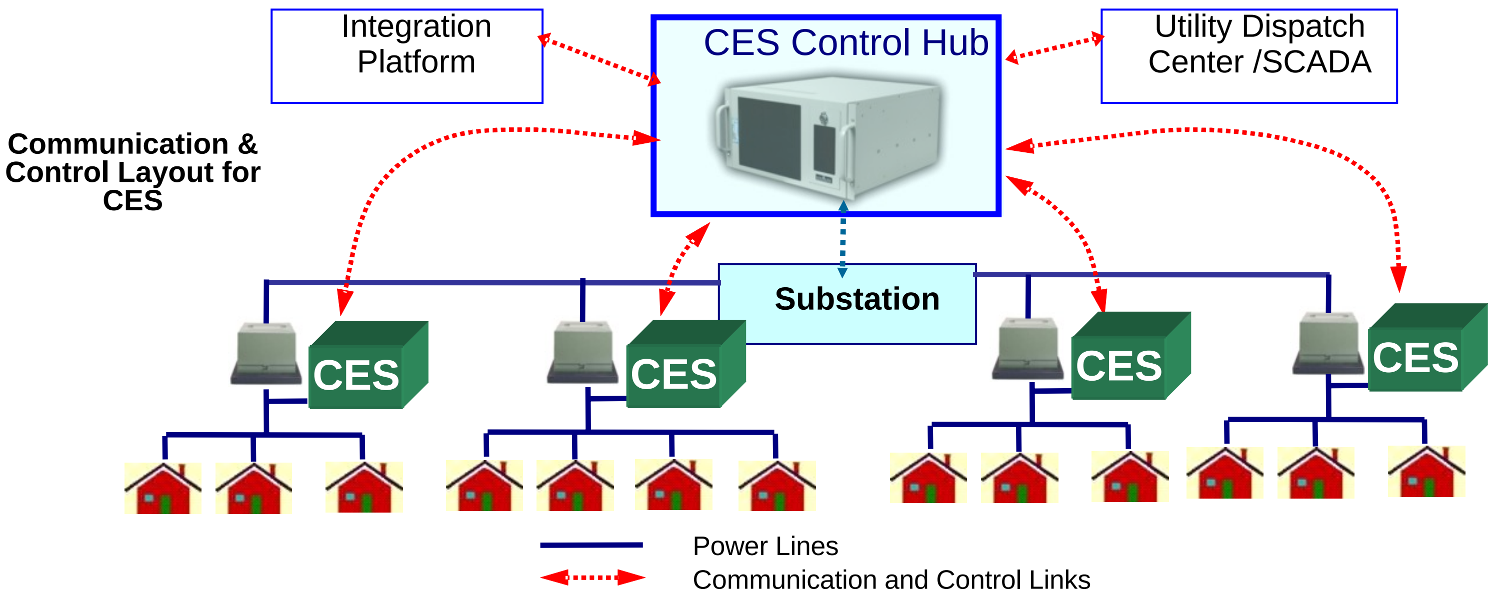
Operated as a Fleet offering a Multi-MW, Multi-hour Storage

Local Benefits:

1) **Backup power**
2) **Voltage correction**
3) **Renewable Integration**

Grid Benefits:

4) **Load Leveling at substation**
5) **Power Factor Correction**
6) **Ancillary services**



CES – Needs two interoperable control systems

EPRI implemented the OpenDSS modules to enable simulation of CES

Storage System:

Independent Function

or

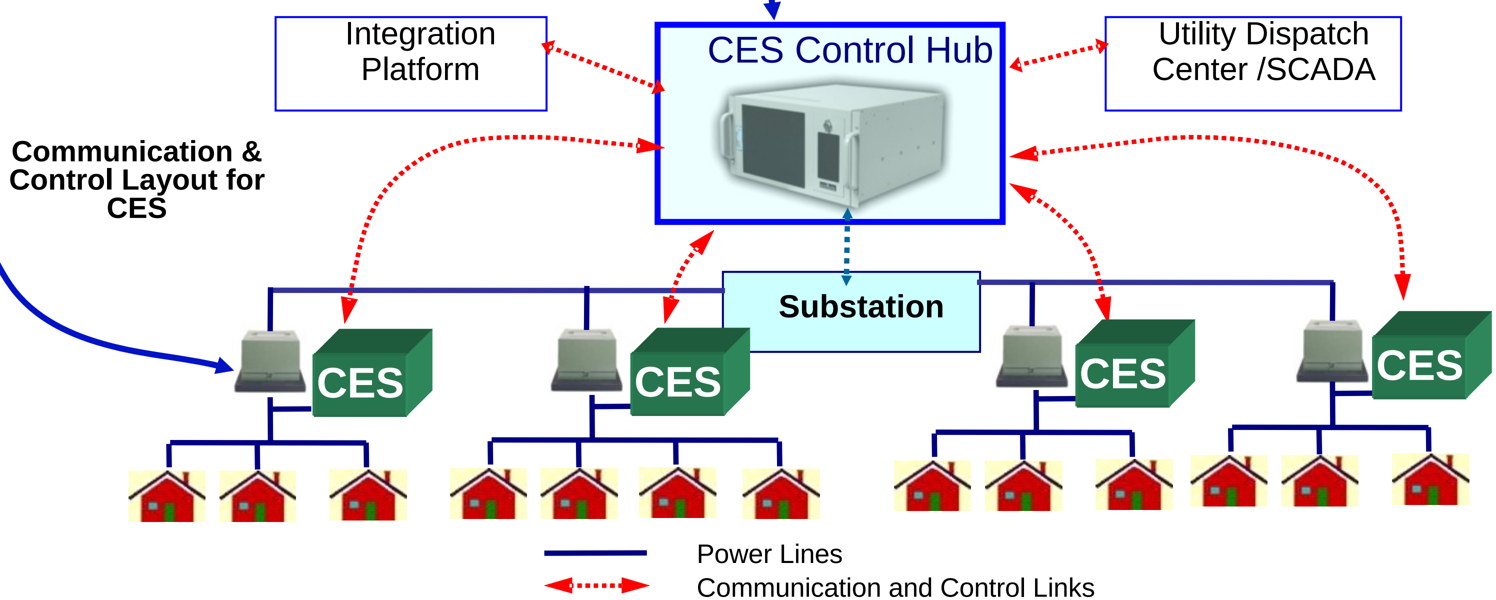
External Control Interface

Storage System Controller:

Controls a fleet of storage units

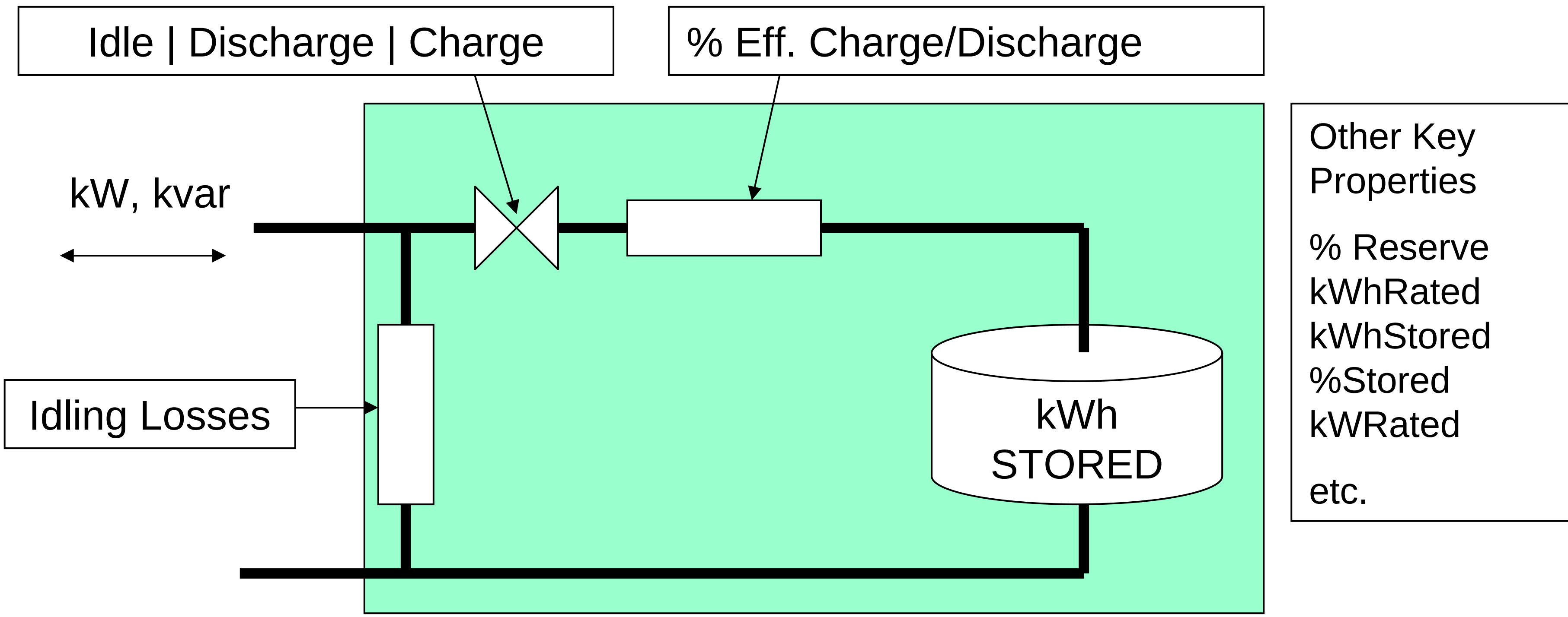
Simulates substation storage

Dispatch algorithms



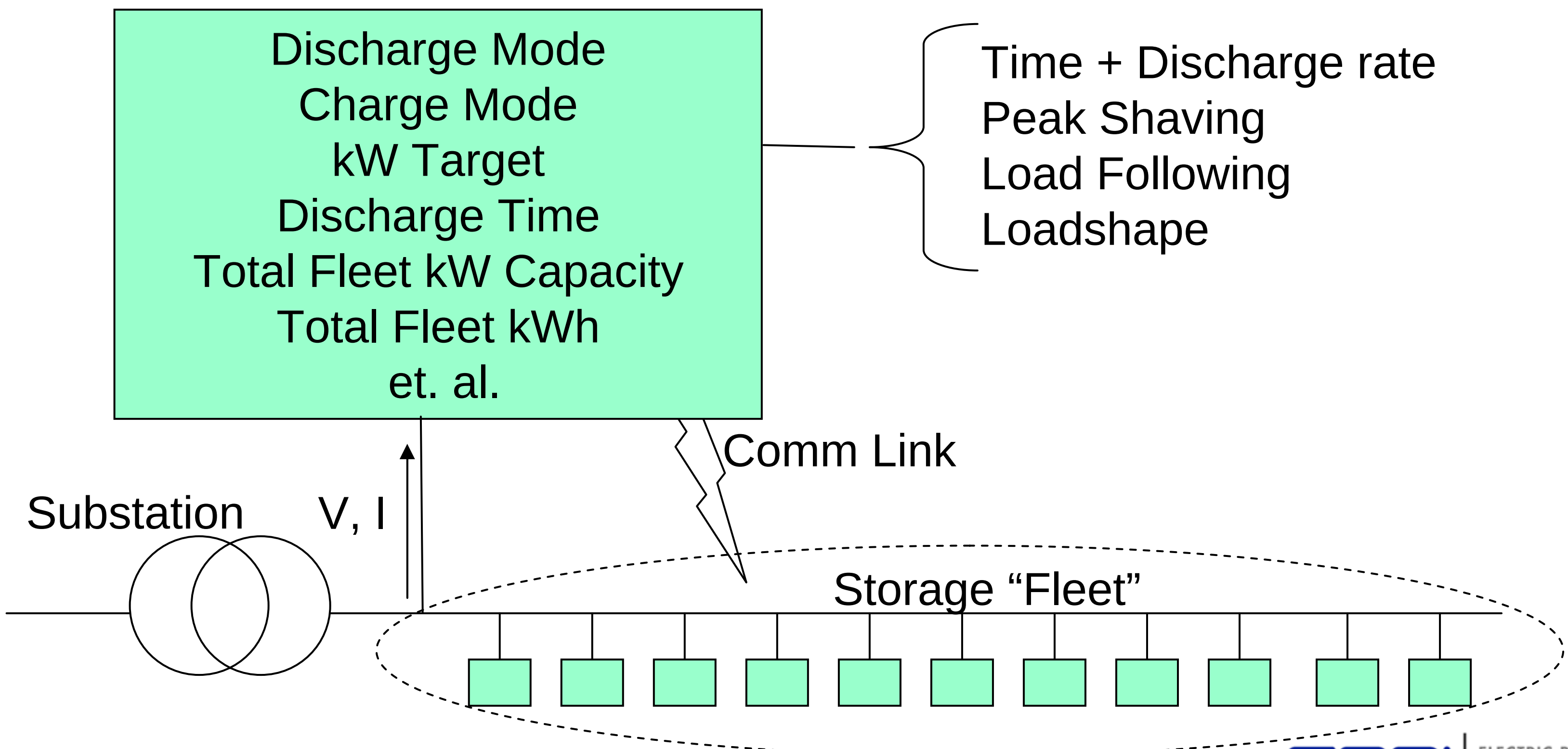
Storage Element Model in OpenDSS

- **A storage element is defined by a list of properties**
- **A storage element can either act independently or be controlled by a *StorageController* element.**

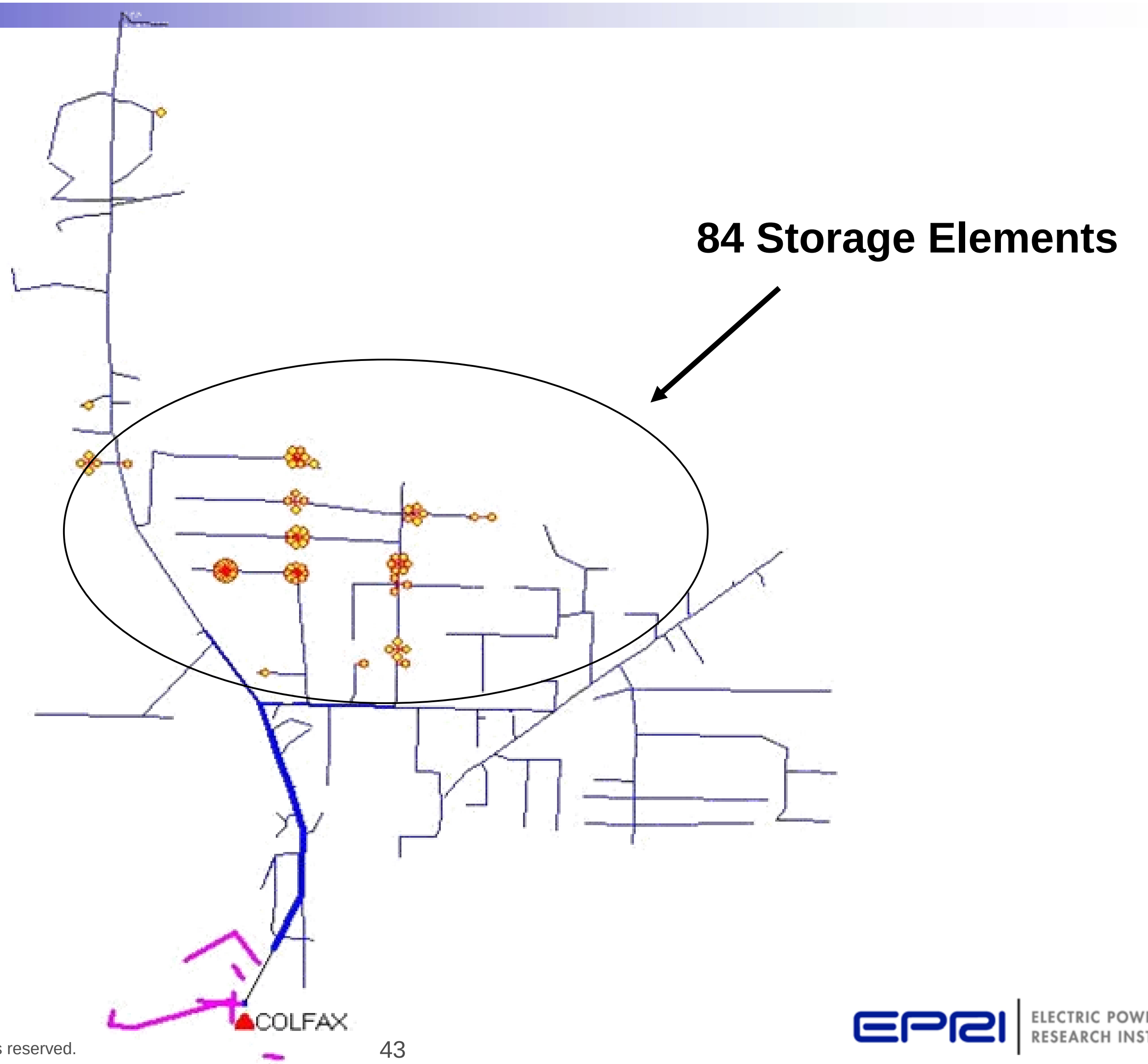


StorageController Element in OpenDSS

- **A storage controller controls a fleet of storage elements (storage units)**
- **Implements operating modes such as: load following, DR support, load shape, and timed dispatch**



Simulation identified 84 storage element locations



"Learnings" from CES simulations

- **25 kWh storage is quickly depleted when used for day-to-day peak shaving. This requires an accurate discharge algorithm.**
- **Load following with a later time trigger is likely more useful than a fixed discharge rate or an early time trigger**
- **75 kWh capacity would enable a peak shaving strategy that results in fewer instances of depleting the battery early.**
- **AEP plans to deploy Community Energy Storage (CES) as part of its gridSMART℠ initiatives.**
- **Modeling and Simulation helps us truly understand the issues involved with the deployment of smart grid technologies and prepare to address any challenges before these systems are deployed across the AEP system.**

Together…Shaping the Future of Electricity